

The Maximum Sensibility of a Duddell Vibration Galvanometer

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XXXVI. *The Maximum Sensibility of a Duddell Vibration Galvanometer.* By H. F. HAWORTH, *Ph.D., M.Sc., B.Eng., A.M.I.E.E.*

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IN order to try and improve the sensibility of a Duddell vibration galvanometer,* particularly at high frequencies, the permanent magnets were removed and replaced by a field-magnet system after the manner of the Duddell oscillograph. Some experiments were made to determine how the sensibility of the instrument, as an ammeter and as a voltmeter, varied with the strength of the flux in the gap.

The connections to the galvanometer were as follows:—*ab*, Fig. 1, is a double-pole change-over mercury switch; with this switch to the left, a_1a , b_1b , and K_2 closed, current from the alternator AC passes through the high resistance R_2 (from 10^4 to 10^6 ohms) and through the galvanometer. A low-reading Ayrton-Mather electrostatic voltmeter, EV (max. 8 volts), is shunted across R_2 and so the galvanometer current is measured, the galvanometer deflection is noted, and from these data the current sensibility is determined.

On moving the double-pole switch over, closing contacts aa_2 and bb_2 , the current flows through a resistance, R_1 , of about 100 ohms and through the low resistance R_3 (from 0.1 to 1 ohm) across which the galvanometer is now shunted. The electrostatic voltmeter is now shunted across R_1 , thus determining the current through R_3 and so the voltage across the galvanometer. Hence, the galvanometer deflection being noted, its sensibility as a voltmeter may be determined.

The field coils of the instrument were connected through a potential divider to the 200-volt mains. The total flux was measured by means of a search coil of one turn wound on the field magnet near the gap, comparison being made with a Hibbert standard.

The direct-current sensibility was measured by putting the double-pole switch to the left, opening the key K_2 and closing K_1 .

The current through the strips was adjusted by means of a resistance, R_4 , and measured with a sensitive milliammeter, A. In most of the experiments the maximum flux had the same

* "Proc. Phys. Soc.," Vol. XXI., pp. 774-787.

value—namely, 93,600 lines, the gap flux density for this maximum flux being 14,000 lines per square centimetre—and the direct current through the galvanometer was adjusted until a steady deflection of 70 divisions on the scale was produced with this flux. Readings of volts and deflection, amperes and deflection were then taken with this value of the flux. The field current was then varied, and the flux was measured by pressing the key K_1 , K_2 being open with the double-pole switch to the left, the flux being practically proportional to the deflection as the control was strong compared with any magnetic control which might be set up due to magnetic particles in the phosphor bronze strip.

Knowing the direct-current sensibility the magnification with alternating currents, due to the synchronous motion,

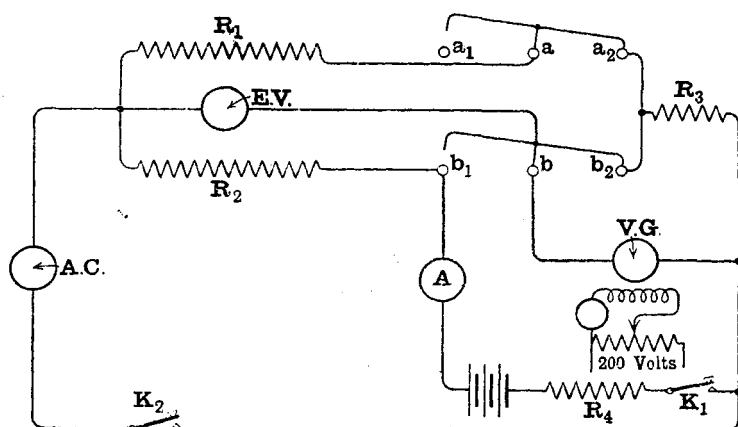


FIG. 1.

may be calculated. The following results (Table I. and Figs 2, 3, 4 and 5) show the effect of flux alterations on the sensibility of the galvanometer.

As would be expected, the sensibility of the instrument when used as an ammeter increases as the flux increases, and the limitation of sensibility is simply the limitation of the flux due to saturation of the iron.

On turning to the curves of sensibility as a voltmeter we have a different state of affairs.

Up to frequencies of 500 or 600, depending on the length of the wire, the sensibility increases from zero as the flux increases, until it reaches a well defined maximum, after which any increase of flux decreases the sensibility of the instrument.

If the apparent resistance V/A of the galvanometer be calculated from the voltmeter and ammeter flux curves, it is found

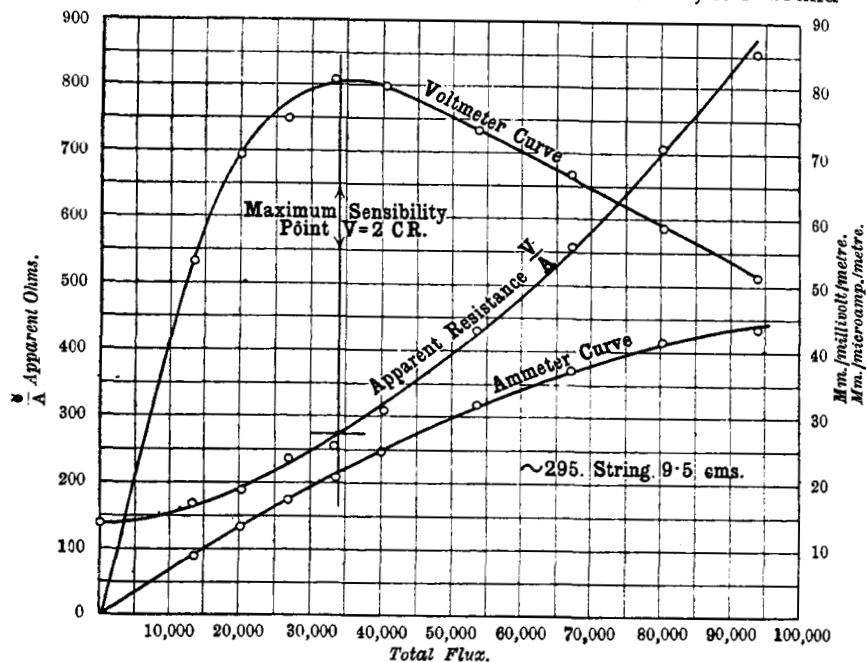


FIG. 2.

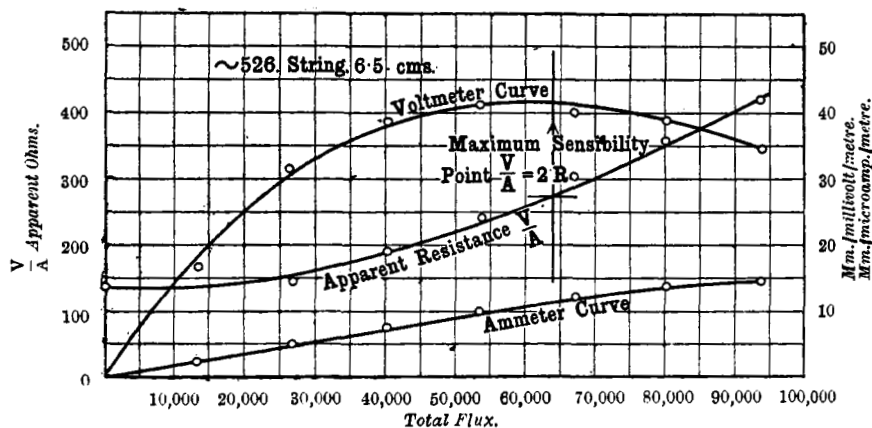


FIG. 3.

that the maximum sensibility of the galvanometer used as a voltmeter is reached when the apparent resistance is equal to twice the ohmic resistance of the instrument.

Treating the galvanometer as a motor of resistance R , and having a back E.M.F., E_b , if a forward E.M.F., E , is applied we

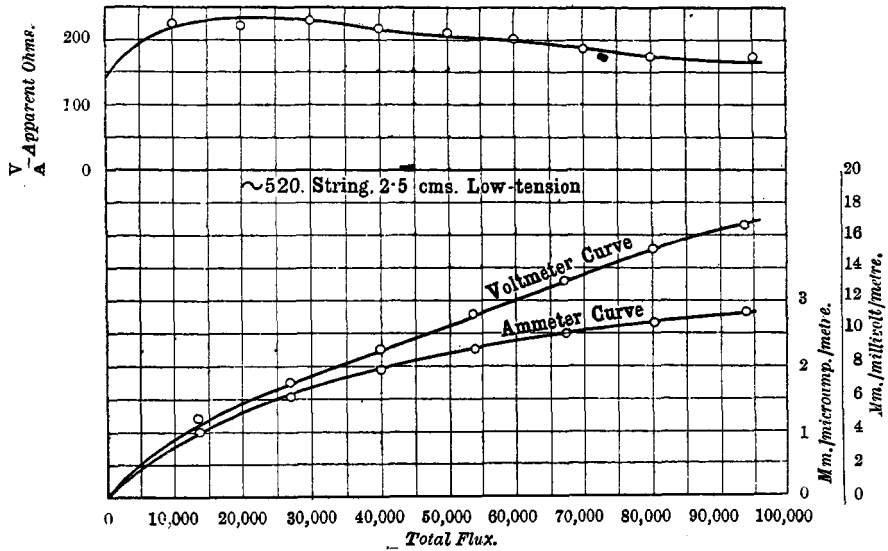


FIG. 4.

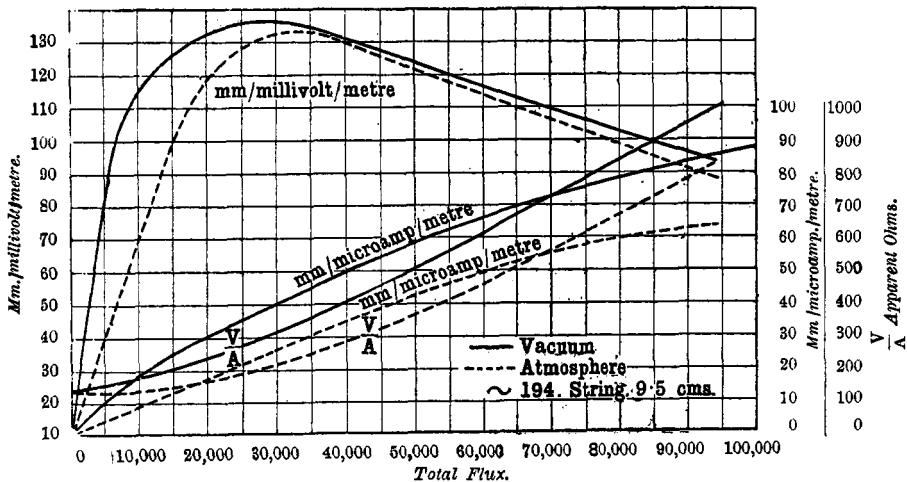


FIG. 5.

produce the greatest transference of electrical into mechanical energy when $E_b = \frac{E}{2}$ —i.e., when half the input is transformed

TABLE I.

Length of string, cm.	Tension.	Frequency.	Maximum voltmeter sensibility, mm./milli-volt/metre.	Total flux for this maximum sensibility.	Apparent resistance for this maximum sensibility.	Max. mm. per micro-amp. at metre for flux 93,600 lines.	D.C. sensibility, micro-amp. per mm. at a metre for flux 93,600.	Magnification ratio of A.C. to D.C. sensibility.	Curves.
9.5	Low	237	95	30,800	275	46	6.75	310	... Fig. 2.
	Medium ...	295	81	35,500	275	44	10.7	470	
	Full	320	74	38,500	275	38	13.8	525	
6.5	Low	310	73	55,000	275	26	13.2	343	... Fig. 3.
	Medium ...	410	53	57,500	275	22	26.2	576	
	Full	526	41	61,000	275	14.5	44.2	640	
2.5	Low	520	No maximum sensibility. Value at flux 93,600	93,600	Varies up to 200	3	90.5	271	Fig. 4.
	Medium ...	740	17			2	179	358	
	Full	960	10			1.6	265	424	

into mechanical work and the other half into heat; then

$$C = \frac{E}{2R}.$$

The back E.M.F. of the galvanometer is approximately 180 deg. out of phase with the current and corresponds to the back E.M.F. of the motor above; as such it may be treated as an additional resistance to the galvanometer, and so we obtain the greatest transference of electrical energy into mechanical energy, or motion, in the galvanometer, when the apparent resistance of the instrument is twice its ohmic resistance, or, in other words, when the back E.M.F. of the galvanometer is equal to its ohmic resistance drop. In this case the current and applied E.M.F. are in phase.

Mr. Butterworth ("Proc. Phys. Soc.," XXIV., p. 83, 1912) has shown mathematically that if a vibration galvanometer is placed in a circuit of self-induction L and resistance R , and if the various constants of the circuit are adjusted, a maximum deflection is obtained under certain conditions, and the current when this absolute maximum has been obtained is given by $I = \frac{E}{2R}$, and it is in phase with the applied E.M.F.

A very convenient way of altering the constants of the circuit so as to obtain maximum sensibility is to vary the flux through the gap of the instrument until, for a certain want of balance in the bridge, if used for bridge work, a maximum deflection is obtained. The back E.M.F. of the galvanometer is then equal to its ohmic resistance drop and is in phase with it.

If the length of the strings is kept constant the flux for maximum sensibility increases as the tension increases.

For high values of the frequency obtained by using short strings the flux can be increased to saturation without reaching a maximum sensibility, so it is advantageous to use an electro-magnet system with a vibration galvanometer, because (1) for low frequencies and long strings a weak flux can be employed, as this is the condition for maximum sensibility, and (2) for high frequencies with short strings a very much stronger flux can be used than could be obtained with a permanent magnet, thus giving greater sensibility both as an ammeter and as a voltmeter. The sensibilities at high frequencies were only limited by the saturation of the magnet, and the back E.M.F. of the instrument was always less than its CR drop.

The sensibility of a Duddell vibration galvanometer throughout its scale would be much more uniform if some flux-squeezing device could be arranged, so that as the strings were shortened

the total flux could be concentrated on the parts of the strings between the bridges.

In the table three sets of readings are given, each taken with a different length of string, and for each length of string three tensions are used, (1) with the string nearly slack, called the low tension; (2) a medium tension, somewhere about 10 grammes weight; (3) a full tension, about 20 grammes weight. It will be noticed that as the tension increases the flux for maximum sensibility increases and the magnification (*i.e.*, the ratio of the alternating-current sensibility to the direct-current sensibility) also increases.

When the strings have been shortened to a certain length the sensibility as a voltmeter does not pass through any maximum value even up to the greatest flux possible, so, with these and shorter string lengths, it is advantageous to work with the maximum magnetic field. In Fig. 2 it will be noticed that the maximum sensibility is obtained with the 9.5 cm. string with only one-third of the maximum flux, and that the maximum is sharply defined; with the higher frequency and shorter string length of Fig. 3, the maximum sensibility is reached with about two-thirds of the maximum flux, but it is much less sharply defined than in Fig. 2; in Fig. 4, with a very short string, the sensibility does not pass through any maximum value, and so the full excitation may be used.

The experiment of running the galvanometer in a vacuum was tried, but the results obtained were not very encouraging considering the trouble involved. The results of this experiment are shown in Fig. 5. At 194 \sim and maximum flux the current sensibility was increased from about 65 mm. per micro-ampere at a metre to about 85 m./m./m., apparently showing that the greater part of the mechanical work produced was used in overcoming the molecular friction of the system, and that a much smaller part was used to overcome the air damping. The voltmeter sensibility reaches its maximum value in a vacuum for a smaller value of the flux than required in air.

At a 1,000 \sim the increase of sensibility on running the instrument in a vacuum was somewhat greater than at 200 \sim (as might be expected), being about 40 per cent., as against a 30 per cent. increase at 200 \sim .

Conclusion.—In a moving coil vibration galvanometer the maximum sensibility as a voltage detector will be obtained if the flux through the coil is so adjusted that at any time the back E.M.F. of the coil is equal to and in phase with its ohmic resistance drop (CR).

ABSTRACT.

The maximum sensibility of a moving coil vibration galvanometer as a voltage detector is obtained when the flux through it is so adjusted that the back E.M.F. of the coil is equal to its CR drop; then the back E.M.F. is equal to half the applied voltage, and the current is equal to $V/2R$ and is in phase with the applied voltage.

Increases of current sensibility of about 30 per cent. at 200ω and 40 per cent. at $1,000\omega$ were obtained on running the instrument in a vacuum, thus showing that a large part of the mechanical work produced was used in overcoming the molecular friction of the system. Tables and curves are given showing the variations of voltage and current sensibility with alteration of flux, &c.

DISCUSSION.

Mr. A. CAMPBELL remarked that he had convinced himself that the chief energy loss in his vibration galvanometer was in the elastic hysteresis of the wires. In Duddell's galvanometer the moving wires are so light that he thought it might be otherwise, but Dr. Haworth's Paper showed that the damping was still chiefly due to the same cause.