Reprinted from The Horological Journal, *Dec.*, 1924—*Jan.*, 1925.

"Some Recent Developments in Electrical Clocks."

BY

Major C. E. PRINCE, O.B.E., M.I.E.E.

An Illustrated Lecture given at the Horological Institute, London, on November 19th, 1924.

London.

Spenser Press, Limited, 45, Great Eastern Street, E.C.2.

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MAJOR C. E. PRINCE, O.B.E., M.I.E.E., interested and entertained a large audience for over two hours at the Institute, on Wednesday, November 19th.

Mr. F. Hope-Jones, M.I.E.E., F.R.A.S., who was elected Chairman of the Council of the B.H.I. a few minutes before the meeting, occupied the Chair and introduced the Lecturer.

The CHAIRMAN, introducing the Lecturer, said that the British Horological Institute would to-night have the pleasure of listening to one whose scientific work and whose researches in electrical, and particularly in wireless matters, deserved their profoundest respect. Major Prince had received recognition, perhaps inadequate recognition, for the good work he did during the war, and he was chiefly known in connection with the application of wireless telephony to aeroplanes.

Major PRINCE said :—

Although the art of horology is very old, the introduction of electricity is affecting it profoundly, as, indeed, it must, and should.

In order to have a clear idea of the bearings of the subject, I beg leave to emphasise certain aspects of facts which are well known to you.

In the first place, though we do not always realise it, the function of a clock, in ordinary daily life (apart from scientific and astronomical purposes), is not time-keeping but synchronisation—that is, its agreement with other clocks. Each place, as we know, has its own real time, but it would be so awkward to adhere to this (as for example, if London and Bristol had different times) that, merely as a matter of convenience, the world is mapped out into areas, within each of which we agree to go by a time that is standard throughout that area. "Daylight Saving" has taught us that for the purposes of daily life you can put your clock a whole hour wrong without inconvenience, provided all other clocks agree with it. It would not even matter very much to us if one hour were shorter and the next longer, provided all the clocks of England followed a similarly erratic course; you would still catch your train and still keep your appointment.

In older days, before electricity, and when there were none but mechanical clocks, the only way in which this agreement could be maintained was by setting up, in one place and another, unit or solo time-keepers, of as great accuracy as possible. The real use of accuracy was that this agreement with other units should be maintained as nearly and as long as possible; and these solo time-keepers were checked at rare intervals, how and when convenient.

Now with the advent of the electric telegraph, there became available a means of checking these units accurately and regularly—in short, the first and most obvious application of the new power was in the distribution of time, and hence the synchronisation or agreement over a definite area; and, in later and more developed forms, and with the elimination of the human element, distribution still remains one of its most important functions. It will be noticed by the observant that this distribution or checking tends to take place at intervals longer as the area is larger—by minutes or half-minutes in the house, hourly in the city, daily from the observatory—and accuracy, retains its importance for the isolated units, though each unit may be a system of many clocks.

In many cases this is the only use made of electrical means. Time is kept by an ordinary mechanical clock, which either periodically synchronises other mechanical clocks at rare intervals, or advances the hands of Slave Clocks at short intervals. We can call this system, briefly, "Mechanical Time Electrically Distributed."

Electricity has also attracted the attention of makers of solo clocks as a convenient source of power instead of a spring or weight, and a number of clocks have been devised on this principle. These also we should not class as "electric clocks" in the sense in which I hope to define this expression. They may be called "Mechanical Clocks Sustained by Electrical Power."

spring—and one can truly call a pendulum hanging from a steel suspension and otherwise untouched a "free" pendulum. If that is so, and the suspension spring is admitted, then by what has gone before we must admit also the side springs, and can call the whole system a "free pendulum" within the practical human meaning of the term. We see, then, that in this simple way we could cause a pendulum to register its vibrations electrically without any inconstant mechanical interference. As it stands, however, it would be very crude, mainly for three reasons. Firstly, the current would be very wasteful, as it would be flowing continuously, either through one contact or the other and, secondly, the pendulum itself, would break the circuit, with some danger of adhesion, caused by fusion by the break-spark; and thirdly, not only mere registration is needful, but also sustaining, which we will consider presently.

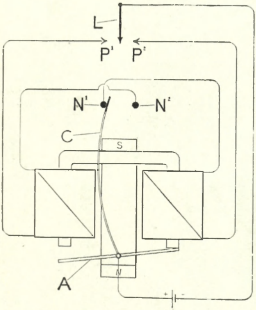

FIG- 1.

THE REVERSER.

In my clock all the switching and other mechanical actions are taken care of by a polarized electro-magnetic device which I have called the "Reverser" (Figs 1 and 2.)

Suppose the tip of a short iron rod is placed between the poles of a horse-shoe magnet. It will be attracted to one pole and will stick there. If, however, by means of a winding and a suitable current, its induced magnetism can now be reversed, it will fly over to the other pole and stick there instead. A subsequent current in the reverse direction will send it back again. An instantaneous current will be enough to effect the change-over, but, once effected, it will remain held as long as you like. It thus becomes, as it were, a change-over switch, which is economically thrown over by a momentary current. This is, broadly, the principle of the reverser. The moving part, or armature A, carries a contact arm C moving between two fixed contact points N_1, N_2, and the whole is so connected with respect to the circuits of the clock, that as soon as the pendulum L touches one of the side springs (P_1 or P_2) and so establishes a circuit, the reverser throws over, opens the circuit, and prepares the circuit on the other side, ready for the moment when the pendulum shall touch the other spring. Thus a current of very short duration flows in the circuit, and this fleeting current is made to actuate a step-by-step dial. In order that this current shall have an appreciable duration, the contact C carried by the reverser armature is made flexible, so that it keeps in touch until the armature has moved through nearly half its travel. This duration I call the "time-period of the reverser," and it is of the order of .04 to .05 second.

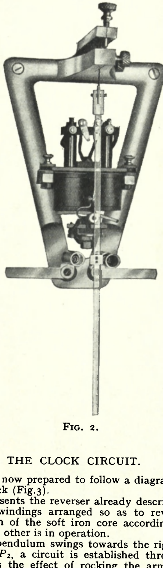

FIG. 2.

THE CLOCK CIRCUIT.

We are now prepared to follow a diagram of the whole clock (Fig.3).

R represents the reverser already described, and the two windings arranged so as to reverse the magnetism of the soft iron core according as the one or the other is in operation.

If the pendulum swings towards the right so as to touch P_2, a circuit is established through O_2 which has the effect of rocking the armature A (the polarizing magnet is not shown) to the other side. A fleeting current thus flows through the dial D, advancing it a step, and the circuit is then opened at N_1 and the alternative path is prepared at N_2, ready to be energised when the pendulum on by the pendulum, and the current so established then shifts the movable stop right out of the way to *T*. The result is that on its return journey the spring follows the pendulum back to its fixed stop —a greater distance than it was carried out—and the difference represents a gain of energy to the pendulum. The magnitude of the sustaining impulse is thus entirely independent of any variation in the battery working the clock. The movable stop *T* is very conveniently made by an extension or " tail " connected with the armature or the reverser, so that no additional mechanism is required. The other spring has its outward and inward excursions equal, and hence serves merely to make contact.

is no escape from this. If, therefore, it is impulsed say, once a minute, that inpulse must be sixty times as great as that of an impulse every second. It would seem to follow directly from principles that the latter must be more accurate. In the one case you have a pendulum whose amplitude is kept constant by successive small gains of energy supplied as fast as it is lost; in the other, one which is subject to a decay or decrement, but is periodically restored to its original amplitude by having the total sum of all the energy lost in sixty vibrations violently supplied to it in one single impulse. It is analogous to spark versus c.w. methods in wireless. Of course in practice we would be dealing with

A little reflection will show that fine adjustment of the sustaining impulse, and hence the amplitude, is under easy control. You have only to alter the relative distance between the fixed and movable stops of the sustaining spring, by moving either the one or the other. In the actual clock it is the former that is adjustable by a touch to the crankled arm which carries it. Again, to get an even " tick," the non-sustaining spring should be picked up at the same distance from zero as the sustaining spring. Hence the former has only to be adjusted, in an equally simple way, to make the tick absolutely regular to the ear.

As the result of all this we have now achieved a pendulum which both registers its vibrations by fleeting currents and is sustained, without the employment of any wheels, pivots, or any other devices depending on the perfection of human workmanship. We deal with nothing but natural forces and the properties of materials—gravitation and the elasticity of steel—and, moreover, by methods of extreme simplicity.

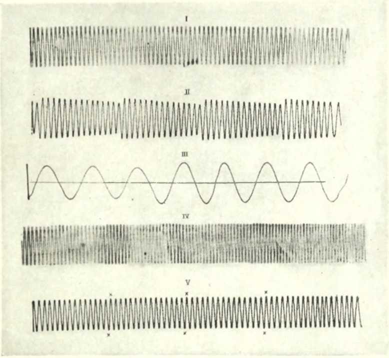

FIG. 5.

It is plain that, in place of the contact springs, gravity arms could be used. This, however, would re-introduce the factor of workmanship, in the pivots, and it would seem better to keep to the action of natural laws only.

Before leaving this part—this vital part—of the subject, I should like to discuss three points with regard to this method of sustaining, which either are liable to be misunderstood or are sometimes the subject of hasty criticism.

These are—the *frequency* of the impulse, the *position*, and the *moment* of its application.

As regards the first. It is certainly desirable to interfere with the free swing of a pendulum as little as possible, but since it loses its store of energy at a certain rate (which is constant), it must have that loss supplied, either in large doses at longer intervals, or in smaller doses at shorter ones. There

small values, but I see no escape from the general conclusion. Moreover, one cannot forget that all the horological achievements of the past have been made with continuously impulsed time-keepers. Possibly the rare impulsing of most electric clocks has arisen less from considerations of principle than of convenience, especially for system working, or from the difficulty, in past designs, of doing otherwise; especially of sub-dividing the supplied energy into sufficiently small portions, so to speak, But where, as here, it can be done by a method of differences, these portions can quite practically be reduced to any minuteness down to zero.

I have here some graphs (Fig. 5) traced by an actual pendulum, which will help us to make clear what actions are taking place in these cases where the pendulum is impulsed every thirty swings.

The first three graphs were purposely made with an abnormally light pendulum in order to make the effects more apparent. No. 1 for a comparison shows this pendulum swinging freely. It will be noticed

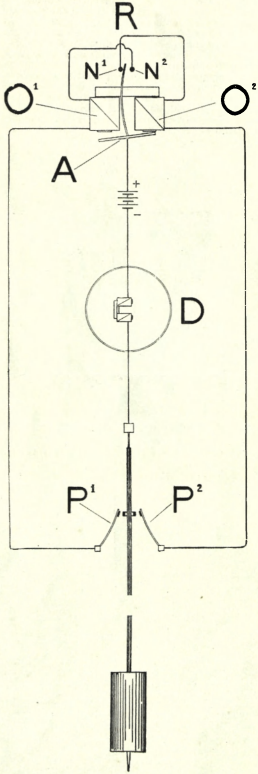

FIG. 3.

its return touches P_1. It will thus be seen that the pendulum contacts never have to break the circuit. In practice, although not shown in this diagram, appropriate condensers in series with a resistance shunt the inductance of the circuit in order to eliminate sparking.

SUSTAINING THE PENDULUM.

You have no doubt noticed that, so far, I have confined myself to registration, and have made no mention at all of sustaining the oscillations of the pendulum. It is here that every clock, however free, however excellent, must perforce depart from the theoretical perfection of principles, and submit to the limitations of our imperfect world.

In my first experiments I was tempted, like others, to apply the sustaining impulse electro-magnetically.

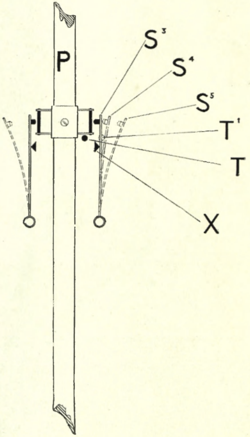

FIG. 4.

After many experiments and exhaustive tests I was forced at last to this conclusion : that except, possibly, under exceptional laboratory conditions, electro-magnetic sustaining could not give constant time-keeping. The actual method of sustaining finally adopted was to apply the impulse through the side contact springs themselves—or rather, one of them (see Fig. 4). One of these springs S_3 instead of coming to rest on its fixed stop *X* near the zero position of the pendulum rod, is slightly bent aside or deflected from it by a movable stop T_1 to S_4 and is held there until it is picked up that, in spite of its lightness the rate of decay is small.

In some "rare impulse" electrical clocks the pendulum is made to turn a count-wheel, at each revolution of which a mechanical impulse is given to the pendulum. No. 2 is the graph of the same pendulum operating such a count-wheel, where the decay introduced by the effort and the sudden restoration of the energy lost is clearly shown. No. 3 is the same, with a different time axis, so that the actual moment of application of the impulse can be more closely observed.

In actual practice of course much heavier pendulums are used, so that these disturbances are of a smaller proportion of the total energy. Fig. 4 was taken with a 5 lb. bob and Fig. 5 with a 10 lb. bob. In the latter the effect is almost completely masked, though the same effects can be observed by close observation, the moment of impact being marked by a cross.

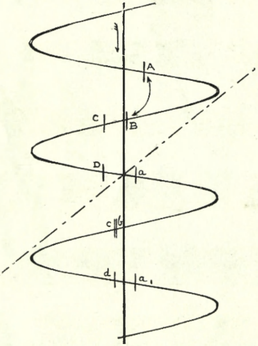

FIG. 6.

As regards the second point—the position of the impulse—it is sometimes objected that my clock violates an important principle, because, so it is said, the pendulum is touched at a point other than the zero or middle position. This objection does not, I think, bear examination, which is best done with the aid of a curve (Fig. 6).

I have here an ordinary sine curve (which was actually produced experimentally). The time axis is vertical, so that it represents the curve that would be traced by a pendulum on a piece of paper drawn away from an observer facing the clock. The pendulum, being supposed to be an infinitely thin rod, we can easily mark on the curve the exact positions and times when it touches the side contact springs. The diagram is roughly to scale, for an actual clock having an amplitude of $1\frac{1}{10}°$ on each side.

Now if there were no question of sustaining, the side contacts could be picked up right from the zero line, or rather, just so near it that the pendulum does not touch both at once.

But since we must give a sustaining impulse, the impulsing spring which is left at *B* must be picked up at *A*—the difference in the distance of *A* and *B* from the axis representing the magnitude of the impulse. Theoretically, we need not alter the left-hand spring at all, but unless we do, the tick will sound uneven; and so, merely to please the ear, it is adjusted until it is picked up at *C*, whose distance from the axis is the same as *A's*. Since this spring does no impulsing, it is left at *D*, a similar distance from the axis. We have thus a small gap on each side, represented by the distance from the axis to *A*, to *C* or to D, when the pendulum is swinging out of contact with the springs. This we may call the normal action; but if it is wished, these gaps can be reduced by a slightly different adjustment, which is shown on the part of the curve below the dotted division.

Instead of beginning and ending the whole impulse follow-through on one side of zero, it can cross the axis. The spring is picked up earlier than before at *a*, and allowed to follow the pendulum to the left as far as *b* (the whole distance *a*—*b* being equal to the original *A*—*B*. The pendulum can then immediately pick up the other spring at *c*, and return it to *d*, where it has perforce to leave it. It then picks up the sustaining spring at a^1 again, and the whole sequence is repeated. There is now no appreciable gap when the pendulum is untouched by the springs, except at *d*—*a*, which being equal to the original *A*—*B*, is only half the former gap.

Now it seems that, at best, I have had to confess to allowing the springs to first touch the pendulum a little way from zero position, although I acknowledge the rule that any such interference should only be made at that moment.

But consider what is meant by zero position. It means simply the moment when the whole energy of the pendulum is kinetic—I need not remind you that, as it vibrates, the energy of a pendulum is changing alternately from potential (when it is at rest at the end of its swing) to kinetic (when it has its maximum velocity, in passing the vertical). The curve before you, which was actually traced by a free pendulum, represents the transformation of the energy from the one form to the other, and the ***rate*** of the transformation is shown by the ***rate of change of curvature*** at any part.

Now if you look attentively at such a true sine-curve you will see that the portion crossing the axis is changing its curvature very slightly indeed—it is nearly indistinguishable from a straight line. This means that the change of form of the energy, very rapid near the end, is very slow here; that is, a vibrating pendulum performs a large part of its excursion from zero before any appreciable portion of its kinetic energy is changed into the potential form. This gives a very wide latitude to the expression "zero position"; so that the points *A* and *C* on this diagram are really, in their physical meaning, almost indistinguishable from a point on the zero line. They are separated in space, they are separated on the diagram, but mechanically they are nearly identical.

The third point which we set out to discuss (the moment of the impulse) is apparent, and almost settles itself, by considering this diagram. There is no particular moment of energising or impulsing the pendulum. It is kept sustained simply because the total energy stored up in the outward flexure of the spring from A to the end is less than the total energy given back by it during its return to B, the difference being actually supplied by the movable stop. The pendulum, therefore, has its inevitable losses supplied continuously, smoothly, and not by a sudden push at a given moment.

THE EFFECT OF THE SIDE CONTACTS.

It seems, then, from this analysis, that, by extremely simple means, and without any aid from fine workmanship, we can produce a time-keeper which, in principle, is very near theoretical perfection. There is, in fact only one loop-hole by which imperfection can creep in, and that is, the friction of the side contacts. If, however, this may be assumed to be constant, it merely becomes a loss, like air resistance, which simply means that a little more energy must be supplied to the system; and we shall see that this loss is exceedingly small.

This is a very remarkable conclusion, but I have here some more graphs (Fig. 7), which show that it is borne out by experiment. Some of them are partly repetitions of the former ones, but all these were made with the same pendulum—one with a 5 lb. bob—so as to afford a direct comparision.

Like the others, they were traced by regularly drawing a strip of paper soaked in iodide of potassium and starch between the end of the pendulum and a brass table or tube approaching it very closely, while a high tension spark from a spark-coil passed between the pendulum and the table. There is thus no interference caused by the method of recording, and although the line is a little fuzzy, the graph can be depended on to whatever accuracy it can be read. Some of the differences are not quite apparent to the eye, but could be discovered by careful measurements on the paper.

The pendulum was a seconds one, and the graphs all start with approximately the same total amplitude—that given by 1.5° each side of zero.

A is the graph of the pendulum swinging entirely freely from its suspension spring.

B and C were made by the same pendulum turning a count-wheel but not sustained.

D is the same as B and C, but sustained by an impulse every 30 vibrations, that is, every half minute. The loss and sudden restoration of amplitude is very perceptible (but the edge of a portion of the graph and a straight line has been inked in to make it more easily visible).

Graph E is very remarkable. It is that of the same pendulum working on my principle and with the side contact springs in operation, but not sustained. The rate of decay is in this period of time not measurably different from A, that is, the pendulum with its contacts behaves almost precisely like the free pendulum.

F, which represents the same, but with my usual " frequent " sustaining in operation, has, of course, no decrement or variation of amplitude at all, but is again not measurably different from A and E.

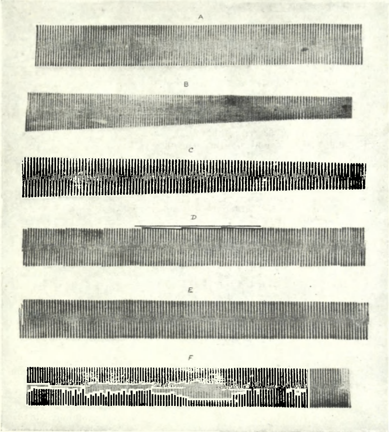

Fig. 7.

Comparison of A, E, and F will show what an extremely small loss of energy is introduced by my method of recording, and hence what infinitesimally small accretions need be given by the sustaining impulse to keep a constant amplitude.

The rate of decay in graphs both A and E being so small that it is practically unmeasurable in the short duration of the test period, another experiment was made over a longer period in order to compare my pendulum with a free one. This was easily done by making the pendulum trace its own amplitude at three intervals of five minutes. The results when plotted out are shown in Fig. 8.

My pendulum, with the side contacts in position, but not sustained (the lower line), starting with an amplitude of 54 mm., lost 9.5 mm., in fifteen minutes, or 900 vibrations, which is .02110 per cent. per vibration.

The same pendulum entirely free, after the side contacts had been removed (see the top line), lost 9 mm. in the same time, or .02000 per cent. per vibration.

The difference, therefore, between the two, in so far as it was measurable at all by this method, was just over one-thousandth of one per cent. per vibration.

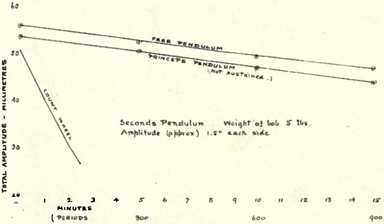

FIG. 8.

For comparision, the decay of the same pendulum turning a count-wheel has been also plotted, in which the loss of amplitude is 20 per cent. per minute, or 0.33 per cent. per vibration.

THE DIAL MECHANISM.

Before going on to describe the actual clock in which I have tried to embody the principles just discussed, let us turn our attention for a moment to the recording mechanism or dial. In its essence this is a very simple affair, for it merely involves the turning of a wheel by a step-by-step movement, actuated by the fleeting currents; but in practice it is not one of the least difficult or troublesome parts of the whole business.

So far we have been dealing more or less completely with natural actions, but here we come to mechanical devices, and the factor of human workmanship. It has been rather surprising to me that in this matter, which is common to all electric clocks—the conversion of the impulses into rotary movement—inventors do not appear to have made any great progress beyond variations or improvements on the click and ratchet. There seems still much scope for ingenuity in this direction. The pallet-drive movement, which I am about to describe was developed for me by Mr. Sidney Smith, a member of your council, whose fertility of resource and great ability of craftsmanship I am happy to have enlisted, and it has been standardised for normal work. It will be understood from Fig. 9.

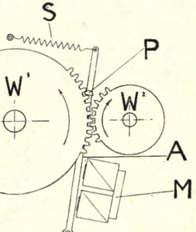

FIG. 9.

W1 is a 60-tooth wheel mounted on the centre arbor. *W2* is another wheel meshed with it. The pallet *P* is carried on an armature *A* which is drawn to the right by an electro-magnet *M* and returned by the spring *S*. In moving to the right the pallet *P* progresses the wheel *W2* half a tooth. *W1*, being in mesh, follows suit, and in doing so brings its next tooth sufficiently forward for the pallet, on its return, to enter. Thus for each electrical impulse the wheel *W*, is advanced one complete tooth. The arbor of this wheel carries the seconds hand and is connected by the usual clock gearing to the minute and hour hands of the clock.

THE MASTER CLOCK.

We are now in a position to consider the clock as a whole, a specimen of which I have here, and which perhaps some of you may care to examine more closely afterwards (Fig. 10).

This clock has been designed to work on four volts, which is convenient for either dry batteries or accumulators. The resistance of both the clock magnets and each limb of the reverser being 40 ohms., the normal working current is 50 milliamperes, the duration of the fleeting current being approximately .05 second. The consumption is then .01 watt seconds per impulse, or 22 ampere hours per annum. Dry cells of the size of the Siemens " P " Type should therefore last for well over a year.

SYSTEMS OF SLAVE CLOCKS.

So far we have treated this clock as a self-contained or solo clock, which was, indeed, the original conception. As such, and taking advantage of the principles and construction which I have described, it is possible to make a clock which will simply keep as good time as the pendulum will set; this time is abnormally good. It is not at the mercy of any imperfection of workmanship, and the clock can therefore be far cheaper than any other clock of even approximately equal performance. I wish to emphasise this point, as it was not originally designed simply as an impulse transmitter or master-clock for systems, but as a contribution to the art of making clocks as such by the aid of electrical means. It is also well to point out that my present aim is not to make a clock of astronomical accuracy, but a sound and simple timekeeper whose performance is up to, and far exceeding, any ordinary commercial requirements. Although I have

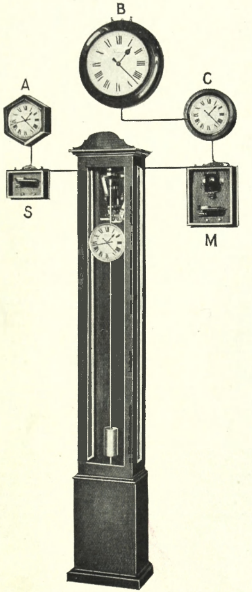

FIG. 10.

not yet done so, I do not see why it should not be possible to construct observatory clocks of the highest degree of accuracy by the use of the same principles; though in that case one would introduce many refinements which are at present quite superfluous.

As a matter of fact, though, this clock does make a very good master clock for system working, so let us turn to this application of it.

It is plain that if we introduce a suitable relay, either in place of the dial, or in series with it, this will close its contacts momentarily every second—that is, every impulse—and this contact can be made to control any number of seconds impulse slave clocks.

I may say at once that I am all in favour of the proper use of relays. It seems to me better to remove all extraneous work to an extraneous circuit, and not to trouble the clock itself with the external

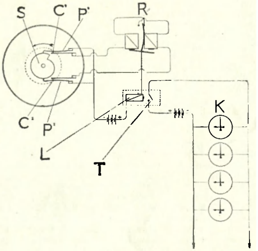

FIG. 11.

work which it controls. I confess to having been largely influenced by the practice of telephone engineers. Telephony deals with magnitudes and conditions akin to ours, where absolute reliability is essential, and we may very well take hints from the practice that they have adopted.

Half-minute impulse slave clocks, however, are very popular, show a great economy of consumption, and are to be recommended for general use. Let us see how they can be worked off our system. Now the only place from which half-minute contacts can be controlled is a comparatively slow-moving wheel, and the problem is, how to produce from it a fleeting current, without the use of such mechanical monstrosities as steep cams and so forth. We accomplish this by, as it were, repeating the whole clock circuit, with a reverser and relay attachment; a snail and drop contacts on the master dial taking the place of the pendulum and side contact points in the original diagram (Fig. 11).

The "snail" *S* is mounted on the centre arbor of the master dial and therefore makes one revolution per minute. The outer springs P_1 and P_2 rest on the snail, and normally hold the contacts C_1 and C_2 open.

It will be seen from the diagram that these contacts are connected to the reverser *R* in just the same manner as the pendulum contacts are connected to the reverser in the master clock.

The relay *L* is in series with the common return just as is the master dial in the clock, so that with each half-revolution of the " snail " *S*—that is to say, every half-minute—one or other of the contacts $C1$ and $C2$ is dropped ,a circuit is closed, the relay operates and the reverser armature rocks over, thus breaking that current and preparing the alternative path. It is only necessary therefore to connect the system of slave clocks *K* and their independent battery across the relay contacts *T* in order to operate a half-minute system.

The dial mechanism of the "half-minute" slave clocks is similar to that of the master dial except that the gearing is rearranged.

We have thus a plan by which the master clock, working either a seconds or half-minute attachment, or both, can make similar momentary contacts at seconds and half-minute intervals, and so control numbers of seconds or half-minute slave clocks, or both types at once.

The observant will have noticed that the slave clocks are always shown joined in parallel, not series. Without being necessarily tied to either choice, I have adopted comparatively high-resistance clocks and parallel connection for normal working ; though one may in a large installation make any combinations of series and parallel that good engineering practice may indicate.

The arguments in favour of parallel connection seem to be preponderating.

In the first case, each slave clock is independent and can be connected or disconnected at will without interfering with the others, and a failure or breakdown in the wire only affects one clock. Additional clocks can be added to the system at any time without any alteration, or even stopping the others for a moment. Clocks for any special recording purposes can be applied to the system for short periods. As regards the battery for supplying the system, the consumption of half-minute slave clocks is so very small (being only 1/30th of the master) that the cells which could work the latter for a year would nominally last a slave dial for 30 years ; that is, if in series, they would deteriorate long before their ampere-hour life was utilised. Lastly, the number of cells in the system battery is constant ; it is only necessary to be sure that the internal resistance is not too high for the work, whereas in series it is necessary to increase the voltage according to the number of clocks on the system. Moreover, considerations of the inductance of the systems and of the spark at breaking, are simplified.

As one example of the advantages of parallel working for recording devices, I may show here an invention which I have just protected for recording the time of the failure and repair of electric mains. Two dials, keeping normal time and controlled by the usual master impulse, are attached to a pair of electrical interlocking relays--energised by the mains supply—which operate in such a manner that on the failure of the mains one clock stops, permanently indicating the time of failure, while the second clock continues operating as long as the mains are " dead." On the resumption of the supply the appropriate relay is in a position to be energised and stops the second clock, thus indicating the moment of repair. The readings having been checked and the clocks reset, they are restarted simnltaueously by pressing a key.

THE COTTAGE SYSTEM.

I have here a modification of the system as shown in the larger clock adapted to a small clock with a half-seconds pendulum. This will drive and control up to three other slave clocks from its self-contained dry battery. No relay attachment is required. In spite of the pendulum being a half-seconds one the clocks are driven by seconds impulses. This is achieved as follows : Since the fleeting currents flow through two paths alternately there are two circuits which are only completed at every other vibration of the pendulum. By inserting a balanced number of

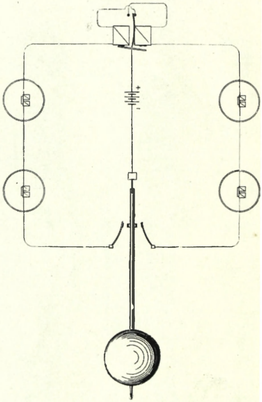

FIG. 12.

slave clocks in these circuits instead of in the common portion (see Fig. 12), each pair will receive an impulse alternately and can therefore be standard " seconds impulse " slave clocks.

SOLO CLOCKS.

It is possible to make the reverser, not only sustain the pendulum, but also mechanically operate the clock movement. I have here such a clock, which embodies all the advantages of my free pendulum. It has this disadvantage, that the design is not so flexible owing to the mechanical connection between the reverser and the movement.

LARGE CLOCKS.

One of the problems of our work is to drive turret or other large clocks or to work timing or switching mechanisms, with sufficient power. I have here as a matter of interest a laboratory model of a motor-driven clock synchronised by system impulses by a method which I have protected, although the mere idea of driving a clock by a motor is not novel.

The model which you see is only driven by a toy motor taking less than two watts, but in consequence of the enormous gear reduction the minute wheel cannot be stopped by hand. By this method mechanism of robust engineering design could be controlled by exactly the same impulses as are used for the ordinary system of clocks.

A discussion followed.

MR. WHITE objected to parallel wiring on the grounds that a short circuit disorganised the whole system. This was from the point of view of malicious interference.

With regard to the position of zero, he was inclined to agree with Major Prince that it had never been definitely set. He thought that we had to unlearn some of the things we had been taught in the past.

He congratulated Major Prince on his use of light springs for sustaining. As an engineer, he did not always believe in charts, but Major Prince's charts certainly tended to prove the freedom of the pendulum. As a manufacturer, he did not altogether agree with the frequent impulse, owing to its greater consumption of battery power; although he agreed with Major Prince on this point mechanically, he did not agree electrically.

He would like to ask Major Prince whether he had considered the question of making the inertia of his Master and Secondary dial movements the same as the inertia of his reverser armature.

MAJOR PRINCE, in his reply, stated that he had adopted parallel wiring after mature consideration and experiment, but that he was quite prepared to adapt the particular method of wiring to the requirements of the system being installed. In some cases it might be advisable to use series connections, or some combination of series and parallel, but he was firmly of the opinion that parallel wiring with high resistance Slave Clocks was the most satisfactory system for ordinary practice. The question of malicious interference would apply equally to both systems.

With regard to the current consumption, naturally the more frequent impulses consume more ampere hours, but the total consumption is quite small, and it is a necessary corollary of "frequent sustaining," whose advantages have already been discussed. It gives the possibility of using seconds-impulse slave clocks if desired; and except for this, only applies to the master clock itself. It is, in fact, a very small price to pay for all the advantages gained.

Major Prince said that the question of inertia of the various moving parts of his system in relation to the duration of the impulse had been the subject of very careful experiment and design. He showed a slide of the clock impulses taken upon undulator tape (Fig. 13), which showed an impulse duration of .047sec., both through the original reverser and also the contacts of the system relay. The two lower records were interesting as being portions of some of the long time-tests undertaken to check that there was no missing of impulses.

MR. LOW objected to a steel pendulum rod moving in a magnetic field, and suggested other materials.

MAJOR PRINCE replied that he thought that neither the magnetic fields of the earth, or those used in his clock, were likely to have an appreciable effect on the pendulum rod, and that although in astronomical work they might be taken into consideration, the time-keeping recorded by the Princeps Clock showed that in commercial work it was not worth considering.

THE CHAIRMAN (MR. F. HOPE-JONES) expressed the wish that Major Prince would abandon the use of the words "Slave Clock," as this had been already applied in another connection. He suggested the words "Electrically Impulsed Dials," or a similar alternative.

He agreed that in Major Prince's system of

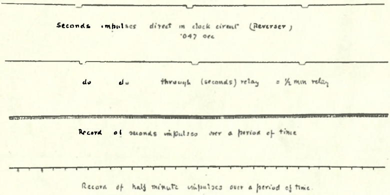

FIG. 13.

sustaining it was possible to divide the impulse minutely, but that manufacturers using the half-minute impulse would find this impossible, because the amount of impulse necessary would be out of proportion to the friction of the pivots used in the falling weight.

He could not agree with Major Prince that his pendulum was absolutely free, and pointed to the fact that it had to deflect springs even at the ends of its swing. Surely, academically, this was interference?

He agreed with Major Prince that the zero position of the pendulum had never been defined. Actually, it was a broad patch in the middle of the swing.

He agreed with Mr. White's opinion with regard to parallel connection. He maintained that the series system produced greater inductance, which could be made use of.

Major Prince's method of sustaining reminded him of Lord Grimthorpe's gravity arm, but he congratulated Major Prince on having overcome the difficulty in Lord Grimthorpe's method, where the pendulum had to release the weight, whereas in Major Prince's system it did not have to do such work. Although he had to point out the question of interference with the pendulum at the end of the swing, he must point out that Major Prince's system of sustaining was extremely like that of Loire, who supplied a clock which has been keeping time for the Eiffel Tower in Paris since 1912, which distributes the wireless time signals to the world.

MAJOR PRINCE, in his reply, said that he had decided upon the name "Slave Clock" deliberately because he thought that it was very much more intelligible to the ordinary man than the more complicated scientific titles. Actually, of the clocks called "Slave Clocks," there were only about six in existence, whereas there are many thousands of what he preferred to call "Slave Clocks." (Applause.)

With reference to the subdivision of impulses, he did not see why with his system of sustaining it should not be possible to obtain the finest subdivision necessary, even for astronomical work. It was purely a question of the strength of the springs used, and of the adjustment of the differences.

Dealing with the contention that his pendulum was not free because it was interfered with by having to deflect the springs right up to the end of its excursion, he submitted that the word "interference" was not a correct description of the action. If it meant that the deflection of the springs was a force tending to bring the pendulum to rest, then gravity itself was such a force. A pendulum or balance-wheel in its essence was simply a mass in motion (that, by the ordinary Newtonian Law, would tend to continue so for ever), which was very difinitely interfered with, or acted on by some constant force tending to bring it to rest. In a pendulum the force chosen was gravity; in the balance-wheel it was the force exerted by the elasticity of steel. In the practical physical pendulum a combination of both was usually employed, the latter being exerted by the suspension spring; and his side contact springs were only a slight additional force acting in exactly the same way. To object to their mere presence would be equivalent to objecting to the action of gravity itself. The only real meaning of interference was inconstancy of the forces in action, and it could not be applied to their positive value. Even the force of gravity was not identical in all places, though it was constant at a given place. That the effect on the pendulum of the side springs was of the same nature as that of the suspension spring was shown by the curves produced, as well as considerations of principle.