LA

PENDULE ÉLECTRIQUE DE PRÉCISION

DE

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Communication faite à la Société des Sciences naturelles de Neuchâtel
dans la séance du 6 Mars 1884

PAR

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NEUCHATEL
IMPRIMERIE DE LA SOCIÉTÉ TYPOGRAPHIQUE
1889

HIPPS' PRECISION ELECTRIC CLOCK

Translation of

Dr. Hirsch's Address to the Neuchâtel

Natural Sciences Society

of

March 6th, 1884

NEUCHATEL

Typographical Company's Reprint

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The precision clock occupies an important place in the armoury of scientific instruments. This is especially true in astronomy, above all in that branch of the science which was formerly its sole concern, and which has again assumed a principal rôle, to wit, the motions of celestial bodies, wherein the clock in no way yields in importance either to optical devices or to the division of circles. Fortunately, a long time ago the astronomical clock attained a degree of perfection excelling the other observational instruments of the beginning of the last century and equalling them at the commencement of the present. Thereafter, a notable degree of isochronism was obtained through the Graham escapement and the spring suspension: since then, mercury compensation - theoretically, perhaps, less perfect but in practice much easier to control than the gridiron arrangement - an almost complete mastery of the principal source of variation of rate has been obtained. It might have seemed that little was left to be desired. Using these means the well-known English and French clock-makers, Dent and Breguet amongst others, provided observatories with clocks whose diurnal rates did not exceed a tenth of a second and, in certain masterpieces fell towards the half-tenth whilst the annual variation of these latter held to a half-second limit.

Nonetheless, the outstanding progress of our powerful modern instruments in the direction of optics and mechanical arrangements, has overtaken the astronomical clock and this ought to seek to encourage new improvements in these delicate machines. This is the more so since the introduction to astronomical practice of electrical recording by chronograph, which readily allows estimations of seconds to about one or two hundredths, whilst reducing the observer error of good observers to three to four hundredths of a second. This has, on the one hand greatly improved the means of control of the daily rates of clocks, whilst on the other, has laid upon clocks a new duty, that of contact-closing, and one which provides a powerful source of variation requiring exceptionally good regularity of rate if chronographic measurements are to bring to precision measurement all the benefits they comprise.

It would seem again that electricity is destined to fulfil such progress in precision time-keeping and our skilled and ingenious colleague, Mr. Hipp, whose chronographs and chronoscopes have so to say, done so much to enable us to put a microscope on time, has now succeeded in building a precision electric clock. One may hope that this device will contribute greatly to the reduction of the remaining shortcomings of the best astronomical clocks.

These shortcomings are basically two in number: the first is the need to use oil to ease frictions in the clocks: despite the efforts of chemists and clockmakers, an oil has yet to be found which will resist changes due to elevated and reduced temperatures and which will keep for two or three years; on the score of the temperature factor there is thus a substantial cause of annual variation in clocks. We shall see that Mr. Hipp has succeeded in the entire elimination of oil and this along constitutes a notable advance which should make history in precision time-keeping.

The second disideratum of astronomical clocks is their removal from the influence of barometric variations - an influence which has not been fully studied but which exists nonetheless and is productive in our climates of a total variation of as much as 3 or 4/10 seconds. All means for barometric compensation which have been tried having failed the only thing which remains to be done is to run the clocks in vacuo or at constant pressure. Despite all the efforts of inventiveness, it will be realised that it is well nigh impossible to set up and maintain under such conditions a weight-driven clock which requires to be wound up periodically, but with an electrically driven clock, maintenance is effected by the agency of two thin conductors. The latter device thus readily lends itself to operation in vacuo. We shall shortly see how Mr. Hipp has at last succeeded in keeping the pressure constant.

But, if the skilled clockmaker is progressing along these two avenues, it is essential that the ingenious electrician - which he must also be - should remove the serious shortcomings which have until now, and with more or ,ess justification, been laid against most electrical clocks, such as the changes in rate which they suffer through current variations and most of all the frequent interruptions to which they are subject from rapid oxidation of contacts, the more or less slow running down of batteries and sometimes complete and sudden failure of current.

In order to explain how and how far Mr. Hipp has succeeded in overcoming these troubles and has realised the great advantages mentioned above, it is necessary to give a brief explanation of the constructional details which Mr. Hipp has used in the precision electric clock and which he has developed little by little as a result of experiment and observation over many years, experiments to which I submitted the clock at our observatory and through which I was happy to assist the efforts of our colleague.

Without wishing to give a detailed description of the instrument, we shall confine ourselves to saying that the pendulum is fitted with the electrical escapement of Mr. Hipp and which is well known as being invented by him thirty years ago and which he has excellently adapted to the precision clock.

The swinging palette is no longer hanging, but is fixed vertically upon a jewelled semi-cylinder, the axis of which rides upon a platinium - iridium knife edge, thus allowing the palette to swing about 40° either side of the vertical, under the influence of another fixed palette, carried upon a crossbar fixed to the pendulum: this latter palette is formed from a stone (sapphire, chrysolite or ruby) and bears a small groove.

The operation of the escapement may be followed from an examination of the figures II, III, IV, V and VI; so long as the amplitude of oscillation of the pendulum is large enough to allow the tip of the crossbar palette to take the palette r right and left and overshoot it in so doing (fig. III & IV) no current flows, but as soon as the pendulum amplitude decreases through air resistance and the work done in closure of the seconds contacts adjacent to the suspension (less than one minute of arc compared with maximum amplitude), the palette is caught by the crossbar palette and causes the tilting of the mounting of the palette r on lever l, which latter rests upon knife edges, towards the right. The left hand end of l rises and makes the circuit through a single cell and the magnet coils m, which then pull a soft iron pole-piece fitted to a crossbar on the pendulum thus giving impulse to the pendulum.

It will be seen that this ingenious arrangement brings into action the electricity and gives impulse not at each second or two seconds as is usual in most electric clocks, but only when it is required to restore the full amplitude of oscillation after its gradual loss by the pendulum. It is clear that when the current strength giving impulse to the pendulum is great so will be the impulse and in consequence will require longer time to fall back to the minimum amplitude at which the current will be turned on again. If, on the other hand, the current strength is low, the intervals will be diminished. The advantages of such an arrangement are as follows; since the minimum electrical energy is used, the battery discharges more slowly and also, the operation of the clock is assured even with a considerable drop in battery power, the clock simply making more frequent calls upon the battery. If, for example, one records the length of impulse every day, a very delicate indication of the current strength is obtained and sufficient warning is always given to renew the battery. We have made trials of the effect of intentional reduction of current strength upon the duration of impulse and find that battery variations do not alter the clock rate so long as they are less than 20 to 25%.

We shall shortly return to the other advantage of this escapement, namely that of there being no need for oil, since all details are carried upon knife-edges and there are no pivots or bearing surfaces whatsoever to need oil.

The constructor being thus assured of the going of his clock under conditions of constancy and extreme accuracy, it is essential on the other hand to avoid another cause of falling-off or alteration of constancy which so seriously compromises precision electrical equipment, to wit oxidation of contacts, engendered by sparking arising from the back e.m.f.s. at the instant of breaking the main current. Mr. Hipp has attained this desideratum which is essential to reliability of electrical operation, by means as simple as reliable, by closing a circuit for the back e.m.f. formed when the principal current is broken, just at the time of break. Fig VI. When k opens, another circuit via k'closes, through which the back e.m.f. passes, so that there is no sparking at k, thus avoiding any oxidation of the contacts. Examination of the surfaces of these contacts after several years operation confirms absolutely their perfect preservation.

The efficacy of this simple scheme is again brilliantly confirmed in the seconds contacts used to supply currents for driving the seconds dials, and which are to be found immediately below the suspension clock (S, Fig. 1). These contacts operate according to the schematic arrangement of Fig. VII.

The pendulum P, in swinging to right and left, presses via the two small contacts b,b', on two platinum iridium leaves l,l', carried upon knife edges, also of platinum iridium, c,c', in lightly touching and depressing these leaves initiates currents of opposite sense through the external circuit of the dial drive magnet coils. At the instant of depression, the laminae l,l' leave the stops a,a' below their ends remote from the pendulum, and conversely, at the moment the tips b,b' leave the springs, they fall back upon their stops a,a'. Thus/

Thus, in Fig. VII the pendulum has just made contact to the right, the battery current flows via b', l, c', E', l, a, B. At the instant when the pendulum leaves b', from the leaf l'the back e.m.f. so produced finds a path simultaneously through via a'. Likewise on the opposite side. In this way all sparking is avoided and, indeed, the contacts of a clock which we have had at the observatory for the past four years have functioned regularly and continuously without ever having been cleaned. Now, during a year a pendulum swings 15,768,000 on each side and it has thus been shown that the same contacts may operate more than seventy million times without appreciable oxidation.

In this way, Mr. Hipp has completely succeeded in removing what has been until now the main objection to electric clocks: there remained, however, one further trouble, almost as serious as the first. This difficulty is the more or less heavy drain of the batteries. The result of this drain is that at a given instant, the enfeeblement of the cells becomes such that they cannot drive the electromagnets and the clock fails to function. The work at the observatory over more than four years has sufficiently made clear this difficulty, but has also, I hope, helped to overcome it.

A distinction must be made between the battery which is used to drive the clock and that which is the source of current for the dial. As to the first, which is called upon every couple of minutes or so, only, and therefore discharges much more slowly, there is, as already mentioned, a very delicate indication of its condition,besides, the pendulum does not stop operating the dials for some minutes after the last pulse, and so there is ample time to change the battery at the time it has been seen to be giving impulses at too brief intervals. This change can be made without interruption of the running of the clock.

Matters are not so simple in relation to the seconds battery. Not only a drain each second -86,400 discharges per day - discharges the battery rapidly, but also/

also it is difficult to measure currents of only a fraction of a second's duration, whilst finally, it is difficult to replace failing cells or batteries without interruption of the dials, by ordinary means. However, as it is absolutely necessary to overcome this grave disadvantage if the device is to be used as an observing tool, I asked Mr. Hipp to use two batteries, one always being at rest and fully charged, and to install a changeover switch which could, by a smart action of a lever, bring in the spare battery in a small fraction of a second, to replace the discharged unit in the interval between two successive emissions of current, so that the operation would not drop seconds from the dial. On the other hand we have introduced a specially damped indicator into the circuit, this being so constructed as to permit the brief current pulses each second to hold the needle almost steady at some mark on the scale related to the state of a fresh battery. As soon as an indication of failing battery power below the set limit appears, a new battery may be connected. Whilst the latter is working, the old battery is recharged to become the next new battery.

In this way it is possible to ensure the same continuity of operation of an electric clock as that of its weight driven counterpart. Indeed the latter must be rewound monthly or weekly and for rewinding of Mr. Hipp's clock it is enough to change batteries as described.

The pendulum battery consists of three Lechlanché cells of large size and of Mr. Hipp's improved form and these need to be changed as a rule about every six months. The dial battery is composed of four large Meidinger cells and is changed monthly. If this be not done, it would be necessary to renew completely instead of merely cleaning them, adjusting the water or copper sulphate and replacing as required spent zinc or copper plates.

Although this procedure may confer upon electric clocks the same constancy and continuity of operation/

operation as that of weightdriven clocks, it might seem irrational to wish to replace them with an expensive and capricious driving force for their pendulums to substitute for the free and uniform motive power of gravity, unless that substitution were to present certain major advantages to counterbalance the disadvantages and justify their use in observatories and other scientific establishments. We are thus led to develop with some detail the progress to date in time measurement by means of the electric clock, which we have briefly noted at the beginning of this notice.

We have already seen that Mr. Hipp's clock avoids altogether the use of oil. Not only horologists but astronomers likewise will appreciate the value of freedom from an inexhaustible source of trouble with clocks by the removal of oil. Naturally, the exclusion of oil does not extend to the train of the dials, the pivots of which must perforce be lubricated, but as this work has no mechanical connection with the pendulum as being coupled electrically only, it cannot be affected in the same way as it would be in a mechanically coupled train.

In the Hipp clock, the escapement which gives impulse is entirely free from oil. The movements when at rest are balanced on knife-edges and in the escapement palette, any frictional forces are between jewels or stones and platinum iridium, the hardest and most chemically inert material known.

The introduction into clockmaking of platinum-iridium alloys, upon which I advised Mr. Hipp, represents significant progress. Mr. Hipp originally tried steel and gold for his palette, but after some time that section of the palette which slides every second over the counterpalette stone and periodically tilts it, began to wear slightly. This was not the case with platinum iridium alloy, in which the iridium content was gradually increased to 40% from 10% and successfully kept the palette free from wear. Likewise, Mr. Hipp gradually replaced all the knife edges, hitherto in steel, and which although not oiled, became fouled with a thin layer of rust or dirt-probably produced/

produced by metal oxides formed under the joint influences of friction and atmospheric moisture. Here, again, platinum iridium shows itself far superior to the hardest steel. Finally it is used for the contact leaves, numbering three per side of the pendulum, which provide the currents for the seconds dials.

We have already noticed the second great advantage of Mr. Hipp's electric clock, which is that it is entirely removed from the effects of variable atmospheric pressure. To this end, the pendulum together with its escapement, the electromagnet and contact springs, manometer and thermometer are placed within a cylinder of glass, closed at its upper end by a brass plate screwed to a very thick and solid plate of iron and fixed by large studs on to the pillar carrying the whole equipment. The lower end of the cylinder is likewise closed by a brass plate which is drawn up against its end by four brass tie rods outside and parallel to the cylinder. Once the vacuum is established in the cylinder, the nuts on the ends of the brass tie rods are released and the lower plate is held in place solely by atmospheric pressure. The glass cylinder is cemented at the ends in two annular grooves cut in the brass closures. In spite of these precautions, Mr. Hipp struggled vainly for more than a year without succeeding in making the seals airtight, and after an extensive search came to the conclusion that the sealing plates were porous, although the plates were cast from best quality brass, 12 mm. thick. That this was indeed the fact was confirmed when the castings were replaced by rolled brass sheet and the closure remained perfect. We ran the pendulum at a pressure of about 77 mm. Hg. for about five months and found that the daily variation of the manometer never exceeded 76,2 to 78.6 mm. that is, the variations going both ways would be explained by temperature changes and their effects upon the vapour tension of moisture remanent in the chamber.

I can now report that the experimental work on the clock has shown that the rate variation per millimetre pressure change is 0,012 sec. Now, as the amplitude of the annual barometric variation is, for this area/

area, an average of 30 mm. and 34 mm. maximum it appears that the annual suppressed rate variation is of the order of $0^s,35$ average or $0^s,41$, maximum and ultimately that the remaining pressure fluctuations within the sealed chamber cannot influence the rate by more than two hundredths of a second, about.

The regularity of rate of the clock is very satisfactory. Observations from 29th November to 29th March, in which the clock ran under constant pressure, showed its mean daily variation was ± 0,068 sec. For the two latter months, the daily rate had been too great at first (8.88 sec.), a half second advance a day, the mean diurnal variation is almost the same at 0,600. As the pendulum has not yet been directly applied to meridian determinations, it has been necessary to compare it daily with the meridian clock, and as these comparisons are made by chronograph their uncertainty is of the order of + 0.15 sec. so that when the electric clock is used for observations of the meridian, its variation will be reduced to about ± 0.05 sec.

I have sufficient information to believe that the major part of the variation arises from a remanent compensation adjustment error, and which will be put right during next summer's run, which will permit of its determination precisely. Finally, it must be remembered that the figure given for the variation of the clock must of necessity include the uncertainty of two hour determinations and above all, the variation in the personal equation of the observer, which together, may be put at ± 0,25 sec.

As to long-period variation amplitude,this has kept within a half second, to date, but it is essential to carry on much longer observations in order to fix this with certainty as an annual quantity.

To sum up, in the present condition, the diurnal variation does not exceed a half-tenth second, and as this will be reduced to 0,03 to 0,04 sec. after definitive adjustment of the compensation, it will be seen that this clock is at least equal to the best known to date.

In conclusion, I shall reiterate one of the advantages offered by electric clocks and which will be appreciated by directors of observatories, which is that the same clock, set up in conditions of optimum stability and temperature constancy, for example, underground, can be made to operate a number of dials in the various places of observation and distribute standard time identically throughout the entire observatory.

In our own observatory, it provides star time for our two large instruments, the meridian and equatorial telescopes, besides recording seconds upon the chronograph.

Finally, there is another advantage of electric clocks to practical astronomers, wherein the beat of the electric clock is much stronger than that which can be had from an ordinary regulator with anchor escapement, so that a seconds beat can be placed so as to be visible directly to the observer as he makes his North or South sights.

All in all, it must be recognised that Mr. Hipp's electric clock has occasioned considerable progress in time determinations.

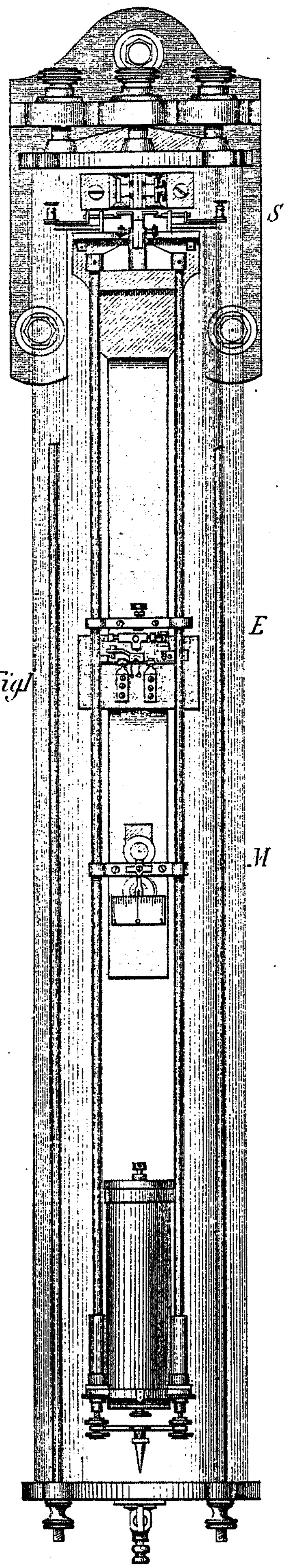


Fig I

Fig.II

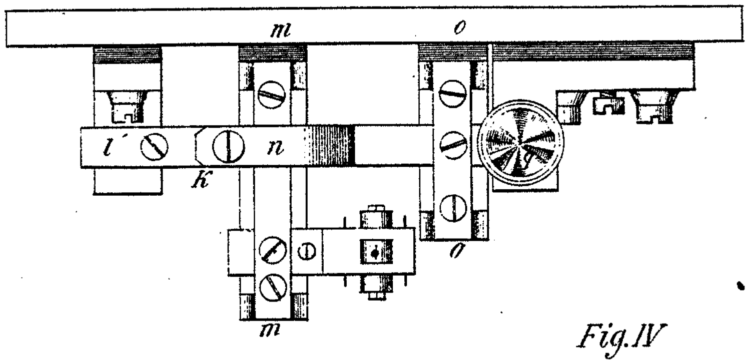
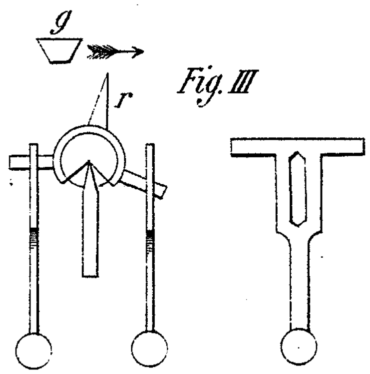


Fig.IV



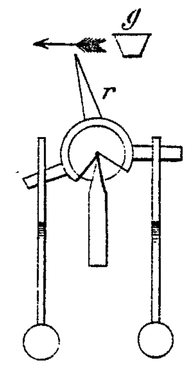


Fig.V

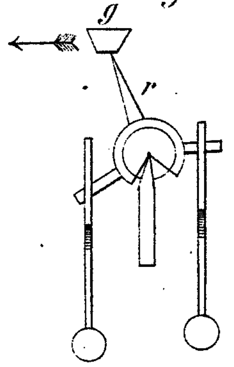


Fig. VI