Ferdinand Berthoud

Jacob Auch

How to Make a Verge Watch

Translated by

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and

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Edited by

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Foreword

Origins

Professor D.S. Torrens, of the medical faculty at Trinity College Dublin, was an avid collector of horological books and tools. From before the First World war until his death in 1967 he amassed a vast private collection, possibly the largest that has ever been or ever will be seen.

After his death, his executors arranged with Malcolm Gardner to sell his books, and in 1971 Gardner produced his *Catalogue XVI, Horology and allied subjects in English and various other languages, being the remarkable library formed by the late Professor D.S. Torrens Trinity College Dublin.* This contained more than 2,053 items including some extremely rare books.

Item 77 was Auch (Jacob) Handbuch für Landuhrmacher, about which Gardner tersely wrote:

This is a handbook for country watchmakers, or for apprentices and amateurs. Author gives step by step instructions how to make a watch, how to take it apart and put it together, how to repair and regulate it. There are very detailed instructions for making every part of a verge watch. Extremely rare and interesting. This book ought really to be translated into English and re-published.

On August 27th 1971, E.J. "John" Tyler purchased the Torrens collection copy of Auch's book from Malcolm Gardner.

John Tyler took Malcolm Gardner's opinion to heart, because over the ensuing years he produced a typed translation of Auch's book, complete with an introduction. Finished in 1995, the 190 pages of the typescript lay dormant for a few years and then, old age creeping upon him as it does to all of us, John Tyler sold his copy of Auch with his translation to Rita Shenton, a horological book dealer.

In the middle of 2003, browsing Rita's list of books for sale on the internet, I noticed Auch listed there with the translation. Some years ago I, too, had read Malcolm Gardner's comments and thought the book must be interesting, but as my ability to read German was poor I had ignored it. But with an already finished English translation? So, after parting with somewhat more money than John Tyler did, the copy of Auch from the Torrens library flew to the opposite side of the world, just about as far away from the centers of watchmaking as anyone can get, without going to Antarctica or the moon[1].

1 My spelling of *center* may arouse some ire amongst English readers.
I have only a few old books in my collection which predate Auch, all of which I examined. Between 1748 and 1825 seven authors use the spelling *centre*, but between 1747 and 1806 eight authors use the spelling *center*. The sixteenth and last book is Reid, *A treatise on clock and watch making*, 1826. This book confused me! Despite using *center* to begin with, most of the book uses *centre*, and so I reluctantly have to make the result an eight all draw. However, I feel there remains sufficient doubt for me to choose *center*, if only to redress the balance a little.

When I first read the translation I found it difficult to understand, in part because it needed some editing, but due much more to my lack of familiarity with the archaic tools and terminology. Even so, I found Auch's detailed descriptions of early nineteenth century techniques fascinating. However, above all else I felt sad that someone had done all this work and it had never seen the light of day. I had what could properly be called a labour of love which might, when I died, end up in a rubbish bin on a small antipodean island.

Fortunately Rita Shenton knew John Tyler and acted as an intermediary to get a letter from me to him. He was, not surprisingly, pleased by my unexpected letter and my proposal to try and get his translation of Auch published. So I set about editing it.

First, despite Auch suggesting his book could be understood by amateurs, his approach assumes the reader is an apprentice working under a master; and consequently his explanations are frequently terse and incomplete, assuming there would always be a guiding hand close by.[2]

Second, Auch provides an interesting insight into apprentice education. Throughout the emphasis is on learning to use tools and making watch parts with no insights into the underlying principles, and in the very few places where there is an attempt to explain concepts, such as relating balance sizes to pendulum lengths, the reasoning is poor and inexact. Clearly the apprentice was to learn by unquestioningly following instructions.

Auch's approach reflects the education of the times and it is echoed in other contemporary books. François Crespe[3] sums up the situation very well when he says: "*Several erudite books were printed in Paris, but the treatises of Thiout the elder, Berthoud and Lepaute are esteemed. The excessive price of these books prevents the majority of workmen from getting them. ... It is true that these men wrote more for scientists and it is necessary to educate the ignorant who form the majority. As very few can read and understand the descriptions, all the terms of which are unknown to them, it is only those who have studied mechanics who can benefit from them; and they are so few that only one in a hundred bother with them.*" And before him Thomas Hatton, recognising this problem in 1773, attempted to provide some elementary education so that the apprentice (and master!) might have some insight into watchmaking[4].

Third, Auch was a less-than-perfect writer. Although John Tyler performed a near miracle converting highly convoluted language printed in gothic script into reasonable English, the result contained many doubtful and uncertain passages, which is not surprising when we remember that Auch assumed there was a master watchmaker close at hand to sort out the apprentice's problems.

I quickly decided that, if I were to do a satisfactory job of editing, I needed some help. So I turned to the only other book I know of that describes how to make a verge watch in detail: Ferdinand Berthoud's *Essai sur l'Horlogerie*. This treatise, spanning the theory and practice of clock and watch making, finishes with a long chapter giving step-by-step instructions for making such a watch, and so it closely parallels Auch's book.

2 A hundred years later Donald de Carle adopted the same approach when he wrote With the Watchmaker at the Bench.

3 François Crespe: *Essai sur les montres a repetition*, 1804.

4 Thomas Hatton, *An introduction to the mechanical part of clock and watch work.*

Auch was put aside and Berthoud brought to the computer[5]. Unlike Auch, Berthoud wrote concise, simple French and, except for a very few problems, was translated and edited in about a month. But unfortunately, this enjoyable exercise was not very useful and did not help much with editing Auch's words!

More to the point, I was now embarrassed by riches, having two translations on the same subject! Just as I would feel sad if John Tyler's translation of Auch was never made available to other horologists, I felt just as sad at the thought that Berthoud's words might disappear into my filing cabinet. The only solution was to publish both together and hope the reader wouldn't mind the obvious similarities between the two.

This is the result.

Rita Shenton had commented on the Auch translation as tersely as Malcolm Gardner: "in some places slightly misleading unless experienced horologist". That the translation bore this hallmark is perfectly understandable and exactly the same comment applies to Berthoud's writing. If Rita Shenton's words were taken to heart they would require writing a new book, re-organising, filling out the gaps and moving the focus from purely practical experience towards understanding. Neither John Tyler nor I had any intention of writing such a book, and so the translations remain a little obscure and reading them requires a reasonable knowledge of watch making and verge watches.

I do not see this as a significant problem. The casual collector is unlikely to read this book and those people who will be interested in it must inevitably have a strong interest in and a reasonably deep understanding of watchmaking. Also, the modern reader has access to a number of books which the students of Berthoud, Hatton, Crespe and Auch did not. Finally, I have annotated both translations in the footnotes and provided additional illustrations to make the reader's life a little easier.

In addition to the many general books on horology there are five I would strongly recommend:

George Daniels, *Watchmaking*, 1981.

Henry Fried, *The Watch Repairer's Manual*, 1986, several editions.

W.J. Gazeley, *Watch and Clock Making and Repairing*, 1953, reprinted several times.

Claudius Saunier, *The Watchmaker's Hand Book* (translated by Tripplin and Rigg), 1881, reprinted several times.

Leonard Weiss, *Watch-Making in England 1760-1820*, 1982

Acknowledgement

I want to thank Theodore R. Crom for giving me permission to use an illustration from his book Horological Shop Tools 1700 to 1900. I must recommend all of Ted Crom's books, which are superb and beautiful essays on horological tools.

5 Unlike Berthoud, Auch and John Tyler, I am working in the computer age. All the books I work on are scanned into computer files, converted into text using optical character recognition software, and then translated, formatted and edited.

The Plates

The plates from the two books have been renumbered and augmented as follows:

Plate 1: Figures 1, 2, 4, 9 and 10: from Plate 37 of Berthoud's *Essai*. There is no Figure 3 on the original plate.

Plate 2: Figures 5, 6, 7, 8, 11 and 12: from Plate 37 of Berthoud's *Essai*.

Plate 3: Figures 1 - 12: from Plate 38 of Berthoud's *Essai*.

Plate 4: Figures 13 - 19: from Plate 38 of Berthoud's *Essai*.

Plate 5: Figures 20, 21, 23, 24: from Plate 38 of Berthoud's *Essai*.

Figure 1: from Plate 13 side KK of Diderot and D'Alembert *Encyclopedie ou dictionnaire raisonne des sciences, des arts et des metiers section on horlogerie*.

Figures 2 - 4: photographs of turns runners in my own collection.

Plate 6: Figure 1: from Plate 14 side LL of Diderot and D'Alembert *Encyclopedie ou dictionnaire raisonne des sciences, des arts et des metiers section on horlogerie*.

Figure 2: from Plate 10 side CC of Diderot and D'Alembert *Encyclopedie ou dictionnaire raisonne des sciences, des arts et des metiers section on horlogerie*.

Figure 3: from Plate 7 of Berthoud's *Essai*.

Figure 5: from Plate 24 of Berthoud's *Essai*.

Plates 7, 8, 9: Plates 1, 2 and 3 of Auch's *Handbuch*.

Plate 10: Figures 1, 2, 3, 7: photographs of late 19th century tools (a cylinder height tool, a dancing master made by Stubs, a turning arbor and a screw ferrule).

Figure 4: based on in-text illustration from Auch's *Handbuch* page 80.

Figure 5: from Plate 19 of Berthoud's *Essai*.

Figures 8 - 12: photographs of parts of a verge watch signed Chs Le Roy Paris (circa 1780).

Figure 13: figure 5 from Plate 18 of Berthoud's *Essai*.

Plate 11: Development of the calibre for Auch's *Handbuch*.

Plate 12: Figure 1: photograph of the top plate of a verge watch signed Chs Le Roy Paris (circa 1780).

Figure 2: from Ted Crom *Horological Shop Tools 1700 to 1900* (Figure 68, page 50 of that book).

Figure 3: development of a calibre for Auch's *Handbuch*.

Figure 4: ruler and compass method to inscribe a pentagon in a circle.

Richard Watkins

December 2004

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Ferdinand Berthoud

The Construction and Execution of a Watch

in which is included all that can contribute to its accuracy

Translated by
Richard Watkins

ESSAI
SUR
L'HORLOGERIE;

DANS LEQUEL ON TRAITE DE CET ART,

Relativement à l'uſage Civil, à l'Aſtronomie & à la Navigation, en établiſſant des Principes confirmés par l'expérience.

Dédié aux Artiſtes & aux Amateurs.

SECONDE ÉDITION.

Par M. FERDINAND BERTHOUD, *Horloger-Méchanicien du Roi & de la Marine, Membre de la Société Royale de Londres.*

TOME PREMIER.

Avec Figures en Taille-douce.

A PARIS,

Chez J. G. MERIGOT le jeune, Libraire, quai des Auguſtins.
DIDOT fils, = JOMBERT jeune, Libraires, rue Dauphine.

M. DCC. LXXXVI.

Avec Approbation, & Privilége du Roi.

Essai sur l'Horlogerie

Introduction

The following is a translation of part of Ferdinand Berthoud's *Essai sur l'Horlogerie*.

This two volume treatise, first published in 1763 when Berthoud was only 36 years old, is a comprehensive study of clocks and watches, containing both theory and practice.

Volume 1 is primarily descriptive. The first 35 chapters describe clocks, watches, escapements, tools (including wheel and fusee cutting engines), faults in watches, judging new designs, and barometers and thermometers. The last chapter is a 261 page, detailed explanation of how to make a repeating clock by hand, including dial making and casing.

Volume 2 is a technical study with details of Berthoud's own experiments on pendulums and balances. The first 46 chapters include levers, gears, calculation of trains, simple and compensation pendulums, astronomical regulators, the balance, balance springs and isochronism, friction, temperature compensation, descriptions of watches and clocks, two marine chronometers (with details of manufacture), and additional notes. The last chapter is an 83 page, detailed explanation of how to make a verge escapement watch by hand. It is this chapter, titled *Construction and execution of a watch in which is included all that can contribute to its accuracy*, that concerns us at the moment and is the core of the following translation.

Because Berthoud had already described many of the tools and techniques in his explanation of how to make a clock with repetition, the chapter on making a verge watch is quite short. Instead of repeating himself, he makes frequent references to other parts of the book and indeed, his instructions on how to make the watch are scattered throughout the two volumes. Consequently, in order to extract the description it has been necessary to bring these separate parts together.

To present these fragments coherently, I have done two things:

Firstly, I have provided translations of three chapters, chapters 31 and 32 from volume 1 (only including the sections referring to verge escapements) and chapter 47 from volume 2. However, these are presented in the order 31, 47, 32 which is more natural in the present context.

Secondly, I have inserted the text of cross references in the places where Berthoud mentions them, which is not the order in which they were written. Most of these cross references explicitly refer to the clock with repetition, and so they often discuss matters which are irrelevant to, or done differently in, watch making. I have edited them to remove the obvious problems caused by this, but in some places I have retained the original references to clock work where that seemed preferable. Consequently, the reader needs to remember that some measurements and processes require to be modified for watch making.

My focus is solely on practice, on the step-by-step hand-making of a timepiece. And so I have deliberately omitted cross references to principles and theory. This is, in fact, sensible as Berthoud largely ignores theory when he describes watch making.

I take a rather strict view of the word theory. To me, theory means a predictive explanation; for example, the mathematical laws of gravity and pendulums allows one to determine the length of a pendulum with a particular frequency of vibration. Well, it would if gravity was the same everywhere! In contrast, principles are statements derived from experiment and often do not fit nicely into mathematical expression; the values of gravity at many different places are known but can only be tabulated. Closer to home is the table of rules given by Berthoud to determine the sizes of pinions. These are magic numbers resulting from experiment and having almost no foundation in theory.

I am happy to quote Berthoud's principles when relevant, but I avoid any theory that he presents. I leave it to the reader to contemplate the quality of Berthoud's arguments and, except for a couple of notes, I have deliberately avoided expressing an opinion. After all, watchmaking is a mechanical art.

To assist the interested reader, I have retained Berthoud's numbering of *articles*, or paragraphs, so that the translation can be easily related back to the original. And all the cross reference material is indented for clarity.

As my aim is to provide a readable translation, I have replaced obsolete terms (such as *small middle wheel*) by their modern equivalents (*third wheel*), omitted a few sentences which are irrelevant to watchmaking, and re-expressed the text in hopefully reasonable English. Although Berthoud's writing is clear and simple, there were a few occasions when his meaning was obscure. I have loosely translated these sentences, hopefully teasing out the correct interpretation.

Finally, Berthoud's footnotes are all marked by an asterisk (*) while my additional notes are numbered. My notes clarify terminology and ambiguities, and I make no attempt to analyse Berthoud's methods, except for a couple of comments on inconsistencies between theory and practice.

Richard Watkins

December 2004.

The care necessary in the design and construction of a watch.[6]

550. If it were necessary for me to go into all the details of the design and construction of a watch here, it would take me far too long; because this machine requires a great deal of care and attention, which cannot be neglected with impunity. But as I have already exceeded the length that I had proposed for this essay, I will consider only the most essential things. Moreover, the principles which I will establish in the second part of this work and the experiments which follow them will be, I believe, sufficient and will supplement these details.

The regulator

551. The balance being the regulator of the watch and the accuracy of this machine depending solely on it, it is with this part that it is necessary to start the design of a watch.

552. The balance of a watch must have a very light center, and for this it is necessary that the arms and the center have the smallest possible width. The seat of the balance must be very small and light; by this means one gives all possible inertia to the rim, which forms the balance proper, and at the same time the pivots support only a light weight, from which results the least friction and consequently the least deterioration of the motion. It is necessary to remove the angles of the arms and to round them, so that dirt cannot lodge there.

553. The balance being very large, and having its load proportioned to the rubbing parts of the pivots, less wear of the holes and less variations will result.

554. If one makes a heavy balance it is necessary that the pivots are longer without being larger, and that they exactly fit their holes throughout their lengths, so that the load of the balance is divided over the length of the pivots; because in this case, the load being related to a bigger length, each part of the pivot will be pressed on by a smaller quantity, from which less wear will result. Thus if the balance is made lighter by half, one can shorten the pivots by half without them having more or less friction than before.

555. Although one can increase the length of the pivots, and by this means decrease the wear of the pivots and the holes, one cannot in the same way increase their diameter or size with impunity. Because, by increasing the size of a pivot (the load of the balance remaining the same) one increases the friction, which is measured by the space that they traverse and by the loads which bear on them. Lengthening pivots decreases the effect of friction, since, as I said, the load is distributed between more parts; thus the pieces of matter or *eminences*, which form the surface of the pivot, penetrate less into the pores of the hole. It thus follows that: 1, the length of the pivots must be proportional to the weight of the balance; 2, that if one makes very small and longer pivots, their friction will produce less wear on the holes; 3, that if the weight of the balance is reduced, the length of the pivots can be decreased without changing the nature of the friction; and finally, 4, if one decreases the weight of the balance without touching the length of the pivots, the pivots will have a less friction and they will be altered less by the action of the balance.

6 Articles 550 to 577 form chapter 31 in Volume 1.

Ferdinand Berthoud

Observations on making the balance of a watch

556. The *maker of the movement in white*[7] should not finish the balance of a watch; it is the work of the *finisher*. The ebauche workman should do nothing but rough it out and leave it overweight, so that the finisher can carefully complete it. The finisher must start by turning it to a perfectly equal thickness, so that nothing remains but to remove the turning marks and to polish it. The outside and inside edges must be rounded; the rim of the balance must form a ring so that it will experience less resistance from the air. A balance carefully made, and turned true and round is naturally in equilibrium, so that when it is mounted on its staff it is not necessary to remove a little matter from the side opposite to the banking pin[8]; one should not make a notch opposite the pin with a sage-leaf file, as some awkward workmen do when they are obliged to remove much material because the balance is of unequal thickness and out of round. When the balance is too heavy, they remove material by forming a slope underneath which increases the surface of the balance. The best method in this case is to narrow the rim making sure that it remains in the shape of a ring. For the rest, in order not to make a balance while groping for its weight, one will make use of the rules and calculations given in the second part of this work.

557. As for the metal which should be used to make balances, it is obvious that the one which is preferable is that whose specific gravity is largest (that is, which holds the greatest quantity of matter in same volume), because by this means the balance will have less resistance to the air. However, it is known that the specific gravity of steel is 7.738, of brass 8.781 and of gold 18.166; from which one sees that brass is preferable to steel, and gold to brass, since in same volume it contains more than double the amount of matter. Steel is thus the metal least suitable for a balance by reason of it being lighter. There is also another reason to prefer gold or brass; it is that these metals are not effected by magnetism like steel, the action of which can disturb the oscillations of the balance and consequently the accuracy of the watch. Finally, gold is preferable to brass because it is not prone to rust or verdigris. Moreover, gold expands less than brass. It is true that it expands more than steel, as I will show, but this difference is not worth the trouble to take into account, and it is much less than the amount by which the effect of the expansion of the balance can be compensated for in the manner that I explain for the balance spring (see the second part, Chapter 30[9]). One can thus successfully use gold to make balances; by this means one will partly overcome the effect of the resistance of air, magnetism, rust, etc. But it is necessary to use gold alloyed with copper, so that it can be hammer-hardened well to prevent the balance being easily bent. The gold that I use for my balances is 18 carat.

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7 The ebauche.

8 *cheville de renversement*, literally pin of inversion. Without this pin it is possible for the verge to rotate so that both pallets are out of mesh with the escape wheel, allowing the train to run freely and almost certainly causing some damage. Berthoud's remark only makes sense if the balance is made of gold and the banking pin of brass or steel so that it lightens the balance on that side.

9 This chapter examines the effect of heat and cold on watches. It is not included in this translation.

The escapement

558. I will show in the second part that the larger the arcs described by a balance, the better it acts as a regulator. Indeed, a watch must have a greater accuracy when the vibrations of the balance are less affected by the motion of being carried. However, it is understood that the faster these vibrations are done the less they are influenced by this movement. It is thus necessary to make the escapement so that the arcs described by the balance are large and always of the same extent. For this, it is necessary to reduce the friction in the escapement to the smallest possible quantity. It is necessary that the teeth of the escape wheel are as close together as is possible, so that there is the least drag on the part of escapement on the verge, since the width of the pallets depends on the size of the escape wheel teeth.

Remarks on the escapement of a verge watch

559. I will show in the second part, by reasoning and experiment, that the isochronism of the vibrations of a regulator depends to some extent on the amount of recoil in the escapement in relation to the space traversed by the wheel. From this it follows that it is possible to make a verge escapement which is nearly isochronous. Because, if one makes the teeth of the escape wheel approach very close to the center of the staff, one will be able to find a point where the recoil of the escape wheel is very small and will have this relationship to the space traversed by the wheel; the oscillations of the balance will thus be isochronous.

560. The isochronous verge escapement cannot be used with a pendulum because of the large arcs which it requires.

561. To make the verge escapement so that the wheel passes very close to the center of the balance, it is necessary to notch the pallets, as is done in pendulum clocks.

562. To prevent this escapement banking, it is necessary to open the pallets beyond square; that is, to approximately 100 degrees.

563. It is necessary to take care that the pallets are of the exactly the same width, and that the arbor of the escape wheel is perpendicular to the verge staff.

564. If the teeth of the escape wheel are left too strong or a little open, the pallets are prone to rub; to cure this problem one is obliged to give too much drop to the wheel, a defect which it is necessary to take great care to avoid.

565. It is necessary to observe that verge watches with slow vibrations are very defective, because the balance is heavy and consequently has much inertia, and so the movement while the watch is carried makes them prone to bank. Because in such escapements the balance can only describe approximately 240 degrees, but the arc of vibration of the watch differs only a little from 240 degrees, and the least jolt makes the banking pin hit against the slide. Watches whose vibrations are rapid and whose balances are light do not have this defect. They must beat approximately 18,000 vibrations per hour.

566. We will observe here that it is necessary to make the rosette wheel as large as possible, so that the rack moves further; then when the oil thickens one is not obliged to shorten the balance spring, but one can advance the rosette hand enough to adjust the watch. It is also

necessary to use balance springs which make several turns, so that a degree traversed by the rosette hand does not advance or retard the watch too much. The top plates of English watches are preferable to ours because the rosette wheel can make several turns and the rack can move further, which joins together two advantages: 1, to have the longest balance spring; and 2, the distance which the rack can move is more than sufficient to regulate the watch at all times, without being obliged to touch the stud and shorten the balance spring. One will unite these two advantages in our top plates by employing a large rosette wheel and a long balance spring.

567. If the balance cock of a watch is too thin, heat and cold will be able to dilate and contract it, so that it will give too much or not enough play to the balance; especially if this cock were badly hammer-hardened. This effect will make the watch vary. The upright parts in the frame are exposed to the same defect. Thus one cannot pay too much attention to making all the parts stable, and giving suitable play to the wheels and the balance; so that in spite of the continual variation of the metal the accuracy of the machine will not change appreciably.

The train of the watch

568. The perfection of a train depends on the exactness of the teeth of the wheels and pinions, which must be such that: at all points where these wheels and pinions touch, the motive force acts with an equal power on the regulator. The perfection of the train also depends on proportioning the diameters of the wheels and their loads with the size of the pivots, the force of the motive power and the running time of the watch.

569. To meet these conditions, it is necessary: 1. So that the gearing is good and it is not sensitive to inequalities of the curves of the teeth, it is necessary, I say, to use a pinion of the greatest possible number of teeth. Then the driving will be done as if the wheel actuated the pinion by simple contact. In order not to increase the diameters of the wheels when increasing the number of teeth of the pinions, it is necessary to increase the number of teeth of the wheels. Because, even though they are smaller, their strength will always be sufficient for the force they receive from the engine; moreover, by being smaller they become shorter.

570. 2. It is necessary to make the lightest wheels possible without harming their solidity; by this means there will be less friction on the pivots.

571. 3. It is necessary to proportion the size of the pivots to the load on the wheels and the force which makes them turn. Thus the pivots of the center wheel, being immediately driven by the engine, must be longer and of a larger diameter than the others. The pivots must decrease in size and length in proportion to the force which moves them. Thus the force transmitted by the leaves of the escape wheel pinion being very small, its pivots must be smaller and shorter. This is a continuation of the remarks on the balance.

572. The gearing of the contrate wheel with the escape wheel pinion requires much care. It is especially necessary to make sure that the contrate wheel does not have any end play, because if it did the meshing would be strong or weak depending on whether this wheel approached one or the other plate. For the same reasons it is necessary that this wheel is strong and it cannot be bent, because then the meshing would be alternately strong and weak.

573. When one lays out the calibre of a watch, it is necessary to ensure that no parts pass over pivot holes, for such a part would attract all the oil contained in the sink, which would cause friction, the pivots to corroded, etc. For the same reason, wheels and pinions must be mounted a little away from the pivots. That is, it is necessary have between the pinion and the plate a part of the arbor which is called a *pivot shank*, which prevents the oil for the pivot flowing to the pinion.

574. As for the bridges and barrettes which are used to create pivot shanks, I agree that they are of value when they are perfectly adjusted. But as very few workmen are careful with these delicate adjustments, I advise the removal, as far as possible, of these pieces and the use of simple plates. They are more solid and simpler; and to allow for pivot shanks the frame should be given more height.

575. Counter-potences are rarely well made, so I still prefer a simple stud.

576. The chain-guard which is called *à plot* is preferable to that with a simple spring[10].

The motor of the watch

577. Finally it is necessary that the motor or mainspring always acts equally on the train, and that the force it transmits to the regulator is always the same; without which the regulator will make vibrations of unequal in duration according to the inequality of the force which drives it. For this it is necessary that the fusee is equalized perfectly with the mainspring.

10 Literally *with stud*, which is the chain guard shown in Plate 2, fig. 6. The other form is a simply a spring with an integral lever.

Ferdinand Berthoud

The construction and execution of a watch in which is included all that can contribute to its accuracy[11]

2361. After having concluded all my efforts to discover the principles of the accuracy of watches, and to establish a theory which serves as a basis for the construction of these machines, I believe I have put myself in a position to give to a watch the most advantageous design, so that this machine measures time with all the accuracy of which it is capable. It thus remains for me to describe the design and construction of a good watch, and the most essential details which contribute to this goal; it is the task which remains for me to complete this work.

2362. I propose the construction of a simple verge watch whose movement is large, for the following reasons.

2363. I choose a verge watch because: First, I believe it most suitable to measure time with precision (see Art. 559, page 7). I will also observe here that the verge escapement has an essential advantage; it produces a very large movement of the balance with a very small space traversed by the escapement, from which it follows that it has little friction; the pallets are not seen to be marked after several years of running. Friction is thus constant, unless by accident oil is communicated to the pallets; then they are hollowed out and the watch varies, but this defect is easy to avoid.

2364. Second, because these kinds of watches can be made and repaired by ordinary workmen.

2365. Third, because such a watch will last much longer without needing to be repaired. Because the escapement has as little friction as is possible; and as for other frictions, we will render them as constant as it is possible by our construction.

2366. Fourth, I prefer a large watch because: 1, it has, according to our principles, a greater momentum; and 2, it is much easier to give to each part the required perfection, not only for construction, but also for the arrangement of the parts; because such construction can be done in a large size but would be very difficult to achieve in a small size.

Our current aim relates only to the highest perfection, and the difficulties which one has in making small watches do not tend to give more accuracy, and are therefore of no purpose. I look at them as defective in their capacity as watches; they are nothing more than jewels. I acknowledge however that these trinkets make the fortune of many watch makers, and I sell them myself, but after having explained what I think of them. For the rest, these small watches go well when they are perfectly made, provided that they are not cleaned by bad workmen and they are not damaged by accidents.

11 Articles 2361 to 2561 form chapter 47 of Volume 2.

Preliminary observations to be used for the design of the watch and to trace the plan or calibre of this machine

2367. The calibre of a watch is a brass plate of the size to be given to the pillar plate[12]. One projects on this calibre all the parts of the watch, the wheels, balance, parts on the plate, etc.; in a word, the calibre contains all dimensions of the machine. There is nothing so common as the manufacture of calibres; even the least worker gives himself the airs to trace them. However, there is nothing more difficult and more essential; because to do it with intelligence it is necessary to have in one's head all the principles which have been examined above. And it is necessary to join experiment to these principles; it is only then that I can begin to create a good design for a watch. I thus propose only to give a description. I do not claim that my rules are always exact and I only propose the results of research. I will give some opening remarks which should be used as a basis; and as for their application, we will be regulated by experiment.

2368. The constant accuracy of a watch is founded on two principals. The first is the harmony or relationship between the regulator and the motor; the principles which I established above for compensating the effects of heat and cold. The second is the constant uniformity of friction. I treated the subject of friction above; but here it is examined in connection with the means of making friction constant.

2369. With respect to friction, one should not lose sight of the following principles: 1, that *it is not the absolute quantity of friction with which it is necessary to be concerned, but its constant uniformity*; and 2, that *the time of oscillation of a body will always be the same if resistance to the movement is always the same, so that the motive power acts with a constant force.*

2370. In watches all their accuracy is based on the constancy of friction; because even the compensation for various temperatures is founded on friction. Thus our aim is to make friction constant.

2371. I showed that to decrease, as much as is possible, the inequalities produced by the driving force, it is necessary to give a large momentum to the regulator; and, the motor being powerful, changes in the oil would cause a smaller decrease in the movement. We will establish by experiment the limits of this moving force.

2372. Another consideration which one should not lose sight of with regard to friction, is to enlarge the surfaces of the rubbing parts, because of the pressure and to give them a suitable size to avoid wear.

2373. I have said that to divide the pressure between each pivot it is necessary that the force acts in the middle between the two pivots. This consideration is very essential to decrease friction and to make it constant.

2374. Finally, to make friction constant it is necessary to use large oil sinks for the pivots, so that the oil that one puts in them remains fluid for a long time.

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12 Berthoud uses *cuivre*, copper, throughout, although it is clear that he means brass. When he means copper he writes *cuivre rouge*.

2375. I have said (Art. 565, page 7) that verge watches must beat a greater number of vibrations than those with a cylinder, in order to avoid the banking pin of the balance hitting against the slide, a defect which causes the watch to vary when it is carried. This is a particular consideration with verge watches, but I must observe that in general it is preferable that there is a greater number of vibrations when the momentum must be large. Because, with slow vibrations one needs a heavy balance and the pivots are liable to be broken by the least fall. It should also be observed that the friction in the escapement becomes more harmful; because supposing the same momentum in the balances of two watches, one making five vibrations a second and the other one, and that the wheels have the same number of teeth, thickness, diameter, etc., then the force on the circumference of the wheel for the watch with slow vibrations will be to the force of the other wheel as 5 is to 1. Thus the pressure on the cylinder will be five times larger and its destruction sooner. It is true that, in the watch with faster vibrations, five times more distance will be traversed by the escapement; but if the thickness of the wheel is proportional to the pressure, wear of the parts will not take place as in the other watch whose wheel has the same thickness; thus friction will be more constant. To correct this defect in a watch with slow vibrations which has a greater momentum, it is necessary to increase the thickness of the wheel in proportion to the force which it has at its circumference. It should then be supposed that the teeth are formed exactly, so that they relate on all their points to the escapement; because if that is not the case, friction will be the same as if the teeth were thinner; however in this case, faster vibrations by a thinner wheel will produce this effect less ambiguously.

2376. These are the main considerations which must guide us in the construction of our watch. It is now necessary to go into the details of construction.

2377. The balance is the principal part of a watch, and its dimensions will determine all the parts of the machine, because the force of the mainspring must relate to the momentum of the regulator; and the size of the wheels, the numbers of teeth, etc. relate to the action of this mainspring. To correctly build this regulator, we will do so according to a watch made to my principles, whose accuracy is very good and which has suitable dimensions. In this watch the balance is 10 lignes in diameter and it weighs 7 grains, the arcs of lifting are 40 degrees, and it makes 17333 vibrations per hour. To maintain the movement of this regulator, one needs a mainspring whose force counter-balances 6 drachm applied at 4 inches from the center of the fusee[13]. This is what determines the height of the frame and its diameter.

2378. To have a mainspring able to produce this force, it is necessary that the barrel is 2½ lignes high and more than 8 lignes in diameter; that gives the pillar plate a diameter of 18½ lignes. Plate 1, fig. 1 represents the inside of the plate on which the calibre is traced.

2379. The barrel *c* is put beside the fusee *d*; by this means it has the full height of the frame, from which two advantages result. The first is that the spring is better. The second is that the barrel is less likely to waver on its axis, and that the lid and the bottom can have bosses which give thick holes which will not enlarge, and have, moreover, oil sinks to make the friction constant.

2380. It is necessary that the center wheel *f* is inset in the thickness of the pillar plate; because, 1, the barrel, as I have just said, has the full height of the frame; and 2, the fusee also has the full height of the frame, so that one can use a good English chain.

13 *gros*, drachm. Ambiguous, but most likely one sixteenth of an avoirdupois ounce.

2381. It is necessary to distribute the third and contrate wheels so that the foot of the potence can be flush with the plate, so that the escape wheel is as large as possible; on which, however, there remains a pivot shank to keep oil away from the pallet, which also moves away from the pivot the force that the bottom pallet receives from the wheel. The positions which I give to these wheels in the calibre satisfy these conditions. They have, moreover, the advantage of making the watch easy to assemble, which is not the case with ordinary watches; in them the third wheel passes between the top plate and the escape wheel arbor.

2382. I give the frame just enough height for the barrel and the escape wheel, and I increase the height of the space under the dial. By this means I have very high bridges under the dial; thus the pressure of the wheels is in the middle of the length between the two pivots. See Plate 1, fig. 4, which shows all the wheels of the watch in profile and arranged on the same line; this figure presents, in an easily understood way, the elevation of each part of the watch.

2383. To facilitate the execution of the wheels, they are made as large as the space allows. But to determine their size exactly, relative to their position, it is necessary to have regard to the number of teeth which these wheels must have compared with those of the pinions; so that these wheels are made and positioned with the gearing as close to their true point as is possible. Thus all the wheels do not equally approach the center of the pinions in which they gear, because that varies according to whether the pinions have more or less leaves, and whether there are greater or fewer revolutions for one revolution of the wheel which drives them. For example, the fusee wheel, which must have 54 teeth and gear into a pinion of 12 (thus making 4½ turns for 1 of the wheel), must approach the center of its pinion less than the center wheel which has 60 teeth and engages a pinion of 6 (making 10 turns for 1 of the wheel), because this pinion must be much smaller than one of 12 leaves. Thus to trace the true sizes of these wheels it is necessary to find the number of teeth of the wheels and pinions; and one consequently traces the wheels by estimating the point engagement, which is judged by the ratio of the size of the pinion to the diameter of the wheel. But one can only determine these sizes correctly when one has made a part according to the calibre, and then it is retouched subsequently. *c* (fig. 1) is the barrel; *d* the fusee; *f* the center wheel: *g* the third wheel; *h* the escape wheel.

2384. To regulate the number of vibrations in a verge watch, it is necessary to consider, as I have already shown (Art. 565, page 7), that the balance should not make slow vibrations because of the banking to which it would be prone when carried in a pocket. I make the beat of the balance in this watch 15600, when the watch is without seconds[14]. And as this calibre is laid out so that one can make a watch with eccentric seconds, the hand carried by the contrate wheel, I then use a beat of 14400. Here I give the numbers of teeth of the wheels and pinions in both.

Ordinary watch

2385. Fusee wheel 54, engaging a pinion of 12 which carries the center wheel. The center wheel has 60 teeth and engages a pinion of 6 which carries the third wheel. The third wheel has 48 teeth; it engages a pinion of 6 which carries the contrate wheel. The contrate

14 Compare with Art. 2377 on the previous page.

wheel has 45 teeth and engages the pinion of the escape wheel which has 13 teeth. It is preferable not to give 13 teeth to the escape wheel; because the diameter of this wheel being given, as well as the size of the body of the verge, the fewer teeth this wheel has the larger is the arc of lifting, and that of recoil will be in a lesser relationship to that of lifting, the condition which leads to isochronism (Art, 559, page 7).

Seconds watch

2386. Fusee wheel 54, engaging a pinion of 12; center wheel 60 engaging a pinion of 8; third wheel 48 engaging a pinion of 6; contrate wheel 48 engaging a pinion of 6; escape wheel 15.

2387. The wheels having been traced, the size of top plate is marked concentric with the pillar plate. It should be made smaller because of the hinge attached to the pillar plate. When the watch is opened, the edge of the frame opposite the hinge describes an arc of circle with the hinge as its center. As the top plate must pass the opening in the case, it needs to be smaller than the pillar plate because of the height of the pillars; this is what is called *Embichetage*[15] (see Plate 10, fig. 6).

2388. When the positions of the wheels contained in the frame have been traced on the calibre, then the top of the plate is traced on the same side of the calibre; that is, all the parts set on the top plate like the cock, the slide parts, the rosette, etc.

2389. The balance is traced according to the disposition of the parts inside, which must combine strength with using the space suitably, so that the foot of potence goes down flush with the pillar plate; there is by this means a larger escape wheel. The balance must be located as near as it can be to the center of the frame; by this means the watch case can be made lower.

2390. The balance position on the calibre, as seen in Plate 1, fig. 1, is marked by the cock, whose size must be the same as that of the balance; thus the two features merge. For indicating the cock, it is necessary to trace the direction *tu* of the feet for the screws. However this direction depends on the place where the rosette is put, because the feet of the cock must be perpendicular to the line which passes from the center of the rosette to that of the balance. To place the rosette, a position should be chosen where no pivot holes are covered, either by the slide or the feet of the cock; because I have already pointed out that when a part passes over the sink of a pivot it attracts all the oil contained in this sink. It is also necessary to choose, as far as possible, a place for the rosette so that it is as big as possible; because it is necessary that the wheel of the rosette is large so that the rack traverses a large space. By this means, all the changes which can occur in the oil, friction, etc. never makes it necessary, as frequently happens, to lengthen or shorten the balance spring at its stud. Also, the rosette must be large so that its divisions are more sensitive.

2391. To trace the top, the rosette *p* (Plate 1, fig. 1) will be placed between the barrel and the fusee. It needs to be rather distant from the hole of fusee, to place one of the feet of the slide between the rosette and the cock for the fusee. The other foot of the slide must be at the same distance from the center of the rosette as the first. The rosette must be attached by two screws, as shown in Plate 2, fig. 8; by this means the figures and divisions

15 See Plate 10, fig. 5. With an 18 ligne pillar plate *d*, ½ ligne for the case seat, and a pillar height *p* of 4¼ ligne, the maximum size for the top plate *t* is about 15 ligne.

engraved on this dial are not covered and the rosette sits better on the plate. The feet *6*, *8* (Plate 1, fig. 1) that the rosette has for these screws, must be positioned so that they do not touch the feet of the slide; and it is necessary, as far as possible, that these feet of the rosette are close to the middle so that it is fixed firmly. To give a symmetry to these parts, which does not harm the quality of the machine, it is necessary to place them on an arc of a circle drawn from the center of balance, and for their distance from the center of the rosette another arc is drawn, whose intersections with the first determine the position of the screws. The feet *l*, *l* of the slide are placed in the same way and at the same distance from the center of the balance.

2392. The wheel of the rosette *m* is traced, as large as it is shown on the calibre; it can be seen that this brings the rack much closer to the center of the balance. The reasons why I give this arrangement to the slide parts are: 1, by having a large wheel for the rosette the movement of the rack is increased, and this allows the watch to be regulated even though the oil has thickened very much, etc. (Art. 566, page 7); 2, one usually makes the banking pin strike on the end of the slide, and this pin passes over the rack and often touches it, which stops the watch. Or the pin passes over the slide, and in this case the watch or the motion work stops and the escape wheel is bent out of shape against the pallets. It is true that these accidents rarely occur in carefully made watches; but then one is obliged to make the slide thicker which makes the cock higher, which is unnecessary; 3, the wheel of the rosette being large, the space traversed by the rack increases in proportion. It can happen that when the slide is cut to a suitable length to stop the banking pin, the rack would be almost entirely exposed and its adjustment less certain. I cure these problems by leaving a large width outside the rack. Then, to make the banking I form the notches *p q* on the slide, as shown in Plate 2, fig. 8, and the pin, which can be very long, turns around the rack and the material left for the slide, and strikes against the end of the notch, which is moved back as is necessary. I keep the slide as long as it is needed to cover all the way traversed by the rack. As the ends of the slide are rather far from the screws which fix it to the plate, it could happen that these ends rise up when the rack is moved; to avoid that, two claws are fixed on the plate to hold the slide against it.

2393. The coqueret[16] which holds the top pivot of the balance is traced. It will be noted that this pivot is almost always broken by the least fall of the watch. To prevent this accident, in place of the simple coqueret for the balance I use a bridge which moves the pivot away from the balance, so that the balance is also close to the middle of its axis. Then the pivot shank passes with just enough freedom through a concentric hole in the cock; this hole should not be too large. By this means, if the watch falls the arbor bends and the pivot shank receives all the effect of the blow, so that the pivot does not break. But nevertheless, should that happen the accident would be confined there; because the train could not run, nor the teeth of the escape wheel be blunted, as almost always happens to watches where the balance pivot breaks. But if it happens that the fall breaks a balance pivot in my watches, here is how it should be repaired. The pivot shank of the broken pivot is adjusted, and a hood is put on it, on which is made a pivot of the same dimension as that which was broken. To make this hood *ef* (Plate 2, fig. 11), one bores a piece of quite pure steel on the turns, of a size suitable to form a solid cannon around the pivot shank. The hole must be the size of the pivot shank (that is, suitable for the pivot shank to just enter it), and the depth of the hole must be a little less than the length of the pivot shank, because this pivot

16 The steel piece which forms the end "stone" or end-play bearing for the balance staff.

shank must be shortened, so that the pivot which is formed on the hood does not cut into the hole, and there remains some matter as shown in figure 11. The hole being made, one works a broach in it to make it smooth and of a size to go with force on the pivot shank. Then a point is formed on the end where the pivot will be and the hood is put on a turning arbor. The point is thrown so that the arbor runs smoothly and, in this state, the hood is turned and given approximately the shape which one sees in *ef* (Plate 2, fig. 11). That done, it is hardened and tempered to a yellowish blue[17]. The hole is cleaned, it is driven onto the pivot shank to the bottom, and the point is thrown if the balance staff and the balance do not turn truly. That being done the hood is turned for its full length, making the pivot. The hole in the cock is enlarged so that the hood passes through it freely, and the pivot is shortened if the balance is too high in the frame, etc.

2394. When the top pivot of the fusee runs in the plate, the oil which is put in its hole is often attracted by the fusee beak, which is extremely close to this pivot. It is to avoid this defect that I use a cock for the fusee. But it is necessary to make it more solid than cocks are commonly made, because: 1, it must not be bent by the force that it receives when the watch is wound; and 2, it is necessary that the part which receives the pivot is very thick, in order to have a sink which holds much oil. This cock is traced on the calibre; it should not be thin as much depends on its solidity. I consider elegance in useful machines, such as those which measure time, only consists in the intelligence which the artist employs in their design, to have a suitable solidity for each part, and in the accuracy of the rate of the machine.

(In connection with this pivot, several authors who have written on horology are grossly misled when they have said: The top pivot (of the fusee) should have a much smaller diameter than the lower pivot. That is contrary to any principle of mechanics; because it is as if they said that because the wheels of large clocks are heavier than those of a watch, it is necessary to make their pivots smaller. Very far from holding that top pivot of the fusee should be smaller than that of the base, on the contrary it is necessary (the pivot of the base being of good size) that the number of the rubbing parts of the higher pivot should be to the number of the rubbing parts of the lower pivot, as the pressure at the top is to the pressure at the base; so that the friction will be equal on each pivot, and it is constant.)

2395. The top having been traced, it is necessary to mark the positions of the pillars, so that they obstruct neither the wheels contained within the frame nor the parts on top of the plate. The ends of the pillars or pivots, which are pinned to assemble the frame, should pass under neither the cock nor the rosette, but even be rather distant from them so that the pins are not to near any of these parts in order to be able to remove them. It is necessary that the pillar located between the barrel and the fusee wheel does not come too far inside the frame, so that it does not touch the chain when the watch is unwound; that is, the chain surrounds the barrel and there is no more than part of a turn on the base of the fusee.

2396. To decrease the friction which affects the pivot on the outer end of the escape wheel, it is necessary, instead of placing the counter-potence on the edge of the plate and having the arbor pass beside that of the contrate, to place the counter-potence inside, between the contrate arbor and the potence, as it is shown in Plate 2, fig. 6, where *no* represents the counter-potence. From this it will result that: 1, the two escape wheel pivots will

17 Hardening and tempering is described in Art 834, page 41.

experience an equal pressure, which will allow these pivots to be smaller than would be the case without this provision; 2, the engagement with the contrate wheel will be better; and 3, the hole in the nose of potence, in which the inner pivot of the wheel runs, will not wear oval, as happens from the bad arrangement that is given to this part. Thus the escapement will constantly remain the same. One will thus draw a line *yi* (Plate 1, fig. 1) from the center of the contrate wheel to the center of the balance; this line indicates the arbor of the escape wheel. And one will draw from the center of the balance a line *iz* perpendicular to the first, which will indicate the line of the movement of the potence nose.

2397. The barrel being the full height of the frame, one will not be able to place the movement hinge under it, as is practised. So it is put beside the barrel towards the fusee. From the point *a* where the hinge will be, a line is drawn which passes through the center of the calibre. The point *a* on the calibre also represents the position of midday. The opposite point *b* is also marked, being the place of the dial spring.

2398. The calibre thus being traced, holes are bored for each center, wheel, screw, etc. One should not use the same drill for each hole; because those of the pillars must have a diameter of approximately half a ligne; those of the barrel, fusee and the screws of the rosette and slide ⅓; those of contrate and third wheels ⅛; etc.

2399. The holes being bored, one will mark a small line at *a* on the edge of the calibre; this will be used to trace a line *ab* on other side (Plate 1, fig. 2), which passes from the place marked on the edge through the center; this line indicates the position of midday.

2400. On this side of the calibre will be traced the bridge in which the pivots of contrate and third wheels run, as shown at *ik*. To make it solid it is attached by two screws which are marked on the calibre.

2401. By giving the barrel the full height of the frame, as I do here, one cannot use an endless screw to set up the mainspring. So it is necessary to employ, as one does in clocks, a ratchet and click. This method is infinitely preferable, because endless screws are very difficult to make well, there is more work, few workmen do them well, and besides, they do not have any advantage. The click-and-ratchet work to retain the barrel arbor will be set under the dial. This click-and-ratchet work is traced, as one sees it at *gh* on the calibre; the ratchet *g* must be steel. When the watch has repetition, the click-and-ratchet work cannot be placed under the dial, because of the toothed rack[18]; then it is put under the barrel on a square like the wheel of an endless screw, and the click is set up in the same way on the plate below the barrel.

2402. To determine the size of the ratchet for the click-and-ratchet work of the barrel arbor, it is first necessary to trace on the calibre the hour and minute wheels; it is necessary to place the minute wheel between end *i* of the bridge and the ratchet *g*. To determine the size and the position of these wheels, one will be controlled by the number of their teeth and the pinions which drive them. Here the cannon pinion has 10 teeth; it engages the minute wheel which has 30; the pinion which carries the minute wheel is 8; it engages with the hour wheel of 32 teeth. These wheels will be traced accordingly, and then the ratchet is made as large as possible without obstructing these wheels; see Plate 1, fig. 2.

2403. When one designs the layout of a watch, it is necessary to use all the space available to disperse the parts from each other. Our enamel dials, for example, are rather convex,

18 The *cremaillere*, toothed rack or winding rack.

and in order to profit from this it is necessary to raise the motion work or dial wheels. For this, it is necessary: 1, to make a deep recess as shown in Plate 1, fig. 4, to move the pivot of the center wheel as far away from this wheel as is possible; and for this reason it is necessary to benefit from the thickness of the plate, to which I add a bolster or false plate as is seen in the profile[19]; this bolster provides me space for bridges which lengthen the pivot shanks so that the pressure of the wheels is in the middle of the arbors. And 2, it is necessary to raise the cannon pinion *c* far enough above the oil sink of the center wheel pivot hole, so that it cannot attract oil from it. Finally, by this arrangement the minute wheel *e* (Plate 1, fig. 2) is high above the plate, which reduces the friction that is produced when it turns on the plate as is normally practised. However, to further decrease the friction of this wheel, it is necessary to make it run on two pivots, one of which is in a hole in the plate and the other in a hole in a bridge. By this means one will remove any doubt about the play which it must have; because by the ordinary method this wheel is retained by the dial, so that I almost always see these wheels having too much play, to the point of being able to disengage from cannon pinion. When the dial is put on, one cannot see how near the wheel approaches; by the means that I employ, the least skilful can arrange this bridge *d* as it is traced on the calibre and shown in figure 2. Even though this wheel is fastened by a bridge and its pivots, it is necessary to bore the pinion though its length, which will facilitate the execution of the pivots, because then one can turn the whole on a turning arbor.

2404. For the pivot shank to be a good length below the fusee wheel, and to prevent the oil in the sink from being attracted away, it is necessary to make a deep recess in the plate, leaving only enough thickness to firmly rivet a bush there, which is left projecting under the dial, so that the hole has a suitable thickness and there is a sink which holds ample oil. See *gg* Plate 2, fig. 7.

2405. To render the frictions constant, it is essential, as I have already said several times, to make good sinks to hold ample oil. To achieve this when a plate is thin it is necessary to put in thick, projecting bushes so that there remains a suitable thickness beyond the hole to form the sink; it is necessary that the bush be at least twice the length of the pivot. When one puts in barrettes[20] to lengthen the pivot shanks, it is necessary that these barrettes are thick, and if they are not it is necessary to put thick bushes in them. There are many watches which sin thereby, where the oil is in such a small quantity and the hole so thin that it wears and the oil dries up, which damages the watches and they run badly. These projecting bushes of which I speak have another advantage, which is that they protect the oil contained in the sink from dust. It would be very desirable to cover all the holes, because: 1, oil is less attracted from the sink, because it is isolated and retained in its hole; and 2, the dust which falls on the plate stays on it without entering the sink.

2406. I must observe here that one should not use blind holes for pivots. This method is very bad, because the oil which is inside the hole is not renewed, so that the particles which are detached by friction and the atoms which stick to the oil do not have a way to leave the bottom of the hole. Thus the oil is soon blackened, corrodes the pivot, and removes all freedom in the movement. It is for these reasons that it is necessary to make

19 The false plate is a ring which raises the dial to allow more room for the *cadrature*, the dial work, such as the motion work or repeater work. Often it is a separate plate attached to the pillar plate by dog screws, but in Berthoud's watch it is an integral part of the pillar plate.

20 Thin cocks or bridges. There is no English equivalent.

use of counter-potences for escape wheels. I have said in Art. 626 (page 91) that it was necessary to use a blind hole in the nose of the potence to carry the escape wheel pivot, in order to prevent the pallet carrying away the oil, but I had not examined this matter with enough attention. I acknowledge that it is not the only article which I need to correct.

2407. While putting the balance in place, to avoid the bottom pallet taking oil from the sink of the escape wheel pivot, it is necessary to cover this hole with a small, thin plate of steel; this plate will receive the end of the pivot. A boss is put behind nose of the potence to retain oil.

2408. To give to the plates and bars the required thickness, it is necessary to know what will be the lengths of the pivots which must run in them. The proportion which should be followed to determine the lengths of pivots is that they must be double their diameter; that is, if a pivot has a diameter of ¼ of a ligne, it is necessary that its length is half a ligne.

Having given these preliminary observations on the construction of a good verge watch, I will now describe all the parts of it.

Description of the watch[21]

2409. Figure 4 (Plate 1) shows the movement of the watch in profile, with all the wheels placed on the same line and the plates cut by the holes; it is, as I said, to show the elevation of all the parts of the watch. *AA* is the pillar plate, *ee*, its thickness; *aA*, *aA*, the bolster or false plate; *cc*, the bridge retained in the center for the pivot shank of the center wheel; *BB*, the hollow formed by the false plate; *CC* is the top plate (the pillars are not shown here; figure 1 of Plate 3 shows one); *D* is the barrel with the chain which surrounds it; *E* is the fusee; *F* is the fusee cock; *d* is the recess in the plate so that the lower pivot of the fusee has a larger pivot shank; *gg* is the seat or bush riveted to the plate to form the wide fusee pivot hole and the sink for oil; *G* is the fusee wheel; *h* is the pinion of the center wheel which engages with the fusee wheel; *I* is the center wheel which engages with the pinion *k*, on which the third wheel *L* is riveted; the top pivot *1* of the third wheel runs in a hole made in the top plate, and the bottom pivot *2* in a hole made in the bridge *ff* fixed with two screws and two steady pins on the outside of the pillar plate[22]; the elevation of this bridge depends on the height of the false plate and the curve of the dial, indicated by broken lines from *A* to *A*. The third wheel *L* engages with the pinion *l*, on which the contrate wheel *M* is riveted; the top pivot *3* of the contrate wheel runs in a hole in the top plate, and the other *4* in a hole in the bridge *ff*; the contrate wheel engages with the pinion *m*, on which the escape wheel *N* is riveted; the inside pivot of the escape wheel runs in the hole made in the nose of potence *O*, and the other pivot runs in the hole in the counter-potence *n*. The verge *op* has two pivots of which the top one *p* runs in the hole made in the coqueret *P* fixed with a screw and two steady pins onto the cock *Q*; the cock is fixed onto the top plate by two screws and two steady pins; the lower pivot of the verge runs in a hole in the foot of the potence *O*. The verge carries two pallets which gear into the teeth of the escape wheel, which forms the escapement. The balance *RR* is riveted on the seat

21 Another, useful description is in Henry Fried, *The Watch Repairer's Manual*, 1986

22 Compare this arrangement with the conventional verge watch shown in Plate 9, figs, 21 and 22.

5 soldered to the verge *op*. *rr* represents a cut through the slide and the rack attached to the top plate. It is necessary that the balance does not approach too close to either the bottom of the cock or of the top of the slide, so that dust which could settle there cannot stop the movement of the balance. The steel plate *s* is used to receive the end of the verge pivot, so that the shoulder does not rub on the coqueret. I omit the agate stone that is quite commonly used, because it occupies vertical space that is better employed to increase the pivot shank *p*; moreover this plate is made extremely hard and the pivot will not pit it. This plate is fixed by the same screw *t* which holds the coqueret on the cock. The top pivot *6* of the center wheel runs in the hole made in the center of the top plate, and pivot *7* runs in the bridge retained for it in the center of the pillar plate. The extension *78* of this pivot carries the cannon pinion *u* which gears with the minute wheel *S*; that wheel is riveted onto the pinion *x* which has two pivots, one *9* running in a hole made in the pillar plate, and the other *10* in a hole in the bridge *T10* attached by a screw and two steady pins to the plate. The pinion *x* gears with the hour wheel *V* riveted on a cannon which runs on the cannon pinion. End *11* of the cannon pinion is squared and the minute hand *X* is set on this square. The pin *z* passes through the end of the pivot of the center wheel and holds the cannon pinion u11 on the arbor. The hour hand *Y* is held by friction on the cannon of the hour wheel. Pivot *12* of the barrel arbor runs in a hole made in the top plate, and pivot 13 in the pillar plate; the projecting end of this pivot is filed square to receive the ratchet *Z* of the click-and-ratchet work; the extending end *14* of the square is used to give the correct set up to the mainspring contained in the barrel *D*. *15* is the square of the fusee which is used to wind the watch. The notches *16*, *6*, *1*, *3*, *gg*, *7*, *2* and *4* that one sees in the bridges and plates represent the cross-section of the sinks which are made at the ends of the pivot holes to retain oil.

2410. Figure 5 Plate 2 represents the inside of the pillar plate seen in plan view with the parts that it carries when one has just removed the top plate. *AA* is the plate; *1*, *2*, *3*, *4* are the pillars; *D* is the barrel; *G* is the fusee wheel; *h* is the pinion of the long (center) arbor; *I* is the center wheel; *i* is the pinion which carries the third wheel *L*; *l* is the pinion of the contrate wheel; *F* is the hinge which attaches the movement to the case; *R* is the head of the dial spring; *PP* is the recess made in the plate for the center wheel.

2411. Figure 6 Plate 2 represents the inside of top plate with the parts which it carries, to be assembled with figure 5 to form the frame. *CC* is this plate; *O* is the potence attached to the plate by a strong screw and two steady pins; *d* is the potence key which moves the slide *ef*, which carries the nose of potence[23] in which runs the inside pivot of the escape wheel *N* fixed on the pinion *m*. The other pivot which this pinion carries runs in the hole in the counter-potence *no* attached to the plate with a screw *q* and a steady pin; this counter-potence carries the steel plate *o* attached by the screw *p*, and it is on this plate that the end of the pivot runs. The part *r* of the counter-potence is a round boss on the side of the plate to retain the oil for the pivot. The nose of the potence also carries a steel plate to receive the end of the other pivot; I will explain its adjustment later. The plate *P* is attached to the potence *O* by the screw *s*; it is on this plate that the lower pivot of the verge runs. *1*, *2*, *3*, *4* are the holes for the pivots of the pillars; *h*, *i*, *l* are the holes for the pivots of the center, third and contrate wheels. *Q*, *R*, *V* represent the chain-guard; *Q* is the stud, a piece of brass riveted to the plate; it is split to receive the end *a* of the chain-guard, and the stud and the chain-guard are crossed by pin *c* on which the chain-guard pivots; it is the end *b*

23 For convenience, later I use the word *nose* for the whole slide and its end piece.

that comes up to stop the fusee beak (shown by broken lines at *T*) when it is moved up by the chain *S*; the spring *V* presses the chain-guard down, in order to hold it away from the hook as the watch runs and consequently the chain rolls onto to the barrel.

2412. Figure 7 Plate 2 shows the outside of the pillar plate in perspective, with the parts which it carries; they are located under the dial. *AA* is the plate; *BB* is the recess which forms the bolster or false plate; this false plate is broken at *aa* to show the parts carried on the bottom of the plate. *F* is the hinge to open the movement in the watch case. On the side opposite *F* the plate has a spring which holds the movement closed; this spring will be seen in other illustrations. *Z* is the ratchet of the click-and-ratchet work for the barrel and *C* is the click; *14* is the prolonged arbor of the barrel. *gg* is the bush to form the oil sink for the large pivot of the fusee; *D* is the fusee square for winding the watch and this square carries the dust cap *E* which serves to prevent dust, which enters with the key through the hole in the dial, from reaching the oil in the sink *gg*. *cc* is the bridge left in the center of the plate to lengthen the pivot shank of the center wheel[24]; *ff* is the bridge in which the pivots of the third and contrate wheels run. The cannon pinion *u11* sits friction tight on the prolonged pivot of the center wheel; to prevent the cannon pinion from coming too near to the top of the bridge *cc*, there is a shoulder on the pivot on which the lower end *u* of the cannon pinion sits. To produce friction with the pivot *8*, the cannon pinion is split, as shown at *d*; the pinion *u* of the cannon pinion engages with the minute wheel *S*, mounted on the frame between the bridge *T* and the plate by means of the two pivots formed on its pinion *x*, on which the wheel *S* is riveted. The bridge *T* is attached to the plate by a screw and two steady pins.

2413. Figure 8 Plate 2 shows a plan view of the outside of the top plate with the parts which form the top. *CC* is the plate; *1*, *2*, *3*, *4* are the holes for the pivots of the pillars; *F* is the cock for the fusee; *DD* is the slide under which the rack *EE* (shown by broken lines) is driven, carrying the arm *a*, between the pins of which passes the balance spring *bcd*. The slide is attached to the plate by two screws *e* and *f*; and to prevent the ends *g* and *h* of the slide lifting from the plate, they are held by two claws fixed to the plate; these claws are bevelled, as are the ends of the slide, in order not to jut out and touch the balance. *G* is the balance spring stud; this stud has a pivot which enters with friction in a hole made in the plate. It is to this stud that the external end of the balance spring is fixed by means of the pin *i*; the other end *d* of the balance spring is fixed to the collet of the balance spring. *HI* is the rosette or dial which is used to indicate the way that the rack is moved to adjust the watch; this rosette is attached to the plate by the two screws *l*, *m*. The rosette is recessed underneath for the rosette wheel *K*, fixed on the arbor *n* which carries the hand *o*; this wheel gears with the rack *Ea*; thus when one turns the hand *no* by its square, the rack is moved, which lengthens or shortens the balance spring and advances or retards the watch. The steps *Dp*, *Dq* made on the slide are used to stop the banking pin of the balance, which is stopped against the ends *p*, *q*.

2414. Figure 9 Plate 1 represents the balance cock. *AB* are the feet which are used to attach it to the top plate (Plate 2, fig. 8); *1*, *2*, are the holes for the screws; *P* is the brass coqueret in which the top pivot of the balance runs; *t* is the steel coqueret on which the end of the pivot runs.

2415. Figure 10 Plate 1 shows the balance in perspective, as it is when it is removed from the movement, and it is complete. *RR* is the balance; *a*, *b*, the pivots of the verge; *c*, *d* are

24 This is an integral part of the plate made when turning out the recess.

the pallets; *e* is the balance spring collet held by friction on the seat of the verge; *ef* is the balance spring whose end *e* is fixed by pin to the collet; the end *f* of the balance spring is fixed to the stud *gh* by means of the pin *i*; the end or pivot *h* of the stud is held by friction in a hole in top plate (Plate 2, fig. 8); *k* is the banking pin.

2416. *abcd* (Plate 2, fig. 11) shows the balance spring collet in perspective. *a* is the hole which enters the seat; *b* is the slit made in the collet so that it can spring; *cd* is the hole through which the inner end of the balance spring passes to be held there by a pin.

2417. *Pp* (Plate 2, fig. 12) shows the hour wheel in perspective. *P* is the wheel and *p* the cannon onto which it is riveted; on the end *p* of this cannon the hour hand is placed friction tight.

2418. *Gz* (fig. 12) shows in profile the bush *gg* in figure 7, in which the large pivot of the fusee runs: *G* is the part in which the oil sink is made, and *z* is the seat and cannon to rivet this bush onto the plate.

2419. The first figure of Plate 3 shows in profile one of the pillars of the frame of the movement.

2420. The second figure of Plate 3 represents the barrel, its lid, arbor and the bridle. *A* is the lid seen from the inside with the boss which has a concentric hole *a* to receive the pivot *b* of the arbor *B*. *CC* is the barrel seen in perspective from the inside; *gg* is the boss whose hole receives the part *c* of the pivot of the barrel arbor; the edge *h* is recessed inside so that the edge of the lid snaps into it; the hook *o* fixed in inside the circumference of the barrel is used to retain the external end of the mainspring. *D* is the bridle which prevents the spring from bending; this support crosses the barrel in which it is retained; the end *l* of this support enters opening *i* in the bottom of barrel, and the end *m* of the bridle enters the notch *r* in the lid *A*. *f* is the hook of the barrel arbor; this hook enters the hole made in the inner end of the mainspring. *d* is the pivot of the barrel arbor *B* which enters the hole in the top plate; *e* is the pivot of the arbor which enters the hole in the pillar plate; *p* is the extension which is squared to receive the ratchet of the click-and-ratchet work. The notch *q* in the lid *A* is used to remove the lid from the top the barrel.

2421. Figure 4 of Plate 3 represents the fusee arbor in profile and perspective. This arbor is made from a single forged piece, which makes the beak more solid. It is common to solder the arbor to the fusee, but this method is defective, because these types of fusee are prone to come unsoldered. Here, therefore, is an arrangement which is preferable, and which also has the advantage of making it possible to make a new fusee without difficulty by preserving the arbor. This method has the arbor enter tightly into the concentric hole of the fusee *B* (fig. 5) and the arbor is held to the fusee by means of a screw. It is made more solid by making a hollow at the top *b* of the fusee in which the body of the beak sits, and a notch is made in *b* in which the beak enters very tightly; thus it cannot turn separately from the fusee. The screw which is used to hold the arbor is placed in the hollow.

2422. To make the fusee as large as possible, its click-and-ratchet work is placed inside the base. For this, the base *CC* (Plate 3, fig. 5) has two recesses; in the first *aa* is placed the spring of the click-and-ratchet work, and the click is carried on the fusee wheel *DD* (fig. 7). In the second recess *cc* the edge *cc* of the ratchet *E*, shown in perspective in fig. 6, enters tightly; the teeth of the ratchet extending into the first depression *aa* (fig. 5). This ratchet, seen in profile in fig. 6, has two pins *1*, *2* which enter the holes *c*, *c* (fig. 5); thus the ratchet is rotated by the fusee, and remains attached to the bottom of its hollow by means of the fusee wheel which retains it. *F* (fig. 7) is a collet (of steel) which goes friction tight on the fusee arbor and holds the wheel *DD* (fig. 7) against the base of the fusee; this collet is placed in a recess made in the center of the fusee wheel; it is for that purpose that one has the boss *dd*; this boss is placed in the space in the ratchet *E* (fig. 6); *eef* is the spring of the click-and-ratchet work, riveted onto the wheel by small brass pins; *g* is the click.

2423. *A* (Plate 3, fig. 8) show the chain-guard in perspective.

2424. *B* (fig. 8) represents the cock for the fusee, also seen in perspective, with its two steady pins *a*, *b*, and the oil sink for the top pivot of the fusee.

2425. Figures 9 and 10 of Plate 3 represent the potence with its nose and steel plates to receive the ends of the escape wheel and balance pivots. The potence *C* is seen in profile in fig. 9 where *dd* is the groove made for the nose *D* of the potence. The potence key *e* enters a tapped hole in the potence parallel to the nose. The part *g* of this screw enters the notch *h* of the nose *D*, thus moving it in the groove of the potence, according to how the adjustment screw is turned; this movement of the potence nose is necessary to perfectly adjust the escapement of the watch. To retain the nose against the base of the groove *dd* of the potence, the base is pierced at *k* with a hole which a screw enters and whose head presses on the nose. So that the screw does not prevent the movement of the nose, the hole *l* through which the screw passes is elongated. The plate *E* is of steel; it is attached to the top of the potence to receive the end of the verge pivot which runs in the foot *f* of the potence. This foot is rounded into a boss to retain the oil for the pivot between this spherical part and the plate *E*. The steady pins *1*, *2* of the potence fit tightly in holes in top plate.[25]

2426. So that the oil which is put on the escape wheel pivot cannot be carried to the pallet, the elder Julien le Roi thought of covering this hole with a steel plate *F* (fig. 10) which is assembled with the nose and which is retained on it by the screw which fixes the nose. The end of the escape wheel pivot runs on this plate, and to retain the oil at this pivot the rear of the nose of the potence *m* is rounded into a boss, in the same manner as for the foot of the potence. Credit must be given to Messrs Sully and Julien le Roi for this excellent method of preserving oil at the pivots. So that the steel strip moves with the nose of potence, it carries a pin *n* which enters a hole in the steel plate[26]. *G* (fig. 10) shows the steel plate assembled onto the nose.

2427. Figure 11 Plate 3 represents the counter-potence. It is assembled from the piece *H* and a steel plate which retains the end of the escape wheel pivot; it is seen at *I* without the plate. *o* is the part bored for the escape wheel pivot; it is filed into a boss to retain the oil for the pivot at the top of the hole, between it and the plate. *K* is the steel plate.

2428. Fig. 12 Plate 3 shows the rosette viewed from below. *LL* is the hollow for the rosette wheel seen in *MM* and *pp* are the feet used to attach the rosette by the screws to the top plate. The square *q* of the rosette wheel *M* tightly enters the hole of the hand *N*; this square passes through the hole in the rosette. The pivot *r* of the wheel *M* runs in a hole in the top plate, and *s* tightly enters that of the rosette, which covers the wheel and in which it can be turned with light friction.

25 Also see Plate 6, fig. 2 which shows a potence in perspective; *oq* is the foot and *L* is the nose. Both drawings are a bit strange, but between them they give a satisfactory idea of the potence.

26 There is no label *n* on the original plate.

2429. *DD* (Plate 4, fig. 13) is the slide seen from below and the views *EE* show the profile of the slide. The rack *FF* (fig. 14) is seen in plan from the top; it is this side which fits into the slide to move in the grooves made on the rack and the slide. These grooves are represented by the views *GG*, *HH* (fig. 14); *GG* are those of the slide and *HH* those of the rack.

2430. Figure 15 Plate 4 represents the balance cock seen from below. *PP* are the feet which fix it to the top plate by means of two screws which pass through the holes *1*, *2*; the steady pins *a, b* fixed to the cock, tightly enter the holes in the top plate.

2431. *Q* (Plate 4, fig. 16) is the coqueret in whose hole the top pivot of the balance runs. *R* is the steel coqueret which receives the end of the pivot; this steel plate sits on the top of the coqueret. The coqueret *Q* has two steady pins *1*, *2* which enter holes *3* and *4* of the cock (fig. 15); *5* is the hole which is tapped to receive the screw which holds both the steel and brass coquerets to the cock. Hole *6* (fig. 15) is that which the pivot shank of the balance must pass through freely. The coqueret *Q* (fig. 16) is rounded at *q* into a boss to retain oil at the pivot.

2432. Figure 17 Plate 4 represents the balance verge enlarged. The seat *T,* to which the balance is riveted, is ready to go on the arbor *V* to be soldered there.

2433. Figure 18 Plate 4 shows the dial spring. *D* is the spring, *A* is the head or lock which holds the movement in the case, and *B* is the steel plate which one pushes with the finger or finger nail to open the movement.

2434. Figure 19 Plate 4 is a turning arbor which is used to turn balances to the right thickness and perfectly round. For this, the hole of the balance fits tightly on the pivot of the arbor; this pivot and the base *bb*, against which the balance sits, must be perfectly smooth. The balance is held on this base by means of three screws *1*, *2*, *3*, and the plate *cc*. To turn the balance, it should first be crossed out, but it is necessary to make sure that the body of the balance is supported between the base of the arbor and the plate *cc*, from which one sees that it is necessary to have arbors of differences sizes according to the diameter of the balances. But one can compensate for that by employing plates *dd* turned to the same thickness and which are held on the base *bb* by means of pins *4*, *5*, *6*. In the same way one puts different plates over the balance. The screws *1*, *2*, *3*, as well as the arbor *A* and its plate *bb*, are used for all plates.

2435. Figure 20 Plate 5 is a wax turning arbor which is used to turn the plates, slides, etc. of watches.

The method for making a verge watch

I will not spend as much time on the execution of the parts of a watch as I did for those of a clock. The execution of a clock leads to the construction of watches, and what I say here will be little used by workmen. It is for amateurs that I intend this article. There are however workmen whom I would advise to read it.

Dimensions which must be used for the execution

2436. The height of the pillars must be 2½ lignes.

2437. The pillar plate must be made from brass 1¼ ligne thick (well forged), in order to be able to form the bolster or false plate.

2438. When the false plate is formed, the bottom of the plate must be half a ligne thick.

2439. The top plate must also be half a ligne thick: 1, so that it cannot bend under the pressure of the cock, the potence, the counter-potence and slide parts; because the small amount that this plate is curved changes the play of the escape wheel, a very dangerous effect and common enough. I have seen watches, otherwise well made, vary and stop from this cause. And 2, so that the pivots have good sinks for oil.

2440. It is necessary to use turned pillars for simple watches, as with repeaters; they are more solid, and the workman is sure of the brass which he employs. Fancy pillars just retain dirt and cut the fingers of those who clean the watch.

2441. To make the pillars, it is necessary to employ boiler brass[27] which is well hammer-hardened; and to make them a good size, so that the pivots which pass through the top plate can support it with strong pins and without splitting.

2442. The base of the pillar (see Plate 3, fig. 1) has a diameter of $1\frac{8}{12}$ lignes, the body $1\frac{3}{12}$ lignes, and pivots $\frac{9}{12}$. The lower pivot, which must be riveted to the pillar plate, must be larger than the top pivot.

2443. The thickness of the fusee wheel must be $\frac{4}{12}$, that of the center wheel $\frac{3}{12}$, and the others in proportion.

2444. The diameter of the pivots of the third wheel must be $\frac{5}{48}$, of a ligne, the contrate wheel $\frac{4}{48}$, the escape wheel 3½ /48, and the balance $\frac{3}{48}$, of a ligne[28].

2445. As for the brass which it is necessary to employ for the manufacture of watches, I think the best is boiler brass which is fatty and of a gilded yellow. This brass is purer than new brass; either it is of a different nature or the energy to melt it purifies it, and the greases also contribute to it. The holes which one makes in this kind of brass are less prone to expand, oil is preserved purer in it, the holes corrode pivots less, and finally this brass is less likely to split during gilding.

27 *cuivre de chaudiere*. From Berthoud's remarks in Art. 2445 below, this is brass that has been used or processed more than once. Brass was difficult to make (see Rees *The cyclopaedia or universal dictionary of arts, sciences, and literature*) and possibly boiler brass was a more uniform alloy than freshly made brass.

28 Berthoud is requiring measurements to an accuracy of at least 0.02 mm, but I don't know how this was achieved.

To make the plates and mount the frame

2446. To make plates it is necessary to take brass which is double the thickness that they must have; thus for the pillar plate it is necessary to take brass which is approximately 2½ lignes thick, and for the other plate 1 ligne. It is necessary to cut each piece smaller than the plate, because it will increase in size during forging. One will hammer-harden these plates with much care, as I said in Art. 729 and following:

> 729. Thus prepared, it should be hardened by the blows of a hammer, which is called to *forge*, *hammer-harden* or *plane*. For this it should be struck on a stake (which is a type of anvil whose surface is a little round and polished, and which sits on a block) with the side of the hammer which is called a *pean*. The pean must be thick and round, so as not to separate the particles of the brass too much. When the sides of the plates are well forged with the pean, a hammer with a flat face, but a little rounded, is used to erase the marks of the pean, which was used to harden plates to their center; because it should be observed that the flat face of the hammer only hardens the surface, whereas the other tightens the matter through to the center of the plate.
>
> 730. It is necessary to pay great attention to ensure the plate does not split, and also to forge along parallel or circular lines; because if, after it has acquired a certain degree of hardness, one strikes too strongly, either on a side or in the middle, it could split with the blow. In general, it is necessary that the hammer blows are given parallel to the sides when the plate is square. If it is a round plate, as those with which we are concerned here, one can forge it as if it were square, starting at an edge and going by lines parallel to the opposite edge; or one can forge it by circular lines of blows, going from the edge to the center. This method is preferable to keep the plate round; for the other method would make it oval, and to bring it to a suitable size it would have to be enlarged more than is necessary.
>
> 731. To avoid this problem, it is necessary to initially cut the plate square, and to forge it (after having trimmed it) just as if it were to remain square.

2446 cont'd. Plates for watches need to be forged with all conceivable care; because if they are forged a little unequally they will curve during gilding, and sometimes they will even split. They should be brought by the hammer extremely close the thickness which they must have. One should not use the pean of the hammer, it corrupts brass.[29]

2447. The plates having been forged, a small hole is bored in the center, which will be used to trace the size of plates with a compass. Then they are reduced with a file almost to this size. That done, to turn them one will take a wax arbor (Plate 5, fig. 20), heat this arbor and then apply a light layer of Spanish wax to its base. Then the arbor is applied to the pillar plate and the plate heated so that the wax sticks to it. The arbor and the plate are put in the turns with the point of a runner in the hole in the plate and, at the same time as the arbor is rotated, the face of the plate is pressed with the handle of a file, which presses it flat. Then the wax is allowed cool. Initially the plate is turned square on the edge and the size of the calibre. One turns the two sides making sure the outside of the plate, which will be the inside of the pillar plate, is perfectly flat; for this one will lay a rule on the face. One will make the groove *aa* on the edge (as shown at *AB* in elevation in Plate 1, fig. 4 and in profile in Plate 2, fig. 7); it is this groove which sits on the edge of the case and which

29 I remind the reader that the inserted articles relate to the clock described in Volume 1. The apparent contradiction may reflect the different thicknesses of the plates or Berthoud changed his opinion over the time that he wrote the book.

hides the false plate. The size of the center wheel is traced in the center of the plate in order to make the recess for it; this recess is made a little larger and a little deeper than the wheel, because it is necessary that the wheel has play in all directions. A small rule is used to true the bottom of this recess, and one will make this recess quite flat and then smooth it with a water stone. One will cut away the small boss in the center that had been kept for the point of the runner.

2448. The pillar plate *AB* has a second recess *cc*, to prolong the pivot shank of the center wheel; but this is made only after the plate has been turned on both sides. Also the recess *d*, for the large pivot of the fusee, is not done either, but left to last. To make these kinds of recesses, a type of drill is used whose end is flat, and which is centered on the place where one wants to make the recess. For that there is a steel plate *E* (Plate 3, fig. 3) which carries a cannon. The end *i* of this plate is held with pincers, and the hole centered over the place to be bored. To do this, one takes the point *D,* of which the end *l* just enters the hole in the plate *E*; the pin *D* is turned perfectly round and finished with a point. This point is set on the hole to be bored, which centers the plate, and it is then fixed in position by the pincers. The end *a* of the drill with which to make the recess, fits without play in the hole *h* of the cannon; thus one can drill at will. To regulate the depth and to make the bottom of the recess perfectly flat, one places on the drill a ring *ed* which is held in place by the screw *d*; one drills until this ring rests on the cannon of the steel plate and then the hole becomes very uniform. These kinds of drills are useful to finish the holes in bosses; in this case the end of the drill is made as shown at *b* (fig. 3). *Bb* shows the assembled arbor, *f* is the ferrule to turn the drill, *B* is the body of the drill, *ed* is the collet which regulates the depth of the recess, *c* is the part of the drill which enters the hole in the cannon *E*, and *b* is the part of the drill which cuts and forms the recess or the boss. To form a square recess, the drill *A* is used whose end *a* is flat, and to form a boss the drill *B* is used whose end *b* is hollowed out.

2449. The inside of the pillar plate being turned, it is removed from the wax arbor, the turned side applied to the arbor and attached with wax, as was done for the other side, and the plate is adjusted while supporting it by a handle on the part of the edge which has been turned, so that the two sides rotate perfectly true. The edge *Aa* is turned, to which one will give a slope similar to that in the figure. Then the plate is hollowed out from *B* to *B*, so that the bottom *ee* is half a ligne thick, keeping in the middle the boss for the bridge *cc* which must have same height as the bolster *BB*. To dress[30] the bottom of the plate, a small rule is used to make it very true and flat, and to regulate the thickness of it one makes use of a figure-8 calliper (Plate 7, fig. 3). Then the bottom is smoothed with a water stone.

2450. Then the top plate is put on the wax arbor and given the size indicated by the calibre and a thickness of half a ligne. Then it is removed from the arbor and completely dressed with a water stone; because I assume that it has been turned perfectly plane to the center on each side, so that it is the same thickness throughout.

2451. Returning to the pillar plate, the recess for the pivot shank of the center wheel is made, rather deep so that there remains at *c* (Plate 1, fig. 4) only a thickness of a little less than half a ligne; because this pivot is necessarily large and it does not need, relative to its pressure, an extremely long hole, but it is necessary to have enough thickness to form the oil sink there. One will also make the recess *d* for the fusee arbor.

30 *dresser*. Strictly *straighten*, but sometimes I use the less precise word *dress* when it is more suitable.

2452. To make the pillars, one will take good clean brass which will be hammer-hardened flat, so as not to corrupt it, which almost always happens when brass is hammered square by forging it on two sides. The pillars are turned according to the dimensions indicated, as shown in Plate 3, fig. 1. One will give a suitable length to the top pivots so that there remains, in addition to the thickness of the top plate, a sufficient amount to make the hole for the pin. For the lower pivots, it is necessary that their length is greater than the thickness of the plate by the amount necessary for riveting. These pillars are then smoothed, after which they are ready to rivet; but before that it is necessary to bore the calibre on the plates.

2453. To bore the calibre, the dial side of the calibre is put against the inside of the pillar plate and the plate and the calibre centered with great care. For this, the hole in the center of the plate is enlarged to the same size as the hole in the center of the calibre, and a turning arbor is inserted in these holes, making sure the arbor is perfectly square to the plate and the calibre. That is, these parts run true on the turns, which will not fail to happen if the holes are enlarged quite upright; if that is not the case, they must be straightened. That done, one will drive on the turning arbor with a little force so that it holds the calibre and the plate. One will take two pincers with loops or screws (Plate 8, fig. 14) and tighten the plates against each other by gripping them at two opposite places, but so that none of the wheel and pillar holes are covered by the pincers. So that these pincers do not mark the edge of the false plate, a small piece of brass is put under each pincer which will support the bottom of the plate and will cover the outside of the false plate. Thus prepared, drills are made which are exactly the right sizes for the holes of the calibre which must be bored in the plate; these holes are those of the pillars, the fusee wheel, the barrel, the balance, the third and contrate wheels, and finally the minute wheel. These holes are bored, paying attention to hold the drill quite upright; that is, perpendicular to the plane of the plate. The calibre plate is removed from the pillar plate, and the top plate put on in place of the calibre, increasing its center hole so that it just goes onto the turning arbor. Then the pillar and top plates are tightened together with the pincers, taking care that they are put only on the edge and do not cover the holes. Using the same drills, the holes for the pillars, the wheels and the balance are bored. That done, and without disturbing the pincers which hold the two plates together, the holes for the pillars are enlarged, holding the broach quite upright, until the small ends of the pillars just enter; this precaution is essential to mount the frame quite upright, so that the wheels are perfectly upright in the frame. It is to contribute to the same goal that it is also necessary to pass a broach through the holes for the fusee and the barrel to draw them perfectly upright, and they should even be enlarged very near to the size of the pivots; one will do the same with the holes for the other wheels and the balance. Finally, to complete boring the calibre, the top plate is removed from the other, the turning arbor withdrawn, and the calibre is put on the top plate on the correct side, so that the holes bored in the top plate align with those of the calibre, and taking care that the side of the calibre on which the train and the top are traced is outwards. The top plate is centered on the calibre by the turning arbor. Then a second turning arbor, which will also squarely enter the plate and the calibre, is put in the hole for the barrel or the fusee; which will align the position of the holes of the plate perfectly with those of the calibre. In this state the plate and the calibre are fixed together with two pincers and the holes for the screws of the slide and the rosette, and the hole for the rosette wheel are bored in the top plate.

2454. When ebauche makers bore the calibre, they make all the parts which are put on the pillar plate, so that the frame being set up and smoothed, this plate remains flat and it is not necessary to pass a file over it. One will thus cut the opening for the dial spring, with respect to the hinge (Plate 2, fig. 5), and the head of the spring will be made as it is seen in this figure and in Plate 4, fig. 18. *A* is the head which fits on the inside of the pillar plate and the part *a* slides in the opening made in the plate. *B* is a steel plate which is fixed to head *A* by means of a screw *b* and a steady pin *c*; it is on the notched end *d* that the finger acts to open the movement. The spring *D* is fixed on the outside of the pillar plate together with the part *B*; the spring returns the head or lock *A*. This assembly is called a *spring with lock*. The bridge *ff* (Plate 1, fig. 4.) is made the width and length traced on the calibre, and a height of 1²⁄₁₂ lignes. The feet and the cross-piece are made thick so that this bridge can be lowered if it touches the dial.

2455. The calibre thus being bored, the dial spring made, etc., it is necessary to enlarge the pillar holes in the pillar plate until the lower pivots of the pillars enter there very tightly, and a guide mark is put on each pillar for the reasons explained in Art. 746 and 747:

> 746. The pillars being made, the two plates are separated. Taking the pillar plate and a pillar, the pivot which must be riveted is presented to one of the holes; but as these holes are smaller than the pivots, not having been made two lignes, the hole is enlarged until the pivot just enters. That being done, a small line is marked on the end of this pivot, and another is made on the angle of the plate beside the hole for the pillar ; these will be used as guide marks until the frame is assembled. A second pillar is taken and fitted in same manner, and to make the guide mark two lines are made on the pivot and the plate. And for the third, three lines are made. The fourth does not need a guide mark.
>
> 747. The pillars thus fitted to the plate, they are then put in their holes, the second plate is taken, and its guide marks are presented with respect to those of the pillar plate, in order to make the hole of the pillar as it was bored agree with the end of the pivot currently in the hole of the pillar plate. For this, it must be observed that it is necessary that the side which is put against the outside of the pillar plate, when one forms the holes for the pillars, must be the outside side of the second plate when it is put on these pillars. Thus one will take one of the pillars which are currently on the first plate, and insert the pivot in the corresponding hole of the second plate; if this hole is not large enough, it is enlarged with a broach. One then passes to another pillar, always making sure the guide mark on the second plate corresponds to that on the first, so that if there are some differences in the size of the pivots, one does not enlarge a hole for the wrong one.

2455 cont'd. Then the lower pivots which are too long to be riveted properly are shortened; one will finish by adjusting, using the same methods, the top pivots of the pillars in the holes of the top plate so they are perfectly upright. The burrs are removed and the inside of the pillar plate is smoothed. Then the holes on the outside of this plate are chamfered; for this one will use a drill and the holes are carefully cleaned so that no dirt remains. The pivots of the pillars are suitably shortened, so that it only remains to rivet them. The pillars are put in place and the top plate put on, and pure oil is introduce into each pillar hole in the pillar plate, which prevents the mercury driving them out during gilding. The pillars are riveted with light blows, pressing the frame onto a small riveting stake (Art. 748):

> 748. The pivots thus being adjusted in the holes of the second plate, the burrs which the broach has made are removed, and the frame is ready to be put together. By

> putting the second plate on the pillars, it is only a question of riveting the pillars to their plate. For this, one will take a ferrule which is the right size for the ends of the pivots which go through the second plate; it is filed quite flat. It is placed on a *small stake* (a type of polished steel anvil which carries a tenon to hold it in a vice), and the end of a pillar pivot is put in its hole. Tightly holding the frame so that it does not fall apart, a hammer of average size is taken and, using the pean, the pivot is riveted onto the pillar plate. The same operation is done with all the pillars one after another, taking care not to strike so hard as to crush or curve the pillars, but on the contrary doing it with extreme caution. It is necessary that after removing the second plate it can be replaced freely and without difficulty, and that on presenting a square to the face of a plate, the side of the frame is square while turning the square around, which will prove that the pillars are quite perpendicular to the faces of the plates.
>
> 749. Now this is done, one can see the use of the turning arbors which were used to assemble the two plates to bore the pillar holes. Consider that these plates are again put together, according to their guide marks, by applying the outside of the second plate to the outside of the pillar plate, and in this state a hole is bored with a drill through them both. Then putting the second plate in place to form the frame and putting in a wheel whose pivots run in these holes, one will see, I say, that the axis of this wheel will be perpendicular to the planes of the plates; because these pillars, having been bored in the same manner as the supposed hole, are perpendicular to this plane; thus the hole must also be perpendicular. This method is very useful in the construction of clocks to place the wheels upright in the frame in a certain and simple way.

2456. This operation must be done with care, in order to not curve or crush the pillars. It is necessary however that rivet is well folded back, so that the pillars are very solid. The surplus riveting could be left, but for cleanliness it is filed flush with the plate using a shoe file, and smoothed with a stone to remove the file marks. A broach is passed through the pillar holes in the top plate, so that they enter freely and upright, and the frame is assembled. It only remains to bore the pin holes, which is done flush with the plate, having care to direct the drill so that the pins do not pass under any part on top.

2457. The frame thus assembled, it is necessary to make the wheels of the movement. One will choose good clean brass which is hammer-hardened only with the head of the hammer; because the method of forging with the pean is defective in that a blow badly applied is capable of corrupting and dividing the particles of the brass. To make the fusee wheel, one should not use brass which has just double the thickness of the wheel, because this wheel must have a boss in the center, projecting above the plane of the wheel by $\frac{4}{12}$ of a ligne. Thus brass 2 lignes thick is used and reduced by hammering to $\frac{9}{12}$ ligne. For the center wheel one will use a plate which is $\frac{10}{12}$ lignes thick; for the third wheel the same plate; for the contrate wheel a plate which is $1\frac{4}{12}$ ligne, to be reduced by hammering to $\frac{10}{12}$ ligne; the rosette wheel and the motion work wheels are cut from brass which is $\frac{6}{12}$ ligne thick. To make the balance it must have, when finished, a thickness of $\frac{3}{12}$; the brass for it is cut now, in order to forge and turn it at the same time as the wheels. To make it very hard one will use brass which is four times thicker if it is boiler brass, as I suppose is used for all the wheels of the watch.

2458. The wheels being cut and forged, they are bored in the center with holes suitable for riveting to their pinions, and not too small. Thus one will make the hole of the fusee wheel $\frac{8}{12}$ of a ligne in diameter, that of the center wheel $\frac{9}{12}$, that of the third and contrate

5⁄12, the balance 4⁄12, and the motion work 9⁄12. These holes must have this size when they are carefully enlarged and made quite upright and round. If some wheels are much larger than they are marked on the calibre, a compass is used to mark a circle only a little larger than the wheel should be, and the surplus is then filed off.

2459. To turn the wheels, they are driven onto perfectly round turning arbors; care will be taken that the arbor is driven on so that the wheel turns quite upright. They are turned to the size traced on the calibre and to the thickness indicated (Art. 2436 and following, page 25). Care should be taken that these wheels are turned quite flat on the two sides to the center, in order not to have to file them thinner, which would make them of unequal thickness. One will leave in the center of the fusee wheel a cylinder which will be 3 lines in diameter; it will be made into the boss when the wheel is split[31].

To turn the contrate wheel it is put on a turning arbor. Care must be taken, when it is hollowed out, not to approach too close to the arbor, but to leave a small cannon to support the wheel on the arbor until the moment when it is entirely hollowed out. A thick bottom should be left, so that the crossings can neither bend nor be curved, which would disturb the gearing. To judge thickness of the bottom of the wheel, a figure-8 calliper is used. The wheel being turned, a graver is used to take away the small cannon which had been kept in the center of the wheel.

2460. The wheels being turned, they are split with the numbers of teeth marked on the calibre and with the precautions indicated[32]. Then the center, third and contrate wheels are crossed. So that these crossings are solid, they should be done with four arms, as in Plate 2, fig. 5.

> 780. To split wheels, cutters are chosen which are the correct thickness, and here is the rule: the space between two teeth formed by the cutter needs to be less than the tooth, which clock and watch makers call to have *more full than space*. To find the thickness of the cutter, one could divide the circumference of the wheel (reduced to points or 1⁄12 of a ligne) by double the number of teeth which it is to have, giving, in parts of ligne, the width of the teeth and the space, supposing the teeth and the spaces are equal; and then cutter would be made a little thinner. But this is an unnecessary operation, and instead one can take a cutter which one judges to agree with the number of teeth of the wheel and its diameter. The whole tooth is not split, but one will test by marking them with the cutter on the edge of the wheel, turning the dividing plate some divisions. If the small notches which are made on the wheel are narrower than the space between the notches (that is, if the cutter leaves more full than space) one can split the whole wheel to a suitable depth.
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> 781. One can use as a rule for the depth which it is necessary to give to the teeth, that their depth must be approximately the distance from one tooth to the next; that is, that if the point of one tooth to the next is a ligne, the cutter is inserted a ligne and the teeth will be a ligne deep.
>
> 782. When wheels exert much effort, like barrel wheels, they should not be as deep so that they are less prone to break. Also, as the milling cutter describes a portion of

31 Teeth are formed in two steps. First, the wheel is divided or *split* on a wheel cutting engine which makes rectangular cuts using a file or cutter with a rectangular profile. Second, the teeth are shaped by hand using a rounding up file.

32 Some of these concern the details and use of a wheel cutting engine. Such engines are well described elsewhere (for example, Leonard Weiss *Watch-Making in England 1760-1820*, 1982) so I omit Berthoud's description.

circle it hollows out the middle, the wheel being thick, so that when an equalling file is passed to the bottom of the tooth, one finds the teeth deeper than they appeared when splitting them.

787. To cross a wheel, a compass line is traced far enough from the teeth to keep the wheel solid; this is called the *rim of the wheel*. This circle is divided into four parts and two diameters are drawn through these points. Then on each side of these lines other lines are drawn which determine the width of the arms, which must widen from the circumference to the center. Close to the center a compass line is traced which limits the length of these small columns, which are called *arms* or *crossings*. It should be observed that, just as it is necessary to proportion the thickness of a wheel to the action it undergoes, in the same way the rim and the arms must also be proportioned with the thickness of the wheel, etc.

966. The crossings are filed according to the lines made on the wheels. The arms of a wheel are made equally broad, preserving a suitable solidity in relationship to the thickness of the wheel, the width of the rim, and the pressure on the wheel must support; so that if the wheel is stressed, all its parts bend equally, without one of them breaking rather than another. In this way the wheel will remain solid and be as light as possible.

967. To form the crossings, coarse sage leaf files (Plate 6, fig. 1) are used to file the inside of the rim, and coarse barrette files are used for the arms; they are like a rounding up file, but end in a point. To complete the crossings the same types of files, but fine ones with clean and sharp angles, are used to finish the corners of the crossings properly.

968. When the crossings are made, the angles or squares of the arms and the rim are rounded, so that dust cannot lodge in any burrs. Then the width of a smooth barrette file is passed over the length of the arms and the center, to remove the file strokes longitudinally; the inside of the rim is filed the same way. The arms thus smoothed, they are polished using an oval burnisher ending with a point. This burnisher is dipped in oil, and it is passed over the arms, while supporting it carefully, and following the longitudinal marks to erase them. The arms, center and the inside of the rim are thus burnished, and then the crossings are finished.

2461. The wheels being split and crossed, the center pinion with the long arbor is made. For this, some teeth of the fusee wheel are rounded and the measurement for the pinion is taken with a pinion gauge (Plate 7, fig. 4); however this pinion must be 12 and thus one will take 5 teeth on the points and a little more in the gauge (Art. 528)[33].

524. For the small pinions of clocks and those of watches, ... the rules given here, based on experiment and according to the methods of good workmen, should be used.

525. When the wheels are split and one wants to determine the size of the pinions, a pinion gauge is used. If, for example, one wants to make a pinion which has 16 teeth, the gauge will be opened so that it includes 6 teeth of the wheel, from the outside of the first to the outside of the sixth; this is called *6 full teeth*.

526. For a pinion of 15, it is not necessary that the gauge completely embraces the outside of the sixth tooth.

527. For a pinion of 14, it is necessary to take 6 teeth on the points.

528. For a pinion of 12, 5 full teeth when it is a large wheel of a clock; if it is for a watch it is necessary to take a little more than 5 teeth on the points.

33 The articles 524-540 below are also given in Thomas Reid *Treatise on Clock and Watch Making*, 1826. This book extensively quotes from Berthoud translated into English, but only covers the technical sections and omits the practical procedures.

529. For a pinion of 10, 4 full teeth.

530. For a pinion of 9 a little less than 4 full teeth.

531. For a pinion of 8 in a clock, 4 teeth on the points.

532. For watches, it is necessary to take 4 teeth on the points, less a quarter of the space of a tooth.

533. For a pinion of 7 in a clock, 3 full teeth of the wheel and a quarter of the space of a tooth.

534. The pinion of 7 in watches must embrace a little less than 3 teeth of the wheel; it should force the wheel when it is finished.

535. For a pinion of 6, it is necessary to take 3 full teeth for clocks. For watches, a little more than 3 teeth on the points.

536. For a pinion of 5, 3 teeth on the points.

537. For a pinion of 4, it is necessary to take two teeth square and full. When the pinion leads it is necessary to take two teeth square of the wheel, plus half of the space of a tooth. In general all pinions must be larger when they lead.

538. Though the gears of watches and clocks are made on the same principles, and the sizes of the pinions appear to be the same, there is a small difference, of which this is reason. In clocks the wheels have higher numbers than in watches. However, the larger a wheel is, the pinion remaining of the same number, the less the teeth of the wheel and the pinion penetrate each other; that is, the primitive radius of the pinion approaches closer to its true radius. It follows that such gears are the best, since the less the teeth are obliged to penetrate for the gearing, the less friction there is.

539. One sees that the sizes of pinions vary in a clock or a watch, according to whether the wheel is more or less numbered relative to its pinion. Thus, when one makes a pinion of 8 which engages with a wheel of 32 teeth, it is necessary to take less teeth and to hold the pinion smaller than if it gears in a wheel of 72; and always less and less, as the pinion makes a smaller number of revolutions relative to the wheel.

540. Having given a size to the pinion in the way that I have just described, it is still desirable to test the gears before hardening them, in order to fix their size well, to suitably determine it with more or less teeth of the wheel, and to give to the leaves the most favourable curve. This care and attention is very essential; one cannot recommend them too much to workmen and see that they put it into practice.

2461 cont'd. One will choose steel drawn for a pinion of 12 which is of the right size and a suitable length for the height of the frame and for the arbor which carries the cannon pinion; and then this pinion is roughed out and turned. One will make the shoulder to rivet the wheel and leave the teeth a little longer than the thickness of the wheel, (Plate 1, fig. 4). The pinion is thinned and rounded according to the methods in Art. 870 and following.[34] The teeth of pinions are called the leaves; the tip of the leaf is called the face, and the sides are called the flanks.

870. When a pinion has been split, it is placed on the turns, in order to dress the tips of the leaves, which is called *straightening the face*; this operation removes the burrs of the splitting file, and gives the pinion a good shape.

871. The pinion is put back in the hand vice and, to form the flanks of the leaves, angular files are used which are thicker and finer than the splitting files. These files,

34 The following articles refer to clock pinions; Berthoud describes a pinion cutting engine for clock pinions which I have omitted. Watch pinions are generally made from drawn pinion wire, which Berthoud uses.

which are called *thinning files*, end with a small flat which forms the bottom of the tooth of the pinion, making it square (Plate 6, fig. 1). These files are passed equally and upright in each space, thus keeping the teeth equal to each other. The flanks of the leaves are dressed, and the space needed for the gearing is formed; that is, the space must be a little larger than the thickness of the tooth, which watch makers call *more space than full*; this is the opposite to what the teeth of wheels require (Art. 780, page 31).

872. As the pinion is thinned, a pinion gauge is used to equalize it. For this, before using the thinning file, the gauge is opened so that it embraces two full teeth. It is then presented to all the teeth in turn, and one sees if there are teeth more distant from others. When thinning, one passes over those which are further apart, supporting the file against them; by this means one makes a pinion equal.

873. It is necessary to have several of these thinning files for the various kinds of pinions; because they are more or less angular, according to whether the pinions have more or less teeth. The higher the number of the pinion, the less angular these files are, and the reverse. Thus a suitable thinning file is chosen for each pinion, so that the leaves are solid at the bottom without being too thin on top. Also, care should be taken not to unequally deepen the leaves of the pinion.

874. When a pinion has been sufficiently thinned, it is almost finished; it only remains to remove the angles at the tips of the leaves, which is called to *rounding up*. For this files are used which are called *rounding up* files (Plate 6, fig. 1). These files are cut only on one side and the other side is plain and rounded; the tips are finished with the flat side which is cut. Initially a rounding up file which is a little coarse is used to remove the angle; then the rounding up of the leaf is completed with a finer one.

875. In order to make sure that all the teeth are rounded equally, the pinion gauge is used in the manner that I have just described. Care must be taken that the teeth are quite equal in size and rounded equally on both sides, so that the teeth are well directed towards the center of the pinion and that they are not ratchet shaped, that is, straight on one side[35]. It is especially necessary to pay attention while using the thinning file, because the rounding up file should not touch the bottoms of the leaves, but only enter approximately two thirds of the length of the tooth from the bottom.

876. It is necessary to preserve, until the last moment, the splitting marks which are on the tops of the teeth; they are used to regulate the rounding up file.

2461 cont'd. The pinion being made, it is hardened and tempered (Art. 888 below), its points are straightened (Art. 890 and 891), the arbor is turned quite round, and the pinion polished.

887.The pinion is heated throughout its length until it is uniformly hot and a cherry colour. At that moment the pinion is taken in long tweezers and perpendicularly plunged into a vessel filled with cold water; I say perpendicularly, because if this precaution is neglected and it is plunged in flat, the arbor will be very much curved.

888. When the pinion has been hardened, it is whitened using a pumice stone, while supporting it very carefully on a piece of cork; because without this precaution, one will run the risk of breaking it. After having been whitened, it is tempered (Art. 834, page 41) by placing it on well lit coals and allowing it to heat until the pinion is bright blue over all its length. The pinions to which wheels are riveted must tempered a little more at the place for riveting; to, for example, a less bright blue.

889. To prevent the pinions rusting before they are polished, they are coated with oil.

35 But see note 61, page 58.

890. A pinion is taken and a brass ferrule put on the end of its arbor. It is put in the turns to see if hardening has curved it. For this, it is turned slowly by a bow held in one hand while a brass broach finished in a point is held in the other hand and is slowly brought near the leaves of the pinion. If they all touch the point it is proof that the pinion is round. If not, the teeth which touch first are noted and, with a polishing file, the tapered point on the pivot shank is moved to this side; then the pinion is again checked to see if it is round and this operation is repeated until the end of the pinion on that side of the pivot shank is perfectly round. When it is made exactly round at that end, the other end is examined in the same way to see if it is out of round, which is proof that the stem was curved at that end. If so its point is moved, and this is done repeatedly until the leaves of the pinion are exactly central. The stem will no longer be in the center, but this is fixed by turning it with a graver.

891. The pinion being perfectly centered, it will be necessary to finish the points on it, that the filing can have made oval; this is done in the following way. At the end of the pivot shank a ligne width and no more is turned with great care. When this end is quite round, the tapered point is turned conical until it entirely cuts the shank, and is separate from the point which rolls in the runner of the turns. This point being thus cut, the end of the pivot shank is put in the notch of a brass runner, and with a pivot file the point that the graver crossed is made sharp. This new point is put in a small hole of a runner and the brass point is presented to the pinion leaves, to see if it lost its centering during this operation; because in that case it is necessary to move it by filing the point a little and then re-cutting it, in order to be certain that it is not oval. The same operation is done on the other point of the stem, and these operations are repeated until the points are round and well made, and the pinion turns perfectly.

892. When that is done, the pivot shank is turned uniformly over its whole length and then a smoothing file is used to smooth it. Thus prepared, the pinion should be polished.

893. For this, one will put it in a hand vice, supporting it in a notch of wood attached to the vice. To polish the pinion, a piece of walnut wood is filed to same shape as the file which was used for thinning it, and coarse English rouge or fine emery is taken and crushed with oil. The wood is used like file until the file marks on the sides and bottom of the leaves can no longer be seen, and they are well smoothed. It remains to smooth the tips of the leaves. For this, a piece of walnut is filed a little angular, so that it touches only the top of the leaves. This wood will grow hollow with rubbing so that, by putting coarse English rouge on it, the tips of the leaves will be smoothed.

894. To complete polishing the pinion, spindle-tree wood is used[36]. Two pieces of it are cut to take the place of the walnut ones, one for the sides and bottoms of the leaves, and the other for the tops. Fine English rouge is used with this wood, and by this means the leaves will be polished very well.

2462. The pinion thus hardened, turned and polished, the wheel is riveted to it according to the methods indicated in Art. 885, 886 and 897[37] below:

895. The pinion being worked up to this point, the shoulder on which the center wheel will be riveted is turned square and round. The hole in the wheel is enlarged so that it goes tightly on the shoulder of the pinion. It is necessary that the end of the leaves of the pinion are notched; that is to say, projecting a little above the wheel in order to be able to rivet it. But before riveting it on the pinion, the center of the wheel is smoothed with a soft stone and then polished with spindle-tree wood and rotten

36 Peg wood.

37 Art. 885, 886 are irrelevant here; they describe attaching clock wheels to collets soldered onto the arbors. Watch wheels are riveted onto their pinions.

stone crushed with oil. Then the wheel is driven onto the shoulder of the pinion. A ferrule is taken whose hole enters freely on the arbor of the wheel and the pinion is put on a vice open enough to let the stem of the pinion pass through freely. The front of the pinion is seated on the ferrule, which is used as a support, while with the pean of a hammer, the ends of the notched leaves of the pinion are folded back so that they penetrate the wheel and fix it very firmly to the pinion; this is called *to rivet*. When a wheel is thus riveted onto its pinion it is said that it is *enarbrée* (enarbored). To rivet this wheel well, it is a good idea to hollow it a little below against stem, so that while striking with pean of the hammer it is riveted very firmly, which is essential to avoid the pressure of the mainspring loosening the pinion and allowing it to turn without turning the wheel, as I have seen several times in negligent work.

896. When a wheel is riveted a little strongly, by striking unevenly around it with the hammer, it can happen that the shoulders of the leaves penetrate one side of the wheel and it does not turn true. To fix this it is necessary to strike the opposite side of the riveting, in order to bring the wheel back to being straight. If the cant of the wheel is very small it can be rectified by striking the crossings, opening the vice to support the wheel flat and striking that which needs to return.

897. When the wheel is well dressed (that is, it turns true on the sides) it is lightly turned to make it rotate perfectly. It is turned round and filed quite flat, using an English smoothing file to remove the graver marks. Then it is put on the turns and two small light lines are made; one inside the rim to regulate the width of the circle which limits the crossings, and the second to indicate the start of the arms, in order to make the center of the arms exactly round; and consequently, by filing the wheel according to these lines and making the arms equal, the wheel is kept in balance. On each side of the wheel two fine lines are made marking the bottom of the deepest tooth; these lines will be used when the teeth are made, to make the teeth equal in length by deepening those which are shallow.

898. The wheel thus mounted on its arbor, a ferrule is put on the pivot shank to facilitate polishing the stem and dressing the face of the pinion before forming the pivots. One will start with the face of the pinion. For this, a half-inch square steel plate is taken and a hole is bored in the middle of it which is enlarged so that the stem of the pinion enters it freely with play. One face of this plate is dressed quite flat and is used to dress the face of the pinion, which is run on one of its points in the turns and with the other supported by the plate so that it is flat on the face of the pinion. But so that this plate dresses the face of the pinion it is necessary to introduce between it and the pinion some Eastern oil stone, first reduced to powder and then crushed with oil, this stone will cut the face and, as the plate is flat, the face of the pinion will also become flat. This plate is re-dressed as it wears. When the face is dressed so that all of it touches the plate and it is flat, it is polished by taking a brass plate with a hole larger than the stem, so that while moving this plate as the pinion turns, it removes the marks left by the oil stone. To polish the face of the pinion it is necessary to introduce between it and the face of the brass plate fine English rouge or tin putty; if one does not work, the other is used. What requires the ingredient to be changed is that rouge will work better on a very hard pinion and tin putty on one that is softer. In the end this is meticulousness, because whether the face of a pinion is well or badly polished has no effect on the quality of the machine; but it is a good indication of the care for cleanliness which one has. There are many workmen who value it more than the intelligence necessary to build a machine or to make it work well.

899. Before polishing the stem, the hollow made at the bottom of the teeth of the pinion is finished. It is turned with a graver to make it quite flat and to decrease

the edge which is widened by facing. Then this hollow is polished with a wood point and rouge. That done, if it is seen that the edge of the face has been a little dulled by touching it with the wood, it is polished again with the brass plate and tin putty.

900. Then the stem is polished; but to avoid spoiling the face of the pinion, a piece of paper card is cut which is put on the stem and pushed against the face. An oil stone with oil is used on the stem, while turning the pinion, until the file marks are removed. When that is done, a soft file or an iron plate (called an iron file) is taken on which one puts oil stone crushed with oil, and the pinion is rotated until the stem is quite flat. Then the stem is cleaned with a cloth, always leaving the card against the face of the pinion, a well dressed brass plate with tin putty is taken, and this file is used on the stem until it is quite polished and brilliant.

2463. To put the center wheel in the frame, one will first make the large pivot which must be 5⁄12 ligne. The hole in the center of the pillar plate is carefully enlarged, so that the pivot enters it when it is smoothed, and the shoulder is cut back until the wheel approaches the bottom of the recess, but does not touch it; that is, there is a good clearance between them[38]. The shoulder is dressed with an iron file and oil stone, and to polish it, as well as the pivot, one will use tin putty and a brass file. To make the other pivot the plates are assembled, two pins put in and with a dancing master[39] the height of the frame is measured, including the recess made for the pivot shank of the center wheel in the pillar plate; the pivot is turned according to this height and given a diameter of 3⁄12 of a ligne, the length in proportion. It is turned in the air[40] (Art. 903) with a pivot file and polished by the methods indicated.

903. ... A ferrule is placed on the end of the stem, and the small pivot formed; care will be taken to cut it quite round and even. After cutting it with a graver, it is put in a brass runner (Plate 5, fig. 2) in which there is a small notch for the pivot, and it is smoothed with a pivot file, having attention to do nothing but remove the marks of the graver and not to change the shape of the pivot which must be a little tapered; that is, the shape of a good broach. When the pivot and the shoulder are well smoothed, a piece of fine linen is used to clean the end of the runner in the turns so that, when polishing the pivot, there are no grains in the notch of the runner able to cut the pivot. To polish it, a square piece of brass, about the size of a pivot file, is used with rouge. A little quite fine rouge is put on this file and the pivot smoothed with it until the pivot and the shoulder are well polished, which will happen quickly.

904. To give more brilliance to the pivot a pivot burnisher is used. This is a type of file which is the size of a pivot file, but it is uncut; from time to time it is rubbed on a piece of wood on which there is coarse emery. This file is hardened like an ordinary file and it can be made from an old pivot file which has had its teeth removed on a grind-stone or an oil-stone, and then rubbed on wood with coarse emery. The angle of this burnisher is rounded a little, so that when it presses against the polished shoulder it does not cut it.

936. The pivot being reduced to its given diameter, and the shoulder moved back as needed, an angle is turned on this shoulder and a small groove made at the end of this tilted plane where it joins the pivot shank. This groove will limit the oil which, not being attracted by a large surface, will not flow from the sink to the middle of the wheel. To more surely avoid this problem, the pivot shank can be lengthened by

38 *un bon jour*, a good day; a rather vague specification.

39 See Plate 10, figs. 1 and 2 and Plate 7, figs. 5 and 6.

40 The runner (Plate 5, fig. 2) is bored with a hole in which the pivot shank rests and the pivot itself is unsupported in the notch.

hollowing the pinion below the riveting, but without weakening the solidity of this riveting.

937. The pivot and the shoulder are smoothed with a quite soft and square pivot file whose angle is quite sharp. I have already said, with respect to pivots (Art. 903 above), that it is necessary that they taper a little from the shoulder to the point, and this must be done when they are turned ; because the pivot file should not change the shape, and it must only remove the graver marks without diminishing the pivot. The angle which finishes the shoulder at the pivot must be quite true and cut clean with a graver. Finally, if one wants to have well made pivots it is necessary that they are turned by a graver to the size and shape which they must have, and they should not be changed by smoothing and polishing. Thus it is necessary to have good gravers, whose faces are well dressed on an oil stone, and whose angle is very sharp; that is, not blunt at the point.

938. The pivot is smoothed by making it roll in the notch of a runner on the turns. To polish it, this runner is covered by a fine cloth and a brass file is use with fine English rouge, as I explained in Art. 903 and 904. It should be noted that it is necessary to have several brass runners for the turns with notches different sizes and thicknesses, according to the size and length of the pivots.

939. If one does not have a steady enough hand to roll a pivot well, one can compensate for it by the method which is used for watch pivots. This is to place in the notch of the runner (Plate 5, fig. 2) a small screw the width of a pivot file away from the notched end for the pivot. By this means the pivot file sits on the pivot and the screw all the time and, according to whether this screw is raised up or lowered, the width of the file is set square or tilted to the pivot; thus one makes the pivot cylindrical or tapered. The head of the screw is placed on top and is split so that it can be raised or lowered with a screwdriver, according to the size and shape of the pivot; the screw is lowered until the file lies on the entire length of the pivot, and at the same time sits on the head of the screw.

940. I will finally observe that, as the pivot is smoothed by rolling it on the runner in the turns, the pivot file must be put on the cut point of the pivot to make this point uniform and a little blunt; so that when the wheel is put in the frame, this point does not cut the plate while the pivot is brought to its hole. But it is necessary to take care while removing this acute point, that the end of the pivot does not go out of round, so that when it is again placed in the hole of a runner on the turns, the pivot rotates as true as when it was turned. This problem will be avoided, when one cuts the pivot to length, if care is taken to turn it carefully with a graver, but doing so very gently, until the graver arrives at the center of the pivot; one even gives a small spherical curve to the point of the pivot with the graver, instead of making it conical and angular. Thus cut by the graver, the end of this pivot is rolled in the brass runner to smooth it, and one passes the burnisher over the end of the pivot. After the pivot has been polished, the same burnisher is passed over the whole the pivot with the precautions indicated above (Art. 904).

2463 cont'd. As the hole in the center of the top plate was enlarged more than the size of this pivot, it will be bushed. For this, it is enlarged and tapped. A rod of boiler brass it taken, well hammer-hardened and made round. Then a small hole for the small pivot of the center wheel is bored on the turns and the end of this bush is turned by making it roll on a pointed runner; it is given the correct size to be tapped in the hole of the die which was used to tap the hole of the top plate. The bush is cut by a graver to a suitable length, the hole in the top plate chamfered and the bush riveted. The hole is enlarged and the large countersink made in the frame.

2464. The fusee arbor is roughed out to give it the form shown (Plate 3, fig. 4); the stem must be 1 ligne in diameter, the beak $\frac{2}{12}$ thick, the size of the plate 3½ ligne, and the projecting beak 1 ligne. The hole *d* for the screw is bored and the arbor hardened and tempered blue. It is then carefully turned and the pivot *b* (fig. 4) made, giving it a diameter of $\frac{7}{12}$ ligne and moving back the shoulder suitably. The frame is assembled, and the height from the recess made for the fusee to the top plate is measured. Then an arm of the dancing master (Plate 7, fig. 6) is put against the beak *c*, with enough clearance so that it does not touch the plate, and with the other arm the place of the shoulder is marked; it will be made a little higher, in order to be able to move it back when the arbor is put in the frame, so that the beak of the fusee approaches close to top plate without touching it. The hole in top plate is enlarged for the passage of the pivot shank *c* of the fusee, which should just enter it. The top pivot *e* is formed so that it is a ligne higher than the top of the top plate; the size of this pivot will be ½ a ligne. The cock for the fusee is made, the hole for the pivot bored, and this cock is fixed by attaching it with a strong screw; the hole for the screw is enlarged a little, in order to fix the cock so that the fusee shaft remains upright in the frame; then the holes for the steady pins are bored and they are fixed as shown in Art. 958. The fusee arbor is taken out of the frame and the fusee is made.

> 958. To bore the holes for the steady pins, a half-ligne drill is used and then a broach passed through them to make them smooth. A guide mark is made on one of the feet of the bridge and the plate, in order not to change the feet from one side to the other. The bridge is taken off, and pins of brass wire, drawn quite hard, are filed to insert them in these holes; these pins, which are called the steady pins or tenons, must be a little tapered. After being filed quite round and uniform, they are forced into the feet of the bridge, driving them in from the outside; that is, from the same side as the broach was used. They are filed flush with the feet on this side, and left projecting below for the thickness of the plate.
>
> 959. To remove the burrs from the ends of these pins, a tool is used which I call a *tenon drill*. This drill is made from round drawn steel, which is approximately 1½ ligne in diameter. One end of this steel wire is filed flat, and two cross slits are made with a slitting file; so that at the point of meeting a hollow is formed with four edges which are used to cut the burrs on the pins. They are made in various sizes according to the size of the tenons or pins. The end of this tool must be hardened and tempered yellow, and the other end is given a point and carries a ferrule like a drill. If the tenons of the bridge are too tight to force into the holes made in the plate, these holes are enlarged a little; but very slightly, because the pins must enter with a little force.

2465. To make the fusee, one will be regulated by the size that was traced on the calibre, which represents the base; the diameter of the top of the fusee will be $3\frac{8}{12}$ ligne. To make the fusee, good clean brass thicker than the height of the frame is taken, in order to hammer-harden it well so that it only just enters the frame. The hole in the fusee is bored in accordance with the size of the arbor; this hole is cleaned and enlarged until it only just starts to fit on the arbor. The fusee is then turned approximately to the form represented in *E* (Plate 1, fig. 4), keeping it higher than necessary in order to be able to remove some later. The arbor is carefully reduced using a graver until, being well smoothed, it just enters the fusee, and it is adjusted as explained in Art. 2421, page 22.

2466. The fusee being assembled on its arbor, it is turned true on top and on the base. The turning and smoothing of the side of the fusee wheel which fits against the fusee is completed; the other side of this wheel is also turned, so its thickness is correct. Then the hollow for the collet, which is used to assemble the wheel with the fusee, is made. The hole of the wheel is enlarged so that it enters truly on the arbor and the wheel fits on the base of the fusee. In this state, the wheel is put on the fusee and put in the frame; if the wheel touches the plate, the base is cut back until it fits, and there is clearance between the wheel and the plate so that they do not touch. If the center wheel is a little higher than the inside of the pillar plate, the fusee will have to be cut back further. The steel collet *F* (Plate 3, fig. 7) is made and the lower part of the base of the fusee is hollowed out for the click-and-ratchet work; this click-and-ratchet work is then made.

2467. The cylinder and the bottom of the barrel *CC* of a watch (Plate 3, fig. 2) are made from a single piece of brass which is hollowed out and shaped as shown. To make a barrel it is thus necessary to take brass which, after being well hammer-hardened, is as thick as the height that the barrel must have. This brass is driven onto a turning arbor of the size which the pivot which runs in the barrel must have; this pivot will be $\frac{9}{12}$ ligne. Initially the barrel is turned approximately to the width and size traced on the calibre, leaving a rim at *h* approximately the height of the chain; this rim is traced on the calibre, the small circle indicating the true diameter of the outside of the barrel and the large one the rim for the chain. Initially the inside is hollowed out with an ordinary graver, and then with a hook graver (Plate 5, fig. 1); it is used to flatten the bottom. The inside being formed, the outside is turned to the required size, the bottom being given a suitable thickness which one measures with a figure-8 calliper. For this bottom to be solid it must be $\frac{2}{12}$ ligne and the cylindrical part $\frac{3}{12}$ ligne. The ring *gg* is retained in the center of the bottom; this boss must be a little less than the diameter of the barrel arbor, that is a third of the diameter of the barrel, and $\frac{4}{12}$ ligne thick. Finally one will make the snap for the lid (Art. 814 below). The lid is made with a thickness of $\frac{2}{12}$, with a boss the same size and thickness as that that of the barrel, and so that it can be inserted with force into the snap. A notch is made in the lid so that it can be removed.

> 814. When the inside of the barrel is turned, one will cut out a small ring, a good half ligne wide, all around the interior edge, and $\frac{1}{8}$ ligne deep at its top edge and a little deeper on the bottom; it is called the *snap* of the lid. The lid of the barrel must enter this snap with force, and when it is placed there it should only come off with effort; it is for this reason that it is necessary that the snap is cut a little deeper on the bottom side.

2468. To make the barrel arbor one will take steel whose size is one third of the internal diameter of the barrel and the measurement for the length of the head is taken as explained in Art. 818:

> 818. To determine the length of the head, that is, to measure quite exactly the space between the two bosses in the barrel, a piece of brass is taken and inserted in the hole in the lid. It is held against boss of the barrel and a notch is made in this piece of brass at the place of the lid. This notch is cut back until the interior part enters without play between the wheel and the lid. This height is transferred to a dancing master, and used to shorten the head appropriately, keeping it a little longer so that one has some to turn off when completing the arbor.

2468 cont'd. The barrel arbor is roughed out, leaving the stems larger than the holes in the barrel, and then a hole is bored through the head so that the hook for the spring can be driven on. The arbor being roughed out, it is hardened and tempered. Then it is turned, and the shoulders put at the measurement taken for the height of the inside. The pivots *b*, *c* (Plate 3, fig. 2) which run in the barrel are finished and the holes in the lid and the barrel enlarged so that they go upright and free on the pivots of the arbor. The barrel thus assembled, the pivots *d*, *e* of the arbor are made, in order to put it in the frame. For this, the height of the frame is measured with a dancing master. The shoulder for the pivot *e* is made as large as possible in order to have a good square; this shoulder must be distant from the barrel so that, when it is in the frame, it cannot touch the plates.

2469. The arbor is taken out of the frame and the square made immediately, by the method described in Art. 832 and 833 below; and the hole in the ratchet is punched according to Art. 834 below. This ratchet must be made of steel and the teeth inclined as shown in Plate 2, fig. 7. The click and the screw are made and the click set up as it is shown in the figure.

> 832. For this one starts by filing the pivot of the arbor into a square, in order to fit the ratchet onto it; the ratchet must sit near the plate with a small gap so that it does not rub. Thus, while the arbor is in the frame, it is necessary to mark a line on the arbor almost level with the plate, which indicates the start of the square. Then the arbor is removed from the frame, put in the turns and, with a sharp graver, a fine line is made all around the arbor to regulate the start of the square. One then forms, over the entire projecting length of the pivot, four sides or sections which are gradually reduced until they form a square whose corners are not completely sharp. So that the file cannot slip onto the exposed pivot which is at the start of this square, a small ring of brass turned to the thickness of the plate is put over the pivot so that it just covers the line made by the graver which marks the length of square; this ring will hold the uncut side of the file (an English bastard file should be used). When the square is roughed out, the ring is removed and the square gradually filed back until it reaches the line. To make sure that the angles of the square are right angles, a small square is used[41]; and to judge that each section is of the same width, a pinion gauge is helpful if eyesight is not good enough to judge without it. Each side or section being equal and the angles right, the square is well formed, and it is smoothed with a polishing file[42], initially by filing straight transverse to the axis, and then along its length. This last manner of filing is called *draw filing*.

> 833. There are workmen who, to file the sides of the square true, place the arbor in the turns on two points, leaving it mobile, and in this state they complete filing the square, which makes its sides quite flat. After it has been roughed out the same thing can be done in a vice by filing it on a piece of cork approximately 1½ inches square and roughly the length of the jaws. This cork is put in the vice and one can use a file to straighten the parts which are pressed on the cork.[43]

> 834. To make the square hole in the ratchet, one begins by increasing the round hole with a broach until it is the size of a circle inscribed within the end of the square on the arbor; that is, this hole has the same diameter as the thickness of the end of the square taken from one side to the opposite one. Then a steel square is made the same size and shape as the square on the arbor; this square having its corners cut clean and sharp, straight and quite regular. It is smoothed along its length, after having filed it quite flat, and with the same care employed for the arbor square. It is called a *punch*, and is *hardened*. That is, it is heated until it is a cherry red colour and plunged into a vessel filled with cold water. By this means steel will acquire the

41 Although this may work with large clock squares (which Berthoud is describing) it does not seem sensible for watch squares.

42 *carrelette au T*.

43 This is equivalent to using a swing tool. The piece is allowed to rotate freely and it always moves so that the pressure of the file is equal on the surface. This is why some pieces are filed while resting on a finger tip.

greatest degree of hardness. But steel which acquires this hardness becomes very breakable, like glass, and it is of little use except for gravers which need to be very hard. So there is a very simple means of softening it a little. After it is hardened, the sides of the square are whitened with pumice stone and then put on burning coal to let it heat until the steel, which was white, becomes yellow[44]. This operation is called *tempering*. One tempers steel more or less, depending on how hard the part needs to be. If, for example, one wanted to use this square to make a square hole in steel, one would only let down to yellow; but if one wants to use it only for brass, it will be sufficiently hard if it is tempered to a bright blue. The same process is used to harden a drill; it is tempered according to whether it will be used to bore tempered steel or brass, etc. In connection with drills, to harden small drills they are not heated heat on coals, but a blowpipe is used, which is a pipe bent at its small end. The large opening is put in the mouth and small end in the flame of a large candle; by blowing one directs this flame onto the drill until it is red, and then it is plunged into the tallow of the candle which tightens and hardens it. It is then whitened, the end of the hardened drill supported on a file and the stem of the drill is presented to the flame to heat it, so that this stem is tempered, that is, changes colour, while the end of the drill which sits on the file preserves all its hardness without being prone to break. If the drill needs to be less hard one continues to heat the stem and one supports less of it against the file, so it can be tempered as desired.

835. When the punch is hardened, it is driven with force into the hole of the ratchet, which will gradually take the form of the square; one will alternately force the punch in with a hammer blow and take it out to coat it with oil, until the hole can enter very tight and upright on the square of the barrel arbor, and can be inserted to the bottom, except for the burrs that the punch will have raised which are removed by passing a file over the flat sides of the ratchet. Thus prepared, the ratchet is turned on its arbor, and the bottom of the teeth are marked by a line made with a graver on the turns, in order to regulate the depth of them.

2470. The barrel being finished, the potence is made[45]. For this, it is necessary to trace on the inside of top plate (Plate 2, fig. 6) a circle *D* which represents the barrel; this circle lies behind potence *O*. To trace the front of the potence, one will draw from the center *l* of the contrate wheel *m* (shown by broken lines) a line which goes to the center of the balance. Then a line *fe*, which is perpendicular to the first, is drawn from the center of the balance; space is reserved at *f* for the foot of the potence. The potence is continued to *e*, in order to protect the escape wheel in case the chain suddenly breaks[46]. The place of the potence being traced, one will take thick brass which is hammer-hardened until it will enter the frame; one needs the potence to be rather thick at the place of the foot *f*, so that it touches the bottom of the recess for the center wheel when the top plate is set on the pillar plate. The base and the top are filed quite plane and the potence is notched at O for the screw which will attach it to the top plate. This screw *t* is made and the potence put in; the two steady pins are carefully positioned with as large a distance between them as possible. The potence is put in place, the frame is assembled and two pins put in. Then, through the hole made in the pillar plate for the balance, a hole is bored in the potence which is the one in the foot in which the bottom pivot of the balance will run; care must be taken,

44 Not suitable for smaller objects and a watch arbor would be tempered using a candle or a bluing pan.

45 Plate 3, figs 9 and 10 and Plate 6, fig. 2 are upside-down with respect to the normal view in Plate 1, fig 4 and the way Berthoud describes making the potence.

46 *h* in the original. The body of the potence forms a barrier between the escape wheel and the broken end of the chain. See also Plate 6, fig. 2.

when boring this hole, to hold the drill quite upright. That done, the center wheel is put in the frame and the potence lowered until it does not touch the center wheel; the potence is lowered a further 1⁄12 ligne for space for the boot, the steel plate on which the balance pivot runs. The potence being set to height, one will reserve the foot *f*, and move the face *fe* back until it passes by the center of the verge, taking care that this face remains perpendicular to the traced line from the center of the contrate wheel to that the escape wheel. That done, the groove *dd* (Plate 3, fig. 9) is formed; the bottom of this groove must be parallel to the front of the potence and the sides of it must be parallel to the base of the potence; this groove must be 7⁄12 ligne deep and its width 1¼ ligne. The nose of potence is then made. For that brass whose thickness is double depth of the groove is taken; the nose is as shown in *D* (fig. 9); the part *m* must be notched behind as far as the center of the verge and a little more so that the verge of the balance cannot touch it; it will be necessary to notch even more because of the thickness of the steel plate which covers the hole for the escape wheel. The hole for the escape wheel is not made yet; it is necessary to determine its place, in order not to make the elbow *p* too far from this hole, because the nose of potence must enter the escape wheel. The base of the nose must be very flat the sides perfectly parallel and of a width to just enter the groove of the potence. The nose being adjusted, the screw which will join it to the potence is made; then one will make the potence key *g* (fig. 9), and shape the nose *D*. The counter-potence *I* (fig. 11) is then made, which one will place as shown at *on* (Plate 2, fig. 6).

2471. The place of the chain-guard is marked. For this, the line *S* is drawn (Plate 2, fig. 6) which represents the chain; one will place the stud sufficiently near the edge of the plate so that the chain does not approach too near it. The position of the stud *Q* determines the length of the stop piece *R*, because when the fusee beak butts against the end *b*, the line which passes through the middle *ba* of the stop piece must be perpendicular to the front of the fusee beak and should be directed to the center. The stud is riveted onto the inside of the top plate (fig. 6) and a slit is made for the stop piece, which is made as it is shown in perspective at *A* (Plate 3, fig. 8); and a hole for the pin is bored in the stud and the stop piece. The movement of the stop piece around its center must be extremely small; it is only necessary that it can move against the plate (Plate 2, fig. 6). It is at that moment that the beak of fusee butts, preventing further winding of the watch, and it is necessary that the stop piece can deviate from the plate in order to let the fusee beak pass between it and the plate. This movement of the stop piece depends on the way in which one notches the bottom of the plate to let in the stud; it should be only enough to allow the aforesaid movement, because if this movement is too large the end *b* will touch the fusee. The spring *V* is made, the effect of which is to hold the stop piece away from the plate while the chain is not pressing on it.

> 847. Finally it is necessary to make the spring.[47] For this one will take a piece of steel which is approximately twenty lignes long and three broad, and the thickness of the click. Six lignes from one end a 1 ligne hole is bored and the head of the spring is filed to about the shape which one sees at *D* in Plate 4, fig. 18, leaving enough strength around the hole. The remainder is filed, decreasing in width from the head to the end as shown in the figure. When it is filed to a suitable strength for the spring, it is lightly beaten with a hammer along all its length in order to harden it. Then it is smoothed and polished with a burnisher (a tempered steel tool which is oval and

47 This article actually describes making a click spring for a clock, but it is the only description of spring making that I found in Berthoud's *Essai*.

polished) used with soap and a little water, and bent to the right shape. A screw without a shoulder is made the size of the hole, but with a head which covers the spring, and a hole is bored and tapped in the plate for it. To prevent the spring from turning, a small hole is bored through the spring and the plate at the end of the head *D*, and a steel pin is driven into the hole in the spring with force, the end of this pin protruding under the spring so that enters the hole made in the plate. This pin keeps the spring in place; all springs are fixed, for the same reasons, by these steady pins.

2472. To execute the parts carried on the outside of the top plate, (that is, the slide parts, the rosette and the balance cock) one will start with the slide, whose dimensions are traced on the calibre. The thickness of the slide when finished must be 4⁄12 ligne; brass twice as thick is used, so that in thinning it with the hammer it becomes very hard. To form the slide, brass is taken as if to make a wheel whose radius is the distance from one of the feet *P* (Plate 2, fig. 8) to the center *d* of the balance; it is shaped after it is turned. The rack is made in the same way, it being initially necessary to make a wheel which has *Ed* as its radius. The slide and then the rack are cut out. The cut and hammer-hardened slide is dressed with a file on both sides and a small hole bored. Using this hole as a center, several concentric circles are traced. The largest is the external edge *ef*, which is also the size of the balance. The second circle *g* is the size of the rack; and finally the third circle is the interior edge of the slide. That done, this plate is attached to a wax arbor with the traced side outwards. The plate is set up on the turns while the wax is hot and then the groove for the rack is hollowed out with a graver, as is shown in *GG* (Plate 4, fig. 14). One will retain the guide *b* which must enter the groove of the rack; it is actually this guide which forms the slide and it is on its perfection that the quality of the slide parts depend, and it is a part of rather difficult execution. This guide must be cut very cleanly and square in all directions. The depth of the groove must be such that there remains a thickness of 1⁄12 ligne at the bottom. The two sides of the slide are dressed with a graver, so that they are perfectly flat; if it is thicker than indicated it has to be thinned on the turns, because one runs risk, while removing some with a file, of making it unequal in thickness, a defect it is essential to avoid. The groove is carefully smoothed, but preferably it is cut with a graver to finish the bottom. That done, the slide is completely cut away where the interior circle had been traced. The plate which will form the rack is put on a screw arbor whose pivot is 3⁄12 of a ligne in diameter. The sides are turned quite flat, and then the edge until it just enters tightly in the groove of the slide. Then lamp black or oil stone is put on the guide of the slide and the rack rolled in the groove of the slide, so that that the guide will mark the place where it rubs on the rack. By this mark the groove in the rack is made with a well squared graver; one will not make this groove the full depth, that will be done when one has cut the passage in the slide.[48] By this means one will see how the rack fits in the groove of the slide. Then the groove of the rack is completely turned, until the guide of the slide enters the groove of the rack perfectly, and the face of the rack touches the bottom of the groove in the slide. That done, the rack is thinned until it is no higher than the underneath of the slide so that the inner surfaces form a single face; one will thus turn the lower part of the rack to the center. It is then removed from its arbor and the hole for the balance in the top plate is enlarged until it is the same size as the hole in the rack. The rack is then put on the outside of the top plate, putting a turning arbor through the hole for the balance and that in the rack to hold them together. In this state, the slide is put on

48 I have a rosette, slide and rack (the only fragments of a movement) where the rack is dovetailed to the slide; an interesting exercise in turning.

the rack, which will center it with the hole for the balance made in the top plate. Then the slide is tightened on the plate with pincers and the holes for the slide screws are bored in the slide and the plate. These holes are enlarged, the parts disassembled, the holes of the plate tapped, the screws made, and the slide is set up.

2473. The slide being planted, it is cut out according to the figure traced on the calibre. For this, when it is attached to the plate, one will trace from the center *d* (Plate 2, fig. 8) a circle the size of the balance; it is on this circle that one must file the outside *ef*. The notches *DD* for the passage of banking pin should be filed back, but by only half of the circumference; these notches are only cut back to *p* and *q* when the escapement is finished, and it is better if these notches are not made until then.

2474. The slide and the rack being made and set up, the rosette wheel is made. It is made the size marked on the calibre (rather more than less), and is given the same thickness as the rack. This wheel is split into 24 teeth and it is riveted onto a small arbor *qsr* (Plate 3, fig. 12); this arbor is of tempered steel, and is made on the end of a rod of the size *s* of the seat. Initially the pivot *r* is made and then a shoulder to rivet the wheel to it. Then one makes a small stem from the top of the seat *s*; the thickness must be that of the base of the groove in the slide, because the rosette must be the same thickness as the slide, and the rosette should not jut out over this ring. The stem *q* is used to form the square to receive the hand of rosette; the size of this square must be the same as that of the fusee, so that the same key serves both. The wheel is riveted onto its arbor without separating the arbor from its rod, in order to be able to turn the wheel if it is too large for its gearing with the rack.

2475. To find the number with which one should split the rack, so that its teeth are of suitable size for gearing with the rosette wheel, one uses the following proportion: The diameter (or radius) of the rosette wheel is to the diameter of the rack, as the number of teeth of the rosette wheel is to the number required for the rack. Here the rosette has a radius of $2\frac{1}{2}$ lignes = $\frac{30}{12}$ lignes, and the rack is $4\frac{1}{4}$ lignes = $\frac{51}{12}$; there are thus 30 : 51 :: 24 : x and one finds for the 4th term the number 40, which is the number of teeth that the rack must have to gear with the wheel. But as it is the rosette wheel which drives it must have larger teeth, and one will thus split the rack on the number 42.

2476. The rack being split, the teeth are rounded, but they should be kept full so that the gearing is made very tight and without the least play. The rosette wheel is rounded in the same way and, to judge approximately the depth of the gearing, one will rotate the center of the rack on the turning arbor put in the balance hole in the top plate. If the wheel is too large, it is reduced on the turns and rounded again; but one will wait to finish the gearing when the slide, the rack and the rosette wheel have been put in place. However, for that it is necessary to notch the slide at *TT* (Plate 4, fig. 13), so that the rosette wheel can be placed there to reach the rack; this notch *TT* of the slide must be made according to its thickness, in order not to not weaken the slide too much, and besides, the bottom is used to cover the wheel.

2477. To be able to examine and finish the gearing of the rosette wheel with the rack, one can make a window in the slide, as shown at *EK* in Plate 2, fig. 8; but this window weakens the slide, and so it is better to make it in the plate below point of contact of the wheel and the rack. The gearing being finished, the rosette arbor is separate from the rod on which it was made.

2478. To complete what relates to the slide, the rosette is made. For it one takes a silver plate which is hollowed out, as shown at *LL* in Plate 3, fig. 12. Then it is set on the wheel on the plate, which is used to center the rosette. One bores the holes in the plate and the holes in the feet of the rosette, two screws are made, and the rosette is set up. Then one makes the cut or section *qq,* which is an arc of a circle traced from the center of the balance hole in top plate; this section is required for cleanliness, by being perfectly joined to the edge of the slide and the plane of the rosette and the slide merging; that is, the slide and the rosette are of the same thickness and quite flat. The square for the rosette hand is made and the hand, which must be of steel and have the shape *N* (fig. 12), is adjusted to fit.

2479. The hand for the rosette being made and the gearing completed, the slide parts, rosette and its hand are mounted, in order to mark the length of the rack and to subsequently cut it out. For this, the rosette hand *no* (Plate 2, fig. 8) is moved to the end *0* of the rosette and a point *s* is marked on the rack which is about two teeth past the point of contact of the gears *EK*, so that when the hand is moved to this point there is good, full gearing. Then the hand of rosette is moved to the other end *32* of the rosette, and the point *a* on the rack is marked, taking the same precautions; these two points *a* and *s* determine the length of the rack. The hand is again moved to the end *0* and the point *g* on the slide corresponding to *a* is marked; this point *g* must be a little in front of *a* and it marks the place where the slide will be cut so that it always covers the rack when it is moved to *a*. The hand is moved to the end *32* and the point *h* on the slide corresponding to *s* is marked, which again must be a little past the end of the rack. Before disassembling the slide parts to cut them to length, a guide mark is put on the rosette wheel and the rack so that one can always assemble them without having to guess the position of the gears; this guide mark must be in the middle of the length of the rack and for that it is necessary to move the hand to the figure *15* on the rosette, so that when the needle of rosette is at zero or 32 the gearing is made at the ends of the rack. The arm which carries the curb pins for the balance spring is put at the end *a* of the rack. By this means one will place the balance spring stud away from the slide, which is preferable; and besides, by this provision the arm *a* of the rack will not pass over any pivot holes and consequently take oil from them, as commonly happens.

2480. To make the cock (Plate 4, fig. 15), the height is regulated by the thickness of the slide, the thickness of the balance and the clearance that there must be between the slide and the balance and the balance and the cock. The slide is 4⁄12 ligne thick, the balance, being of brass, will be 3⁄12 thick, and one will need 3⁄12 for the space around the balance; thus the underneath of the cock will be 10⁄12 ligne high above the plate. It must be 2⁄12 ligne thick, and so the brass for the cock, after being forged and dressed, will have to be close to a ligne thick. Its size is determined by the calibre; the balance is 10 lignes in diameter and it is necessary to allow 1½ lignes more for the feet *PP*. But it is necessary to make the feet longer, so that the cock can be held on the plate with pincers while the holes *1*, *2* for the screws are bored. The cock is put on an arbor and turned quite flat on both sides, and to the required thickness. The hollow for the balance is made, 10 lignes in diameter; this hollow will be made with a graver rather than with a file, and the cock will be better made for it. The cock is hollowed deeply so that there remains only 3⁄12 ligne thickness at the bottom. This bottom is dressed with much care, so that it is of perfectly uniform thickness; then the cock will appear as shown in fig. 15, except for the feet which are formed only after the cock as been positioned.

2481. To position the cock, a line is drawn on the plate which marks the direction of the feet; this line must be, as I have said, perpendicular to the line which passes from the center of the rosette to the center of the balance, and the cock is positioned according to this direction. To center it perfectly with the balance hole made in the top plate, one uses a well turned arbor on which a carefully turned plate is fixed. The stem *a* of this tool (Plate 5, fig. 21) is put in the hole in the top plate, and the plate *cc* on the stem is made to sit very exactly parallel to the top plate, and one inserts the hole of the cock on the prolonged stem *b* above the plate. Then the feet of the cock and the plate are gripped in pincers and the holes for the cock screws in the plate are bored.

2482. The brass coqueret *Q* (Plate 4, fig. 16) is made next. It is attached to the cock by two steady pins *1*, *2* and a screw; the notch *s* is not made until the finishing of the watch. The hole in this coqueret is marked with a drill which just enters the hole in the cock, and then this coqueret is bored with a smaller drill. The steel plate *R* is then made.

2483. The top being completed, the motion work is made. For this, the center wheel is put in the frame, the pillars are pinned, and a mark is made on the stem to indicate the place where it is necessary to form the shoulder for the cannon pinion uz (Plate 2, fig. 7); this shoulder must be above the top of the bridge cc in the center of the plate by about 2⁄12 ligne, so that the oil for the pivot of the arbor cannot be attracted to the cannon pinion. The center wheel is removed from the frame and the pivot for the cannon pinion is turned, which will be 4⁄12 ligne so that the shoulder is of a good width and unambiguously stops the cannon pinion. This pivot or stem for the cannon pinion being well turned, the cannon pinion is made from pinion wire drawn with 10 leaves, cutting off the length necessary so that the stem extends beyond it as shown fig. 7. To choose steel of a suitable size some teeth of the minute wheel, which is split into 30, are rounded, and for the size of the pinion 4 full teeth are taken, as has been explained in Art. 529, page 33; but as it is the pinion which drives, one will make it a little larger and 4½ teeth will be taken. Points which are quite concentric are made at each end of the pinion wire, and then the cannon pinion is roughed out with a file, keeping at one end sufficient thickness for the pinion u, which must be a little wider than the minute wheel. Then it is bored on the turns, according to the method prescribed in Art. 910 below; for this a drill is made a little smaller than the end of the center wheel stem. The hole having been bored, it is enlarged, according to Art. 911; and if the hole is not bored straight it is straightened according to Art. 912:

> 910. A punch mark is put in the middle of each end and a drill is made whose size is a little less than the small end of the pivot for the cannon. A ferrule is put at one end of the cannon and this end put against the tapered point of a runner in the turns. The tool rest of the turns is then turned transversely and put near the other end of the cannon. The drill is supported on the tool rest and held fixed, while the cannon is turned with the bow[49]. In this manner one will bore the hole in the cannon perfectly upright, until the drill has bored the hole from one end to the other of the cannon and it meets the point of the runner. Thus it is necessary to move the stem of the drill so as to be able to enter the cannon completely; but the drill stem is only moved as the drill bores, so that it is more solid and less prone to bend.
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> 911. When the hole has been bored, a good broach is taken and the hole in the cannon enlarged until it is ready to go on the pivot for the cannon, taking care to see that the pivot touches over its entire length. If this pivot were turned more tapered than

49 The drilling is done between centers with the drill itself being one of the centers.

> the broach, one should not enlarge the hole of the cannon pinion so that it goes completely on the pivot, since in this case the end of this pivot would not be tight in the small end of the hole. To ensure this, the end of the stem is presented to the small end of the hole; if it does not go on, the cannon pinion can still be enlarged, supposing that it is not too small at the shoulder. In a word, it is necessary to have care that the pivot touches over the entire length of the hole. When this hole is well formed and the broach touches over the entire length of the hole, the pivot is adjusted to the cannon pinion, by decreasing it on the turns at the places which touch. These places are seen by putting a little oil on the pivot and turning it a little in the hole of the cannon; the spots that are too large are marked black by the cannon. To make it go on completely to the bottom of the shoulder, it is necessary to use a smooth file and then an oil stone on the pivot, until it enters with a light friction.
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> 912. To turn the cannon of cannon pinion, one will make a turning arbor the length, size and shape of the hole in the cannon, so that it touches over the entire length of the hole in the cannon. Thus mounted with friction on this quite smooth arbor (turned quite round), one will see whether the arbor is curved by the cannon, which would prove that the hole is not perfectly straight. If that is the case, to rectify this hole the two ends of the cannon are set on the open jaws of a vice, and one will strike the middle of the cannon to rectify it. To note the place where it is necessary to strike, the cannon on the turning arbor is put in the turns, and the point of a graver is presented to the arbor between the ferrule and the large end of the cannon; the place which touches the graver indicates the side where it is necessary to strike. The arbor is left in the hole during this operation, in order not to change the shape of the hole.

2483 cont'd. When the cannon has been straightened, it is turned to the same size as the fusee pivot on which the square to wind the watch is formed, so that the same key serves for all squares. The pinion is turned to size and thickness, keeping a suitable shoulder on the bottom of the leaves of the cannon pinion to receive the hour wheel, so that it does not rub against the leaves of the pinion; this is a very common fault because workmen, to give their pinions a more beautiful appearance, make a hollow at the bottom of the leaves. The leaves of the pinion are then finished and the faces, the cannon and the pinion are smoothed.

The cannon for the hour wheel is then made. The hole is bored smaller than the cannon pinion, so that it will go on tightly after the hole has been enlarged. Then the cannon is turned, and the wheel riveted onto it. It is finished by making it go on the cannon pinion. But if the cannon pinion is not the shape of the broach which was used to make the hole in the hour wheel cannon, the cannon pinion is turned slightly so that the hour wheel cannon goes on it without any shake at either end; then one makes it turn freely.

2484. The hour wheel being adjusted, the center wheel is put in the frame, the cannon pinion is put on the stem, and the hour wheel on the cannon pinion. Then the measurement for the length of the minute wheel pinion is taken. For this, pinion wire of a suitable size is chosen; this pinion being of 8 and driving the wheel, one will take nearly 4 teeth on their points. A piece of this steel is cut off whose length, in addition to the height taken from the bottom of the plate to the top of the hour wheel, is sufficient to form the pivots which enter the plate and run in the bridge *T*; it is better to cut it a little longer. This pinion is bored on the turns with a hole suitable to receive a turning arbor $\frac{3}{12}$ ligne in size. The pinion is roughed out with a file, leaving a suitable length for the pinion leaves and for riveting the minute wheel. The pinion is turned, finished and hardened. When it had been hardened and tempered blue, it is polished and the place to rivet on the minute wheel is turned. The wheel is riveted and then the lower pivot is made, which will have a diameter of nearly 6⁄12 of a ligne; the shoulder is cut back only a little, in order not to make the wheel lower than the pinion of the cannon pinion. The hole for this pivot in the pillar plate is enlarged, and the wheel is put in, in order to see whether its height is correct to fully mesh with the pinion of the cannon pinion; the shoulder is gradually cut back until that is right. The hour wheel is put in and the pinion of the minute wheel is turned until it is flush with the hour wheel. Then the face of the pinion is made, the pivot for the bridge *T* cut flush with the pinion, and the bridge is made and set up without shake. When the wheel is quite true the two holes are bored into which the steady pins are driven.

2485. The motion work being made, it only remains to make the pinions of the third and contrate wheels, and that of the escape wheel, and one will have an *ebauche*[50]; one will thus make these pinions *k*, *l*, *m* (Plate 1, fig. 4). Pinion wire drawn with 6 leaves is chosen. Some teeth of the center, third and contrate wheels are rounded, and the sizes of these pinions determined according to Art. 535 (page 33), a little more than 3 teeth on the points. The length of the pinions for the third and contrate wheels is from the outside of the bridge *ff* to the outside of the top plate, more rather than less. The pinions are roughed out giving the necessary length to the bodies to rivet the wheels. However, one will observe that the third wheel must pass above the fusee wheel, and that the contrate wheel must be above the middle of the frame on the side of the top plate. The length of the escape wheel pinion is determined by the distance from the nose of potence to the counter-potence. These pinions are turned, taking care not to make the arbors too thin so that they cannot bend, and so that after the pivots are made there remains a shoulder broad enough to be able to recess the plates. The pinions are polished and the pivots made, which are kept large rather than small. The shoulders are kept high so that the wheel can be raised or lowered during finishing, and the pinions put in the frame. The holes for the pivots in the bridge and in the plate are chamfered, so that these shoulders can enter, and the shoulders or seats adjusted for riveting the wheels. These wheels are then riveted and the ebauche is finished.

50 A *movement in white* on the continent and a *movement in the grey* in England. Note that at this stage the escapement has not been made.

Ferdinand Berthoud

Finishing the watch

2486. The dial is made, to which one will give a suitable curve so that it does not to touch the motion work bridges under the dial, and the holes for the feet which attach it to the movement are bored.

Operations required to make an enamel dial.[51]

1164. Though the process of making an enamel dial more particularly relates to the art of the enameller than that of the horologist, I will take leave to describe the principal operations, to give an idea of it to those who want to try and make one, and so to do by themselves all that relates to the movement of a clock. But it is wise to note that what I will say about it is very much shortened, because this matter by itself would require a complete work with several plates.

1. To make the dial plate.

1165. To make enamel dials, an extremely thin red-copper plate[52] is taken, to which one gives the curve that the dial must have. There is, for this, a piece of wood hollowed out with a curve similar to the dial; using a hammer with a head which is a little round, it is easy to make the plate with the appropriate curve. It is put on the plate[53], and the positions of the feet are marked from the holes bored in the plate for them. To make these feet, drawn copper wire is used, which is the size of the holes in the plate, and a small shoulder is made on the end of these feet, which serves to rivet them to the dial. Holes are bored in the dial the size of the pivots of the feet; these pivots should be only a little smaller than the feet in order to be solid. When the feet have been riveted, they are soldered. For that, solder made from copper and brass is used, whose mixture is similar to that of our six sou piece; or, for best, small, drawn brass wire is used. Borax is used, as is done every time one solders.

1166. When the feet are soldered they are straightened, so that they enter the holes in the plate, and the hole for winding is made in line with that in the plate. The hole in the center is enlarged so that it coincides with the hole in the plate. For this, while the dial is posed on the plate, one draws the hole in the dial with a sage leaf file, until this hole is concentric with that in the plate. But this operation is done before it is enlarged, because it is necessary, in order to have a very clean hole, to bring it to the size of the hole in the plate by using a reamer which enters from the under side and, while increasing the hole in the dial, forms a small ridge which is used to hold the enamel. In this way the hole in the dial is enlarged until the borer reaches the hole in plate; thus, by holding the reamer quite perpendicular to the plane of the plate the hole in the dial will coincide perfectly with that in the plate.

1167. The same attention is given to making the hole for the winding square. Thus, it will initially be put upright with that in the plate, and when it is (the hole being smaller than needed), a reamer is taken which is put in from the bottom side and which, at the same time as it enlarges the hole in the dial, will form a small ridge on the top to retain the enamel. But it must be observed that by forming this hole and bringing it to the size of that in the plate, if it is not straight above the one in the plate the reamer, when it touches the winding hole, will move and bend the feet from the pressure of the reamer against the hole in the plate; and consequently the hole in the center of the dial would be moved and would no longer be concentric with the

51 Another description of dial making is given in Leonard Weiss *Watch-Making in England 1760-1820*, 1982.

52 Berthoud uses *cuivre* for both copper and brass and he has specified copper here by qualifying it with its colour.

53 The pillar plate of the watch or the false plate of a clock.

plate. To prevent this problem, it is necessary to insert a second reamer, or a turning arbor, tightly in the center hole, which will retain the hole in its place by keeping the reamer or turning arbor always upright. But to hold the dial more firmly, the edges of the dial and the plate are gripped together by two screwed hand vices, one on each side.

1168. To give the necessary size to the dial and to make it quite round, one will take a compass with a mushroom point and open it to the line marked on the plate for the edge of the dial. With the same opening of the compass, this line is marked on the dial and the surplus cut off with scissors.

2. Enamel and its preparation.

1169. The enamel which is used for our dials is a preparation like glass, which is not transparent but white. To enamel a dial, the enamel is reduced to small grains and water added to it to form a paste, which is then spread over the surface of the copper plate, put into a reverberating furnace and fused, becoming flat. It is on this surface that the hours are painted with a black enamel, which is also fused in the furnace.

1170. The enamel which is employed for our dials, or at least the best, comes from Venice, and it is sold in Paris by dealers in horological tools. There are two kinds of enamel; tender and hard. Tender enamel is distinguished from hard by the former being transparent, whereas the latter is opaque and when broken it has more open pores. This enamel is preferable and it takes a very beautiful polish, but one needs a hotter fire to fuse it.

1171. Enamel is sold in *loaves*. To use it, these loaves are broken into small pieces and then crushed in a tempered steel mortar until the granules are quite fine and approximately equal in size. To prevent fragments of enamel leaving the mortar, the opening is covered with a clean cloth, and a little extremely clear spring water is put in the mortar. One will thus reduce the enamel until it feels like fine sand in the fingers; it should not be reduced to powder.

1172. When the enamel is crushed it is put in a glass vessel, into which very clear spring water is poured. The enamel is stirred up so that that makes the water white and then it is left to deposit. Then the water is removed by gently inclining the vessel; this water carries away any dirt which was introduced into the enamel by the crushing. The enamel is washed several times until the water remains clear. The pieces which remain in the water in which the enamel was washed are kept to use for the *contra-enamel*; that is, the back of the part to be enamelled.

1173. When the enamel is well washed, it is put in a glass vessel and sufficient aqua fortis (nitric acid) is added so that it rises some fingers above the enamel, and the enamel is left in the aqua fortis for twelve hours. This operation is called *scouring* and it is used to clean the enamel of any metal fragments from the mortar which were introduced into it when it was crushed.

1174. When the enamel is removed from the aqua fortis, it is washed several times with common water, until there is no aqua fortis mixed with the enamel and the water is quite clear. Then the enamel is covered with water to keep it clean; moreover, to spread the enamel on the plate it must be taken from the vessel in which the enamel is still in water.

3. Preparation of the dial plate before charging it with enamel.

1175, Before placing enamel on the plate it needs to be scoured. For this, it should be put in second water (a mixture of aqua fortis and common water) until the copper is bright and clean all over its surface. Then a *scratch brush*, (a tool made from a bundle of brass wire) is taken and, holding the plate in ordinary water, it is scratched to remove the crust on the copper. This operation, using scratch brushes and scouring, opens the pores of the copper to receive the enamel, so that it is fixed by the fusion.

1176. Remark. One does not only enamel the side of the dial where the hours will be painted, but the bottom or concave side is also enamelled; so that the enamel on the top, being molten, does not change the curve and deform it. This is called the contra-enamel. The contra-enamel is thus used to balance the action of fire on the enamel on the face of the dial and both are put on at the same time and fired together.

1177. Initially the contra-enamel is put on. For this the pure enamel is not used, but that which is drawn from the dirty water. To put on the contra-enamel, the center hole of the plate is put on a reamer with the concave side on top. With a *spatula* (a thin blade of steel rounded at the end) one takes some of the contra-enamel deposited at the bottom of a vessel. After draining all the water from it, it is spread evenly over all of the concave surface of the plate, putting on only enough to hide the copper; it is essential that the layer is equally thick. To remove some of the water held in the enamel, a dry, clean cloth is taken and rested on the enamel close to the hole; it will attract or pump out the water. But the enamel should not be too dry, because to spread enamel on the top, the plate must be turned over and the contra-enamel could fall off while charging that side.

1178. The plate is turned over and the reamer put in the center hole. Pure enamel is taken, and spread over the top of the dial in a quite even layer, making sure the edges are well covered and edges of the holes surrounded by enamel, so that the action of the fire does not burn them. The water in the enamel is pumped out by pressing on the edge with a cloth. So that all the grains of enamel are close together and occupy the least volume, the reamer which supports the dial is lightly tapped, which shakes and settles all the pieces of enamel and brings out water which is pumped away a second time. Enamellers call this to *beat* the enamel; it is on this settling of the enamel grains and removal of water that the polish or glaze of the dial depends, because the enamel, being compact and with no cavities, keeps its flat surface. The enamel is levelled again with the spatula.

1179. It is necessary, by continuation of same reasoning, to dry the dial before exposing it to the fire which will melt it, because the heat would make the water bubble which would disturb enamel and make its surface rough.

1180. To dry the dial it is placed on a rather large sheet of metal which is put on hot ash, which then desiccates the water gradually; during this time, the fire to melt the enamel (to *fire the dial*) is prepared.

4. The furnace.

1181. The furnace in which enamellers fire dials is built in a chimney, and is raised up on a support, to make it easy to arrange and see the work. This furnace is square and built of bricks. A small opening is left in the top at the back, for the passage of smoke. When the furnace is used to fire large parts, like dials a foot in size, it must be nearly 3 feet square in order to contain enough charcoal to produce a fire able to fuse enamel. The opening of the furnace is closed to the top by a large flat piece of crucible clay, which allows a view of the heat of the charcoal. Similar ones are put on the sides in order to leave an opening only large enough for the free entry of the piece to be fired, which concentrates the heat inside the furnace; thus the front of the furnace is form by these pieces.

1182. When smaller pieces are to be fired, the inside of the furnace is lined with crucible clay to form a smaller furnace, in order not to have to light as large a fire as for a big piece.

5. The arrangement of charcoal and the muffle.

1183. To fuse the dial in the fire most easily, it is absolutely necessary that it is placed in the center of a hearth where all the heat of the fire surrounds it, because it is necessary that it is heated on all sides. To achieve this, a small room of just the required size is built in the furnace, in which to conveniently put the part to be fired, and this room is surrounded by charcoal on all sides except for an opening to put in the work.

1184. To form this room a piece of crucible clay is moulded and shaped into a vault; it is called a *muffle*. There are muffles of various sizes, according to the size of the parts which are to be fired.

1185. Before putting the muffle in the furnace, the sole or hearth is formed from several layers of charcoal made from beech wood; the hearth must have three layers or beds of charcoal. The hearth being made, the muffle is put on it with its opening toward that of the furnace The back and base of the muffle are furnished with charcoal put transversely, to stop this side of the wall. The charcoal must be arranged with much art, so that as it is consumed it does disturb the room formed by the muffle. In the same way the sides and top of muffle are covered with well arranged sticks of beech charcoal, and thus all the space in the furnace is filled with charcoal, which must be the same as the charcoal which surrounds the muffle and forms a thickness of at least three to four inches. Then the charcoal is lit and the front of the furnace closed with blocks of clay, about which I spoke, and the charcoal is allowed to burn by itself, and by the air coming through slits in the clay blocks at the front of the furnace and the opening into the furnace for the passage of the parts to be fired.

1186. When the charcoal is well lit and the fire is most active, it is the moment to fire the dial. This is judged by the activity of the fire and the colour of the muffle, which must be a white red. Then large bellows are taken and blown hard into the muffle to remove ashes or other bits which could detach and fall onto the enamel. And the charcoal is blown to enliven it more.

1187. To fire the dial, it is put on an iron ring whose edge is quite straight; this ring is welded hot (that is, the iron is fused) and the edge covered with Spanish whiting, so that when the contra-enamel is on it, it does not stick to the ring. This ring, which is called the *collar*, must sit on a sheet-metal plate strong enough not to bend, which is used to carry the collar and the dial to the fire with long pincers called a *releve moustache*.

1188. To fire the dial, it is necessary that it is well dried, and it should be gently presented at the opening of the furnace, in order to heat it very slowly, so that if there are still wet parts they dry without bubbling. That done, the sheet of metal is put on the hearth in the bottom of the space formed by the muffle and it is left there until one sees the enamel start to fuse. Then the sheet is gently turned around so that, if the heat is unequal, it evenly fuses all of the surface of the dial. When it is seen that the enamel is molten, which is easily noticed by the enamel spreading and by the smooth look of its surface, it is carefully withdrawn from the fire. It is not immediately exposed to the air, but held for a moment in the opening of the furnace, so that it loses its heat very slowly; because if cold air suddenly strikes its surface unequally, then the enamel with crack and burst.

1189. When the dial has had its first firing, it is put in second water to be scoured again, before being charged with a second layer of enamel. It is scoured this second time to clean the parts of the copper which are not enamelled at the edges and the holes. If there are places under the dial where the copper is visible more enamel is put on, but only on those places because only one layer is put on the contra-enamel. To continue, one takes enamel crushed finer than that for the first layer and it is prepared in the same way. The water which remains in the vessel is removed and it is spread with a spatula evenly over all the convex surface of the dial. The water is drawn from it with a cloth and the reamer tapped in the same way to settle the enamel and to make more water leave so that its surface is extremely flat; it is dried in the same way as the first time. The second fire is prepared with the same care, and the dial is fired at the moment that charcoal acquires its greatest heat. It is removed with the same precautions when one sees the enamel entirely melted and its surface flat and glazed.

1190. So that the enamel is beautiful and the dial surface is perfectly flat, it is charged with enamel and fired a third time, by the same method and with the same care. It will be observed that if the dial has some blisters, it is necessary to open them, enlarge them with a graver, and fill them with fine, well compacted crushed enamel. In these places the enamel must be a little higher than the surface, so that when it melts it fills to the same level.

1191. The dial thus enamelled, it remains to paint the figures with *shell black*, which is a prepared tender enamel. But before painting the dial it should be divided. For this, one will start by tracing fine lines with a compass which has a mushroom head and a black lead in place of one of the points. Initially a line is drawn which determines the edge of the glass and then a second line inside it for the end of the minute divisions (Plate 6, fig. 3), leaving between the first and the second an interval sufficient for the minute figures. Then a third line is traced to regulate the length of the minute divisions; and finally a fourth circle to regulate the length of the hour figures.

1192. To trace the divisions on the dial a wheel cutting engine can be used, if is one available. If not, a platform or dividing plate is made from brass, which is twelve to fifteen inches in diameter and has a circle, concentric to the center hole of the plate, which is divided into sixty parts. The dial is put on this plate, which is pierced with holes to let the dial feet pass freely and so center the dial on the plate.

1193. To place the dial concentrically with the dividing plate, the plate has an arbor fixed in its center, whose stem is threaded and enters a conical support collar that is set in the hole in the dial; it is brought to the center of the plate by means of the pressure of a nut which tightens the conical support collar and at the same time fixes the dial and prevents it from turning. It is presumed that this arbor on the dividing plate turns smoothly, rises perpendicular to the plane of the dividing plate, and is concentric with it.[54]

1194. To divide the dial by the divisions on the platform, an index made from a piece of thin spring is used; one end of this blade goes on the end of the arbor of the platform, and the other sits on the division circle. Thus, by holding the index on a division point, one can trace the minute divisions on the dial with a black lead, as one sees in Plate 6, fig. 3. But before tracing these lines, it is necessary to take care to mark the point of midday on the edge of the dial by a small notch in line with midday on the pillar plate; it is necessary that this point corresponds perfectly with the side of the index when it is set on a division of the circle divided into sixty parts. If not, the dial must be turned, independently of the dividing plate, to bring it to this point.

1195. When the minute divisions are traced, a line is marked on the division for midday, which crosses from the fourth circle to the first; it will indicate the place where one must paint the 60 minutes and 12 hours. The index is then moved five divisions, and a similar line drawn to indicate one hour and the fifth minute; and so on. After that the dial is painted, being regulated by the divisions made with the pencil.

54 This is like the funnel turning arbor; see Plate 9, fig. 30.

1196. The black which is used to paint dials is called shell black[55]. The most beautiful that has been made up to now is sold by Mr. Gaillard, an extremely skilful enameller in Paris. This artist makes this black himself and it is he who makes our most beautiful clock dials. He has advanced his art further than anyone before him. Thus it is to render a service to those who need these pieces that I recommend him.

1197. To use this black it should be crushed very fine in an agate mortar with oil of aspic. To give an idea of the smoothness which it must have, at least half a day should be spent crushing a drachm[56].

1198. After the black is crushed, it is taken from the mortar and some of it is put on a piece of glass (the remainder must be sealed up in a very clean vessel), and to render it more fluid and suitable for use with a brush, new oil of aspic is added and it is crushed with a small steel spatula.

1199. Initially, the lines for the minute divisions are painted with a small brush, and then this brush is put in the compass to trace the four circles. Finally the figures for the minutes and the hours are painted.

1200. When the dial is painted it is allowed to dry slowly under a cover, so that no dirt sticks to it. A fire is prepared in the furnace, it is lit, and when it is it at the right point the dial is fired; it is not pushed in all at once, but on the contrary it is heated very slowly so that it does not crack. It is put on the bottom of the hearth and left there until painting becomes flat and glazed, with a matte finish; the metal sheet is turned so that heat melts the black without burning it. The dial withdrawn with care and it is finished.

2486 cont'd. One commonly attaches watch dials by three feet which pass to the inside of the pillar plate, where each is bored with a hole for the pins which hold the dial. However, this method is defective; because if one needs to take off the dial to examine the dial work, it is necessary to remove the movement from the case in order to draw the pins; and while putting in and taking out these pins, one runs the risk of bending the wheels of the movement. Thus it is preferable to attach the dial by a screw and to have two feet which do nothing but enter the plate to hold it; by this means, the dial can be removed very easily, as in repeater watches. The dial being made and adjusted, the bridges *ff* and *T* (Plate 1, fig. 4) are lowered if they are too high. One should enlarge the winding hole in the dial, for the passage of the key, only when the gearing of the fusee is finished and the two large wheels are planted in the frame; because if the gearing is too weak the fusee would be brought closer to the center, and the fusee square would no longer be in the center of the hole.

2487. The first things which it is necessary to do to finish a watch, are to dress and smooth the plates well, to make the top plate go freely on the pillars, and to pass a broach through the holes for the pillar pins, so that the holes are level with the plate and the pins press the top plate against the shoulders of the pillars; the two plates, when assembled, must be without shake. It is necessary that the four holes in the pillars for the pins are of the same size; these holes can be of $\frac{1}{12}$ of a ligne or more and it is necessary that the pins are strong so that they can be put in and removed easily.

2488. That done, the center wheel is put in the frame, the four pillar pins inserted, and one will see whether the wheel is at a good height; if not, one or the other of the shoulders

55 *noir d'écaille*.

56 Ambiguous, but most likely one sixteenth of an avoirdupois ounce.

is cut back according as is necessary to give clearance to the wheel; that is to say with the plate or the fusee wheel. The shoulders being turned to height, the pivots are polished again. If the holes are too large they will have to be bushed then enlarged, so that, the hole being well cleaned, the wheel turns freely and without play on its pivots. Then the oil sinks are made.

2489. It should be observed here that to bush the pivot holes one should not use brass drawn through a die; the middle of this wire is seldom clean, its particles are divided by drawing and cavities are formed. It is necessary to use boiler brass, of a beautiful yellow and very thick, and to hammer-harden it flat only with the head of the hammer. Then small strips are cut off which are rounded with a file.

2490. The fusee wheel is put in the frame with the center wheel and the frame pinned; the fusee cock is put on, and one will examine the clearance between the center wheel and the fusee wheel, and between the fusee beak and the top plate. If the fusee is too high (that is, the fusee wheel approaches too near to the center wheel and the plate, and the fusee beak to the top plate) then it is necessary to turn a little off the base and the top of the fusee. But if the fusee is not too high yet comes too near one or the other plate, one or other of the shoulders on the fusee arbor is turned down. The pivots and shoulders of this arbor are then polished.

2491. The fusee being set to height, the gearing is examined. For this, some teeth of the fusee wheel are rounded and a hole *t* (Plate 2, fig. 6) is bored above the point of contact of the gears, large enough to be used as a window to see the engagement. The fusee and center wheel are put in the frame and a finger is pressed against the projecting stem of the center wheel, to produce friction to prevent the wheel from turning other than by the pressure of the teeth of the fusee wheel, which is turned with the other hand. By this means one can judge the nature of the gearing perfectly by making touch and sight accord, and one can see all the parts being driven.

2492. If the gearing is a little too deep, the fusee wheel can remain in place without moving the holes, because the fusee is planted and one can just turn a little off the wheel. (It is said that a wheel is planted when its holes are bushed; that is, it is upright in the frame and it turns freely.) When gearing is much too deep and the pinion is of a good size, then one should not turn the wheel, because the pinion would become too large; instead the wheel should be moved outwards. If the gearing is weak, it will be necessary to stretch the hole of the fusee to bring the wheel closer to the pinion with which it engages; this hole is stretched so that the gearing is a suitable depth and the pivot passes through the middle of the hole; by this method one only needs to turn a plug to bush the hole.

2493. The hole of the large pivot of the fusee being thus stretched for the gearing, it is enlarged so that there is a suitable space all around the pivot to fit a thick and solid plug. To bush this hole, a plug *G* (Plate 2, fig. 12) is turned on which is raised a shoulder *z* to form a cannon which enters the hole of the fusee pivot; the cannon goes beyond the inside of the recess by the amount needed for riveting. This side of the hole is chamfered, and the cannon riveted to the plate. Oil should be put in for the reason explained in Art. 2455, page 29; the same should be done with all the holes which are bushed.

2494. The fusee hole thus bushed, it is enlarged so that the pivot goes in upright and freely. The top plate is put in place on the pillars and the hole for the passage of the pivot shank of the cannon pinion is stretched as necessary so that the wheel remains upright in the frame. The same is done with the hole in the fusee cock, which should be stretched so that the wheel is upright and the pivot is upright in the middle of the hole of the bridge, so that it can be bushed in the center. (But if the hole has to be thrown a lot to one side, so that not enough matter remains around the hole, it would be better to cut off the steady pins of the fusee cock and to move the cock, so that the wheel is upright in the frame, and to bore new holes for the pins.) The hole in the cock is bushed with an un-pierced plug. To bore the hole the uprighting tool is used (Plate 8, fig. 17). The hole is bored using the point marked by the tool and enlarged suitably. The fusee wheel being quite upright and free in the frame, and the gearing of a suitable depth, the oil sinks for the pivots are made.

2495. One will mark above the dust cap *E* of the large pivot of the fusee (Plate 2, fig. 7) the place where it must be reduced to start the fusee square; this square is made according to the prescribed instructions[57]. The teeth of the fusee wheel are rounded and the gearing is finished according to the instructions in Art. 972 and following.

> *To make the teeth and to form the gearing on the depthing tool, to plant the wheels in the frame.*[58]
>
> 969. To hold the wheels firmly while the teeth are made, it is necessary to have a board that is put in the vice and against which the wheel is supported by pressing it with a hand against the board, while with the other the teeth are rounded. It is necessary that this board is of a hard wood such as oak, and it should be approximately six lignes thick, three inches broad and six inches long. Several holes, sufficiently large to let pinions pass freely through them, are drilled in this board, so that the wheels sit flat against it. These holes must be drilled close enough to the edge so that part of the wheel protrudes above the edge of the board; thus these holes must be various distances from the edge of the board according to whether they are used for large or small wheels. This board must quite plane and smooth so that the wheel cannot rock or be curved while the teeth are formed.
>
> 970. Before rounding the wheels, it is wise to observe that their teeth should not all have the same shape, and that the origin of the curve must begin more or less close to the top of the tooth, according to whether the wheel engages with a more or less numbered pinion. If, for example, the teeth of the barrel wheel are made, which gears with a pinion of twelve, as the teeth of the wheel must penetrate less into the space between the leaves of the pinion to form the gearing, it follows that the curve of the teeth must be closer to the top; but if, on the contrary, the teeth of the center wheel are made, which engages with a pinion of six, then each tooth of the wheel must lead the pinion during a sixth part of its revolution; that is, to describe 60 degrees. This is what clock and watch makers call *lead*[59]. Thus the lead of the pinion of six being double of that of the pinion of twelve, the teeth must penetrate further and the curve will have to take its origin closer to the bottom of the teeth. By this means one will manage to make the lead of the teeth uniform. For the remainder I refer you to the theory of the curves of teeth in the second part of this book, and especially *Cours de Mathématique* by Mr. Camus. To take the place of them, the depthing tool will be

57 See Art. 2469, page 41.

58 This describes rounding up the teeth of the barrel wheel in a clock, the equivalent of the fusee wheel in a watch.

59 *menée*, the linear or angular value of the movement of two wheels.

used to give these curves, as will be shown below[60].

971. Which wheel to start forming teeth on is unimportant, but one will do well to start with the teeth of the barrel wheel; as these teeth are larger, it is easier to accustom oneself to the form of these curves. The barrel assembled on its arbor is taken and a hole is drilled in the board, suitable for the pivot on the side of the wheel, and this hole will be so far from the edge that the teeth only just project above the edge of the board; by this means it will be easier hold the wheel against the board, without the effort of filing tiring the hand which presses on the barrel.

972. To rough out the teeth, a triangular file is taken and the angles of the teeth filed, inserting the angle of the file in the space between the teeth. It is supported so that the file is in line with the axis of the barrel and the teeth are not inclined to the axis, which is called *to cut teeth with an endless screw*. Care will also be taken to cut down the corners equally on each side of the teeth and each tooth of the wheel until one has made a complete *turn of the wheel*; that is, removed the angles from all of the teeth. When the triangular file has thus passed over the wheel, a coarse rounding up file is used to remove the sides or angles of the teeth, and form the curve on each side of the teeth, always using the file in line with the wheel axle in order not to round the teeth with an endless screw. Care will be taken that the front and back of the teeth are filed to the same curve; for this it is necessary to push the file without raising or dropping it, but keeping it parallel to the wheel axle[61].

973. The wheel thus rounded, an equalling file is chosen which just enters the space between the teeth, and it is used to straighten the bottom and to remove the marks made there and on the sides of the teeth by the cutter. If the teeth are not equally deep, a bastard equalling file is taken and the shallow teeth deepened, the depth being regulated by the line made close to the bottom of the teeth.

974. The teeth thus prepared, it will be necessary, for smoothing them, to present the wheel on the depthing tool with the pinion into which it gears (Plate 8, fig. 16). The wheel is made to approach its pinion until the most suitable distance between the two axes is found, so that the gears engage most uniformly. To judge the effect of the gearing of the wheels in the tool, one hand presses on the pinion arbor to produce friction, while the other hand turns the wheel slowly, in order to see any inequality in the movement which the wheel teeth produce on the pinion. If there is no point where the gearing is done without jumping, it is a sign that the curve of the teeth is not well made; because I presume that the pinion was made the correct size and according to the prescribed rules, and so the inequalities in the movement of the wheel and the pinion are produced by the bad curves of the teeth; that is, they are still too square and not round enough. In this case one will round them again by more strongly cutting down the angles to form a good curve. If it happens that the wheel teeth have been made too empty, and that one cannot form a suitable curve to

60 *Cours de Mathématique* by C.E.L. Camus (1751) contains an excellent explanation of the theory of epicycloid gearing, followed by an examination of the calculation of gear trains. This very important work was translated into English by J.I. Hawkins under the title *A Treatise on the teeth of Wheels* (1806). It should be noted that the theory of epicycloid gears was almost never used to form teeth in watch work, and the shape of teeth was nearly always approximated by thumbs, bay leaves or, much later, circular arcs. Berthoud describes a trial and terror process which illustrates the yawning gulf between known theory and practice.

61 Other than the motion work, the train always runs in one direction and the shape of the backs of the teeth is irrelevant, provided there is enough freedom with the pinion. Although filing the backs to the same curve may have been just habit, it probably made it much easier to visually check that the teeth had been rounded satisfactorily. In Art. 974 below, Berthoud indicates that this is the correct reason.

lead the leaves of the pinion uniformly, one could make this larger curve on one side of the tooth more than on the other; that is, the top, where the curves on each side of the tooth meet, would not be in the middle of the thickness of the tooth, but a little on one side, choosing the side according to which way the wheel must turn. It is seen that by this process the gearing would not be uniform, when the wheel is turned on the side of the large curves as opposed to turning it in the other direction, when the gearing would jump; but one should not be concerned about this claimed difficulty, because in our clocks the wheels always go in the same direction and do not go and return alternately. Anyway, any objection can be prevented by splitting the wheels with thin enough cutters to leave them, as I said (Art. 780, page 31) more full than space, by which means one can form curves suitable for good gearing.

975. When rounding the teeth, it is necessary to take great care not to file completely to the top of the teeth with the rounding up file, in order to preserve them at the same length, and consequently not to harm the roundness of the wheel.

976. When one has retouched the curves of the teeth, the wheel and the pinion are again put in the depthing tool, and the wheel is moved towards or drawn away from the pinion to find the separation most suitable for this wheel.

977. To avoid having to retouch all the teeth of a wheel several times to give them the correct curve, one can initially round only about twice as many teeth as the pinion it meshes with has leaves; thus one will round only 20 or 24 teeth of the barrel wheel and change their curve until the gearing is good. And if it is found that the wheel is too large, relative to its pinion (that is, if this pinion had been made too small), it is necessary to turn the wheel and decrease the length of its teeth, to reduce it to a size suitable to make the gearing uniform. When the curve of the teeth has been determined and the wheel reduced to its correct size, the curves are formed on the rest of the teeth of the wheel, and care will be taken to make them exactly the same as the first. To check this, the wheel and the pinion are put in the depthing tool and the teeth whose curves are not well made are retouched.

978. The teeth being brought to this point, they have to be smoothed. To do this, it is necessary to place the barrel wheel in the turns, rotating on its arbor, in order to slightly trim the tops of the teeth to make them all exactly the same length; clock and watch makers call this operation to *stroke the points of the teeth*[62]. Then a fine rounding up file is used to remove the marks of the graver made on the top of the teeth, and to again reform the curves of those teeth which were longer, and by this means to make them perfectly equal.

979. It is wise to observe that, to facilitate the execution of the curves of the teeth, it is necessary to choose rather thick rounding up files so that they cannot reach the bottom of the teeth, but only to the place where the curve begins; by this means the file is guided by the space between the teeth as by a groove. Thus the back or uncut part presses on the side of a tooth, while the cut part files the side of the next tooth. As one files, one should only turn the file in the hand to round and form the curve.

980. The teeth of the barrel wheel being made, one will round the center wheel by the same methods and with the same care; initially using a triangular file to remove the angles of the teeth, and then a rounding up bastard file of a size and thickness suitable to enter the space between the teeth and to form the curves to the depth necessary for the gearing. The gearing is then examined in the depthing tool by the methods prescribed above, until it is uniform. Then the points of the teeth are stroked; but to do this it is necessary to use two runners with disks in the turns (Plate

62 *friser les points des dents*. Also called topping.

5, fig. 4). In each of them, at the same distance from the center, a hole is bored to take the pivots of the center wheel; and a broach is passed through these holes to make them smooth, so that the pivots turn in them freely and without play. The pivots are put in these runners in the turns, with oil on them to lessen the friction, and the points of the teeth are turned to reduce them to exactly to the same length and to make the wheel perfectly round. Then the rounding of the teeth is completed with a fine file, and the bottom and sides of the teeth are finished with a fine equalizing file.

2496. We are now ready to turn the fusee. For this it must be hollowed in the middle in the shape of a bell. To find the number of revolutions of chain which it must hold, so that the watch goes 30 hours, one computes the teeth of the fusee wheel, in this case 54, divided by the pinion with which it meshes, which is 12 (Art. 2385, page 13); it thus makes one turn in 4½ hours and so there are 6⅔ turns in 30 hours; thus for the watch to run 30 hours it is necessary that the fusee holds 6⅔ turns of chain.

2497. The fusee is cut, as explained in Art. 465 and following[63]. At the start of the groove on the base of the fusee *E* (Plate 2, fig. 5) a hollow for the chain hook is made with a thin cutter and a hole is bored for the pin *p*; it is on this pin that the chain hook is held. One will choose a good English chain which is the right thickness for the groove of the fusee, and one will cut it to length according to Art. 468 below.

2498. At the edge of the barrel *D* (Plate 1, fig. 4), an inclined hole is bored for the chain hook to enter. The chain is wrapped around the barrel and the number of the turns it makes are counted, which will give the number of revolutions that the spring must make (Art. 468 below); if the chain makes 4 turns on the barrel, the spring will have 6½ turns, so that there is one coil left when the spring is wound up and there still remains a half turn so that the spring less likely to break or change force.

468. The first thing that should be done when the fusee is cut is to choose a chain which exactly fits the width of the groove in the fusee and to cut it to the correct length, so that it not only surrounds the fusee, but there enough to reach the barrel and hook onto it. For this, when the fusee and the barrel are in their place in the frame, it is necessary that the chain surrounds the fusee from the base to the top, and that it also surrounds the barrel for about ¼ of a turn. The length of the chain thus established, the length which wrapped around the fusee is drawn from the fusee onto the barrel, giving the number of revolutions which the winding of the chain will make on the barrel, and consequently how many turns the mainspring will make. Suppose that the part of the chain which was on the fusee takes 4 turns to surround the barrel, showing that as the chain which surrounds the fusee unwinds the barrel will make 4 turns. Thus the mainspring only has to have 4 turns. But as it is necessary to have a less unequal mainspring, so it makes more turns than the fusee uses, it is given approximately two more turns; that is, the bridle being put in, the mainspring will have to be coiled so that the barrel makes six turns (the arbor being motionless). One will thus make a mainspring which meets these conditions. The bridle and the mainspring are put in the barrel and the fusee and barrel are installed. By this means one can set up the mainspring ¾ of a turn (the chain being wound to the top of the fusee), and one will be assured that when the chain surrounds the fusee (that is, the watch is wound up), two turns of the barrel still remain to entirely tighten the mainspring.

63 Details of fusee cutting engines and chain making are given in Leonard Weiss *Watch-Making in England 1760-1820*, 1982, and so I omit Berthoud's description.

2499. To put in the mainspring, it is necessary to put the hooks on the side of the barrel and in the arbor. The spring being made, the openings in the bottom of the barrel and the lid for the bridle and the bridle itself are made.

Making the mainspring of the clock.[64]

1255. Though the mainsprings of clocks and watches are not made by horologists, but by particular workmen who do only that, I will take leave to describe their manufacture. I do this to satisfy the people who wish to be educated in all the processes that are employed to make clocks, to satisfy their curiosity as I did in detailing the enamelling of dials. One should not expect me to spend any more time on springs than I did on dials; because I only claim to give in these articles the basic concepts, since to treat each properly would require book on its own.

1. The steel used to make the mainsprings of clocks and the manner of forging these springs.

1256. The steel which is used to make the springs of clocks is called *Étoffe de Pont*[65]. Spring makers prefer English steel, because when employed to make a spring it preserves its elasticity and is less prone to break.

1257. To make a spring such as that for my clock with repetition, it is necessary to take 1½ pounds of steel or *étoffe*. It is first forged and prepared so that it forms a rod whose width is approximately six lignes and its thickness two lignes; this bar is brought to the full length which the steel can give; this is called *thinning*.

1258. When the steel is thinned, one extends it by the heavy blows of a hammer until it has the width which is needed (that is, approximately thirteen lignes) and a thickness of a little less than half a ligne. One and a half pounds of steel brought to these dimensions will form a blade approximately nine feet long, which is more than sufficient for the diameter of the barrel in question.

(In order to work faster, spring blacksmiths, instead of forging a single spring, thin two of them at once of the same size by putting one on the other and heating them together in the middle of their length. When these rods are hot enough, they strike both with heavy blows, keeping them well joined together, so that they are both enlarged at the same time. When they have enlarged the middle for approximately a foot and it has the required width, they separate the two rods. Then they take one of them which they fold at the widened place into approximately the shape of chimney tongs; they heat the nearest parts of the rod which are not yet widened, and they enlarge them with heavy blows of a hammer head making them the required width; thus two parts of the rod are extended at the same time and they heat and hammer the rod to its ends. Then they straighten it and have a spring blade. They then take the other rod again, on which they do the same operation and enlarge it doubled in the same way. Blacksmiths use this method because it is more expeditious and avoids burning the steel blade during heating, which does not happen when they set one on the other because they are mutually preserved, whereas a single blade is exposed to too much heat.)

64 The following is included for completeness. It is not really relevant because of the difference in size of clock and watch mainsprings, but it does give some idea of Berthoud's understanding of spring making. The best description of spring making is in W. Blakey, *L'art de faire les ressorts de montres suivi de la manière de faire les petits ressorts de répétitions et les ressorts spiraux*, 1780. A complete translation appears in M.L. Wayman, *The ferrous metallurgy of early clocks and watches, studies in post medieval steel*, 2000 (British Museum Occasional Paper 136).

65 Obscure, but presumably cemented steel.

2. To shape the spring cold.

1259. The spring being forged, it is heated. For this one fills a large stove with charcoal and when the charcoal is burning, an end of the spring is put in the middle of the fire and left there until it is red. Then the spring is pushed and the part of the blade which immediately follows the reddened end is heated. Thus one heats it bit by bit until all the blade has been heated and reddened by the action of the fire without blowing on it.

1260. When the spring has been reheated, one starts by carefully inspecting the strong and weak parts, which is done by folding the blade; the part which yields first is weak. To equalize them one uses a heavy pean hammer with a narrow edge, so that the blows penetrate the blade. The blows must be given by following the width of the blade (that is, by lines parallel with the sides) and they must be made close to each other; one thus widens and thins the too strong places to equalize the blade, and one passes lightly over the weak places. When the blade is thus beaten and it is equalized, one takes a hammer with a slightly rounded head and flattens and erases the marks of the pean.

1261. The spring having been beaten cold, its sides are cut quite parallel with shears, to make it uniform and of equal width throughout its length; and if there are any cracks, they have to be cut out with the shears, in order to prevent the spring suddenly breaking when it is bent.

1262. If the spring is still too thick (that is, if it is more than half a ligne) it is reheated in the manner I have explained and forged again, until it is equalized and reduced to the correct thickness. It is preferable to thin it with a hammer, because in addition to it being rather better, the blows of a cold hammer give body to the spring and tighten the pores somewhat.

1263. The spring thus forged, one will again use the shears to make the width equal, taking care not to make it too narrow for the barrel it is to go in. Then a long piece of wood is put in a vice and the blade attached to this wood with screw pincers. A very new German file is taken and the spring is filed by running the file strokes along the length of the blade. This is done over the entire length of the blade on both sides, making the blade as equal in strength as it is possible; so that when gradually bending it into an arc, all the parts bend everywhere and are seen to have the same resistance to curving them, with the exception of about a foot at one end of the blade which will be used to form the eye of the spring and which must be stronger.

1264. In this state, the spring must be more than three twelfths of ligne thick, which will be reduced to about two twelfths of ligne when it is completely finished; this is the thinnest part of the blade, which forms the greatest part, since there should be only a foot which is thicker.

3. Preparation for hardening the spring.

1265. As it would be very difficult to heat all of a thin blade about nine feet long at the same time, spring makers had the idea of coiling these springs in a circle about a foot in diameter, so that one can easily heat and harden this spring coiled on itself. But the blade being thus coiled would touch in many places, so that when it is drawn from fire to quench it would not be equally tightened, because there is no space between the blades. To prevent this problem, before coiling the blade spring makers surround it throughout its length with iron wire about half a ligne thick, being wrapped around the blade like a screw with steps of about an inch; thus the coils of the blade do not touch each other and the iron wire leaves a space to heat the blade, and also to tighten and harden it throughout its length when it is cooled. To retain the blade in a circle, it is held by a wire of a suitable length so that the spring forms a circle only a foot in diameter or there about.

1266. To heat the springs before hardening them, spring makers use a reverberating furnace, built like that used by enamellers (Art. 1181, page 52). To place the spring in the furnace they use an iron wheel which is a foot in diameter and crossed to a rim to allow the passage of heat. This wheel is finished with an iron circle which retains the spring to be hardened, and it turns on a pivot on the end of a long iron bar.

1267. When the fire in the furnace is lit, the wheel is heated until it is red. When the charcoal is burning most vigorously, the spring is put on the wheel which is put on the hearth of the furnace; care is taken to turn the wheel so that the spring is heated uniformly. When the spring is heated to the white colour which follows red, the wheel is quickly withdrawn and the spring is thrown into a vessel which contains enough oil to cover the spring. Oil is preferred for hardening springs because they are less hard and they are less prone to break than if hardened in water.

1268. The hardened spring is taken from the oil and all the wire which surrounded the blade is cut with clippers; it is removed from the ends very carefully in order not to break the spring. In the same way the wire which retained it in a circle is cut; the spring will develop a little, but will not straighten completely and will remain curved in a spiral.

1269. To whiten the spring inside, in order to temper it equally throughout its length, bricks and sandstone or sand are used, with which one lightly rubs all the inside of the blade until it is whitened throughout its length.

1270. To temper the spring it is necessary to have a stove filled with well lit coal which is covered by an iron plate about two lignes thick. This plate must be a little rounded or convex. When the plate is red, by only the action of fire and without blowing, the outer end of the spring it put on the convex part of the plate with the whitened part of the spring on top. The end of the blade is pressed on the plate using an iron rod which is held in one hand, while the other hand holds the coil of the blade (it is useful to wear gloves to avoid the heat of fire). Part of the spring is left on the plate until it takes the grey colour which immediately follows blue. As the end tempers to this colour the blade is advanced so that, at the same time as it is tempered or is penetrated by heat, it is straightened. This is continued until the blade has been tempered throughout its length, after which the blade will be as straight as it was before preparing it for hardening.

1271. The blade thus tempered, it is planed or planished by a hammer, with a slightly rounded and polished head, on a rounded and polished stake. The blade is flattened and made uniform throughout its length.

1272. The spring being well planished, one will inspect it to equalize it; one will fold it in an arc from place to place, and the places which are stronger are thinned with a file, attaching the spring to the wood in the vice with screw pincers.

1273 When the spring has been planished and equalized, it should be set to the height of the space in the barrel. It will be made half a ligne lower than the snap of the lid; that is, if from the bottom of the barrel to the snap is 12 lignes, the blade will be made only 11½ lignes, so that the spring has play. It is gauged according to this measurement and made equal throughout its length. Close to the end which will form the eye of the spring, which was left thicker, it must be half a ligne lower than the rest of the spring for about ten inches; this inner end of the spring is made narrower to prevent the eye which surrounds the arbor from touching the lid or the bottom of the barrel.

1274. The spring being set to width, it is cut to length; that is, about seven feet long, which is about the right length for the diameter of the barrel and for the number of revolutions of blade of the spring.

1275. The edges of the blade are rounded with a file, and made completely straight and uniform throughout their length, so that these edges can slide more easily against the bottom and the lid of the barrel when the spring unwinds.

1276. To smooth the spring, a fairly fine English bastard file with oil is passed over its length on each side of the blade, following the marks along the length of the blade to remove the strokes of the German file. This file is used to completely to equalize the blade which will gradually curve into an arc.

1277. To polish the spring it is attached to the wood in the vice and rubbed with walnut wood and emery along all its length, as was done with the English file; but for best one rubs the blade backwards and forwards between two pieces of walnut wood shod with iron and used with emery: this method is preferable because it is quicker and it tends to equalize the blade. For this a long draw bench can be used, like those which jewellers have to draw gold through a die.

1278 After polishing the spring it is blued, using the stove and plate which I described and in the same manner; the blade is tempered to a bright blue for all its length.

1279. Then the holes for the hooks are made. For this, one will first temper a length of about a foot at the end which forms the eye, tempering it more than it had been after hardening; this is to prevent the spring breaking when is bent to form the eye. At the place where the hole for the hook will be made, it is necessary to reheat it (that is, to make it red for an inch at the end). A square hole is made which is lengthened a little and then the end of the opening is filed at a slope on one side, in order to be retained by the hook on the arbor.

1280. To make the opening for the hook in the other end of the blade, only a little at the end is tempered to just soften the place for the hole. The spring being brought to this state, it only remains, to coil it into a spiral and insert it in the barrel.

4. To bend the spring into a spiral.

1281. To bend springs, one uses an axle which runs in an iron frame fixed to a vice. One end of this axle carries a ratchet and the click for it is attached to the frame. In addition to the ratchet, the axle has a crank. The other end of the shaft is pierced with a square hole in which arbors with hooks are placed, similar to those of a barrel arbor. These arbors are of various sizes; the largest can be two inches in diameter and smallest six lignes. When spring makers want to coil a spring, they hang the end of the blade with the eye on the hook of the largest arbor and with one hand they turn the crank, while with the other hand they tightly hold the blade hard against the arbor so that the blade bends and surrounds the arbor, thus going in a spiral. They continue until all of the blade surrounds the arbor. To prevent the spring breaking by bending too quickly from straight to a tight curve, spring makers place folded cards between the first few coils, which prevents the coils from touching; they do this only for the first turns, because when the arbor is surrounded by several turns they grow bigger and the spring is less curved.

1282. This done, a slightly smaller arbor is taken in order to tighten the coils more and to decrease the size of the eye, or the first turn; they thus continue until the end the spring is on this second arbor.

1283. When that is done, a third smaller arbor is taken, near the size of the barrel arbor on which this spring will be placed. The coils are tightened again while turning the crank, until all the parts of the blade touch and surround the arbor.

1284. During these operations, it is necessary to take care that each coil sits above the part of blade which surrounds the arbor and the coils thus rise one above the other, so that the edges of the blade, when it is coiled, are in exactly the same plane. This is absolutely essential, because otherwise its edges would rub on the bottom and the lid when the spring is in the barrel.

1285. The spring thus coiled is finished.

2499 cont'd. The barrel and the fusee are placed in the frame, and the fusee is equalized with the mainspring, as explained in Art. 469 and following below:

467. We have just seen how a fusee should be cut. But it is not enough to form its grooves and to fix its shape; one also needs to equalize the force of the mainspring on the train, to equalize the fusee and determine the depths of its grooves which are appropriate for each degree of force of the mainspring. The following method is used to achieve this goal.

469. To equalize the fusee with the mainspring, the fusee, barrel, and the click-and-ratchet work are put in the frame without any other parts, and the two plates are locked together by putting in the pillar pins. Then an end of the chain is hooked onto the fusee and the other end onto the barrel and, by means of a key, the square of the barrel is turned to wind the chain onto the barrel. A small mark is made on the end of the barrel arbor which is used as index to mark the amount that the mainspring must be set up; if it is ¾ of turn, one notices the moment when the arbor hooks the mainspring and it is tightened ¾ of a turn more. It is necessary to observe that to count this ¾ of a turn the chain is entirely wound off the fusee and that it is only hooked to it.

470. Being thus prepared, a fusee adjusting rod is taken and put on the square of the fusee. Then the rod is turned and by this means the mainspring is wound until the chain is wrapped around the fusee and its beak butts against the chain-guard. In this state, the weight on the adjusting rod is moved along the rod to the point where it balances the force of the mainspring. Then the rod is turned backwards one turn and one will see whether the weight still balances the mainspring. If the mainspring is weaker it is necessary to bring the weight closer to center to again put it in balance with the mainspring. This is continued until the chain has unwound from the fusee. By this means the places where the fusee is too large are found; at these points one needs to put the weight in balance with the mainspring.

471. To equalize the fusee with its mainspring it is necessary to lower the places on the fusee which are too high, to change the balance of the rod with the mainspring, making the weight appear lighter. But before touching the fusee, when it is of a good shape (that is, the diameter of the top does not differ too appreciably from that of the base, and the curve of the fusee is uniform), one will equalize it with its mainspring by increasing or by decreasing the set up of the mainspring, according to whether the fusee appears too small or too large at the top; that is, whether the mainspring does not pull enough or pulls too much from the last coils. The rule which one must follow to change the degree of tension of the mainspring is: when it does not pull enough from the last coils its set up should be increased; and when it pulls too much from the last coils it should be decreased. Before increasing the set up of a mainspring, it is necessary to be sure that when the fusee is full to the top, the mainspring is not completely wound up, but that there is still at least a turn unused; because if care is not taken the mainspring or the chain will break. To prevent this accident, it is necessary to start by counting, as I have just said in Art. 468 (page 60), the number of revolutions which the chain makes on the barrel and those of the mainspring. Thus, if the chain makes 4 turns and the mainspring makes only

5, and if it is necessary to give 1¼ turns of set up to equalize the fusee with the mainspring, one sees that the fusee cannot be wound to the top. Because the chain made, according to our assumption, 4 turns, to which is added 1¼ turns of set up, which makes 5¼ turns; thus one would need another ¼ of a turn to wind the fusee to the top.

472. When it is not possible to equalize a fusee by this method, and supposing a good, well made mainspring, it is necessary to file down all the parts of the groove where the mainspring exceeds the adjusting rod. One will continue doing this so that at each point of the groove, from the top to the base, the mainspring and the weight remain perfectly in balance. That being done, one will have an engine which will act on the train with a uniform force.

473. If a machine to cut fusees is available then, when one has found the places on the fusee which are too large, it is again put on the tool to remove a little from the high turns with a graver. The operation is easier, the fusee has a more beautiful form, and the grooves are better finished by the fusee engine.

474. When the fusee has been equalized with its mainspring, and before disassembling the frame and changing the tension of the mainspring, it is necessary to make a mark or index on the barrel arbor and on the plate, which will indicate the amount the barrel arbor needs to be turned to give a suitable set up to the mainspring; this is called the guide mark. Thus every time the watch is reassembled, the arbor is put on its guide mark and the mainspring is tightened the same amount; thus one is sure that the mainspring acts uniformly on the train.

2500. The chain-guard is set up and the stop piece is thinned if it is too thick, which is seen when it stops the beak before the chain surrounds the top turn of the groove. That being done, one will make an angular notch at the end of the stop piece into which the fusee beak fits, so that the effort of the hand will not be able to wind up the watch further nor force the chain-guard down.

2501. The dust cap *E* (Plate 2, fig. 7) is then put on the fusee square, with its top edge near the inside of the dial, without obstructing the freedom of the fusee, and the bottom sitting on the bottom of the square. This dust cap is made of steel.

2502. The gearing of the motion work is adjusted and, while doing this, the hands are adjusted. I will not repeat these operations here; they are described in Art. 969 and following for the gears (page 57), and Art. 1201 and following for the adjustment of the hands[66]:

1202. To make the hands one will take thin brass about a half a line thick and the length of the hour hand; so that *H* is from the outside of the hole in the dial to the line *h* of the hours (Plate 6, fig. 3), and *M* is from the outside of the same hole to the scale mark of the minutes *m*. The widths should be near that shown on the illustration. These two plates are planed, filed and dressed. Then that for the hour hand is bored with a hole the same size as the outside of the cannon of the hour wheel, and that of

66 This description is for the repeater clock and some of it does not apply to the verge watch. In the clock the pillar plate and false plate are two separate plates, whereas in the watch only a single plate is used (however, watches with complicated mechanisms under the dial can also have separate false plates). Also, the hands of a repeater must be carefully adjusted to the repeater mechanism, which is not necessary in an ordinary clock or watch. Finally, the sizes are for clock hands.

the minute hand with a hole the size of the cannon pinion.

1203. To adjust the hands it is necessary to put the center wheel in the frame, pin the plates, put the cannon pinion on its stem, and put in the minute and hour wheels. The hour hand is put on the dial and a mark made on the cannon of the hour wheel flush with of the top of the hand, which indicates the height of the top of the hour hand. The hour wheel is put on a turning arbor and the seat on the wheel is cut back as much as possible without weakening it. Then the cannon is cut above the mark and reduced to leave it only about a third of a ligne around. This cannon should not decrease from the wheel to the end; on the contrary, it must be smaller at the wheel, so that when the cannon of the hand is put on (which is split to make it spring) it is retained and cannot come off when the hand is turned to put it on the hour.

1205. The cannon of the hour wheel being thus prepared, a piece of well hammer-hardened brass wire is taken and a hole bored in it suitable to go on the cannon of the hour wheel. This wire must be large enough that there remains around the hole sufficient to make a seat to rivet it to the plate for the hour hand. This cannon is cut a little longer than the cannon of the hour wheel, from the plate to the end of the cannon, because of the riveting needed for the hand; and besides, it is to better shorten the cannon when the hand is riveted, to reduce it to the level of the top of the dial. The hole bored in the cannon is the same size as the smallest part of the hour cannon, and it is enlarged it so that the largest end of the hole only just goes on the end of the hour wheel cannon[67]. This cannon is put on a turning arbor and a seat is formed on the largest end to rivet the plate of the hour hand. A little thickness is left underneath for the seat and the rest of the cannon is thinned to its small end so that it is only a quarter of a line thick all around the hole. The hole in the plate of the hand is enlarged to make it fit on the seat on the cannon and riveted. Then a broach is passed inside to remove the burr made by riveting. A piece of wood is made which fills the hole of the cannon from the side of the hand. It is attached to a vice and with a saw the small end of the cannon is slit up to the plate; by this means it will bend and spring onto the cannon of the wheel, and it will tend to stay there.

1206. To finish and give a suitable length to the cannon of the hand, the hour wheel is put on and the hand on its cannon. If the hand does not come close to the dial, without touching, the cannon of the hand is suitably shortened.

1207. The hour hand being adjusted on its cannon, the end of the plate for this hand is filed to a point of the right length to be on the circle of the dial which limits the bottom of the hour figures. Then, with a compass or on the turns, a line is marked around the cannon so that the middle of the hand covers the hole in the dial and enough strength remains around the cannon so that the hand is solid.

1208. It can be seen, by this arrangement of the hour hand, that it can be turned independently of the hour wheel cannon, and, consequently, the hour wheel remains motionless on the cannon pinion, which carries the minute hand. But the minute hand should not be adjusted in the same way; because it is necessary that when it is turned the cannon pinion also turns with friction on the prolonged stem of the center wheel. However, the wheel of the cannon pinion necessarily turns the minute wheel, and its pinion turns the hour wheel; thus, as the minute hand turns the hour hand is involved and advances proportionally with the minute hand. That is, while the minute hand advances a turn, which takes one hour, the hour hand advances a twelfth of a revolution, which is also one hour.

1209. To make the minute hand drive the cannon pinion, the end of the cannon pinion and the hole of the of the hand are filed square. But this would mean that the

67 Broaches are tapered and all broached holes vary in diameter through their length.

hand is prone to waver up and down, if the square of the hand did not have enough thickness to keep the hand level. So a thick cannon is put on this hand and it is in this cannon that the square hole is formed.

1210. When the hour hand has been adjusted, it is set up with the cannon pinion, and a mark is made on the cannon pinion flush with the end of the cannon of the hour wheel; this indicates the origin of the square to be formed. The cannon pinion is removed and put on a turning arbor. A thin line is turned at the mark and the cannon is cut off above this line, leaving about 2½ lignes for the length of the square. This square is filed exactly from the line which regulates its length.

1211. To make the seat of the minute hand, brass wire of a suitable size is taken so that, the square hole being made, there remains enough around it to form the seat and to have a shoulder for riveting; that is, more than 3 lignes in diameter and the length of the square made on the cannon pinion. The hole is bored and it is punched (see Art. 832, page 41) so that it enters very tightly on the square of the cannon pinion, but not right to the bottom. It is put on a turning arbor and turned, and a seat and shoulder to rivet on the hand is made on the small end. The hole in the plate of the minute hand is enlarged so that it goes on this shoulder of the seat, chamfered for the riveting with a chamfer drill, and the hand is riveted onto its seat. The hole is punched out, which leaves some burrs, and then the punching is completed so that it goes to the bottom of the square on the cannon pinion. The surplus of the cannon pinion square is filed off level with the seat, and a deep line is made with a graver, which is the guide mark of the seat with the cannon pinion.

To gild the hands.

1226. To gild with ormoulu, one uses a Dutch gold ducat, which is the finest and the best gold.

Preparation of the gold.

1227. It is necessary to forge the gold and to reduce it to the thinnest plate which can be done with a hammer on a flat and polished stake. The gold plate being thus thinned, it is cut with scissors into very small pieces or paillettes. Then the gold is put in a very clean glass and some mercury is added which is mixed with the gold until it became white. (If one has eighteen grains of gold, one will add two drachms of mercury; that is, eight times more mercury than gold).

1228. The gold thus prepared, a crucible is heated on a stove filled with well lit charcoal. When the crucible is red hot the gold and mercury are put in it, and they are mixed with a wood or brass rod until the gold has dissolved and the mercury has partly evaporated away, the remainder forming a paste. At that moment, it is dropped into pure water. If the paste is malleable it is left in this state. If it is too fluid it is put back in the crucible to evaporate more mercury. If the paste is too hard to be easily spread in the hand, it is necessary to add some mercury and put it in the crucible which has been kept red hot. During this operation, one will avoid breathing the air because of the mercury.

Preparation of the hands for applying the gold.

1229. To prepare the part to receive the gold, one takes a piece of brass which is filed to the shape of a burnisher. It is plunged into aqua fortis and then into mercury, so that the mercury amalgamates with this burnisher, which is called a buff[68]. The buff thus covered with mercury is rubbed on the part which is to be gilt until the part is bleached by the mercury carried by the buff; this operation is called buffing. When

68 *avivoir.*

the piece which is to be gilt has been buffed and covered with mercury, a brush is used to spread the mercury evenly all over the surface of it. Care is taken throughout this operation to hold the piece in cloth so that the mercury does not penetrate the fingers.

1230. When the part is buffed, the prepared gold is taken on the buff and the surface of the piece to be gilt is covered with it. Then it is put on a gentle fire, covered with ash and allowed to warm up until one sees the gold start to bubble. At that moment it is withdrawn and brushed while it is hot, but very gently in order not to remove the gold. The piece is again put on the fire and, as soon as it is hot, it is removed and brushed again, to spread the gold and make it even. This operation is repeated until the gold sets and is perfectly even. Then the piece is left on the fire until the mercury has completely evaporated (which is called drying) and the piece remains yellow.

1231. To make the mercury completely disappear, the piece is put in olive oil and put on the fire until the oil evaporates, and at that point it acquires a reddish colour. Then it is wiped with a cloth. If it remains black, it is a sign that there is not enough gold; in this case, it is necessary to again put on gold with the buff and to restart the process described.

1232. When the part is gilded, its surface is matt and it remains to give a brilliance to the gold. This is done with a scratch brush. For this, urine is put in a new, varnished earthenware vessel. The gilded piece is plunged in it and it is scratched with the scratch brush until it becomes brilliant.

1233. When the gilded part has been scratched, it is put in ordinary water and wiped with a very clean cloth. Then it is placed on fire ashes and allowed heat until the gold, which was pale, changes colour. To judge degree of heat which the piece must be given, one puts a small piece of silk paper above it (or the end of a spiral spring, which, when it becomes blue, marks when the piece must be withdrawn); when this paper becomes yellow the piece is withdrawn and it is again scratched. This operation of putting it in water and then on the fire is repeated up to four times to complete the gilding. These operations to gild a hand can be used for all the parts of a watch, plates, cock, wheels, etc.

2503. The gearing of the center wheel with the third wheel pinion is adjusted. For this, one will first see if the gearing is good; in which case the pivots of the third wheel are formed according to prescribed dimensions, and the holes are tapped and bushed with plugs bored on the turns. The gearing is corrected using a window in the pillar plate to see it, etc.

2504. One could now complete the gearing of the third wheel with the contrate; but as the gearing cannot be adjusted and the contrate wheel planted until the balance and the escape wheel are seated, it is to better wait, finishing this gearing when the escape wheel is planted. I now will speak about the execution of this part.

Execution of the escapement: the balance

2505 I have said that gold is the best metal to use for the balance of a watch (Art. 557, page 6); but not all watchmakers have the facilities to prepare gold, and besides, these balances are too expensive for ordinary watches because of the waste of gold. For them I use brass balances, perfectly hardened and carefully gilded, which protects them from verdigris. Brass is preferable to steel because it is not prone to magnetism (Art. 556 and 557, page 6). To make such a balance it is necessary to entirely finish, poise and gild it, etc., before riveting it. For this, it is necessary to start by determining the weight that should be given to the balance, relative to the number of vibrations, the size of the pivots, and the motive force of the machine, etc.; so that when the balance, the escapement and the watch are finished, there is a suitable harmony between the regulator and the motor. It is should be observed that to follow this method it is necessary to begin with a well built watch which has undergone the necessary tests; then if the mainspring is a little too strong or too weak, it is changed accordingly. I gave (Art. 2436 and following, page 25) the dimensions of such a watch and it is according to those dimensions that this one will be made. Or if one wants to change the weight of the balance to suit to the force of the spring, one will not completely rivet the balance to the verge, and when its weight has been determined one will remove it to gild it before it is riveted and the banking pin put in.

2506. To make the balance, boiler brass is taken which is carefully hammer-hardened until it is almost reduced to the correct thickness, which is 3⁄12 ligne (Art. 2480, page 46). A hole is bored which is smaller than pivot of the balance turning arbor (Plate 4, fig. 19, described in Art. 2434, page 24), and one will make the hole of the balance enter upright on the pivot of the arbor. The balance is crossed in three, leaving broad arms and a broad rim. Then it is turned true and round, but thicker and larger than is required. It is removed from the arbor and filed quite flat on the two sides. The width of the arms and the rim are reduced so that it weighs approximately 10 grains. It is again put on the arbor to complete turning it perfectly round, 10 lignes in diameter and the thickness specified. The arms are completed and are rounded so that dirt cannot lodge on them, and to reduce it to the required weight of 7 grains (Art. 2377, page 12). The rim is narrowed, being regulated by the fine lines which were made on the turns; this attention is necessary so that the balance, when put on the verge, is in poise.

2507. One will fit the boot, the steel plate *P*, on the potence (Plate 2, fig. 6); this plate needs to be only about 2⁄12 ligne thick. It is necessary to bore the hole for the screw so that it is away from the recess made in the pillar plate, so that the head of this screw does not need to be countersunk; the size *Ph* (Plate 2, fig. 5) of the recess is taken and marked on the potence from the center *h* (fig. 6). One will bore the hole in the plate and the potence, tap the hole in the potence, and make the screw with a good head; and so that the head of this screw does not touch the pillar plate, a hole is made there for its passage. The center wheel is put in the frame to see if the steel plate approaches too close; if that is the case, and the steel plate is not too thick, the potence is lowered. That done, the inside of the foot of the potence is filed to reduce it to 3⁄12 of a ligne thickness, which it must be. The brass coqueret of the balance is reduced to the same thickness. The steel coqueret and the boot of potence are hardened. The ends which carry the pivots are not tempered in order to keep them hard, so that they are not hollowed by the friction of the end of the pivot. For this, the ends of the plate and the coqueret are gripped in pincers, and the other end is presented to the candle so that it becomes blue as far as the pincers. The steel coqueret and the boot are polished after having dressed them well with a soft file and oil stone; tin putty and a brass file are used to polish them.

2508. I described the execution of the slide parts with care, so I will not repeat the adjustment of them here; I suppose the slide is made and that it will remain at the height that has been given to it. It is the same for the cock. I presume it has the appropriate height for the play of the balance. It is better that it has more than less, so that if the balance does not turn perfectly truly it will not touch either the cock or the slide. And by the way in which it was made, its feet sit perfectly flat on the plate without it being necessary to file them to straighten them; they are straightened on the lathe, which is preferable. The plane of the balance must be perfectly parallel to the plate; thus one should only put the steady pins in the feet of the cock (which are made with the precautions indicated in Art. 958 and following, page 39) after the cock has been cut out and engraved, as is commonly done and as shown in Plate 1, fig. 9. Regarding the steady pins and screws of the cock, I will observe here that it is necessary to take great care to ensure the pressure of the screws does not tend to bend the plate, as frequently happens; because then that gives too much or too little play to the escape wheel which can cause the watch to vary or stop, as I have seen. To avoid this defect, it is essential that: 1, the feet of the cock sit quite flat on the plate; and 2, it is necessary that the recesses in the cock for the heads of the screws have very flat bottoms and are larger than the screw heads, so that these heads cannot touch the sides of the recesses. These preparations being made, one is ready to make the verge.

The verge[69]

2509. To make a verge one takes small, square English steel; care must be taken to choose that in which the pores are tight, which is pure and without flaws. A piece is cut from the end of this steel, a little more than the length which the verge will have, and it is filed according to Plate 4, fig. 17. The pallets open approximately 100 degrees, a little more than square. The pallets must have a width of more than half a ligne (I will note, in connection with width, that workmen call the *width* of the pallets the distance from *a* (fig. 17) to the center *b* of the body, and *length* of the pallet is the interval from *b* to *c*). The distance between the pallets depends on the height from the foot of the potence to the outside of the top plate; one can make the bottom pallet longer than it should be and cut it back afterwards, as is necessary. To be able to put the verge in the plate, one will make the *entry*, or square opening *dx* (Plate 2, fig. 8); this entry is made rather large, because the escape wheel partly enters it (see Plate 2, fig. 6). When making this opening, one should not completely cut away the hole *d* of the balance, but keep half of it to indicate the center. The plane of the pallets should not be directed exactly to the center of the rod, but a little inside; this is called *not to notch the pallets to the center*[70]; by this precaution the escapement will have less drop. The body of the verge must be filed perfectly round and the same size for all its length; it is necessary that it is less than ⅛ ligne for this watch.

2510. When the verge is made according to the prescribed figure, the seat *T* is fitted on it, on which the balance will be riveted and which will carry the balance spring collet. A small notch is made in this seat to go on the end of the top pallet; workmen make this slit to facilitate polishing the pallet. The seat can be 8/12 ligne diameter and the same thickness. When roughed out and turned, it is silver soldered (Art. 886 and following, below); it is necessary to direct the flame of the blowpipe against the seat, in order not to heat the verge too much, and not to corrupt the steel, which would make the verge prone to break with the least jolt.

> 886. To solder the seat, silver solder will be used. One will take for that a drachm of ordinary silver and a drachm of brass and they are heated together on a coal with a blowpipe until they melt and form a small ingot. It is forged and flattened, and as it

69 A modern description of making a verge will be found in Henry Fried *The Watch Repairer's Manual*, 1986.

70 *ne pas entailler les palettes jusqu'au centre.*

hardens it is reheated and forged until it is a plate the thickness of paper. Then it is reheated again.

887. Small strips of this solder are cut off with scissors. These strips are put against the seat and folded around the stem. Each end of the seat is dampened and powdered borax put on it, and then it is gently heated against a burning coal in a frying pan, to melt the borax so that it does not disturb the soldering. Then the piece is set on a coal and the seat surrounded by small coals, leaving only one opening to see when the solder is molten. One will blow gently at this place, directing heat onto the seat so that the stem does not warm up too much.

2510 cont'd. When the seat is well soldered, the verge is heated evenly by passing the flame over the entire length of its body, and when the verge is a cherry colour it is thrown into water. Being thus hardened, one very lightly whitens it with pumice stone. Then to temper the verge, an extremely thin and hollowed plate of brass or steel is used; the part to be tempered is put on this plate and the plate exposed to the flame of a candle; thus it is tempered evenly. This tool is called a *bluing pan*, and the verge is thus tempered to a yellow approaching blue.

2511. Straightening the verge after it is hardened cannot be done by the points, as is practised with pinions, because that would change the size of the body of the verge and the pallets would no longer be in the center as before. A small, sharp-edged hammer is used, with which one will strike the body on the concave side; and when the rod is perfectly round, it is necessary to heat it again in the bluing pan, so that it becomes a yellow approaching blue, like before. By taking this precaution one prevents the verge curving when it is polished after the blows of the hammer.[71]

2512. The verge being perfectly straight, the seat is turned, and the shoulder and cannon to receive the balance are formed; this shoulder is cut back so that the seat is only $\frac{4}{12}$ ligne thick, sufficient for the thickness of the balance spring collet. The pallets and the body are smoothed using a fine file and taking great care. Then the hole in the balance is made to go firmly on the seat on the verge so that it turns upright.

2513. That done, the potence and the slide are installed. The side of the plate of the potence is turned. The balance is set up, so that that its lower pivot shank passes through the hole in the foot of potence, and the cock is put on with the top pivot shank passing through the hole in the coqueret, the balance dividing the space between the cock and the slide. From the high side of the foot of potence, a line is marked which indicates the place where the pivot shank should be cut; this pivot shank is cut with a graver, taking care to leave it a little long, in order to have some to remove. Then the bottom pivot is made according to the dimensions given and the balance put in again, but this time sitting the pivot on the steel plate. If the balance is too high it is necessary to move the shoulder back appropriately and to shorten the pivot. This pivot being made, one will mark flush with the brass coqueret (the balance and cock being in place) the place where the top pivot shank must be cut and, when this is done, the pivot is formed according to the prescribed dimensions. It is understood that the balance is taken off to more easily turn the pivots. The balance is put

71 W. Blakey (*L'art de faire les ressorts de montres suivi de la manière de faire les petits ressorts de repetitions et les ressorts spiraux*, 1780) and François Crespe (*Essai sur les montres a repetition*, 1804) both note that if a steel piece is straightened by hammering after hardening and then polished, it will bend during polishing; but re-tempering between straightening and polishing prevents this.

on again and it is placed on the poising tool in order to see whether it is in equilibrium; if it is not, it is poised. Then it is gilded and riveted onto its seat. (In connection with this seat, before riveting the balance it should be turned tapered, smaller on the side of the balance than on that of the pallet, so that when the balance spring collet is put on this seat it does not tend to come off.) The balance is straightened so that it turns perfectly upright, and the verge, pallets, etc. are polished.

2514. The pivots of balance thus made, the holes in the foot of potence and the coqueret are bushed. For this, the holes are enlarged so that they are 3/12 ligne; then they are tapped and well hammer-hardened boiler brass is tapped in the same hole of the screw plate. The holes to be bushed are chamfered and the bushes carefully riveted.

2515. The holes thus bushed, the uprighting tool is used to mark the exact places where the holes of the pivots must be bored. For this, the balance is planted. The hole in the cock is put on the lower point of the uprighting tool, and with the other one a mark is made on the foot of potence. The hole for the pivot is bored on this point, using a drill smaller than the pivot; this perfectly upright hole is then enlarged so that the pivot just enters it. That being done, the coqueret is put in place, as well as the cock which carries it, and a ring is put under the plate. The pivot hole in the foot of potence is seated on the lower point of the uprighting tool and with the other a point is marked on the coqueret, by which a hole for the pivot is bored with the same drill. This hole is enlarged so that the pivot enters it. Using a drill, the front of the hollows inside the coqueret and the foot of potence are rounded, so that the shoulders of the pivots cannot touch them and the points of the pivots rest, as they must, against the steel plates.

2516. The balance being set up, one will see whether it has suitable end play. If it is too high, one or the other pivot is shortened. If it has too much end play, it is necessary to file a little from the brass coqueret and the potence.

2517. That done, the outside of the brass coqueret and the nose of potence are rounded, making a boss to hold oil there; but it is necessary to take great care that the top of the boss approaches very near the plate; because without that the oil will escape from the foot of potence and go up the verge.

2518. The balance thus put in and perfectly upright, it is necessary to bush the hole in the cock, so that this hole is just the right size for the play of the pivot shank, which should not touch there but turn freely and concentrically in this hole. This precaution is necessary, as I have said in Art. 2393 (page 15), to prevent the pivot breaking and the escape wheel being bent if the watch is dropped (which would happen if there was a large play between the cock and the balance). A small recess is left on the bush so that, in case of such an accident, this small recess retains the balance, and prevents it from leaving its place. The top of the bushed hole in the cock is chamfered, so that it is the bottom of it that receives the force of the fall; because in consequence the verge is held nearer to the middle and the pivots will be less liable to break.

2519. The balance thus riveted onto the verge and put in the frame, one can plant the escape wheel pinion. For this, it should be observed that it depends on the size of the wheel, and this size itself depends on the space there is from the balance seat to the inside of the foot of the potence. However, to facilitate the execution of the escapement, it is necessary to make the wheel as large as possible. And it is necessary that it is distant from the foot of potence, so that there is a good pivot shank to move the action of the pallet away from the pivot and oil cannot go up to the pallet. It is thus necessary to raise the escape wheel until it is very close to the balance seat; by this means the action of the wheel occurs more in the middle of the balance arbor; here the escape wheel can be $2\frac{3}{12}$ lignes in diameter and 1 ligne wide.

2520. To make the escape wheel, one will take quite pure boiler brass and forge it very hard. Then a $\frac{4}{32}$ ligne hole is bored through the wheel and it is driven onto a perfectly round turning arbor. The wheel is turned to the prescribed dimensions, leaving a suitable strength to the bottom so that, after the crossings are made, it is solid and cannot bend. The body of the wheel, on which the teeth are made, must be thick at the bottom of the wheel and become thinner at the edge for the points of the teeth. But this cylinder should not finish in a peak; on the contrary it is necessary that its thickness is $\frac{3}{24}$, so that these teeth do not dig into the pallets. The wheel thus turned, the crossings are made.

2521. The balance is set up and the wheel is presented to the nose of the potence, so that it is close to the seat of the balance. Using the hole in the wheel, a point is marked on the nose of potence which indicates the height of the hole for the escape wheel pivot; a hole is bored on this point using the same drill which was used to bore the pivot holes of the balance.

2522. If the back of the potence nose comes too close to the body of the verge, it is moved back so that there remains a space for the steel plate which must cover the escape wheel hole. This nose of the potence should not be moved back too far, because then the pivot, being further away from the front of the escape wheel teeth, will experience greater pressure. The back of the potence nose being moved back as appropriate, the front is filed so that there remains only a little more than the thickness necessary for the length of the pivot.

2523. The end of the counter-potence is filed to the same thickness and the steel plate which receives the end of the pivot is adjusted. That done, the pivots of the escape wheel pinion are made. One will start with that on the wheel side, but before that the shoulder for riveting the wheel is formed so that the wheel enters tightly. Then the pivot at the end of the pivot shank is made; it is not necessary to keep it large. The hole in the nose of potence is enlarged so that this pivot enters, and the shoulder of the pivot is gradually moved back until the wheel approaches close to the body of the verge; then the wheel is removed and the pivot completed. The other pivot is made to suit the distance from the nose of the potence to the counter-potence, which is parallel with the potence.

2524. The pivots thus made, the hole in the nose of potence is stopped with a bush which is bored on the turns and tapped; it is enlarged so that the pivot just enters. To finish setting up the escape wheel pinion, it is necessary to bore the hole in the counter-potence at exactly the same distance from the plate as is that in the nose, so that the arbor of the pinion is parallel to the plate. For this the tool shown in Plate 5, fig. 24 is used[72]. The base *b* of the tool is put on the plate and the point *a* is raised to the level of the hole made in the nose of potence. In this state the point, which indicates the height of the pivot hole, is used to mark the counter-potence. For the direction of the axis, one will be guided by the centers of the contrate wheel and the balance. This hole is bored and enlarged so that the pivot enters.

72 This is a *bird*; see also Plate 9, fig. 31.

2525. The escape wheel is put in, in order to see whether it approaches near enough to the body of the verge. To judge this, it is necessary that the pallets are turned away to the side of the potence, so that they do not touch the wheel; for that one only needs to turn the balance. If it is too far away, it is necessary to move back the pivot shoulder a little. Then the wheel is riveted onto its pinion and the outside, front and inside of the wheel are carefully turned. If, on the contrary, the wheel touches the verge, it is necessary to turn a little from the front of the wheel. It will also be seen if the front of the wheel approaches the top and the bottom of the body of the verge equally; that is, if the plane of the wheel is parallel to the axis of balance. If that is not so, it is necessary to re-bush the hole in the counter-potence if it approaches too near the bottom, and to file the base of the counter-potence if it approaches too near the top. Re-bushing the hole can be avoided by not boring it on the line made with the tool (Art. 2524), but a little higher; then the base of the counter-potence is filed until the escape wheel is perfectly upright to the verge. That done, one will be able to check the gearing of the contrate wheel and finish the remainder of the inside of the frame.

2526. The escape wheel being set up, the contrate wheel is put in the frame, and one will see whether the gearing is too strong or too weak, in order to be able to move back one or the other shoulder when making the pivots. Some teeth of this wheel are rounded in order to be able to examine the gearing. If it is too deep, as it should be, the lower part of the cross-piece of the bridge *ff* (Plate 2, fig. 7) is thinned, this cross-piece having been made thicker than necessary. One will also check if the wheel is upright in the frame, in order to stretch one or the other hole before bushing it. One will thus first make the pivot for the bridge according to the prescribed dimensions (Art. 2444, page 25). In the same way the other will be done. The holes are then bushed, enlarging them suitably, tapping them, and then piercing the pivot holes in the bushes on the turns. The wheel is made to turn freely and the oil sinks cut. The wheel is turned quite upright and round, the teeth formed, and the gearing carefully finished, so that it does not bind or drop, but rather the latter that the former.

2527. Finally, one will make the teeth of the third wheel and complete the gearing with the required care, making a window in the pillar plate to see the gearing. I will observe here, with regard to the gearing, that the perfection of this part of a watch is very essential, because on it depends the uniformity of the force transmitted to the escape wheel. But it is not only the accuracy of the watch that will be disturbed, because these inequalities are repeated every day in the same way. These inequalities in the gearing tend to destroy the pivot holes and to change the nature of the frictions, and it is mainly here that bad gearing is harmful to watches. Having done this, one will be able to complete the escapement.

2528. The escape wheel being turned and set up, as explained above, it remains to split it[73]. For this, it is fixed on a stake in the manner explained in Art. 2322:

> 2322. To split a verge escape wheel mounted on its arbor, a chuck is used which is bored to let in its pinion and arbor. To fix the wheel onto this chuck excellent Spanish wax is used. The chuck is heated until the wax is molten and the wheel is put on it.

73 This section refers to Berthoud's wheel cutting machine. However, his description of it is obscure (he says "this machine, as it is described, has not yet been made, but each part has been made separately"), and so I have edited out the details relating to it. However it appears that, in contrast to splitting ordinary wheels, a shaped cutter is used.

It is positioned so that there is no wax between the base of the chuck and the bottom of the wheel; it is best when the wax does nothing but surround bottom of the side of the wheel. While the chuck is hot, the wheel is held down in it, and it is centered by holding a point against the side of the wheel, while the chuck is turned by a bow in the other hand; by this means the wheel turns perfectly true and becomes concentric with the arbor of the wheel cutting machine, but for the wheel to be centered it is necessary that the wax is hot. When the wheel has been split, the chuck is heated to separate the wheel from it, and to remove the wax which has stuck to the wheel it is put in spirits of wine.

2528 cont'd. A cutter of suitable thickness and shape is chosen, which is learnt by experience, inclined 25 degrees, and the index put on the first division of number 13. The first tooth is split half way; then the platform is turned around, so that the plane of the tooth is done in a full circle of the wheel and it cannot bend. This cannot fail to happen when, after having formed a tooth, one forms the following one on the front side of the finished tooth. Because then the tilted plane of the cutter goes against the already cut tooth and bends the point; whereas by the other method the curve of the cutter finishes the tooth without being able to bend it. I go into these details, because to make a wheel perfectly true it is not enough to have a good tool, it is also necessary to know how to use it, and the perfection of the escape wheel is of very great consequence for the accuracy of the watch. Initially the acute ends of the teeth should not be finished, but on the contrary they should be kept square, and when all are cut they are made sharp. A wheel thus split cannot fail to be perfectly true. To finish it, one only has to remove the burrs from the cutter, stroke the points of the teeth with much care (Art. 1320 below), and to draw file the front and back of the teeth with extremely fine files (Art. 1322):

1320. The wheel thus split, it is removed from the chuck and a fine polishing file is used on the sides of the wheel to remove the burrs made by the cutter. ... Then the wheel is put in the turns, running the pivots in the holes of runners with disks; in this state the points of the teeth are stroked lightly and with great care, in order to make the wheel perfectly round.

1322. The rounding up wood (see Art. 969, page 57) is put in the vice and a smooth *verge wheel* file (a kind of sage leaf file[74], smaller and only cut on one side) is taken. The backs of the teeth are smoothed, going to the point where one will remove the small angle which finishes it on the back of the tooth, but not touching the point which must not be removed, so as not to make the wheel out of round. One will do this with all the teeth and draw file them longitudinally.

2529. But if the wheel is badly and unequally divided, one will use the tool represented in Plate 5, fig. 23 to equalize it, which is described in Art. 2355)[75]:

74 *Lime à feuille de sauvage*. I assume *sauvage* is a misprint for *sauge*.

75 I found Berthoud's description extremely obscure. This is a very free translation of what I think Berthoud meant to say, but it is still vague. The platform *H*, which carries the guide *I* and the cutter *D* is mobile and can be tilted so that the cutter can be correctly presented to the wheel. The distance between *I* and *D* is used to measure the spacing of the teeth and then *I* is used as a guide to lightly trim the front of a tooth that is too close to the preceding tooth. Then the cutter, which is shaped and has a curved back, is used to trim the backs of teeth. It is clear that this process would only work if the escape wheel is reasonably close to being correctly divided. As Berthoud uses a wheel cutting engine to divide escape wheels, I am not sure why he included this tool. Also see Theodore Crom, *Horological Shop Tools 1700 to 1900*, 1980, which contains an excellent photograph of a very similar tool, and Leonard Weiss *Watch-Making in England 1760-1820*, 1982. Neither has an explanation of its use.

Tool to equalize the verge escape wheel.

2355. Finally to complete what relates to the tools which are used to make the execution of the parts more exact and easier, I will describe a tool to equalize the teeth of verge escape wheels. This tool, shown in Plate 5, fig. 23, is essential for the perfection of verge escape wheels, which can be made as true as one wants by its use. It was invented by Mr. Crevoisier, tool maker in Paris.

2356. The verge escape wheel *A* (fig. 23) is placed between the point *B* and the bridge *C* of the tool, and runs on the shoulders of its pivots in taper holes made for them. *DE* is an arbor of which the part *D* is a cutter like those for the verge escape wheel; this arbor is driven by means of a bow and the ferrule *H* which it carries. It has two tapered points which run in the holes of the screws *F*, *G* carried by the arms *H*, *E*. The lever *IkL* is mobile at *k* on a shoulder screw. The end *L* of this lever is supported on the end of the screw *MN*, being held against it by the action of the spring *op*; thus, as the screw is turned one way or the other, the end *I* of the lever is made to approach or move away from the cutter; the lever as well as the cutter are carried on the frame *HPQ* which is supported on the end of screws *1*, *2*; thus the cutter can be made to move nearer to or further from the wheel by the movement of H; the height of it is regulated by the screw R. This is the principle of this machine: While supported on H, the cutter and end *I* of the lever are moved to engage in the teeth of the wheel, and the front of the cutter is used to cut from the tooth the amount by which the small teeth of the wheel are too close together, in order to make all of the teeth equally spaced. However this is done only by tentatively feeling one's way, as will be seen by the use of the machine.

2357. The part *S*, on which the screw points *1*, *2* of *H* sit, is mobile on *T*, to which it is retained by the nut *V* which enters a screw on a pin carried by the part *S*; thus it can be inclined as required. The part *T* is formed on a box which moves on the prolonged bar *E*, to which it is held by a screw; it can be moved forward and back to suit the size of the escape wheel. Part *X* is bent to receive the end of the screw *R*; this part is held by the graduated nut *S*. The part *Y* of the bar is used to attach the tool to a vice. *3*, *4*, *5*, *6* are nuts which are used to lock the screws *1*, *2*, *F*, *G*. The pin *B* is locked by the screw or nut *7*. Screws *8* and *9* lock the bracket *C* that can be raised or lowered as required, because of the slots in which the screws pass.

2358. To use this tool, the verge escape wheel is placed between the pin *B* and the bridge *C*. Then one presents *H*, turning the screw *N* until a tooth is supported against the lever *I* and the front of the cutter is ready to touch the next tooth. All the teeth are tested one after the other in order to determine the largest and smallest teeth. One does not at first arrange the tool according to the large tooth; because if one were regulated by it to file smallest, when the wheel had been gone round there would be a tooth much smaller than all the rest. Instead one is regulated by the small ones that are decreased, so that what one removes to increase the space decreases by as much the largest with each revolution. When a revolution is completed, the screw *N* is turned a little to move the lever *I* away from the cutter (the head of this screw is graduated in order to know which way it moves the lever). One thus goes gradually and very slowly until the cutter just touches all the teeth. At the same time as a hand turns the arbor of the cutter with a bow, the other presses on the wheel to support it against the cutter; when the tooth sits on the lever the cutter ceases cutting.

2359. When the fronts of the teeth are equalized perfectly, it is necessary to put the wheel on the turns and to stroke the points of the teeth so that the graver reaches shortest. Then the marks of the cutter are lightly removed with a file and the wheel put back on the tool to see whether filing the front of the teeth changed their accuracy; if it is necessary they are retouched by the method indicated.

2360. That done, it remains to finish the backs of the teeth, in order equalise their points. For this the curved side of the cutter is used. The wheel is put on the tool and the front of the tooth supported against the lever *I*. The lever is moved away from the cutter until the cutter passes in the space of the nearest tooth, and the back of the cutter is ready to cut the back of the tooth, and for that *H* is raised or lowered by means of the screw *R*. For this, one will be regulated by the most pointed tooth, so that the cutter only grazes. Then the lock nut *Z* is tightened, the wheel advanced to the next tooth, and with the bow the cutter will remove the amount by which this tooth is thicker than the first. The same operation is done on all the teeth until they are all acute. It remains, to complete the wheel, to use a very fine rounding up file to round the points of the teeth.

2530. The escape wheel being finished, the escapement is set up. For this, the steel plate *F* (Plate 3, fig. 10) is put on the plug of the potence so that the part *q* of this plate sits against the back *m* of the nose of the potence *D* (fig. 9), in order to receive the end of the escape wheel pivot which must be level with the back of the nose of the potence. It is necessary that in this state the wheel does not approach too near the body of the verge. This plate is hardened and tempered, so that it does not have to be touched again. Then the pallets are gradually narrowed until, at the same time as the teeth no longer butt on the pallets, the end of the escape wheel pivot rests against the steel plate. It is necessary to decrease the pallets with great care in order not to remove too much, which would give drop to the escapement which could not be cured, since the wheel is supposed to approach very close to the body of the verge. It would thus be necessary in this case to decrease the body of the verge, and it is a very long and difficult operation. It is necessary that the pallets are of exactly the same width, so that the liftings of the pallets are equal; a pinion gauge is useful to make them equal, and it should be used all the time that one is narrowing the pallets to adjust their width.

(In a verge watch whose driving force is given, as well as the size of the wheel and number of its teeth, it is essential that the wheel approaches as close to the center of the verge as possible; because 1, the friction of the escapement is less, since the pressure of the wheel is the same and the drag smaller; and 2, the arcs of lifting are larger, and consequently the supplementary arcs smaller, so there is a smaller disturbance from variations of driving force. It is still necessary to observe that to make a verge escapement which has less recoil, it is necessary to have a larger and lower numbered wheel; the body of the verge remaining the same, the arcs of lifting will be larger and the recoil will be less in relationship to these arcs, a condition which leads to isochronism of the vibrations.)

2531. When the escapement is ready to be made, which is when the wheel approaches the body without the pallets touching or butting, it is then necessary to remove the angles of the pallets so that they do not damage the teeth and cannot butt. The escapement being made and the pallets being of equal width, the potence key is turned to find the exact point where the drops are perfectly equal.

2132. The pallet at the bottom to the wheel is reduced, in order to move it away from the pivot so that it does not attract the oil; it is sufficient that the engagement with the teeth of the wheel is done full on the pallet. If the wheel approaches too near the balance seat it is necessary file back this seat a little.

2533. The adjustment of the pivot holes of the escape wheel is completed. For this one will round the bosses behind the nose of the potence and the counter-potence. One will bore at the end *n* (Plate 2, fig. 6) a hole to drive in a steady pin, and lengthen the hole for the screw which holds the counter-potence so that the escape wheel can be put in and removed without taking out this screw[76].

2534. The escapement being entirely finished, the banking pin is put in. For this, one will start by making a mark on the front of the cock with an angular file. It is necessary that this mark is right in the middle between the two feet of the cock; this mark indicates the place where the banking pin will have to stop so that the pallets are equally in mesh with the teeth of the wheel. It also marks the point of rest of the balance spring; that is, the place where pin will stop when the balance spring has been put in place and the balance is free and at rest. Now, to make the guide mark on the balance, which is the place for this pin, it is necessary to set up the escape wheel. One will put a small piece of paper between the balance and the cock to prevent the balance from turning freely. That done, the balance is turned very slowly until a tooth of the escape wheel, which is held by a finger, escapes. At that moment a small mark is made on the edge of the balance, precisely below the mark made on the cock. Then the balance is led back until a tooth of the wheel escapes from the other pallet and a small mark is made on the edge of the balance in line with the guide mark on the cock. These two marks made on the balance show the total arc of lifting. This interval is divided into two equal parts and a mark made at this place which is a little deeper; this mark is the guide mark showing where the balance must stop so that the pallets are in mesh with the wheel and the balance spring is at rest. A hole for the banking pin is bored through the thickness of the balance and close to the external edge, on the line which goes from this mark to the center of the balance. The pin is made from a needle tempered blue and it is riveted onto the balance so that it is perpendicular to the plane of the balance.

2535. Now, to find the point where the slide must be cut back to avoid the banking pin, so that the balance can describe the largest arcs, the following method is used. The cock is put on, and the point *N* (Plate 2, fig. 8), which will also be used as a guide, is marked on the plate immediately below the guide mark on the cock. The escape wheel and the balance are put in and a piece of paper put between the cock and the balance. The balance is turned until a tooth of the escape wheel reaches the end of the pallet without dropping off it. Then a small mark is made on the balance in line with the guide mark on the cock, this line indicating the movement that the balance can make on this side without dropping; that is, without the pallet leaving the tooth of the wheel. Then the balance is led back until the tooth of the wheel being moved back by the pallet reaches at the end of this pallet without dropping off it, and a small mark is made on the balance in line with the guide mark on the cock. Then, using a compass, the distance from the guide mark for the pin to one of the small marks just made on the edge of the balance is taken. The slide is put on and, putting one point of the compass on the guide mark *N* on the plate, the other point traces small lines at *p* and *q* on the slide, which show the places where the notches for the banking pin must end. But to prevent any error which could result from slipping while making the marks, one will not cut back completely to *p* and *q*, so that after having put in the balance and the wheel, one can examine the banking when the pin touches the end of the notches in the slide.

2536. The edges *ph*, *qg* of the slide are filed according to a compass line drawn from the center *d*; the size of this circle depends on the distance of the banking pin from the center

76 The counter-potence pivots on its steady pin.

of the balance. The closer this pin is to the edge of the rim, the less this notch needs to be brought closer to the center; it is sufficient that pin can never touch.

2537. It is necessary to place the balance spring stud away from the slide, as one sees it at *G* (fig. 8); rather distant from the slide so that the arm of the rack, when the needle is at 0, cannot touch the pin of the stud. It must be brought closer to the center of the balance so that the balance spring will not strike against the inside of the slide when it expands. The hole for the stud is bored and enlarged upright, a broach passed through both sides, and a reamer to smooth and harden the hole. This hole should be approximately ½ ligne in size. To make the stud, one will use square, hammer-hardened brass one ligne thick; a pivot is raised on the turns which is gradually reduced until it enters the hole in the plate tightly. This pivot should be almost cylindrical, or better, a little more free on the side of the shoulder, and it is finished on the turns by rounding the end to facilitate entry. The hole for the pin is then bored; this hole must be approximately $\frac{2}{12}$ ligne in size, and it must be perfectly upright and enlarged from both sides. The height of this hole above the plate must be half way between the plate and the bottom of the balance. One will cut the stud on the turns so that only a little remains above the hole, and then the stud cannot touch the arms of the balance.

2538. To make the balance spring collet, one will take well hammer-hardened brass as thick as the balance seat. A hole is bored which, when enlarged, is smaller than the balance seat. The ring is turned on a turning arbor; the size of this collet should be just sufficient to bore in it the hole for the pin which holds the inner end of the balance spring. Initially this hole is bored while directing the drill so that it goes near the turning arbor without touching it. It is enlarged from both sides and the top of the collet turned so that there remains enough above the hole to hold the pin. The collet has to be left thicker so that the hole for the pin can be moved (while turning the edges of the collet) up or down, so that this hole is at the same height as that in the stud, and consequently the balance spring is in a plane parallel with the plate and the balance. The side of the collet which rests against the balance is hollowed out, so that when it is put on it joins exactly. The less enlarged side of the collet hole must be placed against the balance in order that it is retained there and, while turning the collet with a screwdriver, it does not tend to rise up. Before removing the collet from the arbor, it is transversely split with an equalling file; it is necessary to make this slit away from the hole for the balance spring pin, on the opposite side to the hole for the pin; that is, where the inner end of the balance spring enters. This slit in the collet must go to the arbor and cut the collet completely, so that it can spring open when going on the seat and close again when it is on, producing a good friction. The collet thus made it is put on its seat.

2539. It remains, to complete what relates to finishing the top, to place the curb pins on the arm of the rack for the passage of the balance spring. To mark the place for these pins, one will take a compass, putting one point in the center *d* of the balance and the other in line with the inner edge of the hole in the stud. Then, with this opening of the compass, a line is marked on the arm of the rack. Two small holes for the curb pins are bored on either side of this line; these holes should be separated by only enough to allow the balance spring to pass freely. The rosette wheel is put in place on its mark with the rack and the rosette put on, which I presume has been engraved and divided as it is seen in Plate 2, fig. 8. The rosette hand is also put on at its guide mark and this hand brought to 0 (on the rosette). In this position, one will take the drill which was used to make the holes for the curb pins and mark through these holes two points on the plate. The hand is then advanced to division 4 and again two points are marked through the holes; and so on, until the hand has traversed all the rosette. These points indicate the path of the curb pins, and consequently the curve which the balance spring must have when it is at rest, so that its movement is not constrained by one pin or the other.

2540. Before removing the slide, it is necessary to bore in the plate the holes for the two pins which stop rack, so that the rosette hand cannot go too near the balance, which could stop the watch or break a balance pivot. For this, when the hand is on division 0 or 32, the extremities of the rosette, holes *x*, *y* at the end of rack are bored with a drill, in each of which a pin is driven; these pins limit the travel of the rack and the hand. If the ends *g*, *h* of the slide cover the rack, thus going over the end of its path, they are shortened by the necessary amount, level with the rack, so that one can mark and bore the holes. These pins are only put in when the plate is smoothed with a stone and it is ready to be gilt. They should not be higher than the slide.

2541. If one realizes, while turning the rosette hand, that the rack makes the ends of the slide rise up, one will rivet on the plate at the ends of the slide two brass claws *g*, *h* having small bevels which will cover the ends of the slide, which are also bevelled so that these claws do not project above the slide; care will be taken to adjust the slide so that the rack turns under it with a friction neither too weak nor too strong, but soft, and so protect it from jolts which could make it move if it were without friction.

2542. The slide is removed. The arm of the rack is filed and thinned so that it cannot touch the balance spring. The top of this arm is rounded, it is polished on the top and sides, and the two curb pins riveted, which go in from the top and are riveted underneath. These pins are shortened so that they cannot touch the arms of the balance.

2543. The watch being brought to this point, one could test the free running of the balance, in order to see whether the spring has a suitable strength[77], but it is to better wait until the watch has been gilded, the screws cut to length, everything polished, and the wheels freed; because the freedom which one gives the pieces after gilding changes the force which the escape wheel has at its circumference, compared to if it had been run unfinished, as is commonly practised. It can happen that a watch in which the balance ran free at 25 minutes before gilding, ran at 28 or 30 after it is gilded, though the balance did not change weight or the spring its force, and it appears that the watch is in the same state. But more or less play in the holes, etc., appreciably changes the ratio of the driving force to the regulator; and it is on this ratio that depends, as I have shown, the greatest accuracy of the watch. For establishing this ratio, it is necessary that all the parts of the machine have acquired a constant state and all the freedom which they are likely to have; one will thus gild the watch first.

2544. Before gilding the watch, it is necessary to smooth all the brass parts with water stone. But before that it is necessary to shorten all the screws so that their ends are level with the plates or the other parts where they are attached, and the ends of these screws are rounded and polished.

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77 *tirer*. This is running the watch without a balance spring. See also Art. 609-610, page 89.

2545. It is also necessary to cut the fusee square, after having first smoothed the groove for the chain on the turns.

2546. Before gilding the watch, the case and the hinge need to be made, work about which I will not speak, as it has no effect on the goodness of the watch[78].

2547. It is a good idea, after all the parts are smoothed and before gilding the watch, to entirely assemble it and pin the plates as if one wanted to make it run, to see whether all the wheels have the right height in the frame. They must have a little play and the oil sinks must be level with the ends of the pivots; if there are wheels which do not have enough end play, the shoulders will have to be moved back, as also the other parts.

2548. The plates being smoothed, the pins which control the travel of the rack are driven in and riveted; boiler brass is used for them, because wire takes gilding badly.

2549. All the brass parts of the watch must be gilded, except only for the escape wheel, the fusee and the balance spring collet which are polished.[79]

2550. By gilding the watch, gold is introduced into all the holes, so that it is necessary to clean all of them with great care; the holes of pivots with well smoothed broaches, and the tapped holes with the taps which were used to thread them, or instead of the tap one can use their screws.

2551. When the watch has been gilded, one will start by freeing the frame. For this, a broach is passing through the pillar holes in the top plate, and the angles or burrs made by the broach are removed by a small steel cylinder whose end is conical and has three faces; this tool, which I call a burr tool, is represented at *Cg* (Plate 3, fig. 3). It is necessary to remove the burrs in all the holes, especially those of the pivots. Then the holes for the pins of the pillars are broached, and the angles and burrs in the holes removed with the burr tool.

2552. All the broaches which are used to free the pivot holes must of a good shape (a little tapered), and have been smoothed with care using an oil stone, so that these broaches smooth and polish the holes.

2553. One will carefully pass a broach through the hole for the fusee in the pillar plate and remove the burrs. A broach will also be passed through the holes in the feet of the fusee cock, and with each hole that is broached, the small angles in the hole are removed by the burr tool. I will not repeat this operation again. The tap is run through the screw hole of the fusee cock. A broach is passed through the hole for the fusee in the top plate. A broach is passed through the hole of the fusee cock, the cock is put on and, so that its screw enters easily, oil is put in the hole for this screw. The fusee is put in the frame and the plates are pinned, in order to see whether it has suitable end play; one will decrease or increase it in consequence. The holes are examined to check that they are not too tight; it is necessary that they have a little play so that, oil being introduced, the pivot is not too tight in its hole. It is also necessary that the hole is not too large, because then the gearing will change. I would like to be able to state the correct degree of freedom which it is necessary to give to each part, but it is an amount that is rather difficult to describe; it needs a sense of touch which is not easily communicated.

78 For information on case making see George Daniels, *Watchmaking*, 1981 and Philip Priestley, *Watch case makers of England, a history and register of gold and silver watch case makers of England, 1720-1920*, 1994.

79 See Art. 1226-1233, page 68.

2554. One will make free, with the same precautions, the center wheel, the barrel, the third wheel and the contrate. To free the third and contrate wheels, it is necessary to start by freeing the bridge carried by the pillar plate in which the pivots of these wheels run. For this a broach is passed through the holes in the feet of this bridge, and a tap is run through the screw holes; then it is put in place with the screws, having care to put oil on them. To free the escape wheel, it is first necessary to pass a broach through the holes of the steady pins of the potence, in order to free it, and the same is done with the counter-potence. As these two parts are gilded, it is necessary to carefully scrape off, with a graver, the gold which could have stuck to the base of these parts. A tap is run in the screw hole of the potence nose and that of the plate, and the same operation is done for the screw holding the plate of the counter-potence. That being done, a broach is carefully passed through the holes of the escape wheel pivots and they are freed, so that these pivots have neither too much nor too little play in their holes. Taps are then run through all the screw holes in the top plate and the pivot of the rosette wheel is freed. If gold has entered the groove in the slide it is scraped out with a graver. A broach passed through the hole of the balance spring stud, but very lightly in order to remove only the gold, so that this stud is always held by friction. The slide parts, rosette and wheel are assembled, having care to put oil in all the screw holes, and the rack is tested to see if it turns with friction under the slide; if it is too free, it is necessary to file the lower part of the slide a little, in order to make it rub on the rack.

2555. One will pass a broach through the holes of the cock feet and free the coqueret and its screw. One will pass a broach lightly and then a reamer through the pivot hole of the balance; and the same is done with the pivot hole in the potence foot. The balance and the cock are assembled, and the end play of the balance examined first; if it has too much or too little play, which way the cock should be curved is noted and it is adjusted with a hammer. That done, it will be seen whether the holes are of a good size; they should be a little tight, because when explaining their execution, I supposed that they were made just right and without play. However, it is necessary that the pivots have a little play so that oil can be introduced there, and that even when it has thickened a little the pivot is not restricted by it. The balance is then removed and the chain-guard made free; the pin is carefully put in after having passed a broach inside the hole.

2556. The barrel is freed on its arbor, the barrel and the mainspring are cleaned, and the spring inserted in the barrel (all the merchants sell tools for this purpose). Oil is introduced between the turns of the spring, the bridle and arbor put in, and the lid put on; the barrel is then ready.

2557. Finally, to finish freeing the watch, a tap is run through all the screw holes in the pillar plate; the click of click-and-ratchet work for the barrel is set up; a broach is passed through the hole for the minute wheel pivot; in the same way a broach is passed through the holes in the feet of the cock for the minute wheel, and the pivot hole in this cock. The dial spring is put in. The watch is now ready to be assembled, to see if the mainspring is of a good strength.

Remarks

2558. I have shown that the relationship of the weight of the balance to the motive force is not the same for all watches, and that it varies according to nature of the frictions, the moving forces, etc. From which it follows that to surely arrive at compensation for the effects of heat and cold, one can exclude showing how the balance runs free, since, according to our principles, two watches can appear to be made in the same manner, the balance to run free the same number of minutes, and yet to vary with heat and cold differently. It is true that it will be little, if the same dimensions are given; but since the test of the number of minutes of the balance running free is not enough, it is to better resort to an experiment which satisfies all the conditions: which is to test the watch at various temperatures. If it is summer the test becomes more difficult, however I done it in every season.

2559. To assemble the movement, one will clean all the parts carefully. All the parts of the watch are separated from each other and put in a cup or glass filled with spirits of wine. They are left there for approximately half an hour, when they are removed one by one and brushed with purpose made brushes which are dipped in spirits of wine. Then a dry brush is taken which, by removing spirits of wine, cleans the part. When the parts are large, linen can be used to wipe them. All the parts being thus cleaned, peg wood is passed through all the holes in the plates. Initially the bridge of the third and contrate wheels, which is attached to the pillar plate, is set up, and then the dial spring and the click of the click-and-ratchet work for the barrel are installed. This plate is put on the tool called the *hand*[80]. The fusee is reassembled with its wheel, having care to put oil in the hole of this wheel, on the click and at the base of the fusee, and the collet which holds the wheel onto the fusee. The barrel being cleaned, oil is put in the recesses of the pivot holes, lid and bottom, and then the fusee and the barrel are installed. The parts of the potence are assembled, its pivot holes cleaned and it is attached to the top plate. The chain-guard and its spring are set up, the bridge for the fusee attached and a piece of spindle tree wood passed through the hole. The escape wheel is put in, after having cleaned and assembled the counter-potence. The screw of the counter-potence is tightened so that the escape wheel is free but does not have end play and oil is put on its pivots. All the parts on the inside of the top plate being put on, this plate is put on the pillar plate, the pivots put in their holes, and the train is assembled. Pins are put in to hold the frame and the ratchet of the click-and-ratchet work for the barrel is put on its square. The chain is hung on the barrel and the arbor turned by its square until the chain surrounds the barrel, except for the end that hooks into the fusee, and one will continue to turn the barrel arbor until the spring tightens the chain. It is from this moment that one measures the amount of set up of the spring; one will thus turn it until the arbor arrives at its guide mark[81]. The turns of the chain are arranged evenly on the barrel so that they run smoothly onto the fusee without overlapping the grooves. The rosette wheel is put on, the rosette attached by its screws and the hand put in the middle of the rosette, so that the guide mark is presented to the rack. The rack is put on at its guide mark, and then the slide is attached by its two screws. One will examine whether the rack moved from its guide mark when the slide was put on, which will be seen by moving the hand to the ends of the rosette. Oil is put in all the pivot holes of the top plate. The balance is cleaned with a piece of linen, and the pallets and pivots of the verge with cork. The balance is put in. The brass coqueret, after having cleaned the pivot hole, and the steel coqueret are fixed on the cock which is put in place with its screws. The fusee is wound half a turn and the watch will run. Oil is put on the balance pivots. The watch is taken from the hand and replaced on it with the top

80 A movement ring. See Art. 1922 below.

81 See Art. 467-474, page 65.

plate down. Then the spring is wound, making sure that the chain does not cross over the grooves of the fusee. Oil is put in all the pivot holes in the pillar plate and the bridge. The minute wheel, cannon pinion and hour wheel are assembled and the dust cap put on fusee square. Finally the dial is put on and attached by its screw, the hands put on and cannon pinion pinned. The watch is thus completely assembled.

2560. The watch being assembled, a balance spring is chosen and it is attached to the balance spring collet and the balance spring stud. The watch is adjusted; that is, the balance spring is changed until it is approximately regulated. It is allowed to run for a few days at room temperature, noting, as I do for these tests, the how fast or slow the watch is in 24 hours and the degree of temperature to which it is exposed. Then, after setting the watch to a clock, I sit the watch on the tool described in Art. 1921, and which is represented in Plate 6, fig. 5:

> 1921. To check the running of my watches according to their position, inclination, or the degree of temperature to which they are exposed, I built the machine represented in Plate 6, fig. 5.
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> 1922. *ABC* is a tool known to clock and watch makers as a *hand*. It is used to hold watches while they being assembled; for that the plates are held between the three adjustable clamps *ABC*. Here the hand is used to hold the watch in this machine and to put it in all sorts of positions.
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> 1923. The hand is moved with friction on its center *D*. The rim of the hand is graduated in degrees of the circle so that, by turning the hand, one can place midday on the watch at the top or bottom, or any other position. *F* is an index which marks the inclination given to midday. The part *EB*, which carries the hand, is mobile on the center of the semi-circle *IGH* and can turn on its center *G*, so as to place the watch horizontally, vertically or at any other inclination. The needle *GK* indicates the inclination of the watch on the semi-circle (graduated in degrees). Thus the watch can compared in different positions.
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> 1924. To observe the temperature at which the watch is tested, I placed in it a mercury thermometer graduated by the divisions of Mr. de Réaumur. *LM* is the brass plate which shows the divisions and the tube. *NOPQ* is a glass dome which I surround with crushed ice when I want to produce low temperatures.

2560 cont'd. I surround the glass dome which covers the watch with crushed ice, and I note the hour when the ice has caused the thermometer which is inside the dome to drop to its lowest point. I then leave the watch for 12 hours, taking care to renew the ice as it melts. I note the variation of the watch and I say: since the watch was adjusted at a temperature of 20 degrees, I expect it to loose in the cold. It follows from my principles that the balance describes arcs which are too large, and that consequently the spring is too strong. So I weaken it and I repeat the test until the watch does not vary from heat to cold. See the experiments which I have reported on this matter.

2561. When the watch is adjusted for various temperatures, it will have to be regulated in two positions, flat and suspended. For this, after having wound the mainspring fully, it is run suspended and the amount by which it advances or retards in, for example, 12 hours is noted. The mainspring is wound again and it is run flat. If the spring is equalized perfectly with its fusee, one cannot account for the difference in positions by a variation produced by the inequality of the driving force. One can thus, with this precaution, consider the difference in the running of the watch flat or suspended. If the watch advances when suspended, one will lighten the top of the balance, and vice versa. When the watch has run for some time and it is well regulated in all positions, it is disassembled and cleaned, the heads of the screws are polished and tempered blue, and the steel parts are polished. The watch is reassembled and it is then finished.

The causes which make a watch stop or vary with the ways to recognize and fix them[82]

578. The theory of watches that I will give in the second part particularly relates to the most favourable provisions which one can give them when they are built. I was obliged to omit several particular circumstances of practice, knowledge of which is, however, extremely important. I will give here some of them on the causes of the stopping of watches. However, I will not undertake to cover all the matters which should be attended to, the details of which are infinite and would take too long. Besides it is necessary to suppose the artist is intelligent, otherwise all the rules which one can offer him would be useless.

579. As the power which drives a watch is extremely small, it should not be surprising that only a little thing is necessary to stop this machine. Thus to investigate the causes of a watch stopping it is necessary to take great care, and to already understand its construction and the principles of its motions.

580. If the action of the engine or mainspring of a watch is weak, and that when the watch is in a state of freedom the engine does not dominate the regulator, it will happen, when oils starts to thicken and the pivot holes are filled with dirt, that the mainspring having lost its force and there being a greater resistance from the train, it will happen I say, that the watch will stop, the driving force being in balance with the regulator, especially when the watch is carried.

581. A watch stops when it is dirty and the oils thicken; when the gears are badly made; when the pivot holes are too tight; when the hands are badly adjusted and touch, or they rub against the dial or the glass.

582. A watch stops when two wheels of the movement too are close to each other; when they touch or rub on some part; when the balance approaches too near and touches either the cock or the slide; when the banking pin, which prevents banking of the pallets in the verge escapement, is too short and it passes over the slide; when the slide itself is too short, in which case the balance can move further than it should when one of the pallets is engaged with a tooth of the escape wheel.

583. It also happens when the escapement is too tight, or the end or angle of a pallet stops on the point of a tooth of the escape wheel.

584. A watch also stops under the load of the balance; but in general it is less by the load of the rim than through too much weight in the arms and the center, whose useless pressure on the pivots causes considerable friction and requires an excessively strong balance spring; so this resistance counteracts the driving force and makes the watch stop. To cure it, it is necessary to reduce the center of the balance and the arms.

82 Articles 578 to 633 form chapter 32 of Volume 1. The discussion of cylinder watches has been omitted.

585. Here are a few of the causes which make watches stop. But it is not enough to list them. It is necessary to discover the cause which makes a watch stop and, without waiting (as do certain watch makers) until it stops a second time, to seek the cause which made it stop the first time, as I will explain.

586. The first thing which should be done, when a watch has stopped, it is to see, before opening the movement, if the hands are touching; if the minute hand touches the glass or if the hour hand, being too long, touches the fusee square.

587. It is necessary to take the hands off to examine them. Then it will be seen whether the hour wheel has too much end play and if in certain positions it disengages from the pinion which drives it. Then the dial is taken off and it will be seen whether the minute wheel has too much play under the dial and can disengage from the cannon pinion. One will examine the meshing of these motion-work wheels; see if the pinion of the cannon pinion touches the plate, which would cause a harmful friction; and see if these wheels rub.

It will be seen whether the cannon pinion is held by light friction on its stem, if not it should be split and, one will tighten the cannon to produce this friction by means of the tool of which I spoke (Plate 10, fig. 13). There are workmen who simply notch the cannon pinion on one side, but that is worthless; it must be notched on both.

588. Having opened the movement, it is necessary to carefully examine it to check that the wheels do not touch, the balance does not approach too near the slide or the cock, and it does not rub elsewhere; to see that the pallets of the balance are not reversed; the banking pin does not pass over the slide; if the balance is free, which is easy to see by slightly moving the watch to make it turn. If, on giving it this movement, the balance is driven, one will be able to judge if there is neither banking of the balance nor the pin passing over the slide; thus the stoppage comes from inside the movement. Having given this movement to the watch, if for a time it again vibrates and runs, it will be a sign that the pallets hang on the ends of the escape wheel teeth, or it is proof of insufficient freedom of the wheels of the movement, or weakness of the mainspring. Then, to be certain, it is necessary to disassemble the movement of the watch and to examine it.

589. To disassemble the movement of a watch (after taking it out of its case) one will start by stopping the train by means of a hair or a piece of paper; then the screws of the cock are removed and the balance lifted out; for this, one will remove the stud which attaches the balance spring to the plate. Then it is necessary to withdraw the hair or paper which stopped the train, and let the train run until the chain has run off the fusee; after which the slide is removed. A key put on the square of the endless screw to turn it and remove the set-up of the mainspring. In order to give the mainspring the same degree of tension when the watch is assembled after repairing it, one will note the amount the barrel arbor turns. Then the pins which assemble two plates are removed, the train dismounted, and one will examine it as follows.

590. Every meshing should be examined, to make sure that there is neither butting nor a pinion too small. To judge this it is necessary to rotate the wheel and feel if it drives the pinion uniformly and there is not more resistance at one point of the wheel than another. To be able to judge the nature of the meshing, it is necessary to be able to see the wheel; and for this reason it is necessary to make holes in the plates beside the arbors and directly above the meshing.

591. Having examined the gearing, it is necessary, having first taken care to clean the holes, to put each wheel in the frame to see if the holes are not too tight and leave the wheel freedom turn; or whether these holes are too large so that the meshing changes; and to check that the wheel is upright in the frame.

592. It is necessary to observe the play of each wheel in the frame and if, being moved to one side, it can touch another part; and to test them thus one with the another, together and separately.

593. It can happen that the wheels are not quite round, and that at certain moments the meshing is good, then too deep, and finally it becomes shallow. One can judge this important defect by putting the wheels on the turns, and by presenting a point which can only touch the teeth without cutting them; like, for example, a blunt brass point. But before doing this test, one can see whether a wheel is round by examining the gearing; by looking at the nature of the gearing for each part of the revolution of the wheel, which is easy to judge; because if the wheel is not round, the gearing will be alternately strong and weak. One will also observe the sizes of the pinions, their roundness, etc.

594. In verge watches it is necessary to pay much attention to the play of the contrate wheel, and to see that it runs smoothly and upright (Art. 572, page 8).

595. It is necessary to examine the mainspring, to know if it develops well without rubbing on the bottom or the lid of the barrel, by removing the lid of the barrel and winding the spring; and to examine whether the turns rub. And it is necessary to see whether the fusee is equalized to the mainspring; if not, one will use the methods which I have given[83].

596. When the mainspring of a watch has suddenly broken, it is essential to replace it with one which has a suitable strength relative to the weight of the balance, the arcs of lifting, etc. I will give, in the second part, the means of making a spring of a suitable force for the watch[84]. Here is a method which one can employ when the watch is well laid out and it goes accurately: before disassembling such a watch whose spring is broken, it is necessary to notice the degree of the rosette to which the hand is currently pointing, and to put in a spring such that the watch is regulated with the needle remaining at the same point; by this means one will be assured that its force is the same as that of the spring which was broken.

597. To continue the investigation into the causes of the stoppage of a watch, it is necessary to check the play of the barrel arbor, to make sure that the barrel turns freely and that the holes are not too large, so that when the mainspring is wound the chain, by drawing the barrel to one side, tilts it and it rubs against the plates or wheels. A bridle should be put on the mainspring, so that when it is fully wound it does not bend at the place where the eye is formed, which would cause friction between the turns.

598. To check that the collet which holds the fusee wheel on the arbor has a good grip, so that it does not loosen and the wheel which it retains does not rub against other wheels.

599. To check the play of the wheel pivots; it is necessary to be sure that there is space for the oil when it thickens.

83 See Art. 470, page 65.
84 See Art. 2499 and following, page 61.

600. To see that the barrel or its chain does not rub against the case when the movement is closed; and no wheels touch the case.

601. To see if the wheels are not too heavy, especially those of the escapement; if the balance pivots are not too large and the holes too thin; if they do not have too much end play, so that the shoulders of the pivots touch the foot of the potence or the coqueret, which is a very great defect; if the pivots are round and of pure steel, without cracks or flaws.

602. To see if the end play of the balance pivots allows the banking pin to pass over the slide, which makes the watch stop or lets the train run and bend the teeth of the escape wheel.

603. To see that the escapement does not have too much drop, which makes it lose force and tends to hollow out the pallets. To see that it is not too tight, so that the teeth of the escape wheel butt on the angle of the pallets. To see that the drops are equal. To see if the balance pivots are not too tight in their holes, so that thickened oil obstructs its movement; to see that they are not too loose, so that the escapement is alternately strong or weak and varies, depending on the position of the watch.

604. To see that the balance is well poised; if it turns upright and cannot touch the cock or the slide with the watch in any position.

605. When the movement is put in its case, to see that the cock or coqueret does not touch the bottom of the case so that the balance is constrained.

606. To see that the balance spring is well seated and of a good shape. To see that by turning the rack it does not move the balance spring to one side, but the rack follows the curve of the spring.

607. To see that the balance spring moves in the same plane. To see, when one places the cock and the watch horizontally on one's hand, that the balance spring does not touch the balance on one side or the other; an important defect, because the spring pressing on the balance increases friction on the pivots.

608. To see that the bankings for the balance are well made, otherwise: 1, if the slide is not filed back enough, the balance cannot describe as large arcs as are possible without the banking pin hitting the slide; or 2, if the slide has been filed too much, the banking does not stop the tooth of the escape wheel on the end of the pallet, and stops the watch; and finally, to see that the banking pin does not touch the barrettes placed on the plate or the end of the rack.

609. A watch being thus examined and repaired, it is necessary to clean the pivot holes and the pivots, to assemble the pieces and to observe them working with the balance without the balance spring. (When the parts of a watch are assembled it is called remounting the movement; an operation which one should not confuse with that of winding the spring or motor to make it run, which is called remounting the watch. When one speaks of dismounting the movement, one means to disassemble the components of the machine.) When the minute hand marks more than 27 minutes per hour, (that is, in each hour the watch runs 33 minutes slow), it is necessary to remake a balance, or to force the escapement, in order to make the balance describe larger arcs. If it marks less than 25 minutes per hour, the balance must be lightened.

610. This operation is called to *draw the balance* to set it to weight[85]. Thus in this example it is necessary that the balance draws 25 minutes per hour; that is, without the balance spring it must lose 35 minutes per hour. A care which it is necessary to take when assembling all the parts of a verge watch, is to see that the escape wheel is quite free, upright and without play, so that the escapement is in its correct position; because if one does not move the counter-potence (or the stud) in enough, the escapement will have more drop than it should, so that not only will the watch advance, but also it will vary; since in this situation the regulator will no longer be in a suitable relationship with the motive force, a very essential thing as I will show in the second part.

614. All the parts of the watch will be assembled, and it will be seen whether the balance does not describe too large arcs beyond those of lifting, which would prove that the balance is too light. The rule which one can approximately follow is to make that the total arc traversed by the balance three times larger than the arc of lifting; that is, if the lifting of escapement is forty degrees, the balance moved by the train will have to describe about 120 degrees.

616. When one makes the verge escapement, fixes the banking pin, moves back the slide so that the teeth of the escape wheel cannot escape from the pallets by overbanking and the balance can traverse the greatest possible distance, then it is necessary to mark a point on the plate, below the circle of the balance, which is the place where the pin must stop when the balance spring is put on and is at rest; and it is necessary that this point is such that the liftings of the escapement tighten the balance spring equally. For this, one will take a compass, set one point on an end of the slide, and open the other leg so that the small space which is formed by tracing two small marks from each end of the slide, is located at the edge of the balance; this space determines the position of the guide mark for the banking pin.

617. Thus at all times when the length of the balance spring is altered, it is necessary to turn the collet so that the banking pin stops on its guide mark. When examining a watch one will check that the balance spring collet is turned correctly to meet this condition, (to stop the pin at its guide mark) and for this purpose to make similar guide marks on watches which do not have one, which is very convenient to set up their escapement exactly.

620. It is essential that the balance spring follows the curve or path traversed by the curb pins on the rack. For that it is necessary to take care, when setting up the slide, not to place it concentrically with the balance, but so that it comes in a little, according to the curve of the balance spring and so that the path traversed by the curb pins on the rack follows the spiral line of the spring exactly. The balance spring stud must be placed on this same spiral line. By this means the end of the balance spring, being fixed to the stud, will pass freely between the curb pins of the rack and without unexpectedly touching when the rack is advanced or moved back; because the portion of circle which it describes will correspond with the portion of the spiral which the balance spring follows.

621. It is necessary to place the curb pins on the rack so that the balance spring just fits between them, freely and without play.

622. When one bores the holes for the curb pins on the rack, they should be marked on the turntable with a drill; for this it is necessary to turn the rosette hand, and mark points

85 *tirer le balancier*. Elsewhere I use the expression *to let the balance run free.*

on the plate from one step to the next; these points will be used to determine the curve of the balance spring, which will have to pass between these points; thus while one turns the rack forward or backward, to advance or retard the watch, the balance spring will not touch the curb pins of the rack.

626. It is very harmful to a watch with a verge escapement for oil to be communicated to the pallets, which wear hollow and cause great variations in the running of the watch. Often oil reaches the pallets when one sets up the balance. The bottom pallet, passing near the hole of the escape wheel, picks up the oil with which this hole is filled. The teeth of the escape wheel acting on this pallet pick up the oil which stays on them, attracting atoms which grind and corrode the verge. To prevent this, one should not bore the hole for the escape wheel pinion right through, but leave it closed (or cover it)[86].

627. It also happens that the bottom pallet can be too close to the pivot and the oil which is in the pivot hole transfers to the pallet. In this case it is necessary to move back the pallet as much as possible, in order to have a pivot shank which keeps the oil away from the pallet.

629. To solder the balance seat to the verge with tin is a very bad method; it is prone to get out of order. It should be soldered like the seats on pinions, with silver solder.

630. When the pinions are hardened, they are usually curved. To straighten them, workmen use a sharp hammer, which is a bad method, because as soon as the marks of the hammer are removed, they bend again[87]. It is much better to straighten a pinion by filing the points to one side until the pinion is right.

631. It is necessary to use pure brass, clean and hammered, to bush pivot holes; the pivots must be made a little tapered, approximately of the shape of a broach or a reamer.

632. One could test if friction could be decreased by running the balance pivots in holes made with English coin metal[88].

633. Here are basically the steps which one must employ to repair watches. Some of these steps can also apply to finishing. They are presented here without order: I leave it to the workmen to organise them. When one has thus examined and corrected a watch, all the parts should be properly cleaned before assembling.

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86 See Art. 2406, page 18.

87 As noted earlier, W. Blakey (*L'art de faire les ressorts de montres suivi de la manière de faire les petits ressorts de repetitions et les ressorts spiraux*, 1780) and François Crespe (*Essai sur les montres a repetition*, 1804) both point out that when hardened steel is polished it will bend back to its original shape before hammering. But this can be prevented by re-tempering before polishing.

88 *Métal de timbre d'Angleterre.*

Jacob Auch

Handbook for Country Watchmakers

Translated by
E. J. Tyler

Edited by
Richard Watkins

Jacob Auch

Introduction[89]

Jacob Auch was born in 1765 in Echterdingen and then lived at Vaihingen and Seeberg until 1798 when he became Court Clockmaker at Weimar. He was one of the best pupils of Philipp Matthäus Hahn and began his work at a small factory at Ludwigsburg about 1787. A number of his watches have been recorded, some with complications. One of them is marked J. Auch & Sohn, Weimar, but nothing seems to have been recorded about his son. Auch died in 1842 at Weimar. Baillie credited him with two books on horology[90].

Sachsen Weimar was a Grand Duchy with the capital city named Weimar. Charles Augustus, Grand Duke, was born in 1756 and died in 1828. He reigned from 1775 and was a patron of learning and the arts. Goethe and Schiller as well as other literary figures were at his court. In 1816 he created a representative constitution and the fiftieth anniversary of his accession was celebrated in 1825. The capital was as well known for literature as was Dresden for fine arts. Ilmenau, where Auch's book was published, was some 50 km south west of Weimar.

The writers to whom Auch refers were Johann Heinrich Moritz von Poppe 1776-1854, Ferdinand Berthoud 1727-1807, J.G. Geissler, who published a collection of horological writings by other writers in 1793-9, and Benjamin Lewis Vulliamy 1780-1854.

The watch with which the text deals is a verge watch with fusee and chain. It must not be forgotten that watches on the Continent often had a bridge instead of a cock on the top plate to carry the verge, and also that winding through the dial was fashionable. The watch in this book is of this type.

Certain terms have been used in the translation that need explanation. The *great wheel* is the wheel carried by the fusee. The center wheel which rotates once per hour is called the *minute wheel* by Auch. The *small main wheel* or *small minute wheel* is the third wheel, the *crown wheel* is the contrate wheel and the train finishes with the *scapewheel*.[91]

Most of the former German states had their own system of weights and measures which were supplanted by the metric system in the nineteenth century. It is not certain which system was used in Weimar, but a Prussian inch, consisting of 12 lignes equal to 2.179 mm each, was about 26.1 mm. In other states the inch was slightly less than an English inch (25.4 mm), excepting in Baden and Württemberg. The value of a Carolin was about £1 and a Thaler 15p (3 shillings). These values must be multiplied many times to make a comparison with those of the present day. The weight of the balance, given as 6 grains, would be on the Prussian system and is about 6.6 English grains.

During translation, the following works were referred to:

Abeler, Jurgen: *Meister der Uhrmacherkunst*, 1977.

Baillie, G.H.: *Clocks and Watches, an Historical Bibliography*, 1951.

Baillie, G.H.: *Watchmakers and Clockmakers of the World*, 1933.

89 All footnotes by Richard Watkins.

90 *Anleitung zur kenntniss und behandlung der taschenuhren fur uhrenbesitzer*, published in 1808, and *Handbuch fur landuhrmacher*, published in 1827 with revised editions in 1858 and 1892.

91 I have changed all terminology in the text to the modern terms so that it is consistent with my translation of Berthoud.

Britten, F.J.: *Watch and Clockmakers' Handbook, Dictionary and Guide*, 1884.

Schulte, C.: *Lexicon der Uhrmacherkunst*, 1902 reprinted 1978.

Woolhouse, W.S.B.: *Measures, weights and Moneys of All Nations*, 1890.

Blackie: *The Popular Encyclopedia.*

E.J. Tyler

March 1995

Handbuch
für
Landuhrmacher
oder
leicht faßliche Anleitung, wie man, vom geringsten bis zum schwersten Stück, und stufenweise, bis zur Vollkommenheit eine Taschenuhr bauen muß, wie man die Uhr gehörig aus einander nimmt, wieder zusammensetzt, sie gründlich reparirt und abzieht, stellt, regulirt u. s. w.

Für
Lehrlinge und Liebhaber.

Nebst einer vollständigen Beschreibung der hierzu nöthigen Werkzeuge und deren Abbildung auf drei lithographirten Tafeln.

Von
Jacob Auch,
Hofmechanikus in Weimar.

Ilmenau, 1827.
Druck und Verlag von Bernh. Fr. Voigt.

Handbook

for

Country Horologists

or

Easily understood, step-by-step guidance to making a
complete watch, from the simplest to the most difficult
part; and how a watch should be taken apart,
put together again, thoroughly repaired and
examined, put in order, regulated, etc.

for

apprentices and enthusiasts

Including a complete description of the necessary tools

with their portrayal on three lithographic plates.

by

Jacob Auch,

Court mechanic in Weimar

Ilmenau 1827

Printed and Published by the House of Bernh. F. Voigt

Preface

The art of watchmaking that was once held in such high regard, that once enjoyed a golden age and distinguished itself from all others, stands now at the point of falling into decay and sinking into ordinary bungling. We could say with good reason that its art has now going a begging, and woe to the poor art that must beg for its bread! Why has this art sunk so low? Because factories, numerous godless factories, have come into being that deliver masses of watches at great speed, that are less to be recommended for the insignificance of their prices than for their innate badness. These factories destroy our prices and suppress the industriousness and artistic spirit of the individual country maker. Who will buy a watch from him, to which he has devoted all his skill and that he cannot afford to sell at a price that does not reflect his care and the quality of the finished product?

These days, most people buy rough watches at a moderate price and feel pleased to possess them; it is indeed the watch which they own now. The master, who otherwise only makes new works, now sees himself in sad poverty and not able to apply all his hard earned experience embracing many years to repairing master-made watches, but is often limited to bungled factory watches, especially when he is unable to work on the higher levels required by advances in the fine mechanics of this art.

That is the ruin of this noble art! *That goodness goes and comes again* is a right and true proverb, only it appears not to apply to us watchmakers. The good old masters go back to their old masters and the founders of this art, but the new watchmakers are not masters. The factory owners give handwork to them and they lose courage to create something excellent and priceworthy. How can this disadvantage be destroyed? How can the damaging influence of the factories on the activity of the country watchmaker be resisted?

It would be possible to bring back the good old times. But how? By seeking to awaken the sunken spirit and lost courage of artists. By attracting new artists who deserve to push the others to one side. Not all the old masters have departed into the past, there are enough of them available who bring honour to teaching. The watch enthusiast will learn at the end that it is better to have one reliable masterpiece at a fairly high price, whose life is reckoned by the life of a man and possibly by a century, rather than the output of a factory at a bargain price, which cannot be relied on and so continual payments must be made because of its unreliability.

I was persuaded by an old honest Swabian, who was a great master of apprentices and who rejoiced in a very large business, to take a step, possibly the first taken in this connection, to awaken or make a second rebirth of the lost, ancient artistic skill; namely, to write a handbook, an elementary work for friends of this art or those who wish to broaden their knowledge of it. There has been until now nothing like it. There are certainly fine works written in different nations about the watchmaker's craft, but they are only for masters and those who understand, not for apprentices and people who are approaching the craft, people who have not yet penetrated the higher mechanics.

In my writing I teach the apprentice the first ideas and concepts, and continue to the point which borders on the higher parts of the knowledge of mechanics. I begin by teaching the apprentice the names of materials, their working, the names and uses of the watchmaker's tools and the making of them. When the apprentice has learnt this and is in the position to perform the elements of the art, I continue step by step to instruct him in drawing the calibre and in working on all the parts, one after the other in an orderly sequence.

After this, on account of the large number of factory watches which it is necessary to improve, so that the owner is satisfied as far as possible and not entirely disappointed, I teach him to take a watch to pieces, put it together again and finally to adjust it, on which so much depends.

As it is my intention simply to provide an elementary treatment, I advise those who have obtained sufficient knowledge from it to proceed to the higher levels of watchmaking by obtaining the works of Geissler, Poppe, Berthoud and Vulliamy[92]. My little work is only intended as a first step towards these.

Every master who has examined my work cannot deny that I have in no way strayed from the established rules that form the basis of this art. Should other patriotic masters come after me, who find the art in a sickly state, I believe that I will see in my old age our art brought back to its old level. Watch enthusiasts will certainly be convinced that only a good watch made by a master will satisfy, and only those which do not need attention can give satisfaction.

92 G. Geissler, *Der Uhrmacher, oder Lehrbegriff der Uhrmacherei*, 1793-1799, is mainly a compilation from the writings of Lepaute and Berthoud. Poppe wrote 4 books: a history (1797 and 1801); *Praktisches Handbuch für Uhrmacher, Uhrenhandler und fur Uhrenbesitzer*, 1810; *Die Stand, Wand und Taschenuhren, 1822*; and, too late for Auch, *Die Uhren und die Uhrmacherkunst auf der hochsten stufe der jetzigen vervollkommnung*, 1829. As far as I know, no Vulliamy has written a book. B.L. Vulliamy produced a few articles in journals and a pamphlet on clocks, all except one published after 1827. A few books "quote" Vulliamy (Partington: *The clock and watch-makers' complete guide*, circa 1825; ancien eleve de Breguet: *L'art de l'horlogerie enseigne en trente lecons ou manuel complet de l'horloger et de l'amateur d'apres Berthoud et les travaux de Vulliamy premier horloger du roi d'Angleterre George IV*, 1827; Moinet: *Nouveau traite general, elementaire, pratique et theorique d'horlogerie*, circa 1848), but all refer to clocks and are not relevant.

1: The Watchmaker's Apprentice

The learning of this art, of all that appertains to a watch, needs gentleness, lightness of touch and restraint; capabilities that not everyone possesses, for not all have the necessary power of control that is the main requirement for constructing an accurate watch. To succeed in this art requires long study and diligence, and so it is necessary that a young man taking up this work should begin as early as possible. Some knowledge of mathematics and also of mechanics would be of great value, but unfortunately a pupil is not always provided with the time, opportunity and the means to acquire this most useful preliminary knowledge. But he must be able to read, write and do arithmetic.

Not only these, but also moral qualities are necessary; love of activity, alertness, industry and especially temperance; for only these qualities will maintain freedom and strength, and arouse the necessary intellectual power that is so helpful to the fulfilment of our purpose. The pupil should protect himself from dissipation that is so weakening, that kills all dexterity, weakens the eyes and destroys the nerves whereby the hand trembles and loses all its certainty, and which makes it impossible for him to work on the many tiny parts of which a watch is made.

The pupil must begin at fourteen or fifteen years of age and the time needed is about six years. One would otherwise fear that the young man, who starts some years later, would develop a dislike for the art, if he considers the long time which he must spend before he can enjoy the first fruits of his labour. The younger he is, the easier it is to teach him the elements of this art and the more comprehensively it is retained in the memory. The first impressions which we receive, whether right or wrong, are remembered most deeply, and from them habits develop.

Also the apprentice must quickly get accustomed to order, which is necessary in every trade but even more so here, because of the large number of delicate pieces combined together and because of their difference in size. To overcome disorder and confusion, he must learn the particular place for each part, so that from his first moment in this occupation he can seize the right piece immediately and not have to search. He must learn to be tidy, for untidiness brings impatience; and then, paying little attention to reputation and the need to supply an efficient work to the public, he is careless from the first piece which comes to hand and whose purpose he only comprehends to some extent. From this comes the great irregularity of so many watches, whose continual deviations could have been avoided if only one had learnt exactly how each piece stands in relation to the others. The same order must also be observed with tools, so that one has at hand that which one needs at the precise moment. Thus it is concluded, which has been hinted at, that the apprentice has no other option, because only then can he be in a frame of mind to understand the action of these toothed wheels and gearings, set in motion by a spring or a weight, and brought by a good escapement into a regular motion.

Just as lack of diligence prevents the apprentice from making progress, excessive effort can also be harmful. Therefore he should not make too much at one time. He must rein in his eagerness and not attempt something too difficult, because to master it successfully he must master the difficulties which precede it, for generally the key to one lies in the other.

Master and pupil need at least one hour rest at midday. This necessary quiet time and good nourishing food refreshes their spirits and builds up their strength to carry on with the day's work.

2: Duties of the Apprentice

The first obligations of a pupil are cleanliness and order. He must look after his tools and keep them in a place where he can find anything immediately he wants it and replace it after use. He must keep his bench so that not only is it attractive to the eye but also shows the diligence of the workman. This urge to order and tidiness should also be apparent in his clothing. He does not need luxury or the latest fashion. Next, he must also pay the greatest attention to his master and show that degree of intelligence which will lead to progress. When he knows how to accomplish this, he will rise in his master's estimation and his colleagues will try to help him.

His zeal for his master's business must always occupy him above everything else; enthusiasm for his work, politeness to customers, punctuality and industry in the tasks allotted to him. On Sundays and festivals he must remain in the workshop until two in the afternoon. After that he can devote his time to recreation, but he must be back in time for his master's evening meal or at the usual bedtime. It is also his job to open and close the shop.

Before I go on to describe the duties of an apprentice, I should first draw attention to an important matter for all owners of watches. Some persons calling themselves watchmakers will take a watch to pieces and re-assemble it, and it looks dirtier afterwards than before, and a drop of oil only revives it for a short time. When such a man breaks a pivot he files a new one on the arbor and then inserts a long bush to make up for the shorter arbor. It often happens in such an instance that the hole in the bush is not correct, the arbor does not run straight and the engagement of the teeth is thereby wrong. When such a man has some luck with repairs and has made several watches go, he may be given a repeater to do. He will then hammer the polished parts under the dial and try to make them work, and finally the watch will have to go to an experienced master who, not wanting to lose his reputation, will be forced to renew everything, making the job expensive for the owner and sometimes incurring a loss for the craftsman himself. It would be better if only experienced men were allowed to undertake such work, and then the public would not only possess good watches but be insured against all kinds of damage. There ought to be schools established like the drawing schools, where young people who have a taste for the craft can be educated at a nominal cost, and after they have gained experience they can take their place in the trade. In this way, the spoiling of watches would stop.

Since factory made watches have appeared in large numbers all over the world, and are also so cheap that no watchmaker is in the position to maintain the price for a hand made watch, the craft of the watchmaker has sunk so low that one can assume that in ten years there will be very few practitioners of the art left in Germany. Until now there have been, here and there, masters who make new watches and whom young people could be trained to follow and themselves make new watches, and therefore do good repairs as well. As it has now ceased that one person learns from another, there is only one thing left to do: to write books which set forth the rules of this useful and indispensable art, and describe as clearly as possible each part from the smallest to the largest, from the simplest to the most complicated, so that anyone who has taken the preliminary steps can continue and bring himself to perfection.

3: The First Work for the Apprentice

To begin with, the apprentice should make himself some turning tools and seek dexterity in their employment, because in our craft they are of great use and they are often in demand. He cuts them one, two or three inches long out of some cast steel or other good quality steel and shapes them as he has seen his master do. When he has made the number necessary for his bench, he must carefully collect them and give them a proper place for their further use, which will be dealt with later. Then he cleans the bench and the workshop and sweeps up the filings that this work has produced. From this he proceeds to making one or two file handles, which should be of beech wood or elm. When he has made some of these about three inches long, he cuts them square with a knife, about one inch broad and thick, and corrects them with a coarse file. Then he takes a finer file for smoothing them and makes the necessary holes. Before he has done this, however, he must learn how to hold and use a file. When he has fastened the required piece of wood in the vice, he grips the stem of the file with the three last fingers and the thumb of the right hand and lays the index finger, curved, on the blade of the file to move it to and fro. As an exercise for filing steel he takes the end of the steel in his left hand and grips it with the first two fingers below and the thumb above. Holding the piece so, with the right hand he files the piece along its length in a straight line; however, he must take care that on the return stroke he scarcely touches the piece if he does not want to spoil the tool and the work itself.

After this exercise, by which he has already learnt to hold the file, he must file some pieces of iron rod. Firstly he files them to an accurate square section, then he files the four corners so that they become octagonal, then to sixteen sides, and then by filing the sixteen tiny angles he achieves a completely rounded piece. If he holds the file carefully as has been described, he will also learn to file beautifully flat. This work is very useful and necessary to our task, because almost all the pieces to be worked are angular.

4: Concerning Drills

Now that the apprentice has learnt to use a file he must learn to make drills, as they are used frequently in watchmaking (Plate 7, fig. 1). As this kind of tool is prone to break very easily he must know how to make new ones. For making these tools he must use the steel of polishing files that have become worn out with long use, and let it become red in the fire and leave it till the ashes are cold. He then forges it rectangular so that it becomes less brittle. When it is given this form, the four edges have different breadths from one to two lignes, and it is three, four or five inches long. Made in this way, these tiny pieces of steel are very suitable for making drills. One can also split the files with a good chisel lengthwise and correct the ends with a hammer. Each piece is gripped in a vice so that it can be filed square, and it is necessary to ensure that one end must be only half as thick as the other on which the ferrule is put, so that the piece resembles a pencil shaped punch with a flattened end. Once this has been done, the piece is filed with eight and then sixteen corners and then rounded along its length from where the ferrule will be put.

To file along its length, the thick part is held in a sliding or buckle tongs (Plate 8, fig. 14) which is held in the left hand, and the piece is supported in one of the grooves of a filing block held in the vice. With the right hand holding a coarse file that is suitable for steel, with the thumb and forefinger where the stock is held in the handle so that the file lays flat, the file is moved from left to right and back again. Care must be taken that the file only rubs in the forward and not the backward direction. A finer file is then taken and the work continued till the traces of the first filing are removed. A sheet of thin card is then wrapped around the middle of the piece so as not to damage it, and the protected part is held in the tongs so that it points forwards, and it is then placed in an appropriate slot of the filing block and filed octagonal for a length of about one inch. After this preparation the stem is filed to a point so that the ferrule can be fixed on. When the ferrule is fastened, the rear part of the drill including the point projects about 3 lignes. This distance must be adhered to exactly, for if the drill penetrated further it would bend or break when in use.

As soon as the ferrule is fixed, the spade end must be made. The stem is held in the tongs near the ferrule and the long part is placed on the filing block. With a medium coarse file suitable for steel held in the right hand, the piece is filed for about twelve to fifteen lignes tapering to a point until it is of the necessary strength for the breadth of the spade end. A large end must have a stronger shaft than a smaller one. The end must be about twice as broad as the shaft, so that when drilling holes it does not stick and break.

Having reached this stage the spade end is made thus: The drill is held by the ferrule with the two first fingers and the thumb of the left hand and the end of the shaft is laid on the edge of the vice. With the right hand a medium hammer is used to flatten the end of the shaft until it is half the thickness of the middle. The shaft is then turned over and hammered until the end is only one third of the thickness of the middle. By this means the spade end is much better, does not distort so easily and cuts quicker than when it is shaped by a file.

As there are two sorts of drill, although of different sizes, one must learn the characteristics of each. The round ended drills are for steel, copper, gold, silver and other hard materials where the end must be lubricated with oil. The drill for brass, bone, ivory and wood is called an otter's tongue; it is pointed and each side of the spade is provided with two small sharp sides that give it cutting power and make it bore in a straight line.

When one has done this, a candle is lit, whose wick must be somewhat strong, and the drill is then held in the left hand by the ferrule and pointed slightly downwards at a distance of about half an inch from the flame. With a brass or iron blowpipe (*chalumeau*[93]) held in the right hand, with the thick end in the mouth and the thin end in the center of the flame, the flame is blown onto the spade end until it glows, upon which it is plunged suddenly into the tallow of the candle, so that it is completely damped and cooled. The value of this hardening is first seen when the spade end is cool again. For this it is cleaned in the following manner. Some of the burnt wick is taken and mixed with some saliva, and then the spade end is rubbed with it by means of a piece of pumice stone. The shaft is then held in the flame again so that the spade is half an inch on the far side of the flame which heats it until it becomes a pale yellow colour, if the drill is intended for steel. If it is intended for brass it is held until it receives a colour nearing dark brown. When the drill has reached

93 In several places Auch uses French words instead of German, sometimes providing the German equivalents. I have noted some of these places.

the required colour, it is again plunged into the tallow in the same way. One must be very careful with this operation, for continually holding the drill in the flame leads to a dark colour, makes the tool faulty and shows negligence.

After hardening the drill, one face of it is ground white on the oilstone, and then the drill held in the flame and pressed on the face of the tongs, thus giving the spade end the required colour and hardness.

When the spade end has been prepared in this way it only needs to be sharpened, which is done by means of a grindstone or oilstone which has the property of grinding hard steel. When this has been done the drill is ready.

The best material for drills is unquestionably round steel which can be purchased anywhere cheaply and in all sizes. Eight corners are filed for the ferrule as above, and the long part tapered as far as the spade end. The previous method is recommended to beginners as a filing exercise.

The beginner should not be given good files as he might unintentionally or through carelessness rub them on the vice and thereby spoil them. As iron is not so expensive nor as hard as steel, it is better for the beginner to practice on this with old files. Such tools or files that need sharpening after long use are very suitable for this exercise. As soon as he understands how to handle a file, he can be allowed to use a certain number of files of various sorts, whereby he accustoms himself to this sort of work, in which he must be completely skilled, for the frequent use of these tools which are naturally breakable calls for a great deal of diligence.

5: Concerning the Bow

To put drills in motion a bow is used, whose size must be related to that of the work. It is an instrument whose construction must be understood by the apprentice. They are made of whalebone or cane and are about 18 to 20 inches long.

The whalebone is cut so that it is twice as thick at the end that is held in the hand. A hole is then bored in the thick end through which a gut line is threaded, whose strength must correspond to the bow, and it is then wrapped around and fastened by two loops, after enough line has been left as is necessary for the other part of the bow. On the other end of the line a loop is made which is placed over a groove cut in the far end of the bow. After the bow is bent it resembles an ordinary bow or a semicircle. Horsehair is used for the smallest bows and they are called hair bows.

6: Concerning Ferrules

Ferrules serve to carry the line of the bow and are thus put into motion. These ferrules are so necessary that every workman must understand their making and use thoroughly.

For this he is given new files that are only used for working on brass, and only in extreme necessity are used for steel. The ferrules are cut out of brass rod about as thick as a finger. Discs as big as necessary for the tool with which they will be used and about 4 to 6 lignes thick are cut off with a saw. These ferrules must be sawn straight. They are then smoothed and trimmed with a file.

Ferrules are forged cold, as are all pieces made from brass, for when they are beaten warm they spring and are not fit for anything. Only if one wishes to beat something out wide is the part made hot. To forge cold, one lays the part on the surface of an anvil, one does not beat it too hard and one sees that the height is uniform so that the two sides are not at an angle and the height is reduced by about ⅓. When the ferrule is hammered in this manner it compresses and hardens the material, so that it is less porous and is capable of being worked better. During the hammering one must ensure that cracks do not appear on the edges, if so, they must be filed away and the ferrule hammered to the previous required diameter; without this precaution the brass would split. When this has been done, the center is marked with a compass having the point on the edge of the ferrule while the other end is as near the center as can be judged. A scratch is then made with the compass point situated in four positions around the edge of the ferrule, and this forms a tiny rectangle whose center can be marked with a center punch. This hardened steel tool has a somewhat stumpy point at one end and the other end is flat. One hits the flat end to make the point penetrate.

The hole is made by a hand-operated drill that cuts away the edges of the hole. When the ferrule has been centered thus, the boundary line must be made, and should be as large as possible so that only a little brass is lost. The compass is opened so far that one leg stands in the center hole and the other describes the circle very near the edge. Then one fastens a turning arbor, which has a hollow end provided with a little oil, in the vice. This arbor must stick out one inch from the left of the vice and be firmly fixed. In most vices there are holes bored in the side which also serve this purpose and which are to be recommended. One then takes the drill for the desired hole and a bow to suit the drill. The point of the drill which protrudes past the ferrule must be inserted in the hole of the turning arbor fixed in the vice and the spade end in the depression in the ferrule where the hole is to be made. The ferrule to be bored is held firm and straight in the fingers and thumb of the left hand, so that the hole is not askew and the ferrule does not spring out of the fingers. With the right hand the bow, whose string is wound around the ferrule of the drill, is then moved to and fro, keeping it in a straight line, and the movement continued till the hole is bored through.

Now the hole is bored it is smoothed by means of a broach (a hardened steel spike with five cutting edges). A broach is used to enlarge and complete holes to the sizes that they should have. The side where the broach has entered is marked with a small punch mark, because there, where the hole is broader, is where the turning arbor and later the drill itself should be inserted.

After this, the piece is put in the vice so that half of it sticks out above the top of the vice and the metal outside the circle is filed off. Then a suitable turning arbor is taken and the ferrule to be turned is placed upon it. The arbor is put in the turns between two sharp pointed runners so that the ferrule comes at the right, and the screw is fastened so that the turning arbor does not have any play. A little oil is applied. A suitable bow for the size of the work is taken, a little less strong than the bow used for drilling. The grip of the turns is held on the left side in the vice and must be firm. A cast steel graver is then taken; the best are called Lavousi. This is a small rod of square section made of well hardened steel with 4 surfaces and 4 angles. These gravers are of different sizes and thicknesses. They are sharpened on a grindstone or oilstone so that a flat surface is given from one corner to the other, whereby one of these corners forms a point. As soon as this point is long and very sharp, it is brought to the stone and the rough edge wiped from each side. This makes it even sharper.

This tool is held in the right hand by the three last fingers and the thumb. The first finger is crooked and laid on the angle 6 to 8 lignes from the point while the bow is moved with the left hand. The cutting end of the tool is laid on the rest of the turns, which must be fixed in such a position that it does not rub against the work. To make the job easier, the tool is moved to and fro along the work until the latter is round and the file marks disappear. Then with the side of the graver the work is turned until it is equal and smooth all round. One should devote all one's energy to learning to turn as almost all parts of a watch need to be turned.

If the graver is pressed on the rest with the index finger the point can be brought nearer the work so that it makes contact on the down stroke of the bow and vice versa, otherwise it rebounds. There are many people who turn with the left hand and hold the bow in the right, but most people however hold the graver in the right hand and work the bow under the right arm so that the two arms form a cross. For those who do everything with the left hand, the first method is best; for the others the second method. If one can use both hands equally, so much the better.

When the upper part or rim is round and of even height, the sides of the ferrule must be turned with the graver, which must be well sharpened. When the sides have been levelled with the point of the graver and the file marks have disappeared, the cuts made by the front of the graver are turned away, evened and polished. A small ruler is applied so that it can be seen if the surfaces are even and equally flat. Turning the ferrule flat is of no importance in itself, but it is a good exercise for turning wheels and other important parts.

When this operation is complete, the best ferrules in the shop are sought out as models; that is, where the hollow is best and the sides rise equally. The hollow is then made for the line, which must be deep enough so that it will not run off. A file called a rat tail file of a suitable size is then taken and is held in this hollow and moved in the opposite direction to the bow. These movements must correspond and continue until the graver marks have gone, and then a finer file is taken to round the edges of the ferrule so that they do not cut the line. After this, pumice powder as fine as dust is mixed with oil and applied to the work with a stick of willow, well rounded and having the form of a rat tail. The hollow is rubbed until the file marks have disappeared.

To polish the edges of the ferrule the willow must be flat, which gives a nicer and more certain polish. Then the work is rubbed with a piece of linen until it is dry and shiny. To complete the polish, take two more pieces of wood, dip them in crocus and rub the edges and sides of the hollow. Then the ferrule is complete. It is now taken off the arbor using sliding tongs and a hammer, but it must be protected by thick paper or card so that it is not damaged. The ferrule is held by the tongs and the arbor knocked out by a brass hammer.

7: Concerning Wheels

When the apprentice has made an adequate number of ferrules and has become used to turning brass, he must learn to make flat wheels and balances. Brass about one ligne thick is needed for this. He cuts the discs out of a sheet of brass, files the rough edges and hammers them till they have lost half their thickness. He then finds the center with a compass as before, rounds, turns and corrects them, and makes them as flat as the ferrules but without the hollow. However, one must ensure that there is only a small hole in the center because only a small arbor or a small pinion will be mounted. By this means two difficulties are avoided; firstly a piece that is not strong enough will not remain fast on its arbor, and secondly it will not fit the wheel cutting engine on which the teeth have to be cut.

Making these pieces will be of great use to the apprentice. Firstly he learns to make a hollow and to make a toothed wheel equal and round, and secondly he learns to hollow out slides, racks, contrate wheels, escape wheels and barrels.

The apprentice who is now practised in the art of working brass must proceed to steel. For this he must get from a watch material dealer round and square steel rods of sufficient sizes for all kinds of watchmaker's work. The round steel serves for arbors, broaches, drills, screws, turning arbors and other similar tools; that of square section for flat, pointed and rounded chisels, punches, screwdrivers, punches, sink cutters etc. Flat steel of different widths and thicknesses is used for springs, clicks, verges, plates for escape wheels or balance cocks, etc.

8: The Rack and Slide

The slide is a half circle that is cut from a complete circle; thus two slides are made from one circle. The rack is also made this way.

Take brass one ligne thick which is beaten as before. All parts from this metal are so prepared, and when they are reduced to ⅓ or ½ of their thickness and are made equal and smooth, they are hard and less porous.

In order to get the pupil's hand in, some of these pieces have to be spoilt. The economical apprentice with foresight must spend as much time and material as necessary in making these pieces and thereby ensure that they will be fit for use.

To make the slide (Plate 4, fig. 13[94]), take a piece of brass of the above thickness and the size of a 2 Pfennig piece. After it has been cut round, like all other flat wheels or balances, it is filed flat on the edges, the roughness removed and the edges rounded on each side. In this state they are ready to be beaten to the required thickness as explained previously.

The piece has its center indicated by marks forming a rectangle (as already explained under ferrule making) in the middle of which a mark is made with a small center punch and then bored through so that the hole is not too big. The hole is then opened by a broach so that the disc, when it is put on the turning arbor, runs reasonably circular in the turns.

Then, as the beating has made it larger, a compass is used to draw a circle as big as the slide should be. Then another circle is made 1½ lignes larger than the first; this serves for the feet in which the screws are put. The disc is turned on both sides and then with a hook tool (an angled instrument that has a flat cutting edge at the side) a hollow is cut the thickness of a card[95] from the turning arbor and so far out that a rim about 2 lignes

94 Berthoud's slide, shown here, is more than a half circle.

95 Auch does not say what sort of card or how thick it is, but I suspect he means a playing card if that is any help. If the rack is as thick as a card then, from these instructions, a card must be about ⅙ ligne.

broad remains. Then another hook tool is taken of the same breadth as the rack is to be, set in the hollow just made against the rim, and a groove is cut as deep as the thickness of the rack. Care must be taken that the thickness of the plate from the hollow to the other side must be no thicker than a card; if it is more the reverse side is turned until it has the required thickness. Then with the point of an ordinary graver the rim is so turned down that on the edge of the turned groove a rim as thick as a horsehair remains to hold the rack. Also, about ¼ of a ligne outside the groove a small cut can be turned so that the feet for the screws that hold the slide can be filed round more easily. Slides made this way are called *ear slides*, those with handles are called *handle slides*. Those without ears are turned circular, usually the same size as the balance, and the screw holes are bored in the middle of the outer rim of the slide, which must be broader than on slides with handles. The second type of slide is as good as the first provided it is well made. They are then cut out and given a breadth of about 2 lignes according to their diameter.

9: Concerning the Hollowing Tool or Hook Tool

This type of turning tool is made in the following way (Plate 5, fig. 1):

A worn out polishing file is put in a glowing fire and left till the ash is cold. A slot 3 or 4 lignes deep is then filed on one side near the end so that a tooth remains which is 1, 2 or more lignes broad according to the tool needed.

The metal is then filed sloping for about one inch from the inner corner of the slot and it is put vertically on a piece of wood so that the tooth points to the right. The upper edge is then filed sloping until the sloping portion reaches the upper angle and makes it sharp, and the opposite surface of the tooth is only ½ as broad as before. The file marks are then filed away and lastly at the end of the tooth the chisel shaped surface is filed from below. The hook tool is then hardened and ready for tempering. For this, the tooth is fixed in tongs or a hand vice about half-way along its length and the angle is blown on with a blow-pipe until the corner begins to turn yellow. With this treatment the cutting edge remains hard and is therefore less subject to wear.

The edges are then sharpened with oilstone dust or emery until all angles are sharp and the cutting edge is whetted on an oilstone as usual. After this beginning, a number of hook tools of different sizes should be made so that one can be chosen that corresponds to the hollow to be formed in the work. The tool is applied by the right or the left hand with the hook on the tool-rest of the turns, four fingers below and the thumb above. The hook tool is guided like any other turning tool. Contrate wheels are hollowed to ½ or ⅗ of their thickness. The hollow must be flat from the edge to the center, which at first is left somewhat broad.

10: How Contrate wheels are Turned

Contrate wheels are made out of sheet brass, like slides, but the brass for them must be thicker, about 2 lignes. When the disc has been well hammered, a small hole is bored to suit the pinion and the piece is mounted on an arbor. It is turned to the correct size on its edge and then the sides are finished at right angles to it. A hook tool is then taken and the disc turned about ⅔ of a ligne deep, leaving a rim for the teeth about the thickness of a card and at the middle a thick tube on the turning arbor equal to twice the diameter of the latter. When the wheel has been evenly turned a piece of slate filed like a hook tool is used to polish the hollow. After this, the disc is measured with balance spring tweezers (*brucelle*) or figure-8 calliper (Plate 7, fig. 3); however, the callipers must be filed level on the points. One point is set on the bottom inside the contrate wheel and the other placed on the outside to measure the thickness of the bottom. If it is thicker than a card the extra metal is turned away. Then the center, which has remained on the turning arbor and is as high as the rim of the contrate wheel, is turned to about half its length or less. Then the wheel is removed from the turning arbor and the bottom filed flat and smooth. The outer surface is divided into four parts in which four holes are bored, and then the bottom is filed out so as to leave four arms running tapered towards the rim. This crossing out, as it is called, improves the going of the watch as it reduces friction.

11: Concerning Escape wheels

Escape wheels, although they are smaller and have a deeper rim, are made in the same way with an appropriate hook tool. They are the only wheels crossed out with three arms before they are cut and fastened to their pinions. A small tube must be left in the center of these wheels as in contrate wheels. This has the advantage, as with the contrate wheel, that if the riveting and fastening of the contrate and escape wheel pinions is good the wheels run true.

Escape wheels are made in the following way (I omit the beating and drilling). The wheel is turned to the required thickness on an arbor in the turns. Then the outside is turned from the place where the teeth will be towards the bottom with a slight taper. The taper is smoothed with a pivot file, and then the wheel is turned so deep that the bottom and the rim are only as thick as a very thin card. The wheel is then removed from the turning arbor.

A piece of sheet brass as thick as a card is taken and a hole bored in it slightly smaller than the escape wheel itself. The hole is then broached until the escape wheel enters enough to let the bottom project a little and the wheel remains fast. The bottom is then divided into three, three holes bored and it is filed like a three cornered hat. The wheel is then pressed out and the bottom filed flat and smooth. A sheet of brass like this with holes of many sizes is a most useful tool; without such a tool a small escape wheel is very difficult to cross out. The riveting of the pinion and preparing the wheel for cutting will be dealt with later.

12: How the Rack is Made

The metal used and the method of working are the same as for making the slide. The piece is beaten, marked, drilled and rounded, and it should be a little smaller but of the same thickness. It is turned round and flat until it fits in the hollow of the slide. It is then turned flat on both sides and the thickness at the edge of the circumference is reduced to a half or so, so that the edge of the rack is just as thick as the hollow turned in the slide (Plate 4, fig. 14).

Then so much is turned from the outside towards the middle of the disc in a straight line so that the inner raised rim exactly fits the slide and turns freely in it. For this a narrow hook tool is taken that cuts a groove as narrow as the inner rim of the slide and is turned out until the disc for the rack embedded in the slide forms a flat surface when seen from below, and it can be turned without any play or chattering. If it does not fit easily, fine pumice powder mixed with oil is put into the joint and the latter rubbed by moving the bow until it is smooth. Then the rack and the slide are made smooth on both sides using a graver. Care must be taken that the rubbing does not create play and that the parts fit exactly into each other. When these two parts have play the watch is liable to faults and is therefore useless; so great care must be taken here.

After this, the rack is put in a wheel cutting machine and ⅓ of the teeth are cut to the desired size, but not too shallow. Then the division plate is turned half a revolution and the same number of teeth are cut on the opposite side. One should note into how many teeth the rack has been cut (50, 60 or 70) so that the teeth of the rosette wheel fit in the teeth of the rack and stand in the proper relationship. For example, suppose the rack is cut at 60. One takes a pointed compass and measures exactly from the center to the outer edge of the rack. Then one point of the compass is set on the 60 mark on a sector and the sector opened until the other point of the compass stands on the opposite 60 (Plate 9, fig. 20). Then the rosette wheel is measured in the same way and the points of the compass brought to the sector until they come to the correct size.

I have described this procedure in some detail so that the apprentice gets some knowledge of the relationship of wheels.

The easiest way to cut the teeth of racks or rosette wheels is the following:

Three pieces, about 1½ inches long and 3 lignes broad, are cut from a piece of clock spring that has been let down by heat. They are held in a hand-vice and a number of holes bored along the middle, after which they are fastened together with pins. The three pieces are then filed in a vice to the same length and breadth, and a tongue filed on them. After this, transverse marks are filed on one of the edges so that the parts can easily be re-located after filing flat.

When the three pieces have been filed equally thick and flat, the two outer ones are taken and filed into teeth along their length, like those on a fretsaw, and the rough edges are ground or filed away. Then the middle piece is taken and filed on the unmarked part of the top side to a depth equal to the length of the teeth; after which the three pieces are riveted together with iron wire and hardened. The tool is let down, but not beyond yellow, and the rack file, as it is called, is set in a handle.[96]

As many teeth as necessary are then filed on the rack as mentioned above, and also on the rosette wheel where about ⅙ can remain uncut. The teeth are then rounded and smoothed. Then a cut is turned on the raised edge of the rack so that on the outermost part or edge at the hollow a strip is formed as thick as a card. The disc is then cut into two parts or racks with a fretsaw where there are no teeth, the remainder is sawn or filed away after the turned edge is clean, leaving an arm in the center of the rack for the balance spring curb.

96 Like Berthoud, Auch assumes throughout that wheel cutting is done with a “saw” that simply cuts rectangular slots and does not shape the teeth. Consequently two processes are described: *equalising* to ensure the teeth and spaces are uniform, and *rounding* to give the teeth a “suitable” shape.

13: The Rosette

This piece is made out of brass, steel or silver (Plate 3, fig. 12). It does not matter which metal, but it must be made accurately, which is not the case on bad watches which stop frequently. Good rosettes are half a ligne thick, or the thickness of the slide, and are flat above with the edge slightly tapered. The lower part is made broad all round so that the disc sits flat on the plate when it is screwed down. The lower part must have a hollow turned in it for the rosette wheel, the diameter of which is ⅔ the width and half as deep as the rosette. This is the right relationship and adequate space for the rosette wheel. The inner side of the disc is like a flat dish to begin with and when the slide has been fixed the inner side has the form of a shaving basin[97].

To make this piece, one of the above mentioned metals is prepared. It is hammered out as for the other pieces of the watch, a small hole of about half a ligne is bored, it is mounted on a turning arbor and then given the required shape in the turns with the point and flat side of a graver. When it is made of silver it is smoothed using a water stone, but if it is brass or steel an oilstone is used.

The apprentice must have plenty of practice in making wheels to acquire the right touch. He must also do plenty of hollowing out so he knows how to make the contrate and flat wheels as well as the cutting of teeth on wheels.

If an apprentice can do this and understands how to use his gravers and hook tools, he must then learn how to turn the mainspring barrel.

14: The Barrel or Mainspring Container

For this, one takes good brass, either in plates or cast, which is cut to size and beaten. It is then centered and bored, the outer circumference marked and the metal outside it filed away. The hole is then corrected with a broach and the piece is fixed on a turning arbor, which must fit the hole firmly so that it stays in position. This arbor is inserted from the side where the broach entered. The arbor is then mounted in the turns and with a suitable bow the barrel is turned until it is rounded to a convenient size, leaving a rim (the chain protector) on the side where it will be hollowed out (see Plate 9, fig 27 and Plate 3, fig. 2).

When this has been done, the center is turned out so broad and deep that a rim is left of the thickness of two cards. After this, the face is made very slightly tapered against the turning arbor. Firstly this is done with a normal graver and the hollow turned so deep and so wide that the thickness of the barrel is about twice that of the already existing projection. When it is no longer possible to continue with the graver, a hook tool is taken and turning continued until a tube, such as is formed when turning a contrate wheel, stands in the center, and the bottom is as thick as a card and turned flat. At this stage, one checks to see if the bottom had its proper thickness and if it is greater than a thick card more metal is removed and the inner wall made like the outer, only in reverse; that is, the bottom of the wall is slightly deeper although the wall is flat. The advantages of these tapered sides are the following: the tapered outside means that a chain can never run over

97 I have no idea what 19th century German shaving basins look like, but I presume they are shaped to fit against the neck of the person being shaved and Auch is describing the shape shown at *qq* in Plate 3, fig. 12.

the top of the fusee during winding; the chain always pulls itself lower on the barrel in running down. The broadening of the space inside means that the spring when running down will not rise up and push the cover off.

When the wall and bottom are clean and sharp, the groove for the cover is turned with a hook tool whose cutting edge is four sided. It must be lozenge shaped; that is, the inner angle must be longer than the outer and pointed. The long angle of the surface of this tool is held against the edge at a depth of a thick card and the bow moved so that the groove is formed about this distance deep and wide. Like the bottom it must be turned somewhat deeper towards the bottom than at the opening, and a hair's breadth is turned off here so that the cover being sprung in place does not go into the bottom nor over the turned groove in the barrel.

When this tapered surface has been made with the point and edge of a graver, a fine file is rubbed over it and over the surface of the barrel to remove the marks of the graver and the coarser files. Both parts are smoothed with water stone that removes all traces of graver and file. The inside and the groove are smoothed with a piece of soft wood dipped in oil and pumice powder. This operation is continued until everything is well polished and not a trace of graver marks remain.

After that, the tube in the center is turned away with the point of a graver (as described above) so that only about ½ a ligne projects above the bottom and the upper surface is flat and even.

When the barrel has been made, a small sloping hole is made for the chain hook. This small hole must go through the groove so the hook fits well. A point is marked near the chain protector and bored through and finished with a broach till the hook is a good fit. The barrel is then ready for polishing or gilding and is removed from the turning arbor and the bottom filed flat and smooth.

15: The Barrel Cover

The barrel cover is made as follows: A piece of good brass about ¾ ligne thick is taken and is beaten until it is reduced to about half thickness. The center point is marked with a punch, the circumference is drawn, and the metal beyond this line filed off. A small hole is bored in the center like that in the barrel. This hole is made smooth and straight with a broach and then it is mounted on a turning arbor. The side next to the ferrule is flattened first and the edge made round. Then on the other side the corner is broken until the outer edge of the disc is as thick as the groove turned in the barrel. From this point metal is turned off the face of the disc maintaining the same thickness, and a tube left in the middle as in the barrel. After this, the diameter is reduced until the cover just goes into the groove in the barrel. If it is difficult to get it to fit, the edge is tapered until the cover can be put into the groove with some force. It sometimes happens that one has turned the cover too small; in this case it is stretched with a polished hammer on a flat anvil and then turned again. When the cover is ready, more is turned off from the tube and the rear side so that the cover completely fills the groove. It is then smoothed and polished and a round or square notch filed in it to lever up the cover. Then the cover is smoothed on the outside. The barrel and the cover are both complete and only need the arbor. As the apprentice must learn to turn steel, he makes the arbor in the following way.

16: The Barrel Arbor

There are two sorts of barrel arbors. One is entirely of steel (Plate 9, fig 29 and Plate 3, fig. 2). The other, which is less durable, is of brass and steel together, but it performs equally good service apart from this disadvantage.

To make the first type, a piece of round steel about ⅖ the diameter of the cover is used. A piece about 12 lignes long is cut off and held in sliding tongs or a hand vice so that about 4½ lignes protrudes. With a coarse file the end is reduced to about half its thickness. It is first filed square, a little tapered, then octagonal and finally round; then a point is filed on the end which serves to center the body. After both ends have been prepared in this way, leaving a central thick portion about 3 lignes long, the piece is mounted in the turns to see if it runs true: if it does not the points are filed to one side until it does. A ferrule is then fixed to one of the ends, and on the other a long section is turned down, taking away part of the base of the point as far as the runner allows. A polishing or notched runner (Plate 5, fig. 3) is then inserted and the newly turned portion laid in it. A somewhat fine file is then laid on the slope of the point, and while the other point remains in the runner of the turns with the ferrule attached to it, the bow is worked and the file moved till the point is sharp and round. The ferrule is then reversed and the same procedure followed on the other end. This method of working should be carefully noted. It is done with all arbors and especially with pinions, and without it no-one can turn true. The points at the ends that are only filed by hand are useful for rough turning, but the depressions in the runners get worn, rub themselves out, become unequal and lose their sharp taper.

When the points have been well sharpened, one side of the barrel arbor is turned to make a sharp corner at the boss and the latter is turned from this point completely round and the shoulder formed. The end is given the appropriate thickness and not turned too thin, so that it goes into the holes in the barrel. Then the arbor is filed with a fine and sharp pivot file.

Before proceeding further, the inner height of the barrel is found from one hole to the other. To find this height a small piece of brass is cut about as thick as the hole in the barrel and then filed flat above and below. At the end is formed a long lug with a shank behind it and it is then inserted in the barrel and filed until the cover can be put on with the minimum of play. This lug then gives the correct height of the barrel arbor center. It is better if a screwed height-measuring tool is used: it consists of two narrow strips of steel screwed to each other that can be moved by a nut. Below there are two long and thin feet on which two small projections are filed to measure heights; this tool is known as a *dancing master* (Plate 7, fig. 5, and Plate 10, fig 1). When the height of the arbor has been found, it is turned to this measurement and work continues.

If everything is in order, the exact width of the inner part of the barrel is measured and divided into three parts, of which one part is the correct thickness of the arbor. The arbor is turned to this size, and after this a hole is bored through the middle for the hook that holds the spring. The piece is then hardened and let down to blue after having been cleaned off. This is done by taking a rectangular piece of iron, and fine emery and oil are applied by it to the arbor while it is rotated in the turns with the bow string carried on a suitable ferrule. The corners are made sharp where the ends join the center. Finally it is polished to a mirror finish with tin ash or polishing chalk[98].

98 Vienna lime?

An iron spike is then filed and inserted in the hole. On one side of it is filed flush with the arbor, and a hook is formed on the other to take the pull of the spring. The barrel is then finished.

17: How Turning Arbors are Made

This is a good exercise for turning steel. These turning arbors are used so much and are so useful that it is necessary to describe their making at some length. They should be made of different lengths and thicknesses so that when one is needed it is ready to hand (Plate 10, fig. 3).

Pieces of round steel of various diameters and lengths are cut according to requirements. The thickest must also be the longest. The sizes can be limited to 30, 24, 20, 16 and 12 lignes. The middle and smaller sizes are the most used.

When a number of pieces have been cut, one is gripped at the end. If it is a small piece it is put in the center of a sliding tongs or a pin vice that fastens securely. If it is a larger piece it is put in a hand vice. The end of the piece that sticks out is laid on a groove of the filing block and with a medium file the points are formed. When this is done, the piece is put in the turns to see if it is true and does not whip in the middle. If it is correct, a ferrule is put on one end and the other is laid in a grooved runner and points filed and smoothed as described in connection with the barrel arbor.

The turning arbor is divided into three parts (Plate 10, fig 3); one part is the head where the ferrule is attached and this is filed octagonal. At each third a cut is turned with the point of a graver not deeper than the metal to be filed away and sloping towards the thicker part, so that at this point a small collar is formed. Then the arbor is gripped in sliding tongs near the turned collar on the short part where the ferrule is put, and it is filed thinner along its length, slightly tapered and completely round; this is easier to do when a series of grooves has been turned previously.

After this a ferrule of the proper size is fastened to the head, the piece mounted in the turns and, with an appropriate bow, turned with the sharp point of a graver. Then, when the tapered part of the arbor is round and even, it is smoothed with a pivot file, with the bow being moved quickly its entire length. Care should be taken with this operation to ensure that the pivot file is laid flat and not too much pressure is applied, and that as the bow goes down the file is pushed forward for its whole length, and so on until the arbor is well finished. If a file that is too coarse is taken for this operation and too much pressure applied the arbor becomes bent and untrue.

If the work has succeeded, the arbor is gripped near the head which has been allowed to remain and the latter filed octagonal. This is easily done by the following method: Every set of tongs has four sides. The piece to be filed into four angles is laid in the appropriate groove of a filing block and one surface of the tongs is held parallel to the filing block. A safe edge file is taken, the safe edge turned towards the tongs and filing begun so that a surface forms. Then the piece is turned and the filing repeated until the four surfaces are prepared and equal to each other. The four surfaces that are filed next must not be made too narrow in comparison with the four previous ones, and when finished all should be equal. The second four surfaces are filed by turning the work ⅛ of a turn which is easy with the tongs in position. If a surface is not filed enough and the corners are not sharp, that face is done again.

Having got to this stage, a ferrule is fixed to the long part near the end and the piece turned from the point to about 1 ligne from the octagon until it is round. It is then ready for hardening. Small turning arbors are hardened by a candle and blowpipe. The larger ones in a coal fire, thus:

The arbor is put in the fire with the octagon outwards and the fire blown until the metal glows red. It is then allowed to fall into fresh water with a little oil on the surface so that it does not bend. It is removed from the water, smoothed with pumice powder and thoroughly polished. It is then laid on a thin sheet of metal held over a good burning candle and let down to a yellowish brown. Then the eight sides are polished with an iron burnisher and emery powder mixed with oil, a brass ferrule is riveted on and the point is smoothed by means of the ferrule just fixed. At the end, as the bow is coming down, the polisher is moved in such a way as to form an invisible thread on the surface, so that when pieces are being turned they do not come adrift so easily.

If the piece bends during hardening it is reheated and straightened. If it is only a little bent it is laid on an anvil with the bent portion pointing up and hit with the pean of the hammer somewhat strongly in the hollow in a lengthwise direction. This brings it straight again, but occasionally it can break.

18: How Screws are Made

The apprentice who has worked industriously on turning various tools has got his hand in. At the beginning he can make small tools of steel about which I want to speak now and which are as necessary as those that I have already dealt with; for example, screwdrivers of various sizes, file handles for use with any type of file, chisel shaped drills, flat and pointed, tools that serve to make oil sinks, verges and other pieces, to hollow out cocks of various sizes, etc.

To make screws, some pieces of steel rod are cut about 3 inches long. One end is provided with a ferrule, the same as a drill, and a point filed on it. This point must stick out far enough from the ferrule so that sliding tongs can be fixed to it. When this has been done, the long end is put in a suitable groove in the filing block and a pivot with parallel sides and about 2 lignes long is filed on it. For this a file is used that is half round with teeth on the flat part and the half round portion plain (a rounding up file); alternatively a parallel arbor file can be used.

With one of these files, a groove or neck is filed around the piece so that it appears that this neck were to be cut through. When it is as deep as the screw is to be thick the projection is trimmed with a small safe-edge file, so that the smooth narrow side touches the filed groove and is it filed down equally all round.

A point is then filed on it and it is tried in the selected hole in the screw plate. If it is still too thick it is thinned with a fine rounding-up or safe-edge file until it goes into the hole with oil and is cut with a good sharp thread. If it throws up metal during cutting when several turns have been cut, the pivot is filed thinner with a pivot file or other fine file until it takes the required number of threads.

It is easy to break the piece if it is forced, which often happens with apprentices, and this broken off piece must be extracted. To do so, it is drilled with a drill that is smaller than the hole in the screw plate, and this must be carefully done right in the center. When the hole is through, a long pointed graver or drill, that must be somewhat softer than the screw plate itself, is used to get the broken piece out. After this, the tap belonging to the hole is moistened with oil and passed through to make the hole clean again.

If the screw has been properly made, a point is filed at the end to form a center. The rod is then put in the turns and a weak bow is used. To begin with it must be made certain that the rod runs true: if not, it is hit gently on the long part behind the thread where the head is, whereby it becomes straight. If the screw does not run true at the first stroke of the bow, the light blows are repeated, but care must be taken that the thread is not bent too much for it easily breaks. The head of the screw is then shaped with a graver, but one must think of the required form when making it. There are several sorts of screws that are distinguished from each other by their heads: one sort are called countersunk screws, the other plate screws. Among this type there are also those that are countersunk and flat; for example, the escape wheel screw among others. Countersunk screws have a cone shaped head and are usually rounded on the upper part of the head and raised; for which reason they are called round heads or tallow drops. There are also those which have flat heads. The other screws, although they have heads of a different height and shape, have a flat surface on the thread side.

When the head has the proper form and size, the screw is cut or turned so thin behind the head that on being re-inserted in the screw plate the connecting part breaks off and the head sits on the screw plate. The small pip remaining after this operation allows the middle to be found easily for making the slot for the screwdriver, This is done in the following way: The screw plate is held in the left hand and the point of the screw thread is laid in a filing block held in the vice. A slitting file is taken in the right hand and it is applied to the center of the pip in the head which remains from the turning, and a groove made about the size of a thin card to hold the screwdriver blade when screwing up and unscrewing.

As soon as the screw is prepared, the remainder of the pip is filed away with a fine file and then the top is polished with a polishing steel to remove all marks. The screw is then removed from the screw plate by a screwdriver and is allowed to blue on a thin sheet of iron held over a candle.

This is only the usual way of making screws for beginners. When finer screws are wanted another method is used.

19: Screwdrivers

To exercise the hand still more in turning the apprentice must make other small steel tools, because he needs them so often. Among these are screwdrivers of different sizes to fit the various screw heads and small pinions, as all arbors belong in this class. For this he must learn to turn very fine rods from round steel;. Such work as this makes the hand proficient and skilful in turning. For this work he can use English needles and make them about 7 or 8 lignes long. They are first let down to blue, a point is filed at each end and a screwed ferrule fixed on (Plate 10, fig. 7). With a hair bow the piece is worked on in the turns. Thus the apprentice can experiment with turning pivots.

20: Pivots and Arbors

This gives great exercise. The master as well as the pupil should do this work from time to time so that the hand retains the lightness and skill necessary for these pieces on account of their exceptional delicacy.

Small rods are turned from fine English needles. They are let down to blue, have points formed on them and cylindrical pivots, as long as the thickness of a card, are turned with the point of a graver. A polishing runner that fits the pivots is then set in the left end of the turns. The end with the ferrule is put in the right hand side and a hair bow is used. The pivot to be dealt with goes in the groove on the left, and is filed with a pivot file held in the right hand at right angles to the pivot and the runner. Work continues until the pivot is parallel and the corner is sharp. When the file is led properly and not pressed too hard, the pivot is made round and equal. The polishing steel is then used in exactly the same way as for finishing all fine parts. The shoulder of the arbor is turned off with the point of a graver and finished with the side of it. This cut must not be too long or too short, but angled enough to reduce the surface of the arbor and thereby reduce friction. The rough metal is then removed with the polisher. The pivot runner is then removed from the turns and a brass one substituted which has a small plate on the end with a number of small holes drilled in it at the same distance from the center (Plate 5, fig 4). This plate stands at the end of the runner on a pointed stem that is 4 to 5 lignes long. It is as thick as a card and at the back on the edge it is turned half as thick. At this edge a number of larger and smaller holes bored. The pivot is then put in one of these holes either to round or shorten the point if this should be necessary. At first a fine used file is employed to do the rounding, and after that a polishing steel of the same size, and the pivot is polished until it is completely flat so that it does not scrape any more. To test this it is rubbed on the nail of the third finger. If it scratches it is polished further until it is smooth. When it is desired to shorten the pivot it is filed with the aid of the bow and a pivot file, and then it is rounded and polished. Pivots are usually 1½ times as long as they are thick.

21: A Description of the Runners for turning Pivots and Arbors

Pivot runners are made in the following way: After the steel has been cut about 2 inches long and tried in the head of the turns, it has a hole made in each end so that it runs true. A ferrule is then fitted about twice the diameter of the runner and near one end, and the line of a hair bow wound around it. The end with the ferrule is put at the right hand side of the turns on a pointed runner, and on the left side the head is removed and the tool rest put crosswise so that its left side is over the bed. On this rest a groove must be filed which must come in the center of the bed and be at the same height as the pointed runner, so that the runner to be bored comes in line with it. A good hardened drill is then taken of the size of the pivot it is desired to make and laid in the groove of the tool rest, and the end of the runner drilled while being rotated by the bow. The drill is held firmly in the left hand and a hole about ½ ligne bored using oil. The runner is then reversed and the ferrule put on the other end and a smaller or larger hole bored.

The runner is then gripped in a hand vice with a card for protection and a lantern, a flattening of the runner, is filed 6 lignes long and leaving about ⅓ of the diameter, so that at the end of the runner a head or block of ½ ligne remains which is as deep as the hole that has been bored. A fine broach is then used to smooth the hole. In the middle of the flat part about one ligne from the head a hole is bored and tapped. When the swarf has been removed a screw with a broad flat head is made and screwed into the hole. The runner is again put in a hand vice or in the head of the turns, and the heads of the runner and the screw are filed parallel to the flat surface and so that a little more than half the hole remains. Then a tiny notch is made in the head of the runner, and the head and the screw are hardened and left hard. Finally, a flat and broad burnisher is taken and the head and the screw polished at the same time, and the grooves are cleaned.

It will take a long time before the apprentice is skilled enough to make all the types of runners necessary. To prevent boredom he should do other things in the meantime; which, if they offer difficulties, will flatter his ego, whereby he will believe he understands more and his desire to emulate will be aroused. Meanwhile he can be given the crossing out of wheels and balances, which must previously be turned and which must be devoted to (or sacrificed for) his instruction. These wheels are then cut, that is the teeth are formed, and they will later be used to teach him to equalise and round the teeth. But before all other things he must learn crossing out.

22: Crossing Out Wheels

The crossings, arms, limbs or spokes as they are variously named, which give wheels lightness, are usually five in number on the center wheel; which differs from the third wheel which only has four. The contrate wheel also has four. They are cut from the disc which surrounds the central hole and taper towards the rim, which is as deep as the teeth are long. In the escape wheel there are only three, because that is the number which is necessary for so small a wheel. The division of these arms is done as follows:

A circle is drawn on the wheel inside the teeth, leaving a space as wide as the teeth are long. This circle is then divided into five with a well sharpened compass; the marks must be clear because they are the centers of the arms and they must all be equally spaced. The width of the arms is then chosen and the circle again divided into 5 parts, which are also marked with a point at each arm; so the circle is then divided into 10 parts[99]. *Hierauf setzt man den Zirkel zwischen diese markirten Schenkel so in die Mitte ein, daß die freie Spitze des Zirkels die eingetheilten Puncte bei dem Umschlagen oder Hin- und Hertheilen berührt; während man mit dem Zirkel so verfährt, schraubt man ihn so viel auf und zu, bis die Spitzen treffen. Ist der Zirkel also gestellt, so macht man mit der beweglichen Spitze*

99 Inscribing a regular pentagon inside a circle, described by Euclid and Ptolemy, is a complicated and difficult ruler-and-compass exercise. One method (see H.W. Richmond, *A construction for a regular polygon of seventeen sides*, Quart. J. Pure Appl. Math., 26, 206-207, 1893) is illustrated in Plate 12, fig. 4: The two diameters passing through P_1 and A are drawn perpendicular to each other. The midpoint B of OA is found and the line BP_1 is drawn. The angle OBP_1 is bisected and the line BN on this bisector is drawn. Then NP_2 is drawn parallel to OB. The points P_1 and P_2 are two points on the pentagon and the remaining points can be found by copying the angle P_1OP_2.

Auch's glib remarks ignore this and it seems much more likely that a division plate was used in practice.

einen Halbkreis auf dies Rad.[100] This procedure is repeated for each crossing in the same way.

It is important that the crossings are equally spaced and that they all point directly to the center, so that the wheel is in balance. Most people make the crossings with curves, but many make parallel arms with pointed ends, more like the form of an ordinary wheel.

Three punch marks are made in each space that is to be cut out, at a sufficient distance from the lines so that they are not affected by the drilling and cutting. The holes are made bigger with a broach and larger drills, taking care not to touch the lines. The middle hole can be larger than the other two. The three holes are then filed into one with a rat-tail file if the broach has not caused this to happen already. This is only done in the absence of a fretsaw. If one of these is available, the spaces are sawn out ready for fine filing. Having reached this point, a coarse *bird-tongue* file[101] is taken and the crossings and the rim are filed to the lines. Then a fine sage leaf file is used to smooth everything, but care must be taken that the file is held straight and at right angles to the wheel, otherwise the latter will be damaged. When the wheel has been equally filed a piece of wood is taken in the form of the sage leaf file just laid down, dipped in oil and pumice powder or oilstone dust and the crossings smoothed with it in a lengthwise direction till all file marks are gone. After this, the piece is cleaned with a brush so that the inner sides of the crossings are clean and shiny, and then they can be polished using another piece of wood and polishing powder, or with a burnisher.

This process is followed with the other wheels although their crossings are different. The crown and escape wheels are filed sloping from the lower surface where the arms join the rim. In this way the area is enlarged and the wheel becomes even lighter.

The pupil who is now instructed in crossing out wheels must also learn how teeth are made and equally formed, stand straight, have equal strength and equal depth; for their function requires the utmost equality. The slightest difference in the teeth makes them not only of bad form but also faulty in meshing with the pinions.

If I speak of equalising teeth, this is only for those craftsmen who do not have factory aids at their disposal, because a very costly tool exists which, when the worker makes use of it, can cut teeth easily and quickly, round and alike. The management of this tool is very difficult, but those who understand it can achieve much with it and satisfy many customers.

This rounding and cutting machine, which has existed in factories for many years, is not only difficult in its management but the price is also so high that not every watchmaker is able to afford it.[102]

About 40 years ago when I was still in Württemberg, which is my home country, I had a small watch factory in Ludwigsburg with 10 or 12 workers. At that time I could not indulge my wish to have a cutting engine which cost 20 Carolins. I thought, however, of a simpler cutting machine that was easier to operate and found the opportunity to cut all wheels equally and well on my apparatus. I made a cutting wheel, turned it half round on both

100 The original German is given here because four people have read it and no-one understands it.

101 A sage leaf file, Plate 6, fig. 1.

102 Other than the following quite inadequate explanation of a wheel cutting engine of his own invention, Auch does not discuss division or explain wheel cutting engines.

edges and left a projection in the middle. I gave all these parts a fine system of teeth and then made it dead hard. I had made it for a center wheel and I cut such a wheel with it. It appeared so good that the spaces and edges of the teeth looked as it they had been polished. I was very pleased with it as can be easily imagined, to be able to cut and round teeth so easily. But like everything in the world, great joy does not last long. I became aware to my disgust that the teeth were not round, but oval and therefore would not endure. One must not lose courage, however. The first step was taken. I made another cutter and in the middle of the projection I gave it a small hollowing such as a good tooth must have and it exceeded all expectations. For this reason I made a special machine, giving it the form of a turns with 2 heads and 2 runners with one taking the wheel already mounted on its pinion and the other as usual with a sunken end. On both sides of the heads I put rods and on one the main cutter and on the other the rounding cutter. To describe this machine and all its parts and how the cutters are made is too tedious here and does not fall within the scope of this book. Only a few of these machines have been copied so far. It is very easy to make and should be an indispensable instrument in the hands of every watchmaker[103].

23: How Teeth are Equalised by Hand

To undertake this operation the wheel is mounted on the end of a turning arbor so that it runs true. If it is already riveted onto its pinion, a ferrule is fixed on it and it is mounted in the turns and set in motion with the bow. Meanwhile a fine file is set straight on to the teeth and gives the wheel an equal rounding provided the file is held steady. A sharp graver is then taken and a groove cut so deep that it is not lost by polishing. This line is a guide to how deep the teeth can be cut, and one must be careful in performing this operation that the file does not go beyond the line, for if it does the wheel will look bad.

Wheels are equalised in the following way. This operation needs a lot of practice without which many wheels can be spoilt; however, one should not be put off by early failures. The newly cut wheel must be made so that the teeth and the spaces are equal, so that when the space is filed by an equalising or primary file the tooth becomes a little thinner than the space itself, but it must be watched that a good meshing with the pinion is retained.

To begin this operation, a plate of brass is fastened in the vice, 6 or 8 lignes broad[104] and three inches long, and it must be reasonably thick so that it does not bend when being filed. In the middle of one end, one or more holes are bored. If a number are made they must increase in size and be near each other in a row so that they can be used for different sizes of wheels. The other end of the plate is held straight in the vice so that about 2 inches stand out and it is fastened tight so that it forms a good support. If the wheel has been fixed to a pinion, the short end goes into one of the holes, the wheel lies on the plate and the teeth protrude a little over the edge. An equalising or primary file[105] is taken that must

103 A wheel cutting engine which uses round cutters (fraises) must have two axles at right angles to each other; one carries the wheel blank and the division plate, and the other carries the cutter. If a linear cutter (a file) is used, the two axles must be parallel to each other; Plate 12, fig. 2 (based on an illustration in a book by Leutmanns published in 1717) shows such a wheel cutting machine.

Auch's description appears to confuse these two types and is not intelligible, but it seems more likely to be of the latter type.

104 Presumably Auch means 6-8 inches.

105 A thinning file, Plate 6, fig. 1.

be previously chosen for this job and prepared. This file is set straight on the uppermost space between the teeth that are farthest from the metal plate, and the space is filed in the direction of the arbor and the hole so deep that the file reaches the turned circle but goes no further. The operation is continued until the wheel has been dealt with all round, and all teeth are equally deep. A wheel that has been well cut is easy to equalise, especially when the teeth already have their proper depth and stand regularly.

There are, however, many bad cutting engines, which not only cut teeth unequally but also crooked and thick and thin; then one must guide the file with a firm hand and try to correct the teeth and cut some metal from the thick ones. When this has been done to every tooth it must be seen that the teeth and the spaces are equal.

When the teeth are straight and the bottoms of the teeth are flat and filed sharp, the wheel is complete.

If the teeth have more body than the empty space, another slightly thicker file must be taken and used until the wheel corresponds to the relationship that is necessary to get a good meshing.

If the workman has acquired the skill of making the teeth equal, he must now exercise his hand in making the teeth completely round.

24: How Teeth are Rounded

The wheel is held in the left hand as for equalising. The rounding up file (Plate 6, fig 1) is held in the right hand and laid flat on the angle at the end of a tooth. The file must go straight and not sloping and must not stagger, as was mentioned above. It must not go too high nor too low. When the file is correct in all directions, the corners of the teeth are filed off. and the tooth is rounded at the end. Care must be taken that the middle point of the tooth is not touched so that the wheel does not vary in diameter; this irregularity of the teeth can cause a false meshing with the pinion. When the facets of the teeth have disappeared and the teeth are all uniformly rounded, flattened and not pointed and of the same length and breadth, a burnisher is taken of the same form as the rounding up file just used, to polish the sides of the rounding and remove the traces of the file. This protects them from heavy wear and facilitates the meshing in the pinion. To polish the base of the teeth, a burnisher the shape of a thinning file is used. With this the teeth are finished and they are polished on each side with a piece of slate.

Each wheel has a toothed axle known in the trade as a pinion. These pinions are numbered and are very different from each other in quality, size and design. The workman must know how to make them, each in accordance with the requirements of the number of teeth.

This relationship is as follows:

In pinions with 12 leaves, 5 teeth are taken on the wheel which will mesh with the pinion. A pinion gauge is used which has the form of a screw compass provided with broad points (Plate 7, fig. 4). The points are screwed together so that they embrace the 5 teeth and then a piece of steel is taken and the 12 leaf pinion made to this size. For ten leaves, 4 teeth are chosen; for 8, 4 measured on the points; for 7, 3 full teeth; and for 6, 3 measured on the points. This relationship must be taken too small rather than too large.[106]

106 These sizes are slightly different from those given by Berthoud (Art. 524 and following, page 32).

This care must be devoted to all wheels, but especially for the pinion of the escape wheel; its leaves are somewhat weak because of the delicacy of the meshing and cannot bear heavy pressure or friction.

25: How Pinions are Made

A number of pieces of pinion wire of various sizes, strengths and numbers are taken and so much cut from them as is necessary for the arbors to be made. This size must stand in relationship to the greater or less power applied to them. The pinion of the center wheel of a watch must be longer than that of the third wheel, because this center pinion must carry the cannon pinion, which is hollow throughout its entire length so that it can grip the long pivot of the center wheel that sticks through the plate and stands about 2 lignes above the dial. On this pipe is a pinion which meshes with another wheel which also carries a small pinion which drives the hour wheel. Hence the general motion under the dial is brought about by this small wheel. The apprentice must note this extension and note the length of the pinion so that he does not cut it too short or too long and thereby waste pinion steel.

To make arbors or pinions, pieces about 10 lignes long are cut from the lengths of pinion wire and filed at each end so that the toothed portion remains in the center. To carry out this operation, a filing block is fastened in the vice, the pinion steel is held in the left hand and the end placed in a suitable groove in the block. With the right hand a sage leaf file (Plate 6, fig 1) makes an incision in the pinion, taking care that the portion to be retained with teeth is not touched or damaged. First a ring is cut all round and then the necessary cuts are made. When these are fully made and filed down to the center portion, the piece is held in tongs, the end filed smooth and round, and then a point is made as on a turning arbor. After the other end has been dealt with in the same way, the piece is put in the turns and the center portion rotated with the finger or a file to see if it runs true. If it does not, a ferrule is put on, the pinion is rotated rapidly with a hair bow and a piece of chalk or crayon held near it so that where it touches marks the part that is out of round. The opposite side of the point is then filed until the irregularity disappears and the pinion runs true. To see the centering of the pinion better, it is blued beforehand. When the pinion is completely centered, a small portion is turned away behind the point, as previously described, and the point filed with a pivot file. This must not be neglected if one wants to do good work.

The most important thing about a pinion is that it must be well centered, otherwise it gives false meshing causing stopping and irregularity in timekeeping. When the centering has been achieved, the side of the pinion is first turned flat and is made to the required length, and it is also slightly turned on its diameter as pinion steel is never exactly round. The two ends are turned to equal thickness so that the remains of the leaves have disappeared and the arbor is then filed flat and smooth. It should not be forgotten to oil the points so that they do not wear away and the pinion then runs untrue.

When everything has been accomplished, the shaping and rounding of the leaves takes place. Before I proceed with this I will describe the various forms of pinion leaves.

There are many sorts of pinions. The first sort has the *plank* pinion leaf that is of equal thickness throughout and rounded at the top. These odious leaves are made with a flanking file[107] that is inserted to the bottom of the groove, and whose wedge shape makes the leaves of equal thickness all the way.

107 A thinning file (Plate 6, fig. 1).

The second sort is the so called *cherry* or *barley* type, which the old clockmakers had to make for mastership of the guild. They do not serve well for the movement of a large clock and even less for a pocket watch, but are of more use in a screw. This leaf runs thick at the center and is rounded on top and resembles a thick cherry stone.

The third sort is the *lantern* or hollow pinion which is very useful for turret clocks and table clocks. It is to be wondered that they are not used more for table clocks because it is the best pinion, moving easiest with the least friction.

The fourth kind is the wood pinion[108], and on account of its form and light pressure it is accepted by all the great artists in England, Paris and Geneva, and by some German craftsmen, as a mathematical pinion. I have often wondered why the Swiss factory owners do not use this kind of pinion in their factories; although it requires a little more trouble, they have everything at their disposal to make it by machinery as quickly as the plank pinion. If this pinion were introduced into factories and the watches themselves were made slightly higher, the chain would run for longer, the spring could be broader and stronger, and the watch would thereby receive a more powerful driving force and not stop so readily at the slightest thickening of the oil. Through this small improvement, the watch would have a longer life and it would be worth at least 2 Thalers more. I do not know why such an obvious change has not been applied to normal factory watches, but there is no doubt some good reason.

I will now show the apprentice how to make a pinion. For this a tooth cutting file is necessary. This is equally broad and thick and finely cut on all four sides of its blade. A file is selected that does not quite go to the bottom of the space between the leaves. A filing block is then put in the vice, the pinion held with the thumb and forefinger of the left hand and set in the direction as was mentioned in correcting wheel teeth, so that the file operates in the desired space, and work is continued until all spaces have been filed equal. Then the pinion is turned round and the spaces at the other end treated in the same way. This reversal is necessary because one rarely finds a file that is absolutely straight and doing it this way makes a good job. The file must be kept parallel to the axis of the arbor and wander neither to the right nor left. When the bottom of the spaces have been filed so that the leaves are equal and straight. then the ends can be turned to remove file marks, and the cutting repeated so that the corners at the base of the leaves are sharp.

26: The Rounding of Pinions

This is done with a suitable rounding up file. The pinion is held by two fingers, as when deepening the leaves, laid upon the filing block and the edges of the leaves filed into small surfaces like a roof so that at the top a space as big as a hair still remains, and so deep that ⅔ of the tooth is left and therefore only ⅓ is acted upon. The filing begins at the lower angle of the surface and the leaf is made pointed, curved or half round. When all teeth have been dealt with, another rounding up file is taken and the upright surfaces of the leaves filed so that the traces of the deepening file are removed, and then the same done for the curved surfaces. When this has been done, the pinion is examined to see if all

108 *Holztrieb*. Possibly meaning a *leaf* pinion in which case it would be equivalent to the English term “shaped like a bay leaf”. The basic “rule” adopted by Berthoud and Auch is that the teeth of wheels should be rounded like a thumb and the leaves of pinions should be pointed like a bay leaf.

leaves are equal, and if not the necessary alteration is made. The leaves should stand out from the arbor in a wedge shape and the upper part look like the section of a lens.

This pinion, which I have shown the apprentice how to make, is the center wheel pinion. The same method is used on all pinions that are driven by a wheel, only on the smaller ones the leaves are smaller. The method remains the same. Only on the motion work is the relationship reversed. Here the pinions must be rounded and the wheel teeth sharp. The main rule in a well made watch is: that which drives must be round and that which is driven must be sharp. This can be proved with the fingers. The fingers of the right hand are held on the wheel and the fingers of the left hand on the pinion which is driven while meshing. In this way one becomes aware that the pinion in the left hand must be pointed to allow a good meshing. I would gladly explain the mechanical implications mathematically if it were as easy with words as with drawings.

27: Hardening Pinions

When the piece has been prepared this far it is ready for hardening, which must be done well. The process is the same as for turning arbors but the blowpipe is used. The pinion is then cleaned with pumice powder softened with saliva, both on the center and the leaves until they become white. Then the pinion is laid on a blueing sheet and held over a flame until it becomes blue without giving it further time to get paler. It is then thrown into cold water or oil which makes it complete and gives it the right hardness. A ferrule is fastened at one end of the pinion and it is mounted in the turns to test it with a brass graver, to see if the hardening has distorted it. If this is the case the centering is restored by filing the points as previously mentioned. Then it only remains to polish the piece which is done in the following manner.

A piece of hornbeam, spindle-tree wood or other hard wood is cut triangular or wedge shaped, about 7 inches long including the handle. This is then dipped in powdered oilstone or emery mixed with thick oil. After the ferrule has been removed this wood is used like a deepening file until all scratches on the leaves have disappeared. After this the piece is cleaned with a brush and when it is clean it is polished with white chalk and alder wood.

For this, a new piece of wood is similarly cut and dipped in a little olive oil with rouge, tin ash or polishing chalk. This wood is pressed on the pinion as shown above and the piece polished again. When the wood is worn it is re-cut and dipped in the mixture again, and the teeth polished till the piece has a very fine finish. It is then cleaned with a brush or alder.

When polishing is complete the ferrule is replaced at the small end and the pinion is turned for the width of the thickness of the wheel and reduced in diameter about the thickness of a card for riveting the wheel on. The riveting is turned hollow to allow the riveting punch to operate. Many people turn the riveting when the pinion is still soft and not yet hardened, and cut the facets before the wheel is riveted in position. As the facets can be easily damaged by the riveting, it is better to rivet the wheel on first.

After the wheel is fixed, the rough parts are filed away in the turns with a pivot file and burnished with a sharp burnisher. And then the riveting is turned sharp and polished. At the distance of a horsehair from the riveting a groove is cut ready for forming the pivot. From the groove the long arbor is turned a little tapered so that a proportional extension is formed from the wheel, and then this extension is filed with a pivot file and polished as already shown. Then the ferrule is fixed to the long part that has been turned and the arbor is turned its full length from the pinion outwards to about half its diameter, and on the surface of the pinion a hollow is formed with a very sharp graver to the base of the leaves, so that they appear to rest on the hollow which, when the facets are polished, gives a very pleasant appearance.

28: Polishing the Surfaces or Facets of the Pinion

A small piece of sheet iron which has been softened by heat is used, one inch long and the thickness of two cards. It is smoothed on the faces with a medium coarse file and a hole is bored in the middle so that the arbor of the pinion goes through it, and this hole is smoothed with a broach. The surface is then filed smooth and the hole completely cleaned so that the pinion faces are not damaged by the remaining swarf.

When the pinion has been provided with a ferrule and the bow is in position, the end is put in a hollow runner held in the vice, and the facet polisher is held in the left hand by the first finger and thumb. The polisher is dipped in oil and emery and held against the face of the pinion with the arbor going through the hole. The bow is worked and care is taken that the corners remain sharp. When this has been done for a quarter or half a minute, the work is cleaned with wood, being careful that the bow does not come off the ferrule. When the facet is flat the action is repeated until a rim as thick as a hair remains at the root of the leaves.

It sometimes happens that the hollow is too deep and the surface of the polisher is hollowed out. When this is observed to happen the polisher should be filed flat again.

When the facets are well polished the pinion is cleaned, first with a brush and chalk and afterwards with rotten wood or elder pith, into which the pinion is pushed several times to remove all grit, as this damages the polish and makes scratches.

For polishing, another polisher is used with the hole somewhat bigger than that previously employed. This hole must be worked very smooth with a fine file so that the arbor has a little play, and thoroughly cleaned of swarf. It is then provided with a little rouge or tin ash moistened with a little olive oil, the pinion mounted as before and the end of the pinion polished. The pinion must remain flat on the polisher but not pressed too hard. It is then cleaned again and the polisher re-filed as necessary so the tips of the leaves are not rounded, as this makes the piece ugly.

To clean the face and ascertain if it is well polished, a small piece of bread or elder pith is taken in which the pinion is stuck, making sure that the bread or pith does not contain any particles of abrasive which would scratch the surface. This operation with the bread cleans the part where the bread touches, and one can see if there are any scratches. If so, the polishing is repeated until they are gone. There are also round and square polishers in which one can make several holes, but the sheet metal one mentioned is preferred on account of better balancing and control.

When the facets have been polished, the arbor is turned a little thinner, leaving a small ridge by the facets, and it is then smoothed and polished. This ridge protects the facets. Many turn the arbor smooth and polish it before doing the facets. Others, especially the English, smooth and polish the facets at the same time and do not turn the them hollow; this is, however, not easy to do without special preparation, but is to be preferred on account of its natural beauty and simplicity.

29: Concerning the Plan or Calibre of Watches

Now that the apprentice has learnt how to make several different parts, he must make the frame for the wheels, which he must properly understand.

The first thing to do is to design the layout or calibre. This is begun by making a cross on a square plate of brass about as thick as a piece of cardboard. When this cross has been centered, one point of a compass is set in the middle and a circle drawn of the size of the movement. It is better to make a movement 18 lignes in diameter for this is easier for a beginner than a smaller one, as the moving parts are larger and clearer and can be more easily designed.

When the line has been made the sheet metal is filed round it without, however, touching the line. Having done this another circle is drawn 2½ lignes smaller. This space is for the pillars which will be fixed to the larger plate, but their position cannot be determined until the requirements of the moving parts have been met so that their motion is not interrupted by the pillars. Another circle is then drawn in the middle as big as the hollow for the center wheel will be. This consists of more than ⅖ of the diameter of the movement. This circle then shows the correct size and place of the center wheel. A provisional point is made ½ ligne away from the center and the distance midway between this point and the edge of the plate is clearly marked as the position of the hole for the fusee, from which the circle for the fusee wheel is drawn. This circle must be at least ¾ ligne from the center point. In this way the fusee arbor is far enough from the center wheel to get a good meshing (Plate 11, fig. 1[109]).

After this operation the barrel is drawn, which must be as large as possible. One should, however, ensure that it does not go beyond the edge of the plate, for if this were so the barrel would rub as it rotated and the chain could easily come off.

The size or diameter of the barrel is indicated by two circles which stand half a ligne from each other. The smaller indicates the barrel drum around which the chain winds and the larger the chain protector. The size of the barrel is determined by the size of the fusee wheel; the measurement over the chain protector must be exactly the diameter of it.

To find the correct position for the barrel, the radius of the drum and of the fusee wheel are taken and put on a sheet of metal in a straight line. Then the compass is extended to the sum of the two measurements. One point of the compass is set on the fusee center and with the other a curve is struck from the edge of the plate to the edge of the center

109 Plate 11 shows my attempt to draw the calibre using Auch's instructions. I might note that I have not found an explanation of calibre drawing other than Auch's; it is a topic that is studiously ignored by all other writers that I have read. In Figure 1 I have presumed the *diameter* of the pillar circle is 2½ lignes smaller and its radius is 7¾ lignes. The radius of the center wheel *c* is 3.6 lignes and of the fusee wheel *f* 4 lignes.

wheel. Then one point of the compass is set in the center of the center wheel and the other extended to just beyond the fusee center. With this distance a scratch is made across the first curve which indicates the position of the barrel; a point is made and the size of the barrel marked. The smaller of the two circles is drawn first, and it should be noted that it is ⅓ ligne away from the circumference of the fusee wheel so that it does not interfere with the movement of that wheel or the center wheel and its pinion. By means of this circle the edge of the drum must stand about 1 ligne from the edge of the plate, for the very good reason that the chain must not be retarded by the case of the watch. When this circle has been drawn, the compass is opened another ½ ligne and the second circle drawn, which represents the position of the chain protector (Plate 11, fig. 2[110]).

Having placed these parts, one is in a position to work easily on the others. When the barrel is completely drawn, the drawing of the potence is done next. The compass is opened ¼ ligne more than for the chain protector and a quarter circle is struck from the barrel center, from a point about 2 lignes from the center of the movement to the edge of the plate. This line completely defines the position of the potence.

A point is made for the verge 1½ lignes forward of the quarter circle and 2½ lignes from the center point of the movement. Then a small square is laid on the point for the verge so that it covers the barrel and allows the point for the fusee to be seen. In such a way a straight line is drawn beginning 2 or 3 lignes from the edge of the calibre and going to 1½ lignes past the center. Then one edge of the square is put on the verge point so that it aligns with this line, and a straight line for the position of the escape wheel is drawn from this point to the edge of the calibre. Now the rule is laid over the barrel 2½ lignes from the first line and a scratch is made from the quarter circle as long as the first one. These lines form the body of the verge cock, which must be the same breadth all along. The constricted part is the neck of the cock, on the end of which is the nose which is 1½ lignes in diameter and indicates the position of the balance (Plate 11, fig. 3[111]).

The center point of the hollow for the third wheel is drawn 1½ lignes to the left of the fusee wheel. Its central point is the edge of the hollow for the center wheel. Its size must be ⅘ that of the center wheel (Plate 11, fig. 3[112]).

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110 The radius of the chain protector is 4 lignes and the drum of the barrel 3½ lignes. Using the radius of the drum would place the barrel too close to the fusee and I have used the radius of the chain protector, placing the center of the barrel 8 lignes from the center of the fusee. Placing the center of the barrel *just beyond the fusee center* (a little more than 4¾ lignes from the center of the movement) is vague and the position of the barrel is approximate..

111 The back of the potence follows the outside of the barrel *b*. The position of the verge *v* is defined by the intersection of two arcs, one from the center of the movement with a radius of 2½ lignes and the other from the center of the barrel with a radius of 4 (barrel) + ¼ (rear of potence) + 1½ = 5¾ lignes; but see note 128, page 153. However, the face of the potence can only be described when the positions of the verge (the balance arbor) and the escape wheel arbor are known; it must be perpendicular to the latter and surround the former. Consequently, Auch's instructions for the potence are obscure, because the position of the escape wheel arbor is unknown and his instructions allow the square to be placed in many, arbitrary positions.

112 The position of the third wheel *3* is defined by the intersection of two arcs, one from the center of the fusee with a radius of 5½ lignes and the other from the center of the movement with a radius of 3.6 lignes. However, this ignores the size of the pinion on the third wheel arbor, and so I have placed its center outside the circumference of the center wheel. Its radius is ⅘ of the center wheel, or about 2.9 lignes. In section 48 (page 146) Auch plants the third wheel using a depthing tool and the centers of the center and contrate wheels.

The wheel drawn in this way provides the means to find the position of the contrate wheel; its position is marked to the left of the third wheel when the calibre is held so that the hollow of the third wheel comes between the hollow for the center wheel and the edge of the calibre Then the approximate size of the pinion must be reckoned and a provisional point made with a compass on the left edge of the hollow of the center wheel where it is to be placed and can mesh with its pinion. The compass is then opened wide enough for the circumference of the contrate wheel, which is ⅐ smaller than the third wheel. One point of the compass is set 1½ lignes from the edge of the calibre and, with the other point, the provisional center of the contrate wheel is marked. If the measurements have been taken carefully, the wheel is in its correct place (Plate 11, fig. 4[113]).

The contrate wheel, whose placing is described above, must stand 1½ lignes from the edge of the plate for two reasons. The first is that the turned groove on the edge of the plate takes away ¼ of a ligne. The second is connected to the size of the top plate which is smaller than the bottom one, and the contrate wheel, if it stood nearer to the edge and stuck out too far, would be liable to be touched by the case and therefore could be damaged or destroyed. As a watch is frequently opened and closed, the wheel could catch on the case if one had not had the foresight to place it properly. It is therefore necessary to be very careful.

When the wheelwork has been set out, there still remains the space for the potence, the latch, the locking catch, the hinge and the four pillars. The pillar next to the contrate wheel must be ½ ligne nearer the center to get the movement in and out of the case. The top plate is displaced between the barrel and the fusee in relation to the bottom one for this reason and the fastening is diametrically opposite.

This *staggering* is explained as follows. Two pfennig pieces of different sizes are taken and the smaller one is set on top of the larger so that one side of them is level and the opposite side of the lower piece protrudes (see Plate 10, fig. 4); this is called staggering and is necessary for opening and shutting the movement in its case, because of the height of the pillars[114]. This displacement of the top plate is between the barrel and fusee, the natural place for the hinge of the movement whose catch comes diametrically opposite.

The pillars are placed in the following order. The first is put between the hollow for the third wheel and the edge of the fusee wheel and is about 1½ lignes distant. The second is 2½ lignes from the left side of the barrel, to facilitate placing the hinge and to leave enough room for the path of the chain. The third is 2 lignes to the right of the barrel edge; this distance is chosen so it cannot touch the chain. The 4th pillar stands ½ ligne inwards

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113 The radius of the contrate wheel is about 2½ lignes. If it is 1½ lignes from the edge of the plate its center must be 5 lignes from the center of the movement. So its position is dictated by an arc of radius 5 lignes from the center of the movement and an arc of radius greater than 2.9 lignes from the center of the third wheel (allowing for the pinion).

At this point the face of the potence is almost defined. Because the counter-potence is placed on the edge of the top plate, the escape wheel arbor cannot pass through the center of the contrate wheel (both arbors cannot occupy the same space) and so the escape wheel arbor must be put to one side or the other and its pinion has to act slightly eccentrically on the contrate wheel. So the face of the potence is almost (but not quite!) perpendicular to the line joining the verge and the contrate wheel center.

114 See footnote 15 (page 14) and Plate 10, fig. 6. Mounting the top plate eccentrically allows it to be larger, using the space near the hinge. However, although Auch suggests this there is nothing to indicate the top plate of his movement is offset.

from the circle because the space for opening makes this necessary, and also because a better place exists on the left side of the contrate wheel for the catch (Plate 11, fig. 5[115]).

When the calibre has been set out thus far and the points for the four pillars marked on the edge, the holes for the moving parts are bored with a pivot drill, and those for the pillars with a somewhat larger drill. When this has been done, the layout is ready for the reception of the moving parts.

30: The Wheelwork and Making the Plates

The frame is the first part of the calibre which is made. It consists of two plates of good pure brass whose purity is recognised by the way it fractures.

A square plate of this brass is taken about 2 lignes thick and 15 lignes in diameter to make an 18 ligne movement. After the roughness has been filed away, it is beaten with gentle strokes of a hammer until it has lost ⅓ to ½ of its thickness and is equally compressed.

This brass must be exceptionally pure. It must not acquire any cavities or cracks during hammering. If one is careless enough to allow cracks at the edge, the plate will break during gilding.

The center is found and a very small hole bored. With a compass a circle is drawn showing the size of the calibre, and the metal outside this line is removed with a file. The plate is then filed flat on one side with a fairly coarse file, so that it will hold to a layer of sealing wax. The turning arbor for plates is of hardened steel and has a diameter of 2 to 3 lignes and a length of 18 ligne[116] (Plate 5, fig. 20). At the rear is a sharp point and a large ferrule, and on the other end is fastened a disc, 2 lignes thick and about 1 inch in diameter, that has a conical female center. By means of the center the disc has been turned flat with a number of concentric circles on it for holding sealing wax. This disc is heated with a blowpipe from behind and about half a ligne thickness of sealing wax put on the face. The plate is held by means of tongs, heated and put onto the disc, which is reheated so that the plate can slide on the disc; the filed side goes against the disc. The plate is then put in the turns, first the ferrule end and then the point of a runner in the center hole of the plate. The bow is worked and a piece of wood pressed on the edge and face of the plate until it is centered. If the wax sets, the plate and the disc can be freshly heated while in the turns, and this continues until the plate runs true. This arbor is only used in the absence of a hollow spindle lathe; if one of these is to hand the cementing is easier[117].

When the plate has been centered, the hollow for the center wheel is made first, to the size marked on the calibre. The plate is hollowed to about half its thickness and a small lip is left in the center. The hollow should be slightly deeper at the outside so that the center wheel does not rub. It is then smoothed by a stone in the shape of a hook tool.

This done and the graver marks removed, the plate is given its correct size and the edge next to the dial made slightly sloping. Then the groove for shutting the case (*aa* Plate 1, fig. 4) is made ⅓ ligne wide and deep, and smoothed with a square stone; the sloping side

115 The positions of the pillars are approximate. Pillar *y* must be placed close to the barrel (2 lignes from the barrel drum) to leave space for the potence (see Plate 2, fig. 6).

116 *eine 18 zöllige Länge*, which seems wrong.

117 I assume this lathe is like that shown in Plate 10, fig 5.

is also smoothed. The plate is then removed from the arbor by a blow from a piece of wood and both surfaces filed with a very fine file.

The top plate is now made of good brass 1½ lignes thick. It is beaten until it has lost half a ligne in thickness. It is checked with a rule to see if it has been beaten evenly, the center point marked and the circle drawn. It is then centered on the cement arbor in the turns and turned flat. The size is limited by the groove in the pillar plate. It must be 2 to 3 card thicknesses smaller than the groove. When the front surface is turned flat and the diameter fixed, the rear side is turned and both surfaces filed flat with a fine file. Care must be taken not to damage the edge when filing.

After the plate is made flat, the center hole of the pillar plate and of the calibre are made alike, and they are riveted together so that the drawing is outwards and the calibre rests over the hollow. The two pieces must fasten firmly together, and when this is done the holes are bored for the pillars, and then those for the wheels and barrel. After everything has been marked the pillar holes are broached straight and the swarf filed off. The position of the hinge is marked between the barrel and fusee by a small cut (*h* Plate 11, fig. 5).

The two plates are then laid together and the top plate slid towards the cut for the hinge, so that the edge of the top plate is level with the groove or even projects a little. The top plate is then moved so that the sides of both plates are level and both pieces are clamped together in a hand vice. It is necessary to check that they are clamped exactly according to the instructions, and if not this is corrected by loosening the hand vice and moving the plate[118].

When this has been done, in order to hold them better, another hand vice is fixed at the opposite side so that the pillar holes are not covered. If the jaws of the vices are sharp, cards are put in to protect the brass.

A drill is then taken that fits the holes for the pillars already bored in the pillar plate and they are continued through the top plate. They are broached so that the pillar ends will not go completely through. If one has an uprighting tool (Plate 8, fig. 17) the holes for the barrel and fusee are made with an appropriate drill and the fine holes with a pivot drill. After this the hand vices are loosened and both plates filed to remove the swarf.

Many people lay the calibre on the dial side and draw the wheels there, as the lines can be more easily removed, but all in all it does not matter. For the beginner it is advantageous if he makes the drawing first on the frame; he thereby learns the position of the wheels easier, and especially the structure of the whole movement.

31: Making the Pillars

Pillars are made from brass plate 3 lignes thick, which is cut into strips 3½ lignes wide. They are beaten equally thick to about 2 lignes wide without cracks forming. These pieces, about 3 inches long, are cut in half by a saw . The best piece is hammered out completely and is filed, first octagonal and then round. A ferrule is fitted to one end; before this both ends must be filed flat and centered with a deep punch. The piece is then mounted in the turns with pointed runners, and with a weak bow the end turned circular to make a pillar

118 Although Auch *staggers* the top plate, there is nothing in his illustrations or later discussion to indicate this.

of suitable height for the case. The dimensions and shape are according to the taste of the craftsman. In my opinion 3 lignes high is the most suitable measurement.

The end of this pillar is reduced for 7 or 8 lignes to bring the diameter to 2 lignes, then a pivot is formed ¾ ligne thick and about 2 lignes long. The shoulder of the pillar must be quite flat so that it sits firmly on the plate.

The 5 or 6 lignes left over serve for the body of the pillar which should be at most 3 lignes long, whereby it must be observed that the body of the pillar on the side where it will be fixed to the pillar plate is ¼ ligne thicker, so it is a little tapered. Decoration can be applied as desired. The remainder serves for the pivot for the top plate, which differs from the other in that it is not more than 2 lignes long. However, the body of the pillar must be formed first and smoothed with a water stone, on account of the gilding to be applied later. This pivot is made smaller than the other, because it is not riveted but only meant to hold a pin. When the first pillar is made it serves as a model for the others that are made in the same way. They are measured with a pinion gauge.

When the pillars are ready, they are put on the pillar plate. A broach is used to enlarge the holes and each pillar is tried separately. The first comes between the third wheel and the fusee, the second between the fusee and the barrel, the third between the barrel and the potence, and the fourth between the potence and the contrate wheel. These pillars must stand firmly in their holes without too much play. So they do not get changed around they are marked with punch marks, the first with one etc., and the last need not be marked.

With the pillars set in the pillar plate, the top plate is then tried on them. They are first tested for height and any that are too long are modified in the turns. When all are alike they are riveted in, having countersunk the holes on the dial side to give extra firmness. The pivots on the pillars should not be too long but only project about ½ ligne before riveting.

The pillars are riveted with the top plate in position. A broad turning ferrule, which must be thicker than the pivot of the pillar projecting through the top plate and with a hole that allows a little play, is laid on an anvil in a vice. The frame is held with the first two fingers and thumb of the left hand so that the pillar plate is above, and one of the pillar ends is set in the ferrule. The other end of the pillar is beaten with the flat face of a hammer held in the right hand so that the pivot spreads and fills the hole and the riveting obtains its maximum firmness. If the pillar has been struck too hard the small end of the pivot can be heated with a blowpipe; in doing so, as already noted, it necessary that the pillar has the correct length before riveting.

With the pillars well riveted, the top plate should be inspected to see if the holes have become too narrow. If the pillars go in without interference the holes and the riveting are good. If not, the holes must be opened, but not so much that the pillars get too much freedom, which would allow movement. The frame is then re-assembled to see if the top plate goes on without pressure. If this is not so the edge of the plate is hit with a small wooden mallet all round, which sets the pillars straight.

The pillars can also be riveted another way, whereby there is less danger to the top plate and the holes. A piece of hard lead is fastened in a vice and the pillar end at the top plate rests on it; then the process is continued all round. It is better not to firmly fix the first pillar, but go only about half way, and then do the following ones, and continue round the circle until all are done.

The pillars have their proper amount of play when, by turning over the movement the top plate remains in position, but a small blow on the forearm of the hand holding the pillar plate should be sufficient to shake the top plate loose.

The holes for the moving parts are then made in the top plate corresponding to those in the pillar plate. For this an uprighting tool is used in the following way:

The tool consists of two tubes whose centers coincide and are fastened together by screws (Plate 8, fig. 17). The upper part has a curved piece and a rim which lays flat on the disc of the lower tube. Both tubes carry inside them a rod with a point, or a punch, which moves easily and goes in and out with little friction. Each of these rods is completely round as are the tubes themselves. The points must be so correctly placed that they must touch each other to within a hair's breadth when they are put together. With this tool the holes are marked on the top plate in the following way. The frame is set in the tool and the bottom point set in the desired hole of the pillar plate. The top plate is then put on it so that the frame lies firmly on the base, and with the other hand the top punch is pressed down and so makes a mark on the top plate. Then the holes are bored.

32: The Barrette

The hole for the third wheel is righted with a broach. On both sides a circle is drawn which shows the size of the hollow for this wheel. This wheel and the contrate wheel rest on a barrette, which is a brass bridge which covers the hole for the third wheel in the pillar plate and is held firm by two screws and two steady pins under the dial.

Before this hole is cut with a drill and a file, a drill about double the diameter of the contrate wheel pinion is used to make a hole in the pillar plate which is then broached out. A series of holes is then made in the circle about 1 ligne distant from each, and they are enlarged until they run into each other. This hole is first worked with a coarse and then a fine sage-leaf file, and the line must not be exceeded nor left untouched. This hole must be filed straight and square. It must be exactly round and not have any slope.

Having observed this, the file marks are filed away with another sage leaf file and the hole smoothed with water stone. If necessary this hole can be made with a fretsaw; if one is available only one hole is made and the circle sawn out.

Having made the hole, the barrette is placed on the dial side. One point of a compass is put on the center hole of the plate and the other put so that it embraces ⅓ of the hollow for the third wheel, and a line 3 lignes long is drawn on each side of the hole. Then the compass is extended until it reaches about 1 ligne from the outer edge of the hole and two more lines are drawn like the first. In this way the position of the barrette is marked. Screw holes are bored at both ends in the middle, in such a way that the hole for the contrate wheel pinion as well as the hole for the third wheel are a good half ligne away. Then a point is marked at each end for the steady pins, one ligne towards the edge from the screw hole, and their holes, which are smaller than the screw holes, are bored. The barrette is then fixed in position by a hand vice and the four holes bored through. One of these holes is cut with a tap (*taraud*) about size º8 in a screw plate.

The holes are first tapped in the plate. The holes for the steady pins are not touched until the barrette is in position and the holes can be bored concentrically.

The previously mentioned screw plate (*la filière*) has two or three holes of almost the same size. To make the tap, steel rod is first filed square so that it fits into the first of the three holes, and then it is screwed in. When the swarf has been filed away, the tap is inserted again to make the thread sharper and to get rid of the metal particles. The tap is then hardened and let down to a dark yellow; this is the usual practice so that its threads do not wear away in the holes. The next hole of the same number in the screw plate is a little smaller than the first, and it serves to cut the steel prepared for the screw, whose head is inset into the thickness of the barrette.

To make the barrette, a piece of brass is taken and cut in the form of a longish rectangle about 1½ lignes thick, and this is hammered about half a ligne thinner. When this piece of brass is 6 lignes more than the diameter of the hole which it has to cover it has the required thickness and size. It is then filed flat on both sides and left somewhat thicker than the top plate, because to begin with it must be somewhat longer, wider and thicker than it will be after it is finished.

A hole is now bored only as big as the screw itself. On the upper surface of the barrette this hole is countersunk either flat or conical so that the piece is not spoilt or disfigured. The screw is left on its stem while it remains unfinished, so that it can be easily removed and replaced. For this the edge of the plate and the barrette are gripped by screw tongs, after a piece of card has been placed between both so that no scratches are made on either piece. Then the second screw hole for the barrette is bored. This second hole must be equal to the first so that both can accept the same screw.

When these two screws have been made and the barrette fastened to the plate with them, the holes are drilled for the steady pins which are screwed in. The holes for these pins are drilled straight and only half as big as the screw holes, so that the pins can be screwed into the holes in the barrette and are suitable to provisionally hold the plate and the barrette together without using the screws made for it. These pins are cylindrical in form and are not firmly fixed so that the barrette can be easily taken away and replaced; however, they must not have any play in their holes. The ends of the pins must not project beyond the edge of the plate but come level with it. The ends are rounded and polished just as the ends of the screws are.

The width and length of the barrette are marked on the brass plate in the proper position by lightly scratching with a compass point. The barrette is given its form by a file so that the feet do not come too far from the edge. The foot on the winding square side must not interfere with the winding key and allow the winding square to be provided with a dust cup. This device prevents dirt from the winding key clogging the oil of the winding square. One should also take care that the other foot does not interfere with the catch or its spring. The holes for the pivots of the third wheel and the contrate wheel are then drilled in the barrette.

The hole for the center wheel makes it easy for the watchmaker to draw two half circles on the inner and outer edges of the barrette to form the bevel on it. This must be 2½ lignes wide, begin at the edge of one of the feet and continue at the same width to the other foot. The first of these semicircles is above the pivot hole of the contrate wheel; however, the second must be placed 2 lignes from the edge because this gives the work a better appearance[119]. The bevel forms a slope on the edge which must only be one quarter as thick

119 The German text refers indirectly to the contrate wheel which cannot be correct.

as the center of the barrette, to allow the dial to be placed on the plate. If the barrette has been made in the way described and is flat on top, it can now be considered finished.

33: The Fusee Cock

There are two sorts of these. One has the form of a broad comma with the tail to the left, whose form makes it easier to embrace the edge of the rosette (Plate 10, fig. 8). This support has a tube on the top which stands 2 lignes above the plate, in which the pivot of the fusee arbor is contained.

The second sort is a long rectangular brass plate (*d* in Plate 8, fig. 19). Its rounded head stands above the plate as in the first type. This second type, which is not inferior to the first, is easier to make. A light diametrical scratch is made from the edge of the top plate going through the center of the fusee pivot hole and the center of the top plate, and which is as long as the piece will be. On this line the places for the steady pin and screw are marked, noting that the screw and pin must be 1 ligne apart.

A point is made on the line that is one ligne from the fusee pivot and then a second point one ligne further along the marked line and finally a third point one ligne further still. The second of these 3 points is the screw hole and it is bored first, the same size as that for the barrette.

When drilling the three holes, the point must go right through to the opposite side of the hole, so that if a drill breaks it can be pushed back by its point, which serves to extract it where it went in. This operation is very necessary, for when it is neglected, the drill can be gripped too tightly and can easily break in the hole a second time.

When this hole has been bored from each side, a small hole is drilled for the steady pin 1 ligne away on the same marked line. A piece of brass is cut 6 lignes long and 3 lignes broad and thick. This piece is beaten with gentle strokes until it has lost one third of its thickness. It is hammered flat below, and in the middle of its breadth and length a point is made and the screw hole drilled there. Then the piece of brass is held in screw tongs, taking care that the hole must be one ligne away from the tongs, and a cut is made across the piece to one side of this hole. Then the whole length of the end is filed flat and half as thick, but so that this end does not go beyond the space for the screw, whose head is 1 ligne in diameter, and corresponds to the finished size of the piece. The head of the screw must be ⅓ ligne high, flat below and rounded on top. When the screw is finished, it is placed together with the piece on the plate and the steady pin added.

When this is done, the frame is assembled and mounted in the uprighting tool, which is held in the vice. A ring *a* (Plate 8, fig. 17) is placed on the platform of the tool and the frame is put on it. The upper point of the tool is pressed into the fusee pivot hole in the pillar plate, which centers the tool on the hole, but it is necessary to ensure that the frame is properly seated on the ring in the tool so that the point sits in the middle of the hole. The lower point is then used to make a mark on the fusee cock for the pivot hole.

This hole is drilled half as big as the finished size should be, and then opened with a broach, which is inserted from the side where the pivot enters, and made full size so that the pivot can be inserted. The piece is then mounted on a wax arbor in the turns and its head turned until it is about 2 lignes in diameter and a little wider at the top than the bottom, but otherwise equally thick. A small ledge is made at the foot of this head sloping towards the screw. This ledge gives the head of the cock more strength and the whole piece stability and a pleasing appearance. It is then smoothed with water stone. The head is then finished in the turns by cutting a deep groove in the center of the upper part; a very long pointed graver is used for this. The hollow is then broadened until the edge is as thick as a card, and it is polished with water stone. The piece is then loosened from its turning arbor and finished with a file.

The head of this piece must be as wide as the body on each side, and the screw hole must be kept in the middle of the piece when filing. The end at the edge of the plate can be ⅓ broader, but it must not overlap the edge of the plate and should be chamfered at the outer edge.

The body must be filed flat on its upper side until it is half a ligne thick and then smoothed. The screw and the steady pin must not come through the top plate but must be level with the surface and rounded and polished. The part is then finished and can be put in its place.

34: The Position of the Catch on the Plate

One ligne from the edge of the pillar plate on the pillar side, between the contrate wheel and the pillar that is set in, a small rectangle is made diametrically, about 3 lignes long and 1 broad (Plate 11, fig. 5[120]). Three points are then made in the length of this rectangle and must be placed so that the lines are not touched when drilling, which would otherwise spoil the movement of the catch. When the holes have been drilled they are filed with a rat tail file or cut with a fretsaw until they combine.

This slot, the place for the catch, is then filed and finished. It must not cross the outline of the rectangle but only touch it. The sides must be absolutely parallel and upright. The outer edge of the opening must be parallel with the edge of the plate, from which it is only one ligne away. This must also be the case when the catch itself is made.

On the dial side, a notch is made from the edge of the plate to the opening (Plate 10, fig. 10). This notch is one third of the thickness of the plate, and the notch and the opening must be of the same width. This exactness is necessary as it carries the push piece of the catch. The rest of the cut out portion serves to support the catch whose edge projects so that it does not easily come out of place. The inner edge on the dial side is chamfered so that the stem of the catch can more easily go into place, and it must only have enough play to move easily. The place for the catch is now complete.

35: The Catch itself

The necessary skill for making the catch can only be obtained through a lot of practice and industry. The catch is made of steel. If none is available, an old worn out bastard file about 2½ lignes thick is taken and let down in the fire. A piece 6 to 7 lignes long is cut off and fastened lengthwise in the vice so that 3 lignes stand out. This piece of 3 lignes is filed equally on both sides to the width of the push piece and the head of the catch; this thickness must be ¾ of a ligne (Plate 10, fig. 10). The hole in the plate must be 1 ligne broad and 3½ lignes long, and the other end is filed to this size for a distance of 2 lignes.

120 The positions of the catch *k* and the hinge *h* are vague; presumably it is a matter of convenience.

The piece is then taken from the vice and the push piece filed upright and sharp on both sides with a fine file so that the thick piece for the head appears to lean on the push piece. The filed portion is then held in the vice with a brass sheet protecting it, and the push piece is formed by filing about 2 lignes from the head to the brass protector, then the plate is filed about ½ ligne thick underneath, and this leaves 1½ lignes for the head.

The head is then filed, sloping on both sides so that it is almost pointed, sloping towards the push piece and rounded. Finally a groove is filed between the head and the push piece deeply enough for the catch to fit in the notch on the edge of the frame. At the back of the body of the catch so much is filed away that the end of body stands about ½ ligne above the rest and a slot for the catch spring is made, the latter holding the catch in the plate as it moves[121].

There are many sorts of catches. If one is used to one sort, it is easier to make that one. There are, however, those that are screwed together and are provided with a hook at the front on the push piece. These are easy to press but one should take care that the finger nail does not slip and bend the minute hand, which accident is often prevented by the usual push piece.

36: The Dial Spring

The spring for the catch is made separately (Plate 10, fig. 11). It is made of plate steel ⅓ ligne thick, but it is not shaped until the place and the length of the spring have been determined. To determine the size, one leg of a compass is put in the center hole of the pillar plate on the dial side, and the other leg is put ¼ ligne from the inside of the catch opening. The outer edge of the spring is then drawn to about 2 lignes from the barrel hole. The compass is then closed about 1½ lignes and a point marked about 5 lignes distant from the barrel hole which serves for the screw holding the spring. This hole is tapped and a countersunk screw prepared for it. Then the compass is opened again to mark the position of the spring.

A piece of plate steel is cut barely half a ligne wide, which will be sufficient for the spring. The piece is hammered flat and 6 lignes from the end a hole is bored. Two lignes from this hole, which is for the screw and must be in the center of the metal, a line is made the length of the spring. When this steel piece has been fastened to the plate by its screw, a curve is made with the compass to indicate the shape of the spring. The compass opening being reduced by ½ ligne, it will give the center of the spring, and a further reduction of ½ ligne shows the inner edge of the spring. The metal outside the lines is removed by a file. The file must not cross the lines and enough metal must be left to give the spring a pleasing form. For this reason the breadth of the spring is reduced gradually from the head downwards, and the outer end must be ½ ligne broad. The central portion, that reveals any bad work, serves as a guide to determine the size of the head of the spring, giving this end the shape of a broad comma. The screw is inserted in the broadest portion of this end.

The sides of the spring are filed with a fine file to remove all traces of previous filing. Then it is made flat above and below and the spring is put in place. The slot in which the end of

121 The catch in Plate 10, figs. 9 and 10, has a lip on the pillar side so that it can only be put in and removed from that side. As the dial side illustration fig. 9 shows, the end of the catch locks the catch spring between the catch and the plate and so keeps the catch in place.

the spring acts should not be higher than the finished height of the piece. This slot is made, as previously mentioned, below the catch plate so that the catch moves easily, and when it is pressed in the movement comes easily out of its case. If it moves too stiffly the catch is filed at the end of the spring until it is only as thick as a card and forms a small hook that presses on the end of the spring and catches under it. The push piece of the catch is then cut down level with the plate, leaving about ½ ligne for the foot of the hook which gives more firmness to the support for the spring. In this way the catch can be put in position and nothing more remains other than to give the end of the body the correct length and file enough from the push piece that it does not rub on the case lid when opening and shutting takes place. Lastly, the groove for the finger nail is filed. The piece is then hardened, let down to yellow, smoothed and polished in the following manner:

A burnisher is taken that fits the flat part of the catch and touched with slightly moistened, powdered oilstone or emery. The catch is held by the index finger and thumb, the head upwards and the end of the flat part forwards. A piece of cork is put in the vice to receive the latter. With the burnisher the upper portion of the flat part is smoothed so that all file marks are removed, and the head is smoothed on the inner side. Then the catch is laid on the cork at an angle so that the sides can be smoothed so that they are completely flat and free from file marks

This operation is also performed on the slope at the end of the flat portion, but the sides of the push piece and the lower side of the body are only lightly smoothed so as not to remove all file marks, in order that the catch does not have too much play, which one must be careful to avoid. Finally the push piece and the front of the head are smoothed until all file marks or irregularities are gone, taking care not to lose the shape of the piece. When the smoothing is finished, polishing can be undertaken.

This is done in the same way but with rouge or tin ash with oil, or polishing chalk with water which gives the best and finest polish. The polisher must be completely free of oilstone before the polishing mixture is applied; any grains left will spoil the polishing. The cork must also be changed so that no grains get picked up.

The catch spring is hardened as well as the catch itself, except that the spring is let down to blue instead of yellow. The narrow sides are then smoothed and the spring laid on a flat piece of cork and smoothed with a broad, flat burnisher or with a piece of frosted glass. Everything is then polished; a piece of writing paper is laid on the cork with the spring on top of it, and it is polished with the same glass, on which a little polishing mixture has been applied, until a fine surface is obtained. The catch and the spring are then put in the movement. The other steel parts are not polished until the whole watch is finished.

Now one moves to making the wheels.

The different wheels are forged, filed and turned as previously described. After the wheels are made according to their numbers and position, turned and filed flat, they are crossed out, as also already described. When the wheels are finished according to the calibre, the teeth are cut for the pinions on a wheel cutting machine; although the usual practice is to cut the teeth first and cross out afterwards. The wheels to be cut have an order which is determined by the number of teeth in the wheels and the leaves in the pinions. These ratios are:

The main wheel has 60 teeth, the center wheel also 60 and its pinion 10 leaves, the third wheel has 50, the contrate wheel 48 and the escape wheel 13. The pinions for the last three all have 6 leaves. The cannon pinion has 10, the minute wheel 30 teeth and its pinion 8 leaves, and the hour wheel has 32 teeth. The last has no pinion but a tube on which the hour hand is placed.

The pinions of the intermediate wheels, which are longer because of the barrette, are cut out of a piece of metal with a stem about 3 lignes long and 5⁄4 of a ligne for the pinion; these measurements are only approximate. From the pinion a small stem 1½ lignes long is formed. The pinion for the contrate wheel is cut 2½ lignes long, the long stem is 2½ and the small stem 1 ligne. The pinion for the escape wheel is 3½ lignes long, the short stem to the inner pivot is 1 ligne and the long stem is 5 lignes. These dimensions are only provisional and if necessary can be shortened when assembling.

If the pinion of the escape wheel is in the condition described in the paragraph on preparing pinions, it is hardened and the riveting turned about ⅓ of the length of the leaves. The inner pivot is turned first and the escape wheel tried to see if it fits well. Before the escape wheel is riveted in position it must be filed flat and equal on the under surface, the thickness of the bottom being about ¼ ligne. The wheel is then cleaned from filing both inside and out and on the crossings.

When this has been done a suitable stake is put in a vice and the pinion put in an appropriate hole. The underside of the pinion is protected by a very thin sheet of brass which sits on the stake and protects the pinion leaves. The leaves are then riveted over the wheel with a round punch and light hammer strokes until the wheel is firmly fixed and runs true. It is tested for the latter in a figure-8 calliper, in whose points tiny holes are made to receive the pivots (Plate 7, fig. 3). If it does not run true, the punch is put to the high side of the riveting and tapped again until the wheel is true. As soon as the high side has been found, a scarcely perceptible scratch is made on the rim of the wheel to mark the place and after re-riveting it can be tested again.

The stake has a length of two inches, a thickness of three to four lignes and an equal height (Plate 7, figs. 9 to 12). It is made about one ligne thinner on both sides so that the top part stands above the vice and the lower part is grasped between the jaws. It is filed lengthwise and the edges chamfered so that the upper face for riveting has a width of only two or three lignes. On the lower side eight or more holes are made along this section, quite upright and going so far in that only the thickness of a card remains un-bored for the small holes. In this remaining portion the first hole is bored with a drill having the thickness of the escape wheel arbor, the second somewhat larger and so on until the last is about 1 ligne in diameter. Then with a short broach the holes are made tapered, the small as well as the large. Without this the arbors would easily break. The piece is then hardened and let down nearly to yellow and the upper face is smoothed and polished.

37: Planting the Center Wheel

When the pinion has been properly prepared, hardened and polished, and it runs true, it is fitted with a ferrule on the long part for the cannon pinion, put in the turns and the short end that goes in the frame is turned about ⅓ thinner. It is finished with a file and a ferrule put on it and the larger end of the arbor is then turned to about ¾ of its thickness and finished by filing. The riveting section is then turned as long as the wheel is thick so that this either exceeds the distance by a hair or is quite equal, and deep enough to leave about ⅔ of the leaves. The riveting end of the pinion is then hollowed with a very sharp long pointed graver so that the projection is almost sharp. The wheel is then tried in place and riveted home so that it runs true. Should it not do so because the arbor has been bent during riveting, a little filing of the points is the safest method of correcting it.

An arbor can be freely corrected with a hammer. Often during the further processes of turning it may become crooked, and if it cannot be further turned this is the only method.

When the wheel runs true the ferrule is again put on the short end and the hollow is turned sharp and clean. An iron stem is then filed so that it fits in the hollow, and used to smooth the hollow with oilstone and afterwards to polish it with chalk. The riveting is then polished with a burnisher. When this is done properly throughout the whole stroke of the bow it has a pleasing appearance.

About half the thickness of a card away from this riveting, a somewhat deep groove is cut for the pivot and from there the whole arbor is made about ⅓ thinner. It is filed with a pivot file and the corner of the extension made sharp and true. Then a sharp sided burnisher is taken as usual and the extension is smoothed with oilstone dust, but it must be noted that when the filing is done a piece the size of a hair remains which should be removed completely with the burnisher. The burnisher is then filed sharp again with a fine file, some polishing material put on it and the bow is worked while the polisher is moved up and down and the metal receives its highest polish. This extension can also be polished by simply burnishing to save time. The finishing of the piece in this way prevents the lower part of the center wheel rubbing on its hollow in the plate; the cylindrical polished part of the arbor being the pivot of the longer part on which the wheel moves.

The hole in the center of the pillar plate is then enlarged, for it has been kept small up till now, so that the long arbor can go in and stand freely. The metal that has been pushed up at the edge of this hole is carefully removed so that the lower part of the arbor can rest on the edge of it. After this operation, the long arbor is marked with a small scratch on the side where the dial comes. This is the point where the cannon pinion must sit. The arbor is then made thinner for the cannon pinion to be put on, taking care that the mark is not passed. The arbor is then polished, which leaves it finished.

The long end of the arbor is then fitted with a ferrule, and the other end of the pinion hollowed out with a very sharp graver as far as the base of the leaves and then the faces are polished as before.

The smaller end is now reaching completion. Previously ⅓ of its thickness has been removed and now a further ⅓ is taken off leaving a little near the pinion facets so that the latter are not touched when the arbor is polished and thereby spoiled. When the arbor is cylindrical and smooth it is then polished. The facets of the pinion are masked with a piece of card to protect them.

The pivot is formed by taking a piece of brass like the height measurer by which the inside of the barrel was measured. When the distance between the plates has been determined, the pinion is again put in the turns and the measurement marked on the arbor. The pivot is turned according to the previous instructions and polished. The pinion is then ready to be put in the frame. The hole is enlarged for the pivot from the inside until the arbor stands straight and moves freely, and then the first of the moving parts is in its place.

38: Planting the Barrel

It is assumed that the barrel has been made the correct size for the watch. There must be a distance equal to the thickness of a card between each end of the barrel and the plates of the movement. On the lower part of the arbor a small mark is made about the thickness of a card from the bottom of the barrel. The arbor is made about ⅓ thinner along its length, and where the mark has been made a thicker portion is left which is smoothed and polished flat. The body of the arbor must be long enough to stand out 1½ lignes on the side of the plate next to the dial. This projecting piece is for forming a square, the reason for which will be given soon.

When this lower projection is finished, the finishing of the upper part is undertaken. The height is measured by means of a small compass called a *dancing master* which is named on account of its shape (Plate 7, fig. 6. See also Plate 10, fig. 2). It has two straight legs and two turned out feet which can be brought nearer to or further from each other. With this instrument the inside height of the frame is measured. The other end of the tool has the shape of a half circle from which the inner side of both legs shows the height that has been found.

To find this height, the feet of the dancing master are inserted and they are opened until they touch the inner side of each plate. The instrument is then taken and, without closing it, the height is measured with a pinion gauge, which must then be the same as the distance between the plates. One jaw of the pinion gauge is set on the thick portion of the arbor and the other end marked with a scratch. The pivots are then turned and the thick portion reduced to ⅔ after which it is smoothed and polished.

The barrel must stand upright in the frame. A cut is made on the arbor on the dial side to mark the base of the square; after it is smoothed and polished, this cut must stand beyond the surface of the plate by only the thickness of a piece of paper. The upper pivot is allowed to extend the thickness of a card and is rounded and polished in the hole of a polishing runner in the turns. After this one proceeds to the second mobile part.

39: The Fusee

The head of the fusee is a sort of tapered screw on which the chain of a watch passes when it is wound. This form has the function of equalising the strength of the spring, which has too much force when the chain is wound up and vice versa. This equalising is one of the most beautiful discoveries in horology because it ensures the regular going of the watch.

To make this part, a piece of square steel about 2 lignes across is taken, and it is filed tapered so that at one end it is about ⅓ thinner than at the other; then it is filed octagonal and each end given a point. The steel is hardened and let down to dark blue so that the square (*carré*), which should not be too hard, can be filed.

A piece of good brass is then filed somewhat thicker than the space between the plates, and it is beaten equally all over, but left a little thicker than the distance between the plates. A center is marked with a sharp point and a circle drawn about ⅙ less than the diameter of the fusee wheel, after which the center is bored through large enough to take the previously made steel arbor. The small end is inserted until it penetrates about half way, for it will then have more support; this is necessary to form a good square. When the steel is driven in, the points must be protected and for this a thick piece of brass is used to take the blows of the hammer until the steel is in its correct position.

A ferrule is then put on the long protruding end of the arbor, on which the square will be formed, and the piece set in the turns and provided with an appropriate bow. The brass is turned circular with the end surfaces upright, and then the arbor is provisionally reduced at its short end to about half its diameter. The ferrule is then removed from the long end and another one put on the short end so that the long end can be turned in the same way.

After the arbor has been rounded, a hollow 1½ lignes deep and 2 lignes in diameter is cut adjacent to the arbor. Then a hook tool is taken and a second hollow made, beginning 1 ligne from the edge of the first, ½ ligne deep and quite flat, which joins the previous hollow. The first hollow is for the boss of the wheel and the second for the ratchet. When this has been done, the arbor is smoothed with a pointed burnisher and finally polished for a little distance from the hollow. It is not necessary to go further for there is still some more turning to be done. The upper part of the brass portion is then turned until it has reached a diameter suitable for the wheel. After which the ferrule is again mounted on the longer end and the brass turned tapered with the narrow portion towards the shorter end of the steel. To do this, the diameter of the turned end is measured and the distance put on a piece of sheet brass or a card. This distance is then divided into five parts and an amount equal to three of these parts set on a calliper and the small end turned to this size. Then the graver is set ½ a ligne from the thick end of the brass and a curved hollow formed as far as the other end. The end ½ a ligne wide is to take the chain hook and the cutting of the groove is also begun there when the fusee is ready.

For the fusee wheel a piece of brass is taken about 2 lignes thick and beaten until it is about half this thickness, but left thicker in the middle for the boss. When the wheel has been beaten and is large enough, a circle is made a little larger than that drawn on the calibre so that it can be reduced to the correct size by turning. A small hole is then bored in the center; it must be small because if the drill wanders from the center the piece cannot be turned accurately. This small hole is then opened with a broach which is inserted from the side away from the central thick portion so that the latter can be turned easily. The turning arbor used must have a good relationship to the size of the piece and allow it to sit firmly to avoid errors in turning.

When it has been fixed on an arbor, the wheel is turned on its edge and both faces, and the central portion is turned to the height of ½ a ligne to be able to shape and flatten it. The remainder is left quite flat and the opposite side is turned equally flat so that the wheel is thinned about ½ a ligne. Finally the wheel is given its proper size, according to the calibre, and it is then ready for cutting.

When this has been done and the wheel has its proper number of teeth, a broach is inserted from the side with the boss to make it possible to insert a turning arbor and get a good fit. After this the wheel is set in the turns and a flat hollow made with a hook tool about 2¼ lignes in diameter and so deep that it removes ⅔ of the thickness of the wheel. This hollow is for holding the body of the fusee in place, and when it has been smoothed and polished there is nothing more to do but adjust the fusee itself.

To do this, firstly the hole in the wheel is enlarged until a half or at most ¾ of the long end of the arbor goes into it, then the wheel is placed on a *funnel arbor* (Plate 9, fig. 30). This differs from the previous type in that it is provided with a supporting plate in the center that is firmly fixed. Its arbor is perfectly upright and is threaded throughout its length and is the opposite to a normal turning arbor that has a left hand thread. This arbor has a funnel shaped boss on the thread which centralises the piece even if the hole is a trifle large. The piece is held by the funnel and a nut so that it cannot come loose during turning.

When the wheel has been fixed it is put in the turns to finish turning the central boss and smooth and polish the faces. If the hollow for the boss is about 2 lignes in diameter the tube must be 2¾ lignes in diameter so that the surface of the wheel has sufficient strength. The height of the boss is about ⅔ ligne and must be slightly arched; it is smoothed and polished.

When all the file marks have been removed from the piece, it is taken off the arbor and put on the fusee. If the wheel lies properly in place and has the required thickness, a mark is made on the fusee arbor ¼ ligne from the wheel to show where the pivot shoulder comes. If this arbor is 1½ lignes in diameter, it is reduced to about half from the mark, and then smoothed and polished. The hole in the pillar plate is now broached until the pivot goes in properly and then the end of the steel is filed with a fine file taking care not to file the plate. The hole is countersunk to the extent of a hair and the edge of the pivot blunted slightly; and then the fusee is again put in place to see if it fits firmly.

When that has been done, a mark is made on the dial side of the arbor, a card thickness from the plate, and a groove cut all round it to ensure that the winding square is the same on all sides. A piece of brass is then taken the thickness of the distance from the groove to the plate, and a hole is bored in it so that the arbor extension goes through it. The rough edges are filed from the hole and the brass is filed so thin that when it is put over the arbor the groove is scarcely visible. The short end of the arbor is then held in a hand vice so that it cannot turn during filing and the long end is laid on a filing block held in a vice and filed with the safe edge of the file against the piece of brass which has been placed on the arbor. All four sides of the square are filed using the hand vice as a guide, at first only about half of the flat surface, and by turning the hand vice through a quarter of a turn each time the four surfaces are finished and the corners made sharp. Care must be taken that the flattening of the surfaces occurs regularly so that one is not broader than another, and so produces a peg on which a key will not fit.

The piece is now put in the turns for finishing and the surfaces filed with a pivot file. The piece of brass is filed thinner so that the whole of the groove is visible. If desired it can now be dispensed with. A broad polisher is taken and the four faces smoothed with oilstone dust. The hand vice is then put on the arbor and the square is polished, after which the piece is provisionally ready. The wheel is put in place and the pivot in its hole in the pillar plate. The fusee cock is removed from the top plate and the hole in the top plate is enlarged until the pivot fits it. The top of the fusee must stand a good half ligne from the top plate.

To do this, a screw ferrule (Plate 10, fig. 7) is fitted on the square and the piece put in the turns and the arbor turned so that it is 5/4 lignes thick at the neck and at its base more than ¾ lignes[122]. It is then smoothed and polished. It is put in the frame to mark the position of the shoulder about a card thickness above the top plate. The screw ferrule is put back on the square to make the pivot and the rest of the arbor is turned cylindrical to ⅔ of its thickness; then the pivot is polished. If the pivot is too long it is turned so that the point still remains central. 2 lignes are allowed for this pivot to make the cutting of the spiral groove in the fusee engine easier. The fusee cock is then replaced on the top plate to finish the hole for the pivot. The fusee is put in the frame to see how much play should be given so as to allow no more than the thickness of a piece of paper when the top plate is firmly on its pillars. As previously mentioned there must be a space of half a ligne between the top of the fusee and the top plate for the fusee beak, and a little more so that the beak does not scrape on the plate.

40: Putting on the Fusee Beak

To make this piece a square is cut from a plate of steel ⅓ ligne thick and a little larger than the end of the fusee. It is hammered flat and centered by drawing diagonals, then a hole is made in the center and a circle drawn the same size as the end of the fusee. Three parts of the edge are then filed away up to this circle and the remaining part forms the beak to stop the fusee during winding. The sides of the piece are then filed with a smooth file until the piece is flat and the traces of the hammering have been removed. The edge of the circle is filed and the hole enlarged so that the piece can lie on the top of the fusee. A mark is then made midway between the edge of the plate and the center and a small hole bored, after which a corresponding hole is made in the top of the fusee. The hole is tapped with a No. 9 or No. 10 and the plate countersunk for the screw head. The screw is made and the plate fastened with it. If it lies parallel to the plate of the frame it is unscrewed once more, hardened, smoothed and polished.

41: The Fusee Click Spring

The spring is made out of well beaten brass (Plate 9, fig. 24 and Plate 3, fig. 7). It is drilled and made in the same way that one would make a third wheel and of such a size that it fits into the hollow of the fusee.

Having got this far, a hook tool is taken and a rim turned about ⅓ of a ligne wide, and the tool cuts through the disk so that the rim falls off as a ring. Then it is filed flat on both sides and the inner side filed with a sage leaf file. After that, the outside is filed narrower for ⅕ of its circumference to form the spring. Lastly a piece 2 lignes long is filed out of the ring on the end of the broad part where it joins the part for the spring. At this stage it is centered and held on the wheel with a hand vice, and the remaining ⅘ is divided into three parts, by means of punch marks that are made in the center of the ring, and three holes bored with a drill whose blade is ⅓ the width of the spring.

The spring is then, considered from the center of the wheel, placed with the broad part on the right and the narrow part on the left. The holes are then opened a little to take the riveting, then the spring is riveted to the wheel from both sides so that it holds fast. The riveting is then rubbed with water stone and the upper parts polished, after which the hole for the click is made.

122 This is the section of the arbor from the top plate to the fusee bridge.

42: Preparation of the Fusee Click

The click is like a little comma made of steel which has a pivot at its thick end which goes into the hole near the narrow end of the spring[123]. The hole is the thickness of a card away from the end. After the pivot has been made properly round, the length of the click is filed and the under side of the hole is countersunk. While the click is still on the main piece it is then riveted on so that it stands well on the surface of the wheel but does not rub it and has a free movement. The riveting is then filed with a pivot file and the click moved to and fro with the finger of the right hand. It is oiled and then moved again until it is capable of being moved by its spring. It is then cut from the main piece and filed flat so that it does not project above the surface of the spring.

Some people file the click from the main piece and finish it before riveting, but the work will not be as accurate as by the first method.

43: The Ratchet or Winding Wheel

After the inside of the hollow of the click spring has been measured for the size of this wheel, a piece of brass is beaten hard, a hole bored in it a little smaller than that in the fusee wheel and afterwards broached until it approaches that size and is a good fit on the arbor. A circle is scribed the size of the wheel and the it is filed to this circle and rounded in the turns. The sides are flattened and the wheel turned thin enough to fit in the hollow of the fusee wheel. After this the teeth are cut.

The number of teeth is not fixed and is determined by the diameter of the wheel. They must not be too deep, otherwise the click moves too far and causes vibration which makes the click spring weaken and can cause the wheel to become weak where the rivets go into the fusee, whereas this part must possess the maximum firmness. In the opposite instance, when the teeth are too numerous, the wheel is too weak and the click and its spring have too little to do. To take the middle course, 40 to 44 teeth are suitable for the size of the fusee.

When the wheel has been cut, the hole is enlarged and the wheel mounted on the fusee, taking care to get it the right way round so that the click can engage with the teeth correctly.

At a ¼ of a ligne from the base of the teeth, three punch marks are made to divide the wheel into three parts. The wheel is then mounted on its arbor and the three punch marks bored through, going about 1 ligne into the fusee. A brass pin is filed so that it will go into the hole, and made so long that about 1 ligne protrudes, after which it is hammered home and the other two holes dealt with in the same way. The fusee is then mounted in the turns and the wheel turned away in the center to make a hollow to take the thick part of the fusee wheel. The inner edge is made sloping and then the piece is ready to be assembled.

44: The Collet on the Fusee Arbor

This small piece of steel is a clamp which is fastened firmly to the fusee arbor at the place where the hollow in the wheel comes and allows the arbor to turn freely in the wheel.

123 Click wire, drawn in the correct shape like pinion wire, could be purchased, but perhaps after the time when Auch was writing.

A hole is bored in a flat piece of steel ¾ ligne thick which is eventually broached out until the end of the extended piece begins to enter it; that is, the lower part of the extended arbor on the underside where the wheel is placed. The steel plate is then fastened to a turning arbor and turned as large and as thick as the hollow in the wheel, in which it must stand upright and free. Then the face where the broach was inserted is turned flat and the opposite side made round. One should ensure that this rounding does not reach beyond the hollow. The turning tool marks are removed with a fine file and the sharp corners reduced. The piece is polished with a burnisher and let down to blue; it can also be hardened, then let down to blue and smoothed and polished for the best effect.

45: Remarks on the Fusee Engine and Wheel Cutting Engine

The fusee is cut with a tool expressly made for this work; a sort of chisel of which an assortment of various sizes and thicknesses is needed. However, it is usually only found in factories, because it is an exceptional case when a watch being repaired needs a new fusee, which may be only once in five years. This engine is expensive on account of its construction and needs a lot of study for its proper use.

The wheel cutting engine is also expensive and complicated, and it needs no less practice in its use. It is absolutely essential to a watchmaker and yet only a few possess one.

46: The Third Wheel

When the three foregoing moving parts have been made, the fourth, which is the third wheel, can be dealt with. When the preliminary work has been done on this piece, it is given its correct diameter and filed and smoothed flat before the pinion is riveted on. The pinion is No. 6, and has a long cylindrical part that is equally thick to the ends. A point is filed on this part.

To make the pinion, a piece of pinion wire of the correct size and number is held in the left hand and the end laid on a filing block, the right hand holding a slitting file which is used to form the long portion of the arbor, which must measure 4 lignes for the height of the frame. The unwanted leaves are then filed away so that the arbor is quite smooth, and then the body of the pinion is cut at least ⁵⁄₄ ligne long on the side of the small end of the arbor, so that it is long enough to take a ferrule on the pointed end. When the pinion has been centered and the ferrule mounted, it is placed in the turns and the small end is turned cylindrical, but of a diameter no smaller than the roots of the leaves, and the ends of the leaves are then turned upright so that the pinion is about four times as long as the wheel is thick. Then the pinion leaves are deepened from both the long and short ends using a suitably thick thinning file (Plate 6, fig. 1) that does not go to the base of the leaves, and then it is hardened and let down to blue.

The pinion is then put in the turns and tested with a brass graver to see which leaves touch and which do not. It is then removed, being careful not to rub away the marks. The ferrule on the pinion is taken in the left hand and the pinion laid on a steel anvil so that the hollow side is uppermost, and it is hit with the sharp side of a hammer along its entire length until it is straight. The pinion is then tested again in the turns with the brass graver.

The fact that a hard body like hardened steel can be straightened by a blow must be a surprise to many people. Only experience teaches us this. It also teaches us to remove the curves from a piece of steel without letting it down, like a graver that must always remain hard. To perform such an operation, the piece is held with both hands as near to the bend as possible and brought near a candle flame without heating it too much, so that one presses against the curved side during heating. The curve disappears and the steel becomes straight.

There is also another method to straighten pinions. The bent piece is laid on a brass anvil, the curve upwards, and it is beaten with the sharp end of a hammer. With this method however, the piece is often broken if one is not careful. If the pinions are not of their proper hardness they are useless.

If the pinion is now properly straight and smooth, the leaves are smoothed and polished, and the rest of the arbor turned cylindrical and smoothed and polished in its turn. The riveting portion is turned at the end of the pinion next to the small end of the arbor and is the same thickness as the wheel.

The wheel is then riveted on its pinion in the same way as previously described, ensuring that the pinion is hollowed at each end. The wheel is turned slightly hollow and the riveting turned to give it a pleasing finish. The first is done with a sharp graver and the second with a hook tool specially made for the purpose. The hollow in the wheel is turned so that the pinion is not spoilt during the smoothing and polishing process.

At this stage a ferrule is set on the shorter end and the longer end reduced to about ¾ of its thickness. At the same time a scarcely perceptible groove is turned at the end of the pinion as on the center wheel. The arbor is then smoothed and the pinion end polished. A piece of paper protects the pinion end while the parallel portion of the arbor is also polished. A ferrule is then put on the longer end and the riveting is turned hollow and the small end made about ¼ thinner. The rivet is smoothed and then polished with a pivot file. About the thickness of a card from the wheel a scratch is turned to mark the position of the pivot. This is made about ⅓ of the diameter of the arbor and it is polished in a special pivot runner. The face of the arbor beside the pivot is polished with the flat of a graver or a burnisher, the swarf removed and the pivot left about 1½ times as long as it is thick. The end is rounded in a brass runner and polished so that it does not scratch the thumb nail. The length of the arbor is then measured by taking the distance between the plates by means of a dancing master. This is transferred to callipers and measured on the arbor, a light scratch being made to show where the other pivot is to come. The pivot is then made as previously described. Usually the lower pivot is made thicker than the upper one, mainly because there is greater pressure there, but generally speaking it does not matter whether the upper pivot is as thick as the lower one provided that the lower one has the proper size relative to the pressure. Many people believe they are correct when they make the pivots thinner than usual, but they are wrong, for I have often observed that when the key slips the lower third wheel pivot, and often the contrate wheel pivot as well, will break. Such watches are like an elephant with the feet of a deer. Very fine pivots on the other arbors, the escape wheel excepted, are not to be recommended. They cut the holes too much and make the going of the watch irregular. On the other hand, a pivot that is correctly sized according to its load and correctly rounded and polished not only performs better, but when it is hardened it lasts longer.

47: The Contrate Wheel Pinion

The body of this pinion must be longer than the previous one as its wheel comes in the center of the frame. The rim of this wheel should only be ⅕ as broad as the width between the plates so that it looks better. The body of the pinion is cut to a length of ⅗ of the empty space so the mass can be reduced by half. After a proper length has been cut from the pinion wire it is filed as before, except that the longer end is not as long as on the previous pinion and the shorter end has the same length. This time the riveting of the pinion is made on the longer end.

The pinion is made in the same way as before. The wheel should have been previously crossed out, had its teeth cut and be smoothed inside with water stone so that it is ready for riveting. This is done as before, and the pivots can be made and the piece tried in the frame after having measured the space as previously.

A pinion ferrule, which has a larger hole than that for turning an arbor, is then placed on the pinion and the arbor is turned smooth and the riveting flat, and the latter is smoothed and polished. The brass boss in the center of the wheel is also turned and polished. The short end of the arbor is made round and a slight hollow turned in the pinion, the ends of which are then polished. A slight groove is then made the thickness of a card from the face of the pinion and the pivot turned and finished in the appropriate manner. The height of the pinion is then marked on the arbor and the pivot made on the other end. The part is now ready for assembling.

To test the depthing, 4 or 5 teeth are rounded by hand. A mark is made on the top plate at such a distance from the edge that the rim of the contrate wheel is only a card's thickness from it, and near the line for the escape wheel that has already been drawn, so that the arbors of the contrate wheel and escape wheel do not interfere with each other. The hole is then bored straight with a pivot drill that is smaller than the pivot of the contrate wheel arbor. This hole is then broached until pivot fits without play. The bottom hole is located with the aid of an uprighting tool, and after it is drilled the wheel can be inserted.

48: The Depthing Tool

This tool is most useful for the craft, but it is useless unless it is carefully made. It resembles two sets of turns hinged together and carries runners with sharp points on the outer ends, for marking the plate, and hollows on the inner ends for receiving the pivots (Plate 8, fig. 16). The distance apart of the two halves is controlled by a screw and a spring, so that once a distance has been set it is not accidentally altered. The tool is used by opening it wider than necessary for the correct meshing.

The contrate wheel and the third wheel are inserted, each between a pair of runners, and the halves of the tool screwed together until the few teeth cut on the third wheel engage with the contrate wheel pinion. If the teeth drive the pinion properly, the arbor of the contrate wheel is gently turned with a piece of wood to see if meshing is also good from that direction. If a tooth of the wheel falls back as it leaves the pinion, this is a sign that the arbors are too close, and if the teeth jam against the leaves the arbors are too far apart.

When using the depth tool, care must be taken not to screw the two halves together too violently, for the pivots can be easily bent or broken. When the correct depth or distance between the arbors has been found, the contrate wheel is removed from the tool, one point is inserted in the hole in the plate for the contrate wheel pivot and a very slight scratch about 2 lignes long made with the other point. The tool must be held at right angles to the plate. The center wheel is then put in the tool and the depth between this and the third wheel found. One point of the tool is then set in the center hole and another scratch made crossing the first. This is the point where the hole should be, and it is drilled and bored out until the pivot fits it. The opposite hole is then located with an uprighting tool and that hole bored out and cleaned. If the arbors are too long so that they do not have enough play between the plates, the pivots can be turned back slightly, or the plates can be sunk a little on the inner side. If the arbors are too short, there is nothing for it but to make new ones. It is therefore important to measure the arbors correctly and turn them carefully.

49: The Potence and its Accessories

This piece which is found in the center of the movement is a thick piece of metal with two steady pins which are set in two holes in the top plate so that there is no play. It is also held by means of a screw. The end is cut away to allow the free movement of the barrel and the chain. At the end of the head on the under side is a plate which carries the pivot hole for the lower end of the verge (see Plate 3, figs. 9 and 10, and Plate 6, fig 2).

The potence must also have a small steel plate known as the *boot*, which is the same size as the potence and is fastened by a screw.

In the side of the potence is an oblong groove (*coulisse*), half the width of the potence. This holds the *potence slide* (*lardon*) which has at its end a small boss or *nose* to take the pivot of the escape wheel and ensure it comes opposite the verge.

This potence slide is secured to the body of the potence by a flat screw through a slot in the slide, and a screw in the end of the potence moves it backwards or forwards so that it is adjustable. The slot in which the slide works must permit a side to side motion but allow no vertical play. The screw that moves the slide has a broad head which is flat on top and bottom and fits in a groove in the slide. It is called the *nut screw* or *potence key* and its hole must be bored diametrically.

The potence is marked out by taking the radius of the barrel from the calibre with a compass, increasing the opening slightly and marking on the inner side of the top plate, using the barrel arbor hole as center, a quarter circle reaching from within 3 lignes of the center hole to the edge of the plate.

By means of this arc the potence can be drawn with a pleasing shape, and the place for the screw found, which must be in its center; also the steady pins which are placed in the middle lengthwise and on the barrel side, and should not interfere with the potence key.

In order to complete the design, one uses a small square, which is put on the inside of the top plate, in the direction of the slide and the escape wheel, the third side leaving it uncovered. By these lines one can give to the potence a beautiful proportion and form.

One side of the square is set on the verge hole so that the line goes straight between the two pillars one of which is next to the barrel and the other next to the barrette but slightly nearer to the latter. In this way the hole in the center of the plate remains visible and facilitates the drawing of the side of the potence next to the center. The line begins by the center hole and runs to a distance of 2½ lignes from the edge of the plate between the two previously mentioned pillars. When the line has been drawn a parallel line is made somewhat shorter 2½ lignes nearer the barrel. This line goes from the edge of the curve previously marked and parallel to it up to a distance of 2½ lignes from the edge of the plate. This completes the drawing of the body of this piece and makes it easier to set the screw which holds it to the plate in its center. It also helps the location of the feet which are marked in the drawing with a chisel shaped punch and also the screw hole which must be made taking into account the position of the slide and the potence key[124].

When the body of the potence has been drawn in this way, the center point and the direction of the escape wheel arbor are ascertained and the hole for the verge bored as will be described below.

For this purpose the square is laid on the side where the verge hole mark comes so that one end of it passes through the hole for the barrel and the other passes the hole for the contrate wheel at about 1½ lignes distance. A mark is then made from the hole for the verge nearly to the edge of the plate[125].

This mark represents the escape wheel arbor and one end of it shows the position of the center of the counter-potence.

This point is then drilled through the top plate the same size as the center hole of the pillar plate. This hole is one of the most important parts of the watch because it is the center of the escapement, and one works from the center of this hole. This hole is also the central point for the design of the slide parts and their adjustment, the top of the potence and the bar in which the verge pivot runs. The foot of the potence is then filed, and the counter-potence and the escape wheel mounted according to the scratch.

The hole for the screw which holds the potence to the plate must be quite large as the screw has to withstand a large force. The top of the hole is chamfered and the screw is countersunk so that it does not stand above the surface. Then the previously marked points for the holes for the steady pins are drilled, but much smaller than the screw hole. A piece of good brass is taken of the correct size and beaten until it is flat and even, and is as

124 The above is illogical because any number of sets of lines satisfy the conditions. A square cannot be put in *the direction of the slide and the escape wheel* because these directions are unknown.

125 First, to have the escape wheel arbor 1½ lignes from the center of the contrate wheel is far too great a distance; ideally they should be super-imposed (see note 113, page 127) and, as this is not possible, the eccentricity should be kept to a minimum. In Plate 10, fig. 12 Le Roy has gone as far as reducing the diameters of the two arbors where they pass in order to get the escape wheel as close as possible to its correct position. In Plate 11, fig. 6 I have moved the escape wheel arbor to about ¼ ligne away and the small arc indicates the 1½ ligne position suggested by Auch.

Second, no matter how the potence is drawn its face (and hence the slide) *must* be perpendicular to the escape wheel arbor, and the line of the escape wheel arbor *must* pass through the verge *v*. Whether these two lines pass through any other point (such as the barrel arbor) is more luck than design. So, having fixed the direction of the escape wheel arbor the face of the potence is defined. Of course, all this depends on how the point on the plate for the verge is chosen, which Auch has defined without explanation. If *v* moves, so does the potence.

thick as the distance between the plates. It is given slightly more than the correct height, length and breadth according to the drawing, so it can be finished to the correct size. A hole is made in the center somewhat smaller than the screw so it can be worked later. Both surfaces are filed flat and it is fixed to the plate in the proper position. One of the holes for the steady pins is bored with a small drill, and it is fixed before the other is dealt with. When both are done there should be no play or it will affect the going of the watch.

When this piece is fastened to the plate, a line is drawn with a compass, one leg of which has been moved to allow for the unequal height, to mark the curve of the back. The uprighting tool is used to plant the hole for the verge pivot, through the hole that has already been bored. The potence is filed flat and superfluous metal removed from it except from the part where the verge pivot comes, which is not dealt with until all surfaces of the potence have been filed flat. The bottom of this piece, not including its plate, must stand ¼ ligne away from the pillar plate because the size of the plate is the thickness of a card and the bottom part of the potence would rub against the center wheel. One should always try and avoid such interference of parts.

When the potence has been given the correct height, the end where the top-plate center-hole comes is filed to give plenty of clearance. The foot of the potence is then given its correct form, after it has been temporarily fixed in place. This is done by filing away ¾ of it on the side of the center hole, which should clear of the verge pivot hole. The remaining quarter in the form of a block serves for the hole opposite the verge.

A point is made in the middle of the square outer end of the potence for the hole for the potence key. This screw must not stand above the surface so that it does not rub on the plate. This screw must be strong, and straight and flat underneath, and its hole must be bored deep and straight.

The groove for the potence slide (the nose) is marked with a line, which must be nearer to the top plate. Its breadth is about ⅖ of that of the cock. The cut is first made with a screw-head or slitting file and must be equally broad and deep all along, and provisionally ¼ ligne deep. The slot is broadened with a thick sage leaf file without making it deeper, which is done with a thinning file[126]. When finished it must be equally broad and deep throughout its length and the sides must be straight.

50: The Potence Nose

This piece is made from good brass and must be beaten hard and filed flat on the lower side. It must fill the slot for its whole length and at the inner end it is made larger to form the nose, the support for the escape wheel. The body of the potence slide is as long as the face of the potence and is filed flush and square to it, and must not be higher or deeper. The outer end, which on this piece reaches to the edge of the plate, must also have a small thickening, not only for strength but also for the screw to grip it.

The screw which holds the potence slide fast is in the middle of the sliding part between the nose and the rear end of the potence.

126 *Grundirfeile*. I presume a thinning file (Plate 6, fig. 1) and I use this name throughout.

51: The Plate or Boot of the Potence

This piece is made out of a thin steel plate purchased already prepared. A strip is cut, drilled in the middle and hammered flat. A screw is placed in the hole which fixes it to the body of the potence and the outline is drawn on the steel with a very fine, hardened steel point. The plate is then removed and the edges cleaned without touching the line, and it is replaced to see if it is a good fit. It is then smoothed on both sides with a file, hardened and let down to a straw colour, while the screw is let down to blue. The plate is then polished.

52: Making the Counter-potence

This piece supports the other pivot of the escape wheel arbor and is on the edge of the top plate. The inside of its head is square and faces the verge pallets. The head sits in a square hole in the plate, 3 lignes wide and 2 lignes deep from the edge (*b* Plate 8, fig. 18, *fgh* Plate 8, fig. 19, Plate 10, fig. 12, and Plate 12, fig. 1). A line is scratched on the plate showing the position of the escape wheel arbor and it must be followed in setting out the piece. A wing of the body of the counter-potence extends beyond the hole above the plate and along the edge towards the fusee.

The counter-potence is made from a piece of brass 10 lignes long and 5 broad and thick, which is then well hammered. Then about 4 lignes of one end is fastened in screw tongs and the rest filed to about ½ a ligne thick for the wing, which is only a provisional size.

The piece is removed from the tongs and then it is viewed from the side of the head which faces the verge pallets. If the body of the counter-potence is set from the side facing the verge, then a square flat of 1 ligne is made in the front part of the head by filing from the side of the body, opposite the screw, leaving an edge of the thickness of a card. The other side is then filed, from where the escape wheel pivot comes in the direction of the wing that has already been filed, for about ¾ ligne, without touching the bottom of the wing which sits on the plate; no cut should be made which would spoil the whole piece.

When the piece has been worked this far from the rough and filed flat underneath, it can be set with its head in the hole in the plate. However, before this is done a hole is drilled in the wing 1½ lignes from the body of the counter-potence to take the screw for fastening it.

The head is then set square and upright in the hole and the wing should lie firmly against the plate. The pieces are held together by pliers without permitting them to move and the hole for the screw is drilled in the plate straight through from the hole previously drilled in the counter-potence. The screw is put in place and if the piece is a good fit a point is made 3½ lignes from the screw and 1½ lignes from the edge of the plate next to the end of the counter-potence and a small hole made through both pieces. This hole is for the steady pin.

When the piece is in position, a scratch is made on the upper portion near the edge of the plate to indicate where unwanted metal is to be filed away, so that it does not interfere with the shutting of the case. The upper part tapers away to make closing easier.

After this the piece is given its correct shape, and then small holes are bored through the brass plate of the counter-potence opposite the thickness of the edge of the top plate. One serves to take the screw which holds the steel plate firm and the other is for the adjustment screw to make the escape wheel deeper or shallower in the verge; in other words, for adjusting the escapement[127].

The steel plate which is fixed to it is made like the face on which it must rest. After it has been adjusted it is hardened, let down to straw colour and screwed in place.

53: The Chain Guard

The chain guard stud (Plate 8, fig. 18, *fgh*) can be made by two methods the first being easier. A piece of brass is beaten about equal to the form of a pillar but somewhat stronger, until its thickness is reduced to two lignes. A pivot is then turned on one end about one ligne thick and a little longer than the thickness of the plate, leaving a sharp corner. The body of this pillar must be cylindrical, 2 lignes long and 2 lignes in diameter. It is riveted in a hole in the top plate which is drilled between the winding arbor and the place for the hinge, and 1½ lignes from the edge. Then a cut is made in the head, firstly with a slitting file and afterwards with a thinning file, being about the thickness of a card and to within ¼ ligne of the plate, running vertically downwards. This is for the stop piece. This cut is centrally in the stud which is placed about 3 lignes from the winding hole towards the barrel.

The second sort, fixed with a screw, is more elegant. It is made like a tiny cock inside the plate but the head has a different form. It is fixed by a screw in the middle of the body in the same way as the counter-potence for the escape wheel, and the slot made afterwards.

54: The Stop Piece

The piece is made from good steel so that its body, which is thin, can have more resistance to the strain to which it is subjected. The steel is let down and a rod 5 to 6 lignes long, 1 ligne thick and a little broader is cut from it.

It is set in sliding tongs so that about 2 lignes project. It is filed on both sides equally so that it fits into the slot in the fusee stopwork stud. It is then pulled a little further out of the tongs in order to file the head so that the piece can lay comfortably against the plate when the head is in the slot. A small groove is made on the lower side to hold the end of the spring that moves the piece, which is now 3 to 4 lignes long ½ ligne broad and ¾ ligne thick. It is half round above and flat below, and is strengthened on top at the neck by a sloping rim which prevents the piece from being too weak as a result of the slot for the spring. The flattened part is set in the slot of the fusee stopwork stud so that it can move freely and the rim is upward. A hole is then drilled crosswise through the stud and the stop piece, which is held firmly against the plate and the pillar. When this hole has been made with a drill about the thickness of a fine needle, the inner sides of the slot are smoothed and a rivet is inserted which has been polished; the hole in the stop piece must be slightly larger than the hole in the pillar so it can rise and fall easily. The head of the stop piece is filed level with the stud.

127 This screw butts against the edge of the top plate.

55: The Spring for the Chain Guard

This steel spring (Plate 8 fig. 18, *h*) which sets the stop piece in motion should not be too strong, but strong enough to carry out its function. It reaches from the fusee stopwork stud to the pillar hole which is near the verge, but it should not touch these parts. The screw hole is bored in the top plate near the pillar hole and 1½ lignes from the edge. The other end of the spring surrounds the fusee stopwork stud in order to hold down the stop piece when it is not needed. For half of its length it is reduced to half its thickness on the underside opposite the plate to make it more flexible, so that the chain is not pressed too strongly downwards on the fusee.

It is made from a piece of flat steel of the correct length, ½ or ¼ ligne thick and 2 to 3 lignes wide. A hole is bored at one end of this piece of steel and this must fit freely around the fusee stopwork stud. By means of the screw hole already bored in the plate the position of the hole in the spring is marked, drilled and the screw is then inserted and the spring is fastened to the plate. With a sharp tool the edge of the plate is marked on the steel without damaging the plate and then the spring is removed, the superfluous metal filed away and the side filed flat for the whole length.

The edge being prepared, we are now in the position to file the inner side of the spring according to the hole for the stud and the position of the stop piece. The thickness is reduced for half the length on the plate side to make the spring more flexible as mentioned above. The spring is then filed flat, hardened, let down to blue, polished and put in place.

56: Drawing the Balance Cock, Slide and Rosette

The balance cock must be of the correct size to suit the watch and therefore it is given an average size in this design for two reasons: Firstly, because a balance too large must be too thin and subject to variations when the watch is carried. And secondly, because when the balance is too small it needs to be heavy, which may be too much for the verge pivots. When the cock is a little low it can interfere with the balance, or the balance may be interfered with by the slide on account of lack of room and be prone to stop. A cock too high means a thicker case which is not pleasant for the owner.

57: The Size of the Balance

In order to determine the size of the balance and its cock, the number of swings it has to make in an hour is taken into consideration. The more swings it makes the smaller it must be and vice versa. This is important because the correct going of the watch depends on it. The size of the balance is determined by the theory of the pendulum. For example, a pendulum of 36 inches 8⅗ lignes makes 3600 swings in an hour. In order to double the swings the pendulum must be shortened by ¾ to a length of 9 inches 2 lignes so that it makes 7200 swings in an hour.

If a pendulum is required that makes 16200 swings in an hour, the number which roughly corresponds to that of a pocket watch, a pendulum must have a length of 22 lignes, These 22 lignes halved give 11 lignes, which is the diameter of a balance that has 16200 vibrations when the frame is 3 lignes high over the pillars and the plates are 18 lignes diameter. As this size and thickness is not to everyone's taste, smaller watches have been produced that also give good service. One must, as the force available is only about ⅓, increase the number of vibrations from 16200 to 17000 and reduce the diameter of the balance to about 7 lignes, because a larger balance and cock do not fit a small watch. On account of the light driving force, mathematics and mechanics have to be ignored.

A watch with 17800 vibrations requires a balance of 9 lignes and one of 17333⅓ needs at most 7½ lignes. A lady's watch of normal size is given a balance of 5 to at most 6 lignes; which requires calculating the train for 21600 vibrations. I have only so far given the basics for the apprentice on how to make a verge watch but will now continue to broaden his knowledge.

According to the foregoing, and because of the height of the work and the weak pressure of the mainspring, the balance is given a diameter of about 7 to 7½ lignes. I ought now to deal with how a small watch can be made as equally as good as a large one following mathematical and mechanical principles if I had not already interrupted the work already in hand for too long. Also the pupil can be easily led astray this way.

The diameter of the balance cock is lightly drawn on the top plate according to the size of the balance, being made about ¼ ligne larger. The circle is drawn using the center of the verge hole which is also used for the circle of the slide. When the circle has been drawn its diameter is shown by a straight line which extends about 1½ lignes beyond the circle. One ligne from the circle a point is made on this line to show the screw hole for one of the feet.

The line must go from a determined point, from the hole for the pillar that stands between the potence and the barrel, so that the extension for the foot on this side comes more on the side of the potence and the opposite one comes between the counter-potence and the fusee. This placing ensures that the setting disc, called the rosette, is not in the way of this line, and the square for the hand on the rosette comes opposite the middle point at the end of the coqueret.[128]

The coqueret or balance cock end-piece is a small brass plate which is covered by a small steel plate similar to itself, which is fastened in the center of the balance cock and forms an upward extension of it. The compass is set 2 lignes smaller than the previous circle, and a half circle made which indicates the limits of the slide[129]. The center of the rosette is indicated by a punch mark about 2 lignes from the edge of the circle, the rosette area drawn, and a line drawn from the outer edge of the line for the slide shows the position for the screw holes holding the rosette. These must not come in the hollow of the rosette or touch the hole for the barrel arbor.

128 See Plate 12, fig. 3. The maximum size of the balance depends on how far the verge is from the center of the movement. Berthoud states that it should be as near to the center of the movement as possible (Art. 2389), but it must be somewhat further away than the radius of the center wheel pinion, allowing space for the potence foot. A balance of 11 lignes is impossible with Auch's calibre where the verge is 2½ lignes from the center (see note 111, page 126). Further there are clearly errors in the text and a balance for a 17333⅓ train is presumably 9½ lignes. If we compare the drawings of Berthoud and Auch with the Le Roy watch, both Berthoud and Le Roy place the verge about 1.8 lignes from the center, whereas Auch's drawing places it only 1.2 lignes away, contradicting the text. Both Auch and Le Roy have a cock diameter of about 9.7 lignes, suiting a balance of 9.5 lignes. In contrast Berthoud's cock is 10.9 lignes for a 10 ligne balance (Art. 2377, page 12).

129 Ambiguous. I assume the diameter is 2 lignes smaller, 7¾ lignes.

The edge of the rosette is drawn from the point which indicates its pivot and going to the outer edges of the slide. Then a second line is made like the first but 1 ligne less in diameter on which the positions for the two screw holes are made, which lie on a third line drawn so that each of its ends is an equal distance from the outer edge of the slide[130].

58: Placing the Slide

Before the superfluous metal is removed from the center, the edge is filed flat all round with the exception of the corners, which are left thicker as they are needed for the feet. The edge has to be filed exactly to the line that must be drawn after the piece has been filed flat. The two screw holes must be bored as straight as possible and the swarf removed.

The slide is then put on the plate as centrally as possible, compared to the hole for the verge and with the feet covering the screw holes. It is fastened with sliding tongs and with the same drill the holes are bored through and finished. The holes must not be made too wide but just enough for the tap to go in straight. The screws are made in what one considers the most appropriate form.

The slide is first fixed by one screw and if it is satisfactory the other is inserted. The position for the rosette wheel is then marked.

59: Placing the Rosette

The hole marked for the center is drilled as upright as possible, but only half the thickness of the arbor, and then the rosette is adjusted so that it rests firmly on the top plate. It is removed and the holes for the screws are drilled in the plate. Then the rosette, protected by a piece of card, is held on the plate by means of tongs, the screw holes drilled in the rosette from the holes in the plate and the recesses for the screw heads are then made equally deep and to suit the screws, after which the rosette is screwed in place.

60: The Rosette Wheel and its Arbor

The rosette wheel is a small wheel which is not crossed out. It is the same thickness as the hollow in the center of the rosette and as soon as it has been cut, equalised, rounded up and polished it is ready to be riveted to its arbor. Its size is determined by the rack with which it must mesh and the number of teeth must be chosen so that ⅗ of a turn of the wheel brings the whole of the rack into action. In consequence, 30 teeth are cut in the wheel and 60 in the rack; they give a good gearing[131]. It is mounted on a small arbor with a pivot at the bottom and a square at the top to allow for setting. This square must stand beyond the hand to make it possible to apply a key.

To make the arbor, a steel rod is taken about 6 lignes long and twice as thick as the finished diameter. Each end is pointed and a circular portion formed at each end by filing

130 See Plate 12, fig. 3. In all three movements the line from the verge to the rosette center is perpendicular to the line for the cock screws, or nearly so. The size of the rosette is arbitrary, except that it should not cover any pivot holes and it must be large enough to contain a wheel that meshes with the slide.

131 Auch must be specifying the number of teeth in the *whole wheel* from which the rack is cut, so that the rack and rosette wheel have a ratio of approximately 1:1. Otherwise the rosette would bring less than half of the rack into action.

away about half the metal so that a section in the middle about 1 ligne long is left at the original diameter.

It is then hardened, let down to blue, a ferrule fixed to it, and it is mounted in the turns. The cylindrical portions are then turned exactly round. The projection in the center for the wheel seat is turned so that the wheel sits flat and central with respect to the pivot and the edge of the hole in the wheel is slightly chamfered for riveting. The pivot is then finished and polished. The ferrule is mounted on the other end so that the remaining part of the arbor can be turned and the bottom of the seat is turned so that it is only the thickness of a thin card, but care must be taken that it does not create too much play between the rosette and the plate. The size of the arbor must be equal to that of the winding square.

When the rod is the correct size, it and the face of the seat are polished. Half a ligne from the face the rod is made square up to the end and then smoothed and polished. When the square has been formed and polished, the unwanted part is cut away with a graver so that it is only as high as the steel plate on the balance cock. Enough is taken from the lower pivot so it is equal to the thickness of the top plate and then it is polished.

61: The Hand for the Rosette

This is usually made from steel but can also be gold or brass. It serves to regulate the watch by showing the movement of the square.

A piece of steel plate 6 lignes long 2 lignes broad and 1 ligne thick is let down and a hole is made in one end with a drill whose blade is the width of the square across the faces. A tapered square punch is then knocked into the hole over a vice or a hole in a stake and goes so deep that the hole exactly fits over the square on the rosette arbor. This square hole should be made with one corner opposite the length of the hand. The hand is then filed into the desired form, turned sloping at the center and hardened and polished or let down to blue if desired.

62: Making the Balance Cock

This forms the housing for the balance to protect it and the verge from breakage and is mainly intended to support the verge pivot and serve as an ornament to the whole work. It is made to the circle drawn on the top plate showing the limits of the slide and the rack, and is cut from a piece of brass of the correct size and about 4 lignes thick, which is reduced to 2½ lignes by beating. It is then filed exactly flat, but 1 ligne larger in diameter than the finished size, and drilled in the center as upright as possible. The hole is broached until it is a little larger than the hole for the escapement (*echappement*) in the top plate and can fit on a turning arbor with some of the end protruding. Before it is mounted on the turning arbor it should be noted from which end the broach has been inserted.

This having been done, the circle is drawn clearly on both sides and the holes for the screws are bored on a diametrical line, which passes through the hole for the escapement and coincides with the ends of the slides. After the holes have been drilled and their rough edges removed, the projecting piece of the turning arbor is inserted tight into the hole in the top plate so that the cock rests on the plate and the feet that take the screw holes are in their correct positions.

A card is then put on the underside of the top plate and the whole assembly is held in a hand vice and the holes in the feet are bored through from the top plate. When the holes have been correctly drilled, the hand vice is removed and the piece mounted in the turns where it is hollowed out with a hook tool on the underside to the size of the balance and 1½ lignes deep as was done with the barrel, and a small ring is left in the middle to give extra support to the turning arbor. When turning is finished the ring is removed. Care must be taken that the marking line is not gone over and the surface is flat.

The turning arbor is then removed and the excess metal filed away all around up to the line, leaving the feet for the screw holes a little larger than the screw heads. The piece is mounted on a funnel arbor that fits in the hollow and is held by a screw. It is put in the turns and a hollow turned on the outer side with the hook tool about ¼ ligne deep and ½ ligne broad and somewhat sloping on the edge of the cock. A fine file is used to make this hollow smooth and flat while the bow is rotating it.

The cock is then removed from the turning arbor and filed flat on top and on the feet, being supported by the fingers or a piece of cork[132]. The screw holes are then countersunk with a tapered or flat sink and the screws made. The steady pins are inserted some distance away from the screw heads on the side towards the rosette.

63: The Coqueret

To center the screws of the coqueret, one leg of a compass is set in the screw hole of a foot and the other over reaches the center hole of the cock by about ¼ ligne. A light scratch is then made from the edge by the rosette and the same is done using the other screw hole. This forms a cross in the center of the cock. A line is then drawn from the middle of the cock up to its edge. This line is divided equally and the center is the point for the screw hole. From the screw hole the two portions are then divided and the positions for steady pins marked and drilled.

64: Making the Coqueret and its Plate

This piece is made of brass and the plate which covers it is made from steel. In one end of the brass piece that forms the head of the coqueret a hole is bored to take the pivot for the verge. The head sits in the middle of the cock and the steel plate covers it with the pivot of the verge bearing on its lower side.

The brass piece is made from a strip which has been beaten equally thick and flat, 6 lignes long, 3 lignes broad and ⅔ ligne thick. The center line is marked and near its middle the hole for the screw. The end which forms the head of the support must be left a little long. The piece is screwed in position exactly as it should stand, then it is held by sliding tones and the two holes for the steady pins are drilled through the holes already made in the cock. The same drill must be used as was used for those holes. It is then removed and the upper and lower sides made flat while the holes are lightly countersunk. The steady pins are screwed in to make them firm and are filed flush with the surface on the inside of the cock and rounded. The piece is then fixed to the cock once more to find the center, which is done using the uprighting tool.

132 See note 43, page 41.

The tiny hole is marked and drilled straight and a very small turning arbor put into it so that the head can be turned. It is made 2 to 2¼ lignes in diameter with a provisional chamfer which is indicated by the rounding of the head, and then it is worked on with a file. The chamfer must go to the central hole. Above the hole the dimensions must be maintained so that the head of the steel plate sits firmly and evenly when the piece has been polished.

The sides of the piece are then reduced using a half-round file without touching the head. The foot of the piece is broader than the neck and the edges of the sides must be sloping, broader below than above to give the piece more strength. The edges must be a good half ligne from the screw hole on the upper side and the sloping sides flat and straight for their whole length.

The head is then filed without touching the edge so as to maintain its roundness. The edge and sides are then smoothed after the piece has been given its correct length so that it stands about 1 ligne above the surface of the cock excluding the chamfer. After this the screw hole is cleaned, the upper surface filed and then smoothed and polished.

65: The Steel Plate for the Coqueret

This piece is made from steel and exactly like the previous one, but it has a smaller head and has no foot, while a hole is provided for the countersinking of the screw head. The plate is as thick as a card and flat and even on its surfaces, the lower one also being polished so that the verge pivot runs easily and has no endshake.

The size of the piece is the same as that of the coqueret. Its head is formed and rounded with a file. It is hardened and let down to straw colour, smoothed on top and at the bottom and sides, and after polishing the piece is complete.

To sink the holes in the feet for the screw heads, a tool is used with a chisel end about 1 ligne broad, having a pivot in its center that protrudes about 1 ligne.[133] The body is of round steel about 2½ inches long and its rear end is filed to a point. It carries a ferrule as on drills (see Plate 7, fig. 13).

To make the tool, take a piece of round steel 1½ lignes thick and 2½ inches long. At one end file a point and below this make the shaft octagonal for the ferrule. The other end is filed flat and square, and a point marked in the center. This is drilled in the turns with a drill matching the screw to a depth of about 1½ lignes. A runner with a sharp point is put in the turns and a pivot is turned about 1½ ligne thick and ¾ ligne long. This piece is filed back about ½ ligne to a chisel shape, hardened and let down to yellow. The edge is sharpened and the pivot set in the shaft. The sinks for the screw heads are made in the feet of the balance cock using a bow and are cut until the turned portion rests on the surface of the feet; by this means the sinks will be made equal.

There are other types of sink cutter that use tubes with lips which are fastened by a hand vice to the piece to by countersunk and the center marked with a punch. A sink cutter of correct size is then inserted. The cutters usually have a shaft 2 lignes thick and 3 inches long and are provided with a ferrule which is carried on a movable tube with a screw

133 Auch's measurements in this description are inconsistent and have been changed to make more sense.

fastening at the side. The cutter is allowed to project as far as is necessary to cut the sink. Many have another short tube at the top of the other fastened by a screw thread so that the cutter can be lengthened or shortened (see Plate 3, fig. 3).

The cutters are of several sorts: round to make large and small oil sinks; others with a chamfer so that the correct shape can be made; and others which are flat from the size of the balance screw heads to 2 lignes or more.

66: The Balance

This piece can only be made circular because it must move equally freely in all directions, as irregularities have a marked effect on the going of a watch. To improve the going of the watch a spiral spring is placed under the balance. This ingenious invention, which regulates the movement of the balance, is very important and the spring must be carefully chosen in relation to the mainspring, which must have 5 to 5½ turns if it is to have the correct strength.

The weight of the balance is calculated by the going of the watch without the balance spring. If the watch progresses 26 or 27 minutes in an hour without the balance spring then the weight of the balance is correct, and if the going of the watch is regular then all the depthings and placing of the other parts are correct. If the balance is too heavy the watch goes too slow and is more prone to stop; in this case the weight is reduced by filing. But when the opposite occurs and the balance is too light, the rate varies even more and the watch cannot be regulated; the balance must be made heavier, but it is easier to make a completely new balance of the correct weight.

The weight of the balance in a movement which measures 18 lignes should be about 6 grains after it has been crossed out, and it is better to make the balance too heavy, so it can be reduced if necessary.

The balance is made of gold, brass or steel and in my opinion the gold ones are best, only the metal is dearer and more difficult to work. Steel becomes magnetised and is not easily worked and so brass is the best choice.

The wheel is made in exactly the same way as the center wheel, with the exception that the balance is made about twice as thick as the wheel. The size is determined by the size of the cock and is ½ ligne less. The upper side of the rim must be turned flat and even, and be well smoothed. After the balance has been turned it is filed flat on both sides. A circle is then drawn on one of the faces ¾ ligne from the edge. The piece re-mounted in the turns and a circle is marked 1 ligne from the hole with a well pointed graver in order to give a center portion 2 lignes in diameter to support the arms of the balance.

The circumference is divided into 6 with a compass, each point marked and 3 diameters are drawn joining the 6 points, 2 by 2. The lines are only drawn from the inner edge of the rim to the outer edge of the central disc. The lines are drawn to opposite points to make the arms straight and truly diametrical.

Crossing out is done as for other wheels, but each arm is ⅓ ligne wide and of equal width from the central disc to the rim. The arms are then rounded, smoothed and polished, and at the same time the two flat sides of the balance are polished.

Now everything that stands on the top plate is finished, and only the hole at the center of the escapement for the escape wheel has to be made.

67: Making the Hole in the Top Plate for the Escape wheel

A straight line is drawn in the direction of the potence on the inside of the top plate, running straight through the position of the verge, and at a distance of 2 lignes another parallel line which marks the length of the escape wheel. After this the diameter of the escape wheel is ascertained. This is done with the points of a pinion gauge; one point is laid on the top of the plate while the other is screwed up until it is only a card's thickness away from the foot for the verge hole[134]. This gives the means to file the slot for the escape wheel.

The hole is filed from the center of the verge hole outwards in a straight line under the escape wheel arbor as far as the previously made parallel scratch, and so wide that it is about ⅔ of the diameter of the wheel. The length is drawn on the inside of the plate so that the wheel fits well when its arbor is parallel to the plate above it.

The pinion of this wheel, on which the driving force is least active, has an especially delicate meshing which needs great attention during making. The leaves must be thin, sharp and well rounded and the circumference must be absolutely round. The pinion is longer than the others and must be polished throughout its length. Its end must not touch the arbor of the contrate wheel but must stand a little away from it.

The arbor of the escape wheel must be almost ½ a ligne long on the side for riveting, and must be provided with a pivot of almost the same length. The riveting section is turned on the pinion as long as necessary for the thickness of the bottom of the escape wheel.

In order to find the length of this section of the pivot, the length of the escape wheel is measured with a pinion gauge or a compass. One leg then set on the turned extension of the pinion and the length is transferred to the pinion by a small scratch, and a ¼ ligne from it in the direction of the riveting a second scratch is made which shows the outermost point of the escape wheel pinion. The pivot is then turned to its proper length and tapered, and the work is smoothed and polished.

After the escape wheel has been crossed out, and the outer surface has been smoothed and polished, the wheel is fastened to the pinion so it runs true. It is then provided with a ferrule, the pivot mounted in a hollow runner and the outer surface of the wheel turned flat using a hair bow. The outer end of the wheel which receives the teeth is also smoothed and made sharp. The wheel is then mounted on a escape wheel cutting engine using shellac which is heated by a blowpipe. It is held in the tapered hollow of the tool and the end supported in a hollow arbor. When it is made to run true, which is easy when the tool is good, the teeth are cut with a suitable cutter which leaves the fronts sloping and the backs curved with the points almost sharp. The wheel is then removed by heating the head of the tool with a blowpipe, being careful not to touch the wheel itself with the flame. The shellac is mostly removed with a penknife and the wheel put in strong spirits of wine for a few minutes after which the remaining shellac can be removed with a piece of peg wood. The wheel is then mounted in the turns once more, the swarf produced by

134 The diameter of the escape wheel is determined by the space it occupies in the movement.

the tooth cutting is removed both inside and outside, and the surfaces are polished. A fine escape wheel file is used to remove the almost imperceptible swarf from the teeth, and a water stone scarcely allowed to touch the points of the teeth will remove the swarf from them. The teeth are then burnished, the inside of the wheel polished, and it is then ready to mount in the movement.

To mount the wheel, the distance from the top of the foot of the potence to the under side of the balance cock is found and halved. Half of the distance is taken and marked on the nose by a small scratch. At a point opposite the position for the verge a dot is marked on the line and a hole drilled smaller than the size of the pivot and parallel to the plates. The hole is then enlarged with a hair broach keeping the latter in the same direction.

An instrument called a *bird* (Plate 9, fig. 31) is made from brass and is about 6 lignes long 4 lignes high and one ligne thick. A movable piece of steel, like the curved beak of a bird, reaches out for several lignes and is fixed to the longer side so it can be moved with a screw and a spring into the desired position. The bird is laid on the plate and the beak adjusted until it enters the hole for the escape wheel. The tool is then moved so that the beak touches the counter-potence plate for the rear escape wheel pivot and a scratch made. A dot is made in the center of this scratch and the hole drilled. When the front and rear surfaces have been filed the length of the escape wheel pinion can be measured and it can be finished by turning. The hole in the counter-potence is then broached from the inside so that when the arbor is in position the pivot protrudes from it by about ⅓.

If a bird is not available, a strip of brass half an inch long is taken which is somewhat broader than the distance from the escape wheel hole to the plate. One side is filed square and it is placed against the escape wheel hole with the straight edge towards the plate. A scratch is made on it with a pivot drill inserted through the escape wheel hole, and then this hole is drilled through the brass strip. When the strip is put against the counter-potence the hole can be marked through the hole in the tool and then drilled, keeping the drill parallel to the plate.

One can also make a simple bird for this operation with a beak at the approximate height of the pivot hole and a few lignes long. The beak is bent up or down until it fits in the escape wheel hole, by which means the position of the hole in the counter-potence can be found. The regular going of a watch can only be ensured if the escape wheel arbor runs parallel to the plate and the wheel is at right angles to the verge.

The escape wheel can now be fitted in the frame, and after 5 or 6 teeth of the contrate wheel have been cut and rounded up the depthing can be tested. If the meshing is too deep the contrate wheel teeth can be cut back a little, if too shallow there are two means of correcting it. The first is to put a bush in the barrette with a flat surface at its top and sink the pivot hole for the contrate wheel a little into the top plate. The second method is to bend the arms of the contrate wheel, but this looks bad.

If I had not maintained the principle that the pupil must proceed from step to step and from rougher to finer work, I would have shown the fitting of the escape wheel first, because the correct depthing can be found with the aid of the contrate wheel calliper (Plate 7, fig. 7); it is placed on the plate and set with its tooth in the escape wheel pinion so that the correct depthing can be found by adjusting the screw (see the description of Plate 7, fig. 7 in section 86).

68: The Motion Work

The cannon pinion is bored through its length to take the arbor of the center wheel. At the end there is a square to take the minute hand. The cannon pinion is driven by friction and meshes with the neighbouring minute wheel, on which a pinion meshes with the hour wheel whose tube rides on the cannon pinion. The wheels and pinions must stand in the correct relationship to each other and must not be too small or too large so that the motion work is not interfered with by the other parts under the dial.

69: The Motion Work and its Parts

These wheels are flat like the other wheels and about ⅔ ligne thick, but they are not crossed out. The hour wheel is somewhat larger than the minute wheel.

The wheels are usually given the following numbers of teeth. Minute wheel 30, hour wheel 32, cannon pinion 10 and minute wheel pinion 8. Numbers that give a better meshing are cannon pinion 12, minute wheel pinion 10, minute wheel 36 and hour wheel 40.

70: The Cannon Pinion

A piece of pinion wire with the correct number of leaves and thickness is taken, a well centered point filed at one end and a ferrule mounted on it. The other end is flattened, a depression made in the center and it is mounted on a sharp point in the turns. It is rotated and touched with a brass graver to find the high points, which can be corrected by moving the depression.

There is also a simple tool to center pinion wire called a dog's head. It consists of a piece of steel in which there is a funnel shaped depression, in the center of which is a sharp triangular cutting edge. By putting the pinion steel in the depression it pushes back the point which is held by a spring, and by turning with a bow the center depression is made. After this a small drill that fits the job is used, which must be well hardened and somewhat smaller than the pinion steel, and a hole is drilled that can be broached later.

When the tube has been bored its full length, the hole is filed lengthwise and broached so that the arbor fits it exactly. On the end where the pinion is to come a groove is filed marking its height and the unwanted leaves removed. The tube is set on a turning arbor and turned circular to the base of the remaining leaves. The tube is then filed with the file held straight. The leaves are finished, but not to an arch form like the pinions in the train but rounded, as they are intended to drive and not be driven.

When the pinion has been rounded and the leaves filed, it is hardened, let down to blue and then smoothed and polished. The tube is turned at the other end to remove the unwanted portion and the pinion proper is brought to its correct height which must be somewhat more than the thickness of the wheel with which it meshes. The face of the pinion must be kept flat. The tube is filed to remove graver marks and left thicker than the setting square.

When this is done and the polishing carried out, a small hollow is made with a graver at the bottom of the teeth and the face is smoothed and polished. The hand setting square is made the same size as that on the fusee and polished.

71: The Minute Wheel Pinion

This pinion is likewise centered, bored like the cannon pinion and made as thick as the pinion of the cannon pinion, but this pinion has two pipes and at the end where the wheel comes a space is turned for riveting. After the pinion has been turned on a turning arbor it is equalised, hardened, smoothed and polished.

The turned portion on the riveting side is reduced by half and made so long that it does not extend beyond the hollow of the center wheel in the plate. The swarf is then removed.

The leaves are finished so that the correct depthing with the hour wheel can be made and so that the hour wheel cannot go out of mesh with it. Care is taken that the face will not rub on the dial, for which one turns the pipe to have the correct amount of play between the dial and the plate.

This wheel and the tube for the hour wheel cannot be finished until the dial has been finished and set in place. A hollow is turned at the foot of the riveting to the pipe, as is done with all wheels, the work is put together and it only remains to bore the hour pipe, rivet on the wheel, cut and round the teeth, and polish it.

72: The Hinge

This piece is placed on the pillar plate at the 60 minute mark, which should have been indicated on the calibre. It is placed between the fusee arbor and the pillar so that it does not interfere with the fusee wheel. The hinge can be 4 or 5 lignes long and must be placed tangentially. From the center point, two points are made that mark the outer edges of the hinge. A groove is then cut the whole length of the hinge and made as near rectangular as possible without going beyond the marks that have been made.

The hinge is made from a rectangular piece of brass 3½ lignes thick and 6 lignes long and wide. It is beaten until it is 2½ lignes thick all over. Three of the sides are then filed flat and square, two of them reducing the breadth so that is somewhat greater than the groove that has been cut. The third side is then cut through with a saw for its entire length and 4 lignes deep so that this slit is equal all along. The slit is enlarged with a slitting file and other suitable files, taking care that more cutting takes place on the side of the rosette and that it takes the form of the cutaway portion of the plate. The other side of the slit should be flat and square and should be at least ⅔ ligne thick so it can get a good seating on the inner side of the plate.

Having got to this stage the hinge is fitted to the groove and the holes to take the screws or rivets are drilled 1½ lignes from the edge of the hinge and 2 lignes from the edge of the plate. As soon as the first hole is drilled a pin is inserted to hold everything steady while the second hole is drilled. The holes are then broached to the correct size for the screws or rivets. If screws are used the threads should be cut and sinks made for their heads.

The screw heads should not protrude above the surface of the hinge but should come level with it. When the hinge has been firmly fixed by screws or riveting, it is divided into three and the middle section filed away with a hinge file (a thick thinning file) and from the edge of the plate towards the center a slope is formed of about 2 lignes so that the thickness of a card remains. This leaves the two outer parts to fit into the hinge of the case by means of a pin.

73: Putting on the Dial

Watchmakers do not make this part but select it as required and fit it. It is hollow underneath so that there is room for the motion work, otherwise the pillar plate would have to be very thick and the motion work run in hollows sunk in it. The upper surface is convex for the purpose of good visibility and attractive appearance.

When fixing the dial it is important to ensure that none of the moving parts of the watch are interfered with, so that one does not have to remove one of the feet and fasten the dial by other means, which leads to damage. Having selected a dial, the feet are made as straight as possible and it is placed on a piece of card which projects all round. The dial is then turned over with the fingers of the left hand so that the card is uppermost and a very fine file used to remove the card where the feet come so that they penetrate. The card is then pressed home and trimmed all round the edge of the dial. A hole is made in the center and a cut made where the 60 minute mark comes. This mark should coincide with the center mark made on the hinge, and the card is laid on so that the coloured side is next to the plate and the white side is uppermost, so that the holes for the feet are readily visible.

The card is removed from the dial, care being taken that the holes are not altered. The barrette and all other parts projecting from the plate are removed and the center wheel is inserted in the movement with the top plate to hold it in position. The card is set on the center arbor and the cut brought opposite the mark on the hinge. The card must be placed centrally in relation to the plate.

The card is then held on the pillar plate with sliding tongs without shifting it and the places on the plate for the holes for the feet are marked by means of a scratch made with a sharp point in their centers. The holes are drilled on center, first small and then with a larger drill and a broach until the feet go in well. When this is done, the holes are chamfered on the same side to half the thickness of the plate to allow for the little lumps of enamel where the feet are fixed to the dial. This allows the dial to sit better. Each foot is individually fitted until the dial is in a proper position to be fixed. The feet are then cut short leaving enough strength to the ends, the holes drilled in them and the ends of the feet are rounded.

These holes are made in the center of the feet close against the plate and in a direction where the pins cannot interfere with other parts. As the feet are of copper, a medium pivot drill is used with a round shovel end and oil is applied. The hole must be as small as possible as it has been found that a thin pin holds better and does not weaken the feet so much as a thicker one.

The top plate, which has been mounted on its pillars, is put in a large holder from the uprighting tool with the dial in place and uppermost, and the movement is set in the tool with the lower point in the center of the fusee hole, and the upper point, whose end has been smeared with oilstone dust is set lightly on the dial to mark the position of the winding hole. The mark must not be smeared when the work is removed from the uprighting tool. Then one takes a well sharpened graver, its point is put on the marked place with a hand supporting it and the graver is rolled between the fingers to bore the mark on the dial. One must be careful not to work too fast because the graver might run astray and damage the dial. During this operation one must support the dial internally on a rounded head of steel that is clamped in the vice and with the graver vertical and always operated against the point that was first made. A single false prod is likely to cause a piece of the enamel to break away.

As soon as the point of the graver, which must always be kept very sharp, has reached the copper plate between the layers of enamel, one uses a small drill in this hole to cut it away so that the copper is barely bored out, as a precaution against crumbling the enamel. From here one continues with the graver to enlarge the hole till the end of a fine rat-tail file goes in. Work goes on with this file to make the hole round while precautions must be taken not to push the file to the handle or allow scratches on return; to be more certain, the filed out hole is placed on the edge of a filing block whereby the impact on the dial is protected during filing, which thereby has more stability and certainty.

This operation is carried on until the square enters the hole, which means that the arbor must fit well in the movement. One tries to bring the arbor to the center of the hole, otherwise it is necessary to alter the hole and find from which side this must happen and how much it must be altered. It must also be kept round. With the file and with the point of the graver one cuts away as gently as possible, so that the enamel layer does not break on the sharp sides of the hole. The hole must not be too large or this would disfigure the dial.

When the hole is ready it is rubbed with oilstone dust until it is completely round. For this one takes a piece of thick iron wire, twice as thick as the hole and about 3 inches long. At one end is fixed a ferrule and after it has been given a point the other end is provided with a long tapered point which is coated with oilstone dust. The bow is then placed on the ferrule the long point in the hole of the dial and the other point of the tool in a hole on the vice.

The surface of the dial is held straight against the surface of the moving point and the bow is then operated but not with too much force. In this way the hole is properly smoothed, rounded and so made ready. The hole in the center of the dial is finished in the same way. This gives the worker practice in assembling the parts under the dial of the watch (*cadrature*).

74: Preparation and Assembly of the Parts under the Dial

First, the barrette is put on to ensure that its height does not interfere with the dial. Its thickness can be reduced if necessary by thinning the barrette so that its feet and surface come equally in contact with the plate. Then the oil sinks are made and everything is rounded and polished before assembly. The catch must be tried to see if it has the necessary amount of play and whether the hook for the spring interferes with the dial (Plate 10, fig. 9); if so the hook must be tapered. The push piece on the head must be given the correct length and a groove made in the middle of the end to take a fingernail; then the catch is smoothed and polished.

Second, the meshing of the minute wheel with the cannon pinion is checked by putting turning arbors in their pipes and testing them in the depthing tool.

Third, if the diameter of the minute wheel is well planned this wheel will also get a good depthing. Before one entirely rounds up this wheel one should only round up 5 or 6 teeth to ascertain whether the wheel fits and the meshing is good; then the rounding up can continue. If the wheel is too large, so that the leaves of the cannon pinion press against the teeth of the minute wheel as seen by the meshing of the teeth, one turns enough off the wheel until the engagement is satisfactory. If the wheel is too small so that the leaves of the cannon pinion do not mesh with the teeth of the minute wheel and there is play on both sides of the teeth it is necessary to make a new and slightly larger wheel.

For the meshing of the wheels to be satisfactory the following requirements must be fulfilled: It is necessary that the pipe on the hour wheel is made so that the hour wheel is not pressed by the dial, because otherwise a braking effect on the movement will take place; on the contrary it must have the necessary play under the dial. If it has too much play the danger exists that it can come out of mesh and then only the minutes and not the hours will be shown.

To make the hour pipe correctly one gives it about the thickness of a card for the necessary strength, neither too thin nor too thick, and so that the tube does not touch the edge of the hole in the dial.

As soon as these wheels have been prepared in this manner, equalised and made truly round, they are cleaned and polished and are then ready.

The base of the square for the minute hand begins the thickness of a card above the edge of the hour hand pipe to allow play for the latter. The square must be 1½ lignes in height. The long extension of the center wheel arbor which goes through the center of the cannon pinion must extend ½ a ligne above the square so that a diametrical hole can be bored through it immediately above the minute hand square for a pin to prevent the cannon pinion rising from its seat. A heavy blow against the dial could bring this about. When the upper part of the square has been prepared it is smoothed and polished.

To put the pivots of the fusee wheel in the proper condition one first cuts or files the small pivot so much that only a little stands out from its cock. Then a ferrule is fitted on the winding square and the pivot is supported and polished in a pivot runner. Then it is put in the frame, the dial put on and a mark is made with a file on one of the corners of the winding square corresponding to the surface of the dial; after which the square is cut, filed flat and square, and smoothed inside and out and polished. One must make sure that the square is not left too long; otherwise the hour hand might catch against it and stop the watch. If it is too short it does not look right.

Before putting the spring hooks in the barrel and its arbor, the barrel and its cover must be smoothed if this has not already been done. The upper pivot is made as long as the thickness of the top plate and rounded and polished, and a mark is made for setting the spring tension. Enough is removed from the square to adapt it to the curve of the dial, but leaving enough above the ratchet wheel so that the spring can be comfortably set up. The hooks on the arbor and barrel are cut so that they grip the holes in the spring. Then the spring is chosen, wound on a spring winder and set in the barrel.

After the spring has been put in position it is pressed flat on the bottom of the barrel with a piece of wood or bone and it is seen whether the spring has the correct height or whether it comes over the mark. If all is in order, one counts the turns of the spring; if there are 13 to 15 the spring is correct. The arbor is then inserted, the cover is put on and sliding tongs are put on the square, which is protected by a card or a thin sheet of brass. The spring is wound and the revolutions of the barrel are counted. If there are 5 or at most 5½ turns when running down the spring is quite satisfactory. If there are fewer one needs a thinner spring and vice versa.

If the arbor is of the correct diameter in relation to the barrel and occupies about ⅓ of the space it can be accepted as satisfactory. In many watches the barrel arbor is too small so that the spring is greatly over stretched, whereby many breakages occur.

I could say many things about the quality of this work if I did not have to continue to show the apprentice the right way and not to bore him. There are two kinds of the watchmaker's craft. The better sort is to make every part from the beginning in a skilled way and to polish everything thoroughly and to do the gilding one's self. Such a watch is certainly well made and provides an example for all factory watches. Although such a master-work is much dearer, and must be so, an enthusiast will take steps to possess one if he wants this kind of watch. Such a watch needs almost no repair for at least half a lifetime. Experience has shown this to me many times as I will relate.

Sixty or seventy years ago an artist lived in Erfurt by the name of Haberle, who was one of the leading masters of his time and who made double or triple cased pocket watches in both gold and silver; and also table clocks in many shapes and forms according to the taste of that time. The price of such a watch in a very strong silver case was at that time 36 to 40 Thaler, and they are still of great value, costing 20 or more Thaler when they are available, The watches were somewhat thick and made in the English style, with the verge and the escape wheel running in inserted pivot holes called bearings. Many of them have come to me for cleaning but it was seldom that a hole needed re-bushing and it was also apparent that there was no trace of wear on the wheels, pinions and pivots even though they had already been working for two thirds of a century. The table clocks that this great artist made in large numbers with like precision were the same. Those who build such master-pieces are to be considered the leading masters in the mechanical world and thereby deserve all aid and support, as does anyone who strives to produce something special for the benefit of the community.

In this the English deserve special praise. If someone there discovers or makes something of note they receive an award for support or to further their studies, or they receive a patent. This arrangement has ensured that the foremost artists are found in England and receive large sums for their works of art from people in Germany and other countries. If only the German artist was subsidised, as has happened in one or two towns, it would soon be seen that the sharp thinking and no less spirited German would certainly not remain behind.

When the barrel has been placed in the movement with proper care, after the previous operations and ensuring it is free of the plate and does not rub, one gives attention to the fusee wheel, the chain, the fusee beak and the stopwork on the fusee.

To bring this part into order, in the event that it does not stand properly, one first looks at the meshing with the center wheel in order to find out whether it is right, too deep or shallow, and to see whether the hole in the bottom plate must be opened to take a brass bush, which is the best way to achieve a deeper or shallower setting of the large pivot.

After the first two moving parts have been set in the movement in this way, a chain is chosen whose breadth fits the width of the groove in the fusee. It is rolled round the fusee until it is covered with about 1½ inches left over which is provided with a hook, because if the chain were too short it would spring each time it was wound. If on the other hand it were too long it would come off and cause congestion which would reduce the strength of the mainspring and bring the watch to a standstill. When the chain has been corrected, the hook is put into the hole in the barrel, a finger is put on the hook and with a key the chain is moved under the finger and wound onto the barrel. The ratchet wheel and stopwork are put in position and the other hook is put into the hole in the fusee. Then an adjusting rod is put on the winding square and it shows the correct tension by winding and releasing the fusee wheel.

The adjusting rod is a piece of round steel one foot long. It has a sliding weight at one end and at the other a foot or plug in the center of which is a square which one can enlarge or reduce and fix to the winding square by a wing screw. When this has been set up one sees whether the chain fits well in all the grooves of the fusee or whether it is too thick or too thin, in which case another chain must be used. It must be ensured that the chain does not rub against the back of the potence and that it winds correctly onto the fusee right down to the last turn.

When this has been done the equalising of the teeth of the train is carried out (if this has not been done already as I have described); the wheels are cut again, to correct the meshing, and the pivot holes adjusted to let the teeth have the correct play in the pinions and every part of the movement is correct; above all one must work exactly and carefully so that a good piece of work is produced.

For this operation one first puts the center wheel in position and test: 1) Whether it stands upright; 2) whether the hole for its large pivot is correct, because the hole for the long extension must be very exactly made for mounting the cannon pinion so that the bottom of the latter does not rub on the plate; 3) whether the center wheel rubs on the center or edge of its hollow; 4) whether its teeth and spaces are good, whether the center wheel touches the potence or the barrel or other parts; 5) whether or not everything has sufficient clearance as this wheel only needs a little.

The examination of all moving parts must be done before the errors are corrected, so that the most appropriate remedies can be applied. The intelligent craftsman must be able to recognise them, so that when the center wheel meshes too deeply in the third wheel's pinion he able to understand that the tops of the teeth must be brought back a little and then rounded. This must also be done with the fusee wheel if the meshing is too deep. If the size of the moving parts has been correctly set out they need only a little adjustment to their meshing to remedy the rubbing and are easily put in the right condition to carry out their work.

One must be certain that the center wheel does not touch the bottom of its hollow; in this case the hollow itself must be raised by striking the opposite side. On the contrary, if the wheel stands above its hollow one makes the hollow deeper. If the hollow is deepened only a little the end play may not be too much. But if it is deepened a lot and the hole cut lower, a bush must be put in the top plate; this can be done on old watches but absolutely not on a new one because it would completely disfigure it. In this case it is better to make a new pinion to overcome the fault better. When the hole for the wide pivot is too large it must be bored larger and provided with a turned bush. The re-bushing of this and the small pivot must have a thread, because a bush that is set in smooth comes loose after a while.

In this instance the following is done: In the case where the wheel formerly stood upright, first a thread is cut in the hole and then a somewhat thicker brass rod is taken, centered and a small hole ½ a ligne deep is bored in the turns. Then a sharp pointed graver is used to turn the end of the rod so thin that it fits in the hole of the screw plate and a thread cut on it. The bush is screwed into the plate and cut off so that it can be riveted a little, and then it is broached to the correct size of its pivot. The hole could also be bushed and the center found with the uprighting tool. The same can be done with small pivot holes: brass wire about three times as thick as the pivot is cut for threading in the screw plate and filed even after the thread has been cut. Then the center is found with a pivot drill, which is easy, and the point is bored. The wire is threaded in the screw plate and screwed into the prepared hole, leaving on each side about the thickness of a hair which is hammered flat, and the hole is bored through. For this process the pupil must take especial care so that in gilded movements the gold on the plate does not have to be filed, which disfigures the watch and is done through ignorance.

After the hole has been bored, which should be somewhat smaller than the pivot, it is then broached until the pivot goes in, the wheel is horizontal with the plate and the arbor is vertical. If so, the hole is correct and it is smoothed so that the upper pivot has enough freedom in all positions and the wheel turns freely in the lower one.

If this is not so and the wheel wanders too much in the bottom hole, there is nothing to do but bush the hole again. When the hole has been properly enlarged the plates are put together and it is seen whether the arbor has too much or too little end play. If it has too little, the pivot hole must be cut back with a flat countersink tool until there is enough play. On old watches, if it has too much play, a round punch is used with a stake and it is hammered to try to reduce the play; but on new watches a new pinion must be made.

After the previous instructions it is easy to see that if a depthing is too shallow or too deep it can be easily remedied by a bush with an eccentric hole, and by screwing the bush in or out the arbor can be brought nearer or further away. This is used only in the case of repairs; on new watches it must not be done. If by an oversight a depthing is too deep or too shallow it can be improved by twisting the hole and corrected by the new position. If the work is not yet gilded it can be filed.

The pivots on the arbors of the wheels must be so short that they do not come above the plate and touch the upper parts, which could lead to stoppages. It is often said that the small pivots should be about 1½ times as long as they are thick.

This reduction in the length of the pivots makes it easier to form the holes with a conical depression to serve as an oil holder, which oil is put on the pivots to maintain their freedom and preserve them. Too much oil is harmful because it attracts dirt which settles in the oil sink and wears away the pivots so that the work is damaged and needs attention.

If the center wheel is correctly placed, the third and contrate wheels are planted in the same way and with the same care, which involves the correct seating of the wheels and their depthing. When this has been done it is time to attend to the parts of the escapement and finally to complete the movement. The most important part is the escape wheel which must now be adjusted. How it is made has been described above, and now its positioning and related matters will be described.

75: Putting in the Escape wheel

The potence foot, the piece for the verge pivot, needs to be only half a ligne thick to have the necessary strength so that one can make a hole for the pivot at the lower pallet and so that the pallet can grip the escape wheel with certainty. When the foot and the balance cock are fixed the diameter of the escape wheel is measured, so that its diameter is ¼ ligne less than the distance from the upper surface of the top plate to the inner surface of the foot. This limits the diameter of the escape wheel. This requirement is less important than the number of teeth, which depends on the relationships of the other wheels which drive the escape wheel and the relationships which the drawing of the calibre prescribes.

This diameter is marked on the calibre so that one need not fear accidentally opening or closing the measuring tool while making the wheel. When the wheel has been made and crossed out, the outer surface is smoothed and polished and then it is riveted fast to its pinion. The rim is turned with a graver where the teeth come and then the wheel is put in the movement and given its correct play. Then teeth are cut as has already been described.

With this wheel one must be careful to make the teeth neither too thick nor too thin, but to cut them at the proper angle with a specially made, fine escape wheel file and polish and round the tips with a special polishing file, attention being paid not to make any teeth too short or crooked, which would make the depthing wrong and produce an uneven beat.

The sensitivity of this part is so great that it can be disturbed by a hole too narrow or too wide, by a small crack on a pivot, or if the pivot is not properly rounded and the tip not polished, and further by bad depthing. Therefore the greatest attention and care is necessary for this part.

76a: The verge

This piece, which is intended to make the wheels keep time, can be given various forms. The first is called the *rouleau* (the round form) which on account of too much solidity is not the best. The second form, called the *cut through* (*Durchschnittene*), is thinner than the first and has in spite of that more solidity, and if this form is well made it leads to a beautiful escapement. However, the third form, called the *lobe verge* (*Lappenspindel*) is the best, as far as experience goes, when it has the correct opening of the pallets and its body is not too thin nor too thick, because in the former case the stem is too bendable and in the latter it cannot approach near enough and its proportions are not that which are required.

Each of these verges has two pallets of the same width which form the impulse part. The lower pallet is usually not as long as the upper because it must have free passage between the foot of the potence and the nose for the escape wheel. The upper one is longer because the balance must be soldered to it.

76b: Making the verge

This piece is made from well prepared steel, or from the steel called screw steel, that has been filed square for its whole length. When this has been chosen, an end is cut off 8 to 9 lignes long.

For the pallet, this steel is filed from one end for a length of 4 lignes to the foot of the other pallet.[135] This pallet is the small or bottom pallet, on whose end a notch is made 1½ lignes long to form a small rectangular projection for the verge arbor. When this has been done the part which will form the bottom pallet is screwed into tongs or a pin vice and the superfluous metal is filed away from this pallet to the place for the top pallet, which should be at right angles to the other. It is then taken out of the vice to measure its provisional height which is from the foot of the potence to about 1 ligne above the top plate. This height is marked on the piece by a tiny scratch on the front of the pallet and indicates the outer end of the top pallet. Out of the remaining material, that should be about 3 lignes long, the top pallet is formed like the small one, but 1 ligne larger on which the balance seat is soldered.

When the verge has been worked on this far, the edge of the lower part of the bottom pallet is set transversely on the potence foot. If the edge of the pallet is supported in this way, then the top pallet may go above the top plate by at most only ½ ligne, whereby the provisional height is determined.

Then the inside of each pallet as well as part of the body which lies in the same direction is filed flat and square until the body and the pallets have the strength of a fine English needle, and the whole length of the piece, which should be formed like the body of a dragonfly, is uniform.

After this is done, each corner of the stem is filed equally so that it has eight sides and then it is filed round and equally thick throughout its length so that no bends or protuberances remain. The sides of the pallets must be filed equally square and given the measured length so that they clear the escape wheel nose on the slide sufficiently and are not distorted when the verge is put in the movement.

When this piece is cylindrical and uniformly thick, and the pallets have their correct size, then the groove is filed. For this one put one of the pivots in a pin vice and rests the verge on its back on the face of a filing block. Supporting this pivot with the left hand, a good pivot file is taken in the right hand, held by the first two fingers and the thumb. Then the flat side laid on the verge and it is filed straight until the groove is flat without facets and one end not deeper than the other, sharp along the arbor without damaging the latter. The cutting usually amounts to ⅖ of the thickness of the verge, because filing and polishing will remove a little more.

After this cutting there remains a small angle along the whole length of the pallet where it joins the arbor which is removed with the face of a short-pointed graver. With this tool one rounds the stem making it perfectly cylindrical and all angles and flat pieces are removed. With this the forming of the pallets is finished.

Then each pallet is given equal thickness for their whole length and width, which is done at the back of each pallet. They are filed quite flat without touching the arbor, but making them both equal. By this, each pallet becomes half as thick as the arbor.

After this, the pallets are given the correct opening of 2⁄7 of the circumference of the verge, or 12 degrees more than the angle of 90 degrees embraces[136]. Most pallets are set at an

135 Auch's language is obscure. The verge arbor is formed in a corner of a square steel rod, and the rod is filed down in two different directions to form the pallets at a right-angle to each other.

136 The pallets are filed out of the square rod so that they are at right angles, and the verge has to be twisted to increase the opening.

angle of 90 degree, but they give the watch bad running which must always be rectified during repairs. To find this measurement, a circle is drawn and divided into 7 parts, 2 of these give the opening of the pallets, which makes for the best vibration of the balance.

As soon as this extent of opening has been reached the pallets are given the width that they require, which used to be determined by the old rule of a fifth part of the diameter of the escape wheel. Experience has shown many times, in a scholarly manner, that following this rule is not advisable, as I have often seen verges with openings according to this rule with which it was impossible to obtain good vibrations without the escape wheel teeth butting on account of the excessive width of the pallets.

My experience shows that the sixth part should be used, which I have always recommended to my pupils and assistants. It has, however, its limits; there is no rule without an exception.

If the escape wheel does not recoil when it escapes from the pallets, the pallets are correctly made, and if the escape wheel teeth sit close to the verge without touching it, then the escapement is good. After this one must reduce the pallets to this sixth part to get a good escapement.

One therefore makes each pallet equally broad to acquire a good relationship. One files an oblique bevel for the whole length of the back so that the escape wheel teeth cannot butt. This bevel must be only a quarter or at most a third as broad as the pallet and must be filed flat and equally to the edge of the rest of the pallet so that one end is as broad as the other; and both pallets are the identical. When this has been done only the finishing needs to be done. At the end of the verge a well centered point must be made. Then the verge pivots and shoulders are roughed out and it is hardened; which, if the soldering is done with silver or tin, provides a very successful piece of work.

This work involves the preparation of a brass seat, for which a small piece of round brass 1½ lignes long, flat at both ends and 1 ligne thick is used. This seat is bored through and the verge is placed in the hole. With a slitting file or fret saw, a cut is made at most ⅓ ligne deep in the middle of the seat, in which to set the edge of the pallet and to give it more firmness. If one wants to solder it with silver, a little borax is taken, pulverized, damped with a drop of water, laid on the hole and then silver solder is put on both sides of the verge. The whole is then placed on the end of a piece of charcoal 3 inches long, which is heated with a blowpipe held in the flame of a light to make the seat glow and the solder flow. As soon as it is fluid it is thrown into a half glass of water whereby it becomes hard. This hardening can be considered good if the steel has become white all over.

Then a small piece of stone is smeared with oil and the piece is rubbed, taking care not to break the glass hard surface by polishing with a heavy pressure; and then it is tempered dark yellow.

After this, the verge is put in a figure-8 calliper and turned with a finger to see whether it has remained straight or has become bent. In the latter case one sees on which side the bend is, in order to straighten it with the pean of a hammer just as is done with bent pinions.

Then the verge is smoothed over its entire length until all the scratches have disappeared, but it must always remain cylindrical, and the faces of the pallets are polished on all sides as well as possible. The verge can also be hardened and polished before attaching the seat. It is held in soldering tongs and sal ammoniac and oil are mixed and applied to it. It is soldered by the heat of the flame and as soon as the solder flows the verge is quickly put into the hole and the groove, and then is quenched in water. This is the common method of soldering. With high class watches the previous one is preferred.

The finishing needed in order to set the piece in the movement is done as follows: The verge is mounted in a turning ferrule, put into the turns and turned from the bottom pallet so that a small piece the thickness of a card is left between it and the pivot. This pivot is then turned cylindrical and polished until it is ¼ as thick as the verge if the body of the verge is somewhat thick. If it is somewhat thin, the pivot is only made ⅓ or even ½ as thick. After the pivot has been turned cylindrical and of the correct length, its end is rounded and polished until it resists a finger nail. When the pivot has been prepared in this manner, so that it is the correct length to reach the bottom of the verge pivot hole and is able to be properly seated by lowering the hole, so that the hole is the proper length and the pivot protrudes the thickness of a hair, it is completely ready.

Then the tapered shoulder is made on the end of the verge with the point of a graver which makes the part complete. The seat on the verge is turned round and cylindrical, giving it the proper diameter, height and shape for riveting. Then the pivot is put into its bottom hole to check that the seat does not come too low; if so it would require a lot of extra work to unsolder it or to make a new one. If it is too high it must be lowered a little so that the balance, when it is riveted on, has enough room and does not rub on the body of the cock or against the top plate. The balance must occupy exactly the middle of the space between the cock and the plate and it is necessary to see that neither interferes with it.

If this is correct, a small tube is turned half as thick as the body of the seat to which the balance is fastened. The riveting of this seat must stand only very slightly above the hole in the balance and must be drawn up so that the balance can be properly riveted.

When the seat has been finished and the balance is in position, the length of the verge is measured so that the pivots can be finished. The balance cock is set on the top plate and the distance to the bottom of the verge foot is measured, including the steel plates, with dividers or a long nosed gauge, of which one arm is on this surface and the other is on the balance cock; thus the length of the verge is determined. When this has been found, a scratch is made at the upper end and a ferrule is put on the middle, between the upper and lower pallets. Then the pivot is turned to its proper length, filed and polished as previously. After this the verge is ready for riveting on the balance.

For this a tool is used which is called a press, or another tool called a hazelnut, the latter being easier to use than the former. This or another tool is fastened in the vice and the balance is put on the verge so that the upper pallet comes in line with one of the arms, and then the work is lightly riveted using a riveting punch with a hole in the middle. After this, the verge is placed in the movement and it is seen, when the two pallets come against the escape wheel teeth, whether the top of the verge aligned with the balance arm comes between the two ends of the slide. If not the verge is turned in its hole and is riveted when it is correct. When this has been done the pivot holes can be completed and the escapement made.

77: Putting together the Escape Wheel with the Verge, or Planting the Escapement

Planting the escapement (*echappement*) means bringing the escape wheel into action with the verge so that it makes as many vibrations as desired by means of a spring which represents the action of gravity on a pendulum. There are many types of escapement; cylinder, virgule, anchor, half free and completely free. Each of these has a properly made balance with a balance spring as the regulator, which is placed sometimes above and sometimes below the balance. All these escapements and balances are set in motion by the force of the mainspring transmitted through the wheels.

As I will only discuss the verge escapement here, I have to remark that the escapement part is called the verge and the wheel that sets it in motion is the escape wheel.

When these pieces have been put in the movement in their correct places, their pivots in their holes and the teeth of the escape wheel equalised with regard to their length, strength and separation, one sees whether all these teeth are fine enough without being too pointed; that is, they are not too thick at their tips, but strong enough to possess the required stiffness.

The balance staff must be a very straight cylinder and proportionally thick. The pivots must be fine, hard and about 5⁄12 of a ligne long. They must be turned with a graver, rounded with a file, worked on with a steel polisher and their ends rounded and well polished. The pallets must be equally wide, their proportion limited to about ⅙ of the diameter of the escape wheel and further, they must be polished and fastened firmly to the balance.

The escape wheel and the pallets must be made and placed in the movement so that the escape wheel comes diametrically opposite the center point of the verge, and the points of the teeth stand as near to the verge as possible without touching it and enter the pallets as deeply as possible; otherwise the running of the teeth will be too hard and the escapement will be damaged.

To examine the verge and escape wheel, a piece of paper is taken and put between the balance cock and the balance, and then the plate is turned over to see whether the points of the escape wheel teeth go near enough to the verge[137]. When this is done, the paper is taken away to see whether anything catches. If so, the pallets are somewhat reduced until the escape wheel goes past freely. Then the drop of the escapement is examined as follows:

As the potence nose for the escape wheel must be thick enough, in case the escapement needs to be brought a little closer, one files a few strokes off the front of the nose and then sees whether the escapement has the correct depth.

To test the drop of the escapement, the top plate (on which the parts of the escapement are mounted) is held by the first three fingers and thumb of the left hand, and with one of these fingers the escape wheel pinion is lightly turned and the teeth run in the verge. This is to see whether the escape wheel teeth pass by, the verge escapes well and the tips of the teeth do not catch the ends of the pallets. For this a piece of pegwood is taken which

137 All these parts are attached to the top plate, so the pillar plate is left off and escapement depths can be easily seen.

is laid beside the balance next to the banking pin[138] while the escape wheel is turned and the balance oscillates. By this the size and strength of the escapement is learnt and it can be seen whether it is good or bad. If it butts it is too strong and this must be corrected immediately.

To test the arc of the escapement with the peg wood, one must determine the place on the rim where the banking pin will be, where the balance comes to rest. This place must be straight in the center between the feet of the balance cock. A small mark is made, the peg wood is supported beside the balance rim near the banking pin and the escape wheel is turned by a finger of the left hand, which holds the top plate, so that one tooth after another can gently run in the pallets. The balance must be restrained as soon as one feels with the fingertip that a tooth has dropped off a pallet and note how far away the mark on the cock is. These observations are repeated several times. This investigation shows whether the escapement is good or bad, whether it butts or whether it runs well. The drop must be a good two lignes each side of the point for the banking pin; this gives good vibrations and the watch will always keep a good rate.

If the escape wheel has been brought closer to the verge and the drop that is being tested does not amount to two lignes from the banking pin, this is an indication that the pallets have too little opening and they are too narrow. Opening the pallets further involves endless trouble and one cannot be too careful. These pallets can only be improved by transverse cuts into them, or by using a flame or the light of a single thread, which one allows to play on the middle of the verge whose upper pallet is held by a fork that has been specially filed for it, and while it is held over the threadlike flame the lower pallet is twisted using small flat-nose pliers. During this operation the stem becomes a whitish blue and the pallets remain polished white. Only a small amount of practice is needed, but great care is necessary; as it is of special use in repairing it is recommended.

When the pallets have the correct amount of opening, the upper one must form a line with the arm of the balance at whose end is the banking pin[139]. Now the only requirement for the balance is the necessary weight that it must possess, and the balance spring.

The movement is put together, the chain is put in and properly tensioned, and the cannon pinion and the dial are put in place. When this has been done, the balance is put into a figure-8 calliper without the balance spring (that is, the pivots are put in the beaks of the calliper so that they are free without play) and in this condition the balance is turned to see whether it is equally weighted all round; and if this is not so the part which is the heaviest is noted so it can be filed lighter on the underside until it is poised. When this has been done the balance is put in the scales to ascertain its weight, which for the present should not be over 6 or at the most 6½ grains for a movement of this size. The banking pin is put in and the balance is then put into the movement and the cock screwed down. It is noted whether the verge is free, and when this is satisfactory the chain is wound half way onto the fusee to make the watch go.

After this, the minute hand is put on its square and the point is set at the 60 minute on the dial. The time is then noted by a good watch or clock which is visible, and the movement is run for half an hour to see whether the balance corresponds to the motive force. If the

138 *Schwungstift*, swing pin. Auch is a little confused because the banking pin has not yet been put on the balance, so presumably he is referring to where it will be. As it is aligned with a balance arm its position is known.

139 This is wrong. See Berthoud Art. 2534.

minute hand runs 13 or 13½ minutes during this half hour this is an indication that the balance is of the correct weight; this result demonstrates that each of the moving parts of the watch have been correctly made.

If the balance is too heavy or too light it is necessary to make modifications. This is done as follows:

If the minute hand runs more than 13½ minutes in half an hour the balance is too light, which causes many irregularities that are corrected in a new watch by making a new and heavier balance. Care is taken beforehand that the new balance is made heavy enough. To make a balance heavier, the underside can be coated with a layer of tin with a soldering iron, the excess filed off and the balance given the necessary weight; but if the tin is not applied carefully it not only damages the balance but makes it weak. This is only done to very old watches whose owners will not pay for a new balance.

If the balance is too heavy, which is discovered when the minute hand shows less than 26 minutes in an hour, the rim of the balance must be filed in proportion. The arms of the balance must be kept be thin or narrow so as not to uselessly overload the verge, and also to keep the vibrating force towards the rim; however they should not be made too light or they will easily bend. The watch will go better the nearer a balance can be brought to the force of gravity; so good watches have gold balances because this metal is heavy and they take up less room than brass ones, whereby changes in air pressure with the rising and falling of the barometer has less influence; and also it is less influenced by heat and cold. I have come to the conclusion from much experience, especially with cylinder watches, that air pressure has a great effect on the balance, and even pendulum clocks are not excepted.

With a one degree of fall in the barometer a watch runs ½ a minute slow in 20 hours and vice versa. Only with pocket chronometers that have heavy balances and heavy pendulum clocks that possess a good deal of driving power does the difference caused by the rising and falling barometer amount to practically nothing.

To make the balance lighter, one tests how much less than 26 minutes per hour the watch runs, and one estimates how much weight has to be filed off in order to arrive at the correct weight. It is better to reduce the weight two or more times rather than take off too much in one go.

To perform this task, a fine sage leaf file is used and the filing is done all round and equally until the balance shows the correct time. Then it is smoothed using specially cut peg wood with oil and emery, and finally polished completely bright with a steel polisher.

As has been said above, the balance must be weighed to get the correct weight. For example, I use 7 grains to give 18 or 19 minutes and can then file off 1 grain to make it run 26 or 27 minutes. If it should run 23 or 24, one quarter grain is then removed and this will lead to the desired result, so that the balance spring can be made and fitted.

78: Making the Balance Spring Collet

As the seat on the verge is cylindrical to take the balance spring collet, the following method is used to make it and set it in position.

A piece of well hammered brass is cut to the size that the collet will have. A small hole is bored in its center somewhat smaller than the seat itself, and this is gradually enlarged, always from the same side, until it is large enough to fit. When this has been done, a turning arbor is inserted in the same side as the broach entered and made firm. The piece is then rounded with a file, mounted in the turns with a ferrule and the sides are turned flat until the thickness equals the height of the seat. It is then turned on the side until it is the same diameter as the ring in the center of the balance. After this, the face of the piece is hollowed out from the side of the thick part of the turning arbor in order to fit the balance seat.

A point is then made in the middle of the side of the collet which is bored with a fine drill so that it comes out the opposite face. Then a thick thinning-file or a slitting file is used to make a cross cut through the collet to the turning arbor, taking care that the cut is on to the opposite side to the hole for the spring; then it is taken off, put on a wooden peg and the cut filed right through to the middle.

Now the only thing to do is file the outer face flat and smooth and polish it. This operation concludes the making of this part so that the spring can be put onto the collet.

The balance spring is made from steel let down to blue and is like the mainspring in miniature, with the difference that there are no holes in the ends. Its coils are no wider than the stroke of a pen and it is somewhat weaker and narrower at the center end than at the outer end. Many people who do not understand take this spring to be a hair that has come by chance onto the balance and has become entangled. This part, one of the most beautiful discoveries and the soul of the watch, is usually placed between the plate and the balance and the inner end is fastened to the collet by a tiny pin set in a hole.

Before the spring is put in, the correct strength and size must be found in order to pick a suitable one. In order to choose the spring, the balance is taken out of the movement and placed upside down on a piece of paper on the bench. Then a spring is chosen that fills about ⅔ the diameter of the slide. It is gripped with spring tweezers at the outer end and the inner end is hooked on the top pallet which lies on the paper and the balance lifted up.

If the weight of the balance gives the spring the shape of a cone that is too long, the spring is too weak and another must be chosen. When on the contrary it does not form a rounded hollow it is too strong. However, if the hollow is deeper than its diameter one can install it and try it.

The spring is not fixed to the collet until the latter has been put on the seat, so that when the balance is put in the movement the outer end of the spring comes to rest inside the end of the slide on the side where the pivot of the barrel arbor is located on the top plate.

One ligne inside the end of the slide a hole is made in which the pivot of a small piece of brass, the balance spring stud, is to be fixed. This stud has the shape of a rectangle ⅔ ligne high and ½ ligne square.

Before the hole is bored in the top plate the spring must be fixed to its collet, put parallel to the arms of the balance and the coils must run regularly from the collet outwards. The balance is then set in its place and the outer end of the spring indicates where the hole for the spring stud should be marked and drilled.

For this, the top plate is taken off after the balance has been removed, and the hole is bored as straight as possible and broached from the inside of the plate so that the stud cannot escape from the place where it is fixed. This hole should be at most ¼ ligne in diameter so that the stud sits comfortably and the pivot can be inserted firmly.

79: Making the Balance Spring Stud

The stud and its fixing are dealt with after the above-mentioned hole has been made. For this a hard brass rod is taken that is a good 1½ inches long and 1 ligne in diameter. Points are filed on the ends and a ferrule is put on it. It is put in the turns to make the foot or pivot cylindrical until it begins to enter the hole in the plate and the piece sits firmly in place, which can only occur with a sharp shoulder and a uniform pivot. When the piece has been turned this far, one ligne long is filed rectangular, the stud is made equal to the height of the slide with a graver in the turns, and the hole for the spring is bored in the middle, just large enough for the spring to be properly inserted.

When this has been done, the spring stud is polished on its four sides and cut off the rod which held it to enable it to be smoothed and polished. Then it is set in place. After this last operation it is in its finished condition and ready to receive the spring and its securing pin.

Next, the spring is installed. When the spring has been fixed, the rack put in the movement and it shows us where the spring curb should be made on the rack so that the spring can be lengthened or shortened by the rosette when a correction of the rate is required. The cut should be broad and deep enough so that the coil of the spring can freely vibrate and can touch both sides as the watch runs[140].

80: To give the Escapement with the Balance Spring a Uniform Rate

When the balance has been provided with all that is necessary, it is put in place to see whether it is a good working escapement. To ensure this one uses the following procedure:

The end of a thumb is placed on the rim of the contrate wheel until the balance comes to rest and it is noted where the verge stops. Then the wheel is advanced until one pallet escapes and it is seen how far the verge has moved from the point of rest before it runs back again. When this has been observed and the verge has come to rest again, then the other pallet is made to move in the same way, whereby it is easy to see whether it has moved the same distance; if so this is a sign of a good escapement. However, when the distances are unequal it is necessary to correct the error.

To do so, the side on which the drop is greater is determined. If it is on the right side this is the side of the top pallet and if on the left side then it is the side of the bottom pallet. The way to correct this error is to move the spring collet; but first it must be seen whether it needs to be moved a lot or a little.

This error is corrected the following way: If the drop is longest on the right side, that is the top pallet, the balance is taken out of the movement, the verge is held perpendicularly with the finger tips of the left hand and a screwdriver is taken in the right hand and set in the slit in the balance spring collet. When the tool is correctly set and operated with the right hand, the collet is turned on the verge from right to left an amount according to whether the drop is stronger or weaker on the top pallet, which is the right side and thereby differentiated from the left side which is the bottom pallet. This operation is linked

140 Rather than using two pins, the curb is a slot cut in the body of the rack.

to putting in the balance spring stud, because of the greater distance of the right drop from the mark on the left. Therefore it is necessary when putting in the balance spring stud to see if it is suitably placed in relation to the balance collet to modify a drop that is too great. When this has been done the balance is replaced in the movement to see whether the escapement is working properly. If it is not, a fresh start is made until it is correct.

As soon as this problem has been fixed, the watch is set going to see whether it overbanks or causes knocking[141]. If either is the case, or both errors occur at the same time, the correction is made as follows:

Knocking occurs either because the balance spring is too strong or the ends of the slide are too long, or also because the banking pin is not central in the space under the cock between the slide ends and the edge of the plate. These faults can also occur if the pallets are too closed, which brings about vibrations that are too fast, and this fault, like the others, shows the method of correction to be used by its nature. This problem can be corrected by making the slide ends shorter if the banking pin strikes the slide at both ends, or by cutting back one end when it hits only on one side, if one is convinced after a careful examination that this is the true cause of it and that this correction can be used. Also one can correct this error by giving the pallets the appropriate opening, as stated above, if one should consider this means expedient in the circumstances. With a new verge that is made according to the rules, the last situation cannot occur; thus it is important to take the greatest care when making it.

There are also other variations:

First, if the slide ends are too short it would be ridiculous to correct this fault by putting in two banking pins in a new watch; this should only be done during an overhaul in order to save the owner money. The second case can arise from a too long or too short banking pin. In the first instance it can touch the plate or hit the rack; if it is too short it can go over the slide and thereby come to a standstill. Third, the error can be too much play in the escape wheel, which is corrected by loosening the adjusting screw of the counter-potence and pressing on the counter-potence so that it moves towards the bottom of its notch. Fourth, if the verge pallets are too closed this means that in a new watch a new verge should be made, because as previously mentioned it would not be proper to correct this fault by making notches in the pallets that would disfigure them.

As similar repairs are needed when watches are overhauled, the workman must know how notching should be done to ensure that the watch owner does not have to pay too much.

To notch the pallets a small burnisher is taken that is somewhat narrower than the pallet on the verge which it is desired to notch. With the left hand the pallet is laid on a filing block and with the right hand the burnisher, which is covered with moistened oilstone dust, is rubbed straight through the inner edge of the pallet without passing over the sides. The cut is made as flat as possible. In order to open it more, pressure is put on the burnisher so that the oilstone has more effect at the edge of the pallet than on the body, until the body and the edge are alike. When this has been done the inner side of the cut is polished flat so that the teeth of the escape wheel can run more lightly: if the pallets do not have enough opening, the same work is done on the other pallet.

141 *Anprallen*. Knocking occurs when the banking pin strikes its stop during normal balance movement.

There is another way to open or close pallets; namely the verge is heated in the center and turned sufficiently as shown above; which, when one understands how to do it, is the best method.

Now my pupil has finally progressed so far that he has made a working watch from the easiest to the most difficult part, that can be put into a brass, silver or gold case and fastened by a hinge, whereby nothing more remains other than to gild the plates, the balance cock (that is decorated by an engraver) and the wheels, and to polish the steelwork and blue the screws.

If the pupil has progressed this far, so that he understands how to copy all parts according to the reasons and rules, he can thoroughly repair all old watches, and especially factory watches. For as I have already shown in the preface (I believe clearly enough), no one is in a position to repair and put a watch in its proper state who does not thoroughly understand how to make all parts from scratch; which is demonstrated today by the dreadful watches that come from the hands of ignorant and inexperienced people.

It is true that more attention is needed to repair a watch, where all parts have to be examined and more errors corrected, than with a new watch. A new one is made from top to bottom according to rules so an error cannot easily occur, and if it does it is corrected by a new part or by an appropriate method. In an old watch there are many and various kinds of fault which cannot be discovered by someone who is inexperienced. All the faults which can bring a watch to a standstill are too numerous to list; they amount to hundreds and to put them all together would require a volume, and if they were all enumerated there would be no thanks for it. How, therefore, can an ordinary cleaner and fumbler who understands nothing, neither turning nor making the simplest part, help as a watchmaker or artist when just one part is broken? Should I be charged with commercial jealousy because I have described everything truthfully about unskilled work for the benefit of the watch owner? Oh No! If I possessed that kind of self interest I would not have written a little book for the apprentice, which I hope will hinder botching a little in the future, so that the watch owner will suffer less damage and less cost.

The scandalously made watches are to the true artist an abomination and if he wants to repair them, or in order not to lose trade must repair them, it often happens that the owner does not understand the need for new parts and improvements and does not want to be cheated. So the craftsman repairs the watch from a sense of duty and takes upon himself the cost in order to avoid an unpleasant situation.

These are the reasons that moved me to write this little book for the student and the laity, so that all those who have been attracted to this art from their birth could be thoroughly informed, as far as it is possible with the pen, of all parts and processes, so that everyone who has the desire to succeed can do so by themselves. Many people might say that botching has not diminished because of this book but on the contrary has increased! To this I reply not at all! and I will maintain the opposite as long as my experience confirms it. The grounds which lead to my belief are these: A person who from birth has felt a great attraction for this art will not refrain from encouraging his interest and keenness for the subject. He will begin by polishing the parts of a wooden Black Forest clock that he has taken to pieces. This stimulates his interest until he moves to finer work, and this he naturally spoils. If he has such a textbook he can easily help himself and gradually reach fulfilment. If this useful and indispensable craft were brought into a guild or in some other way promoted, the destruction of watches would stop.

To stay no longer on this subject I will proceed to the dismantling, examination and repair of new watches; these most certainly require many improvements, which arise from their low price and even more from the low wages which the factory worker receives.

81: Methods by which Watches are Taken to Pieces according to the Principles of the Art

In dismantling and repairing one is compelled to take the movement down and to examine every single part. This operation takes place as follows:

The movement is held by the edge of the plate and attention must be paid not to touch the contrate wheel, because otherwise the pivots break or the wheel is damaged; and even the escape wheel pivots or teeth could be damaged, which is very possible on account of their delicacy. The center of the minute hand is raised by means of a sharp knife moved round it and taken off the square, taking care not to bend the center arbor on which the cannon pinion rides. Then, while protecting the dial, the hour hand is removed from its tube and put aside.

Then if the chain is wound and the watch has not run down, a long thin pin or horsehair is put between the crossings of the contrate wheel so that one end touches the pillar plate and the other rests on the edge of the top plate and touches the nearest pillar. This pin must not be touched so that nothing gets bent.

When these precautions have been taken and the wheelwork has been brought to a standstill the screws of the balance cock are removed and the cock is taken off together with its screws, without the balance tangling with the balance spring. When this part is lifted off it is taken with its screws, so that they do not get lost, and put on a piece of paper on the bench and covered with a glass. These precautions are also taken with the remaining parts.

After the balance cock has been removed, the balance spring pin is removed from the stud with tweezers, and one must remember not to bend anything which could bring the watch to a standstill. When this is done the balance and its spring and anything connected to it are removed by spring tweezers and put under a glass. Then the pin is removed from the contrate wheel and the watch allowed to run down to the end of the chain so that no accident can occur.

Then the slide and rosette are unscrewed and put in a safe place, the dial feet are pushed out of the plate and the dial and motion wheels are taken out with the cannon pinion from its arbor. As a precaution, the mainspring is slowly let down using a key or tongs on the square of the barrel arbor when the click has been released.

When this operation is done, the barrel ratchet with its click and screws are put in a safe place and then the ends of the four pillars are pushed out of the top plate, the plate removed and everything taken off the pillar plate. The chain is removed, straightened out and put in a safe place.

The screw of the counter-potence is removed and the escape wheel carefully removed, taking care that its teeth and pivots do not suffer, and this piece is also be covered by glass. Finally, the screws holding the potence on the plate are removed and then the whole work has been dismantled.

82: The Investigation of each Part of a Movement for Repair

One sees whether the screws which fasten the parts to the pillar plate do not stick out and get in the way of any pieces, and whether the heads protrude from their sinks. When this has been checked it is seen whether the click and its spring function properly. The dial is put on to see whether the parts which it covers are impeded, which must then be modified, and whether the barrette and its screws which are on the pillar plate are in the way.

Then the fusee wheel is put in and the top plate put on to see whether the dust cap has enough clearance and does not hinder the key when winding is taking place; whether the motion wheels interfere with the cannon pinion; whether the winding square interferes with the hour hand, and whether the latter has enough play. All these faults must be carefully remedied.

When this is finished, both plates are tried to see if the pillars fit their holes and the plates can be properly fixed.

Then the center wheel is placed in the frame by itself and the pillars pinned, to ensure that it has enough play. Without these pins one can easily be mistaken, particularly if one or two of the pillars were shorter than the others, and one could easily assume that the wheel had the correct amount of play when it did not. When the frame has been fitted with its pins one should now see whether the extension for the cannon pinion is sufficient, whether the pivot holes are correct or too large and whether the center wheel stands upright in the movement so that the following causes of interference or friction are avoided.

If the wheel projects from its recess it can interfere with: 1) the top of the barrel; 2) the fusee wheel; 3) the verge pivot plate on the potence; 4) the base of its recess because the hole for the pivot is too low or the surface is badly made, and it can easily foul the third wheel if this is sunk in the plate; 5) if the shoulder for the cannon pinion is too small, which is a very great error and which is found too often; 6) if it does not run true so that it makes a faulty depthing and causes friction; 7) if it is soft (that is, badly hammered) so that it rapidly wears away and easily bends; 8) if it is too thick and takes up too much room so that it not only hinders other parts but also gives a bad depthing; 9) if it is too thin or too soft it wears out more quickly; 10) when the pivot shoulders are too thick they wear and cause too much friction; 11) when its riveting is loose it causes stoppages; and finally 12) if its pinion is too thick, too full or too small so that it does not mesh properly.

These are the errors to which this part is prone and they show by themselves the means by which they should be corrected. When all these problems have been investigated and corrected, the wheel is put into the movement as finished.

When this piece has been modified and put in place it is also easy to put the motion work right. For this the cannon pinion is set on the center-wheel arbor to see if the lower part of the pinion touches the plate, which can occur because the center arbor shoulder below the cannon pinion is short. This error is corrected by making a flat recess which must be deep enough to clear the pinion by the thickness of a piece of paper. This recess must be broad enough so that the tips of the leaves do not touch its edge and stand free.

The fusee wheel is put in to see whether its meshing with the center wheel is correct, which can be recognised by the meshing of the teeth of the wheel into the pinion. If it is too strong or too weak the wheel is moved by means of a depthing tool to increase or decrease the depthing.

I cannot avoid advising the repairer or examiner about the faults that one often finds in the pinions of common watches. They are often too thick or run badly and are not central on their arbors. Before a watch is dismantled one must thoroughly examine whether the pinions have the required strength in order that they may be properly adjusted.

To put the pinions to their proportionate strength one rotates the wheel which meshes with them. Then the pinion is examined to see whether the leaves are too thick. If this is the case they can be dealt with in the following way: A mark is made on the riveting of the pinion arbor and on the wheel by means of a graver point, and the pinion carefully hammered off on a stake. It is then turned with an extra good rounding-up file, and if the pinion is too hard with a graver, smoothed and polished and re-riveted according to the previously made marks.

A second method is to hold it by the finger tips and lay it flat on a filing block held in a vice. With the other hand a well sharpened, hard graver is taken, and the upper surface of a leaf is cut equally for its entire length where it is too thick. The same is then done to all the leaves. It is better that this is done many times in order not to remove too much in one operation. This is carried on until the necessary strength is reached, and this can be done with all other leaves and pinions. If this were done in the turns, the pivots would easily break.

When the pinion has reached its correct size, each of the leaves is rounded with the angle of the graver taking care that the adjacent leaves are not damaged. They are cut through their length as equally as possible on each side, so that both angles of the leaves form 3 equal faces of which one is to the right and the other to the left. Then the small corners are removed, which makes a good rounding up.

This operation is done on all the leaves. They are smoothed and polished and so the pinion is put into the condition necessary to carry out its task well. This can now be done to all pinions that are too large.

After this, the motion work is given attention. The cannon pinion is set on its pivot, the minute wheel is put in its place and the depthing tried. If it is too deep or too shallow then the hour wheel is put in and it is seen whether this is also too deep or too shallow. If that is correct and otherwise the wheels and pinions stand in good relationship to each other, if it does not have pipe there is nothing else to do but to set the minute wheel deeper or shallower by turning a bush and riveting it in, or to make the wheel larger. If it has a pipe, as most minute wheels do, this is turned away and a pivot of the correct thickness is put in. If the lower engagement with the minute wheel is correct and the hour wheel is too deep with the minute wheel pinion, the hour wheel is turned enough until it fits. If this depthing is too shallow there is nothing to do but stretch the hour wheel by hammering it larger, provided it is not the pinion that is at fault and it is too small compared to the teeth of the wheel. It depends whether the wheel is thick enough to be hammered out; in the first instance the pinion must be brought deeper so that the mesh with the hour wheel is achieved and the minute wheel turned away.

Then both wheels under the dial are given the necessary amount of play and the hole in the dial is filed big enough for the hour wheel tube, if it is not big enough to prevent rubbing by the hour hand.

After this there is nothing to do but make a small mark on the end of the center arbor that must be ½ ligne higher than the cannon pinion, where a hole is drilled to take a pin to retain the cannon pinion. This pin, that is rarely fitted on watches, ensures that the cannon pinion and hour tubes cannot rise up and cause stoppages, which often happens.

After this examination and adjustment the dial work is correct. Now the dial is taken off, the motion work removed and the pins taken out of the movement so the center wheel can be removed. The barrel click is then fastened by its screw to see that the screws of the dial work do not project inwards from their holes and interrupt the moving parts. When this fault has been corrected their heads are polished and blued.

Then the spring hook in the barrel and that of the barrel arbor are examined and they are checked for length and undercutting, so that the mainspring does not come off but is firmly held. Then the mainspring is wound into the barrel.

After this the barrel is put into the frame, and this must not be forgotten when overhauling a watch. Having placed it, it is seen: whether it stands up straight or it is inclined and touches above or below; whether the clearance is sufficient; when it touches nothing and is upright, whether the end of the square interferes with the dial; whether the space between it, the adjacent pillars and the rear of the potence is sufficient in order that the chain is not interfered with, which would cause stoppages. After this, the hole for the chain hook is examined by putting the hook in place and seeing whether it lies comfortably on the barrel; otherwise it would be a major fault as it would probably spring off the first time it was wound. Then it is seen whether the barrel comes too close to the center arbor or the escape wheel teeth. The nature of these faults show the methods of their correction without weakening the moving parts.

When the work on the barrel is finished it is taken out of the movement and the spring is wound to see whether it is fixed at both ends and how many turns it makes; so that when the movement is assembled again, its turns correspond to the chain and it can be given the right tension.

Now the winding is examined. It is seen whether the fusee wheel collet is too tight, whether it is too large for the concavity in the wheel and whether it holds wheel firmly. Further, whether the fusee click and its spring are in good order, whether these parts prevent the wheel from being straight or whether there is too much pressure on them, and whether the end of the screw of the fusee cock extends too far and catches the fusee beak or the stop piece.

When faults are found in this examination they show by their nature how they should be corrected. Then the wheel and the arbor are cleaned and a little tallow is put on the arbor to lubricate it, so that when the wheel is fixed it can easily turn as the chain is wound.

When this is done and the arbor and all that belongs to it is put in place it is seen whether the head of the fusee beak stands out from its hole, which could cause pressure on the plate, as also when the end of the screw and the feet of the fusee cock project, which should be corrected immediately.

It is also seen whether the fusee cock is firm, whether its steady pins are fast and whether the screw grips properly. If so the fusee is put into the movement to examine its pivot holes and see, if it does not stand straight, to which side it leans and on which side it must be corrected. In this case the center wheel is put in and the depth tried, after which it is apparent whether the wheel must be brought deeper or shallower or if the depthing is correct. If the depthing of this wheel in the center wheel pinion is too deep it can be turned off a little, or a turned bush put in and a rat tail file used to correct the depthing towards or away from the centers.

When the distance between the fusee wheel and the plate is too small, so that the wheel touches the plate, it is turned, if its thickness allows, a little thinner, smoothed and polished. However, if it is already thin enough it must be brought higher by a bush or, if the difference is only small, by a punch. If the beak touches the top plate there are three ways to correct it. In the first case the beak is made thinner when it is possible and it has too much thickness. In the second case the top plate can be turned away a little with the correct turning tools, a centering tool and a hook tool. And thirdly the fusee can have a little turned off it.

When making the fusee wheel it must be made too big rather than too small, so that before it is rounded up it is easier to reduce it to get a good depthing; it is only when repairing a watch that one finds the depthing too shallow. To correct this fault it is certainly best to make a new wheel of the correct size; to avoid spoiling the faulty one so that it might perhaps be used on another occasion.

As soon as the fusee is properly set up and its clearance and depthing are correct, the barrel is put in to see whether the wheel of the fusee touches it. To correct this fault is not very difficult. The thickness of the barrel is reduced a little and it is then polished again. When the fault is very prominent it is better to make another barrel a little smaller than the first or to move it with the aid of turned bushes. When this has been done the examination of the first three mobile parts is complete and one now works on the chain guard and its spring.

The fusee is put with its small pivot in the top plate and it is seen whether the stop piece forms a right angle with the beak, which is measured with a small square by putting one side at the pivot hole and the other on the edge of the beak. It is easy to see whether the stop piece is of the correct length and forms the correct angle. This length must be exact if the chain guard is to be certain, for when the stop piece is too long, which often occurs in new watches, it easily happens that a violent winding bends it, and if it is too short the same thing can happen, especially with a weak stop piece. If it is too short a new one must be made with due care to prevent the owner from displacing the chain by this part. The end must be thick enough so that the beak cannot glide over or under it and the stop must be far enough from the grooves for the chain that it cannot rub on them which would cause a stoppage.

Furthermore, the face of the beak must go straight into the notch in the head of the stop piece and have enough clearance that it stands freely and cannot not shift. Also the spring should not be able to lift the stop higher than necessary, and the beak should not pass freely below the stop piece. This beak should only be as thick as necessary to ensure that on winding the chain does not run over the stop and when running down it does not touch the stop.

When this has been taken care of we pass to the third wheel, whose correction and setting requires a lot of diligence. This wheel, which like the contrate wheel is supported by a barrette under the dial, must stand exactly in the center of its recess in the movement so that it does not touch the edges; this barrette is necessary for the gearing as has been previously drawn on the calibre. The place for this wheel is the middle of the space between the bottom of the center wheel and the barrette. It must stand equally from both parts so that it touches neither, which could cause a stoppage.

The holes for its pivots must be well placed, the pivots run free and not have too much play. For this the depthing with the contrate wheel and the center wheel is examined. If the former is good but that with the center wheel is too strong or too weak both are put in the depthing tool and a mark made where the hole should to be.

Before the depths are examined it must be ensured that the wheels are truly centered in relation to their pivots. If this is not so the wheel is put in the turns and the teeth trimmed with a file; otherwise there might be a bad depthing.

The pivot holes on the pinion end need more care than those at the opposite end, because the pivots at the pinion end must resist the pressure from the wheels and can wear quickly and give a bad depthing.

Now the contrate wheel must be dealt with. The ends of the pivots are placed in the figure-8 calliper to see if the wheel is evenly poised. If this is not so the inner edge of the wheel is filed where the weight is greatest. One checks to see that the teeth are of equal height and concentric; if they are not, it is put on a stake and corrected with a punch.

When this has been dealt with, it is seen whether the pivot holes are good and in the case of errors they are corrected immediately. The escape wheel is put in to test the depthing of its pinion with the teeth of the contrate wheel so that it is known whether it has to be raised or lowered. This is done by altering the pivot holes so that the depthing is corrected and the wheel receives its correct amount of play.

Finally the screws holding the parts on the top plate are examined. It is seen whether they sit properly, whether they project from their holes and whether they rub against anything, which naturally must be corrected. Their heads are polished and then they are let down to blue. In this condition they cannot cause any interference with moving parts.

Now the escape wheel is examined to see whether it moves correctly, and if the pivots are too thick they are reduced and the arbor rounded. Also the steel plate end-pieces for the holes are polished when this has not been done, as is usual in factory watches. Now it is seen whether the teeth of the escape wheel are equal, and whether they are too thick or too sharp; the former is corrected with an escape wheel tooth file, the latter with a polishing file.

When this examination is finished, every part of the movement is carefully polished with a soft brush and burnt mutton bone dust or fine chalk. When the surfaces are dull and do not shine enough, spirits of wine are mixed with somewhat finer chalk, the mixture put on the parts with a paintbrush, and they are polished till they are dry, the dust removed and the holes cleaned with peg wood.

As I have shown how a watch is taken apart, I will now show how the parts are put together again.

83: How a Watch is Put Together again after it has been Cleaned

In order to make assembly easier, the pillar plate is put on a brass or wooden ring from 8 to 10 lignes high, which has been put on a sheet of white paper on which all polished parts are placed under a glass so that nothing is lost and they can be easily distinguished.

When the plate has been set with the pillars upward, each of the parts is picked up with spring tweezers and put in its place. One must not touch anything with the fingers or the polish will be spoilt. Firstly the third wheel is put in its cavity, then the center wheel in its place, then the fusee with its square and the barrel with its square. After which the running of the chain is considered, and it is confirmed that it hangs properly so it is not necessary to remove it again, which would spoil the polish. Then the pivot of the contrate wheel which is on the pinion side is put into its hole.

The top plate is then put on a piece of white linen with its inner side upward; the linen must be old and worn so that its softness protects the gilding and there are no hanging threads. This linen is taken in the left hand so that one can set the pieces which are on the plate with tweezers in the right hand.

When the plate has been so arranged, the potence is taken in the tweezers by the head of its screw plate with the nose towards the escape wheel, and the foot slid into its place; then the screw which fixes it is screwed home.

Then the chain guard stop piece is put in place and fastened with a suitable pin so that it has no play in its length. Then its spring is put in; however, if the stop piece spring is made with a hole that surrounds the stop stud, the spring must be put in first.

After this work an oiler is used, a small tool that the watchmaker makes himself from a pin-shaped piece of brass. It can be 3 inches long and its small end resembles a bent hook, or better, a pointed head filed round the neck, which picks up the necessary oil drop and puts it on the pivot.

The oil used for watches must be specially made and as good as it can be, because it deteriorates easily and it can stop even the best watches. Very often we watchmakers are deceived by it, and we shrink from the prices necessary in order to get the best. The oil that we use must be kept in a small, well-stoppered bottle so that neither dust, sunlight nor air can spoil it. When it is used, a drop is put into a small, clean watch glass that is immediately covered with another glass. This oil must be renewed every day.

Returning to our assembly, the oiler is taken, the necessary oil picked up and put it in the hole for the verge from the balance side, and in the escape wheel hole. The pivot holes are not given more oil than they can contain excluding the rims. Too much oil sticks to the wheelwork, remains in places where it does not belong and mixes with the dust that is in watches, and makes them gain or completely stop.

When the oil has been applied, the counter-potence is put in its place at the edge of the top plate and it is held a little open with one of the fingers which holds the top plate, and with the other hand the escape wheel is taken in the tweezers, its inner pivot is set in the potence nose and the other pivot in the counter-potence. Then the counter-potence is pushed home, the plate is turned over and the screw fastened.

Then the play of the escape wheel is increased or decreased by means of the screw, but only as much as is necessary for it to run free, because too much play would make the escapement motion smaller and too little would stop it.

With this wheel in place, the rear pivot is oiled and the wheel blown lightly from the side, to see whether it is completely free and moves easily; and if this is not so, the fault must be corrected before the top plate is put on its pillars.

After this examination, the top plate is put on the pillars of the pillar plate with the escape wheel underneath. The frame is now held with softer and whiter linen, and with the right hand the pivots are guided into their holes using tweezers. After this, two of the pillars are secured by provisional pins so that the pivots cannot come out of their holes, and then the remaining pins can be put into the two empty holes. Then it is seen whether the wheelwork stands free and runs well; if this is not so the cause must be found so that the error can be corrected.

Good pins are made out of hard brass. They must be well rounded and filed only slightly tapering so that they completely fill their holes and project from them for only about 1½ lignes on either side. Both ends of these pins, as well as the body, must be rounded and polished.

After the movement has been fixed by its pins and everything runs freely, it is put on the paper with the long arbor upwards so that the pivots of the center wheel and the cannon pinion can be oiled. Now the ratchet is put on its square on the barrel arbor and the click screwed in so that it falls by its own weight into the ratchet.

Then the chain hook that is intended for the barrel is examined; it must have a projection which will hold it and remain firm. This hook is then put on the barrel in the small sloping hole which is under the chain protector, and the thumb held over it so that the hook and the chain are held fast as the chain is rolled on. It must be noted that the chain must go inside the pillar that lies between the barrel and fusee. Then the end of the barrel square is held with tongs in the right hand and the chain rolled on until only half an inch of the length remains unrolled. It must be ensured that the ratchet and click are in good condition to hold the chain, and then it is pulled out ½ inch further at this end and held by the left thumb, so that it is possible to easily pick up the end in the tweezers, from between the pillar and the fusee, and to fasten the hook at the end of the chain in the bottom of the fusee. The thumb is then taken off the barrel, because now the chain is pulled by the barrel and it cannot rush back.

Then it is calculated how much the chain and the spring should be tensioned. Assuming that the spring, before it is put into the movement, has 5¼ turns, and also assuming that the chain needs only 4 turns to wind onto the fusee, then 1¼ turns of the spring remain. This is divided in half, or at most ¾ of a turn extra to wind. This can easily be seen from the square, and so the mainspring can be set up with the tongs. As it is necessary that the spring is set up only half the extra turns, it is given ⅝ or at most ¾; this is to ensure that the tension is in good relationship, and the turns of the tongs can be counted by the square on the barrel, each of the faces being ¼ turn.

As I have remarked, a spring too tightly tensioned can break. Further, a spring too highly tensioned can cause irregularity because it will pull more at the beginning than at the end, which should not be the case because the force must remain equal and be controlled by the shape of the fusee. This can be ascertained by the adjusting rod, which should not only be used in making new watches but also in repairing factory watches, and it is very necessary in old watches to ensure the correct force.

If the watch has not enough power it will run fast to begin with and slow at the end. Even in the most humble factory-made watches the fusee is in the right relationship to the barrel, which ensures the fame of the maker even though he must work quickly on account of the low wages.

However, in old watches the fusee is pointed or almost equally thick. In the latter sort, if one does not want to alter the fusee there must be a spring with a large number of turns to get even power. In the former case, which is more common, a spring with fewer turns is needed. When the power has been corrected, the pivots on the dial side are oiled and the motion work and the dial are put on the plate and fastened. Care must be taken that the parts between the plates are not constrained.

If the fastening pins are too near the edge of the movement they would hinder opening the watch, and when it is shut they would be caught by the case and could easily come out and fall in the movement, which would stop it. Then the rosette is put into position and screwed fast, the regulator hand put on its square and set in mid position, and the middle of the rack is slid into the pinion. Then the slide is put on and fastened. It is then seen whether the rack functions properly or if it is too free or too tight. These faults are corrected immediately and the means of improvement are obvious.

When this has been done, it is seen whether screwing pieces up tight has trapped various parts in the movement, which could harm the running. The edges of the plates and the visible parts are polished in case they were dirtied during assembly, but it would have been better to do this earlier, before the pivots were oiled. Then it is seen whether the pivots of the verge are well rounded or whether they are scratched which would cause a stoppage. This must be dealt with at once before the verge is put in place.

Then the balance spring is inspected to see whether its coils have been bent, and if so they must be immediately corrected, as well as the verge and the balance.

When all is ready, the verge is put into its hole in the potence beside the teeth of the escape wheel and the balance spring stud fastened so that the spring comes in the middle of the curb slot in the rack. There are curbs that are flat and use two pins to hold the balance spring, and there are others which are raised and have a suitable slot to take the spring, without it touching the edge or the bottom, much less the plate or the stud. As soon as the balance cock and its pivot hole have been cleaned, it is oiled and fastened by its screws.

Then it is seen whether the verge has the correct amount of end play, or too much or too little. If it has too much the upper part of the balance cock is hit with a small hammer inwards, and vice versa. This is done before putting on the chain.

Disturbances of the balance are caused by: pivots that rub in holes that are too narrow; too little play for the balance or the escape wheel; a badly formed balance spring; a poorly soldered balance seat; the balance cock screw projecting through its hole; the balance being badly riveted on. Further, if the curb piece is too short or too long, the pins too close or too far apart and not concentric with the spring. Other disturbances can be caused by the rack if it is too long, by an elevated balance spring stud, and by the balance rubbing on its cock or the slide or the inner edges of the feet. The balance cock screws can also interfere if they extend beyond the feet, and a banking pin that is too long can touch the rack or the notch in it, which interferes with the freedom of the balance. Finally the balance is also disturbed if it rubs on the edge surrounding the slide. These errors must be sought out and corrected before the balance spring is put on the verge.

When these examinations and corrections have been dealt with, the chain is wound half way on the fusee without fear of it recoiling or springing off, and it is seen whether the balance moves freely or whether any disturbances occur which need to be corrected.

Then the chain is arranged on the barrel so that it runs onto the fusee correctly and does not tangle, which causes a watch to run down six hours early and the chain to recoil onto the barrel, which often causes it to break.

If the movement is well made, finely polished and put together with the great care which the work deserves, it is not difficult to keep it in good condition, especially when the balance spring and the balance are suitable for the escapement.

When the movement has good and regular vibrations it often needs regulating, which can only be effected by means of the balance spring, which must be lengthened or shortened until it is regulated. When one has put the balance spring stud in its hole, the balance is usually out of step and beats unequally; which is corrected by turning the collet. If the watch is one hour slow in 24 hours the balance spring must be shortened to increase the vibrations by $\frac{1}{24}$; that is, as the watch has only recorded 23 hours in 24 the vibrations must be made 24 for every 23.

The outer end of the balance spring, depending on whether it is weak or strong at this end, is pulled more or less through its stud. If it is very weak at the inner end it is better if the outer end is repeatedly broken off in lengths of about 1 ligne and tried again, which may amount to one turn. By this repeated fastening the escapement becomes naturally deranged and must be adjusted by turning the collet. Most factory watches that are repaired have the spring too strong, which often means a new, weaker one has to be found. This is especially a problem for the country maker.

To help in this situation, to make the spring weaker, the following methods can be used. Some people dip the spring in aqua fortis and etch it somewhat weaker, afterwards rinsing it in pure warm water and laying it in fine oil when it is dry. The second method is better. The spring is laid flat on a flat oilstone and rubbed evenly with a cork and good oil. If this is done with proper care the spring remains in shape and a correction is seldom needed. The third method scrapes it with a sharp graver on a flat surface and finishes it with a small oilstone or polishing stick. There is a useful small tool for doing this. It is made out of brass or steel about 15 inches long and 5 or 6 lignes wide. The underside is put in a vice and the top is filed flat lengthwise. On one end there is a steel plate with a steel peg and a small hand-screw by which the end of the spring is screwed tight under the plate. When the spring is fastened so that the flat side lies against the tool, a thin burnisher is taken, or another suitable tool, and it is laid on the spring and scraped from the secured end, applying as much pressure as is considered necessary. This scraping always runs from the point of fixing and never the reverse, because from this side it has a secure stop. If deemed necessary, the tool can be provided with another small screw and the spring fastened at the other end by a small screwdriver, which is only necessary for a less experienced repairer. If there is a suitable turns the above tool can be dispensed with. The turns are put in the vice as usual, the left runner removed and the tool rest taken off. Then the spring is slid between the bed and the tool-rest support and fastened with the securing screw. When the spring has been properly weakened it is put in position on the balance and the watch set going.

Now that the movement has been properly restored, a pair of appropriate hands for the dial are sought.

The pipe of the hour hand is filed out equally with a round file so that it fits on the hour wheel pipe. Then the hand is put on an appropriate runner, the pipe properly turned so that the latter does not rub on the dial, and as much of the length of the pipe is turned off so that the hand lies as close to the dial as possible with the cannon pinion and hour wheel in position. Then the hand is bent to match the curve of the dial. If the hour pipe stands more than a card's thickness above the hand it is turned off. Now the square on the cannon pinion is examined to see that it is filed correctly, so that the square begins close to the hour pipe; if this is not so the square is filed down. The square in the minute hand is filed with a square file so that it goes on the square of the cannon pinion. Then it is finished with a sharp file and the hand is bent to the curve of the dial.

Care must be taken that the minute hand does not wobble on the square and does not touch the glass above or the dial below, and does not lie too close to the hour hand. Further, the minute hand must not be disturbed by the key, whereby the hands might rub each other and stop the watch, which often occurs. It must also be seen that the cannon pinion fits its arbor exactly, that it does not lift and it is not too tight or too loose. The rising of a cannon pinion can be easily prevented by means of a hole which is drilled in the center arbor just above the square and in which a pin is placed; provided the arbor stands above the square or a little can be removed from the square. If the cannon pinion rises, the hour tube and the hands rise too and the motion work under the dial can disengage, which can upset even the best watch. If the cannon pinion turns too hard its hole is slightly broached out, because otherwise the center wheel teeth, or even the teeth of the third wheel, can be damaged by a violent setting of the hands; also this can cause the escapement to overbank. However, if the hands run too freely, they often stay still even though the watch is going. When only a small difference is needed a hair can be put through the tube of the cannon pinion and in this easy way the cannon pinion can be made to go. It is always better to file a lantern on the tube (that is, the cannon pinion is flattened on both sides) and the ribs are hammered slightly together. However it must be ensured that from the beginning of the square down to the pinion a section the thickness of a card is left so that the hour pipe has a firm support, and the square for the minute hand has enough length above the hand that the key does not wander during setting.

The reader will at last recognise that only by the maximum care and patience can a good movement be restored, and that the slightest carelessness can lead to irregularity, not for an instant but for the future of the watch, however well it is made.

So one completes the machine that by the labour of artists has been created from rough metal and by its construction orders the passage of time. I flatter myself that my task has been achieved by this description and I believe that at no point have I deviated from the true foundation of this art which has been followed by all masters. If I have been understood and followed by friends of the art and the apprentice, their further studies will be made easier as they turn towards higher mechanical knowledge.

84: Conclusion. Survey of the Rotation of the Wheels and the Vibrations of Measured Time

In this survey, the lover of this art and the apprentice will be able to learn the workings and times of revolution of the wheels, and the number of vibrations brought about by the balance, and not less the manner in which the wheels work in their depthings.

The time of rotation of the barrel, that determines that of the other parts and must be measured by the size of the movement, is determined by the chain which covers the fusee and rolls onto the barrel, usually $3\frac{3}{4}$ to $4\frac{1}{4}$ turns. Its running time cannot be exactly determined because, for one reason or another, the watch goes a longer or shorter time. According to the description that I have given, the fusee wheel must have 60 teeth and it meshes with the center wheel pinion of 10 leaves; this results in the fusee wheel revolving in 6 hours and accordingly turning four times in 24 hours. Therefore ten teeth of this wheel mesh with and pass the leaves of the pinion in an hour. Then the center wheel makes one revolution in an hour, therefore 24 revolutions in 24 hours. These are the movements of the first three mobile parts.

The center wheel also has 60 teeth that mesh with the third wheel's pinion of 6 leaves, that wheel having 50 teeth. This determines the rotation of this last wheel to be 6 minutes; therefore it rotates 10 times in an hour and 240 times in 24 hours.

The contrate wheel, which has only 48 teeth and a pinion of 6 leaves with which the third wheel meshes, revolves $8\frac{1}{3}$ times in 6 minutes, therefore $83\frac{1}{3}$ times in an hour, 250 times in 3 hours and 2,000 times in 24 hours.

This contrate wheel meshes with the escape wheel pinion of 6 leaves, causing it to make 8 turns while the contrate wheel makes only one. So the escape wheel makes $11\frac{1}{10}$ turns in a minute or 670 in an hour, 3000 in 3 hours and 16000 in 24 hours.

The escape wheel has 13 teeth which impulse the verge and the balance so that there are 26 vibrations to one revolution of which $4\frac{4}{5}$ vibrations occur in a second, almost 289 in a minute and $17{,}333\frac{1}{3}$ in an hour. In 3 hours it makes 52,000 vibrations and 416,000 in 24 hours.

The wheels in the motion work are moved by the long stem of the center wheel on which the cannon pinion sits by friction and makes a revolution every hour, moving the neighbouring minute wheel once in three hours. This carries a pinion of appropriate size which meshes with the hour wheel which makes two revolutions in 24 hours.

Compact summary of rotation times (in a table.)

The uncertain rotation of the barrel has already been explained.

This is the summary of the rotations and vibrations which the watch will give, if sufficient force sets the balance and the balance spring in motion and they receive homogeneous vibrations from a good escapement.

	in one second	in one minute	in one hour	in 3 hours	in 24 hours
Revolutions of the fusee wheel	-	-	-	-	4
Revolutions of the center wheel	-	-	1	-	24
Revolutions of the third wheel	-	$\frac{1}{6}$	10	30	240
Revolutions of the contrate wheel	-	$1\frac{7}{18}$	$83\frac{1}{3}$	250	2000
Revolutions of the escape wheel	-	$11\frac{1}{10}$[1]	670[2]	2000	16000
Vibrations of the balance	$4\frac{4}{5}$	about 289[3]	$17333\frac{1}{3}$	52000	416000
Revolutions of the cannon pinion	-	-	1	-	24
Revolutions of the minute wheel	-	-	-	1	8
Revolutions of the hour wheel that moves the hand of this name	-	-	-		2

Table notes: 1: Incorrect; actually $11\frac{1}{9}$. 2: Incorrect; actually $666\frac{2}{3}$. 3: Actually $288\frac{8}{9}$.

85: List of Watchmaker's Tools

1) A flat rectangular *anvil* 3 inches in cross section that is set in a wooden block 18 inches high.
2) A *planishing hammer* with a round head about 2 inches in diameter whose sides are flat and the narrow side of the opposite end is about 2 inches long.
3) A *vice* that closes well and is provided with a strong screw for fastening it to the bench. The spindle must be provided with a lever with which the jaws can be opened and shut.
4) A coarse or *bastard file*, also called a *carelette*, 8 inches long, 12 lignes wide and 3 lignes thick. This is used to make pieces smaller and flat. The new ones are only for brass, so long as they cut well. Later, provided their teeth are good, they are used for steel for which they are better than new ones.
5) *Half coarse carelette* or hand file, 5 inches long, 8 lignes wide and 1½ lignes thick, which is used for finishing small pieces and filing them even and fine. The best files of this sort, as is well known, are the English or those designated by T. These make very even cuts and are exceptionally hard. The extremely fine carelettes have the same form and size but their cut is much finer; they bear the same sign.

6) *Filing block*. This is made of beech or an equally hard wood, 13 inches long and 3 to 4 inches square, and finely cut or planed. It is held in the vice so that objects held by hand can be filed on it.

7) File grip or *hand vice* for holding the piece which is being made on the filing block. There is a much smaller form which, on account of its long handle, is called a *handle grip*.

8) *Spring* or *sliding tongs* for holding small parts while filing.

9) *Cutting tongs* which have two cutting blades and are used to cut wire or other soft objects by pressure on the handles.

10) Small and large *flat tongs* with which the hinge pin and other small pins are taken out and, with its flat nose, are put in place.

11) *Brucelle*, *pincers*, *spring tweezers* having two long flat arms with which the balance spring is put in order and the pivots put in their holes when assembling.

12) A *saw* of the size of a tree saw to be able to cut brass and a small *fretsaw* for cutting out or forming the crossings of wheels.

13) A small *protractor* or *square* to examine the surfaces on pieces.

14) A *blowpipe* with which parts are let down or hardened in a flame

15) A *compass* with two sharp points to measure or draw parts, which can be made wider or narrower by means of a screw.

16) A *thick compass*, called a *figure-8 calliper* because of its shape, which is used to measure the size of pieces between its arms. It is also used to see if a wheel runs true when the pivots are put in the small holes bored in the ends of the arms.

17) *Pinion gauge* for measuring pinions and other parts.

18) A small *anvil* on which small pieces are hammered.

19) *Riveting stake* with several holes used for riveting or loosening. These are made of brass and steel. Both are useful.

20) *Riveting punch*, *riveting chisel*. There are several sorts that the watchmaker makes for himself. These tools are small slender pieces of hardened steel 2½ to 3 inches long, although of different sizes and thicknesses. Some are flat at the end, others round to drive holes together or make them narrower. Pinion riveting punches are half round and have a flat surface on one side; others have this surface hollow and are used to rivet wheels onto pinions. The best riveting punches are those with round holes with the holes larger at the rear and hammered together at the front; they should be filed after use.

21) *Hammers*, classified according to size. Some are round and spherical, others round and flat, and of different weights. They have on the opposite end partly round and partly sharp ends for the correction of hardened arbors.

22) *Screw plate* with different sized holes from the smallest to 1 ligne in diameter. It must have sharp threads. Those of Lavousi are considered the best.

23) *Turning bows*. Whalebone or wood that are fitted with catgut according to their size. Smaller ones of different strengths are fitted with horsehair.

24) *Drills* of all sizes. The shovel end is round for steel and rectangular for brass, and the other end is provided with a brass ferrule. There are also very small ones called pivot drills which the watchmaker makes for himself according to the size of the pivots.

25) *Broaches*. These must be in stock from the largest to the smallest and pivot holes are opened out with the latter.

26) *Turns*. The turns with its various runners. The first pair of runners have at one end a point and at the other a depression in which the piece to be turned is set. The second pair has at one end a long pointed pivot at whose end a very small hole is made, and at the opposite end a similar pivot but the side of the rod filed away and likewise a small hole made in it. They are called pointed runners and are used for turning fine pivots.

    The third pair is likewise pointed at both ends but somewhat less. At the ends fine holes are drilled and are funnel shaped, and near the funnel a flattening or lantern is filed on one side. The fine hole serves for the pivots and the funnel for the support of the arbor so that when turning a wheel with fine pivots the pivots do not break. They are called pivot runners.

    The fourth pair belong to the pivot runners. They are about half an inch long and about ⅔ is flattened, while at the end there are half heads of various lengths. In the center is a groove for various sizes of pivot. Behind the head is a screw to regulate the pivot file so that the pivot is equally made (see Plate 5, figs. 1-3 for similar runners).

    The fifth pair is of brass and has on one end heads with holes of various diameters in which the pivots are rolled and polished. The opposite ends are formed like the pointed runners.

27) *Turning arbors* provided in different sizes. They must be accurately round and imperceptibly tapered, dead hard and furnished with good ferrules. They are indispensable tools to the watchmaker. To keep them in good shape it must not be forgotten to oil them when in use.

28) Turning arbor with a left hand thread.

29) A *funnel shaped arbor* with a central screw that presses a funnel shaped tube into the larger holes so that a wheel or other part that has to be turned sits centrally and holds fast (see Plate 3, fig 30).

30) The *balance turning arbor*.

31) *Gravers*, rectangular and sharp that are very hard.

32) *Turning hooks* to turn hollows in parts as necessary.

33) *Sink cutters*[142]. Small cutting tools of various forms and sizes. They are filed on long, round and equally thick rod. They are applied to the place where it is desired to make a sink or decoration through a tube called the cannon, which is centered and held fast by a hand vice.

34) *Spring winder* with which mainsprings are wound into the barrel.

35) *Bluing pans* of various sizes that the watchmaker makes himself out of broad clock springs and thin pendulum spring ends. They are about 5 inches long and are shaped rather like a gutter tile.

142 Incorrectly called *fraises* by Auch.

36) An *eyeglass* to see everything clearly.
37) *Slitting* or *bottom files*, coarse, half coarse and fine, well chosen and strong.
38) *Barrette* or taper point files.
39) *Rounding files*.
40) *Screw slitting* or *cutting files*.
41) *Sage leaf* or *Bird's tongue files*.
42) *Escape wheel files*.
43) *Pivot files*.
44) *Square files* for hands.
45) *Rat-tail files* of different sizes.
46) Fine files for working on pinions.
47) Files for equalising teeth.
48) Pivot polishing tools.
49) *Escape wheel cock files*.
50) *Screwdrivers*.
51) A kind of *hand drill* without a ferrule[143].
52) *Dancing master callipers*.
53) A small tube of brass or steel to drive the steel collet onto the fusee wheel.
54) *Riveting stake* for the verge.
55) *Uprighting* or *planting tool* provided with several rings, to put wheels upright in the frame.
56) *Dividers*. To draw the positions for the pivot holes.
57) *Pen knife* to remove the pins from the frame and the dial, and to remove the hands.
58) A *straight edge* with two sights to see whether wheels and balances run true and round.
59) A collection of steel punches with different heads to beat out cases.
60) An *oilstone* to sharpen tools and to smooth steel pieces.
61) *Pumice* to rub brass flat.
62) *Water stone* to rub brass very fine.
63) *English Rouge* or polishing powder, polishing lime for polishing steel. There are also qualities for gold, silver and brass, but tripoli can also be used for the latter.
64) Polishing steels of various suitable forms.
65) Files of soft iron to smooth and polish steel plates.
66) Small tweezers for hands and screws.

These are the tools the watchmaker uses. The machines, such as those for dividing teeth and those for cutting the grooves in fusees, are not essential and are only to be had at a high price. A watchmaker who needs wheels and fusees cut could well find a friend who possesses these machines and take the opportunity to pay him for doing it.

143 Archimedes drill?

Jacob Auch

86: Explanation of the Illustrations

Explanation of the illustrations in the three lithographic plates, on which the necessary watchmaker's tools, from the simplest to the most complicated, are shown with their various working parts and use, as well as the main parts in building the watch and the calibre. To simplify the instructions in this book for apprentices and lovers of the watchmaker's art.

Plate 7

1) The normal brass drill called an *otter's tongue*. Drills for steel and other metals are round at the cutting edge.
2) The *turning arbor* with which one turns barrels, thick wheels, tubes and accessories.
3) The *figure-8 calliper* with which the sizes of wheels, movements, barrels, etc. are measured. Also, with which the wheels on their pinions and the balance on its verge are tested to see whether they are truly round (for this purpose the pivots are put in the holes in the beaks). For the last purpose many different forms are required.
4) *Pinion gauge* or *dividers,* with which all small objects are measured.
5) The narrow, thin-ended height measurer or *dancing master* with which the inner height, the hollow in the barrel for the barrel arbor, the length of the center wheel arbor, the verge and the barrel arbor in the movement are measured in order to turn the pivots correctly.
6) The normal *dancing master* with feet turned out to find the length of the third and contrate wheel arbors for the position of the pivots.
7) *Dancing master for contrate wheels* with feet pointing inwards. When the escape wheel is put in position the dancing master is put on the top plate over the escape wheel pinion and the point *a* screwed as deep as the contrate wheel should engage in the pinion. Then the feet are set straight across the contrate wheel teeth when the extremity of the point indicates the position of the shoulder of the pivot on the arbor.
8) *Balance spring tweezers*, or *brucelle*, serves to take hold of fine parts when putting the watch together. With it the wheels are put in place and the pivots in their holes. Used mostly for correcting and setting the balance spring.
9) The *riveting stake* seen from above with different holes to rivet wheels on to their pinions.
10) The *riveting stake* viewed from below.
11) The *riveting stake* viewed from the side with the edge to hold in the vice.
12) The *riveting stake* viewed from the end.
13) The *balance cock countersinking drill* for screw heads of equal thickness and equal width.

Plate 8

14) The very convenient and indispensable *sliding tongs* with which small parts are held for filing.
15) The buckle which is slid to and fro to fasten pieces in the tongs.

16) The *depthing tool* to find the depthing of the wheel in the pinion. The points or pivots of the arbors are set in the pierced centers and fastened with the screws *c*. The screw *d* serves to center the parts and, using the steel points *e* as a compass, the distance is carried to the plate so that one point is set in the already drilled hole and with the other a tiny curve is struck.

17) The *uprighting tool*. The stand is flat on the lower plate. The lower point *b* is placed in the already drilled hole while the upper point *c* marks the hole on the other plate. If screws or supports are in the way so that the plate cannot lie flat, a ring *a* is put under it, of which small and large ones, and ones with slots in them must be in stock.

18) The *top plate* from the inside: *a* the potence (the cock for escape wheel and verge pivots); *b* the counter-potence; *c* escape wheel and pinion; *d* escape wheel slide; *e* the potence key, the screw with which the escape wheel is brought to the center of the verge or the escapement is centered; *f* the stop piece or chain guard which the beak of the fusee buts against after winding is complete and stops the fusee from moving; *g* the chain guard stud with a slot in which the stop piece is fastened and made movable by a pin; *h* is the stop piece spring with its screw.

19) The *top plate* from above: *a* the balance cock with its screws; *b* the coqueret; *c* the rosette with screws and hand; *d* the fusee cock; *e-e* the slide feet and their screws with which they are fastened; *f* the counter-potence with its screw; *g* the screw for fastening the steel plate on which the pivot of the escape wheel runs; *h* the adjusting screw for adjusting the depthing of the escape wheel in the verge.

Plate 9

20) The *sector* for measuring wheel teeth. If I have, for example, a center wheel of 60 teeth whose size is already limited by the calibre, I bring the half or whole diameter with sharply-pointed dividers to the sector on the position of number 60. If it is desired to provide the third wheel with the usual number of teeth which is 50, the points opposite each other at 50 are measured with the dividers without moving the sector, so the wheels will correspond in the proportion of their teeth. If this wheel should have slightly smaller teeth a few points less are taken. This instrument is indispensable for the watchmaker, especially in regard to wheels.

21) The *pillar plate* with the pillars shown in perspective: *a* the hole for the center wheel; *b* the circular opening for the third wheel that goes right through the plate; *c* the position of the fusee wheel; *d* that of the barrel; *e* the hole for the head of the boot screw on the potence; *f* the hole for the stop piece; *g* the hinge; *h* the catch; *i* the three holes for the dial feet.

22) The view under the dial: *a* the barrette for the third and contrate wheels with its two screws; *b* the setting up ratchet; *c* the click for setting up the mainspring; *d* the hole for the pivot of the fusee; *e* the shutting catch; *f* the dial spring with its screw which penetrates the catch; *g* the hinge; *h* the three countersunk holes for the dial feet; *i* the position of the minute wheel in the dial work; *k* the hole for the head of the potence boot screw.

23) The fusee with its groove on which the chain is wrapped in winding: *a* the winding arbor with its square; *b* the fusee wheel collet with which the wheel is fastened to the fusee and left movable by friction.

24) The fusee wheel from the side nearest the fusee with the click and its spring.
25) The fusee from the inside and its ratchet.
26) The fusee from above with the snail shaped beak and its screw.
27) The barrel with its boss in the center.
28) The barrel cover.
29) The barrel arbor with its hook.
30) The almost indispensable *funnel turning arbor* which is used for many purposes while pieces are being turned. They may be very thin and have large or small holes, but they run evenly because of the fixing screw, and their holes are not enlarged as is so often the case with smooth arbors. The body *a* is of hard steel, filed four or eight sided, and below is the funnel shaped piece *b* which fits without play on the well turned pivot, underneath which is the nut *c* with a left hand thread. The bell shaped head is brass and has opposite the funnel an evenly turned track and at the pivot a turned hollow for the funnel; *e* is a brass ferrule for the bowstring.
31) The *bird* shown larger to give a better view. The long rectangle *a* is of brass about 1 ligne thick and it is flattened at *b-b* for its whole length so that the lower part forms a foot. The beak *c* is of hardened steel. With its point *d* the horizontal line of the escape wheel pivot hole is found, the spring *e* pressing the beak up so that it can be moved up and down as desired by the screw *f* behind the beak. When the inner escape wheel hole (in the potence) has been bored this instrument is placed on the plate and the beak screwed up or down until the point fits exactly in the already drilled escape wheel hole. The instrument is then turned around in the same position and a scratch is made on the counter potence for the other pivot. It is also used the reverse way, particularly with old watches where very often the escape wheel pinion is not horizontal to the plate and thereby causing a faulty meshing with the verge.

Fig. 1

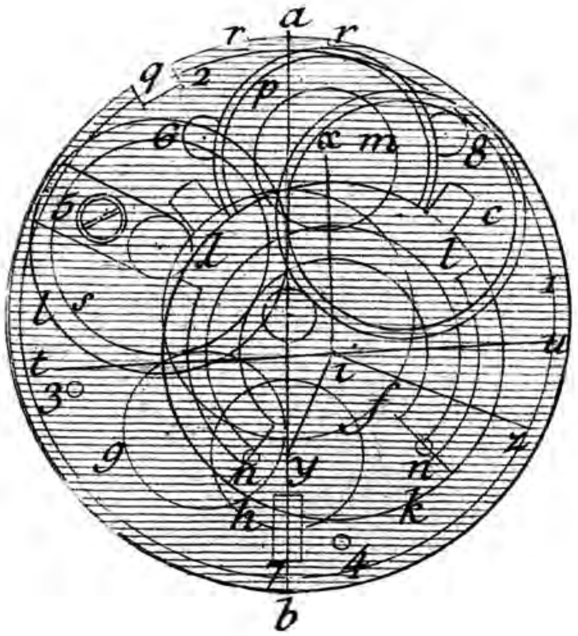
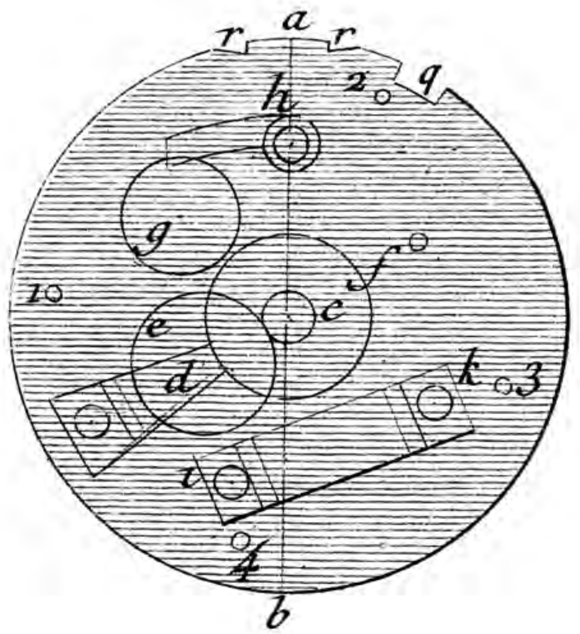


Fig. 2



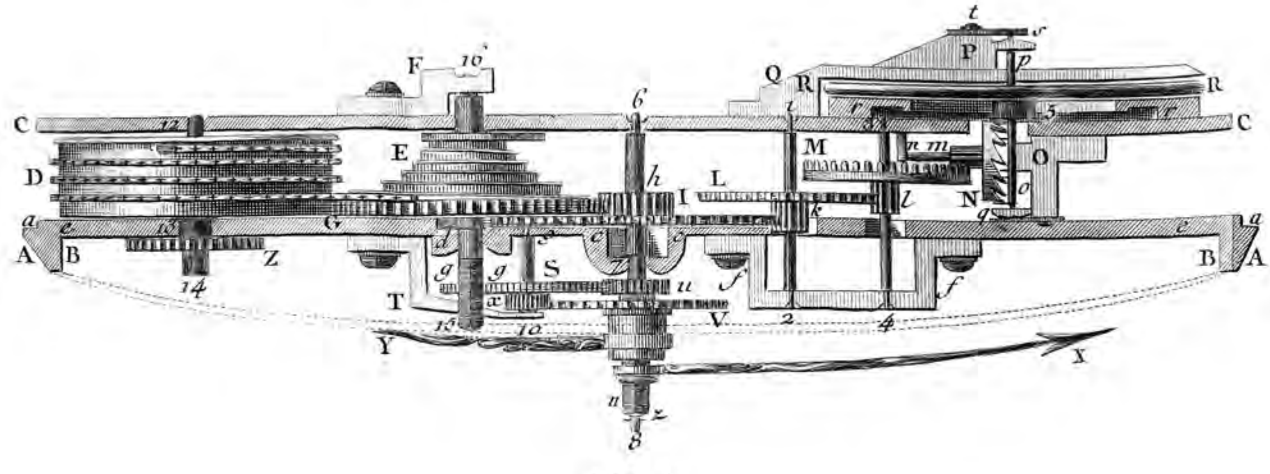


Fig. 4

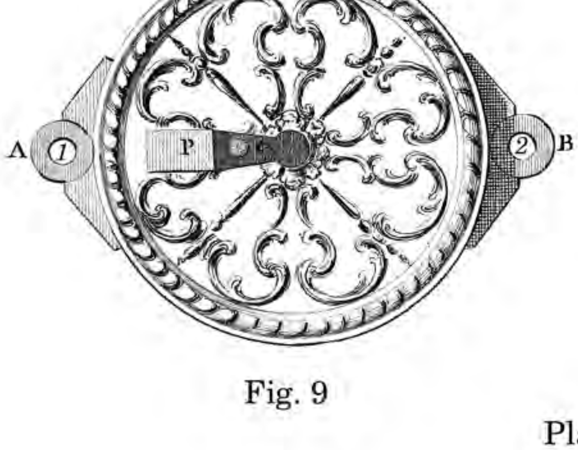


Fig. 9

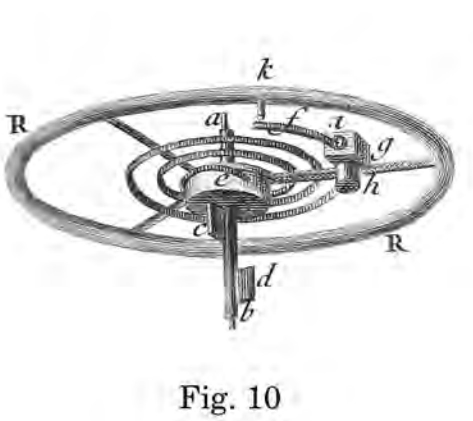
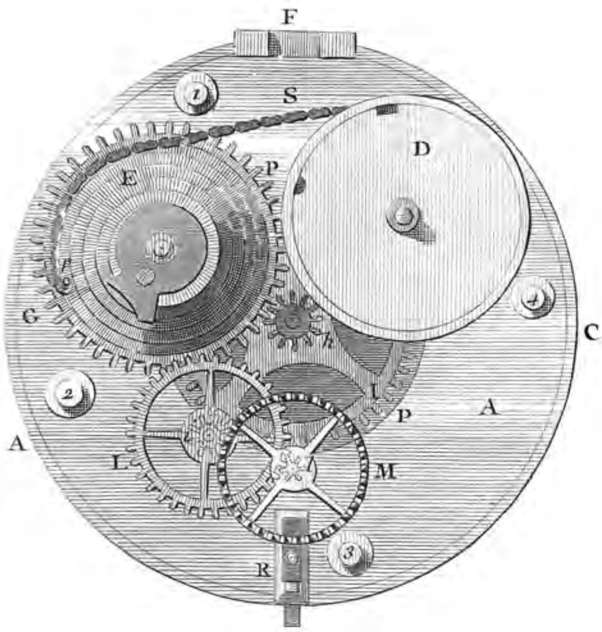


Fig. 10

Plate 1



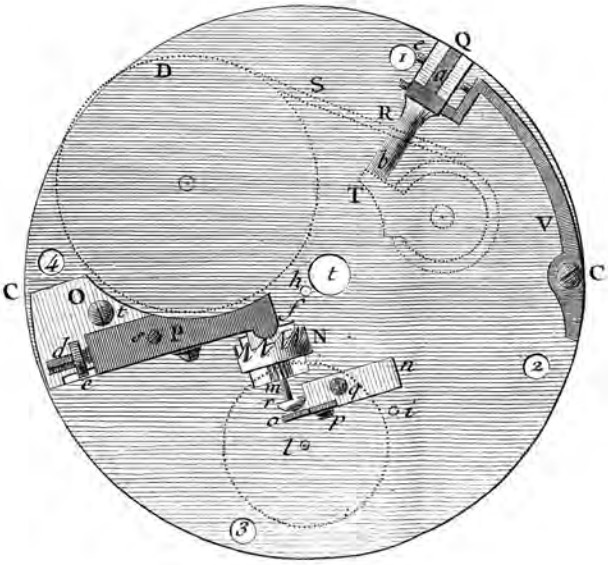
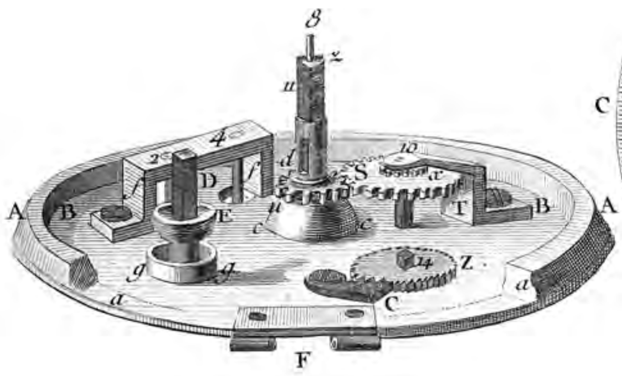


Fig. 5

Fig. 6



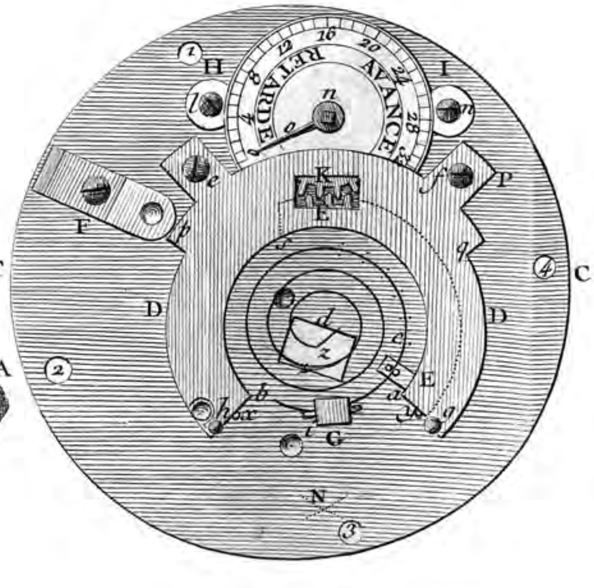


Fig. 7

Fig. 8

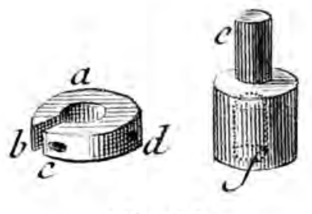


Fig. 11

Fig. 12

Plate 2

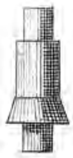


Fig. 1

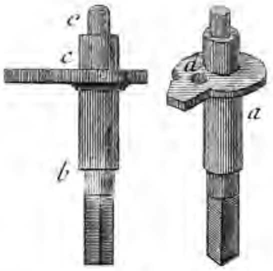


Fig. 4

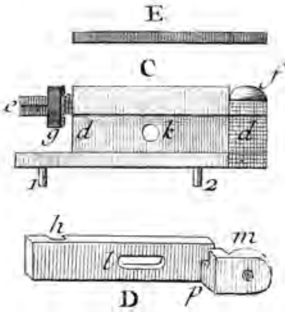


Fig. 9

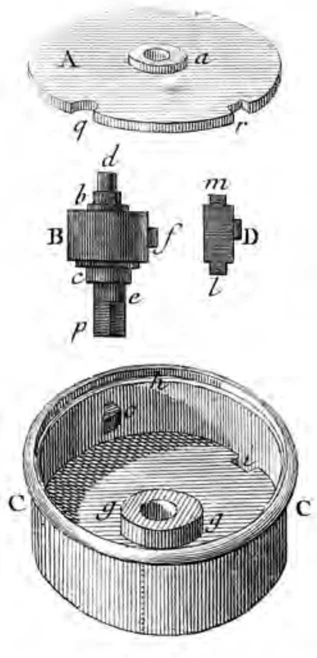


Fig. 2

Fig. 5

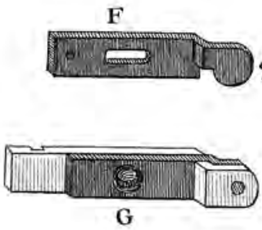


Fig. 10

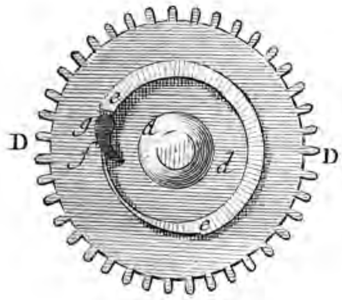


Fig. 7

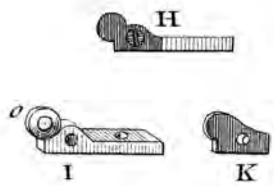


Fig. 11

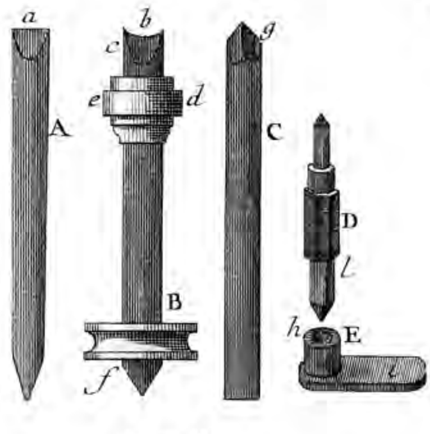
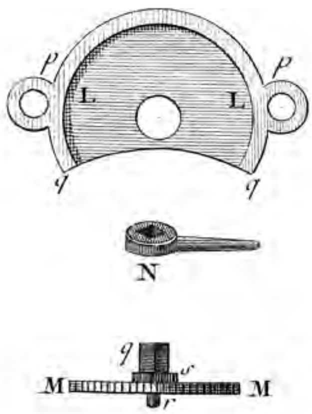


Fig. 3



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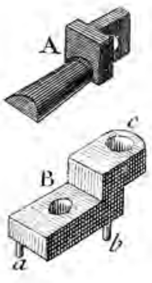

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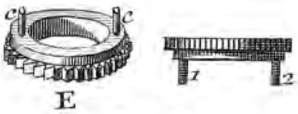
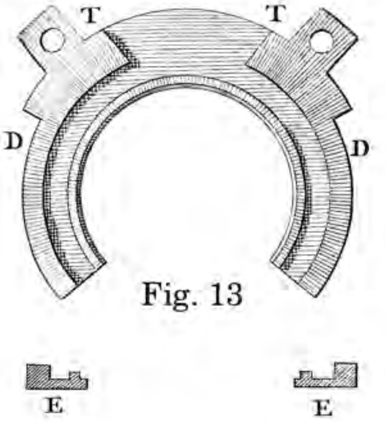


Fig. 6

Plate 3



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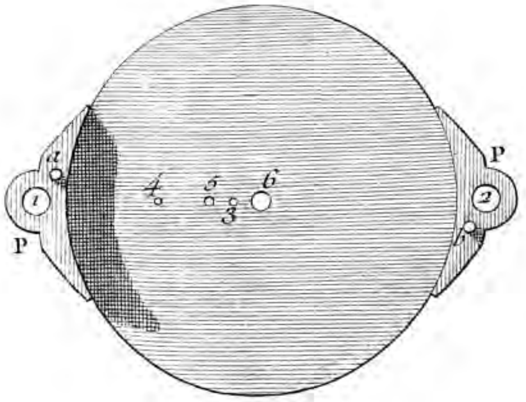

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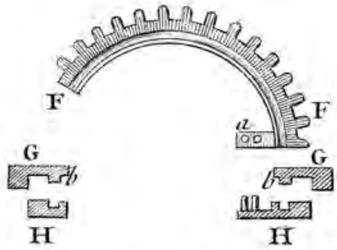


Fig. 14

Fig. 16

Fig. 17

Fig. 18

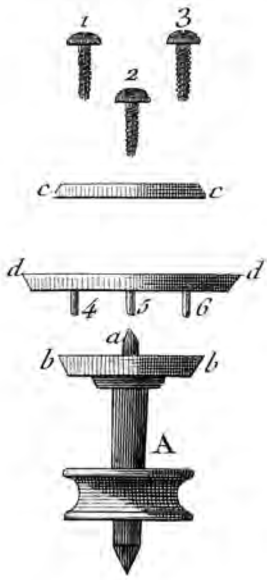
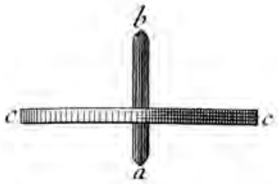


Fig. 19

Plate 4

Fig. 20



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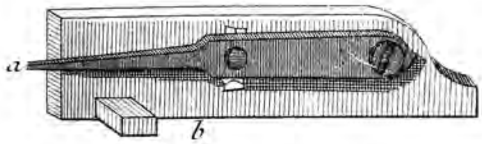

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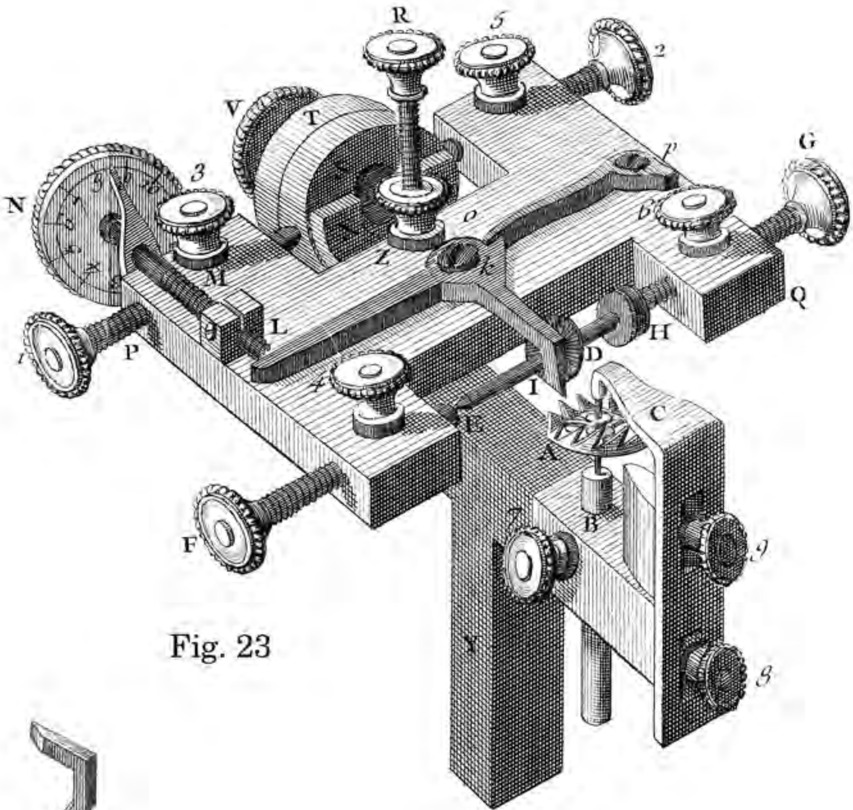

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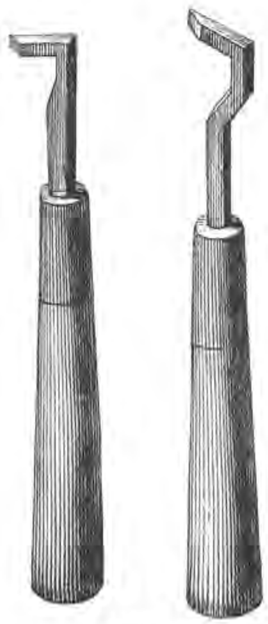


Fig. 1

Fig. 2

Fig. 3

Fig. 4

Plate 5

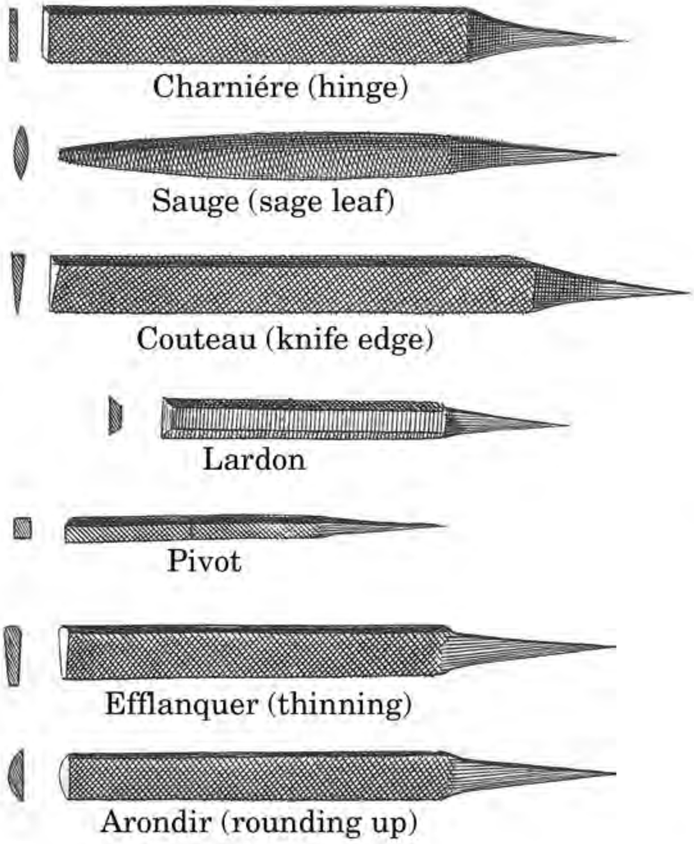
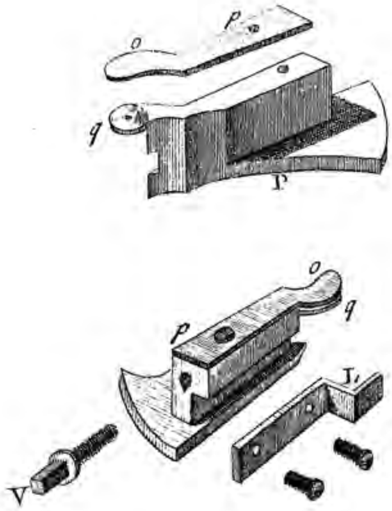


Fig. 1



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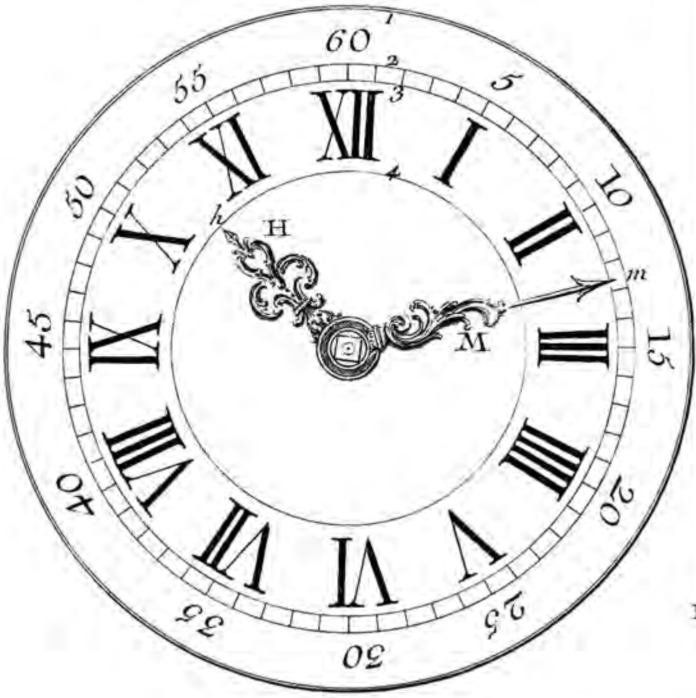

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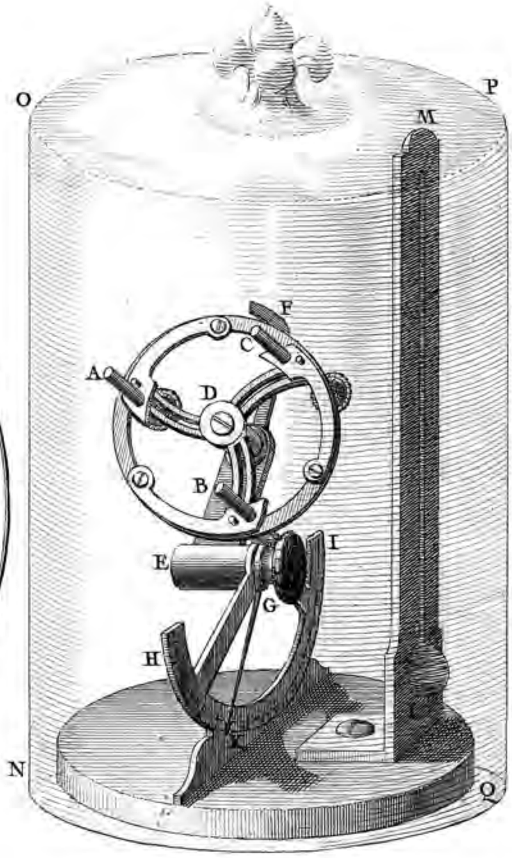

Fig. 5

Plate 6

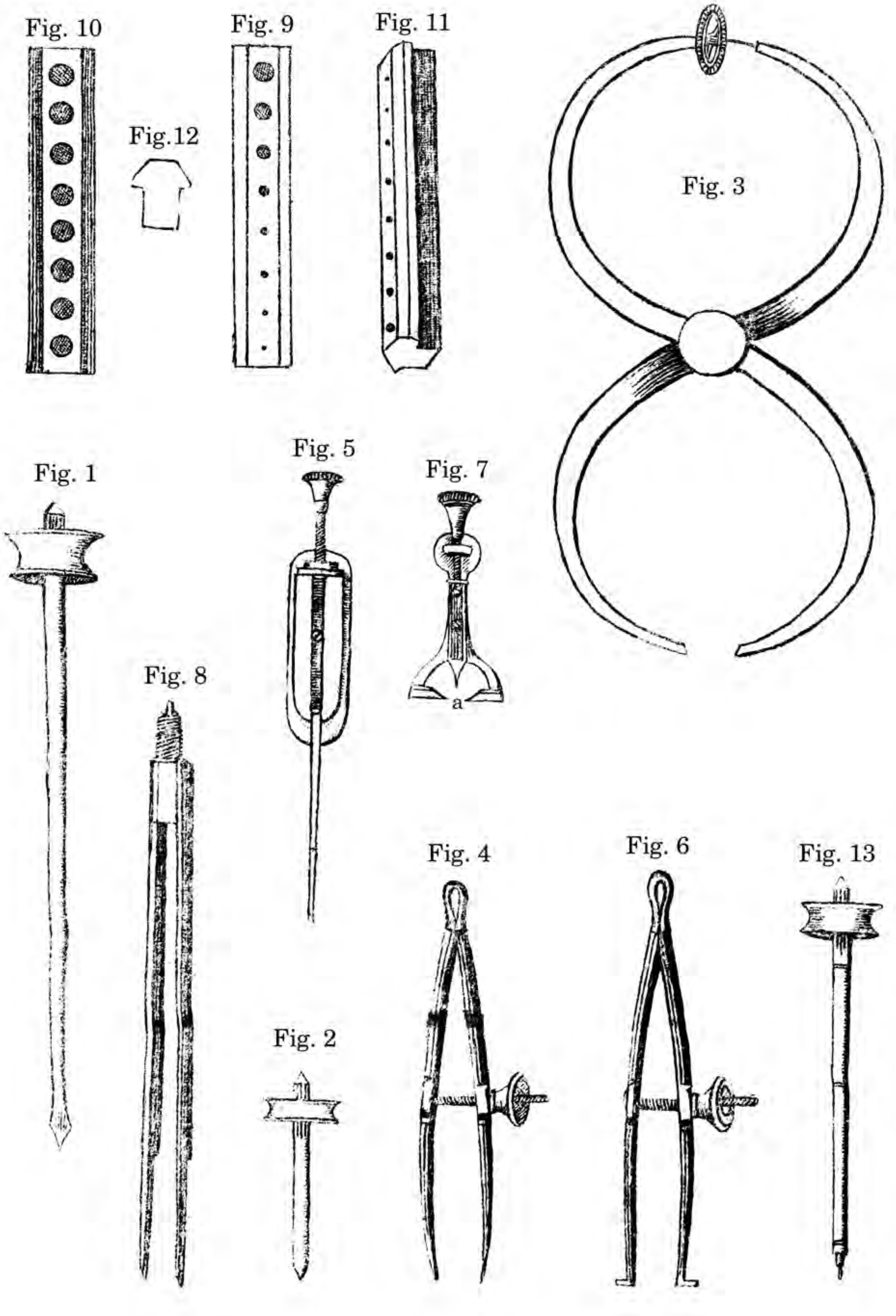
Fig. 10
Fig. 9
Fig. 11
Fig. 12
Fig. 3
Fig. 1
Fig. 5
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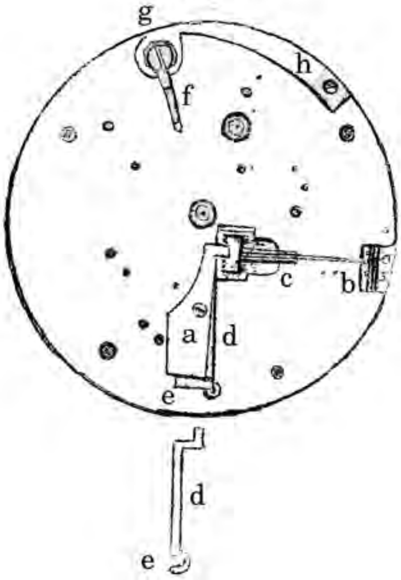
a
Fig. 8
Fig. 4
Fig. 6
Fig. 13
Fig. 2

Plate 7

Fig. 18



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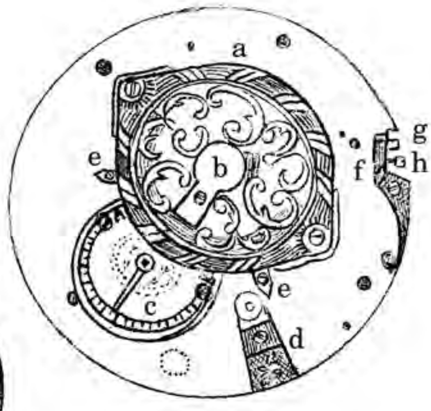

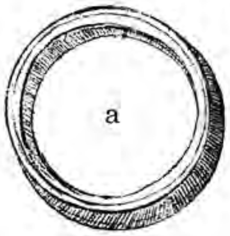

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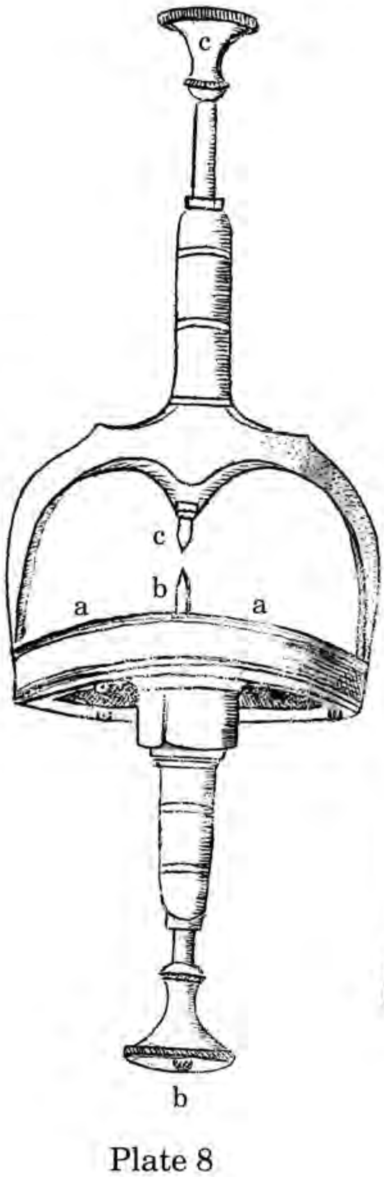

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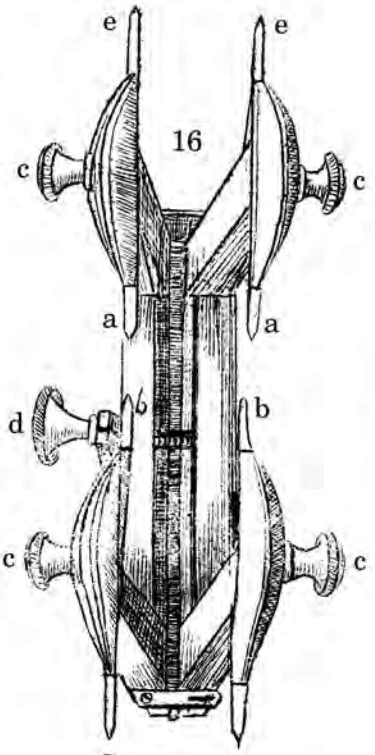

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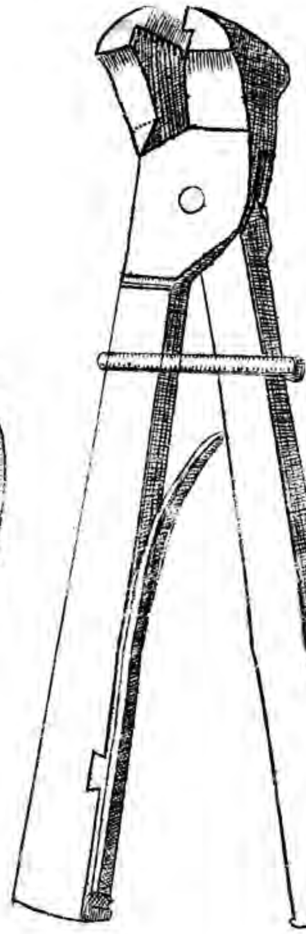
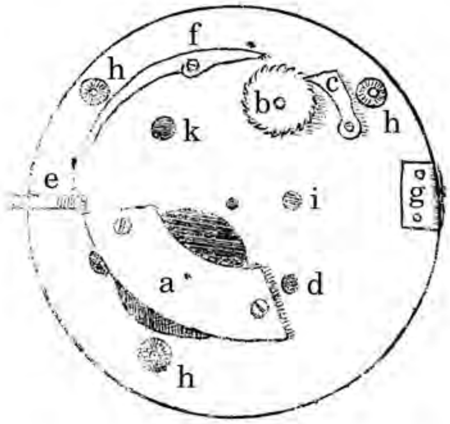


Fig. 15

Plate 8



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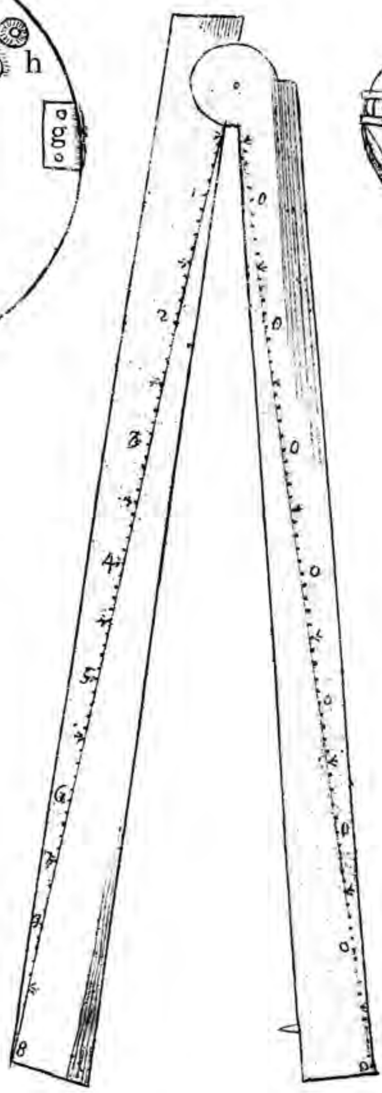
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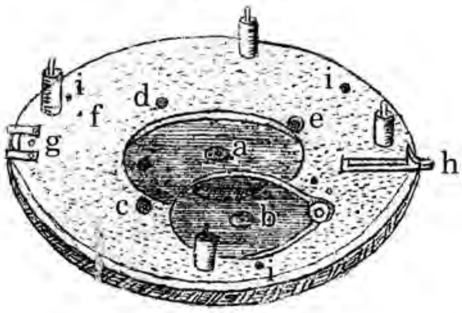

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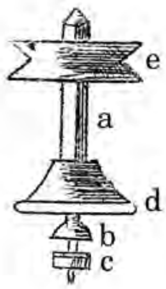

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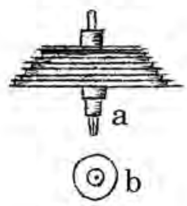


Fig. 23


Fig. 24

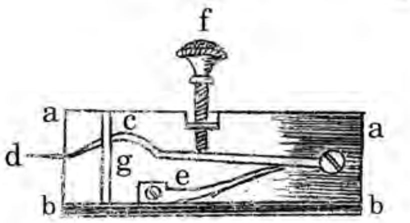


Fig. 31


Fig. 26


Fig. 25


Fig. 28

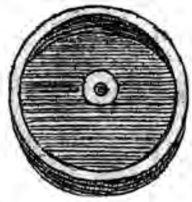


Fig. 27


Fig. 29

Plate 9


Fig. 1


Fig. 2


Fig. 3


Fig. 4

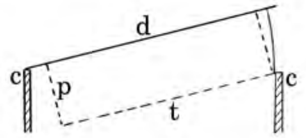


Fig. 6


Fig. 7

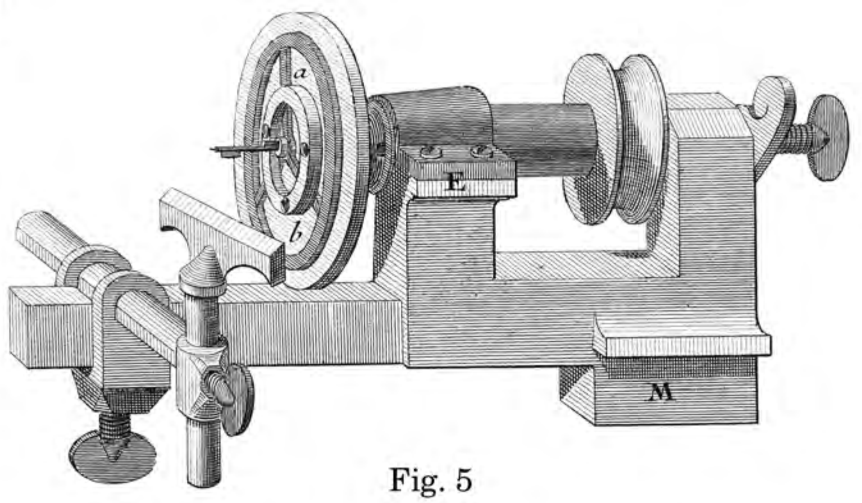


Fig. 5


Fig. 8


Fig. 9


Fig. 10

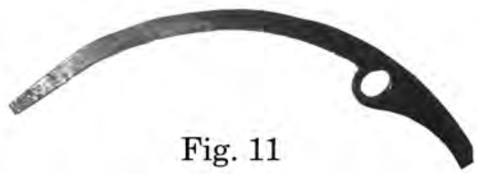


Fig. 11


Fig. 12

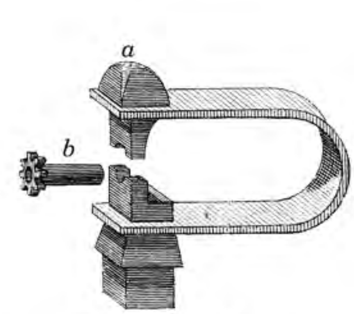


Fig. 13

Plate 10

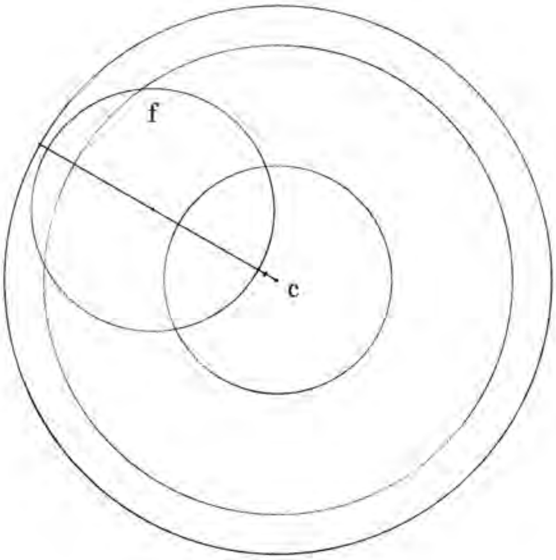
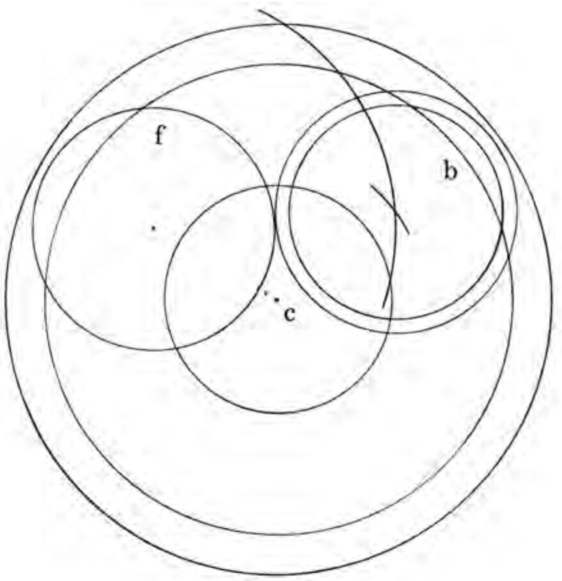


Fig. 1



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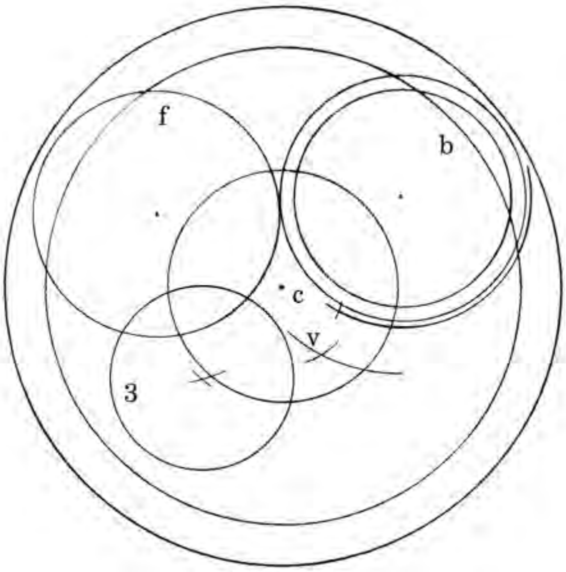

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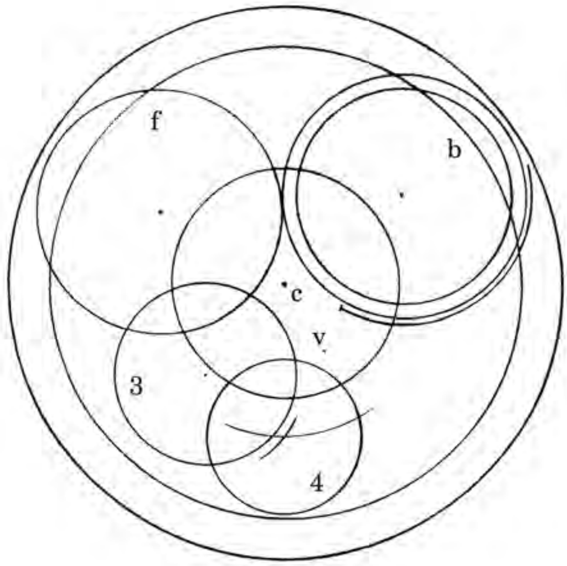

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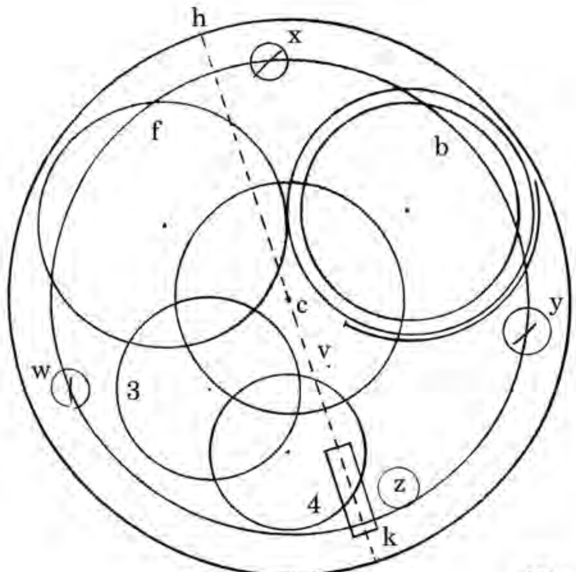


Fig. 5

Plate 11

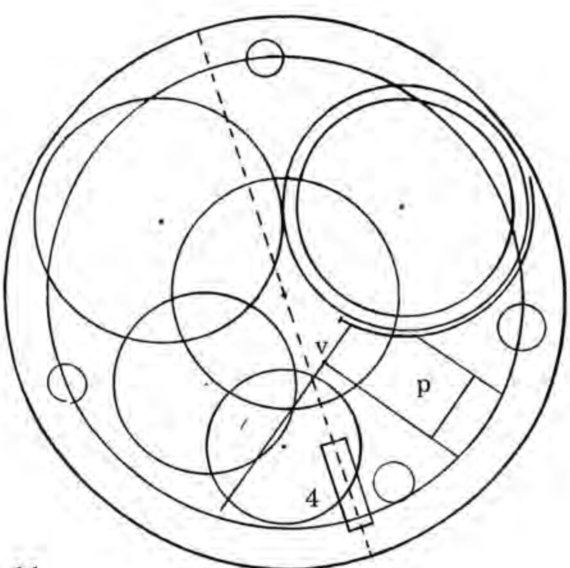
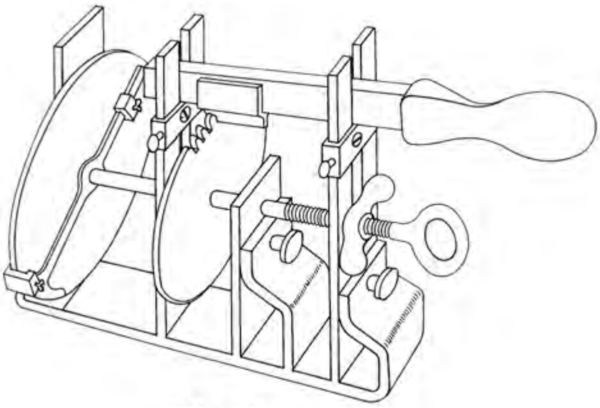


Fig. 6

Fig. 1



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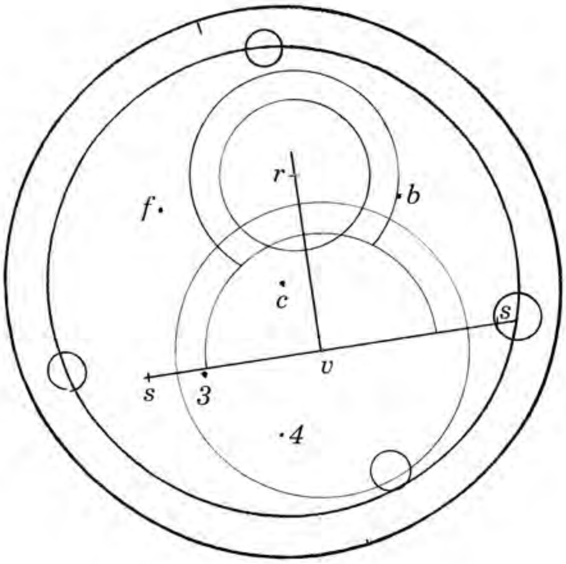

Fig. 3

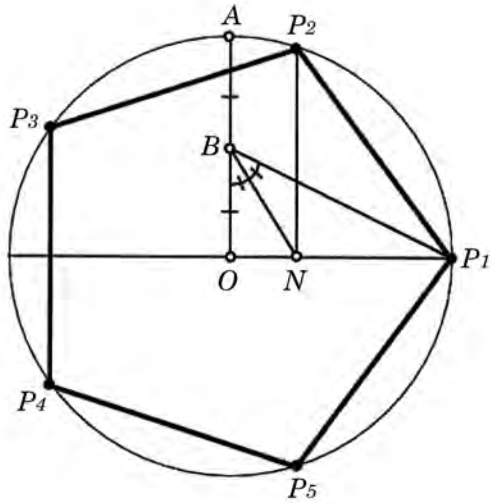

Fig. 4

Plate 12