The Construction of Non-Inductive Resistances

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Prof. Ramsay said that for substances in states analogous to those of perfect gases the quantities were approximately constant, but when the liquid state was approached this was no longer true. According to Prof. Tait the two states were not continuous.

Prof. Herschel remarked that Prof. Tait had established his law on the assumption that the co-volume is four times the volume occupied by the molecules. This law, he said, had been amply verified by experiments on explosions.

Dr. Burton, referring to Prof. Ramsay's remarks on the compressibility of molecules, said the law of force between attracting molecules should be accurately known before any deductions were made; and he pointed out that at constant volume the pressure should be proportional to the absolute temperature if allowance be made for the negative pressure of attraction.

Mr. Blakesley, in speaking of molecular forces, said he had observed that when water is allowed to evaporate from glass, a furrow is formed in the glass which marks out the original boundary of the liquid. To all appearances the particles of glass are torn away by the molecular forces acting along the boundary.

XXIX. *The Construction of Non-Inductive Resistances.*

By Prof. W. E. AYRTON, F.R.S., and T. MATHER.*

[Plate X.]

WITH all electric methods devised for measuring the power given by a varying current to a circuit that may possess inductance or capacity it is necessary to employ a resistance which shall have zero inductance, consequently it is important to consider how such resistances may most easily be made.

If the inductance of this nominally non-inductive resistance be not zero, the error thus introduced into the measurement can still be made relatively unimportant if the time-constant of this portion of the circuit be made small. For, as shown

* Read June 26, 1891.

by Dr. Sumpner and one of us, in a paper* read before this Society on June 12th of this year, the following proportion holds true in all the nine methods of measuring power there considered:—

$$\frac{\text{the watts as measured}}{\text{the true watts}} = \frac{1 + \tan \theta \cdot \tan \phi}{1 + \tan^2 \phi},$$

where θ and ϕ are the angles of phase-difference between the current and the P.D. for the circuit the power given to which we desire to measure, and for the auxiliary circuit respectively.

Now for any given configuration of a circuit, the time-constant will be the smaller the higher the specific resistance of the conductive material; hence it is very desirable to use a material of high specific resistance, like carbon. For this reason, glow-lamps constitute valuable small time-constant resistances, but carbon has the disadvantage that its resistance varies rapidly with temperature. Hence, since with the methods of measuring power referred to it is necessary to know the resistance of the non-inductive circuit at the moment of making the measurement, it follows that if carbon be employed an extra measurement has to be made.

When the non-inductive resistance is put in series with the circuit the power given to which we desire to measure, as, for example, with the three-voltmeter method of measuring power, a measurement of the resistance of the glow-lamps merely means the reading of an extra instrument at the moment the power-test is made; but when the two circuits are joined in parallel, as, for example, with the one-voltmeter and two-ammeter method of measuring power, a measurement of the resistance of the glow-lamps cannot be made simultaneously with the power-test, since to do this would require the introduction of an ammeter, and therefore of inductance, into the circuit, which should be non-inductive.

Further, carbon is unsuitable for portable resistances on account of its brittle nature. Platinoid, on the other hand, is flexible, has a low temperature-coefficient, and a high specific resistance, though not of course nearly as high as

* "Alternate Current and Potential Difference Analogies in the Methods of Measuring Power," *ante*, p. 172.

that possessed by carbon. Platinoid therefore appeared to us to be the best material to employ in the construction of non-inductive resistances to be used for power-tests.

It is well known that a wire doubled on itself has a very small inductance, which approximates to 3.77 times the total length of the wire in centimetres as the parts approach each other. This value can, as Maxwell pointed out, be reduced by using flat strips instead of round wires; and, if the strips be bare and be placed vertically, it is clear that the cooling action will be considerable, so that relatively strong currents will produce but little rise in temperature or increase of resistance.

We therefore decided in 1887 to construct the non-inductive resistance seen in fig. 1, Plate X., consisting of twelve platinoid strips, each 6 metres long, 4 centim. wide, and 0.25 millim. thick. Each strip is doubled on itself, two layers of carefully shell-lacqued silk, 0.075 millim. thick, being inserted between the front and back portions. The whole is bound together by means of a narrow silk ribbon wrapped round spirally, considerable gaps being left between the spires of the silk ribbon so that the platinoid should have plenty of free surface for cooling.

For the purpose of expelling moisture from the silk and the shell-lac varnish, when the resistance-strips are first put up, a current was passed through each strip strong enough to make it fairly hot. During this heating frequent short-circuitings occurred from rough points of the metal piercing the silk, a single layer only of which was originally employed to separate the front and back portions. An additional layer of silk was therefore inserted. Trouble was also experienced from the rough edges of the metal causing short-circuits; but by cutting the silk wider than the metal and by folding the edge of the silk over the edge of the platinoid strip, this difficulty was overcome.

The doubled strips are permanently joined up in sets of three, and to the ends of each set are soldered mercury-cups and binding-screws. The four sets of three can be joined up in series, or in parallel, or in parallel-series by bridge-pieces dipping into the mercury-cups, and, when all are in series, the resistance of the 72 metres of strip at 15° C. is 2.932

ohms. The resistance of the arrangement does not alter by more than one tenth per cent. when a current of 15 amperes is passing through each strip.

The wooden frame which carries this series of platinoid strips hangs on paraffined ebonite pegs attached to one of the laboratory walls, so that it is well insulated.

The inductance of the set of strips, even when all are in series, is so small that we have not been able to measure it even with the secohmmeter. Some of the tests have given indications of a small negative result, which, if true, would mean that the capacity-effect slightly overbalanced the inductance; but a calculation, which we have made, appears to show that with the dimensions in question such a result is impossible. We can therefore only conclude that this resistance-frame, which was constructed by two of our former students, Messrs. C. G. Lamb and E. W. Smith, fulfils the object for which it was intended so well that the inductance cannot be detected with certainty by any test that we have hitherto tried. We therefore have decided to duplicate the arrangement, the wooden framework (only one half of which is seen in fig. 1) having been constructed large enough to hold a second set of strips.

Another method of constructing non-inductive resistances for large currents, which has been in use at the Central Institution for the past eighteen months, is illustrated in fig. 2, and consists in winding two bare platinoid wires of equal length and thickness into two spirals, one right-handed, the other left-handed, the diameters of the two spirals differing slightly from each other so that one spiral can be placed inside the other. They are then connected up in parallel, so that when a current is sent through them it circulates clockwise round one spiral and counterclockwise round the other, the magnetic effects of the two thus tending to neutralize one another and to produce a combination with small inductance.

The inductance of coils constructed in this way is almost as small as if the wires were doubly wound like an ordinary resistance-coil, *but they possess the great advantage that parts differing much in potential are not close to one another.* The wires therefore require no insulating covering, for no

harm will occur if one spiral accidentally touches the other, provided that reasonable care has been taken to space the convolutions fairly uniformly. Further, as the cooling surface, for a given total cross section of the conductor, is much greater for two concentric spirals than for a single spiral of thicker wire, it follows that this method of constructing a resistance not only greatly reduces the inductance, but also enables a much larger current to be carried for a given variation of resistance produced by the current. Hence for a given current and for a given permissible rise of temperature finer wire can be used; the coils can therefore be made shorter, and the inductance for this reason still further lessened.

Lastly, even when such right- and left-handed spirals are traversed by a direct current, much less disturbance is produced in a neighbouring delicate galvanometer than if a singly-wound spiral resistance be employed; so that these right- and left-handed spirals of bare wire are valuable in the construction of resistance-frames for large direct as well as for large alternating currents.

A number of portable resistance-coils have been constructed in this way for general use in the laboratories of the Central Institution. One of these is seen in fig. 3. It has also been found convenient to fit up a number of stationary right- and left-handed concentric spirals of platinoid in the dynamo laboratory, for use in the regular experiments with alternate currents.

Table I. gives the particulars of some portable sets of stand coils in the laboratories of the Central Institution, the second three of which have been composed of right- and left-handed spirals in the way just described and illustrated in fig. 3.

Table II. gives the results of experiments made on the sets marked 2, 3, 4, 5, 6 by means of the secohmmeter; the set marked 6 being tested when each pair of coils were joined up in parallel so as to increase the inductance as well as when joined up so as to diminish it.

TABLE I.

Particulars of Portable Stand Coils.

Mark on the Stand.	Resistance, in Ohms.	Number of Spirals in the Set.	Length of each Spiral.	Number of Convolutions in each Spiral.		Outside diameter of the Convolutions.		Size of the Wire (S.W.G.)
1	1·8	6	inches. $18\frac{3}{4}$	78		inches. $1\frac{3}{8}$		No. 12
2	2·54	12	$16\frac{1}{2}$	63		$1\frac{3}{8}$		No. 10
3	8·59	12	$16\frac{1}{2}$	84		$1\frac{1}{8}$		No. 13
				Outer.	Inner.	Outer.	Inner.	
4	1·4	20 double, that is 40 coils in all. " " " ,	$16\frac{1}{2}$	15	21	inches. $1\frac{1}{2}$	inches. $\frac{7}{8}$	No. 13
5	5·0		$16\frac{1}{2}$	27	37	$1\frac{1}{2}$	$\frac{7}{8}$	No. 15½
6	99		17	54	79	$\frac{3}{4}$	$\frac{1}{2}$	No. 27

TABLE II.

Portable Platinoid Spiral Resistances (fig. 3).

Mark on the Stand.	Winding.	Resistance, in Ohms.	Inductance, in Secohms.	Time-constant, in Seconds.
2 ...	Set of Singly-Wound Spirals ...	2·54	0·000059	23×10^{-6}
3 ...	Set of Single-Wound Spirals ...	8·59	0·00015	18×10^{-6}
6 {	Set of Doubly-Wound Spirals ; Current circulating in all in the Same Direction	98·1	0·0021	21×10^{-6}
6 {	Same set of Doubly-Wound Spirals ; Current circulating in Opposite Directions	99	0·00013	$1·3 \times 10^{-6}$
4 {	Set of Doubly-Wound Spirals ; Current circulating in Opposite Directions	1·4	0·000004	$2·8 \times 10^{-6}$
5 {	Set of Doubly-Wound Spirals ; Current circulating in Opposite Directions	5·0	0·0000094	$1·9 \times 10^{-6}$

The mean time-constant, therefore, of one of our sets of spirals, whether singly-wound or doubly-wound, provided that the current circulates in all the convolutions in the same

direction, is about 21×10^{-6} ; whereas if the spirals be doubly-wound and the current be circulating in opposite directions in the two sets of spirals, the mean time-constant is about 2×10^{-6} , or about one tenth of the preceding.

As there happens to be in the laboratory a solenoid, the silk-covered copper wire on which is wound in a series of concentric sections, it was thought interesting to compare the time-constant of two of the sections joined up in parallel, when the current circulated round both in the same direction, with the time-constant when it circulated in opposite directions. Figs. 4 and 5, Plate X., show the direction of the current in the two cases.

	Resistance, in Ohms.	Self-induction, in Sechoms.	Time-constant, in Seconds.
Currents flowing round both coils in the same direction (fig. 4) ... }	0.346	0.00059	17×10^{-6}
Currents flowing round the coils in the opposite direction (fig. 5) }	0.346	0.000024	0.69×10^{-6}

The self-induction and time-constant have therefore been reduced to one twenty-fourth part by sending the currents in opposite directions round the two, but the method of winding shown in fig. 5 could not, of course, be employed with the non-inductive resistances constructed of bare wire for large currents described in this communication; since the fundamental condition—that *parts differing much in potential should not be near one another*—would not be fulfilled.

XXX. A Theory concerning the Constitution of Matter.

By CHARLES V. BURTON, D.Sc.*

THE theory described in the following pages is based essentially on one fundamental hypothesis; without the aid of any further assumptions, equations of motion can be deduced, and these, when simplified by certain conditions of symmetry,

* Read November 20, 1891.