Description of the printing chronograph

Sitter, W. de

BULLETIN OF THE ASTRONOMICAL INSTITUTES OF THE NETHERLANDS.

1925 September 19 — Volume III. — No. 84.

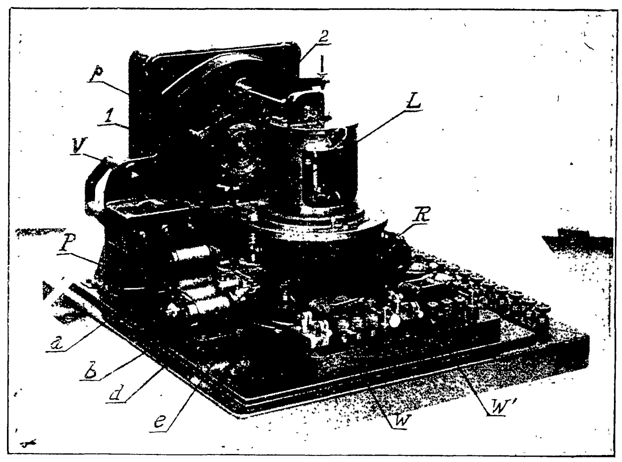
COMMUNICATION FROM THE OBSERVATORY AT LEIDEN.

Description of the printing chronograph, by *W. de Sitter.*

The printing chronograph, constructed bij the Société Genevoise d'Instruments de Physique, has now been in use at this observatory for a considerable time. As it is the first apparatus of this type of which so much experience has been accumulated, and as it has been subjected to a severe practical test, and many improvements were made as a consequence of this, it has been thought of interest to publish a description of it. The figures 1 and 2 give general views of the instrument. In fig. 2 the back cover has been removed to show some of the wheels of the clockwork, and the synchronising device. The figures 6, 7, 9, 10, 11, 12 show parts of the instrument or auxiliary apparatus, 3, 4, 8 show the electrical connections, and 5 gives an example of a printed record. The lettering is the same in all figures. The electric current enters the apparatus through a series of terminals, designated by **A**, **B**, ... , **Q**, mounted on the base, and shown in figs 1 and 2, **A** being the first to the right in fig. 2, and **Q** the last to the left in fig. 1.

Fig. 1.

Fig. 2.

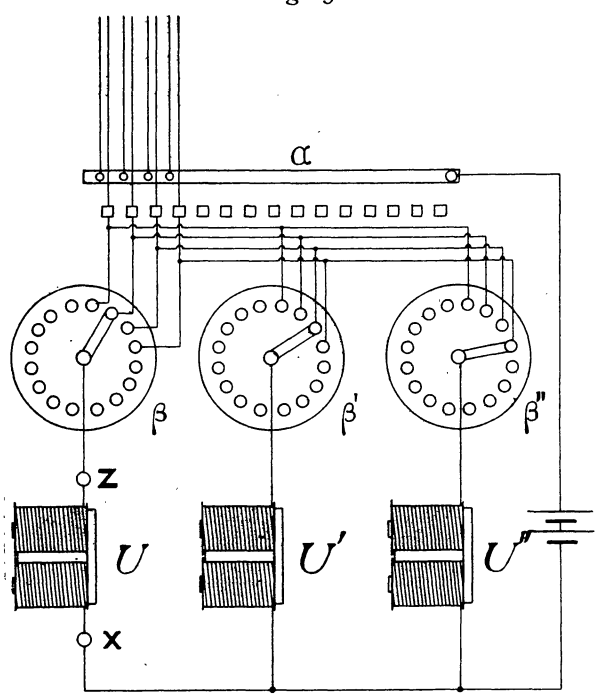


The instrument consists of an electric motor, driven by a continuous current of 12 volts, and making 80 turns a second. It is geared to a clockwork, three wheels of which of the same diameter, and mounted next to each other on the same axis, rotate in one second, one minute and one hour, and are divided in 100, 60 and 60 parts respectively, the divisions being marked by figures in relief on the outer circumferences of the wheels. Between these wheels are fixed index-marks. An ink ribbon and a strip of paper run close to these wheels and marks, and can be pressed against them by five hammers, so that the minutes, seconds and hundredths of seconds corresponding to the instant of the action of the hammers are printed on the paper together with the index-marks.

The hammers, which are actuated by an electro-magnet *H*, are *thrown*, not pressed, against the wheels, and rebound immediately, even before the current through *H* is interrupted, so that their action does not cause any friction, which might retard the motion of the clockwork. The same current also flows through another electromagnet *P* , which advances the paper strip and ink ribbon by about one cm each time. The hammers are thrown against the wheels by the *closing* of the current, the strip is advanced when the armature of *P* is released at the *breaking*, i. e. after the printing has taken place. The strip can also be moved independently from the hammers, so that different series of signals can be separated by a clear interval on the paper strip.

The electrical connections for the printing and the motion of the strip are shown in the figures 3 and 4. In the chronograph room three switches β, β', β'' are mounted corresponding to the three chronographs. On each of these switches are 15 contact-studs corresponding to 15 different points in the buildings. From each of these points two wires run to the chronograph room, one of which is connected to the rail α (and through it to a battery of 4 volts) and the other to the corresponding studs on the switches β, β', β''. The central core of each of these switches

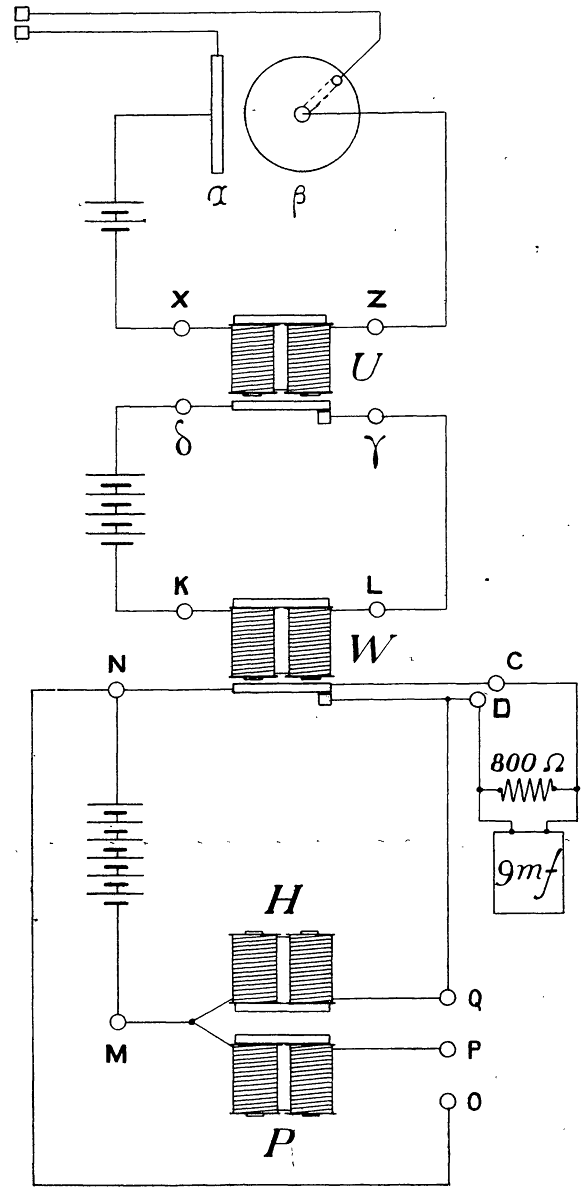
Fig. 3.



is connected to one of the relays U, U', U'', each of which actuates one of the chronographs. Thus, by putting the arm of one of the switches on the stud corresponding to his number, an observer in any of the 15 rooms can register his signals on any one of the chronographs. Thus if the position is as drawn in fig. 3, the observer Nr. 2 works on the printing chronograph, Nr. 3 on "Hipp" and Nr. 4 on "Mayer and Wolf." The relays U' and U'' are built into their respective chronographs, U, belonging to the printing chronograph, is a separate relay.

Figure 4 shows the arrangement of the different relays and electromagnets of the printing chronograph. When the observer presses his key, or a contact is made on the drum of the impersonal micrometer, a current is sent through the relay U, the armature of this relay is attracted, and consequently the current through the relay W is interrupted, and the armature of this relay, being released, closes the circuit through the electromagnets H and P, the terminals **P** and **Q** being normally connected. If the connection **PQ** is broken, and **OP** established, then the current from the battery of 12 Volts, connected with the terminals

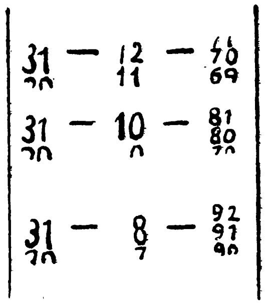
Fig. 4.



M and **N**, is sent through P only and not through H, and consequently the strip of paper is moved without any printing being done.

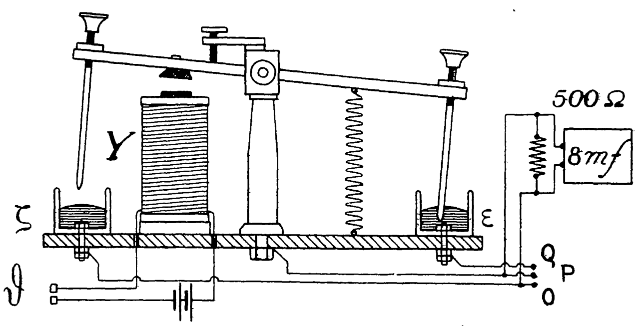
The armature of H throws the hammers against the strip of paper and the wheels, when it is *attracted*, i. e. at the closing of the circuit; the armature of P causes the strip to move on by about one cm when it is *released*, i. e. at the breaking of the circuit after the action of the hammers and the corresponding printing. A reproduction (actual size) of part of a strip showing three consecutive printings (read: $31^m8^s\cdot91$, $31^m10^s\cdot81$, $31^m12^s\cdot70$) is given in fig. 5. *)

Fig. 5.



The connections between **O**, **P**, **Q** are regulated by the arrangement shown in fig. 6. This auxiliary apparatus, which was made in our workshop, consists of two basins of mercury ε and ζ, mounted on an ebonite base-plate, and a balancing arm carrying two points dipping alternately in these two basins. Normally, when no current passes through the electromagnet *Y*, the points **P** and **Q** are connected through ε, as shown in the figure; when a current is sent through *Y* this connection is broken and the connection **O P** is established through ζ. The length

Fig. 6.

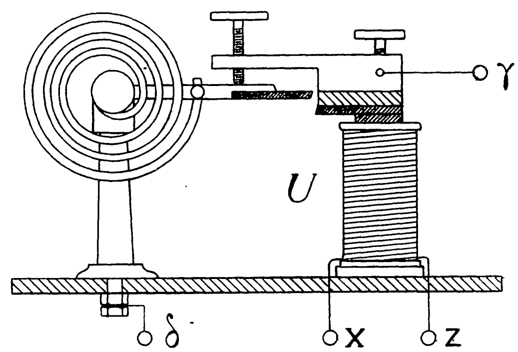


of the points is so adjusted that the contact at ε is broken *before* that at ζ is established. No spark can ever occur at ε, as no current flows through this point at the moment when the contact is broken. To avoid a spark at ζ when the current through *Y* is interrupted, a resistance and a condenser are inserted, as shown in the figure. By a special switch the terminals ϑ can be connected to a key or button in each of the observing rooms. By pressing this button the observer can consequently move the paper strip of the chronograph without printing on it at the same time.

The terminals **C**, **N** and **O** are connected with each other in the base of the instrument, and so are **D** and **Q**. To avoid a spark at the armature of *W* a resistance and condenser are inserted between **C** and **D**.

The relay *W*, connected with the terminals **K** and **L**, is built into the apparatus as delivered by the Société Genevoise. As some of the signals from the registering micrometer on an equatorial star follow each other with an interval of only $0^s.4$, and the duration of one signal is not much longer than 1/40 of a second, the relay *W* had to respond very quickly. Although the relays constructed by the Société Genevoise are extremely sensitive, it was found that it did not always do so, and especially the electromagnet *P* sometimes failed to move the paper sufficiently, so that consecutive printings were superposed. To remedy this defect the relay *U* was inserted. It was constructed in our workshop on a suggestion of Mr. FERRAND TURRETTINI, one of the directors of the Société Genevoise. It has the double advantage of prolonging the duration of the current through *W* and allowing a higher voltage to be used for this current. Its construction is shown in figure 7. It is mounted on an ebonite base-plate. When no current passes through the electromagnet *U*, the armature, which is connected to the terminal δ, is pressed by a spiral spring against an adjusting screw in a brass piece, which is connected to the terminal γ, and isolated from the core of the magnet by a strip of ebonite. When a current is sent through *U* the armature is pulled down, the connection between γ and δ is broken, and the interval elapsing before it is re-established depends on the elasticity of the spiral spring and the position of the adjusting screw, both of which can be regulated. This device has worked very successfully ever since its installation.

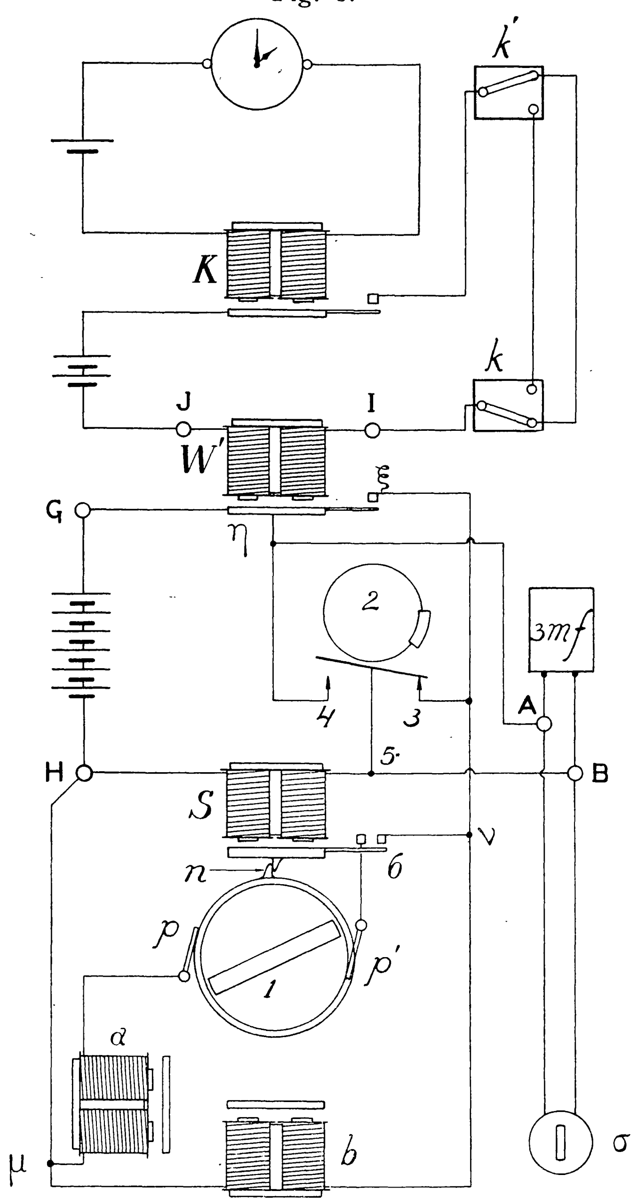
Fig. 7.



*) These printings belong to a series obtained by causing the synchronising clock to register its (alternate) seconds, while the motor was not being synchronised, and the contact at *V* (see below, fig. 10) was lowered by one complete revolution of the screw from its correct position, so as to diminish the speed by ·05 of its value.

We now come to the description of the method by which the motor is synchronised by the sidereal clock. This is shown diagrammatically in figure 8. The clock is mounted in the hall of the observatory. At every alternate second (the odd ones) it makes a contact which closes the circuit **I** k k' **J** through the relay W', which is built into the chronograph and

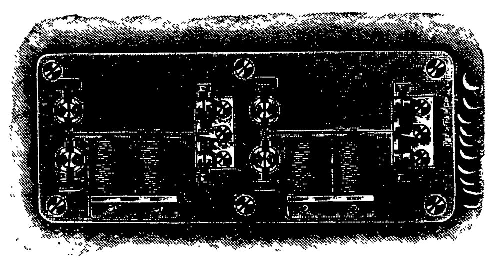
Fig. 8.



connected through the base with the terminals **I**, **J**. The relays W for the printing and W' for the synchronising are well visible in fig. 2, and are shown separately in fig. 9. They are both so constructed that they can be used either for closing or for breaking the secondary circuit. As the instrument is used here, W breaks and W' closes a circuit by attracting their respective armatures.

The armature η of W' being attracted, a contact is made at ξ, and the circuit **H** S 5 3 ξ η **G** is closed. It remains closed for about half a second, or somewhat longer, depending on the duration of the contact made by the clock, and is then broken again. The wheel **2** is connected with the clockwork, and completes one revolution in two seconds. It carries a piece of ebonite, which at the even seconds presses down a spring balance, thereby breaking the contact at 3 and establishing it at 4, and thus closing the circuit **H** S 5 4 η **G**. The piece of ebonite is so adjusted that the contact 4 is closed a little less than one second after that at ξ. Thus at the exact odd seconds, and a few hundredths of a second before the even ones, the armature of S is attracted, and it is released again a little more than half a second later each time. The wheel **2** and the contacts 3, 4, 5 are shown in more detail in figure 12, in which the circuit is shown as for the even seconds, while fig. 8 shows it for the odd seconds. The terminals **A** and **G** are connected in the base of the instrument, and **B** is similarly

Fig. 9.



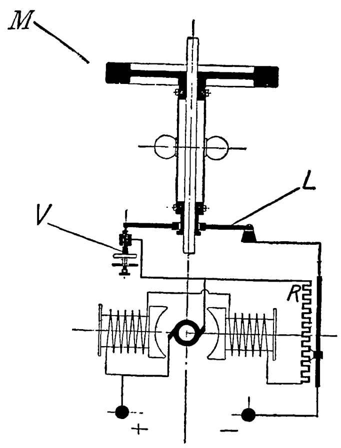
W' W

connected to 5. Between the terminals **A** and **B** a condenser is inserted to prevent sparks at ξ.

For correct synchronising the motor must be a little — a few thousandths of a second per second are sufficient — fast on the clock. The first wheel of the clockwork (**1** in the figures 2, 8 and 12), rotating in one second, carries at its circumference a projecting tooth n, which, if the motor is fast, runs up against a similar tooth n' on the armature of S, by which the clockwork is instantly stopped. As the connection between the motor and this wheel is effected through friction by a spiral spring (f in fig. 12), the strength of which can be regulated, the motor runs on, so that, when the armature is attracted, thereby liberating the projection n on the wheel **1**, the clockwork is immediately started again. The motor carries a flywheel M (fig. 10), the inertia of which is very large compared to that of the clockwork. The motor consequently does not lose its speed when the clockwork is stopped, and as the clockwork immediately after the release of the tooth n takes up again the full speed of the motor, its motion between two stoppings is entirely uniform. At the intermediate seconds, when the current is sent through the magnet *S* by the wheel **2** instead of by the relay *W'*, the armature is always attracted before *n* reaches its lowest position, and the clockwork is not stopped. The synchronising thus only takes place at every alternate second, and the wheel **2** only serves to make the passage free for *n* at the intermediate seconds.

The speed of the motor is regulated by the screw *V* (fig. 10). As the motor gets up speed the two brass balls mounted on flexible springs separate by their centrifugal force, and thereby lift the lever *L* until the contact at *V* is broken. The current for the armature of the motor is then compelled to pass through the resistance *R* instead of through the lever *L*, and the motor is consequently slowed down until the contact at *V* is re-established. When the motor

Fig. 10.

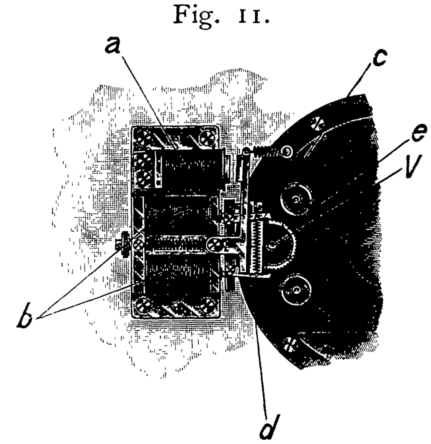


is running the lever *L* is in continuous rapid vibration (several hundreds of vibrations per second, according to the statement of the Société Genevoise), and the flywheel *M* keeps the speed of the motor practically entirely uniform. As has been explained the motor, for perfect synchronising, must be a little fast on the clock. The speed depends on the position of the contact at *V*, which can be regulated by a screw. In the apparatus as originally supplied this adjustment had to be made by hand, and to be entirely secure the motor had to be about ·005 to ·008 seconds per second fast. A drawback of this was that on long winter nights, probably as a consequence of a thickening of the oil by the cold, the motor often had a tendency to decrease its speed, and the screw *V* had from time to time to be screwed up, sometimes several times per hour. In the new apparatus this adjustment is made automatically by the arrangement shown in figure 11.

The axis of the screw *V* carries two toothed wheels *e*, on which can act two pawls *c* and *d*. The pawl *d* screws the contact up, and thus increases the speed of the motor, *c* lowers it and diminishes the speed. At the odd seconds, when the armature of *W'* is attracted, a current is sent through the electromagnet *b* by **H** μ *b* ν ξ η **G** (fig. 8). The armature of *b* is consequently attracted, and when it is released again after about half a second one of the pawls *c* or *d* acts on the corresponding toothed wheel *e*. If no current passes through *a* at the time, as shown in the figure, then *c* is brought in action, and the motor is slowed down, if on the other hand the armature of *a* is attracted at the same time, then *d* acts, and the motor is accelerated. The correction applied to the speed of the motor by one stroke of each of the pawls amounts to some thousandths of a second per second.

When the armature of *S* is attracted a contact is established at **6** (fig 12), and a current can pass

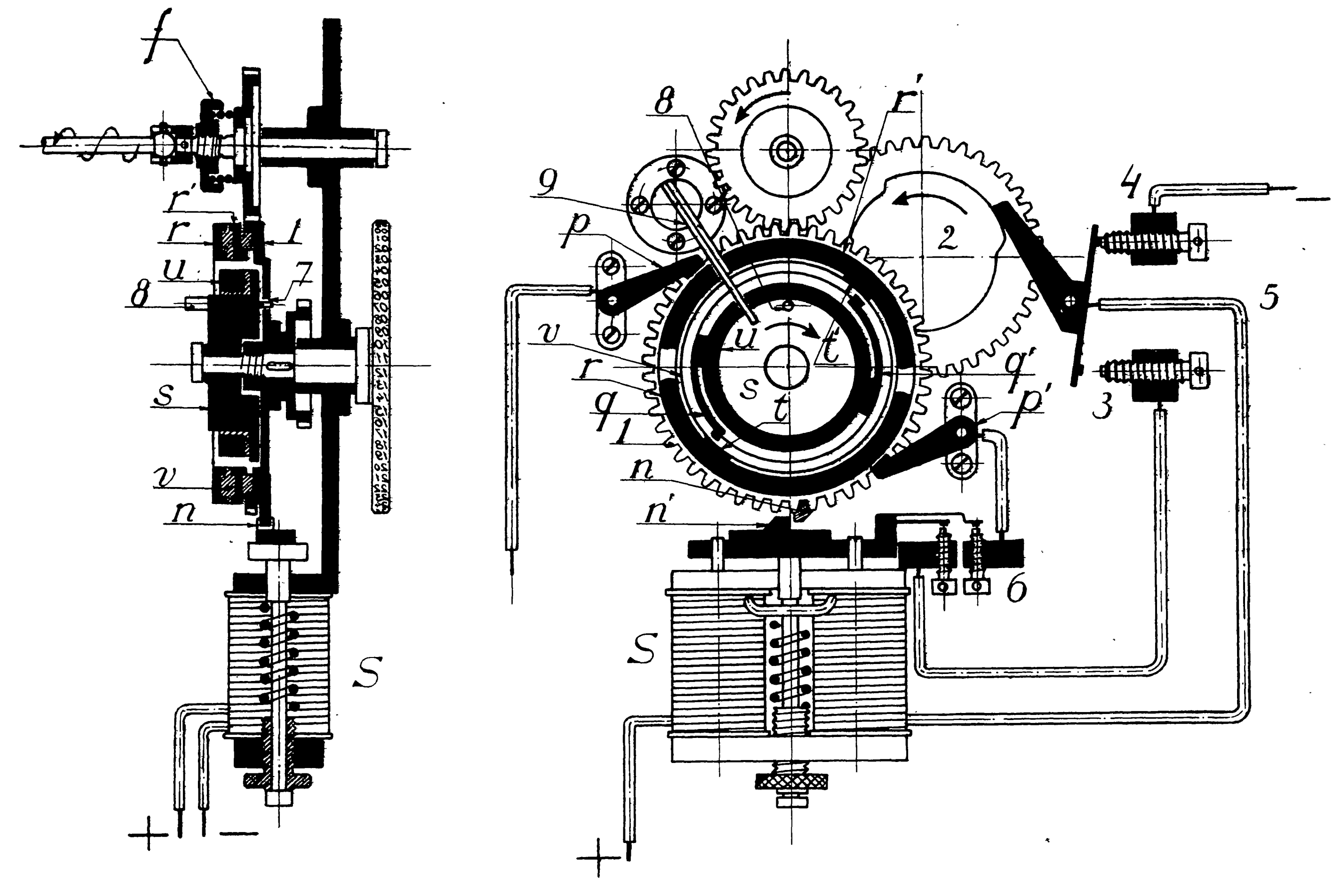
Fig. 11.



through *a* by **H** μ *a p p'* **6** ν ξ η **G**, if there is a connection between *p* and *p'*, and it cannot pass if this connection is interrupted. The contact at **6** is established *before* the armature of *S* is so far down as to liberate the projection *n*, if this has been arrested. By a very ingenious device the connection between *p* and *p'* is broken whenever the projection *n* is caught by *n'*, and it is maintained when *n* passes free of *n'*. We will first describe this device as it was originally made by the Société Genevoise, which is represented in the figures 12 and 2.

p and *p'* are two brushes sliding against two isolated brass rings *r* and *r'*, which are inlaid in an ebonite ring *v* attached to the wheel **1**. Each of the rings *r* and *r'* has on its inside a projection *t*, *t'* reaching to the inner surface of *v*. On the axis of **1** a heavy brass disc *s* is mounted so as to be free to rotate independently. This disc carries at its circumference an isolated ring *u*, to which are attached two flexible steel springs *q*, *q'* ending in flat platinum points. The rotation of *s* relatively to **1** is limited by a slit **7** in

Fig. 12.



1, forming a circular arc of about 30°, into which the pin 8 projects. Originally the disc *s* was placed loose on the axis. It was found that this caused too much friction, and we have inserted a ball bearing, not shown in fig. 12, but represented in fig. 12*a*.

So long as the clockwork runs regularly, *s* is carried on with 1 by the pin 8, the springs *q*, *q'* rest against the projections *t*, *t'*, and a current can pass from *p* to *p'* by *p r t q u q' t' r' p'*. When, however, *n* is caught by *n'* and 1 is arrested, *s* runs on by its inertia, the springs *q*, *q'* slide from the projections *t*, *t'* on to the ebonite ring *v*, and the connection is interrupted.*) No current can then pass from *p* to *p'*, the armature of *a* is not attracted, and the motor is slowed down. A short time before *n* reaches its lowest position again, the pin 8 strikes against the flexible spring 9, the disc *s* is thereby brought back in its original position, and the same series of events is repeated, if *n* is again arrested by *n'*. If on the other hand *n* passes free of *n'*, which happens if the motor is slow, then a current passes from *p* to *p'* and through *a*, the pawl *d* is brought into action, and the motor is accelerated.

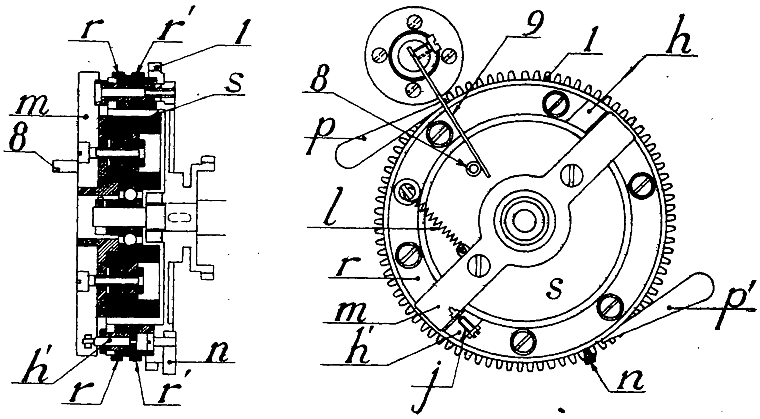
At the intermediate seconds, when there is no contact at ξ, but the current is sent through *S* by 2, no current passes through either *a* or *b*, and the speed of the motor remains unaltered.

This arrangement has worked very satisfactorily for several months, but it required constant supervision and great care. The springs *q q'* needed very delicate adjustment (for which screws are provided), so as not to cause too much friction against the ebonite ring *v* and at the same time to provide a sufficiently close contact at *t*, *t'*. Also particles of the brass projections *t*, *t'* were carried over by *q* and *q'* onto the ebonite *v*, and particles of ebonite onto the brass, so that frequent cleaning was necessary. This led to some correspondence with the Société Genevoise, who then supplied another arrangement, represented by figure 12*a*.

The disc *s* is mounted as before on a ball bearing on the axis of 1. On it is fixed, isolated from it, a permanent magnet *m*. On the front ring *r* two pieces *h* and *h'* of soft iron are mounted, also isolated, which attract the magnet *m*. One of these pieces, *h'*, is connected through *r* with the ring *r'*, and carries a

*) It is to be noted that no current passes through *q*, *q'* at the moment when they are separated from *t*, *t'*, and no spark can consequently occur at these points.

Fig. 12*a*.



platinum contact, adjustable by a screw *j*, which rests against a small piece of platinum inserted in the magnet *m*. The spring *l* counteracts the attraction of the pieces *h*, *h'*, but it is not strong enough by itself to separate the magnet from its contact with *h'*. Thus, so long as this contact is not broken, a current can pass from *p* to *p'* by *p r l m h' r' p'*. When however, the wheel **1**, carrying the rings *r*, *r'* and the pieces *h*, *h'*, is suddenly stopped, *n* being arrested by *n'*, then the inertia of *s* causes it to run on, the spring *l* increases the separation, and no current can pass, until after about 7/8 of a revolution *s* is brought back to its original position by the spring **9** acting against the pin **8**. The advantage of this arrangement over the former one is that all friction is avoided, and moreover the smallest separation between the magnet and the contact at *h'* is at once automatically increased as well by the diminishing of the magnetic force by distance, as by the action of the spring *l*. It should therefore be much more effective than the former arrangement. Its sensitiveness can be regulated by adjusting the contact on *h'*, by means of the screw *j*, which determines the minimum distance between the magnet and the pieces *h*, *h'*. This should be so adjusted that on the one hand the contact is always good when *s* is carried along with **1**, and on the other hand the magnetic force maintaining this contact is only a very little stronger than the tension of the spring *l* endeavouring to separate *m* from *h'*. The adjustment is a very delicate one, as in the case of the springs *q* and *q'*, and perhaps even more so. But a slight deviation from the most perfect adjustment does not make the arrangement less effective (as it did in the other case by increase of friction), but only a little less sensitive. The new arrangement has now been in use for some time, and it has never failed to work satisfactorily.

On the face of the instrument there are two dials showing the minutes and seconds corresponding to the divisions on the wheels which are opposite the hammers. The printed figures thus always are the same as the reading of these dials at the instant of the action of the electromagnet *H*. The printed seconds can be made to coincide with those of the synchronising clock by the following device. The terminals **A** and **B** are connected to a switch σ (see fig. 8). When the instrument is in use the switch σ must be off, so that no current can pass from **A** to **B** unless a contact is made at ξ. Before the beginning of the observations the switch σ is put in. A current then passes through *S* by **G** η **A** σ **B 5** *S* **H**, and the armature of *S* remains constantly attracted. The motor consequently is not synchronised. Then by the switch *k*, which is mounted in the chronograph room near the instrument, the relay *W'* is disconnected from *K*. At some definite (odd) second, say 15, the switch σ is pulled over, the current through *S* is interrupted, and the clockwork is stopped at that second. The observer then goes to the hall, where the switch *k'* is mounted next to the clock, and about half a second before the clock shows the same second (15 in our case) closes the circuit through *W'* by the switch *k'*. At this moment the synchronising begins, at the exact second (15) the projection *n* is liberated, the clockwork is carried on by the motor, and the chronograph henceforth continues to show the same seconds as the clock. The minutes can be made equal to those of the clock by turning the knob placed on the face of the instrument between the two dials.

To test the uniform running of the chronograph when synchronised by the sidereal clock, a mean time clock can be made to register its seconds on the chronograph. The printed hundredths of a second should increase regularly, so as to gain a whole second in 366 (sidereal) seconds. In applying this test, the even and odd seconds were discussed separately. In both series the sequence of the readings is very regular, the deviations from a linear formula corresponding to a probable error of a single printing of about $\pm 0^s{\cdot}015$. This, of course, includes not only the errors of the chronograph, but also those of the signals. There is no sign of a periodicity in the residuals, and also the residuals of immediately consecutive even and odd seconds are generally of the same sign. This proves that during the period of two seconds elapsing between two successive synchronisations the motion of the clockwork is entirely uniform. Other tests were also made. The synchronising clock was made to register its own seconds, while synchronising, and also while the motor was not being synchronised. It does not appear necessary to give the details of all these tests. The general conclusion drawn from them is that errors in the printed signal of $+{}^s{\cdot}01$, ${}^s{\cdot}00$ and $-{}^s{\cdot}01$, due to the motor and the synchronising, are about equally frequent, but errors of $\pm{}^s{\cdot}02$ or larger do practically not occur. As only the nearest hundedth of a second is read off, and no attempt is made to estimate the thousandths, this is all that can be expected. The errors due to irregularities in the time of reaction of the relay U (and perhaps of W, and of H) may occasionally, though not often, amount to $\pm 0^s{\cdot}02$, or, very rarely, to $\pm 0^s{\cdot}03$. They have a tendency to conserve the same sign for 5 or 6, or even 10 consecutive signals, but are entirely of the character of accidental errors in larger series.

We can thus conclude that the errors introduced by the chronograph and the relays are entirely negligible compared with the ordinary errors of observation.