THE DUDDELL PATENT THERMO-GALVANOMETER.

AN INSTRUMENT FOR MEASURING EXTREMELY SMALL CURRENTS AND POTENTIAL DIFFERENCES.

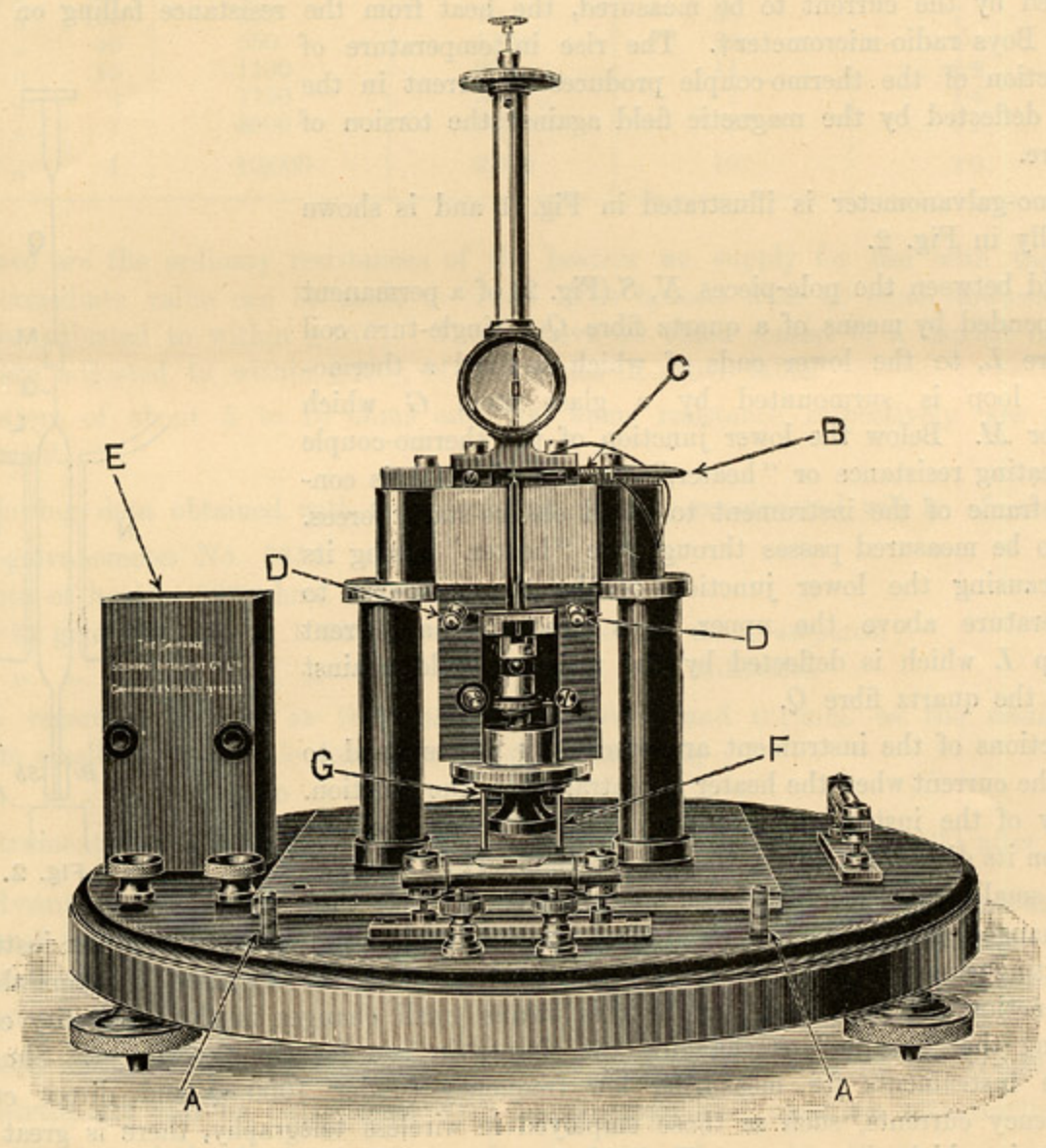


Fig. 1.

SOLE MAKERS:—

THE CAMBRIDGE
SCIENTIFIC INSTRUMENT COMPANY, LTD.
CAMBRIDGE, ENGLAND.

THE DUDDELL PATENT THERMO-GALVANOMETER.

For a long time the need of an instrument capable of accurately measuring small alternating currents has been keenly felt. The high resistance and self-induction of the coils of instruments of the electro-magnetic type frequently prevent their use. Electro-static instruments as at present constructed are not altogether suitable for measuring very small currents, unless a sufficient potential difference is available.

The thermo-galvanometer designed by Mr W. Duddell can be used for the measurement of extremely small currents to a high degree of accuracy. **It has practically no self-induction or capacity and can therefore be used on a circuit of any frequency (even up to 120,000 ~ per sec.) and currents as small as twenty micro-amperes can be readily measured by it*. It is equally correct on continuous and alternating currents. It can therefore be accurately standardized by continuous current and used without error on circuits of any frequency or wave-form.**

The principle of the thermo-galvanometer is simple. The instrument consists of a resistance which is heated by the current to be measured, the heat from the resistance falling on the thermo-junction of a Boys radio-micrometer†. The rise in temperature of the lower junction of the thermo-couple produces a current in the loop which is deflected by the magnetic field against the torsion of the quartz fibre.

The thermo-galvanometer is illustrated in Fig. 1 and is shown diagrammatically in Fig. 2.

In the field between the pole-pieces *N, S* (Fig. 2) of a permanent magnet is suspended by means of a quartz fibre *Q* a single-turn coil or loop of wire *L*, to the lower ends of which is fixed a thermo-couple. This loop is surmounted by a glass stem *G* which carries a mirror *M*. Below the lower junction of the thermo-couple is fixed the heating resistance or "heater," one end of which is connected to the frame of the instrument to avoid electro-static forces. The current to be measured passes through the "heater," raising its temperature, causing the lower junction of the thermo-couple to rise in temperature above the upper, thus producing a current round the loop *L* which is deflected by the magnetic field against the torsion of the quartz fibre *Q*.

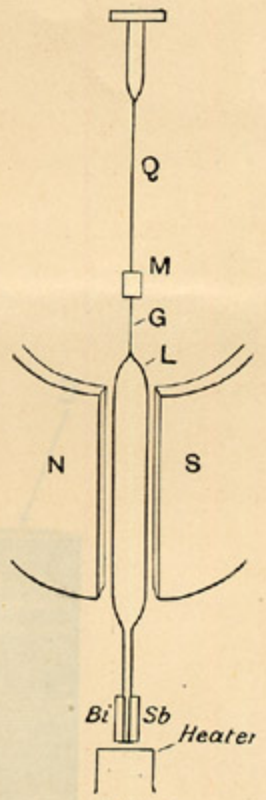


Fig. 2.

The deflections of the instrument are practically proportional to the square of the current when the heater is central under the junction. The sensibility of the instrument depends on the resistance of the "heater" and on its distance from the thermo-junction. The "heaters" are set up in small protecting cases with contact rings, so that they can be interchanged quickly when it is desired to greatly alter the sensibility of the instrument.

An adjusting-screw *F* (Fig. 1) is also provided so that the distance between the "heater" and thermo-junction can be varied, and by this means small changes in the sensibility can be made without altering the "heater" or changing the shunts in use for the experiment. Shunts may be used with the instruments for measuring low frequency (under 1000 ~) and direct currents, but for high frequency currents, such as those employed in wireless telegraphy, there is great uncertainty as to the ratio in which the current will divide between the instrument and shunt circuits.

* As an example of the sensibility attained with the thermo-galvanometer it may be mentioned that if a Bell telephone-receiver is connected to the instrument a comparatively small noise of the right pitch is sufficient to generate enough current to throw the spot of light off the galvanometer scale. Another experiment showed that if the thermo-galvanometer was connected to the line wires of a microphone-transmitter arranged in the ordinary way, whistling at a distance of from 15 to 20 feet from the microphone caused deflections of several hundred scale divisions. See "Instruments for the Measurement of Large and Small Alternating Currents," W. Duddell, *Phil. Mag.*, July 1904.

† For a description of the details and theory of this interesting instrument see *Phil. Trans. Roy. Soc. London*, 1889, CLXXX. p. 159.

The base of the instrument is fitted with levelling screws and levels. Fig. 1 shows the heavy metal plate *E* which protects the couple removed and standing on the base of the instrument. A stout mahogany cover (not shown in the illustration) protects the instrument from dust and heat radiation. The mirror *M* (Fig. 2) is plane, but the instrument is fitted with a lens which gives an image on the scale at a distance of 1000 mm. when used with the ordinary galvanometer lamp and scale.

The following Table shows the approximate sensibility of the instrument with heaters of different resistances.

Table of approximate Sensibilities. Scale distance 1000 *mm.*

Resistance of heater	Current to give 250 mm. deflection	Current to give 10 mm. deflection	P.D. to give 250 mm. deflection	P.D. to give 10 mm. deflection	
ohms	micro-amperes	micro-amperes	millivolts	millivolts	
about 1000	110	22	110	22	heater close to junction
" 400	175	35	70	14	
" 100	350	70	35	7	
" 40	550	110	22	4·4	
" 10	1100	220	11	2·2	
" 4	1750	350	7	1·4	
" 1	3500	700	3·5	0·7	
" 1	10,000	2,000	10	2·0	heater lowered away from junction

The above are the ordinary resistances of the heaters we supply for use with the instrument; but any intermediate value can be made to order. The heaters from 40 ohms downwards are metal wires and are adjusted to within ±15%. Those above 40 ohms consist of a deposit of platinum on quartz and are adjusted to within ±25% of the values in above table.

Two heaters of about 5 to 10 ohms and 100 ohms resistance respectively are supplied with every instrument.

The following data obtained with an instrument recently constructed will be of interest:—

Thermo-galvanometer No. 3354.
Resistance of heater, 927 ohms.
Current to give 250 mm. at 1000 mm. scale distance 117 micro-amperes,
P.D. " " " " " " 108 millivolts.

So that regarding 10 mm. as the *smallest measurable* and 0·1 mm. as the *smallest detectable* deflection, the smallest measurable current is 23 micro-amperes,
" " detectable " " 2·3 "

The instruments generally attain their full deflection to within 1 part in 500 after 10 seconds.

The advantages of and uses for an instrument like the thermo-galvanometer are so many and so obvious that it is almost unnecessary to enumerate them. The following are some of the very evident advantages and some of the applications that have already been made.

Extremely small currents, whether direct or alternating, can be accurately measured.

The instrument can be calibrated with continuous and used on alternating currents.

The resistance of the instrument can be varied within wide limits.

The instrument is dead-beat, unaffected by magnetic fields and has practically no self-induction or capacity.

Currents of any frequency can be measured.

It has recently been shown that currents of extremely high frequency should be used to prevent polarization when measuring the resistance of electrolytes. See Appendix II, On the Resistance of an Electrolyte, "On the Resistance and Electro-motive Forces of the Electric Arc," by W. Duddell, *Phil. Trans. Roy. Soc.* A, Vol. 203, pp. 305—342.

The Currents in the receiving Aerial used in Wireless Telegraphy can be measured.

See "Wireless Telegraphy Measurements," by W. Duddell and J. E. Taylor, *Journal of the Institution of Electrical Engineers*, Vol. 35, p. 321.

Telephone Currents can be measured.

See "Instruments for the Measurement of Large and Small Alternating Currents," by W. Duddell, *Phil. Mag.*, July 1904.

The Currents used in X Ray Tubes and in the secondaries of Medical Induction coils can be measured.

	£	s.	d.	Code Word
Price of Thermo-galvanometer with 4 and 100 ohm heaters	15	10	0	*Hegira*
4 ohm heaters		7	6	*Heifer*
10 „ „		7	6	*Heirdom*
40 „ „		7	6	*Heiress*
100 „ „		7	6	*Heirless*
400 „ „		10	6	*Heirship*
1000 „ „		12	6	*Heirloom*

Full instructions for using the thermo-galvanometer are supplied with each instrument.

NOTE.—November 1905. Thermo-galvanometers fitted with pointers and scales suitable for measuring the current in the secondaries of medical coils, wireless telegraphy, &c., are now being constructed, and prices, &c., will be published shortly.

AYRTON-PERRY-DUDDELL TWISTED-STRIP AMMETER.

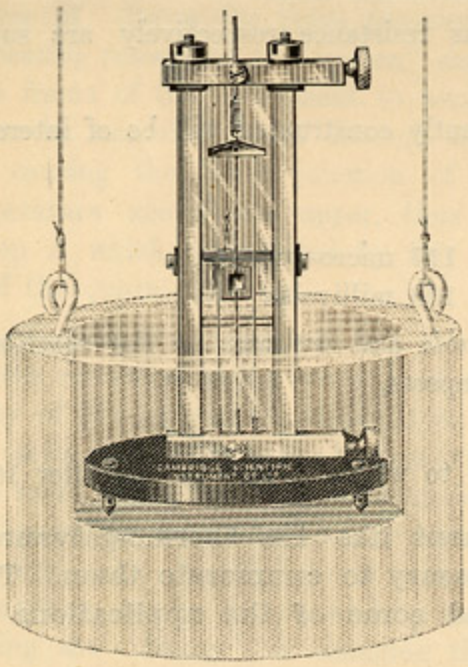


Fig. 3.

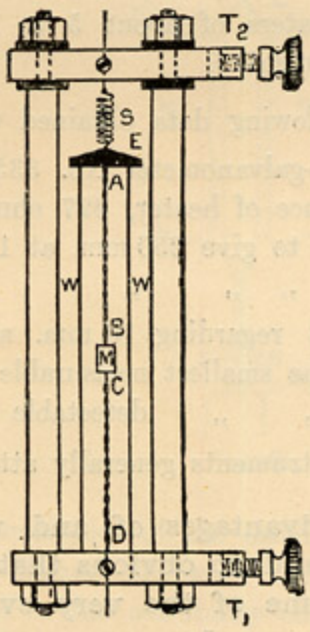


Fig. 4.

This instrument is essentially a very sensitive Ayrton-Perry twisted-strip ammeter with the important addition of a temperature-compensation device to minimize the zero-creep when the temperature of the whole instrument changes.

The instrument is shown in Fig. 3, whilst the working parts are shown diagrammatically in Fig. 4. *ABCD* is the Ayrton-Perry twisted strip, of which the part *AB* is twisted in one direction and the part *CD* in the opposite. A mirror *M* and a very thin mica damping vane are fixed at its centre. The strip is stretched in a frame formed of a brass block T_1 carrying one terminal and a piece of ebonite *E*, the sides of the frame being formed of wires *WW*. This frame itself is stretched by means of a spiral spring *S* fixed to the other terminal block T_2.

The twisted strip *ABCD* and the wires *WW* are made of the same metal; in fact the strip *ABCD* is actually rolled from a piece of the same wire as *WW*, so that the twisted strip and wires have the same temperature-coefficient of expansion. If the wires and strip rise in temperature equally, then the whole frame $EW.T_1W$ simply gets longer and no twist of the mirror ensues. If, however, a current be sent from T_1 to T_2 through the strip, then it heats and twists up, rotating the mirror *M*. Owing to the fineness of the strip (0·025 mm. PtAg) which is heated by the current, the instrument is very quick in action. The mechanical periodic time is very short, about $\frac{1}{15}$ sec.; so that it is able to follow currents which vary over a small range as rapidly as one or two cycles per second.

The following data obtained with one of these instruments will be of interest :—

Resistance 20 ohms.
Current to give 250 mm. at 1000 mm. scale distance 22×10^{-3} ampere.
P.D. „ „ „ 0·44 volt.

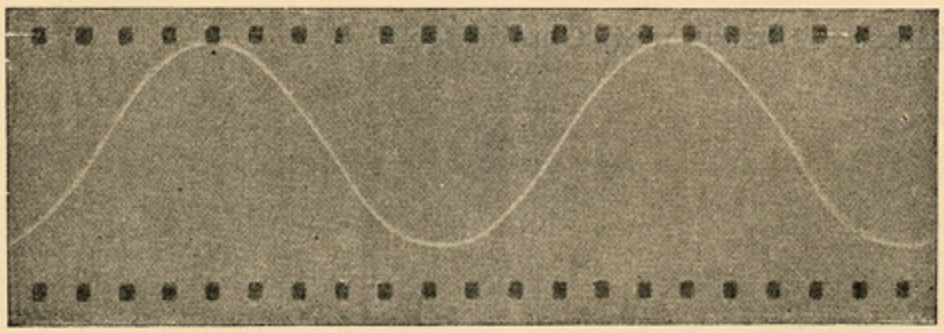
Taking 10 mm. as the *smallest measurable* deflection, and 0·1 mm. as the *smallest detectable* movement—

The smallest measurable current is $4{\cdot}4 \times 10^{-3}$ amperes.
„ detectable „ $0{\cdot}5 \times 10^{-3}$ „
Watts required to produce 10 mm. deflection = 387 micro-watts.

The instrument requires screening from quick vibrations of the order of $\frac{1}{15}$ sec. This is accomplished by standing the instrument in a heavy metal block (see Fig. 4) which is suspended by means of three wires.

These instruments are most useful for observing the quick variations of the R.M.S. voltage in supply stations produced either by cyclic irregularity of the engine or by phase-swinging between alternators, converters, &c.

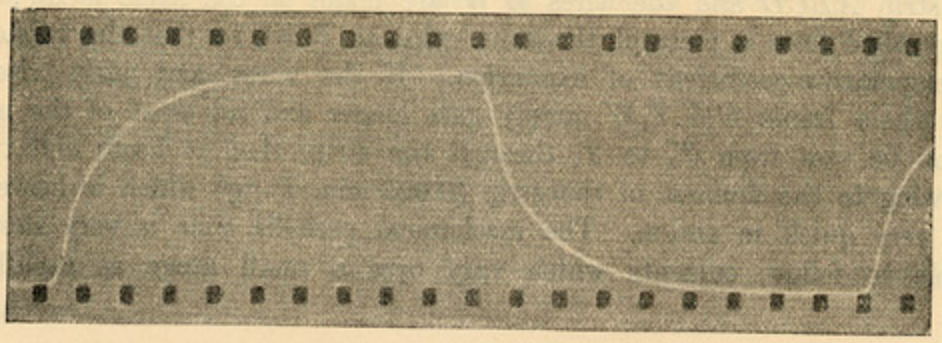
By working to a false zero a sensibility of 10 mm. change in deflection for 1 per cent. change in the P.D. may be obtained. By observations of this kind it is often possible to trace the causes of alternators not operating properly in parallel, and to find which engine and which particular defect is the cause.



1 second

Fig. 5.

Figs. 5 and 6 are two records (taken by an oscillograph film-camera) obtained on a circuit in which there was purposely produced a cyclic irregularity having a known wave-form. In each case the cyclic change on the voltage was about ± 1 per cent. from the mean. In Fig. 5 the voltage was changing sinusoidally about 121 ~ per minute, and in Fig. 6 it was changing along a square wave-form about 68·5 ~ per minute.



1 second

Fig. 6.

In this latter record the shape of the curve of growth and decay of deflection and the consequent rounding off of the corners of the curves are well shown. In both records 10 mm. = 1 per cent. change in voltage, and 100 mm. = 1 second.

Advantages of the Ayrton-Perry-Duddell Twisted-Strip Ammeter:—

It is very robust and can be carried about in the pocket.

It is easily set up and requires no levelling.

It is independent of changes in atmospheric temperature.

The self-induction and capacity are extremely small.

It has a wide range of usefulness—as a voltmeter it can be used down to 0·1 volt, and when in series with high resistances up to 10,000 volts. It can, of course, be shunted to measure large currents.

	£	s.	d.	Code Word
Price of Ayrton-Perry-Duddell Twisted-strip Ammeter with heavy suspended metal base as shown in Fig 3	7	10	0	*Hellenist*
Camera for Cinematograph film to take Records similar to Figs. 5, 6, with hand-feed arc lamp and lantern	To order.			

The Cambridge Scientific Instrument Co., Ltd., Cambridge, England.

Telegraphic Address: "Instrument, Cambridge."

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