**Physics.** — *"A quick coil galvanometer."* By Dr. W. J. H. Moll. (Communicated by Prof. W. H. Julius).

Galvanometers are applied for the investigation of a great variety of phenomena. The demands which the instrument is to meet, will differ according to the nature of the investigation, and therefore many different kinds have a claim to existence. If we confine ourselves to those cases where the galvanometer has to measure a direct current, and a great sensibility is required, even then the choice of the instrument that will best serve a definite purpose, is often difficult.

For some methods of investigation, in particular those in which the galvanometer is inserted in a circuit of great resistance, its own resistance will be of little importance. In those cases the string galvanometer is preferable, which is very sensitive, exceedingly quick in its indication, and not easily disturbed. For completeness' sake we must mention a galvanometer (part of the "Kardiograph") constructed in the course of this year by Siemens and Halske, about which however no particular data have been published as yet.

In many other methods of investigation, however, the resistance of the circuit is comparatively slight, and the above mentioned galvanometers cease to be sensitive on account of their great resistance. In those cases we must choose between the needle galvanometers and the coil galvanometers.

Of these two types the needle galvanometers will only be selected for those measurements, for which the utmost sensibility is required. As a matter of fact they are greatly subject to disturbances, and it is extremely difficult to protect them, especially in cases of great sensibility.

The coil galvanometer is much simpler in its use and for most purposes sufficiently sensitive. It surpasses the needle galvanometer not only by its being less readily disturbed, but also by the ease with which the damping may be regulated and dead beat conditions attained. These two advantages account for the preference which is generally given to this apparatus.

The common coil galvanometer is, however, by no means quick; the time of its indication varies from 10 to 30 seconds for the different patterns. This drawback makes itself felt, when the investigation requires a long series of readings; the observation of rapidly varying phenomena is evidently impossible with such a slow instrument, while the string galvanometer, which is exceedingly quick, is generally not sufficiently sensitive on account of its great resistance.

Here a galvanometer is required which is at the same time sensitive *and* quick.

In what follows a method will be discussed by which quickness of indication may be reached for the sensitive coil galvanometer.

Let us call $K$ the moment of inertia of the coil; $D$ its directive force; $T$ its semi-period of oscillation with open circuit; $F$ the total area of its windings; $H$ the intensity of the uniform magnetic field round the coil; $W$ the resistance of the circuit, in which the galvanometer is inserted; then the sensibility $P$ of the galvanometer, i.e. the angle of deviation (supposed small) for the unity of electromotive force in the circuit is given by:

$$P = \frac{(HF)}{DW} \quad \ldots\ldots\ldots\ldots \quad (1)$$

while

$$T = \pi \sqrt{\frac{K}{D}} \quad \ldots\ldots\ldots\ldots \quad (2)$$

Since we confine ourselves to the case of aperiodicity, we have moreover, neglecting the air damping,

$$W^2 = \frac{(HF)^4}{4\,DK} \quad \ldots\ldots\ldots\ldots \quad (3)$$

and the time of indication is approximately given by $\tau = 3\,T$.

Six quantities occur in the three equations (1), (2), and (3), if we count $(HF)$, the so-called dynamic galvanometer constant, as one. We can divide them into two groups, $P$, $W$ and $T$ being quantities, which can be measured directly, and which characterize the instrument.

The equations enable us to calculate from them $D$, $K$, and $(HF)$. Thus for the most sensitive galvanometer constructed by SIEMENS and HALSKE according to JAEGER's directions:

$$T = 7{,}5 \qquad W = 100\ ohm = 10^{11} \qquad P = 1{,}7 \times 10^{-5}$$ [1]

are given, from which we calculate in round numbers:

$$(HF) = 280\,000 \qquad D = 0{,}18 \qquad K = 1{,}0.$$

For the quickest galvanometer of the same firm, designed by DIESSELHORST:

$$T = 2 \qquad W = 1{,}8 \times 10^{11} \qquad P = 0{,}6 \times 10^{-5}\ .$$

from which

$$(HF) = 200\,000 \qquad D = 0{,}19 \qquad K = 0{,}08.$$

[1]) This corresponds to a deviation of 3,4 mm. for 1 microvolt on a scale at 1 meter's distance.

Not only does the above reasoning give us valuable information about a given instrument, it also leads the way in the construction of a new one, satisfying special demands. For the construction of a galvanometer which is at the same time *sensitive and quick*, we have to solve the problem how to choose $D$, $K$ and $(HF)$ so that $P$ be great and $T$ small.

Here we have to consider that the six quantities are related in still other ways than expressed by the three equations. Indeed, the mode of suspending the coil, the kind of wire of which its windings consist, and its form will furnish additional relations between the six quantities, and it is the question whether a certain change of $D$, $K$ and $(HF)$, which would seem desirable according to the equations (1), (2), and (3), is practically feasible. The equations will only indicate the direction in which we have to seek.

The quickness of the galvanometer only depends on the directive force $D$ and the moment of inertia $K$ of the coil. In order to simplify the calculation we will therefore leave the dynamic galvanometer-constant $(HF)$ out of consideration, and we do this the more readily as this quantity may be modified within a wide range independently of the five others. After the elimination of $(HF)$ two equations remain:

$$T = \pi \sqrt{\frac{K}{D}} \quad (2) \qquad\qquad P^2 = \frac{2T^3}{\pi^3 KW} \quad (4).$$

We see from this that $T$ is diminished when $D$ is increased, but that $P$ is diminished in a corresponding degree. A second means of increasing the quickness, namely diminishing $K$, will not alter the sensibility so much, since $K$ also occurs in the denominator of the second member of (4). A third means, however, can lead to our purpose. For a given value of $W$, $P$ remains unaltered when we leave

$$\frac{T^3}{K} = \pi^3 \frac{\sqrt{K}}{D\sqrt{D}} \text{ unchanged.}$$

Therefore by greatly decreasing $K$, say to one thousandth, and at the same time diminishing $D$ to, say, one tenth, $T$ will be reduced to one tenth, while $P$ remains the same.

That such a change of $K$ and $D$ is actually feasible, may appear from the following data.

For the coil galvanometer, by means of which the rapidly varying radiation of the sun was registered during the central part of the solar eclipse of 1912 [1]), we have:

[1]) W. H. Julius. The total solar radiation during the annular eclipse on April 17, 1912. Astroph. Journ. Vol. XXXVII, p. 225.

$T = 0,4 \quad W = 2 \times 10^{10} \quad P = 1,0 \times 10^{-5}$
$(HF) = 25\,000 \quad D = 0,12 \quad K = 0,002.$

For a very sensitive instrument of the same kind:

$T = 0,65 \quad W = 1,5 \times 10^{10} \quad P = 3 \times 10^{-5}$
$(HF) = 14\,000 \quad D = 0,03 \quad K = 0,001\,5.$

The sensibility of this coil galvanometer with a time of indication of less than 2 seconds is *greater* than has ever been reached even in the slowest instrument. It corresponds to a deviation for 1 microvolt of 6 mm., on a scale at 1 meter distance.

For a third, very quick but less sensitive specimen:

$T = 0,12 \quad W = 2,8 \times 10^{10} \quad P = 0,45 \times 10^{-5}$
$(HF) = 18\,000 \quad D = 0,14 \quad K = 0,000\,45.$

$K$ may be still further diminished, but then one has to face rather great technical difficulties, and soon the moment of inertia of the mirror will play a too important rôle. For a mirror e.g. of a radius of 2 mm. and a thickness of 0,2 mm. this amounts to 0,000 06.

It may seem strange that this rather obvious measure of diminishing the moment of inertia of the coil has not been made use of in the construction of the coil galvanometer since long; the reason will probably be a difficulty which arises when this principle is applied. In the usual construction of the apparatus the coil is suspended by a thin strip, which at the same time conveys the current to be measured; the current is led off by means of a metal band so slack as to have no appreciable share in the directive force of the coil. When now the moment of inertia of the coil is made very small, and consequently its weight very slight, it becomes subject to inevitable vibrations to a much higher degree, than is the case with a heavy coil This disadvantage may, however, be obviated by not suspending the coil in the usual way, but stretching the slack band.

The reliability of the indication of a galvanometer with a coil fixed in such a way appears convincingly from the results of the above-mentioned eclipse observations published elsewhere [1]).

*Conclusion.*

In the construction of a coil galvanometer it is desirable to take the moment of inertia of the coil *much* smaller than was usual hitherto; and not to suspend the coil, but to stretch it between two metal bands.

Galvanometers constructed according to my directions are furnished by the firm P. J. Kipp and Sons at Delft.

1) W. H. Julius. Loc. cit.