CONSTANT SHUNT METHOD FOR THE MEASUREMENT OF LARGE CONTINUOUS CURRENTS.

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[Read at the stated meeting of the Section, held March 1, 1892.]

The constant, Vienna or Munich, shunt method, as it is variously termed, is something which is by no means novel and is, indeed, well known to some of the section, having been used by them at the Electric Exhibition of the Institute, in 1884. But I believe that the method is not so well known, or at least not so much in use as it should be, and I hope, by calling attention to some of its advantages and by pointing out and showing how to avoid certain errors incident to it, one or two of which are not generally known, to do something toward bringing it into more general use.

For the measurement of continuous currents we have the various forms of ammeter, the Siemens dynamometer, the Thomson platform galvanometers, and the Thomson balances, the tangent sine and cosine galvanometers. With the objections to the ammeters all are doubtless familiar. They are inaccuracy of graduated scale, errors due to residual magnetism or to loss of permanent magnetism, and lack of wide range. The Thomson platform galvanometer does not measure large currents without the use of the permanent magnet which is objectionable if considerable accuracy is desired, and it requires a knowledge of the horizontal component of the earth's magnetism H . The Thomson balance is an instrument of much greater value than the above, being independent of H , having greater range and greater precision, but being even more costly.

The tangent galvanometer requires the value of H , and has only a limited range, which the sine and cosine, though better in this last respect, are tedious to use on account of time required in setting the coils.

The great advantage of the shunt method over all these is that, by the aid of fairly simple and cheap apparatus, currents varying from one to 1,000 ampères or more may

be measured with quickness and a very great degree of accuracy over the whole range.

The shunt method is really a comparison method, and depends upon Ohm's law that the potential difference between two ends of a resistance is proportional to the current flowing through the resistance.

Let AB be a conductor whose temperature is kept constant, its resistance will therefore be constant, but need not be known. Pass the current C , which we desire to measure through AB , there will then be a potential difference PD between A and B .

Let G be a mirror galvanometer with telescope and scale, then the deflection d is proportional to the current through it, which is proportional to PD , as long as resistance of galvanometer and leads is constant, $d_1 \propto PD_1$ or $d_1 \propto C_1$.

Pass any other current C_2 through AB then $d_2 \propto C_2$ and

$$C_1 = \frac{d_1 C_2}{d_2}$$

If the resistance of the galvanometer and leads be not constant, the algebraical result is less simple and, moreover if the deflections become very large, they are not strictly proportional to the current through the galvanometer which we will call C_g . Hence the comparison of large with small currents will be somewhat inaccurate. This leads us to a little different method. Place a resistance box R in the galvanometer circuit. Pass current C_1 through AB , causing a potential difference PD_1 , and sending through G a current

$$C_1 g = \frac{PD_1}{R_1 + g}$$

where g is the galvanometer resistance.

Then

$$d_1 \propto C_1 g \propto \frac{PD_1}{R_1 + g}$$

or

$$C_1 \propto d_1 (R_1 + g)$$

in the same way

$$C_2 \propto d_2 (R_2 + g)$$

then

$$\frac{C_1}{C_2} = \frac{d_1(R_1 + g)}{d_2(R_2 + g)}$$

or

$$C_1 = \frac{d_1(R_1 + g)}{d_2(R_2 + g)} C_2$$

Now, if when C_2 were flowing we had accurately measured

it by a tangent galvanometer or by the electrolytic cell, the quantity

$$\frac{C_2}{d_2(R_2 + g)}$$

would be known. Call it K the constant of the shunt. Then we have the general formula for the shunt that the current whose value we desire is equal to

$$\frac{d(R_1 + g)K}{d_2(R_2 + g)}$$

Now, by using the resistance box, and by adjusting it to

give about the same deflections on the galvanometer in different measurements we have secured two important advantages.

(1) We have done away with the error of assuming that the currents through the galvanometer was strictly proportional to its deflections.

(2) The resistances R being large in value with reference to galvanometer and leads, and being of platinoid or some metal with very low temperature coefficient, any change in temperature of galvanometer and leads will produce little effect on the result.

Like all other methods this one is liable to certain errors, some of which I will mention and briefly suggest their remedies. The way in which they affect the result will also be stated.

(1) *Reading of Deflection.*—Suppose you could read to within .01 cm. on the scale. If the deflection were 10 cm. the error would be

$$\frac{.01}{10} = 1 \text{ part in } 1,000.$$

The error is evidently diminished as we increase the deflection.

(2) *Error Due to Temperature Change of Galvanometer and Leads.*—If these are of copper their resistance would change four-tenths per cent. per degree Centigrade. This correction could be applied, but if the resistance in R is large with respect to g , this correction will be negligible; (2°) then conflicts with (1°), and we must compromise. Suppose $R_1 = 20 \text{ } g = 2$, and temperature rise = 10° C. then the true value of

$$R_1 + g = 20 + 2 + 2 \times \frac{4}{100} \times 10 = 22.08$$

and the error in neglecting the

$$.08 = \frac{.08}{22} = 1 \text{ in } 275$$

(3) *Error Due to Temperature Change of Box.*—This is .02 per cent. per degree Centigrade for platinoid coils, and may be

corrected for, or neglected, according to the desired precision of our results.

(4) *Error Due to Determining Constant K .*—The constant is best determined in most cases by electrolytic cells, say three in series. If one has a tangent galvanometer of proper range, 1-5 ampères, and knows H to the desired accuracy this may be used. A Thomson deci-ampère balance would be very convenient for subsequent determinations of the constant, if its readings were known to be correct within the desired degree of accuracy. An error of '1 per cent in K causes an equal error in the subsequent measurements.

(5) *Error Due to a Rise in Temperature of the Shunt.*—This may be due to two causes: a rise in the temperature of the room, or the heating effect of the current. Both may be obviated by placing the shunt in liquid artificially cooled

FIG. 1.

by cold water coils, and keeping constant the reading of a thermometer placed in the liquid close to the shunt.

Suppose the rise in temperature were 5°C . If the shunt were of German silver the change in its resistance would be '04 per cent. $\times 5 = \cdot 2$ per cent. or two parts in 1,000, and the results of the measurement would be in error by this amount. If of platinoid, the error would be but half as much.

(6) *Error Due to Change of Value of H .*—This would be possible if the galvanometer had the earth's field for a resting force. If great accuracy be desired, obtain the value of the constant frequently, and see if it changes. As I have before said a Thomson balance would be most desirable for this, and many laboratories can afford one Thomson balance. Also if we had a galvanometer whose damping could be removed, we could determine whether H had changed by its time of vibration. The sources of

error so far mentioned are well understood and looked out for, but the following are, I believe, not so well known. At least the amount of the effect is not so generally appreciated, and they have, so far as I know, received exhaustive study only at the hands of Mr. W. L. Puffer, of the Massachusetts Institute of Technology. His results are to be found in the *Proceedings of the American Academy of Arts and Sciences*, January, 1888.

(7) *Error Due to Thermo-electric Effects.*—We are obliged to make the resistance of our shunt very low to prevent undue heating, hence the potential differences set up at its terminals are very low. In this case any thermal E. M. F.'s, which might be caused by differences of temperature at the junctions of the different metals, would be liable to affect the readings of the galvanometer. This trouble may be obviated by so making the shunt as to put the junctions under the surface of liquid whose temperature is maintained constant and may be detected by running the galvanometer leads to a mercury cup commutator and testing with reversals.

(8) *Error Due to Electro-chemical Action.*—The shunt is placed in liquid and under the action of the potential differences set up at its terminals there is electrolytic decomposition, (if the liquid be one which can be decomposed as water). This will cause the end having the higher potential to be darkened, owing to oxidization of the German silver by the oxygen set free, while the other end will become whiter or cleaner in appearance, owing to the reduction of the film of oxide on its surface by electrolytic hydrogen. These actions will evidently set up E. M. F.'s, and if the shunt resistance is very low, will cause considerable error in the result. This source of error could be avoided by placing the shunt in some liquid incapable of decomposition with low E. M. F.'s. Chemically pure water would do, but for the trouble of obtaining and keeping it so. Petroleum oils would act slightly on the bare piece of metal composing the shunt, thus producing a battery effect. We must either immerse the bar in some liquid incapable of acting on it or cover the shunt very carefully with some substance not acted upon

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by the liquid in which it is placed. Everything considered it seems to me that very carefully covering the shunt with several coats of shellac and afterwards with copal varnish, and immersing it in distilled water would be the most satisfactory method.

Design and Construction of Apparatus.—Suppose we desire to measure currents of from one to 1,000 ampères. This would require a set of five tangent galvanometers of different sizes, the three largest of which would be impracticable. (The diameter of the largest would be about seventy-five feet.) With the sine or cosine galvanometers or Siemens dynamometer we could do better in this respect, but they are still out of the question.

With the Thomson platform or balance we should need three different instruments, which are exceedingly costly.

FIG. 2.

Moreover, none of these could be used near dynamos and this means that we must lead the whole of the current we wish to measure perhaps a considerable distance, thus entailing expense for wire and perhaps leakage.

Suppose we make one shunt of resistance $\cdot 001 \omega$. If of German silver 9 inches wide, $\frac{1}{100}$ inch thick, two strips 24 inches long joined in parallel will be nearly the required dimensions. The object of making them so thin is to offer large surface to the water so that they may quickly dissipate the heat produced by the current. The rate of production of heat with the maximum current 1,000, ampères, will be $\cdot 24 C_2 R = \cdot 24 \times 1,000^2 \times \cdot 001 = 240$ calories or enough per second to heat 240 grammes of water 1°C . if none of the heat be dissipated. We must now provide a containing vessel large enough to hold so much water that it will not be

unduly raised in temperature, and large enough to admit of placing in it coils of pipe which shall carry cooling water if this be found necessary with the larger currents.

The two German-silver strips should be joined thus by massive cast copper blocks, to which they are carefully soldered. To make the junction doubly secure, thin strips of copper $9 \times 1 \times \frac{1}{4}$ inch are screwed and soldered on over the German silver, as shown. The vertical projecting copper bars *D* and *F* are for connecting the shunt into the circuit where we wish to measure the current.

The arrangement so far described would collapse, owing to the thinness of the German silver. So it is necessary to hold the copper blocks apart at the top and bottom by some arrangement which shall be insulated from the shunt. This can be done by screwing on to both top and bottom of the copper blocks, a piece of board $24 \times 4 \times 1$ inch, as shown in drawing. The board on top should be pierced with a large number of holes, as shown, in order to facilitate the circulation of water. The ends of the boards touching the blocks should be soaked thoroughly in melted paraffin and coated with shellac. The screw holes in the blocks should be filled with paraffin, the screw heads countersunk in the wood, as shown, and melted paraffin poured over them. The whole arrangement should then be coated with shellac and copal varnish *thoroughly*.

The containing vessel may be of wood, paper or galvanized iron, about $32 \times 14 \times 13$ inches. Such a vessel will contain, besides the shunt, about 85,000 grammes of water. Now, the number of heat units, small calories, developed in one second by 1,000 ampères flowing through .001 ω is in one second as before stated, such as would heat 240 grammes of water 1°C . Hence it would take to heat 85,000 grammes 1° , a time $\frac{85000}{240}$ seconds, or about six minutes, if there were no radiation. But it is probable that this heat produced will not be instantly communicated to the entire mass of water, hence, for the large current measurements it will be advisable to lead coils carrying cold water close to the German-silver strips, both inside and outside, if we desire great accuracy in our measurements.

Galvanometer.—Any form of sensitive reflecting galvanometer which is dead heat and wound with coils of low resistance may be used. If the instrument has the earth's field alone for a restoring force, as is generally the case, (neglecting torsion), it would be convenient to have the

FIG. 3.

damping copper mass easily removable. The following will illustrate the design :

Suppose the scale of telescope is divided into millimetres, and we can read with an error of $\cdot 1$ mm. by eye estimation, then with a deflection 10 cm. the error in reading would be $\frac{1}{1000} = 1$ in 1,000. If our scale were distant from mirror of telescope by 1.5 metres, the deflection of the mirror for a reading 10 cm. would be about 2° for $\frac{1.0}{150} = \tan. 2^\circ$ $a = 2 \tan.$

a approximately. $\tan. a = \frac{10}{300} = .033$ and a the deflection of mirror $= 1^\circ 54'$.

When 1,000 ampères are flowing, the potential difference acting to send a current through the galvanometer is $100 \times .001$ or one volt. Suppose we put in the galvanometer circuit 10,000 ohms, the maximum of an ordinary box, then the current through the galvanometer will be .0001 ampères. With sufficient accuracy, we may apply the tangent galvanometer formula,

$$C = \frac{10 H \gamma \tan. a}{2 \pi n}$$

from which we have

$$n = \frac{10 H \gamma \tan. a}{2 \pi C} = \frac{10 \times .2 \times \gamma \times .033}{2 \times 3.1416 \times .0001}$$

Assume a mean radius $\gamma = 2.5$ cm., then n the number of turns $= 266 = 41.78$ metres or about 136 feet of wire. If we take a copper wire whose diameter bare is .036 inches the resistance will be about 1.1 Ω , and the wire will lie in a groove $1 \times \frac{5}{8}$ inch, whose mean radius is 2.5 cm., or about one inch.

When one ampère goes through the shunt the potential difference will be $1 \times .001 = 1$ volt. Then to give about 10 cm. deflection we should insert such a resistance that the galvanometer current would be .0001, and this resistance would be about nine ohms. Then should the temperature of the galvanometer coil rise 5° C., the resulting error would be but two parts in 1,000 from this cause alone.

A galvanometer of the D'Arsonval pattern might be used and would have the advantage of being independent of any changes in H , and of being very dead heat. It should be designed with as low resistance as is consistent with the condition that a current .0001 ampères shall produce a deflection of 2° .

Two commutators are necessary. The larger receives the six coarse wire soldered into the copper lugs DF of the shunt, shown in *Fig. 3*. These wires should be No. 0000 B. and S. three in parallel, and the commutator of the mercury cup

variety, so arranged that the shunt can be entirely disconnected from the dynamo circuit.

Into each of the holes at *H* and *K*, *Fig. 3*, should be soldered, carefully, a No. 18 B. and S. copper wire thoroughly insulated, and the joint covered carefully with shellac and copal. These are led out to the small mercury commutator for the galvanometer circuit arranged like the other so that the galvanometer can be isolated from shunt and main circuit. Then any thermo electric or electro chemical effects can be detected and studied. For instance, disconnect galvanometer entirely from commutator and note reading. Connect it to commutator with shunt uncon-

FIG. 4.

nected, and there should be, of course, no deflection even by reversing the commutator. Connect shunt (still with no current in it) to galvanometer commutator, and see if there is any deflection, reversing this time the connection from shunt to galvanometer. Finally, run current through shunt, and see whether changing the commutators produces any change in deflection, being sure that this current is maintained constant. Disconnect shunt from dynamo circuit, and see whether there is any appreciable deflection. The time occupied for these tests is very short, if the commutators are properly arranged, and if the tests show no appreciable thermo-electric or chemical effects, we may feel

sure that our apparatus is satisfactory in this respect. Finally, provide a sensitive thermometer whose range is from about 60° F. to 80° F., or 15° C. to 27° C., and arrange so that it will be placed close to one of the German-silver strips of the shunt. Read when no current is flowing, and then when the maximum current flows. Then if these readings differ 5° C., or 9° F., the error would be two per cent., as previously stated. If greater accuracy be required send cold water through the coils, and read the thermometer, then by sending the water through fast enough, the heating effect of the current may be nullified to the desired extent.

The sketch below shows the general appearance of the completed shunt, together with the commutators.

Recent researches of Prof. Ayrton on the D'Arsonval galvanometer indicate that such a type wound with plati-

FIG. 5.

noid with phosphor-bronze strip suspensions would be most desirable, and, therefore, the following arrangement commends itself, more especially where the field around the galvanometer is subject to fluctuations. Use for the shunt bar a sheet of platinoid, to which the wires carrying the main current should be soldered. Preferably there should be several such wires soldered on the end edge of the sheet and distributed at equal distances along the edge so as to secure uniform distribution of current in the strip. *Inside* at the points *A* and *B* the leads (of platinoid) to the galvanometer commutator should be fastened. If then a D'Arsonval, made as above and having its telescope and scale rigidly attached to itself, be provided, it may be used where the other arrangement would be out of the question, namely, near the dynamo room. Moreover, by making everything of platinoid, we have done away with temperature correc-

tions, provided the platinum strip be of such dimensions that the maximum current doesn't heat it appreciably. The strip then may be kept in air, the only danger being a greater liability to thermo-electric effects due to differences in temperature at the junctions, and this can be tested by commutation.

Using the D'Arsonval, we can get a greater deflection for a given potential difference at its terminals, therefore, the resistance of the strip may be made lower and less energy be used up in the method of measurement, and in some cases this is an important advantage. On the other hand, since we measure with smaller potential differences, any thermo-electric effects will produce a greater error in our results.

CEREBRAL RADIATION.

BY PROF. EDWIN J. HOUSTON.

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GENTLEMEN: I have thought it possible that it might interest you to consider some rather wild speculations in which I have indulged for a number of years past, but which I have heretofore refrained from publishing. In these speculations, to which I was first led by a suggestion from a friend, I have endeavored to correlate, to some extent, the phenomena of thought with grosser physical phenomena. Although the suggestions I have to offer as a basis for a hypothesis of the mechanism of cerebration, are confessedly incomplete, and, perhaps improbable, yet I have concluded to place them on record as of possible interest to the scientific world.

I am, of course, aware of the fact that the psychical operations of the brain are by no means understood. It is generally believed, however, that the seat of psychical activity is the cerebrum. The manner in which the brain acts to produce, record, and reproduce thought is unknown, and will probably remain unknown.