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XLI. *A new form of Amperemeter and Voltmeter with a Long Scale.* By BENJAMIN DAVIES *. (Communicated by Prof. Lodge.)

THESE measuring-instruments, which are intended for continuous currents, are of the so-called d'Arsonval type, and their chief feature is their long and uniformly divided scale. Mainly on account of these advantages, I am of opinion that the instruments may become generally useful for electrical measurement on switch-board or on the bench, and particularly in the laboratory for purposes of experiment and research.

With the exception of instruments depending on magnification, these (so far as I am aware) are the only long-range ones yet designed; a brief description of them may, therefore, not be unwelcome †.

It is evident that a long scale is a desirable addition to the best of instruments, provided the extra length can be produced without increasing the waste-power of the meter, or without reducing the deflecting moment. It is evident that this is a question of design only, and the instruments described below have a satisfactorily large deflecting moment, although the scale covers an arc varying from 210° to 230° . By sacrificing a little of the deflecting force, or by increasing the voltage drop at the terminals of the moving coil, an instrument may be constructed with a scale-length equal to an arc of 270° .

The magnetic circuit also has one distinct point in its favour, viz., its single air-gap. This air-gap may be as narrow as $\frac{1}{8}$ of an inch, reducing the demagnetizing force to a small quantity.

The permanent magnet and the magnetic circuit generally may have many forms, each having its own advantages and

* Read February 10, 1899.

† After this paper was read I found I was by no means the first in the field as regards "long range." Professor Ayrton kindly sent me a sketch of an amperemeter by M. Carpentier, built on precisely the same principle as those mentioned in this paper. The Carpentier instrument, however, is not of good design, resulting, I should imagine, in an excessive drop of voltage at the terminals of the moving coil. The Carpentier meter, I am told, was brought out in 1889. The first form of mine was made in 1895.

disadvantages. The construction of the earliest form is shown in fig. 1. A is an iron case, either wrought or cast. B is the soft iron polepiece, which is carried and maintained in position by the permanent steel magnet M.

From a physical point of view, this combination forms a very good magnetic circuit, for the reluctance of the air-gap between polepiece and box is very small, owing to its extensive area. The relative thickness of the gap shown in the figure is much greater than it is in the actual instrument.

Fig. 1.

The form of Magnetic Circuit first employed.

When this form was tried it was found to have some defects on practical grounds ; the attachment and adjustment of the moving system became a difficult matter. Once made, however, an instrument having this form of magnetic circuit is not at all a bad one, and of all forms it offers the longest range.

The moving coil was rectangular in shape, and one side of it—forming the axis around which it rotated—passed through the central hole in B, while the opposite side moved in the narrow air-gap. This form of magnetic circuit (fig. 1) is not unlike that adopted by Mr. W. Hibbert in his apparatus for

a standard magnetic field, except that in mine the steel magnet is eccentric *.

The next form is shown in fig. 2. This is much more easily manipulated, and the difficulty of adjusting the movable system is considerably reduced. M is the steel magnet, A and BD are the two wrought-iron poles. The frame supporting the moving system is in this case mounted on the polepiece A.

Fig. 2.

Another form of Magnetic Circuit.

In fig. 3 we have a plan of a still better form considered from a practical point of view, though less elegant and compact than its predecessors. The construction is evident from the figure. M M are the magnets, now of the horse-shoe shape, A and BD the polepieces. This form of circuit has been adopted mainly in order to increase the induction. The previous forms do not lend themselves to the use of large cross-sections of steel without becoming inconvenient in shape. In this pattern it is evident that any desired quantity of steel may be used.

On the soft-iron cylinder B is mounted the brass frame carrying the entire moving system. The air-gap is adjusted

* See Proc. Phys. Soc. vol. xi. p. 303.

for uniformity of induction by means of the D portion of the polepiece, the details of which for the sake of simplicity are not given in the figure.

Fig. 8.

The latest form of Magnetic Circuit.

Considering next the electric circuit. The main parts of this are the moving coil and the spiral springs. The coil is wound on an aluminium rectangle, which serves the double purpose of a frame to stiffen the coil and a circuit of extremely low resistance for damping.

In the voltmeter the moving coil contains some 100 or 200 turns of the finest wire, while the amperemeter coil has some 20 turns of a moderately thick wire.

In series with the voltmeter moving coil there is placed in the base of the instrument a resistance-coil, on the value of which depend the readings of the meter.

In parallel with the amperemeter-coil is placed a short length of conductor of a similar material to that of the moving coil. Through this shunt flows the main current in all meters except the centiampere and milliampere ones.

The current is led into and out of the moving coil by the spiral springs, which also provide the opposing or controlling force. To partially counterpoise the coil it is placed—with

respect to the axis—opposite the pointer. The coil and pointer are shown in position in the plan given in fig. 3.

A coil of this kind, swung on one of its sides, was used long ago by Lord Kelvin in his Siphon Recorder. It is also used at the present time by Professor Ayrton in the now well-known Astatic Station Voltmeter.

Fig. 4 gives a better view of coil, springs, and pointer, and the general method of mounting the entire moving system on the iron cylinder. K is the coil, P the pointer, and Z the

Fig. 4.

The central polepiece to which is attached the brass frame supporting the coil, pointer, and spiral springs.

arm for zero adjustment. There is here a compactness that becomes important in practice, for by loosening or tightening one screw the moving system with its frame can be removed bodily and placed in position again with ease, and without interfering with the magnetic circuit. The method also renders the balancing of the coil an easy matter.

In all the meters, when the air-gap is made uniform in thickness, the induction density in the gap has practically a constant value throughout its entire length (except in the immediate neighbourhood of the two ends owing to the effect of prominences). This is the case even for the magnetic

circuits of figs. 1 and 2, where the induction is rather low, viz. (about) 400 per sq. cm. in the gap. With a magnetic flux of 400 the reluctance of the air is about 300 times that of the iron; so that the lines distribute themselves pretty uniformly on the polar surfaces if the intervening gap is made uniform in thickness. For the higher inductions of 800 or 1000 (for which the magnetic circuit of fig. 3 is designed) the magnetic force in the gap becomes still more uniform, for now we have the reluctance of the air 500 times that of iron.

There is another arrangement of polepieces which I would like to describe, although it has not yet been made into an instrument. It furnishes a great deflecting moment, but it has the rather serious disadvantage of being complex in design and—I am afraid—difficult to build. This arrangement, like the previous ones, may be attached either to a bar or a horse-shoe magnet, and may be arranged to give with a single moving coil a maximum deflexion of 220° , or it may be designed to give 80° or 90° with a double or twin coil. It may also be designed for small deflexions with a spot of light to be used as a galvanometer, in which case there is no difficulty at all in the construction.

Fig. 5 shows the form of the 220° polepieces without the magnet. The coil is entirely enclosed in iron, and its three

Fig. 5.

sides are active. In all other respects the arrangement is precisely the same as the previous ones.

Let fig. 6 represent a vertical section through DD' in fig. 5, and let fig. 7 be the movable coil.

Fig. 6.

Fig. 7.

The lines of force cut the coil perpendicularly at all points. Let l be the length of the periphery of the coil, r the radial side, and n the number of turns in it. Considering one of the horizontal sides of the coil with a current c flowing in it, the moment of force acting at a distance x on an element dx is

$$= H n c x dx.$$

The moment acting on the vertical side is

$$= H n c \left(\frac{l}{2} - r \right) r,$$

H being the intensity of the magnetic field.

Therefore, the total deflecting moment M acting on the coil is

$$= H n c \left[\left(\frac{l}{2} - r \right) r + 2 \int_0^r x dx \right].$$

So $M = \frac{1}{2} n c H l r$.

Unlike the old coil (that considered in the first part of this paper) this new coil has a deflecting moment increasing always in proportion to its radius if the magnetic field is kept constant. The moment is therefore a maximum when r is as nearly $\frac{1}{2}l$ as the constructional details of the instrument will permit. For the old coil the maximum moment is got when $r = \frac{1}{4}l$, *i. e.*, when the coil is a square. I offer the description of this instrument partly on account of its leading to (what is to me) a novel form of a ballistic galvanometer.

There may be more serious difficulties in the way of constructing a galvanometer on this plan than I at present anticipate.

Ballistic Galvanometer.

We evidently have in the arrangement shown in figs. 5, 6, and 7 favourable conditions for a ballistic galvanometer, since the deflecting moment and the moment of inertia of the coil attain their maximum values for the same value of the radius. The period of swing and the deflecting moment may therefore be increased simultaneously without making any addition to the weight of the moving system.

Let fig. 8 be a section through the polepieces of a ballistic

Fig. 8.

fig. 10 the other coil. Let $r_1=6$ in the first case, and let the depth of the coil be 1. In the second, let $r_2=\frac{1}{2}$ and the

depth of the coil = 6. Considered alone, the two coils are therefore similar in all respects. They are moreover supposed to be suspended in two fields of equal intensity, and to convey the same current.

Fig. 10.

For the sake of symmetry the wire in figs. 8 and 9 has to be divided between two rectangles, which, however, does not affect the argument.

The suspension in both cases having to bear the same load, the relative sensibilities of the two arrangements for continuous currents will therefore be as their deflecting-moments directly.

For fig. 9 the moment

$$M_1 = \frac{1}{2}ncHlr_1,$$

and for fig. 10

$$M_2 = 2ncH\left(\frac{l}{2} - 2r_2\right)r_2,$$

so that

$$\frac{M_1}{M_2} = \frac{lr_1}{4\left(\frac{l}{2} - 2r_2\right)r_2} = 7;$$

therefore $M_1 = 7M_2$ for steady currents.

Time of swing of the two coils.—The time of the swing varies with the $\sqrt{\text{moment of inertia}}$.

In fig. 9 the moment of inertia is

$$I_1 = mr_1^2\left(\frac{l}{2} - \frac{r_1}{3}\right),$$

and for fig. 10

$$I_2 = 2mr_2^2 \left(\frac{l}{2} - \frac{4r_2}{3} \right)$$

where m stands for the mass of unit length of the periphery.

Therefore

$$\frac{I_1}{I_2} = \frac{r_1^2(3l-2r_1)}{2r_2^2(3l-8r_2)}.$$

Hence for the particular size of coils under consideration,

$$\frac{I_1}{I_2} = \frac{1080}{19}.$$

So that

$$I_1 = 57 I_2 \text{ nearly.}$$

Therefore, the time of swing of the coil in fig. 9 will be 7.5 times that for the coil in fig. 10, and the deflecting-moment or the sensitiveness of the coil in fig. 9 for continuous currents will be 7 times that of the coil in fig. 10.

Now as regards the "throw." The relative throws of the two coils for the same quantity of electricity will be

$$= \frac{M_1}{M_2} \cdot \sqrt{\frac{I_2}{I_1}} = \frac{7}{7.5} \text{ about.}$$

So that we have for the two coils throws of nearly equal magnitudes, although one coil moves 7.5 times as slowly as the other.

It is almost needless for me to mention that I have been greatly assisted during the experimental period of the measuring instruments described above, and I wish to express my gratitude to Professor Oliver Lodge not only for his suggestions and criticisms but also for his kind encouragement at all times. I am also greatly indebted to Dr. Alexander Muirhead for much help in practical details, and for the considerable experimental facilities he has always been ready to present.

DISCUSSION.

Prof. AYRTON said the instruments appeared to be very successful; he could bear witness of their value particularly as regards the length of range. The general principle by which long range was to be obtained on moving-coil, portable instruments was developed some ten years ago by

M. Carpentier, of Paris, who used a central magnet surrounded by a concentric hollow cylinder, with only one side of the coil in the magnetic gap between them; but it was not then a portable form of instrument, for the coil was suspended. Prof. Ayrton and Mr. Mather had worked in this direction in their "astatic station voltmeter." In that instrument there were three magnetic circuits arranged to give astaticism; this was described in 1892 or 1893.

XLII. *Note on the Source of Energy in Diffusive Convection.*

By ALBERT GRIFFITHS, *M.Sc. (Vic.), A.R.C.S. (Lond.).**

AT the conclusion of a paper on "Diffusive Convection"† the author, partly in the hope of producing a discussion, asked certain questions relating indirectly to the source of energy in the apparatus under consideration.

After the publication of the paper in the Philosophical Magazine, Prof. FitzGerald made some remarks on it in 'Nature,' and gave a concise account of the actions at work. He pointed out, what was already known to the author, that there is a tendency towards cooling when diffusion causes the rise of the centre of gravity. Stimulated by Prof. FitzGerald's interest in the work, the author has taken advantage of the Christmas vacation to study the question in some detail.

*On the Fall of Temperature when Diffusion occurs upwards
if the Solution has a Density greater than that of Water.*

Consider a vertical cylinder of length $(l_1 + l_2)$ and sectional area A . Let d_2 equal the density of length l_2 , and d_1 the density of length l_1 . Let it be assumed that there is no change of volume when the two liquids mix.

Taking a plane through the bottom of the cylinder as one where bodies at rest possess zero potential energy, it can readily be seen that before mixing, through diffusion or otherwise,

* Read March 10, 1899.

† Phil. Mag. ser. 5, vol. xlv. p. 453 (1898); Proc. Phys. Soc. *ante*, p. 230.