AUTOMATIC CURRENT RECORDER

BY

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One of the principal subjects discussed by the International Electric Congress held in Paris in 1884, was that of "Earth Currents" and the result of the congress as regards earth currents, was "that the conference expresses the wish that observations of earth currents be pursued in all countries." This resolution together with others has been communicated to various governments and our government having conformed to the wish of the conference, it was decided that the observations of Earth currents be made by the Telegraph Department, in which I am a chief engineer. It thus devolved on me to take the subject up. A little consideration suggested by the results of preliminary observations* I have made of earth currents showed me that in order to carry out systematic observations of earth currents, which, from time to time, vary in strength and direction, it is almost necessary, or at least extremely convenient, to have at our disposal, an instrument which will automatically record the strength and direction of a varying electric current. In view of this, I have designed and constructed a recorder the description of which I have now the pleasure of communicating to the society.

In order that an instrument may automatically record a varying electric current it is necessary that it ought to fulfil the two following conditions:—

1. That the motion of the needle of the galvanometer (which is a part of the instrument) be such that the same position of the needle always corresponds to the same strength of current which passes through it; that is to say, that the motion be non-oscillatory.
2. That the position of the needle of the galvanometer may at any moment be recorded.

I shall first explain generally how these two conditions are satisfied in the recorder I am going to describe.

As regards the first condition. This condition is satisfied by having a galvanometer whose needle consists of a coil of fine wire suspended in a powerful magnetic field, after the manner of the Siphon Recorder of Sir William Thomson. It is easy to show mathematically that in the case of an ordinary galvanometer which consists of a magnetic needle suspended inside, or in the neighbourhood of, a coil of wire, this condition, can not conveniently be fulfilled without diminishing its sensibility. On the other hand, in the case of a galvanometer consisting of a coil hung in a strong magnetic field as above described, it is easy to obtain a great sensibility and at the same time a non-oscillatory motion of the needle as will be seen from the following investigations.

Let a be the angle of deflection of the coil at any time t; and let T be its period of oscillation when no current is circulating through it; then we have, for the equation of the motion

$$\frac{d^2 a}{d t^2} + \frac{4 \pi^2}{T^2} = 0.$$

But when a current circulates through the coil, the equation of the motion will be altered owing to a retardation of the motion due to the current induced in the coil. Let us consider the magnitude of this retardation. If I be the intensity of the magnetic field which the coil occupies at time t, A the area encompassed by all the turns of the coil, and if we neglect the self-induction of the coil on itself (which I think we can confidently do); then, plainly N, the no. of lines of force which passes through the coil at time t is.

$$N = I\, A \sin a,$$

hence $$\frac{d N}{d t} = I\, A \cos a \frac{d a}{d t}.$$

But $\frac{d N}{d t}$ is the $E. M. F.$ due to the inductive action; hence if R be the resistance of the circuit, and a be small, C, the current induced in the coil at any time t is approximately,

$$C = \frac{I A}{R} \frac{d a}{d t}.$$

Now the couple or torque due to the action of the field on the current is CIA; and therefore the retardation of the angular velocity of the coil at any time t is,

$$\frac{I^2 A^2}{M R} \cdot \frac{d a}{d t}.$$

where M is the moment of inertia of the coil. Hence we have, for the equation of the motion of the coil,

$$\frac{d^2 a}{d t^2} + \frac{I^2 A^2}{M R} \cdot \frac{d a}{d t} + \frac{4 \pi^2}{T^2} a = 0.$$

The motion represented by this equation will be oscillatory or non-oscillatory according as, $\frac{2 \pi}{T}$ is greater or less than $\frac{I^2 A^2}{2 M R}$, so that in order to the make the motion of the coil non-oscillatory, all that is necessary is, to have the magnetic field so strong that, I^2 is greater than $\frac{4 \pi}{T.} \cdot \frac{M R}{A^2}$.

Now as regards the second condition. The method, commonly used, of recording the motion of the needle of a galvanometer, is the photographic method, which is undoubtedly very satisfactory. But this method, besides requiring an elaborate arrangement of several pieces of apparatus, has a serious disadvantage, namely, that the observations must be made in a darkened room. The method adopted in the recorder is one, which, though perhaps not so accurate as the photographic method, possesses the advantage of being very simple and convenient. In this method, which may be called the electrical method, there are several electrical circuits, each of which is closed when, and only when, the coil or the needle comes to a certain definite position corresponding to it, and each circuit, when closed, makes a mark on a moving paper ribbon chemically prepared somewhat in the same way as in Bain's Telegraph. If the coil turns round in one direction, it successively closes those circuits, which make marks on one side of the centre of the ribbon, and, if in the opposite direction, those circuits which make marks on the other side; and further the distance of the mark from the centre of the ribbon is greater or less according as the turning round of the coil is greater or less.

How these electrical circuits are exactly arranged will be seen later on by reference to the diagrams of the actual instruments. As present it suffices to explain how the coil or needle closes each electrical circuit separately and without its motion being checked or impeded. This is effected by taking the advantage of one of the well known properties of matter, viz. the "surface tension of liquids." When a capillary tube is partly immersed in a liquid, which wets the tube, like water, the liquid ascends in the tube, and the smaller the diameter of the tube the greater the height to which the liquid ascends, and vice versa. In fact, it can be shown that if θ be the angle of capillarity, γ the radius of the tube, W the weight of unit volume of the liquid, T the surface tension, per unit length, of the liquid in contact with air, then, h, the height to which the liquid rises, is,

$$h = \frac{1}{\gamma} \cdot \frac{2\,T \cos\theta}{W}.$$

But the liquid is drawn up in the same way in the space between two parallel plates. In this case if d be the distance between two plates, then, $h = \frac{1}{d} \cdot \frac{2\,T \cos\theta}{W}$;
which shows that the height to which a liquid rises between two parallel plates, is equal to the height to which it rises in a tube whose radius is equal to the distance between the plates.

Imagine now that there is a large number of capillary arrangements, each consisting of two very narrow plates standing in a vessel containing water at a small distance from one another, and arranged in an arc of a circle, while the needle of the galvanometer is disposed in such a manner that, as it turns round, it successively comes in contact with the water drawn up between the plates of each of these capillary arrangements, and thus closes several circuits in order; or else, that there is one such capillary arrangement, while the needle carries a large number of points so disposed that, when it turns round, these points successively come in contact with the water in the capillary arrangement, and thus close several circuits in

Fig. 1.

$\frac{1}{3}$rd full size.

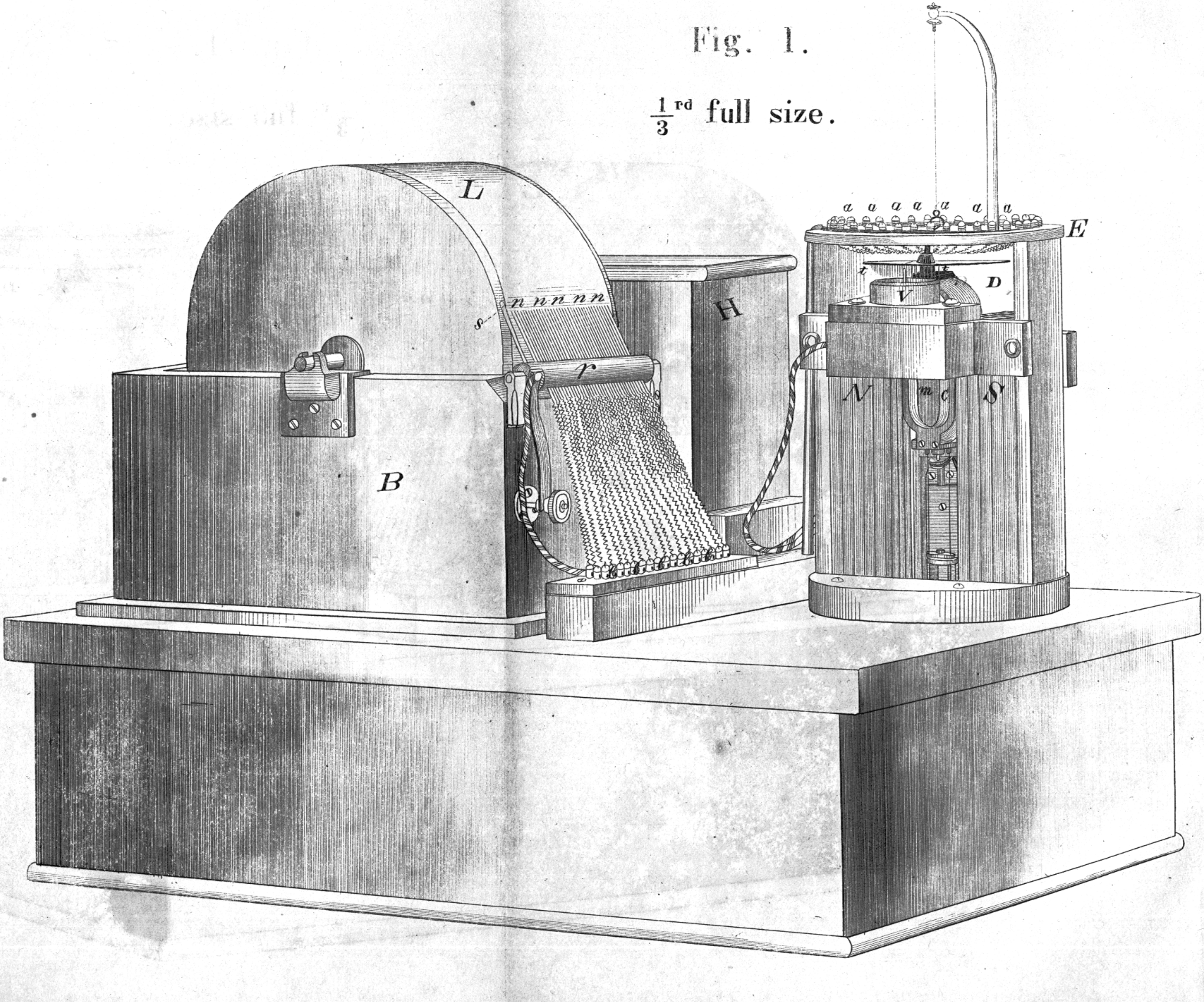
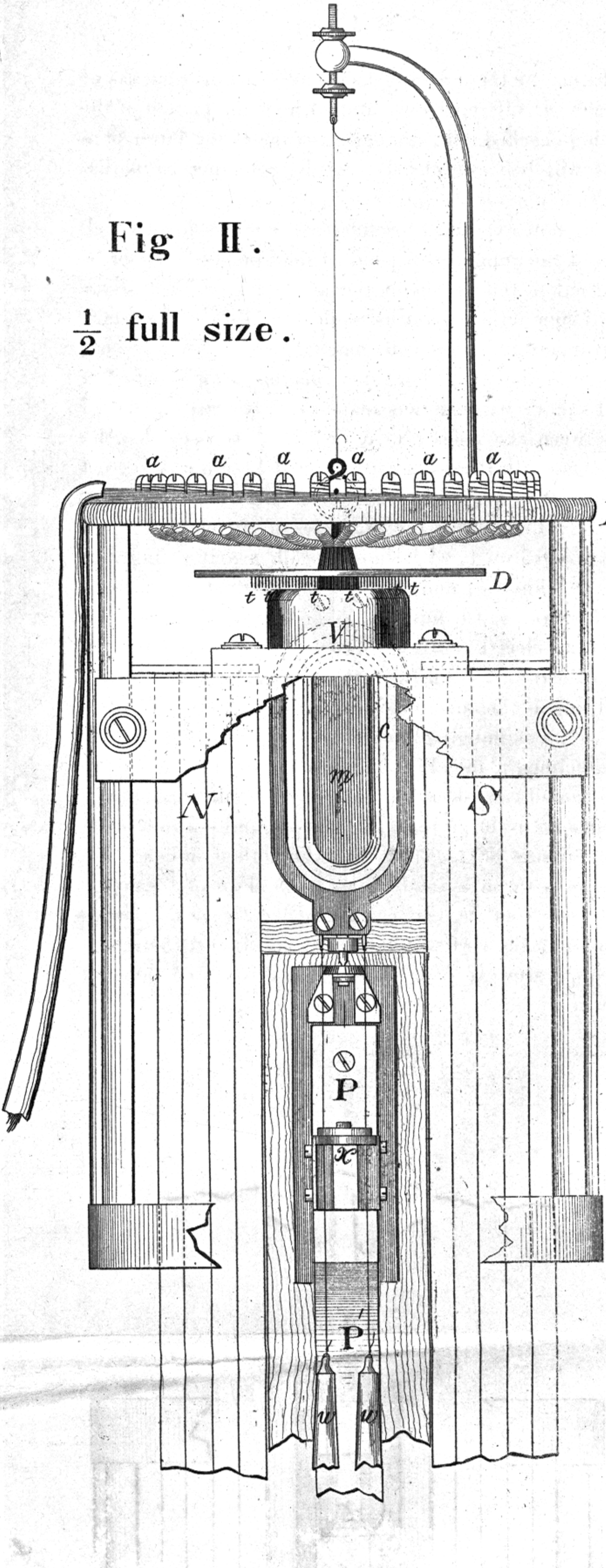


Fig II.

$\frac{1}{2}$ full size.



order. Either of these arrangements affords us the means of closing each circuit separately and without the motion of the needle being checked. In the new instrument the latter plan is used as will be more clearly seen by reference to its diagrams.

Having now explained briefly the principles upon which the action of the apparatus depends, I shall proceed to describe the construction and action of the apparatus. Fig. I shows the general view of the apparatus; while Fig. II shows the details of the arrangement of the coil, magnet, &c. (N) & (S) are the poles of a powerful horseshoe magnet consisting of a bundle of square bar magnets made of very hard tempered steel. Between the poles (N) & (S), there is suspended, by means of a fine silk thread, a coil (c), which contains a great many turns of a very fine insulated wire, whose plane is parallel to the line joining the two poles of the magnet. (m) is a piece of soft iron fixed inside the coil, nearly filling, but no where touching, it, and serves to intensify the magnetic field in which the coil is hung.

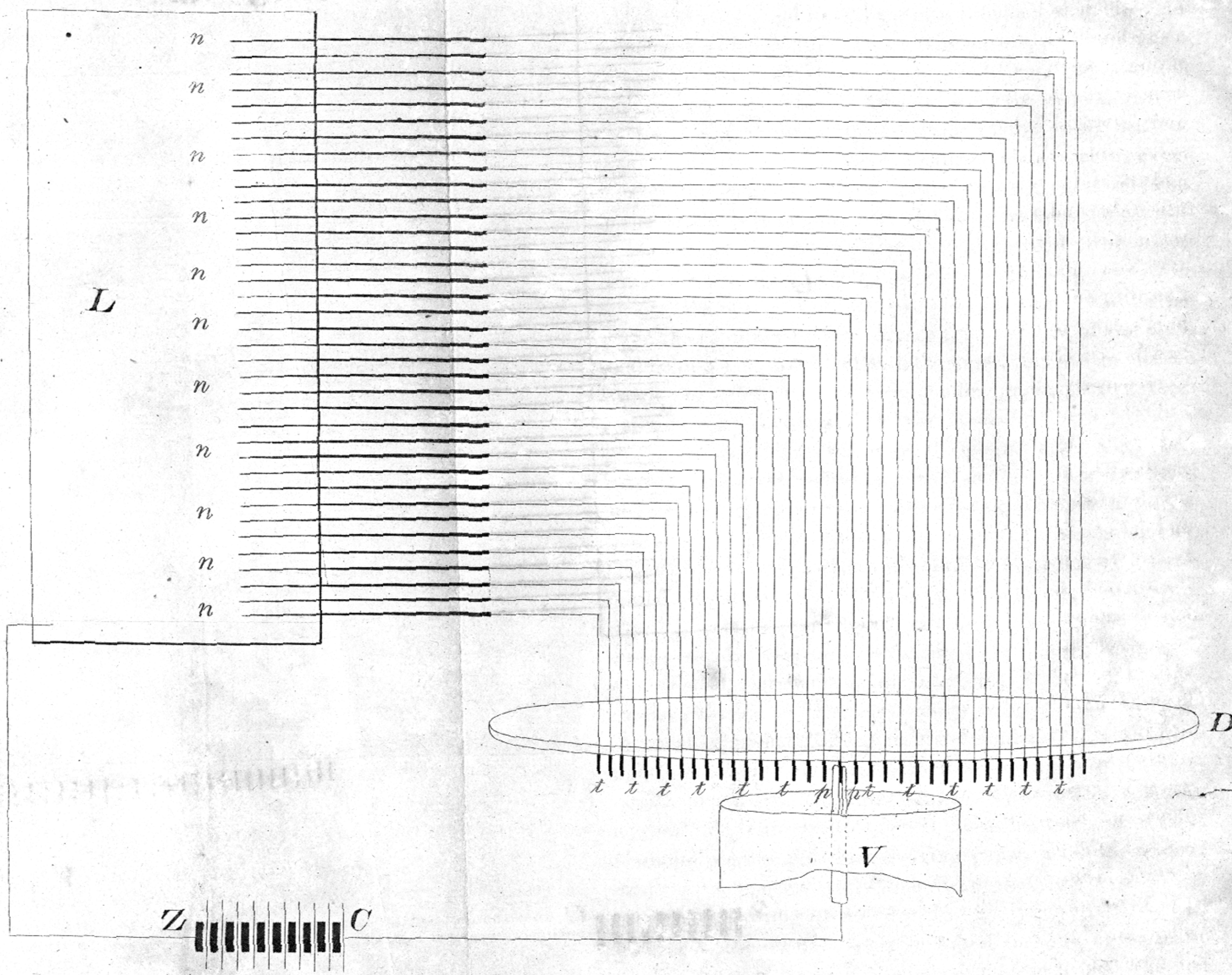
When an electric current passes, the coil tends to turn round a vertical axis in one direction or in the opposite direction according as the current is positive or negative. The two weights, (*w*), (*w*) hanging from the coil can slide up and down the inclined plane (P). These weights resist the tendency to turn round caused by the passage of a current through a coil, and serve to bring the coil to its original position when the current ceases. The cords by which these weights are suspended pass through small holes in a piece of brass (*x*), whose distance from the coil can be varied by moving it up and down along the vertical plane (P′), and thus the sensibility of the apparatus can be altered. The strength of the field is so great that the motion of the coil caused by the passage of a current is almost non-oscillatory.

Attached to the coil (c), there is a thin disc of ebonite, (D), whose axis coincides with the vertical axis of the coil passing through its centre, so that any angular rotation of the coil causes exactly the same angular rotation of the disc. This disc carries, on its underside and near to a portion of its circumference, a number of platinum teeth (t), (t), (t), &c. Directly underneath these teeth, and rigidly fixed to the frame-work of the instrument, is a vessel, (V), containing acidulated water, and in this vessel is provided a capillary arrangement which consist of two very narrow platinum plates (p), (p) (which shall, hereafter, be called "capillary plates"), standing vertically up, side by side, from the central part of the vessel, and drawing up the water of the vessel between them. The position of these capillary plates, when every thing is in its normal position, is such, that the platinum tooth in the middle is in contact with the water between the capillary plates, and that when the coil, and therefore, the disc is deflected to the right or left, the other platinum teeth on the left or right, successively come in contact with the water between the capillary plates. Every time any one of the platinum teeth comes in contact with the water, it closes an electric circuit (to be described) corresponding to it, so that these platinum teeth may be called "circuit-closers."

(L) is a cylinder of wood lacquered all over. It is covered with a platinum sheet, and on this sheet is rolled a ribbon of white paper nearly as wide as the length of the cylinder. A portion of this cylinder is in the rectangular box, (B), which contains a chemical solution, consisting of a ferrocyanide of potassium, and of nitrate of ammonium and water mixed in certain proportions. Further, the cylinder (L) is made to revolve with uniform velocity by means of a clock-work arrangement placed inside the box (H). Thus the paper on the cylinder as it rotates, comes out moistend with the chemical solution. Resting on the cylinder, (L), and fitting tightly in a rod of ebonite, (r), there are a number of platinum needles (n), (n), (n), &c; these needles may be called "marking needles" for, if an electric current passes between any of these platinum needles and the revolving paper, a bluish mark is made on the paper directly underneath that needle.

These marking needles are electrically connected, each to each, with the circuit-closers in order, there being as many needles as there are circuit-closers; that is to say, the first needle (on the right or left) is in connection with the first

Fig. III.



circuit-closer (on the right or left), the second needle with the second *circuit-closer, the third with the third, and so on.* The small terminal screws (a), (a), (a), (a), &c, on the ebonite plate, (E), which is fixed to the frame-work of the apparatus, and also the screws (b), (b), (b), &c, are provided for facilitating these connections. Exceedingly fine wires (insulated) connect the screws (a), (a), (a), &c., with the circuit-closers, and they all hang down from the screws in the form of spiral springs, meeting together in the common axis of the disc, (**D**), and the coil, (c), and thence go to the circuit-closers so that it is to be understood that the resistance these wires offer to the motion of the disc or coil is so small as to be negligible.

Now the platinum sheet on the cylinder (L) is in connection with one pole (Z) of the battery (CZ) by means of a platinum spring (s), resting on it; while the other pole (C), of the battery is in connection with the capillary plates (See Fig. III). Consequently when there is no current passing through the coil, the positive current flows from the copper pole of the battery through the capillary plates, and the circuit closer in the centre, and thence through the corresponding marking needle (the centre one), rotating paper and platinum sheet, and back to the zinc pole of the battery, making a blue mark on the rotating paper just underneath the marking needle; while, if a current passes through a coil it is deflected to the right or left according to the direction of the current, the circuit-closers *on the left or right of the centre successively come in contact* with the water between the capillary plates in order, the result being that the corresponding needles make blue marks on the rotating paper. But since the paper revolves with uniform velocity, it is evident that the longer the time of contact between a circuit-closer and the water between the capillary plates, no matter which circuit-closer it is, the longer the length of the mark on the paper underneath the needle corresponding to that circuit-closer; and the shorter the shorter.

From the preceeding description it will be clear that when an electric current, varying from time to time, in strength and direction, passes through the coil, (c), we shall get a curve made up of dots, or of dots and lines, on the moving paper ribbon, the nature of the curve determining the strength and direction of the current at any moment. Fig. IV shows one of such curves experimentally obtained by allowing a varying current to pass through the coil. Now since the motion of the paper ribbon is uniform it is easy to find out the point in the curve, or the position of the coil, corresponding to any moment, and since the motion of the coil is non-oscillatory, each position of the coil corresponds to a certain definite strength of current, which can easily be determined by a simple experiment. So that by an examination of the curve thus obtained, it is easy to find out what was the strength of the current which passed through the coil at any moment.

With regard to the sensibility of the recorder (this special recorder), it has been found by experiment, that when the recorder is adjusted to its greatest sensibility, the weakest current which it can record is about $\frac{1}{6}$th of a milliampere, while the strongest current it can record is about 8 milliamperes.

One defect of the recorder, it may be argued, is the fact that it does not record any current which produces such a deflection of the coil that, none of the circuit closers is in contact with the water between the capillary plates. This defect, however, is not a very serious one, for, since the recorder is intended to be used for recording varying currents which would give rise to a curve made up of dots, or of dots and lines, on the moving paper ribbon, it is easy, by examining the positions of dots and lines, to complete the curve to a certain degree of approximation. If, however, a greater accuracy be needed, all we have to do is to diminish the angular distance between the circuit-closers, and to increase their number. In the next recorder to be made, I am going to introduce a few improvements, of which the most important is the mode of arranging the circuit-closers and capillary plates. Instead of having the circuit-closers movable with the coil, and the capillary plates fixed, we may arrange so that the capillary plate moves with the coil, while the circuit-closers are kept stationary; and by this means, it is possible to diminish the angular distances between the circuit-closers and to increase

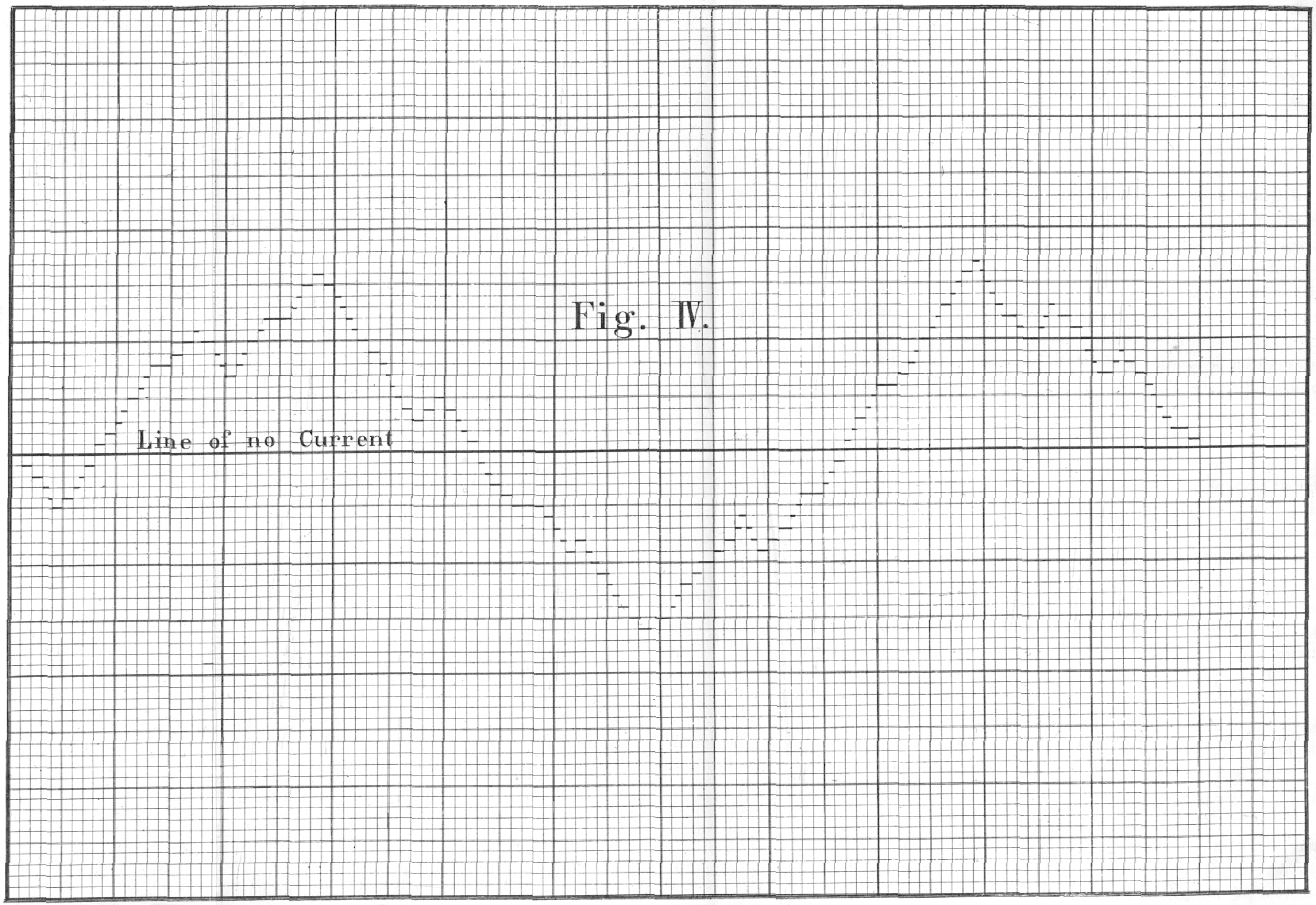


Fig. IV.
Line of no Current

their number without increasing the moment of inertia of the needle, and thus to obviate the above defect to a great extent, and at the same time to give to the recorder a greater sensibility.