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Let a_1 = number of beats of pendulum (1) per period $= \frac{1}{c_1}$;

Let a_2 = number of beats of pendulum (2) per period $= \frac{1}{c_2}$;
 c_1 and c_2 being small fractions less than e_2 .

Let N_1 = whole number nearest to n_1 ;

Let N_2 = whole number nearest to n_2 .

Then

$$n_1 + c_1 = N_1.$$

$$n_2 + c_2 = N_2.$$

$$n_1 - n_2 + c_1 - c_2 = N_1 - N_2 = M, \text{ a whole number.}$$

$$n_1 - n_2 + c_1 - c_2 \text{ is less than } 2(e_1 + e_2).$$

If, therefore, $2(e_1 + e_2)$ is numerically less than $\frac{1}{2}$, then $M = 0$,
whence $N_1 = N_2 = N$.

$$\frac{n_1}{n_2} = \frac{N - c_1}{N - c_2} = \frac{t_1}{t_2} \text{ and } N = \frac{c_1 t_2 - c_2 t_1}{t_2 - t_1}.$$

Eight determinations of the rate of an Ut_2 fork, made by the preceding method, gave the following results:—

Temp. Fahr.	v. s.	v. s. at 60° F.	Diff. from mean.
54·0	128·134	128·090	+ 0·003
56·3	128·114	128·087	0·000
58·0	128·102	128·087	0·000
60·0	128·090	128·090	+ 0·003
62·2	128·077	128·093	+ 0·006
63·0	128·060	128·082	− 0·005
64·5	128·050	128·083	− 0·004
73·5	127·984	128·084	− 0·003

XV. On a New Form of Ergometer*.

By FREDERICK JOHN SMITH, B.A.†

IN the present period of electrical science, in addition to that branch which deals with lighting, another very important branch has grown out of the great stock, viz. the distribution of power, as the different Companies call it.

In estimating the qualities of various electromotors, and also in certain physical experiments connected with motion (for instance, to illustrate the amount of work done to keep the balls of a centrifugal governor at any given angle), some sort of very sensitive ergometer is required. In dealing with a few foot-pounds per minute instead of many horse-power, great care must be taken that the ergometer be of considerable range, dead-beat in its action, and that it have no internal

* The term "Ergometer" is now logically used for Dynamometer. See Thomson and Tait's 'Elements of Natural Philosophy.'

† Communicated by the Author.

source of error arising from the position of the spring by which the tension of a belt is estimated.

There are several forms of ergometer in which a fast-and-loose pulley are connected together by a spring *b* (fig. 1) or springs, and in which any advance of the loose pulley on the fast one extends the springs. Now as long as the springs are very rigid, such as those used in large ergometers, there is but little tendency to bulge out as they fly round and assume the position shown at *a* (fig. 1). But if the springs are suitable for measuring small quantities, then they are not rigid enough to keep their shape while subject to centrifugal force: such deformation introduces serious error into the total result; it is therefore necessary that the spring be so placed that it is in no way, or but very slightly indeed, affected by centrifugal force. The author finds that this end can be attained if the axis of the spiral be made to coincide with the axis of the moving pulleys. In fig. 2 it will be seen that the spring *A* is placed in a hollow shaft *B C*, part of which *E F* is in the form of a link

Fig. 1.

Fig. 2.

to take the spring. This shaft carries three pulleys; of these *L* is loose, *G* fast, and *D* is geared to *G* by means of three mitre-wheels (part of the wheel *G* is supposed to be removed to show these). The mitre-wheels *K* and *M* are provided with flat pulleys, to which the cross bar *P* is attached by two pieces of strong catgut. By this arrangement any advance of *D* upon *G* extends the spring *A*, a light rod connected to the cross bar moves in the tubular shaft, and the projecting end actuates either a pointer *Q*, or an integrating apparatus not shown. With regard to the latter apparatus, the most convenient form perhaps is that in which a diagram of the work done is drawn on a sheet of paper attached to a revolving drum, as used in the ergometer of the late Mr. W. Froude and some others. The area of the diagram can be estimated by the well-known method of

the planimeter; or, if the paper is of great homogeneity, the area may be cut out and estimated by weight (this method is Morin's). The author finds that far the best results are obtained by the use of tinfoil or thin lead instead of paper, as paper is subject to damp and rapid variation of weight. In order that the instrument may be of considerable range, springs of different strengths can be easily interchanged. Since the weight of the indicating rod and bar is slight, the indications are dead-beat. A speed-indicator (this is Young's form of instrument), R, showing the number of revolutions at any instant, is attached to the hollow shaft, and is so placed that its reading and that of the tension-indicator can be seen at a glance. This is found sufficient for most purposes; but when continuous work is being done, such as charging a Faure battery, then the diagram-drum is attached.

For a continuous record, the following form of integrating apparatus has been also employed:—

Hydraulic Integrating Apparatus.

In using the ergometer, it is not always necessary to attach the recording drum, unless some special curve be sought for, such as that which is produced when the instrument is measuring the work done in charging an accumulator. The following apparatus has been devised by the author to take the place of a disk integrator.

A very small double-acting pump, D, oscillating about the point H, and having a long rod, E G, not shown at full length in fig. 3, is actuated by a link A B (rocking about the point B), to which reciprocal motion is given by the connecting-rod, C. This rod receives its motion from the revolution of the shaft; the position of the end of the pump-rod, E, and hence the length of the stroke, is controlled by the rod E F, which is con-

Fig. 3.

nected to the spring of the instrument, so that any extension of the spring moves E towards A, and consequently lengthens the stroke of the pump. Now, when no energy is being transmitted the spring of the ergometer is not extended and E has a definite position between C and B; and then the water discharged by the pump is proportional to the number of revolutions of the shaft; but as soon as energy is transmitted the spring is extended, and the discharge of water is increased by the stroke being thus lengthened: the discharge then becomes a measure of the work done in driving any given machine. Instead of a small pump, a ratchet arrangement was tried; but the results were somewhat inferior to those with the pump. The constants of the ergometer are found in the same manner as when a disk integrator is used.

The Speed-Indicator (second form, by the Author).

This is based on the principle involved in the velocimeter of Ramsbottom. In this instrument oil in a glass cylinder is caused to rotate, the depression caused by rotation being a measure of the number of revolutions. As this instrument does not admit of sufficiently close reading for the ergometer, the author uses mercury instead of oil; this is whirled in a cup with inverted edges. Into the centre of the mercury a fixed tube dips, the end of the tube in the mercury being of twenty times the capacity of the rest of the tube; the tube is partly filled with a tinted liquid; the column of liquid is supported by the mercury. Now, when the mercury is whirled the centre, in sinking, alters the capacity of the large end of the tube; and therefore the indications of the liquid in the small end of the tube are very large for any change in the depression of the mercury. The cup is caused to rotate by means of any two of a set of change-wheels, these wheels being used either to reduce or augment the speed of rotation of the cup as the case may require.

The speed-indicator is attached to the shaft driven by the engine, and not always to the ergometer itself, because in dealing with small amounts of work it is well that the work done in moving the speed-indicator should not be added to the work under test.

The central shaft was made of compressed steel, by Sir J. Whitworth Co.

Taunton, December 19, 1882.