FREE PENDULUMS FOR EVERYDAY USE

A LECTURE DELIVERED AT THE B.H.I.

By Mr. F. HOPE-JONES, M.I.E.E., F.R.A.S., F.B.H.I.

On October 16th, 1895, just 35 years ago, I came up to London as a young man, and described from this platform an electric clock which made its contact without taking any energy from the pendulum or the wheelwork which drove it. It seemed to me that that was the one thing needed to lift electric clocks from the slough of despond in which I found them. Every other known system, English or foreign, was dead or dying; my invention fell rather flat, and my proposals aroused little enthusiasm, since the profession was not, at that time, in a receptive frame of mind. The fact was that those watch and clock makers who had been enterprising enough to take up the subject at all had been badly let down. The prejudice against the use of electricity was deep-rooted, and all the force of youth and enthusiasm was required to combat it.

In those days, your President was Lord Grimthorpe. His opinions were always forceful and downright, and on the subject of electric clocks he voiced the general opinion prevailing at that time when he wrote, "They never answered in any practical sense; nor would anything but the strongest evidence, independent of the inventor, convince me that any independent pendulum directly maintained by electricity succeed in keeping good time for any considerable period. . . . And anyone who sets to work to invent electrical clocks must start with this axiom, that every now and then the electricity will fail to lift anything, however small."

He just let it go at that, without any investigation as to the root causes of the failures, and I took up the question exactly where and when he left it in 1895, determined to find the real reasons of the failure.

Applying the acid test to the question, "Where does the contact energy come from?" all the then existing systems were damned, and most of those which have followed since then have been similarly damned. Consider how few systems there are on the market to-day; they represent less than *one per cent.* of the electric clock inventions patented.

No wonder the trade was tired of a subject in which 99 out of every 100 inventions failed, and there is some excuse for the apathy they have shown since, but it is time they realised that the experimental stage is past and that a large share of their legitimate trade is now being taken from them by the electrical engineer. Reliable systems have been available since the beginning of the century, but have received scant encouragement. A standard practice, peculiarly British in its simplicity and reliability, has been established, superior to that of any other country. How far superior will be apparent to anyone acquainted with the polarised parallel systems still general on the Continent, the "minute jumpers" and the synchronising systems of the U.S.A., or the latest German types now being reviewed in the pages of a contemporary, which are positively grotesque in their intricate complications of electro-thermic and pneumatic dial movements, regulating, synchronising, and reporting back recording devices.

Thanks to the publicity afforded by this platform and The British Horological Journal, the world was shown, 35 years ago, how simple uni-directional impulses and "one-wheel" dial movements could be relied upon for electric time service, and though the world took no notice, it laid the foundation-stone of British standard practice.

It is strange to think that no other country understands or appreciates the merits upon which our practice is founded, such as:—

(1) Free detached gravity escapement with impulse at zero.
(2) No contact energy taken from the pendulum, and any interference confined to zero.
(3) The transmission of energy through the surfaces of the contact.
(4) Uniform wave-shape of impulses, clean in make and break.
(5) Duration of impulse dependent upon the self-induction of dials.
(6) Security that every dial gets all the current it wants.
(7) Compensatory action in varying current conditions.
(8) Battery warning.
(9) Impossibility of stoppage in closed circuit.

The horological press of the Continent and of America have ignored them. It is their loss, and until they take the trouble to assimilate them they cannot even understand how the record for accuracy of time measurement has been recovered by England.

Most of my audience will be acquainted with the mechanisms which embody these principles, and I need not do more than illustrate three stages in their development.

(1) The Synchronome Remontoire in its earliest form, as shown in this room in 1895.

(2) A stage in its development ten years later.

(3) As a free pendulum combined with a slave by means of Mr. Shortt's hit-and-miss synchroniser.

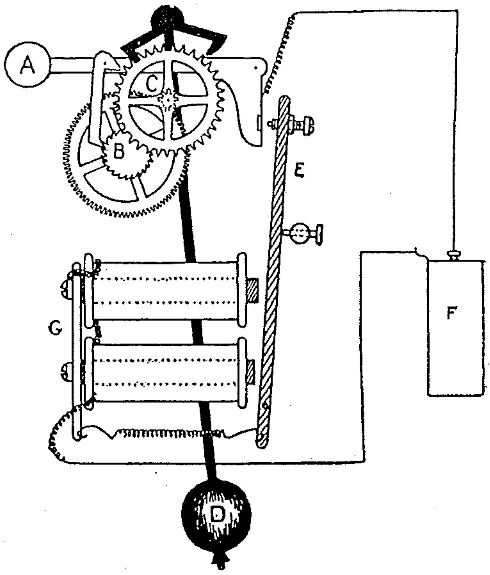

FIG. 1.—*The Synchronome Remontoire, 1895.*

In the latter, the slave pendulum performs the time counting and releasing. The achievements of the free pendulums are known to most of you, but I am not discussing them to-night. We are concerned this evening with the fact that, from its nature and the nature of its job, its use is limited to observatories. It could never be supplied in a form or at a price which would appeal to the public.

Why should we leave the free pendulum on a highly scientific pedestal beyond the reach of ordinary mortals? Can we not bring it, or something very like it, into common use? It is one thing to break the world's record for accuracy of time measurement and quite another thing—and from some points of view a greater thing—to raise the standard of time-keeping of the community by providing the public with more accurate clocks.

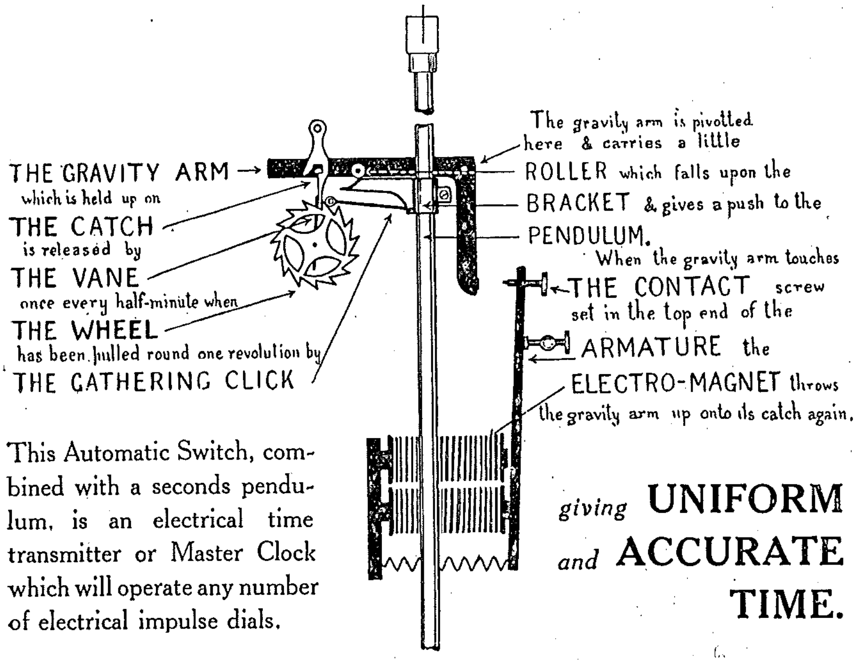

FIG. 2.—*The Synchronome Switch, 1905.*

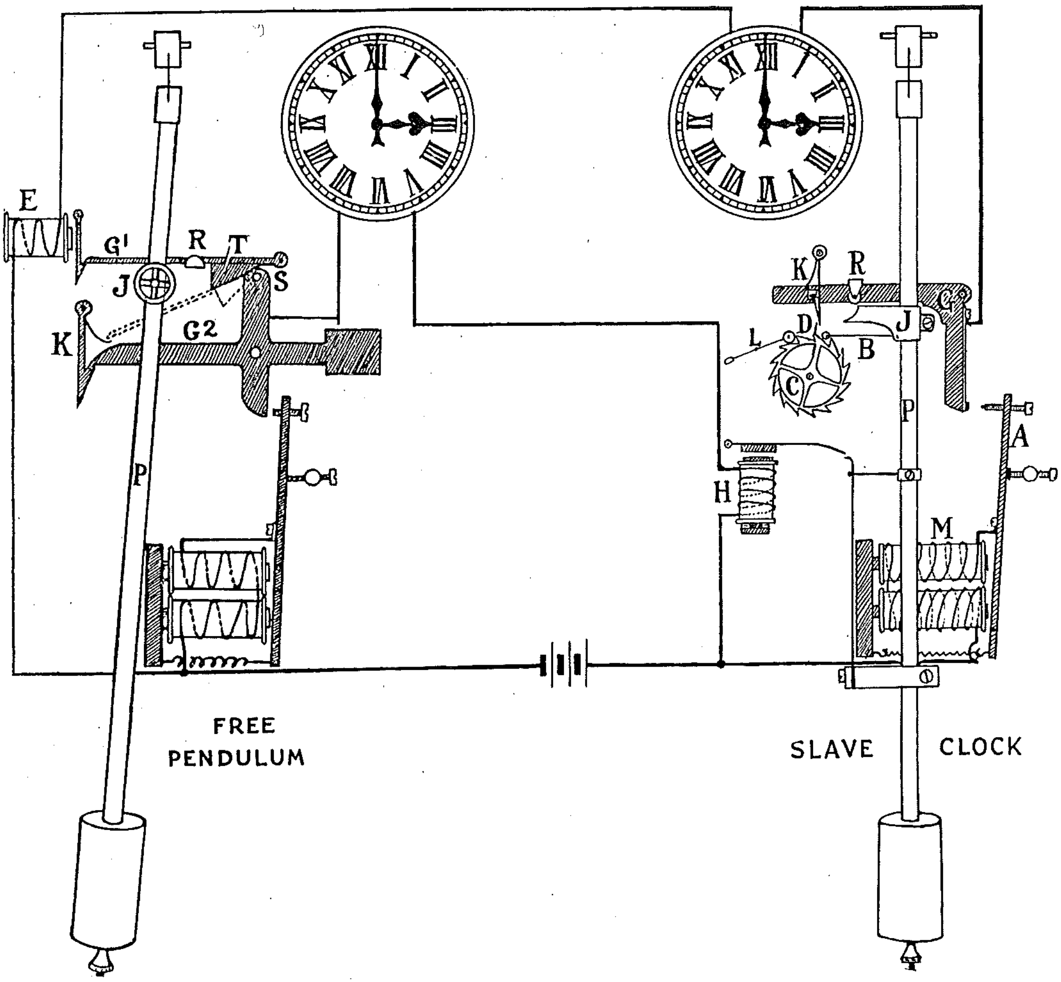

FIG. 3.—*The Synchronome Master Clock as a free pendulum combined with a slave by Mr. W. H. Shortt's synchroniser.*

The one thing needed is, of course, to get your pendulum to make an innocuous contact during its swing. That it could possibly do so, and yet remain a free pendulum, is paradoxical, or would be if it were not for the Synchronome switch, which is apparently the only thing in the world which will make a robust mechanical contact off a pendulum without the pendulum being aware of it. But in the Synchronome free pendulum this contact is necessarily made as a result of the impulse, and must therefore follow it. So it can only be used as a synchronising signal to keep another pendulum in phase, a slave clock which will in turn perform the escapement function for the free pendulum, and it cannot be used directly to release its own gravity lever at or just before zero.

Is it really impossible to apply some other kind of electrical contact to the free pendulum which shall be innocuous, which shall take place at or before its zero position, instead of some distance after it, and which can therefore be used to perform the escapement function and perhaps the time counting also?

That is what I have attempted, and it is the subject-matter of this lecture.

If it could be done, it would give us a free pendulum without the necessity of providing a slave clock. We should get rid of that bugbear, *the last wheel,* and produce a Master Clock of the highest precision at an inexpensive price.

You can, of course, fix a bent pin on the pendulum and let it pass through an upstanding globule of mercury, but you will rightly dismiss that as childish.

You can use mercury in a sealed glass tube, but that implies tilting the tube, unless you adopt some such method as that advocated by Dr. Robertson in the April, 1930, issue of THE HOROLOGICAL JOURNAL, a method which, unfortunately, gives a contact only at the ends of each swing instead of at or near the middle.

And you can put a mirror on your pendulum to deflect a beam of light upon a photo-electric cell, or you can let your pendulum, as it swings, alter the capacity of a critical condenser in the circuit of a triode valve, but if you are wise you will dismiss these also as being equally childish, on account of their delicacy and their high cost of maintenance.

Sooner than embark on these uncertain and perilous courses, I would be content, in a commercial article, to accept something just short of the highest scientific standard, to accept a pendulum which is not absolutely free, but so near it that no one outside an observatory could discover its error.

In the working models exhibited and illustrated diagrammatically in Fig. 4 you will see that a small horse-shoe permanent magnet is carried by the pendulum swinging freely under a pair of contact springs, one of which is provided with an armature. The resulting contact passes current of not more than $\frac{1}{10}$th of an ampere at a few volts through an electrical impulse dial which indicates seconds only, and that dial movement shunts each thirtieth impulse through an electro-magnet which releases the gravity arm.

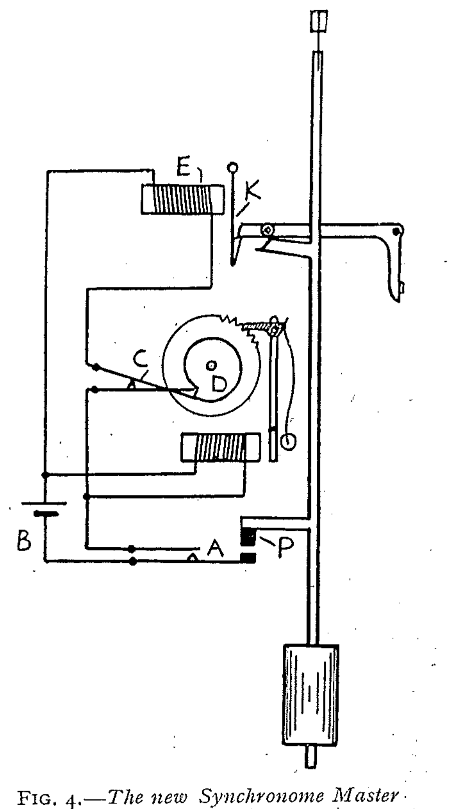

FIG. 4.—*The new Synchronome Master Clock (free pendulum type.)*

Thus we have a substitute for the time counting and releasing formerly accomplished by the 15T wheel and the vane on its axle. Since the pendulum touches nothing, it is obvious that we are now taking very little energy out of it.

You may wonder that I should propose magnetic interference with a pendulum after all the hard things I have said of Wheatstone's induction method, but he attempted to make his pendulum generate sufficient power to drive a *group of dials,* whereas I only want enough to release a Synchronome switch—not even that—but only enough to make a contact which shall enable a dry cell to release it.

The all-important thing we want to know is the extent of this interference, and fortunately it is quite easy to make a complete analysis of the forces we are handling.

There are two ways of doing it, for we can approach the problem from either end. We know the energy required to maintain an absolutely free pendulum at a constant arc by multiplying the weight of the gravity lever by its fall, and we note the rate at which the pendulum dissipates its energy by observing the dying down of the arc when we deprive it of its impulses.

By a simple process of trial and error we can ascertain exactly what increase in weight in the gravity lever is required to maintain the same arc when (*a*) the pendulum is carrying a permanent magnet past an armature on a contact spring every second, (*b*) when it is gathering the 15T wheel every two seconds, and (*c*) when it is releasing or unlatching the gravity arm; and we can check our figures by noting how long it takes to die down from one arc to another under each of these conditions.

I have made these tests and can therefore give you these energy figures with confidence in the form of a graph, Fig. 5.

To maintain an absolutely free pendulum at a semi-arc of 40 mm. (i.e., a total arc of about 4°, which is customary in the commercial

Synchronome standard Master Clock), 4.5 cm.-gr. per half-minute is required. This is almost entirely expended in overcoming air resistance. Smaller arcs will,

(*c*) The mechanical releasing of the gravity arm requires a further 1.1 cm.-gr. per half-minute.

Thus the mechanical operations require

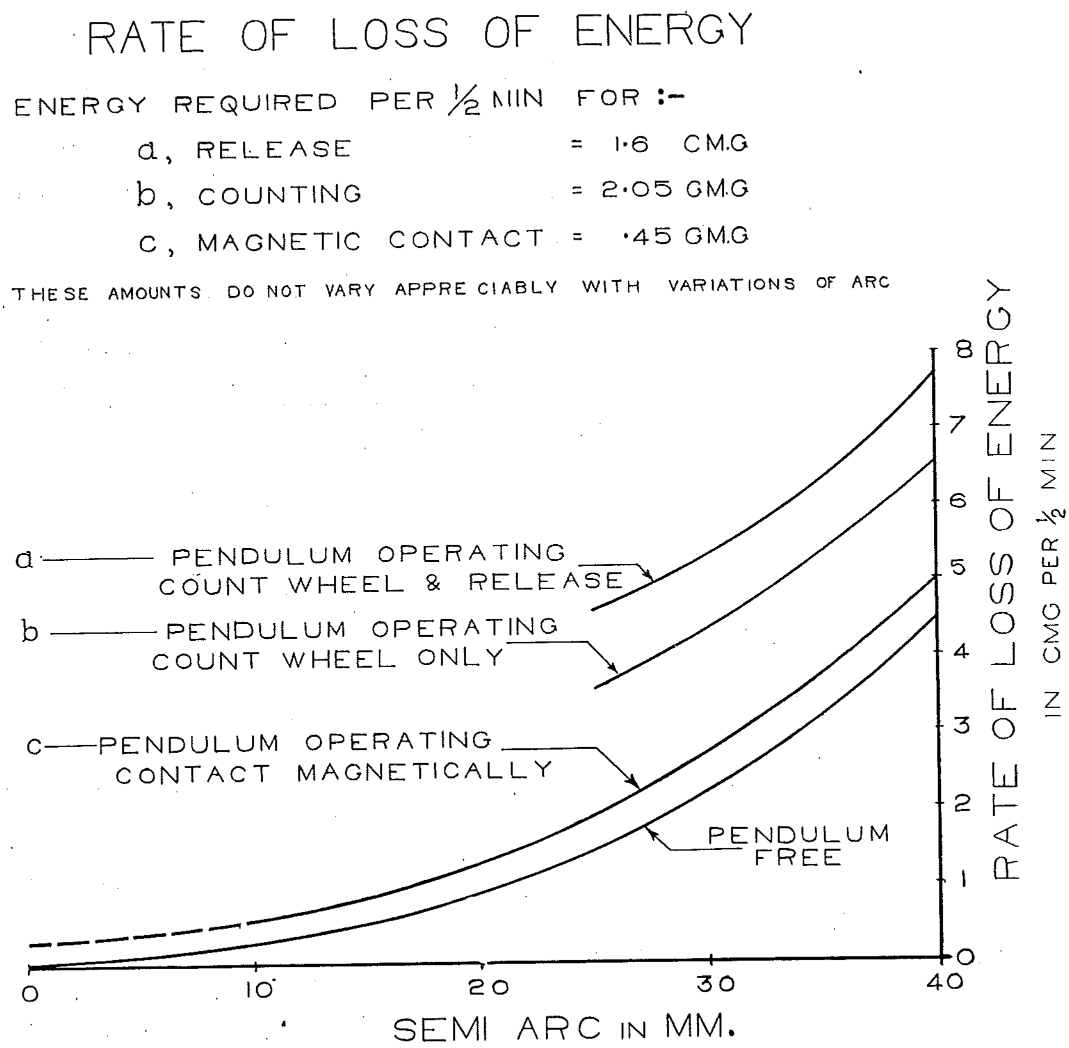

FIG. 5.—*Analysis of forces.*

of course, require less energy, and you will observe that for half the swing (20 mm. plus 20 mm.=2°) less than 1 cm.-gr. per half-minute will suffice.

(*a*) The addition of my magnetic contact requires the addition of .45 cm.-gr. per half-minute, an increase of only $\frac{1}{10}$th of what the pendulum requires to overcome its air resistance at a semi-arc of 2°;

(*b*) The mechanical gathering of the 15T wheel requires the addition of 2.05 cm. grammes per half-minute; and

3.15 cm.-gr. as compared with the magnetic contact, which takes only $\frac{1}{7}$th of the energy, viz., .45 cm.-gr.

I suppose I ought to stand in the white sheet of penitence, or sit in sackcloth and ashes with regard to (*b*) and (*c*), but in palliation of the offence I plead that every other kind of escapement is infinitely worse, and that the Synchronome Master Clock in that form has done much to raise the standard of time-keeping in business establishments.

(*To be continued.*)

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(*Continued from page* 61.)

Has it occurred to you how impossible it is to analyse these forces in any other kind of escapement ? Take a dead beat, a half-dead beat, or anchor escapement : how much of the energy produced reaches the pendulum and how much is lost in friction ? There is no way of disintegrating it, since impulse and friction are coincident and continuous.

I have brought the contact springs in half a dozen different forms. The two shown in Figs. 6 and 7 are intended to be fixed in the case just above the path of the permanent magnet. Those in glass tubes are designed to be exhausted or filled with an inert gas, and to be as rapidly interchangeable as lamps.

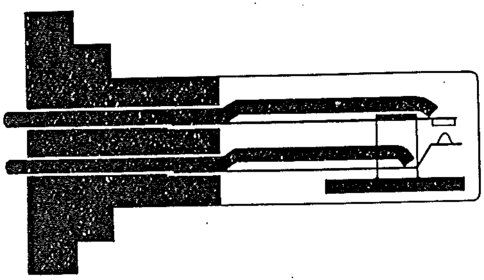

FIG. 6.—*Magnetically operated contact.*

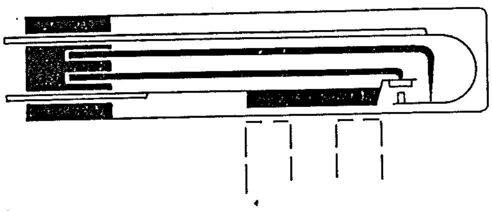

FIG. 7.—*Magnetically operated contact.*

They are capable of passing $\frac{1}{10}$ amp. at 4 volts for $\frac{1}{10}$ sec. indefinitely, even if the circuit is highly inductive, which it is not. Condensers and choke resistances are unnecessary, and the contact tubes are so inexpensive that if it was desired to do so a reserve one can always be supplied as a spare, held in a clip in a corner of the case.

In order that the dial on the Master Clock may serve as a pilot representing the time-circuit, its minute and hour hands are driven by a half-minute electrical impulse dial movement in series with all the rest. The seconds hand on the inset circle has its own impulse movement, and the driving of it is the only duty of the magnetic contact, except that once every half-minute the release magnet is also operated.

It is to be observed that this secondary contact C, Fig. 4, which merely selects the 30th second, is never closed or opened alive.

The automatic acceleration and retarding of the circuit of dials are greatly simplified, since it is now merely a matter of switching. Having turned the switch to R on the first Saturday in October, for reversion to G.M.T., the pendulum will still have a substantial arc after swinging for an hour. That in itself is an illuminating demonstration of its freedom, and it suggests several methods of making both daylight saving changes absolutely automatic, but I must not be tempted to discuss them now.

It has hitherto been impossible to indicate seconds on a Synchronome Master Clock in its simplest form, since it is limited to steps of two seconds and the dial cannot be centrally placed. This new method, however, lends itself to the production of a popular self-wound clock provided with centre-seconds dial, capable of acting as a Master Clock if desired, and applicable to pendulums of any length, even half-seconds. But there is one failing which is inherent in this contact in its natural form, and that is when the pendulum stops, as it would do, of course, if the half-minute time-circuit was disconnected, then the primary local circuit would remain closed and its battery of two cells will be killed if its warning remains unnoticed.

The only remedy which occurs to us is the contact illustrated in Fig. 8, in which

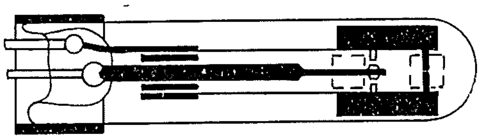

FIG. 8.—*Plan view of magnetic contact open at zero.*

there are two armatures and contacts which operate as one when the permanent magnet is passing, but is open in the central position.

There are many other purposes for which seconds or half-seconds contacts of this type will be useful, and if too much is not demanded from them, I have no hesitation in saying that they are substantially reliable.

If by any mischance the seconds dial was to be wrongly set or missed a beat, it would automatically set itself right by what I call "phase corrector."

The release takes place when the top corner of the impulse curve is just arriving under the roller, the pendulum travelling from left to right. If the dial was one beat out of phase, then it would occur when the pendulum was travelling in the opposite direction, and it would fall upon the dead surface of the impulse pallet. By the simple expedient of dividing the pallet into two insulated halves an extra impulse is transmitted to the dial movement which corrects its phase.

Here let me remind you of the nature of the half-minute impulse imparted to the pendulum and the extreme gentleness of its beginning and end. For this purpose I reproduce as Fig. 9 the force curve constructed in 1910 by Mr. W. H. Shortt. The

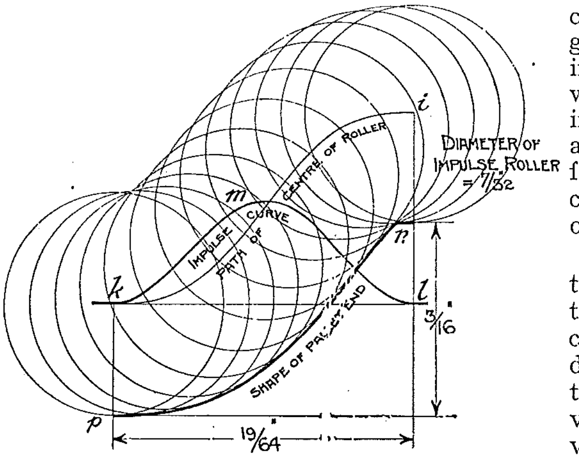

FIG. 9.—*Impulse force curve.*

curve *n p* of the pallet end is mathematically produced from the ideal force curve *k m e*. As the angle of the inclination of the impulse surface alters, so does the resultant horizontal thrust.

Just as we only permit ourselves to impel the pendulum with a force gradually applied and gradually withdrawn, so also with regard to the magnetic interference it begins and ends with extreme gentleness, equally disposed before and after zero, and, like the impulse, it is absolutely constant in value.

Apart, therefore, from barometric error, which we shall refer to later, the only way in which variation of rate could occur would be in the event of variation of arc, bringing in the circular error.

Before discussing circular error, I feel it essential that you should see it in its proper perspective, to enable you to judge of its relative importance. It is the variation from absolute isochronism due to the pendulum following a circular instead of a cycloidal path.

In the case of all mechanical clock escapements where the scape wheel is almost continuously engaged with the pallets, and where a long mechanical train of wheelwork inevitably results in frictional changes which affect the impulse, variations in the arc are constantly occurring, and the circular error assumes considerable importance, but in the clock we are discussing the pendulum is to all intents and purposes *free*, and is only subject to the "interference" involved in imparting an impulse to it during a period of about $\frac{1}{200}$th part of the time measured. And that impulse is given by the most constant means we can conceive of—a gravity arm of invariable weight falling an invariable distance. There is no train of wheelwork to cause variable friction, and in this latest pattern even the one wheel and the mechanical release is abolished in favour of a magnetic operation which is constant and gentle and equally disposed on each side of zero.

Since circular error cannot exist unless there is variation of arc, and we have seen that the arc cannot be otherwise than constant, logically I should refrain from discussing it, but when we come to consider the barometric error we shall find that variations of air density will cause slight variations of arc, so it is desirable that we should see what there is about our clock which would make it go faster or slower if the swing of the pendulum *did* become a little larger or smaller. Recollecting that a pendulum takes longer to swing larger arcs than smaller ones, I shall use the expression "plus to circular error" to mean an influence which acts in the same direction, adding to circular error, and "minus to circular error" to refer to something which acts in the opposite direction and tends to compensate it.

The contact springs are intentionally placed *above* the permanent magnet carried by the pendulum, so that the attractive force tends to lift the pendulum towards the armature (action and reaction having equal and opposite force). That is equivalent to taking a regulating weight off a tray at that point and slowing the pendulum for a short but definite period in the middle of each swing. If the arc increases, this slowing effect of the permanent magnet's pull will be relatively less, since the time and space through which it operates is less in proportion to the total arc; this is equivalent to a gaining tendency, and is therefore compensatory or minus to circular error. If you wish to do so, it is a simple matter to neutralise this force at its source by mounting the permanent magnet horizontally and letting it embrace the two contact springs with an armature on each. As shown in Figs. 10 and 11.

As the permanent magnet approaches the armature there is also a lateral attraction, and as it passes beyond it there is lateral detraction, the effect of both of which is to

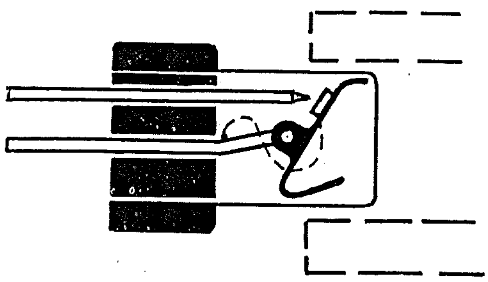

FIG. 10.—*Contact embraced by permanent magnet.*

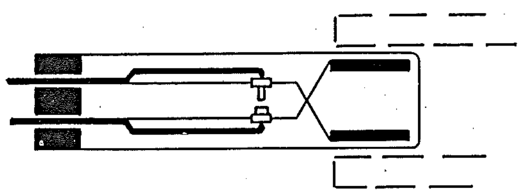

FIG. 11.—*Contact embraced by permanent magnet.*

increase the force of gravity and produce a gaining tendency through a definite space and period. This quickening effect will be relatively less if the arc increases and will be equivalent to a losing rate, and is therefore plus to circular error.

The impulse begins when the pendulum is at zero and continues for about half a degree thereafter. Throughout this period it is fighting against and diminishing the force of gravity, and therefore slowing the pendulum. If the arc increases, this slowing effect will be relatively less, since the time and space through which it acts will be less in proportion to the total arc, and if the arc diminishes, then the slowing effect will increase, since its effect is much greater when exercised near to the end of the pendulum's path.

This is minus to circular error, and is the valuable means of compensation suggested by Mr. Shortt in the discussion of my I.E.E. Paper of 1910.

So much for the effects of circular error. We have shown that it doesn't exist because the arc is to all intents and purposes constant, and that if it did we could compensate it.

I have left the most difficult subject until the last—barometric error—and I cannot attempt to do more than give the outlines of the problem at this late hour in the evening.

A free pendulum will swing more quickly in vacuum than in air; the difference is 9 seconds a day, taking our atmospheric pressure at the average of 30 ins. of mercury, so if we have rated our pendulum to G.M.T. *in vacuo*, and then let the air into the case, we shall have to raise the bob about .25 mm. to make it keep the same time.

It would be a simple matter if it ended there, but unfortunately the density of the air is constantly changing, and the rate would change with it (to the extent of .3 second per day for every inch of the level of the mercury in the barometer) if we did not take steps to compensate it.

Air pressure affects the pendulum in several different ways.

It floats the bob, reducing the force of gravity.

And if you put some thistledown in a clock case, you will find that the pendulum bob sets the air in motion.

The effect of the former can be calculated, but the effect of the latter can only be estimated. Both are affected by variations in density.

Increased air pressure reduces arc. That can be tried out, and the effect in circular error can be ascertained precisely.

It is a complex and difficult problem, and it was never satisfactorily solved when it was inextricably mixed up with escapement errors, but we can attack it with a prospect of success now we have definitely and finally removed every other source of irregularity.

We have eliminated the whole subject from the Shortt free pendulum by the simple expedient of eliminating the air itself, but we cannot do that in a commercial instrument, and I would put the problem up to our horological professors and schools as their job.

It has been said that Germany's success in manufacture is due to their factories having back doors leading straight into their universities. There is truth in this, and I have benefited greatly from our observatories and from the National Physical Laboratory, but this is a problem for you.

I recommend as a starting point Sir Henry Cunynghame's Cantor Lectures, Royal Society of Arts, 1908. Mr. Shortt also stated the elements of the problem very clearly from this platform in January, 1912.

Please find some means of compensation which does not involve some external mechanical application. Take warning from Sir George Airey, who floated on the mercury one end of a lever whose other end carried a permanent magnet adjacent to the pendulum, but the remedy was worse than the disease.

Correspondence.

The columns of THE HOROLOGICAL JOURNAL *are open to expressions of views from all sections of the trade. Contributors write on their own responsibility and their opinions do not necessarily represent the views of the Council of the Institute.*

To the Editor of THE HOROLOGICAL JOURNAL.

SIR,—The reply by Mr. Player to a correspondent asking for data on correct dimensions of pendulum bobs, which appeared in the September number of the Journal, just to hand, interested me, as experiments on pendulums with Invar rods, cast iron, lead, zinc, brass, and gunmetal bobs, with gunmetal or brass tubing as compensators, have been my hobby for the past three years. All have been tested under laboratory conditions with very varying results. The best results so far have been obtained from a pendulum constructed from data given by Sir H. H. Cunynghame, in the Cantor Lectures on "The Theory and Practice of Clock-Making," delivered at the Royal Society of Arts in 1908. In these lectures he deals fully with time of swing of a simple and of a compound pendulum, and then describes one with Invar rod and typemetal bob 10 cms. diameter and 12 cms. high, with a brass tube compensator fitting loosely on the outside of the bob, and supported by an iron cap under the rating nut. The bob of typemetal and compensator in the pendulum lately constructed are exactly 4 inches in diameter, the rod of Invar, 1 cm. diameter, artificially matured, co-eff. of expansion 0.0000017, certified by the National Physical Laboratory, the suspension spring of Invar, co-eff. of expansion 0.0000013, and the whole carefully computed and checked for the 4 inch bob. The pendulum has only been tested in air, that is, in an ordinary regulator clock case, and on a home-made regulator, and throughout the trials it maintained a steady rate under 20 variations of temperature. It is not often that the mathematically calculated position of the bob on its rod coincides with its position under time tests, but on this pendulum it happened that the rating nut did not need to be touched after the pendulum was started, and its rate was − .17 secs. per day. This was maintained, with one variation of + .13 secs. (probably caused by a slight earthquake) throughout the 28 days' trial. How it will perform on the regulator under construction and for which it has been made has yet to be tested.

To me the pendulum which does not keep a constant plus or minus rate when enclosed in an air-tight case and kept at a constant temperature, is not worth the metal of which it is made. My aim is to construct a pendulum that will maintain a constant rate running in air under all varying barometric and temperature variations, but a competent authority informs me that "this is impossible!" Many thanks for publishing the papers on "The Theory of Pendulums and Escapements," by Professor Robertson. They are most interesting and informative.

Yours, etc.,
F. R. A. S.

WELLINGTON, NEW ZEALAND.

To the Editor, Practical Column of THE HOROLOGICAL JOURNAL.

DEAR SIR,—After reading the article you kindly published in your November "Practical Column" relating to the co-efficients of Invar steel, I am convinced there is an error in the letter from the makers of my rod. This letter, which is typewritten, clearly sets out the co-efficient of the rod as $.1,3.10^{-6}$, but the information very kindly supplied by the English makers of Invar solves the enigma, and I am satisfied that the rod's co-efficient must be 1.3 (.0000013) and not .00000013.

It is regrettable that a typist's error should have caused you so much trouble. But the information it has elicited is interesting and instructive, not perhaps to the experts, but to those of your readers who, being "amateurs" from taste and attachment to the art, strive nevertheless with keen interest to follow the valuable contributions which appear in the columns of THE HOROLOGICAL JOURNAL.

You doubtless number amongst your readers many such "amateurs" with little or no knowledge of the theoretical or mathematical side of horology who despite their shortcomings glean from your articles much that is profitable and helpful to them in the acquirement of useful knowledge.

Yours faithfully,
L. D. L., Sussex.

Summer Time. Summer time was introduced into the Argentine on December 1st for the first time, all clocks being put forward one hour at midnight.—Reuter.