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1642.

ON THE

CONSTRUCTION AND THEORY

OF THE

DEAD ESCAPEMENT

FOR

CLOCKS.

BY

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PREFACE.

The following papers, on the construction of Graham's Dead Escapement for Clocks, were written so long since as the year 1823, and appeared in the *Journal of Science*, edited by Professor Brande, and published at the Royal Institution, Albemarle Street. The first on an improved method of constructing the Dead Escapement. The second on the theory of this Escapement, and its employment in Clocks with pendulums beating seconds, or longer intervals. The idea of republishing these papers first occurred to me from the circumstance of my being applied to for a translation, for the purpose of being introduced into a very splendid work on Horology, edited by M. L. Moinet, and now in the course of publication at Paris. I am not aware that any preferable Escapement for Clocks has been proposed, or a better mode of constructing this Escapement suggested, since these papers were originally published: moreover, the work in which they appeared having become scarce and expensive, even supposing it to be practicable to obtain the single numbers, I have determined on reprinting them for the benefit of the trade at large, and the amusement of such individuals as take an interest in matters of this sort. If, as I believe is the case, this Escapement, when well made, is the best, after all, that can be employed for Clocks intended for astronomical purposes, it becomes important, at a period when the science of astronomy is making such rapid progress, and so many new observatories have been and are about to be erected, to make any information relating to the construction of Clocks intended for astronomical purposes as public as possible.

I have always considered the taking out of patents for all matters connected with science as a thing desirable to be avoided; and the applying the word patent, where, in fact, no patent was ever obtained, or even caveat entered, as an excellent illustration of the puff oblique. Yet this is done daily; I had almost said hourly. Patents are very proper for improvements in articles of general traffic, in which, from their great facility of execution, an interest cannot be secured in any other way; such as corkscrews, snuffers, buttons, and others of a similar description: and the individual who employs this species of monopoly for the sake of any real or supposed pecuniary advantage, must be content to relinquish the station of a man of science for that of a general manufacturer.

On the subject of patents, real or presumed, as connected with Horology, I will notice the following curious case, which clearly shows how desirable it is that all inventions of this description should be made as public as possible. Some years since, an Escapement was brought into notice, and known by the appellation of the Patent Lever, from the circumstance of a patent having, in this case, really been taken out, to secure to the owner the profits resulting from the use of it, which he effected, by granting permission, for a pecuniary remuneration, to such makers as chose to employ it. This Escapement may be considered as a modification of Graham's Dead Clock Escapement applied to a watch, with the motion communicated to the balance by the application of a rack and pinion; but this mode of construction being found objectionable, several others were adopted which were not secured by the patent; but, nevertheless, the Escapement, in all its varied forms, was, and still is called, by the general appellation of the Patent Lever. Now it is a curious circumstance, that the Escapement, with the rack and pinion, for which the patent was taken, exactly resembles one described by Berthond in his first great work, entitled, *Essai sur L'Horlogerie*, 4to. *Paris*, 1763. Vol. II. Page 194, Nos. 1933, 1934, Plate 23, Figs. 5, 6; consequently, the patent subsequently taken out was not of any value whatever. Of the other modes of making this Escapement, and which were not secured by a patent, one of the best I am acquainted with, was invented by the late Mr. Mudge, and is described in a work published by his

Son, entitled, *A Description, with Plates, of a Time-Keeper invented by the late Mr. Thomas Mudge,* 4to. *London,* 1799, Page 173, Plate IX. Figs. 1, 2, 3. This Escapement was first applied by Mr. Mudge to a watch he made for Her late Majesty Queen Charlotte, which is referred to in several letters from Mr. Mudge to Count Bruhl, particularly those dated 6th November, 1772, 3rd January, 1773, and 11th January, 1774; from which it appears that this watch was made about the year 1770. *See* page 27 and following of the same work.

The account here given of the Patent Lever Escapement, is a very good practical illustration of the little value of patents as applied to watches, whether real or assumed, except for the purpose of advertising; while the motives for affecting the latter, as is too frequently done in the present day, are too obvious to require explanation.

I cannot conclude without returning my very sincere thanks to Mr. Murray for the loan of the original Plates, which he has, in the most obliging manner, afforded me.

B. L. Vulliamy, F.R.A.S., F.R.G.S., A.I.C.E, *&c.*

ON AN

IMPROVED METHOD OF CONSTRUCTING

THE DEAD-ESCAPEMENT FOR CLOCKS.

THE dead-escapement originally invented by G. Graham, F.R.S., being perhaps practically the best clock escapement known, any improvement in the method of executing it, whereby the practice is made more exactly to agree with the theory than has hitherto been the case, may not be unworthy of notice.

The principle of the dead-escapement is well known; the motion of the pendulum is maintained by the action of the wheel on the inclined planes of the pallets, which occupy a portion of the arc of vibration of the pendulum, equal to the angle of the pallets; during the remainder of the vibration, the tooth bears on the circular parts, or rests of the pallets, which are portions of two circles, concentric with the axis of the verge, or centre of motion of the pallets, and consequently there ought not to be any recoil in the escapement, if properly executed. Various constructions and shapes of pallets and pallet-frames, each supposed to possess some peculiar advantage, have, at various periods, been adopted; but the whole have been executed with the file. The construction of the dead-escapement, of which the following is a description, and which I have employed, is, with the exception of the inclined planes of the pallets, and forming the frame out of the turned piece or pieces, entirely executed in the lathe; and if the parts are accurately turned with a slide-rest, must of course possess a degree of precision, independent of its other advantages, which pallets executed with the file cannot possess.

Fig. 1, Plate 1, of which Fig. 2. is a section, represents a circular brass plate, with a square groove, A B, turned in it. Fig. 3, represents a steel ring, of which Fig. 4, is a section, turned very exactly of width and thickness to fit perfectly into the groove, A B, portions of which form the pallets. Fig. 5, represents the pallet-frame made out of the circular piece of brass, represented Fig. 1, and L and M, Figs. 2, 5, and 8, are two pieces, fixed with screws to the frame to retain the pallets immovably in the grooves. Figs. 6 and 7, represent each a pair of pallets, made of part of the steel ring, the one with short, the other with long, inclined planes; 1, 2, and 3, 4, are the inclined planes of both pair of pallets. Fig. 8, represents the pallets placed in the frame, and held firmly in their places by the pieces L and M. The preferable mode of making the pieces, L and M, is out of the extremity of a piece of what remains of the piece, Fig. 1. after the pallet-frame is formed, reduced to a proper thickness, because the end of the piece is of necessity a portion of the same circle as the end of the arm.

In the common construction of pallets there is no method of opening and closing the pallets to the wheel, but by filing the inclined planes, or faces, of the pallets to open them, and bending the arms to close them; to obviate this inconvenience, jointed pallet-frames have been adopted; but these, unless planned and executed with more than common care, are as defective in principle as in execution. In the construction of the pallets above described, the pallet-frame is not jointed, but made of a single piece, and there is no adjustment in the frame for opening and closing the pallets to the wheel; but the same end may be obtained, though not in the most perfect manner, by loosening the pieces L and M, (see Fig. 8,) by which the pallets are held fast in the frame, and pushing the pallets backwards and forwards in the groove. This, though infinitely better than the old method, is not easy, it being difficult in practice to remove the pallets a very minute quantity; and to open or close the pallets by this method, it is necessary to disengage the pallet-frame, and all the parts to which it is attached, from the frame of the clock, an inconvenience which is entirely obviated by the method about to be described.

To remove this difficulty, the following mode of constructing the pallet-frame may be adopted. It admits of the pallet-frame being made jointed upon the same principle, and with equal accuracy; and the opening and closing of the arms being regulated by a screw, their quantity of motion may be infinitely small, and determined to the greatest nicety. For this purpose a second piece, exactly similar to the piece represented, Fig. 1, is required. See Fig. 9, of which Fig. 10 is a section.

When the pallet-frame is intended to be made jointed, the sink, E F, represented in the section Fig. 2, must be turned in Fig. 1, on the reverse side to the groove, A B, and a similar sink, E F, must be turned in the piece, Fig. 9, on the same side as the groove. See Fig. 10. It is requisite those sinks should be exactly the same size, and in depth half the thickness of the piece. The two circular pieces, Figs. 1 and 9, being of equal thickness, and the sinks each equal to half the thickness of the piece in which it is turned, it necessarily follows that, when the surfaces of the two sinks are brought together, they will equal in thickness the remaining part of either piece. That this should be the case is indispensable to the correct performance of a jointed pallet-frame, made on this construction. Perhaps the best mode in practice to make the sinks equal, is to turn a piece of brass as a guage, to let into the pieces, Figs. 1 and 9, which will ensure the sinks being in every respect the same. The section of such a piece is shown, W, Fig. 10. Exactly half the pallet-frame is formed out of each of the pieces, Figs. 1 and 9, and the two halves are represented, Figs. 11 and 12, and the two put together are represented, Fig. 13. To strengthen the long arms that carry the pallets, there is to each half of the frame a portion of the original piece left concentric to the sink, which forms a connexion between the upper surfaces of the long and short arms; and to strengthen the long arm it is continued a little below the arm. By this means the strength of the frame is greatly increased, and the fitting together of the two arms does not entirely depend on the good fitting of the holes through their centres, on the steel cylinder, or verge, that passes through the common centre of the two. This is shown more plainly in Fig. 11, than in Fig. 12, the whole surface of Fig. 12, being on the side represented in the figure on one plane, whereas in Fig. 11 (on the side represented in the figure), the two arms and connecting part are on one plane, and the sunk part represented by the complete circle on another, half the thickness of the piece below the upper plane. The manner of fixing the pallets to the axis of the verge connecting the two arms together, and opening and closing them, is represented in front, Fig. 15, and in profile, Fig. 14. A A, Fig. 14, is part of the verge, to which is immovably fixed the collet, C, with a long socket; D is the pallet-frame, and G a collar in front of the frame. These parts are held together by the two screws, X and Y, Fig. 15, which are tapped into the collar, C, Fig. 14, and exactly fit the holes they pass through in the collar, G. By this means the two arms forming the pallet-frame are held together, and firmly fixed between the collet, C, and the collar, D, and consequently attached to the verge, A A. It is to be observed, that the screws, X and Y, must not be screwed so tight that the regulating screw, H, has not power to overcome the friction of the arms of the pallets between the collet, C, and the collar, G, for in that case the whole intention of the jointed pallet-frame would be frustrated. To enable the arms to open and close, there are two circular notches in the same places in each half of the pallet-frame, concentric with the centre (see Figs. 11, 12, and 13), through which the two screws, X and Y, Fig. 15, pass, and the quantity of motion of the arms is determined by the length of the circular notches. The two studs, F and F, Fig. 15, through which the regulating screw, H, passes, are connected with the upper arms of the pallets by pivots, which pass through them, and are held in their places with collets and screws.—See Fig. 14. Care must be taken not to screw the studs so tight as to prevent their turning on their centres, otherwise the regulating screw, H, will be bound. This screw, H, being of two different threads, the one coarser than the other, thereby producing a very fine motion, has the effect, when turned in one direction, to open the pallets; and turned in the other, to close them.

The great advantages in this mode of construction are, 1st, That the rests of the pallets are correct portions of circles, the centre of which circles is the centre of motion of the axis of the verge, and the pallets move in the same circles, and, consequently, there will not be any recoil in the escapement. 2nd, That the pallets must be of equal thickness, and consequently the drop the same on both. 3d, That the pallets may be made perfectly hard, if properly treated, without risk of altering their shape: and should a pallet be spoiled by any accident in hardening, or a flaw or imperfection of any kind be discovered, another exactly similar is easily made to replace it out of the original ring. When the pallets are made out of the same piece of steel as the arms of the frame, it is difficult to preserve their shape correctly in hardening, and to retain the acting part of the pallet perfectly hard. To obviate this difficulty, the pallet has sometimes been made a separate piece, with a short arm, by which it is fixed with two screws to the arm of the frame; but this is only to exchange one evil for another, for, independent of other disadvantages, which it is unnecessary to enumerate, it is very uncertain, with the pallets fixed in this manner, whether or not the rests of the pallets are concentric with the centre of the axis of the verge. The slightest deviation from its original direction in the arm of the pallet, by hardening or any other cause, has the effect of removing the centre of the circle, forming the rests of the pallets; from the centre of the axis of the verge to some other place, the consequence of which is to render the escapement a recoil escapement. 4th, That the mode here recommended of constructing the pallets, offers a great facility for making the inclined planes of the pallets equal to one another, or of altering them as may be required; and consequently the angle which the pendulum is led by one pallet, will be equal to the angle it is led by the other.

Figs. 14 and 15, as before mentioned, represent the jointed pallet-frame in profile and in front, with all its parts complete, attached to the verge, and the pallets in their places. To Fig. 15 is added the scape-wheel, and the pallets are represented in the situation in which they will appear, when the wheel has led the pallet to the extremity of the lead. The angles of lead (more particularly noticed hereafter) of the pallets being each supposed equal to an angle of 2°, it follows that the pendulum is led 1° on each of the perpendicular line, O P, by the action of the escapement, and that the wheel will escape when the pendulum vibrates the smallest quantity more than 1° on each side of the line it subtends when at rest. Now, supposing the arc of vibration of the pendulum to be 5°, that is 2° 30′ on each side of the perpendicular, and the angle of lead of the pallets 2°; the tooth of the scape-wheel rests 3° on the rests of the pallets, 1° 30′ on each rest, during each vibration of the pendulum, the pendulum vibrating an angle of 5°. From the above, the great importance of the rests of the pallets being concentric to the centre of motion of the axis of the verge, is sufficiently obvious. The line, O P., Fig. 15, passing through the centres of the axis of the verge and the axis of the wheel, is the line the pendulum subtends when at rest, and the lines, A R and A T, forming together the angle, R A T, supposed of 2°, are the lines the pendulum will subtend, when led to the extremity of the lead by the action of the wheel upon each pallet. In Fig. 15, the pendulum is supposed to subtend the line A T.

The following is a brief description of a method by which the inclined planes of the pallets are finished to the required angle.

Fig. 16 represents a brass plate, about three or four inches in diameter, the size is not very material, and about two inches thick, with a groove turned in it similar to the groove, A B, Fig. 1. The angles, B A C, and D A E, are drawn equal to the proposed angles of lead of the pallets, and in this case are supposed angles of 2°. To determine the line of the face of the inclined planes of the pallets, from the points, G and H, where the lines, A B and A D, intersect the exterior circle of the groove, draw the lines, G I and H K, which may be considered as chords subtending equal arcs, intersecting the lines, A C and A E, at the points, L and M, on the inner circle of the groove; the lines, G L and H M, may, relative to the two circles of the groove, be considered as representing the inclined planes of the pallets. Now, supposing that portion of the original piece of brass subtended by the chord, X Y, carefully removed, and the surface made perfectly flat, and at right angles to the turned face in which is the groove, it follows that a piece of the steel ring, Fig. 3, one end of which has been brought, by filing very near to the required angle, may be placed in the groove, and ground and finished in the most accurate manner. By this method, the surface of the pallet will be made perfectly correct. The other pallet may be finished by a similar method.

It may not be unnecessary to observe, for the preservation of the figure, that the principal bearings of the tool should not come in contact with the grinding surface during the operation.

We will now proceed to the second part, namely:—the investigation of the circumstances connected with the theory of this escapement.

Strongly impressed with the great practical superiority of the dead escapement, when properly constructed and executed, over every other, for clocks with seconds or longer pendulums, I have taken much pains to ascertain whether any rule of general application has been laid down by different authors who have written on the theory and practice of clock work, to determine the distance between the centre of the escapement wheel, and the centre of action of the pallets, which, as far as relates to the theory of the escapement, is of the utmost importance, and not the less so as regards reducing that theory to practice; and generally for determining the relative proportion of the parts of the dead escapement, as usually made for clocks. I regret to add, that my inquiries have not been attended with the success the importance of the subject (as connected with the accurate measurement of time by clocks) had induced me to expect.

The merit of the invention of the dead escapement is, I believe, unquestionably due to that celebrated clock maker, George Graham, F.R.S., but unfortunately he left no written description of it, that

I am aware of, and the chief mention I have found of the principle of his escapement is in the works of the French authors.*

Thiout l'ainé, in his *Traité de l'Horlogerie*, 4to, Paris, 1741, on the subject of Escapements, Vol. 1st, page 103, thus expresses himself:—" Fig. 19, (Plate 43, Vol. 1st,) is a dead escapement for clocks, as made by Mr. Graham, clock-maker, of London. The rule I have discovered for making it, and which I apprehend to be a good one, is to place the centre of the anchor at the distance of one diameter of the wheel from the wheel" (that is a diameter and a half of the wheel from its centre), " as shown in the figure. The centre of the anchor must be placed on the perpendicular line, passing through the centre of the wheel, and the wheel cut into thirty teeth, beginning from the above-mentioned perpendicular line; and the teeth which suit the best must be chosen, to determine the place of an arc drawn from the centre of the anchor upon which to form the pallets, which must be so made, that the seconds does not recoil." Here follows a description of the action of the escapement.

From the above, it is evident, that M. Thiout's knowledge of this escapement was very limited.

The subject of the dead escapement is entered into at some length by F. Berthoud, F.R.S., of Paris, the author of several horological works. In his *Essai sur l'Horlogerie*, 4to, Paris, 1763, Tom. 1, Première Partie, Chap. xxi. No. 397, page 129, he thus

* I fully expected some account of this escapement in the Transactions of the Royal Society, of which, Mr. Graham was a member: but by reference to the Index of the Transactions, there is no mention of Clock Escapements; at which I am the more surprised, as there is a communication from Mr. Graham on the subject of his invention of the Mercurial Pendulum, and the measuring the lengths of pendulums at different places. Mr. Graham was the immediate successor to Tompion, and the art of Clock and Watch-making is so much indebted to him for its advancement, that I consider it due to his memory to insert the following memorandum.

He was born in 1675, was elected an Assistant of the Court of the Company of Clock-makers of the city of London, the 18th April, 1716, and served the office of Master of the Company, 1721 and 22; was elected a Fellow of the Royal Society the 9th March, 1728, and died the 16th November, 1751. His remains were intered in the aisle of Westminster Abbey.

expresses himself: "397. The distance between the centre of the anchor of the escapement and the centre of the wheel, depends upon the arc the pendulum is required to vibrate;* if it is to describe large arcs of 10°, for example, then the centre of the anchor must be at B." See Fig. 1, Plate II. (Berthoud, Fig. 8, Plate XV.)

398. "But if, on the contrary, it is to describe a short arc, of 1°, for example, the centre must be at *a*. See Fig. 2, Plate II. (Berthoud, Fig. 10, Plate XV.) at the distance of about a diameter and a half of the wheel, A, from the centre of the wheel;† observing

* This is not perfectly well expressed, as by the arc the pendulum is required to vibrate, might in this case, mean the arc the pendulum must describe, to enable the pallets to escape; or, in other words, the quantity the pendulum is led by the action of the wheel upon the inclined planes of the pallets, and not the total arc of the vibration of the pendulum; (at No. 399 and 400, M Berthoud describes the difference between the total arc of vibration of the pendulum and the arc led by the action of the wheel upon the pallets), neither is this a correct statement, for the quantity the pendulum is led by the action of the wheel upon the pallets, depends upon the angle of lead of the pallets, or the length of their inclined planes; as well as upon the distance between the centre of action of the pallets and centre of the wheel, and consequent number of teeth the pallets take over. In illustration of this (See Fig. 3, Plate III.) to the same wheel are applied two pairs of pallets, which, taking over a different number of teeth of the wheel, are consequently, at different distances from the centre of the wheel; and yet, from the difference of the angle of lead of the pallets, the pendulum will be led an equal quantity by the action of the wheel upon either pair of pallets; the difference between the angles of lead of the pallets compensating for the difference between the distance at which each pair of pallets is placed from the wheel.

In the figure, the four triangles, B A C, D A E, F W G, and H W I, which express the angles of lead of the pallets, are drawn equal to one another, and equal to the triangles, K A L and N W M, also equal to one another, which show the quantity the pendulum is led by the action of the two pair of pallets, on each side of the perpendicular line, A X.

† I believe that Mr. Graham, Mr. Shelton, who worked with him, and most of the clock-makers of that period, who trod in the footsteps of Mr. Graham, in the construction of their seconds pendulum clocks (the scape-wheels of which were necessarily cut into thirty teeth), made their pallets take over eleven, twelve, and thirteen teeth of the wheel; and the distance between the centres, was one diameter of the wheel in the case of taking over eleven teeth; about one and a half diameter, in the case of taking over thirteen teeth; and between one diameter and one diameter and a half, in the case of taking over twelve teeth. The French clock-makers, who copied Graham's escapement, followed nearly the same rule.

in both cases, that the opening of the compass that describes the rests, or circular faces of the pallets, is such that drawing a line from the point, 5, Fig. 1, Plate II., through the centre, B, of the anchor, and drawing from its extremity, 5, a line, *z* A, that shall pass through the centre, A, of the wheel; these lines are so situated, that the line, *z* A, shall be perpendicular to the line, 5 B;* and by the same rule, if the anchor is placed at *g*, the pallets, or inclined planes of the anchor, should act upon the wheel at the points, *e f*; this understood, the portions of the circles, 1 C, 3 D, Fig. 2, Plate II. (M. Berthoud transfers his description to Fig. 10 of his work,) must be drawn of the same radius, *a* C; and in the same manner, 2, 5, and 6, 4, taking care that the space, or thickness, C 5, 6 D, between these portions of circles, is a little less than half the interval between the teeth of the wheel.

"Now, to determine the inclination of the planes, from the centre, *a*, Fig. 2, draw the straight lines, *a f* and *a g*, forming the angle, *f a g*, being half the angle the pendulum is required to be led;† though the points 2 and 1, where these lines intersect the arcs, 2, 5, and 1, C, draw the straight line, 2, 1, which gives the inclined plane, 2, 1, by a similar operation, the inclined plane of the other pallet is obtained. There are several other practical methods, which are easy of application, but difficult to explain."

And again, at Nos. 1324 and 1325, page 449, (in what follows the scape wheel is supposed made, and the original text is abridged, such parts only being translated as immediately relate to the laying

* (See Fig. 1, Plate II.) In the case of the anchor, whose centre of motion is at B, M. Berthoud determines the centre of action of his pallets, by the intersection of two tangents drawn from the points where the circle of the inner rest of the pallets prolonged intersects the circle than circumscribes the wheel. By this mode, the two centres are nearer together that they would have been, had he determined their distance by tangents drawn from the points where the circle of the outer rest intersects the same circle.

That the points found by the intersection of tangents drawn from either of these points is not the proper centre of action of the pallets, will be shown hereafter,—in the one case, the centres are too far apart; in the other case, they are too near together.

† See note, page 3.

down of the lines of the escapement,) "To draw the anchor piece of the escapement," (Berthoud here supposes the drawing to be made upon a brass plate, and the distance between the centres already determined,) "the distance on the pillar plate between the centre of the scape wheel and the centre of the verge of the pallets must be taken:* from the centre, *a*, of the anchor, see Fig. 3, Plate II, (Berthoud, Vol. ii. Plate XXIII. Fig. 3; part of Berthoud's figure is omitted, no more being drawn than immediately relates to the text,) the line, *a b*, must be drawn just to touch the circumference, *b c*, of the wheel; if, from the point, *b*, where the two lines touch each other, the radius, B *b*, is drawn, it will be perpendicular to *b a* (as may be geometrically demonstrated,) and, conformable to mechanical principles, the action of the wheel upon the pallets should be at the point *b*; consequently, *a b* is the length to be given to the arm of the anchor, to enable the wheel to act upon the pallets in the most favourable manner possible."

1326. "Place the wheel in the plate with its centre on the point, B, then place one of the points of a pair of compasses on the centre, *a*, of the pallets, open the compasses to the quantity, *a c*, and turn the wheel on the centre, B, until the front of one of its teeth meets the other point of the compasses on the circle of the wheel at *b*; that done, keep the wheel immoveable, transport the other point of the compasses to the other side, and see if it will reach the back of the point of another tooth at *c*: if it does not, the opening of the compasses must be varied until it reaches from the centre, *a*, at the same opening the points of the two teeth, the nearest to the

* From this it would appear, that M. Berthoud's plan is to determine the distance of the two centres from each other on the plate of the clock, and then to adopt his escapement to those distances; which, as the number of the teeth of the wheel is regulated by the length of the pendulum, to preserve the angles, B 5 A, B 6 A, *g e* A, and *g f* A, Fig. 1. Plate II., right angles, can only be done by making the pallets take over a greater or lesser number of teeth; or, if necessary, by altering the size of the wheel; or, if this cannot be done for want of room or any other cause, then, and quite contrary to his leading principle, the angles, B 5 A and B 6 A, &c., must be increased or diminished.

points, *c* and *b*: draw the portions of circles, *b t*, *c p*, which will represent two of the circular faces of the pallets."*

1327. "To find the other two circular faces, the opening of the compasses must be altered in such a manner, that the teeth of the wheel having advanced a quantity equal to half the interval between them, they pass a second portion of a circle drawn from the same centre, *a*, and intersecting the circle of the wheel; but as that may equally be done by opening or closing the compasses, a quantity equal to the space between two teeth, it is preferable to use that of the two openings, which will occasion the distance of the lines from the centre to vary the least from the points *c* and *b*, which points are to be varied from as little as possible. That done, trace the other two faces of the pallets, *d s* and *e g*,† which are here, by preference, drawn within the others, to diminish the space the anchor has to move, and, consequently, the friction of the pallets. In this manner are described the four circular faces of the two pallets, placed in such a manner as to let the teeth of the wheel alternately escape as the pallets approach and recede from the centre of the wheel by the action of the pendulum."

1328. "The length of the pallets is regulated by the quantity of the angle of lead that is to be given to the escapement, which we will here suppose of 5° on each side, or thereabouts."

1329. (This part is very much abridged in the translation.) "To describe the angle of escapement, prolong the line, *a b*, to *f*. See Fig. 3, Plate II., and draw the angle, *f a g*, of 5°, the point, *d*, where the line, *a g*, intersects the inner circular face of the pallet, determines the length of the pallet; for the wheel, in passing the pallet, causes it, by its action on the inclined plane to describe an angle of 5° to have the inclined plane, draw the line, *d b*, passing through the points, *d* and *b*, where the straight lines, *a f* and

* This is not correct, because *c p*, Fig. 3, Plate II., is not a face of the pallet.

† This again is incorrect; *d s*, Fig. 3, Plate II., is not a face of the pallet, and cannot be considered as such.

a g, which form the angle, *g a f*, intersect the portions of circles, *d s* and *b t*."

1330. "To draw the inclined plane, *c e*, it is to be observed, that, as the pallet, *d b*, is drawn 5° within the circle of the wheel, it follows that the pallet, *c*, must be situated without the same circle, and ready to come into action as the other pallet escapes from the wheel. Prolong the line, *a c* to *h*, and draw the angle, *h a i*, of 5°, which will determine the measure of the inclined plane, *c e;* it only then remains to draw the line, *c e*, which passes through the points, *c* and *e*, where the straight lines, *a h* and *a i* intersect the portions of circles, *c p* and *e q:* thus will be given the inclined plane which is to terminate the pallet, and so situated, that when the tooth, *C*, shall have led the pallet without the circle of the wheel, a quantity equal to an angle of 5° the pallet, *c e*, shall also be led an angle of 5° and within the wheel; consequently, when the tooth, *r*, shall have led the pallet to escape, the pallet, *c*, will have described an angle of 5°, whence it follows, that the total lead of the escapement will be 10°"*

* This is a mistake; the total quantity the pendulum is led being an angle equal to the angle of lead of either of the pallets; (it is supposed that the angles of the two pallets are equal to one another, as they ought to be,) and the pendulum is led nearly an equal angle, ascending and descending on each side of zero, (or the perpendicular line on the degree plate,) by each pallet alternately; but the advance of the wheel, and, consequently, the friction upon the inclined planes of the pallets, is not uniform during the ascending and descending of the pendulum at each vibration, but exists upon a greater proportion of, and is consequently greater upon, the pallets as the pendulum ascends than as it descends; for, supposing the inclined planes of the pallets divided at that point which the extremity of the tooth of the scape-wheel has reached when the pendulum is perpendicular, the portion of the inclined planes the tooth of the wheel acts upon, as the pendulum descends, is less than the portion acted upon as the pendulum ascends.

It is possible to make the inclined planes of the pallets so long, that the angle of the total vibration of the pendulum will not exceed the angle of lead of the pallets, in which case, it will be visible that the total angle the pendulum is led is only equal to the angle of one of the pallets.

M. Berthoud has fallen into the same error at No. 399.

To illustrate as much of the above as refers to the irregularity of the friction upon the pallets, suppose Fig. 1, Plate III., the pendulum at rest, and perpendicular upon the line, X W, bisecting the angle, Y X Z (which angle is equal to

1331. "The escapement thus drawn will be a dead escapement, because it is formed of portions of circles concentric to the point, A (396), but," &c.

the angles, B X P and D X Q, of lead of the pallets), and the lines, A B and C D, the inclined planes of the pallets; the dotted lines, E F and G H, will represent the lines of the inclined planes, when the pendulum subtending the line, X Z, is led to the extremity of the lead one way; and the dotted lines, I K and L M, the inclined planes when the pendulum subtending the line, X Y, is at the extremity of the lead in the other direction (it cannot be too often repeated that the angle of lead must not be confounded with the angle of vibration), and the points, N and O, where a supposed circle, circumscribing the points of the teeth of the wheel, intersects the inclined planes, A B and C D, are the points upon one of which (determined by the pallet from which the wheel has last escaped) the wheel will be in contact with the pallet, when the pendulum, having advanced half the angle of lead, subtends the perpendicular line, X W. Now it is visible that the portions, N A and O D, of the lines, A B and C D, which are the parts of those lines the teeth of the wheel act upon when the pendulum ascends, are greater than the lines, N B and O C, which are the portions the teeth of the wheel act upon when the pendulum descends; consequently, the velocity with which the wheel advances is not equal during equal portions of the lead of both pallets.

By altering the shape of the inclined planes of the pallets from straight lines to portions of circles, the advance of the wheel may be made nearly proportional to the advance of the pendulum. Suppose, Fig. 1, Plate III., the pendulum to subtend the perpendicular line, X W, and, consequently, to have vibrated half the angle it is led, and the inclined plane of the pallet, Æ, instead of being the straight line, D C, to be a portion, D T C, of a circle, passing through the three points, D S (where the radius, R V, bisects the arc, M G, of a supposed circle circumscribing the wheel), and C; the consequence resulting from giving this shape to the pallets will be, that the wheel will have advanced to the point, S, half its total advance, and have acted upon very nearly half the surface of the pallet, when the pendulum has vibrated half the angle it is led; for the portion, C S, of the circular face of the pallet upon which the wheel has acted during its advance from the point, G, to the point, S, is less than the portion, S D, of the pallet upon which it must act during its advance from S to D, by the quantity, S T; which difference between the arcs, C S and S D, is very trifling, when compared with the difference between the straight lines, C O, and O D, which form the inclined plane, C D.

The same effect takes place in the pallet A B, but from the relative position of the parts, in a much less degree; the circular face of the pallet requiring to be a portion of a much larger circle: and here it is worthy of notice, that the faces of the two pallets being portions of different circles, the one is, in fact, a longer line than the other, and consequently, with circular faces, as just described, there is more friction on one pallet than on the other; and more on both than when the acting faces are straight lines.

The late Mr. Cumming, F.R.S.E., in his *Elements of Clock and Watch Work*, London, 1766, page 43, No. 176, states, that Graham made his pallets take over twelve teeth. In his Plate II., in which he represents the dead escapement drawn very large; and in detail, Mr. Cumming places the centres at the distance of exactly one diameter of the wheel apart, and makes the pallets take over eleven teeth: and in a note, p. 44, he thus expresses himself, "Fig. 3, Plate III. (Cumming's Work) exhibits at one view, the length of the pallet, and the distances of the centre of the verge, from that of the swing wheel, according to the number of the teeth of the wheel which the pallet takes in, from two to twelve,* (the wheel is

The proportional advance of the wheel and pallets was probably considered by Mons. L. Berthoud (chronometer maker to the French Navy during the period of the Republic), of great importance in the case of the dead anchor escapement, when applied to watches; he having given this shape to the pallets of some of his box marine chronometers, that I have had an opportunity of seeing.

The friction is also unequal upon the rests of the pallets, without regard to the shape of the inclined planes, whether straight or curved: for the arc of vibration on each side of zero on the degree plate must necessarily subtend equal angles, and the angles of lead on each side of zero being also equal, it necessarily follows that the angles of rest must be equal; but the rests of the pallets being at unequal distances from their centre of motion of a quantity equal to the thickness of the pallet, it also follows, that though the arcs which subtend the angles of rest subtend equal angles, yet, that one of them must necessarily be larger than the other, being a portion of a larger circle; and consequently, the friction greater upon the one than upon the other; the difference, however, is very small, and this is an evil, that from the construction, cannot be avoided.

It is scarcely necessary to add, that for the clock to be in beat, it is requisite, not only that the angles the pendulum is led, should be equal, but that the angles of rest, on the circular faces of the pallets, should also be equal; otherwise the total angles of vibration on each side of zero, on the degree plate (which represents the perpendicular line when the pendulum is at rest), will not be equal, and consequently, not be performed in equal times. The above observations will, I believe, be found to be of universal application in this construction of the dead escapement.

For further illustration on the subject of the angle of lead, see "Astronomical Observations," by the Rev. Wm. Ludham, 4to., Cambridge, 1769, note, page 86.

* In the plate of Mr. Cumming's work, the number of teeth taken in by the pallets is from three to thirteen, not from two to twelve, as stated in the text, and

supposed a wheel of thirty teeth), by which it appears, that the distance of those centres is the secant, and the length of the pallets the tangent of half the angle subtended at the centre of the swing wheel by such number of teeth." To illustrate Mr. Cumming's observation respecting the secant and tangent of half the angle of the number of teeth taken over; suppose the case of the pallets taking over twelve teeth (see Fig. 4, Plate V.), D C, the distance between the centres will be the secant, and D B, the length of the supposed pallets, the tangent to the angle, A B C, which angle is half the angle subtended at the centre of the wheel by such number of teeth. Here, Mr. Cumming determines the centre of action of the pallets by tangents drawn from the points of the teeth of the wheel; which, as will shortly be shown, is not the most correct method.

I. A. Le Paute, in his *Traité d'Horlogerie*, 4to, Paris, 1767, page 188, No. 58, states, that Mr. Graham made his dead escapement for clocks, with the rests at equal distance from the centre of action of the pallets, as represented, Fig. 2, Plate III., and has so represented them in Plate XIII., Fig. 9, of his work.

Whatever advantage may be supposed to result from the rests being at equal distance from the centre, it is more than counterbalanced by the inequality of the distance from the centre of the pallets, at which the impulse is given by the wheel. In the first place, this difference of distance causes the lengths of the inclined planes to be different from each other, (see Note page 3, and Fig 3, Plate III., where the same effect is more visibly shown,) and in the second, and this is a most material objection, would entirely prevent the application of the rule about to be shown for deter-

as marked in figures in the plate. Fig. 4, Plate V., represents the tangents drawn, taking in from two to twelve teeth, as quoted in the text, Fig. 5, taking in from three to thirteen teeth, as represented in Mr. Cumming's figure.

It is worthy of notice, that in the case of taking in thirteen teeth, the distance between the centres, supposing the tangents drawn from the points of the teeth (see Fig. 5, Plate V.), is not exactly 1 and ½ diameter of the wheel, the distance determined by the supposed rule of Graham's, but a little more.

mining the distance between the centre of the wheel, and the centre of the pallets.

Ferdinand Berthoud, in his last and great work, *L'Histoire de la Mesure du Tems,* 4to. Paris, 1802, in vol 2, page 26, speaking of Graham's escapement, which he does very briefly, thus expressss himself, quoting M. Thiout, "La règle qui j'ai trouvé (dit M. Thiout,) et qui me paroit assex convenable est d'eloigner le centre de l'ancre de la circonférence de la roue d'un diametre du rochet comme la figure le représente." This is translated at page 2, under the head of M. Thiout.

In Dr. Rees' Cyclopædia, 4to edition (Vol. XIII., Part II.), under the head of "Escapement," among other escapements described, is the "Anchor Escapement, by Clement, or Dr. Hook," and "Graham's dead beat." In the first, it is inferred, that the distance between the centres of the pallets and scape-wheel, regulates the arc of vibration of the pendulum. This, as has been before observed, is not the case (see note, page 3); and in both, that the distance "is determined by tangent lines." This cannot be better explained than by the following quotation from the explanation of "Graham's dead beat," which applies equally to the principle upon which the anchor escapement is constructed. "In this construction, as in the preceding one, the distance of the centres of motion, *a*, *b*, (Fig. 4, Plate XXXII., Rees' Cyclopædia,) is determined by the tangent lines meeting the radii at the points of the acting teeth; when the distance is an exact diameter of the escapement wheel, we find that the pallets take in just ten teeth out of thirty, which is the case in the figure before us; but when twelve teeth are taken in, the centre of the anchor's motion falls at *h*, just a diameter and a half from the centre of the wheel." This is not correct, for it will be found, by reference to Fig. 4, Plate V., that when the pallets take in ten teeth, the centre of motion of the pallets, determined by "tangent lines," is at a distance from the centre of the wheel, considerably less than a quantity equal to one diameter of the wheel; and, that when the pallets take over twelve teeth, the distance is considerably greater than one diameter of the wheel. Also, by reference to Fig. 5, that when the pallets take over eleven teeth, the distance is exactly (or very nearly so) one diameter; and when they take over thirteen teeth, a little more than one and a half diameter of the wheel. It is unnecessary to make any remarks on the continuation of the description of "Graham's dead beat," with regard to Berthoud's rule, after the notice that has been taken of Berthoud's account of the dead escapement at the beginning of this paper. In the representation of Graham's Escapement, in Rees, Plate XXVII, Fig. 4, before mentioned, the centre of the pallets is placed at one diameter of the wheel, from the centre of the wheel, and the pallets take over eleven teeth. In the representation of the anchor escapement, Fig. 3, the pallets take over ten teeth, and their centre of motion is less than one diameter of the wheel from the centre of the wheel.

It may be considered requisite, in reference to the subject, that some notice should be taken of the escapement under the denomination of "Modification of the dead beat, by Grinion," described immediately after Graham's dead beat. I shall content myself with observing that Mr. Grinion describes his dead escapement as constructed on the same principle as I.A. Le Paute states Graham to have made his (see page 10, and Fig. 2, Plate III.), with the rests of the pallets at equal distance from their centre of motion, and with the centre of the pallets placed at the distance of one diameter of the scape-wheel from the centre of the wheel. In the figure (see Fig. 5, Plate XXXII., Rees' plates), the pallets are represented with the angle of lead of both pallets entirely within the periphery of the circle of the wheel; with the pallets so constructed, the point of the tooth of the wheel would drop on the rest of the pallets, at a very considerable distance from the inclined plane, and, consequently, the friction be very much increased; and, moreover, the pendulum must vibrate a very long arc, to enable the pallets to escape at all.

"Bennet's dead beat," represented Fig. 7, is also in the same case with the angle of lead of both the pallets, entirely within the periphery of the circle of the wheel.

I apprehend a very general and correct rule, and one easy of application, for determining the distance at which the centre of action of the pallets ought to be placed from the centre of the scape wheel, and for drawing the lines of the dead escapement, may be given.

Having determined the diameter of the wheel, the number of its teeth, and the number of the teeth of the wheel the pallets are to take over, draw a circle circumscribing the points of the teeth of the wheel, and upon this circle at the proper places as determined by the opening of the pallets, mark the thickness of the pallets, which, making no allowance for drops, should always be half the space between two points of the teeth for each pallet; that done, draw two straight lines between the points that mark the thickness of the pallets upon the circumscribing circle; these lines will be chords to the portions of the circle they subtend; prolong these two lines until they intersect each other; the point where they meet will be the proper centre of motion for the pallets. Next, to describe the circular faces of the pallets; from the centre of motion as above determined, draw portions of two circles that shall intersect the circle circumscribing the wheel at the four points which mark the place and thickness of the pallets. The angle of lead, which is quite optional, must then be determined—this is done by drawing two lines from the centre of action of the pallets; the one within and the other without the lines by which the said centre was found, and forming with those lines two equal angles: the angle of lead determined, it now only remains to draw the inclined planes or acting faces of the pallets; this is done by drawing two diagonal lines from the upper to the lower points of intersection of the lines forming the sides of the two angles of lead, by the circular faces of the pallets.

To illustrate this further, suppose A B C, Fig. 1, Plate IV., a scape wheel of six teeth, to which it is required to apply a pair of dead-beat pallets, which are to take over two teeth, or, what is the same thing, occupy the portion of the circle contained between three teeth*; circumscribe the points of the teeth of the wheel by a supposed circle, Y E Z, divide each of the spaces, D E and E F, between the teeth, D E and F, into two equal parts at G and H, draw the straight lines, D G and F H, and prolong them until they meet at I; the point, I, will be the proper centre of motion for the pallets; from the centre, I, draw the two portions of circles, K L, and M N, intersecting the circumscribing circle at the points, D G and H F, the circular rests of the pallets will be a portion of these circles; the inner rest of the smaller, the outer rest of the larger circle. To determine the angle of lead of the pallets, prolong the two lines, I H F and I G D to O and P, and from the point, I, draw the two straight lines, I Q and I R, forming the two angles, O I Q and R I P, equal to one another, and, from the points, F and S, of intersection of the sides of the angles by the portions of circles, K L, and M N, in the one angle, and the points, D and T, in the other; draw the straight lines, F S and D T, these will be the inclined planes or faces of the pallets.

As this mode of proceeding would be very difficult, not to say impossible, in practice, except in the case of large wheels, on account of the little distance, the points that determine the thickness of each pallet are from each other; the preferable mode is, after having determined the place of the pallets upon the circumference of the wheel, as above described, to draw from the centre, X, of the wheel, Fig. 1, Plate IV., the two lines, X U and X U, bisecting the arcs, F H and D G, which mark the thickness of the pallets; and from the points, V and V, where those lines intersect the circle,

* It may be worth while to notice, as a general rule, that a pair of pallets always occupy the space or portion of the circle contained between the number of the teeth they take over and one more, thus taking over two teeth, they require the space contained between three teeth; were they to take over ten teeth, they would occupy the space contained between eleven. The reason is evident; in the one case, the thickness of the pallets is without the teeth, and the other within, and the thickness of each pallet being equal to half a space, the thickness of the two together must be equal to one entire space; no allowance, as before observed, being made for dross.

to raise the two perpendiculars, V W and V W, which lines will be tangents to the circle; and that done to draw the lines, F H I and D G I, parallel to the two lines, V W and V W and the point, I, where they meet, will be the centre of motion of the pallets, and must be the same originally formed; for a chord will always be parallel to a tangent touching the same circle, when the tangent touches the circle at a point equidistant between the two points where the chord meets the circle; and that is the case here, for, by the construction of the figure, the angle, X V W, is a right angle, and the angles, V X F and V X H, equal angles. The chord, H F, being parallel to the tangent, V W, it follows that the line, O I, which is the chord, H F, prolonged, must be parallel to the same tangent, V W. A similar demonstration will apply to the chord, D G.

That there is but one proper place for the centre of motion of the pallets, and that it is the point found as above described, will be evident, when it is considered, that, for the pendulum to be led an equal quantity by the action of the wheel on each pallet (the inclined planes of which must be of equal length, otherwise the action will not be the same on both), it is requisite, making no allowance for drop, that, at the instant the wheel has advanced a quantity equal to half the space between two of its teeth, the lead of the pallet should be completed, and that the tooth, which has just led the pallet to the extremity of the angle of lead of the pallet, should quit the pallet; and, at the same instant, the other pallet should present itself in such a situation, that another tooth of the wheel may come into action with it; that when that tooth shall have advanced the same quantity as the preceding, that it shall also have led the other pallet which it has acted upon to the extremity of its action of lead; and have brought the first-mentioned pallet into a situation to receive the following tooth of the wheel to that by which it was previously led.

This can only be the case when the lines, I O and I P, which pass through the circumscribing circle, intersect it at the points which determine the thickness of the pallets, which, from the construction, it is evident in this case they do. By reference to the figure it will be seen, that in consequence of the angles, O I Q and P I R, being equal to one another, and the sides, I O and I P, of the same angles intersecting the circumference of the circle at the points, H F and G D (equidistant each to each from the point, I), where the circles forming the circular rests intersect the circle circumscribing the points of the teeth of the wheel, the pendulum is led a quantity equal to each of those angles at each vibration. For, supposing the wheel advancing, at the moment the tooth, 2, has reached the extremity of the inclined plane of the pallet, A A, the point, S, of the pallet will have reached the point, H, and the point, T, of the pallet, B B, will have reached the point, G, ready to receive the tooth, 1, which, at that instant will drop upon it; and when, by the action of the tooth, 1, upon the pallet, B B, it is returned to its former place, the point, F, of the pallet, A A, will be ready to receive the tooth, 3, which will at that instant drop upon it.

To render the above demonstration as apparent as possible, the wheel has been drawn with only six teeth, because, supposing a wheel, even of the size of the wheel in the figure, with thirty teeth, (the number for a second pendulum), in which case the pallet would be only one-fifth of their present thickness, the portion of the circle the chord would subtend would be so short, and, consequently, the space between the chord prolonged, and the tangent so small, that the distance between the points, I and W, would be much less apparent. In the case of a scape wheel of the size usually employed in second pendulum clocks, in laying down the lines for the purpose of determining the distance between the two centres, it will be sufficient, unless when very great accuracy is required, to draw two lines, bisecting the points which mark the thickness of the pallets upon the circle of the wheel, and upon those lines, at the points where they intersect the circle of the wheel, to raise two perpendiculars, and to take the point where these perpendiculars meet, as the centre of motion of the pallets.

Were the centre of motion of the pallet placed higher or lower than the proper place, as above determined; See Fig. 2 and 3,

Plate IV., in both which the angle of lead is drawn the same as in Fig. 1. In the one case, the action of the tooth of the wheel upon the inclined plane of the pallet, A A, See Fig. 2 (here the centre of motion of the pallets is raised), would lead the pendulum an angle less than the angle of lead, O I Q, as drawn, by a quantity equal to the angle, O I X, and, consequently, the point, T, of the line, T D, or inclined plane of the pallet, B B, instead of having advanced a sufficient quantity to meet the tooth, 1, at the point, G, will only have advanced to H, and the point of the tooth, 1, would drop upon the inclined plane, H K, of the pallet between H and P, and the pallet advancing with less rapidity than the wheel they will meet nearer P than H.*

In the other case (the centre of motion of the pallets is dropped nearer to the centre of the wheel) the action of the wheel upon the inclined plane of the pallet AA, Fig. 3, Plate IV. would lead the pendulum, an angle exceeding the angle O I Q of lead already drawn, by a quantity equal to the angle, I O X, and consequently the pallet BB will be led so much too deep into the wheel, that the point of the tooth, 1, instead of dropping safely upon the pallet, will drop upon its circular rest at a very considerable distance from the point H.†

It would be impossible for any clock to go with the pallets shaped, as drawn, Fig. 2 and 3, Plate IV.; but it does not follow that pallets could not be made, preserving the same centres of motion, which would perform; and at first sight, and upon a small scale, appear as mathematically correct as the escapement drawn Fig. 1, Plate IV. Such pallets are represented, Fig. 2 and 3, Plate V., applied to similar wheels; taking over the same number of

* The effect that would result in practice from the tooth dropping on the inclined plane of the pallet, would be to cause the scape wheel, and, consequently, the whole train of wheels to recoil; an evil subversive of the principle of the escapement.

† The effect produced by the tooth taking more hold on the circular rest than is absolutely necessary for safety, is to considerably increase the friction on the rest. In practice the tooth should drop just on the circular rest, and no more.

teeth, and acting on the same centres as in Fig. 2 and 3, Plate IV. These pallets will be led an equal angle by the action of the wheel on each pallet, and lead the pendulum an angle equal to the angle it is led with the centre of action of the pallets in its proper place, as in Fig. 1, Plate IV.

This effect is produced in Fig. 2, Plate V, by increasing the angle of lead of the pallet AA, and diminishing that of the pallet, BB; and it will be observed, that though the two angles, BI C, and D I E, the angles the pallets are led, are equal to one another, and consequently, that the pendulum will be led an equal angle by the action of the wheel on each pallet; yet that the angle, A I C of lead as drawn of the pallet, AA, is greater than the angle, B I C the pendulum is led, by the angle, A I B, representing the difference between the two: and the angle, D I F of lead as drawn of the pallet, BB, is less than the angle, D I E the pendulum is led, by the angle, F I E the difference between the two. Consequently, the total difference between the angles of lead as drawn, is an angle equal to the two angles, A I B and F I E.

A similar remark applies to Fig. 3, with this difference, that the same effects take place on the reverse pallets; the angle of lead of the pallet, AA is diminished, and that of the pallet, BB increased; the angles, B I C and D I E, the pallets are led by the wheel, as in the former case, are equal to one another; but the angle, A I C of lead of the pallet, AA, is less than the angle, B I C the pendulum is led, by the angle, A I B; and the angle, D I F of lead of the pallet, BB, is greater than the angle, D I E the pendulum is led, by the angle, F I E; and the difference between the two angles of lead as drawn, is an angle equal to the two angles, A I B and F I E. This alteration of the shape of the pallets, requires a corresponding alteration in the shape of the teeth of the wheel, which must be longer and more undercut, and consequently, weaker than when the centre of motion is determined, as shown by Fig. 1, Plate IV.*

* In the case of the centre being placed as in Fig. 2 and 3, Plate V., and the angle of lead of the pallets supposed to be originally drawn as represented Fig. 1,

It now remains to point out the difference between the pallets, as drawn Fig. 1, Plate IV., and Fig. 2 and 3, Plate V. In Fig. 1, Plate IV., the angle of lead of the pallets as drawn, and the angles they are lead are one and the same, and equal to one another; and consequently, the pendulum is led an angle equal to either of these angles, by the action of the wheel on each pallet. In Fig. 2 and 3, Plate V., this is not the case, it is true, the pendulum is led an equal angle by the action of the wheel upon each pallet, the angles, B I C and D I E, Fig. 2 and 3, Plate V., being in each figure equal to each other, but the angles, A I C and D I F of lead of the pallets, are of necessity, to enable the escapement to perform, drawn different from each other, and different from the angle the pendulum is led; the one being greater and the other less than the angle. The consequence of this is, that the length of the inclined planes of the pallets is also very different, the one being much longer than the other, which renders the fraction upon the two unequal, and pro-

Plate IV. the escapement will yet perform, and the pallets lead an equal angle to one another, by the action of the wheel on each pallet, by only altering the angle of lead of one of the pallets, as originally drawn. This is shown, Fig. 1, Plate V., where the centre of the wheel and pallets are placed, and all the parts, the angles of lead of the pallets excepted, are drawn as in Fig. 2, Plate V.; the angle of lead of the pallet, AA is drawn the same as in Fig. 1, Plate IV.; but the angle of lead of the pallet, BB is diminished to an angle sufficiently small to be led by the wheel an angle equal to the angle the pallet, AA is led with its angle drawn similar to Fig 1, Plate IV, and the two centres placed as in Fig. 2, Plate V.

In this figure, see Fig. 1, Plate V., the angles the pallets are led, and consequently the pendulum, though equal to one another, are less than in Figs. 2 and 3, same Plate, where they are purposely made to lead angles equal to the angle led, Fig. 1, Plate IV, at the same time they are led angles equal to one another.

If, instead of the angle of lead of the pallet, AA, Fig. 1, Plate V., being drawn, as in Fig. 1, Plate IV., the angle of lead of the pallet, BB had been so drawn, the angle of the pallet, AA might equally be altered to suit the action of the pallet, BB, and similar effects would result as to the difference between the angles of lead of the pallets as drawn, and the angles led by the action of the wheel on the pallets; and consequently, the angle the pendulum would be led, would be considerably greater than in Fig. 1, Plate IV., instead of less, as in Fig. 1, Plate V.

bably, in the same ratio, as the difference in their lengths, and consequently, the impulse received by the pallets must, from that cause, independent of any other, be unequal. That this is an evil of the first magnitude in the dead escapement, it would be a waste of time to demonstrate; it is only sufficient to observe, that the impulses received by the pallets being unequal, the lengths of the arcs of vibration of the pendulum will be unequal, and consequently, performed in unequal times.*

The angles, A I B and F I E, Fig. 2 and 3, Plate V., in each figure, being equal to each other, it will be found in all cases, that the excess of the angle led by one pallet, above the angle of lead of the same pallet as drawn; will be equal to the excess of the angle of lead, over and above the angle led by the other pallet.

Supposing the distance between the centres of action of the pallets and the scape-wheel, determined as above described, see Fig. 1, Plate IV., and lines drawn from the points where the teeth of the wheel act upon the rests of the pallets, to the centres of motion of the wheel and the pallets, they will form the one an obtuse, and the other an acute angle; and both angles will differ an equal quantity, half the thickness of the pallet from a right angle. Now, in principle, the most advantageous point of action for the wheel upon the rests of the pallets, is at right angles to the two centres of motion; but as it is impossible that the points of action on the two rests should form right angles with the centres, (for were the one a right angle, the other would be the thickness of a pallet greater or less than a right angle,) it follows, that the best construction is, that in

* This is correctly true in the case of the pendulum being supposed a beam and vibrating a short angle; or in the case of a pendulum with a very light bob suspended on a knife edge, as many of the old clocks were made; but in practise, in the case of a seconds' pendulum, and still more, a two seconds' pendulum, and a heavy bob, the power of gravity will very nearly overcome the difference in the impulse: nevertheless, the inequality of the impulse must, in a certain degree, be prejudicial, particularly when very accurate performance is required.

In the case of the anchor escapement, as applied to watches, the evil would probably be greater and more felt, and cause the arcs of vibration of the balance to be very unequal.

which the action of the teeth of the wheel on both rests differs the least possible quantity from a right angle, and is that which will have the least tendency to wear; and as observed by M. Berthoud, No. 1325, "the most favourable possible."

There is a construction of the dead escapement, in which the point of action of the wheel upon the rests may be at right angles to the centres on both pallets, and, consequently, the rests at equal distances from the centre of motion of the pallets; but in that case, the impulse upon the two pallets is not at an equal distance from their centre, but the thickness of a pallet further from the centre upon one pallet, than upon the other. See Fig. 2, Plate III. The impulse upon the inclined planes of the pallets being at an unequal distance from their centre, is a most serious defect, and the cause that this construction of pallets is no longer employed.*

Another advantage resulting from the mode of placing the centre of action of the pallets as above proposed, is that the wheel will require to be undercut the least possible quantity; for, if the centre of action of the pallet is raised above its proper centre of motion, it will cause the wheel to be more undercut than it need otherwise have been, to free the pallet upon the inner rest on which the wheel acts, otherwise the point of intersection of the inclined plane, and rest of the pallet will cause the wheel to recoil, by coming into contact with the face of the tooth of the wheel: and if the centre of the pallets is brought lower than the proper centre of motion, it will cause the wheel to be more undercut to free the pallet upon the outer rest on which the wheel acts, otherwise the action of that rest will occasion the wheel to recoil (though the effect is very much less considerable in this case than in the former), consequently, the proper centre of motion of the pallets is the most advantageous to the shape of the teeth of the wheel: for, as has been before noticed,

* It has been before noticed, that I. A. Le Paute, in his *Traité d'Horlogerie*, 4to., Paris, 1767, page 188, mentions, that Mr. Graham made his dead escapement for clocks with the rests at equal distance from the centre of motion of the pallets, and has so represented them in the plates to his work.

I do not recollect ever having seen a clock of Mr. Graham's with the pallet made in this manner, though I have seen such applied in old clocks.

the less the teeth of the wheel are undercut, the shorter, and, consequently, the stronger, they will be. It may be further observed, supposing the centre of the pallets to be in its proper place, that the greater the number of the teeth of the wheel the pallets take over, the less the teeth of the wheel require to be undercut. It must not be concluded from this, that the number of teeth the pallets take over can be too great, for I believe the contrary to be the case, inasmuch as it is more advantageous in practice to communicate the impulse to the pallets at a moderate distance from their centre of motion, which will be the case when they take over six, seven, or eight teeth, than at a very considerable distance, as in the case when they take over eleven, twelve, or thirteen teeth.

To conclude: the great advantage of the mode of determining the distance between the centres of the wheel and pallets, and laying down the lines of the escapement, as above described, consists not only in enabling the escapement to be made with the least possible drop, and, consequently, with the least loss of power, and with the action of the wheel and the friction upon each pallet as equal as it can be in the dead escapement made according to the usual construction with the wheel between the pallets, but on its being of general application, and equally correct, whatever may be the size of the wheel, the number of its teeth, or the number of teeth the pallets are made to take over.

In the above, the drop of the escapement has only been mentioned incidently, and no allowance made for that part of the action of the escapement, which, by clockmakers, is termed the drop, or beat. In the dead escapement, in common with all other escapements, the drop is an unavoidable evil; and it is sufficient to observe, that the more correctly in principle, and accurately in execution, the escapement is made, the less will be the quantity of drop requisite, and, consequently, the less the quantity of power lost.

The following observations have arisen out of the preceding pages, and although not immediately relating to the subject of this paper, are, from the relation they bear to the construction of the dead escapement, here inserted:

It has before been observed (see note, page 3, and Fig. 4, Plate III.), that the quantity of the angle of lead of the escapement depends upon two things; the angle of the inclined planes, and the number of teeth of the wheel the pallets take over; and that the escapement may be constructed to lead the pendulum an equal quantity, with the pallets made to take over a few teeth, and with a low angle of lead; or with the pallets made to take over a greater number of teeth, and with a high angle of lead. It may further be noticed, that the lower the angle of the inclined planes, the less will be the friction upon them, and, consequently, the easier the action of the wheel upon the pallets: because the lower the angle the shorter the inclined planes: and, on the contrary, the higher the angle and the longer the inclined planes, the greater the friction, and the more unfavourable the action of the wheel on the pallets. At the same time, it is to be observed, that the less the friction on the inclined planes, the greater the friction on the rests. Supposing the case of two dead escapements, similar in every respect, except the angle of lead, of which the pendulums are made to vibrate equal angles (here the angle of vibration must not be confounded with the angle of lead), and the pallets of the one constructed with a low angle of lead taking over a few teeth, and the pallets of the other with a high angle, and taking over a greater number of teeth; there will, in the first case, be less friction on the inclined planes and more on the rests; and, in the second, more friction on the inclined planes and less on the rests; and, consequently, in the case of the pallets with a low angle of lead, of the total space of time which is occupied by each vibration of the pendulum, a less portion will be engaged during the advance of the wheel and the giving the impulse, than during the action of the wheel on the rests of the pallets; whereas, in the case of the pallets made with a high angle of lead, the direct contrary will occur; unless, indeed, which is a possible case, the angle of lead should lead the pendulum exactly half the angle of vibration, when the portion of time the wheel is engaged on the inclined planes will be equal to that it is engaged on the rest of the pallets. This observation is made on the supposition that the whole vibration of the pendulum is made with equal velocity, which is not the case; but, as the pendulum is acted upon by the clock through the inclined planes of the pallets, both during its ascent and descent, in the arc of vibration, I do not apprehend the distinction to be very material. Now, as all irregularities resulting from the train of wheels, must be more felt during the period the impulse is being given, than during the period of rest, it follows, that, on that account, a low (or short) angle of lead is much preferable to a high one.

It is also worthy of notice, that, in the case supposed above, of two pendulums made to vibrate equal angles, by the action of dead escapements similar, except in the quantity of the angle of lead; the pendulum applied to the pallets with the high angle, will be much more liable to come to rest than the other, on account of the excess of the angle of vibration, over and above the angle of lead being less than in the case of the pallets with a low angle of lead.

In a former paper, I described a new mode of constructing the pallets and their parts, by which great accuracy in the execution of the escapement is obtained. It might appear requisite that I should, to complete the description of the dead escapement, describe the method of dividing and cutting the teeth of the scape wheel. But the subject of dividing and cutting wheels has been so fully entered into, and so much has been written on the subject, and much to the purpose, by various authors, who have written on clocks and watches, that it is quite superfluous to add anything further on the subject.

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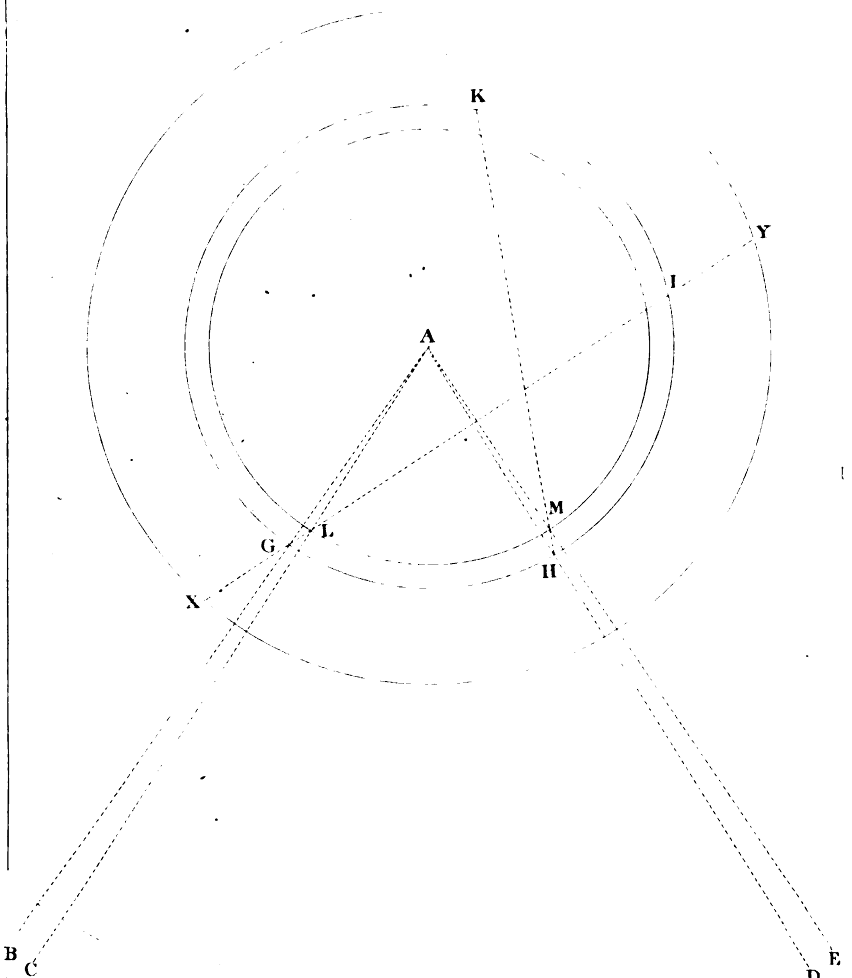
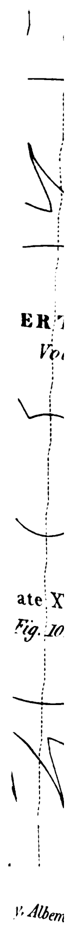
Fig. 16.

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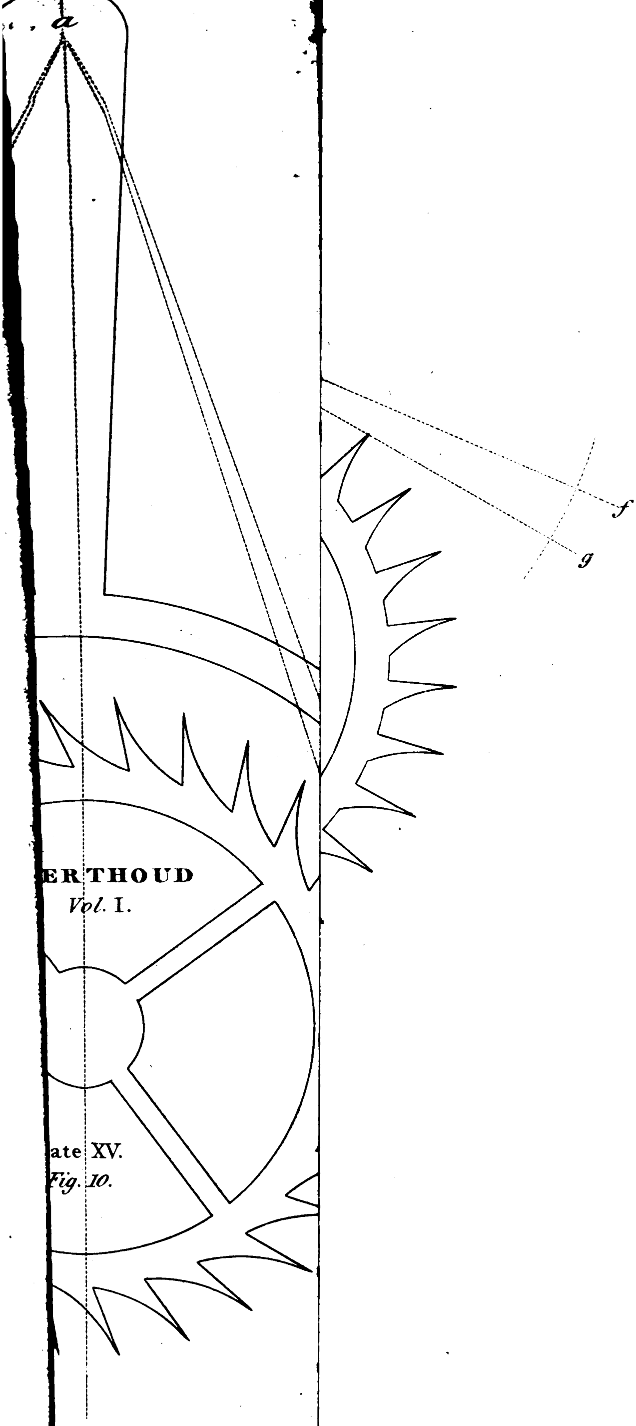

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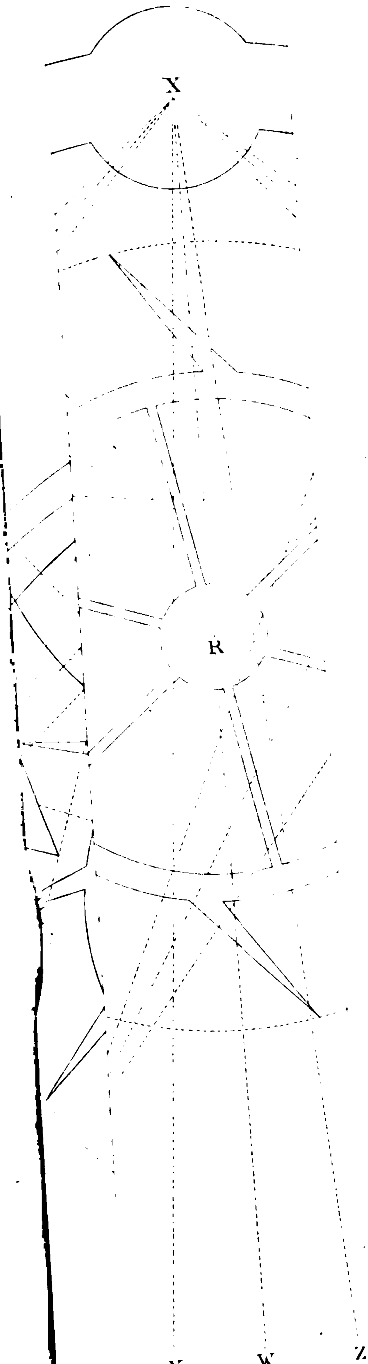

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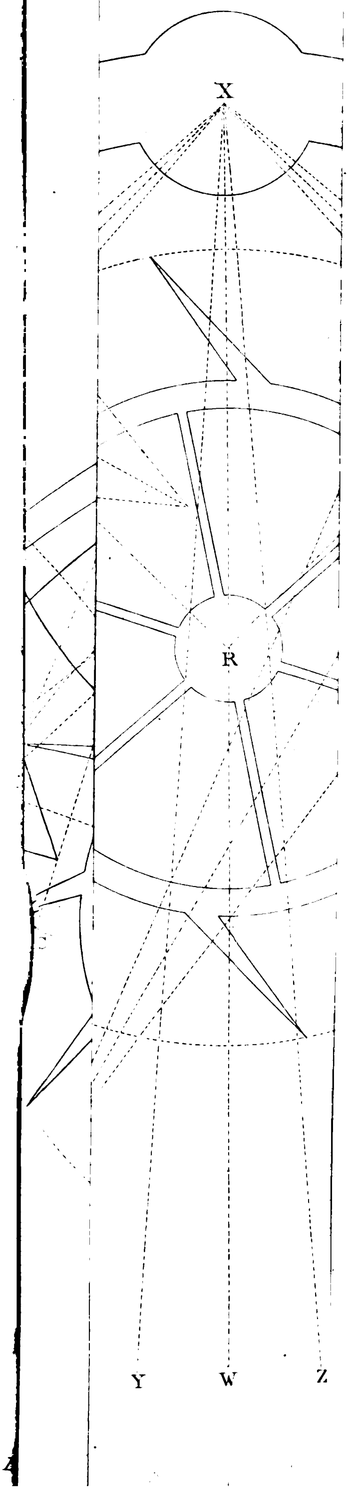

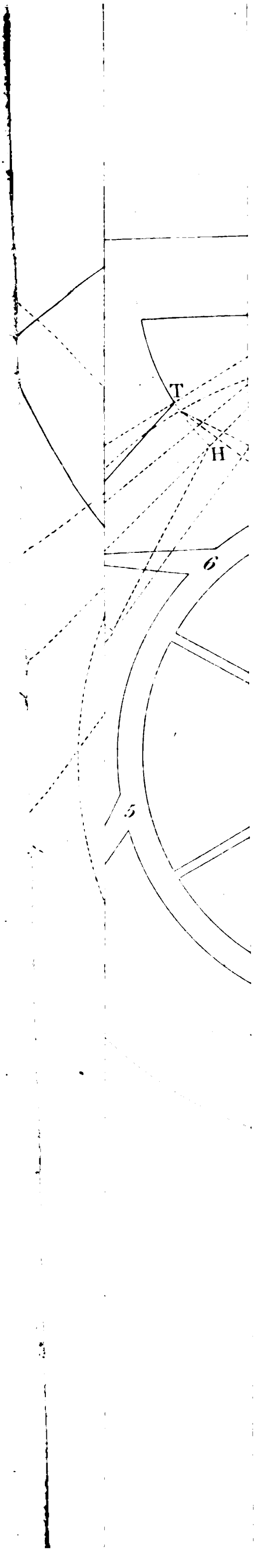
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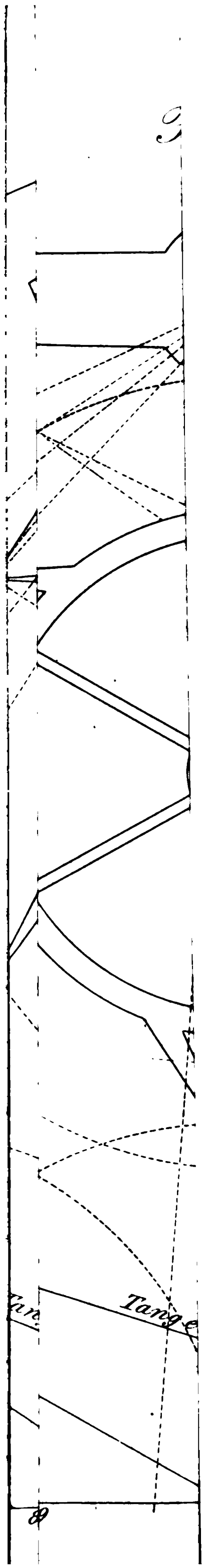
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