II. *On the Automatic Registration of Magnetometers, and Meteorological Instruments, by Photography.—No. IV.* *By* Charles Brooke, *M.B., F.R.S.*

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On the Automatic Temperature Compensation of the Force Magnetometers.

A PORTION of the funds liberally contributed by the Government for the advancement of science, and placed at the disposal of the President and Council of the Royal Society, having been entrusted to the author for the accomplishment of the above object on a plan which was submitted to the Astronomer Royal and Colonel Sabine in the spring of last year*, and by them considered feasible, he considers that he cannot better fulfil the obligation of reporting progress at the present period, than by laying before the Royal Society a description of the instruments now constructed.

So long as the results of the variations of magnetic force were deduced from eye-observation only, at the periods of which the temperature as well as the position of the magnets was recorded, a correction for the influence of change of temperature on the instruments themselves could be readily estimated and applied; but in deducing mean values from the photographic registers, especially those for intervals involving considerable changes of temperature, it is manifest that the greatest degree of accuracy cannot be attained, unless either the apparent values were individually corrected by means of a separate register of the thermometer enclosed in the box with the magnet, or the instrument possessed within itself an approximate automatic correction for the effects of change of temperature.

The object would not be unattainable by the former means, but the process would be both difficult and laborious; it therefore appeared more desirable to attempt its accomplishment by the latter. Referring therefore to the equation of equilibrium of the bifilar magnet, viz.

$$mX = W\frac{ab}{l}\sin\theta,$$

in which m is the magnetic moment of the bar, X the horizontal component of the earth's magnetic force, W the weight of the suspended bar and its appurtenances, l the length of the suspension skeins, a and b the upper and lower intervals of their centres, and θ the angle of torsion, it is evident that the object in view would be

* The author feels bound to express his belief that a somewhat similar plan of compensating the force magnetometers subsequently proposed by Mr. Brown at the last meeting of the British Association was entirely original.

accomplished, if by any mechanical agency either of the quantities W, a, or b could be *simultaneously* influenced by change of temperature, and *proportionally* to the altered value of m.

As it would be desirable that the correction should involve the small coefficient of the second power of the temperature, a very definite value of which has been determined*, it was at first proposed to act on W by means of a hollow glass globe attached to the suspension frame of the magnet, with a vertical tubular stem dipping into a cup of mercury. It is clear that as the elastic force of the air contained in the bulb is diminished by heat, a column of mercury in the stem would fall, and the diminution of the suspended weight thus occasioned, might by a due adjustment of the capacity of the bulb be rendered equivalent to the constant part of the loss of power in the bar, and would thus represent the coefficient of the first power of the temperature, while an equivalent to the coefficient of the second power might be obtained by a due adjustment of the *diameter* of the stem. It is evident that the smaller the diameter of the stem, or in other words, the longer the space occupied by the mercury depressed during a large interval of temperature, the greater would be the difference of the spaces corresponding to successive small intervals. But this arrangement would be liable to several small sources of error; first, an alteration of the suspended weight by hygrometric changes in the length of the suspension skein; secondly, a change in the bulk of the air in the bulb corresponding to barometric changes; and thirdly, a small and uncertain secular variation, from the evaporation of mercury in the cistern in which the stem would be immersed.

From these considerations, it has been deemed advisable to abandon the attempt to introduce in the compensation an equivalent for the small coefficient of t^2, and to rest satisfied with acting on a or b by means which would effect an equal change for equal intervals of temperature, and would therefore represent the coefficient of t only. Metallic expansion naturally suggested itself as the means of accomplishing this object, and b the lower interval of the skeins as the most appropriate point of application, inasmuch as the compensating apparatus would then be in close proximity with the magnet, and being isolated from the surrounding atmosphere by enclosure in the same case or cases, might be presumed to vary in temperature *slowly* and *simultaneously* with the magnet; and if the changes in temperature were not sufficiently simultaneous, the radiating capacity of the magnet might be increased by partially coating it with dead-black varnish, or diminished by gilding and burnishing it, to any required extent.

The compensating apparatus consists of a glass rod clamped at its middle point to the centre of magnet, the axes of the rod and bar being parallel: the free ends of the rod are enclosed in two zinc tubes, at the inner ends of which, where they nearly meet in the centre, and to their upper surface, two hooks are attached: two loops at the ends of the suspension skein are attached to these hooks, the skein passing over

* See a paper, No. III. by the Author in the Phil. Trans., Part I. for 1850.

a pulley at the point of suspension. Towards either end, the rod and tubes are connected by a moveable clamp, by which the two may be clamped together at any required distance from the centre. It is evident that by elevation of temperature the free ends of the zinc tubes will be approximated to each other by a quantity equal to the difference of the expansion of the lengths of zinc and glass that intervene between the sliding clamps and the free ends of the tubes, and consequently that a diminution to the same extent of the distance between the lower ends of the suspension skein will take place. The variation of the interval between the lower ends of the skein, corresponding with any given variation of temperature, may be made to bear any required ratio to the whole interval, first by a due adjustment of the upper and lower intervals of the skein, and secondly by varying the position of the sliding clamps, that is, of the acting lengths of the expanding tubes: the former may be considered as a coarse, the latter as a fine adjustment. The glass rod rests on rollers attached to the under surface of the tubes opposite to the hooks, in order that no jerking may be occasioned by the expansion or contraction of the zinc tubes. By these means the quantity b in the preceding formula may be made to vary by change of temperature, proportionably to the change of the quantity m with any required degree of exactness; so far, at least, as the variation of m is directly proportional to the variation of temperature.

In the adjustment of the instrument the following steps are necessary. First, let the temperature coefficient of the bar be determined by the method described in the Paper No. III. previously mentioned; secondly, let the lower interval of the skeins be taken, such that the ratio of the difference of linear expansion of the whole length of the tubes and glass rod (which for convenience is made the same length as the bar), between 32° F. and any given higher temperature, say 92° F., to the distance between the threads, may be considerably less than the whole correction for that interval of temperature; ample scope will thus be allowed for determining by experiment the requisite amount of compensation, as is the case in the adjustment of chronometers.

The pulley over which the skein passes at the upper point of suspension being made of brass, there will be an increase of the upper interval between the threads, with increase of temperature: in order to compensate for this, it will be necessary to take the acting lengths of the compensator somewhat greater than the calculated length, expressing the value of the temperature coefficient.

The instrument having been thus approximately adjusted, the magnet and its appurtenances are now to be enclosed in a rectangular jacketed zinc box. The water in the jacket may be raised to any required temperature, and the temperature maintained nearly constant for any required period, by heating a pipe connecting the inlet and outlet of the jacket by a jet or jets of gas.

A uniformity of the temperature of the jacket is obtained by the introduction of suitable diaphragms to ensure a complete circulation throughout its entire extent. A photographic register of the variations of the instrument is now to be obtained by the means described in the two first papers of this series*, the temperature of a thermometer enclosed in the zinc box, and placed as near as possible to the magnet being simultaneously recorded at convenient intervals of time, corresponding to temperature changes of not more than two degrees. If the change of temperature is slow, that is, if a variation of 40° FAHR. is spread over a space of at least six or eight hours, the temperature of the mercury may fairly be assumed to be the same as that of the bar. If, in order to avoid the consumption of time, or for any other reason, it should be found desirable to observe during more rapid changes of temperature, some such means as those before mentioned must be employed to ensure a uniformity of radiating capacity in the magnet, the compensator, and the thermometer.

A photographic register of the bifilar variations during known changes of temperature having been thus obtained, should now be compared with that of another bifilar instrument of which the temperature has undergone comparatively little variation, as will be the case under ordinary circumstances: a comparison of these will readily show whether the instrument under trial is over- or under-compensated, and the requisite correction may be made by shifting the sliding clamps. A few repetitions of the same process will suffice to give the requisite accuracy of correction.

It may be remarked that the most satisfactory method would be to register simultaneously a carefully compensated instrument on the same sheet of paper; the means of doing this are not however at present in existence.

Compensation of the Balanced Magnetometer.

The horizontal displacement of the centre of gravity by metallic expansion is the most palpable means of effecting a compensation for the changes of temperature in this instrument; the only question is the precise method by which the numerical value of the temperature coefficients can be most nearly represented. The plan adopted has been that of attaching a small thermometer parallel to the axis of the magnet, and as nearly as possible in the same horizontal plane with the centre of gravity of the magnet and its appendages. The statical moment of the mercury displaced from the bulb of the thermometer by any given elevation of temperature, as $x°$ above 32° FAHR., may be represented by the same formula which expresses the temperature coefficients, namely,

$$cx+ex^2.$$

For let w be the weight of mercury contained in one degree of the tube, and let the tube be taken such that the distance from the centre of the bulb (which is presumed to be a symmetrical figure of revolution) to the point 32° FAHR. may be kc, and length of one degree $2ke$; then at any temperature $32°+x°$ the statical moment of the mercury displaced by a small change of temperature, dx, will be $w\,(kc+2kex)\,dx$,

* Published in the Philosophical Transactions, Part I., for 1847.

and consequently the statical moment of the mercury displaced between the temperatures of 32° and 32°+x° will be $(kcx+kex^2)\ w$; let now v be the weight which, placed at a unit of distance from the point of support, will represent the temperature correction for 1° above 32° FAHR.; it will only remain to obtain a bulb of such size that

$$kw=v;$$

we shall then clearly have the statical moment of the mercury displaced from the bulb by x° of elevation of temperature above 32° FAHR., and transferred to the vacant portion of the tube represented by

$$(cx+ex^2)\ v,$$

and consequently a correction in weight equivalent to the temperature coefficient will have been applied to the bar.

As the change of density of the thread of mercury in the stem has not been taken into the account, it will be better to place the point of the tube which corresponds to a distance $\frac{1}{2}kc$ below the point 32° opposite the knife-edge; the error from this cause will then be quite negligible.

The value of v is to be determined experimentally by observing the displacement of the register line occasioned by a small known weight placed on the bar at a known distance from the point of support, and comparing this with the scale coefficient obtained in the usual manner.

Owing to the short period of time that has elapsed since the completion of the instruments, and the difficulty of making accurate magnetic observations in a locality subject to the constant tremors and vibrations of a London thoroughfare, the constants have not been determined with a sufficient degree of accuracy for publication; when satisfactorily determined, they will be communicated to the Society in the form of a Supplement to this paper.

Description of the Plate.

Figs. 1 and 2. Plan and elevation of the bifilar compensator, half the actual size. *a a* the magnet, *b* the clamp which attaches the glass rod to the magnet. *c c* the zinc tubes enclosing the glass rod. *d d* the adjusting clamps, consisting of two parts; the outer encircles the zinc tube, the inner passes, and nearly fills the interval, between the tube and glass rod. They are capable of sliding for adjustment when the screws are loosened; when tightened, the rod and tubes are held together. *e e* screws for adjusting the distance between the hooks *h h*; these should be withdrawn, when the clamps *d* are fixed. *o o*, fig. 2, are the ends of the clamping pieces interposed between the tubes and the rod.

Fig. 3. The brass collar to which the hook is attached seen in section, full size. The glass rod *f* rests on a roller *g*, that there may be no jerking in the expansion and contraction of the tube; *i i* two screws for fixing the collar while the scale and temperature coefficients are determined; when these are tightened the clamps *d* and screws *e* should be relaxed.

Fig. 4. Plan of the balanced magnet compensator. *k k* the magnet. *l l* the thermometer tube held in two Ys by a spring *m* tightened by a screw. *n n* the clamp that attaches the magnet to the frame in which the agate knife-edges are fixed.

Fig. 1.

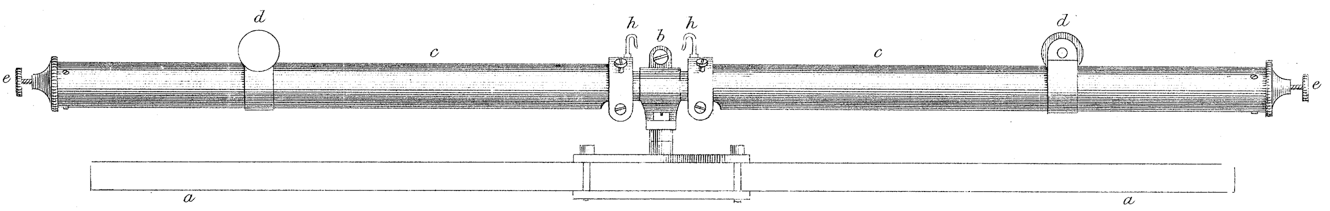

Fig. 2.

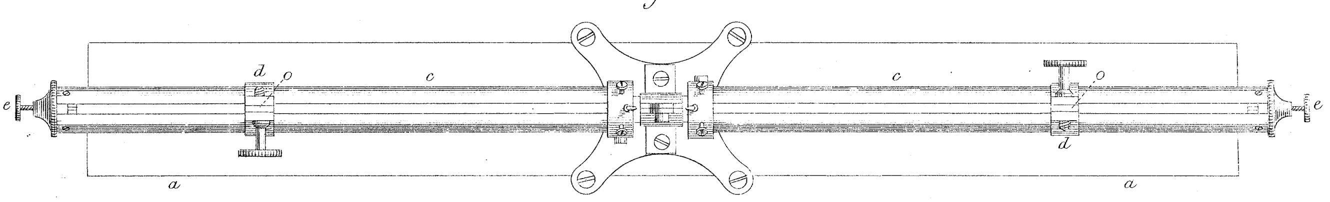

Fig. 3.

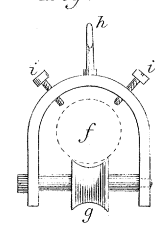

Fig. 4.