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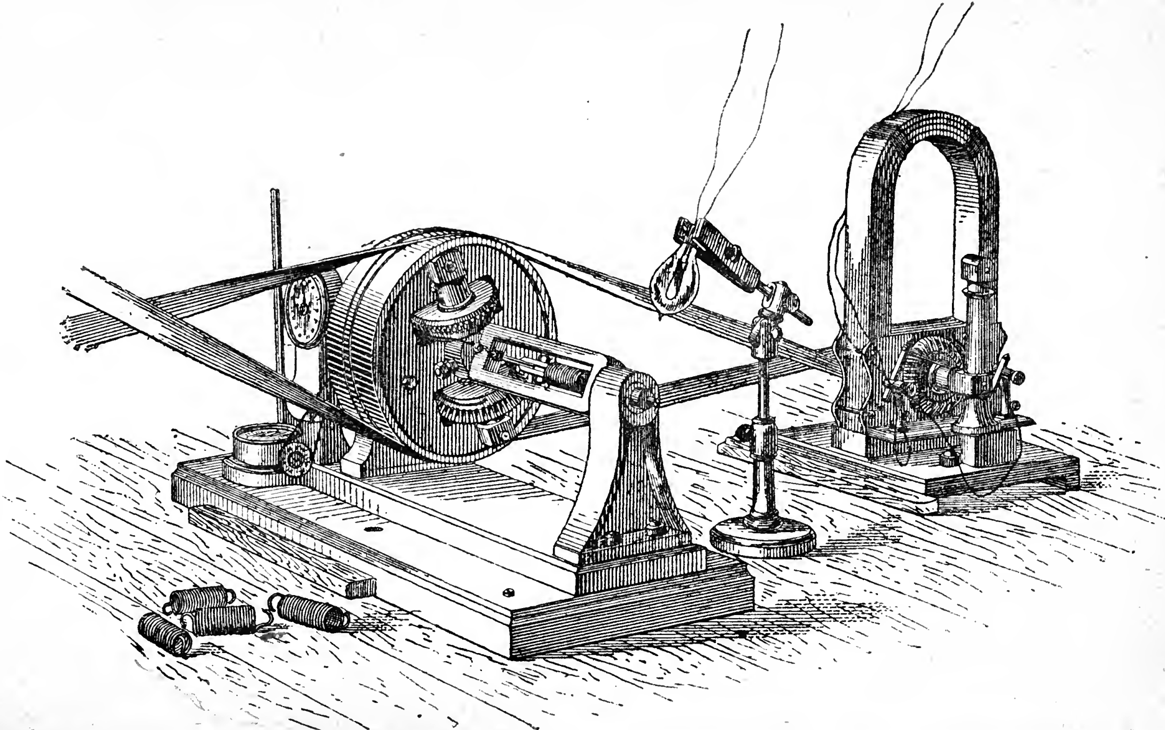
F. J. SMITH.



SMITH'S TRANSMISSION ERGOMETER. *See Fig. 4, Section (9).*

ON SOME

NEW FORMS OF

WORK-MEASURING MACHINES

AS APPLIED TO

Dynamos and Electro-Motors.

BY

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Introduction.

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[1] In the following pages will be found the results of some work which has been carried on by the author since the year 1880, the object in view being to produce some machines and apparatus for measuring the work done by electro-motors, and also the work done by prime movers, such as water wheels, turbines, steam and gas engines, in working dynamos. Two kinds of work-measuring machines have been dealt with, viz., the absorption machine and the transmission one.

Many questions of late as to how dynamos, &c., should be tested have led the author to publish the following few pages, in the hope that some of the methods shown may possibly be of use to others who may be engaged in this exceedingly interesting branch of measuring. Many of the methods have already been made known in a brief form in the *Electrician*, 1881, p. 261, *Electrical Review*, 1881, p. 397, *Philosophical Magazine*, vol. xv., pp. 87, 424, and vol. xvii., p. 59. The method of making an electro-motor or dynamo into its own ergometer is taken from a paper read in November, 1883, before the Physical Society of Bristol.

The word Dynamometer.

[2] The term dynamometer has usually been applied to that class of instruments by which weighing is performed by means of a spring, as in the dynamometer of Regnier and the Salter balance, and if the instruments were only used for this purpose the term dynamometer would be correct, coming as it does from the two Greek words δύναμις, force, and μέτρον, a measure. But the word dynamometer is also applied to that class of instruments by which *work* is measured. Now since *work** is force multiplied by length, the word dynamometer or force-measurer appears no longer to be the correct one to be applied to an instrument by which *work* is measured; for this reason the word ergometer, or work-measurer, from the Greek words ἔργον, a work, and μέτρον, a measure, will be used in this little book instead of dynamometer, as the name of that class of instruments by which *work* is measured.

* The abstract equations which express the "dimensions" of the Physical quantities, "velocity" and "acceleration," with respect to the fundamental quantities, length and time, are as follows. From this it will be clearly seen how Work is made up:—

	Units.	Dimensions.
	Fundamental—	
	Length	L
	Mass	M
	Time	T
	Derived—	
	Area = L × L	L^2
	Volume = L × L × L	L^3
v	Velocity = $\frac{L}{T}$	$L\ T^{-1}$
a	Acceleration = $\frac{\text{Velocity}}{\text{Time}} = \frac{L}{T^2}$	$L\ T^{-2}$
f	Force = Mass × Acceleration = $\frac{M\ L}{T^2}$	$M\ L\ T^{-2}$
	Work = Force × Length = $\frac{M\ L^2}{T^2}$ ...	$M\ L^2\ T^{-2}$

[3] If we wish to measure the work done by any engine, either steam, gas, or electrical, we could do so by causing it to wind up, by means of a drum and rope, a certain weight from a shaft in the earth of indefinite depth. Then the number of feet through which it is lifted per second, multiplied by the numerical value of the weight in pounds, gives us the work done in foot pounds per second. Since such an experiment could not be carried out, some constantly opposing force acting at a tangent to the face of the drum must be used instead of the weight lifted out of the shaft.

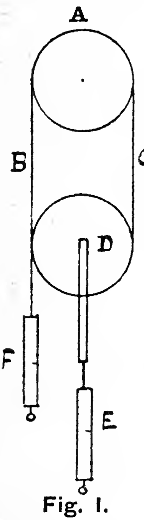


Fig. 1.

[4] This end may be obtained by using a friction break acting on the face of the drum; friction thus set up takes the place of the weight just mentioned. In Fig. 1 we see how this may be arranged: *A* is the side view of the drum driven by the machine which is being tested, this is partly covered by a cord or belt *BC*, which also passes round the wheel *D*, the pull of the spring *E* transmitted through the wheel *D* causes the pull on each of the sides *B* and *C* to be equal, and by means of an adjusting screw any necessary pressure may be put on. The spring balance *F* is attached to the side of the cord or strap *B* so that its pull is tangential to the face of the drum *A*, and the pull due to friction at the effective radius is shown on the scale of the spring balance *F*.

In using this instrument, the value of the pull on *F* in pounds is multiplied by the velocity of the circumference of the drum in feet per second; this gives foot pounds per second; or taking n the number of revolutions of the drum per minute, r the radius of the drum, w the pull on the balance *F*, and $\pi = 3.14159$.

$$\left.\begin{matrix}\text{Work done}\\ \text{per second}\end{matrix}\right\} = \frac{2\pi r n w}{60} = \frac{\pi r n w}{30} \quad \ldots (1)$$

[5] It will be noticed that this form or instrument, although springs are used, differs very materially from

Navier's* form; in it a drum was embraced by a belt and a spring balance was put on one side and a weight on the other until the required friction was produced, recently Navier's method appears to have been greatly improved on by Professor W. C. Unwin.† If the drum be made of cast iron, truly cylindrical and well polished, and the band be hard twisted cord, constantly lubricated, very good results may be obtained. Messrs. Ayrton and Perry‡ have recently invented a very beautiful form of friction ergometer, in which the friction is kept constant by the cord which passes over the drum being of different diameter on the two sides of the drum, which in their machine is a grooved wheel. The effect of any increase of the coefficient of friction is to wind the thicker end off the drum and at once reduce the coefficient of friction. Should the coefficient of friction diminish then the thicker end rises on to the drum and so the coefficient of friction is increased, the result of all this being that changes in the coefficient are compensated for rapidly and a practically uniform coefficient of friction is the result.

[6] When small electro-motors have to be tested great care should be taken not to introduce any extraneous friction from the instrument employed to measure the work done by them. To obviate this difficulty the author devised the following plan, first used in testing some Trouvé motors in the year 1881.

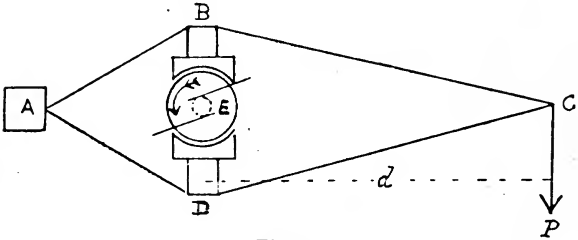


Fig. 2.

* Weisbach Mechanics of Engineering, vol. ii., p. 66.
† Paper read before G section British Association, 1883, by Professor W. C. Unwin.
‡ Proceedings Telegraph Engineers and Electricians, vol. xii., 346.

The motor as a whole is virtually converted into its own ergometer. The field magnets and frame are balanced with counterpoise weights so that the whole motor, when the axis of the armature is placed between suitable centres, is in equilibrium, the bearings in which the spindle of the armature runs are carried on friction wheels so as to prevent any unnecessary friction from the weight of the field magnets and frame. When the motor is doing work the reaction of the armature is against the field magnets and frame; now if the frame be attached to a spring balance and so prevented from revolving, the moment of the couple can at once be determined, and if the spring be applied to a point in the frame at a distance from the axis equal to the radius of the driving pulley, then the work done will be expressed by the equation (1) used in the question of the friction-break ergometer, the spring being so placed that the direction of its pull is tangential to the face of the driving pulley; or, instead of a spring, a lever and weight may be used, thus (see Fig. 2):—*B D* are the field magnets, *E* the armature. If the armature revolve within the field magnets certain tangential forces f_1, f_2, f_3 will be acting, tending to turn the frame *ABCD* and field magnets in the direction of the arrow, these forces acting at the effective radius will give us the moments $f_1r, f_2r, f_3r = \Sigma fr$ about the centre *O*, and we have another moment Pd, the whole frame without the weight P is balanced, so that the weight P alone acts at the distance d. When equilibrium in the system is obtained we have

$$\Sigma fr = Pd. \quad \ldots \quad \text{(A)}$$

Next take the angular velocity at a unit distance from *O*, then the work due to the above-mentioned forces for one revolution will be

$$\Sigma fr \, 2\pi.$$

Let n denote the number of revolutions per minute of the machine, and W_f the work done against the magnetic friction in a second, then

$$W_f = \frac{\Sigma fr \, 2\pi n}{60} \quad \ldots \quad \text{(B)}$$

Put the value of Σfr in (A) into equation (B) and we have

$$W_f = \frac{\pi n}{30} Pd.$$

Thus a dynamo-machine has become its own ergometer.

This process is reversed when a dynamo is tested on a similar system of supports; instead of the dynamo driving, it is driven. The same line of calculation as that given shows the amount of work done in giving its armature rotation when yielding a current.

There is a curious and interesting similarity in the action of the dynamo ergometer just mentioned and the turbine ergometer of the late Mr. W. Froude; in each the resisting couple increases as the velocity increases, the regenerative action in the turbine ergometer being closely allied to that of a dynamo during the period of time that the field magnets are getting saturated. This is only a rough statement of what takes place in each machine; the points of similarity are now being carefully compared and worked out.

[7] When dealing with small motors it is necessary to count the revolutions of the motor without introducing friction by attaching a speed-counter to the motor direct; the author's plan of doing this is as follows:—In the first experiments, one, of two cog wheels having the same number of teeth, was fixed on the spindle of the armature of the motor, the other was fixed on the spindle of a speed-indicator—Young's speed-indicator, now so much used, is a considerable improvement on the one used in these first experiments—two metallic springs pressed very lightly against the teeth of the cogs; in the earliest experiments these springs were placed on sound boards attached to resonators, so that a very loud and clear note was given out both by the wheel and spring attached to the motor, and the wheel attached to the speed-indicator, now when the speed-indicator was so driven by hand that the note produced by its spring and cog was of the same pitch as that of the spring and cog of the motor the speed of revolution shown by the indicator was recorded, and therefore,

evidently, the speed of the motor, because the same number of revolutions would give the same note in each instrument. When the revolutions are very high a wheel cut with three cogs will be found to answer.

This method has since given way to either of the two following plans, if the spaces between the cogs are filled up with a non-conductor, and turned off so as to be smooth, then a telephone and battery placed in circuit with the two wheels and springs on the motor and speed indicator tells one very accurately when the same note is produced by both motor and speed indicator. It will be found most convenient to use a telephone wound with two distinct circuits, one being in connection with the spring and wheel of the motor, the other in connection with the spring and wheel on the speed indicator. An attempt was made to affect the telephone by a current induced by that which was driving the motor, but experience showed that the former of these methods was the best. This way of measuring the revolutions, not only of electro-motors, but anything which is easily stopped by friction, might be introduced in many instances in the physical laboratory.

The Transmission Ergometer.

[8] It may be well to preface the description of this class of work-measuring instrument by showing briefly the general principle involved in Transmission Ergometers. Fig. (3) shows what has to be put into a practical form.

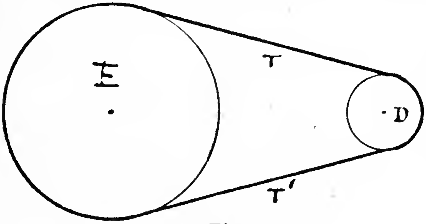


Fig. 3.

Let it be supposed that *E* is the driving wheel of a prime mover such as a steam engine, and that *D* is the pulley of a dynamo, and that *E* drives *D* by means of a strap; then if we could make spring balances parts of the strap *T T′*, and if we could read the difference of the tensions *T* and *T′*, and if we multiplied this *T*—*T′*, expressed in pounds by the velocity of the belt in feet per second, we should then have the foot pounds per second necessary to drive the dynamo, and from this the H.P. if we wished by dividing it by 550.

Or H.P. $= \frac{(T - T')v}{550}$ where v denotes velocity of belt in feet per second.

[9] Now since such an arrangement as this cannot be easily carried out the usual method is to place between the engine and dynamo some instrument capable of showing the tension of the belt in lbs. and the velocity of the belt, and in certain cases a continuous record of the work done. The following machine and apparatus has been devised by the author to obtain such a combination.

A side view of the machine Fig. (4) [see front page

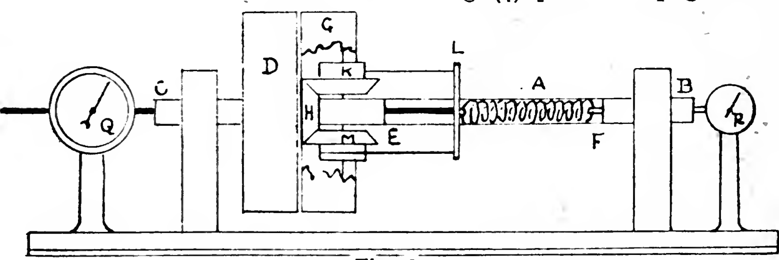


Fig. 4.

also], shows how the ergometer has been arranged. The central steel* shaft *C B*, which is tubular at each end and link shaped between *E F*, carries two pullies, *D* and *G*. *G* is keyed to the shaft, and carries two bevel wheels *K M*, these engage with the bevel wheel *H*, which is part of the pulley *D* which is loose on *C B*.

* The tubular steel shaft was made by Sir J. Whitworth and Co. of their compressed steel.

K and *M* are each furnished with a cylindrical drum, on these either gut or steel tape is coiled over three-fourths of their faces, and the gut or tape is attached to a cross head *L*, which is attached to the spring *A*, placed within the link, and from which a rod of steel passing through one end of the link actuates the pointer of the dial *Q*, whereby the pull on the spring attached to the end of the link is shown. *R* is the speed indicator.

If a continuous record of work is required the steel rod is attached either to a recording drum or to an integrating apparatus; see section (13).

The machine having been placed between a prime mover and a machine to be tested, the belt from the prime mover drives the pulley *D* and another belt from the pulley *G* drives the machine to be tested. The tension on the driving side of the belt causes the spring* to be extended by means of the bevel wheels, and therefore this tension is made known by the pointer of the dial *Q*. The instrument is calibrated by hanging known weights from strong thin cords or cat gut passing round the pullies and marking the dial in accordance with the weights.

[11] There is another method of calibrating which the author believes to be new; it is as follows:—Let a prime mover (a water wheel appears to be the most steady) drive the transmission ergometer, and let the ergometer drive a pulley on a shaft embraced by either a Prony, Appold or suitable friction ergometer, and let the work done against friction be calculated. This should agree with the results of the transmission machine. If it does we may conclude that it has been correctly calibrated. The advantage of this method is that the transmission machine is tested while running in its usual condition. When testing a dynamo care should be taken that the speed indicator be well attached to the shaft the velocity of which it is measuring. A piece

* The spiral springs were made by Messrs. Salter and Co. After many severe tests they seem to be quite unaltered in their value of pull. It is convenient to use four sizes of springs, which may be extended to two inches respectively by 50, 100, 150 and 200 lbs.

of coil spring such as is … in a dentist's lathe answers well to connect it to the … chine with.

[12] The leading fe… of this instrument is the position of the spring in … The axis of the spring and of the shaft coincide; … result of this is that it is hardly at all affected … centrifugal force. When a spiral spring is whirled … in the position it usually occupied in ergometers … liable to deformation from the effect of centrifugal … When springs of slight pull are used and the … meter is driven at a great velocity the deformatio… considerable, and would introduce considerable … into the result.

The deformation of … spring has been fully appreciated by Schuckert,* a… therefore he has placed the spiral springs of his erg… in cylindrical cases.

When the spring is … with its axis coincidental with that of the mach… no such error can be introduced, and the fricti… a spring against a case is avoided.

Reco… Drum.

[13] When a contin… record of work is required a cylinder not shown i… Fig. 4 (but shown in Fig. 9 to the right hand) is … d at the dial end of the instrument, it carries a … of paper which receives a continuous trace from … self-feeding ink pens; one pen is attached to the … which is moved by the extension of the spring, … it writes ordinates directly proportional to the am… of extension of the spring at any instant; the sec… pen, attached to the lever of an electro-magnet … tized by a current controlled by a seconds p… um, describes a V-shaped marking at each secon… third pen traces a datum line, the $o\,x$ line in geom… to which the ordinates are perpendicular.

The recording drum … be made to revolve at any convenient ratio to the … utions of the belt wheels.

* See list of Tran… sion Ergometers, p 30.

The Diagram of Work recorded.

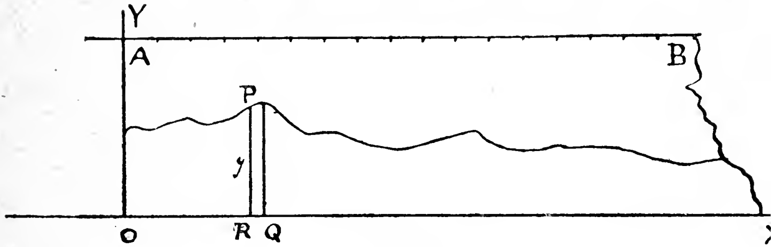


Fig. 4a.

[14] *OX* is the datum line previously spoken of, let the curve be referred to rectangular axes, the ordinate *y* represents the tension of the spring, and *RQ* is proportional to a small length of belt that has passed over the pulley of the machine, then the rectangle *PQ* represents the work done at the point *P* when the *RQ* is indefinitely diminished, if then we take the sum of all such rectangles we have the whole area of the curve, which therefore represents the work done during any time recorded on the time line *A B*.

For the purpose of seeing at a glance the value of the height of any of the ordinates of a curve traced out, it will be found convenient to have a rectangular wooden frame of the size of the edges of the diagram taken from the recording drum. Thin wires are stretched the long way of the frame, so that their distance apart equals the ordinate which represents any given pull of the spring experimentally determined.

Suppose that such a spring be used that the increase of extension is not directly proportional to the increase of weight (this is sometimes the case in very light springs), then if a frame be wired to suit the conditions of the extension of the spring it will enable one to make quickly a correct interpretation of the value of the ordinates of the diagram. The correction is very slight, but in certain experiments in connection with the mechanical equivalent of heat and the laws of viscosity it was necessarily introduced.

[15] The process of integration is carried out practically by cutting out the area of the curve and finding out by weighing how many times it contains the weight of a piece of paper the area of which represents a certain known amount of work done; if the paper be well selected and be of uniform thickness excellent results may be obtained, and by properly adjusting the speed of the drum, 1000 foot pounds may be represented by 0·5 grm. This method of calculating work-done by weight of paper is due to General Morin (see "Description des Appareils Dynamometriques," Morin.

Hydraulic Integrating Apparatus by the Author.

[16] 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 or secondary battery. The following apparatus has been devised by the author to take the place of a disc integrator.

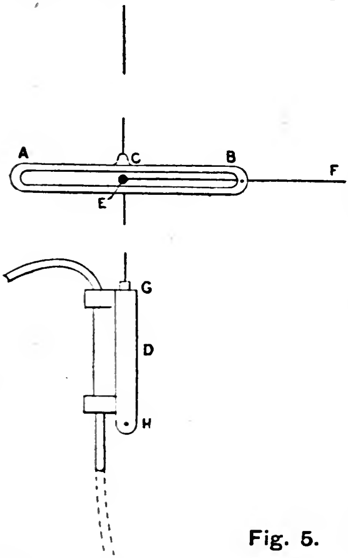


Fig. 5.

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. 5 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 *EF*, which is connected to the spring of the instrument, so that any extension of the spring moves *E* towards *A* and consequently

* For the method of making the connecting rod, virtually of infinite length, see p. 21.

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.

In this pump arrangement it will be noticed that the volume of the water discharged varies directly as the length of the stroke when the speed of the stroke is constant, and directly with the speed of the strokes when the length is constant, hence the volume varies directly as the product of these two, viz., length of stroke and speed when both vary; now since its speed is proportional to the speed of the belt, and the length is proportional to the tension, therefore the volume varies directly as the product of tension of spring by speed of belt, and is thus a measure of work done.

The Morin Disc and Roller Integrator.

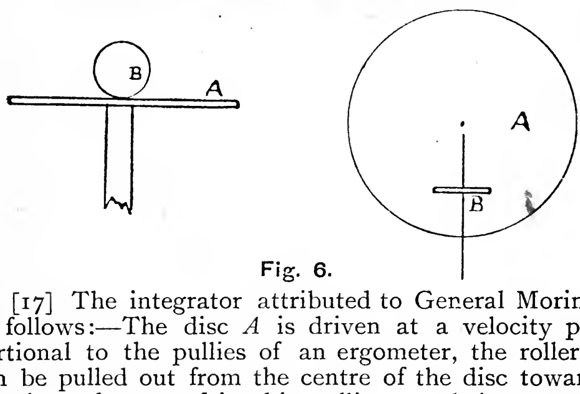


Fig. 6.

[17] The integrator attributed to General Morin is as follows:—The disc *A* is driven at a velocity proportional to the pullies of an ergometer, the roller *B* can be pulled out from the centre of the disc towards the circumference of it, this pulling out being proportional to the tension on the belt of the ergometer, the numerical value of the revolution of *B* becomes a measure of the work done.

Then it, when the roller is at any distance from the centre, the speed be constant the angular velocity of the roller is proportional to the tension. If the tension be constant, then the angular velocity of the roller is proportional to the angular velocity of the disc, and therefore when both the tension and the angular velocity of the disc vary together the angular velocity of the roller varies as the product of these two, and therefore is proportional to the tension of the belt multiplied by the velocity of the belt, or to the work done.

Beautiful as this arrangement is, there are two things which are somewhat against it. The first is that the roller in contact with the disc has a grinding action, and it has this because while the edges have the same linear velocity they have to travel in paths which are concentric circles on the disc by which the roller is driven. The second defect is that, since the roller has to be moved with its axis parallel to a radius of the driving-disc, its edge has to be *scraped* across the disc. The result of this is, that while a certain amount of friction is required to ensure good rolling contact this very friction prevents the roller from being easily moved with its axis parallel to a radius of the driving-disc.

[18] In the form of this apparatus devised by the writer of these lines * instead of the roller being solid

* See Phil. Mag., vol. xvii., p 59.

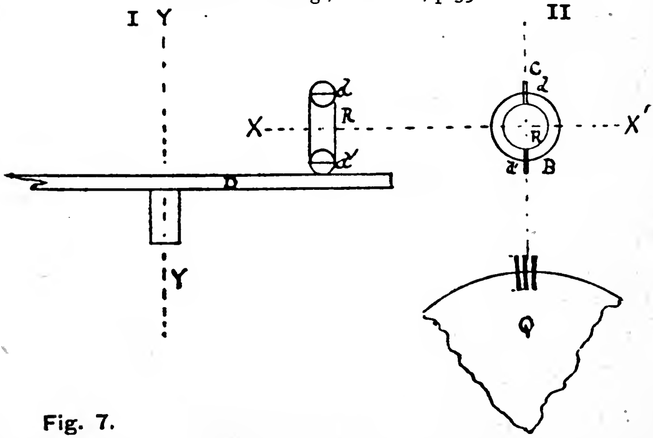


Fig. 7.

the face of it is notched in a dividing engine with a circular saw; each notch so formed carries a little disk, the edge of which is rounded to the curvative of the circle *C B*, Fig. 7; a ring of steel piano wire forms the axis of all the little disks placed round the circumference of the roller *R* (only two little disks *d* and *d'* are shown in Fig. II.). In Fig. 1 *D* is part of the large driving disk which drives the roller *R*, *Y Y'* is the axis of the disc *D*, *X X'* that of the roller *R*. The roller so constructed is found to move with the utmost freedom in the two directions required, and it will do so without any "slip," whether the motions are simultaneous or not so. By making the number of little disks large, and facing the disc *D* very carefully, the action even at an unnecessarily high speed is quite smooth and free from vibration. *Q* shows a portion of the roller, with only three disks attached, full size.

[19] Ratchet and link integrator by the author, Fig. 8, shows the construction, *L K* is a link vibrating about the point *M*. A connecting rod from the ergometer attached at *K* moves it to and fro, or it may in practice be driven much faster than the ergometer pullies by means of intermediate gearing, so that its vibrations are proportional to the revolutions of the pullies. The T-shaped piece *S* is controlled in its movement by the spring of the ergometer. Motion in the direction of the arrow would result from the extension of the spring. To this T-piece the piece *H* is attached by means of a rolling contact *R*. *E* is connected by the same device at *R'*. The piece *H* is connected to *F* by a pin which slides in the link *L*. The piece *E* works the two arc shaped pieces *C D*. These are furnished with pauls acting in opposite directions. The ratchet wheels are denoted by the inner circles, the outer ones denote cog wheels in gear at their point of contact. It is evident that whichever way *E* moves it will be driving round the wheels *A B*. These wheels drive an ordinary recording train of wheels. The arc ended pieces *H* and *F* are used so to connect the systems together that the effect is the same as if connecting rods of infinite length were used. What has been said about

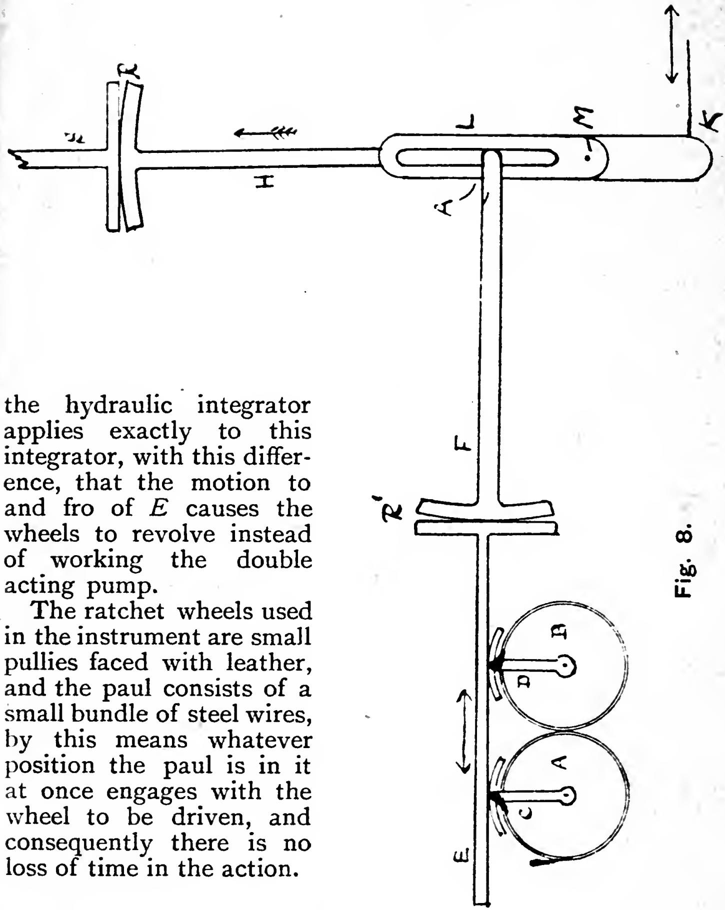


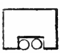
Fig. 8.

the hydraulic integrator applies exactly to this integrator, with this difference, that the motion to and fro of *E* causes the wheels to revolve instead of working the double acting pump.

The ratchet wheels used in the instrument are small pullies faced with leather, and the paul consists of a small bundle of steel wires, by this means whatever position the paul is in it at once engages with the wheel to be driven, and consequently there is no loss of time in the action.

Modification of the Differential Ergometer (White's), by the Author.

[20] The two pullies *A B*, each carrying a bevel wheel and running loose on the same fixed shaft, are in gear with a third bevel wheel of equal diameter, the axis of which is carried at right angles to the axis of the other two by a sector shaped casting. This sector while carrying the intermediate wheel is capable of angular displacement, this displacement being controlled by a spiral spring within the case *F*. The spring is so attached to the sector that its pull acts tangentially to it. An upper sector *H*, fixed to the under sector and counterpoised, carries the light rod *G D*, attached to the sector by two cross cords. The section of the rod is



thus, the cords lie side by side within the groove. A connection such as this prevents any "back lash" in the movement of the point *D*. The point *D* traces on the drum *E* an ordinate proportional to the extension of the spring. The drum is driven by a screw and tangent wheel at a given ratio to the speed of the pulleys *A* or *B*. The counter *K* records the number of revolutions. The area of the curve traced on *E* when interpreted, as in the case of the diagram previously mentioned, shows the work done. The hand wheel *L* was added to this instrument when it was exhibited in the International Exhibition of Electricity, Paris, 1881.* A lever *M*, carrying another tracer and controlled by an electro-magnet in connection with a seconds pendulum, records on the drum the time during which any experiment has lasted.

[21] A torsion ergometer (Fig. 10). This form of ergometer is very different from any already described. It was used to control the motion of a dynamo worked by a windmill. The first windmill to which this arrangement was applied was nearly destroyed by the storms of September, 1882, at Taunton. Since then the plan of placing the dynamo in the head cap of a windmill,

* This exhibit was awarded a medal and decree.

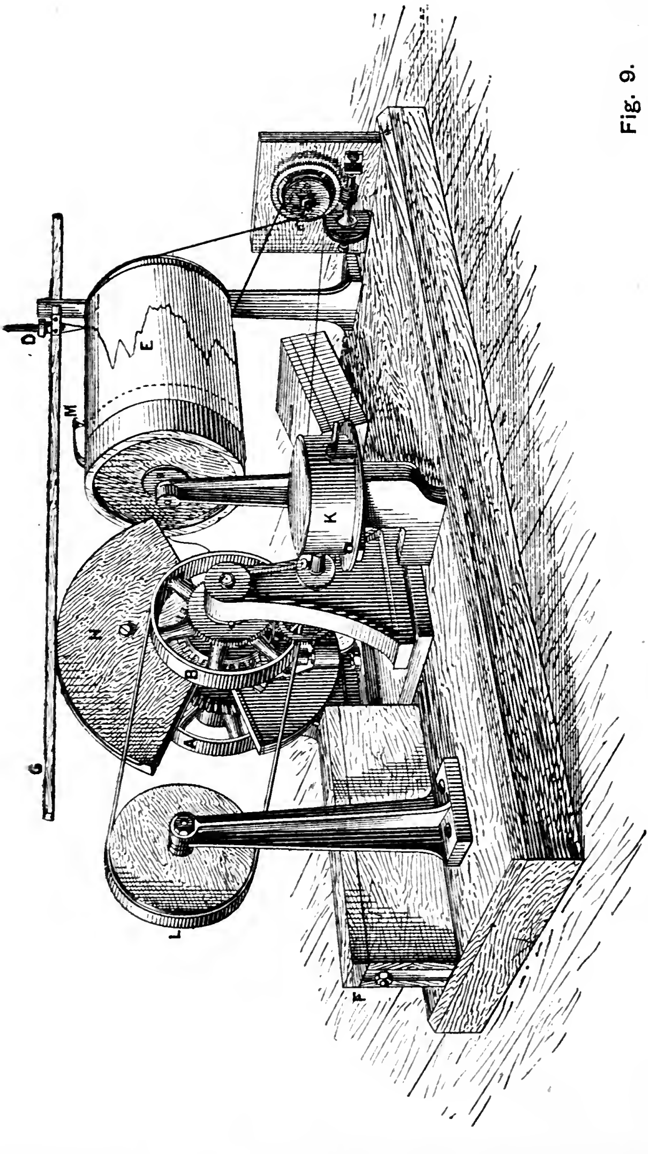


Fig. 9.

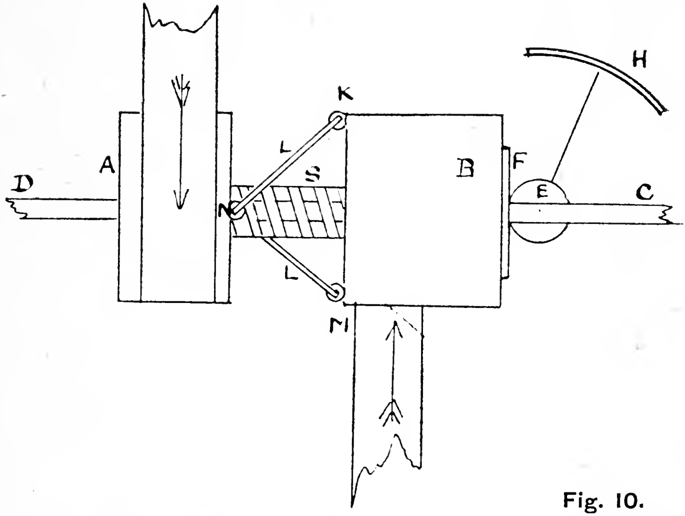


Fig. 10.

thus avoiding the introduction of long shafts to bring down the motion has been found to answer well, the conductors alone are brought down, the connexion with the head cap being made through rubbing contacts of copper on rings of the same metal. The wheel *B* is attached to the pulley *A* by means of two links, *L L*, as shown at *K M N*. The wheel *A* is fast on the shaft *C D*, and *B* is loose. If *B* be turned as shown by the arrow on the belt *M* the tendency of the links is to make the pulley *B* approach *A*, and thereby compress the spiral spring *S*. A gun-metal wheel *E*, kept by means of a spring against the disk *F*, which is part of the pulley, moves a pointer over the dial *H*, and thus the tension of the belt at the effective radius is read. A speed indicator is attached as in the other machines. The central spring at the end where it comes in contact with the pulley *B* is furnished with a sleeve which slides on the central shaft. The end face of the sleeve is grooved, and the part of the pulley opposite to this groove is also grooved in a similar way. Several steel balls are placed between the grooves, and render the contact between the spring and the pulley as frictionless as possible. The pulley *B* has a larger face than *A*, to permit of the slight side motion necessary to act on the spring.

[22] Mercurial speed indicator. This part of the apparatus belonging to the ergometer is based on the principle involved in the velocimeter of Ramsbottom. In his instrument oil in a glass cylinder is caused to rotate, and the depression of its surface caused by rotation is used to denote the velocity of the shaft to which it is attached. As this instrument does not admit of sufficiently close reading for the ergometer, mercury has been used instead of oil; this is whirled round in a cup with inverted edges *A* Fig. (11). Into the centre of the mercury a fixed glass tube (*B*) dips; the end of the tube in the mercury has fifty times the capacity of the rest of the tube. The tube is partly filled with a tinted liquid, the column of liquid being 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 this alteration of capacity, even when slight, is clearly shown by the displacement of the liquid in the stem of the tube. The cup is caused to rotate by means of any two wheels of a set of change-wheels attached at *C*, these wheels being used either to reduce or augment the speed of rotatation as any particular case might require. The relationship between the depression and the angular velocity is that the depression varies as the square of the angular velocity.

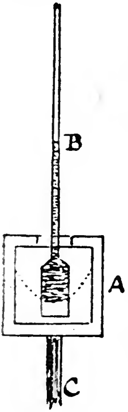


Fig. 11.

[23] When using ergometers in testing a dynamo or electro-motor, it is hardly, perhaps, necessary to mention that the mechanical h.p. may be compared at once with the electrical by testing the circuit with an Am-meter and Volt-meter during the trial. Instruments suitable for this purpose are the graded galvanometers of Sir W. Thomson, the Am-meters and Volt-meters of Professors Ayrton and Perry, and the combination instrument of Siemens.

[24] Electrical energy in terms of foot pounds and horse power.

A Watt, which is the received unit of power, is defined as "The power conveyed by a current of an Ampére through the difference of potential of a Volt," so that the Watt expresses the rate of an Ampére multiplied by a Volt.* The English horse power is equal to nearly 746 Watts, and the French Cheval de Vapeur to 735 Watts.

In the centimetre gramme second system the value of the Ampére is 10^{-1} C. G. S. units, and the Volt is 10^8 C. G. S. units; therefore the Ampére × Volt or Watt $= 10^8 \times 10^{-1} = 10^7$ C. G. S.

Now 1 foot lb. $= 1.356 \times 10^7$ ergs.†

$$\therefore \text{one erg.} = \frac{1}{1.356 \times 10^7} \text{ ft. lb.}$$

and the Watt or 10^7 ergs. $= \dfrac{1 \times 10^7}{1.356 \times 10^7} = 0.73747$ ft. lb. per sec. Now 550 ft. lb. per sec. = 1 h.p.

and $\dfrac{550}{0.73747} = 746$ nearly, so that there are nearly 746 Watts in the English horse power.

* See Report of the British Association, "Nature," vol. xxvi., p. 391.

† See *Units and Physical Constants*, by Prof. Everett, p. 16.

SHORT NOTES, WITH REFERENCES,
ON
TRACTION, FRICTION, AND TRANSMISSION, ERGOMETERS.

Traction Ergometers.

McDougales.—*Rees' Cyclopedia*, plate xxvi., vol. A.—This is one of the earliest machines of the traction ergometer type, the date of the plate is 1809. A spiral spring was placed between the load and the horse drawing it, the spring was furnished with a rack and pinion; by this means the extension of the spring was indicated on a dial.

Salmon.—*Rees' Cyclopedia*, plate xxvi., vol. A.—A similar device attached to a horse when working a horse-mill.

Morin.—*Description des Appareils Dynamometrique.*—A Poncelet spring balance, made of two flat springs, was placed between a wagon and the horse drawing it; the extension of the spring was recorded on a band of paper.

Messrs. Easton and Anderson.—*Report of Royal Agricultural Society.*—A machine for testing the draught of ploughs and implements. A spiral spring is placed between the horse and the implement drawn, a record of the work done is made by means of an integrating apparatus; a "dash-pot" is introduced to diminish the vibration of the machine when in use.

MM. Vaillemin, Guebard and Dieudonne.—*Spon's Dictionary of Engineering*, p. 1306.—A traction ergometer railway car, used to test the resistance of a train; in this machine a composite spring is used, one side of each spring being flat the other slightly curved; an integrating apparatus records the work done.

Smeaton.—*Tracts on Hydraulics*, p. 48.—Small windmills, having different forms of sails to be compared, were placed on the end of a radial arm to which motion could be given by means of a handle, this caused the windmill sails to strike against the wind and raise weights by means of a cord attached to a drum connected to the sails.

Transmission Ergometers.

INVENTOR: MORIN.—*Descriptions des Appareils Dynamometrique*.—Two pullies are placed on the same shaft, one of them is fixed, if the other, which is loose on the shaft, be angularly displaced with regard to the fixed one, its displacement deflects a straight bar spring, the centre of which is fixed to the shaft. A recording drum attached to the pullies and going round with them, records in the form of a diagram on a strip of paper, a curve, which being duly interpreted shows the work done.

MESSRS. EASTON AND ANDERSON.—*Report of the Royal Agricultural Society*.—Two pullies are used as in the preceding machine, instead of the bar spring two curved ones are used, and a continuous record of the work done is kept by means of an integrating apparatus of the disc and roller type.

HACHETTE.—*Mechanics of Engineering*, Weisbach, vol, ii., p. 46.—Three cog wheels are placed side by side in gear in the same straight line, the central one is attached to the end of a steelyard and is forced down when work is being done, the pressure on the cogs is estimated by means of the steelyard, this being known and also the velocity of the wheels, the energy transmitted may at once be adduced.

SHINZ.—*Mechanics of Engineering*, Weisbach, vol. ii., p. 49.—Essentially the same as the preceding.

RITTINGER.—*Same reference*.—The same improved; it is called the pillow-block ergometer. In this machine only two cog wheels are used, and the pressure on the bearing is used to indicate, as in the preceding machine. A portable hand machine similar in action to this is shown on p. 510 of *Spon's Dictionary of Engineering*.

WHITE. — *Spon's Dictionary of Engineering*. — Two pullies, each attached to a bevel wheel and running on the same fixed axis, are in gear with two other bevel wheels carried with their axes at right angles with the common axis of the former on a lever to the other end of which weights are applied, by this means the pressure between the cogs is measured, and the velocity being known, the energy transmitted is at once deduced.

FREDERICK J. SMITH.—See p. 22 of this book and p. 17 *Paris Electrical Exhibition list in Proceedings of the Telegraph Eng.*, 1881, also *Electrician*, Sept. 10, 1881.

7. WAGNER.—*Mechanics of Engineering*, Weisbach, vol. ii., p. 55.—Three bevel wheels are in gear instead of four as in White's, and the difference of pressure on the teeth of the wheels causes a lever carrying a weight at its end to be raised through an arc, as in an ordinary index balance for weighing letters; the pressure on the cogs is estimated by means of this.

HAGENBACH.—*Telegraphic Journal*, 1881, p. 65.—The same in principal as Hachette, a spiral spring taking the place of the weights in the former machine.

PROFESSORS AYRTON AND PERRY.—*Proceedings of the Soc. Tel. Eng.*, 1881, p. 163.—A fast and loose pulley on the same shaft are connected by means of four spiral springs, angular displacement between the two pullies causes the springs to be extended, the extension is made known by means of the change of position of a bright bead attached to a light lever moved by one of the pullies.

RAFFARD.—*Proceedings of the Soc. Tel. Eng.*, 1882.—A train of cog wheels are so arranged that the pressure on the teeth may be estimated by means of a lever and weights. The reference and diagram should be seen to understand the construction.

HARTIG.—*Polytech. Centralblatt*, 1857, No. 1; also *Separat-Abdruck aus dem Bayerischen Industrie-und Gewerbeblatt*, 1883, heft. i.—Six cog wheels are so engaged that the pressure on the teeth of a pair of wheels can be estimated by means of a Poncelet spring. The diagram of the machine should be examined.

FREDERICK J. SMITH.—*Philosophical Magazine*, vol. xv., p. 87.—Fully described in this book at pp. 13, 14, 15.

W. Froude.—*Proceedings Inst. Mec. Eng.*, 1858.—The tension of the belt driving a machine is measured while moving, the pullies over which it runs being placed on a scale-beam controlled by a spring balance, by it the tension of the belt is estimated, a recording drum is attached and by it a continuous record is kept of the work done.

Edison.—*Scribner's Monthly*, vol. xix., p. 543.—The driving belt of a dynamo is passed under a small pulley attached to a weight placed on the platform of a weighing machine, the tension of the belt when running causes the weight to be lifted and its force on the weighing machine to be diminished, by this means the tension of the belt is estimated and from it (the speed of belt being known) the horse power.

F. Von Hefner Alteneck.—Professor M. Schröter (*Separat-Abdruck aus den Bayerischen Industrie-und Gewerbeblatt*, 1883, heft. i.).—The difference of tension on the two sides of a driving belt is estimated by causing pullies over which it runs to be displaced. The reference should be consulted, the description is quite beyond the scope of a mere note.

E. Thompson.—*The Scientific American*, quoted from the *English Mechanic*, vol. xxxii., p. 607.—A modification of the machine of Alteneck. The tension of the driving belt is estimated by means of a steelyard and weights, the lever being so graduated as to read off horse-power at once, the velocity of the driving pulley being kept constant.

Emerson.—*Journal of the Franklin Institute*, Sept., 1882, and *Spon's Dic. Eng.*, p. 628.—This machine is designed to attach to any shop machine; the pulley of the machine to be tested is removed and is replaced by the ergometer, the tension of the belt causes a weight to be raised through an arc, as in the machine of Wagner, and a pointer on a dial shows the amount of tension, a speed indicator driven by a worm wheel gives the number of revolutions made by the machine.

Schuckert.—Professor M. Schröter (*Separat-Abdruck aus den Bayerischen Industrie-und Gewerbeblatt*, 1883, heft. i.).

—A fast and loose pulley are placed on the same shaft and they are connected by springs, as in Messrs. Ayrton and Perry's machine, but in Schuckert's machine the spiral springs are placed in cylindrical cases. The angular displacement of the two pullies is made known by means of a rod thrust out in the line of the axis of the wheels, and the machine registers its results.

RIELER.—*Same reference.*—Three cog wheels are in gear as in Hachette's machine, a spring taking the place of the weight in Hachette's, and a registering apparatus has been added.

Friction Ergometers.

PIOBART AND FARDY, 1820.—Applied a brake to determine the power of water wheels.

PRONY.—*Spons. Dic. Eng.*, p. 616.—A pulley or shaft of the machine to be tested is embraced by two jaws of wood; these jaws are furnished with an arm to which weight may be attached to prevent them being carried round with the shaft. When the shaft is running at its usual speed weights are applied to the arm till it assumes a horizontal position, then the moment resulting from the co-efficient of friction is balanced by the moment due to the weight on the end of the arm. From this the work done is calculated, as shown at page 8. The same sort of machine has been used by Lowell in his hydraulic experiments on turbines with the plane of rotation horizontal. See *Mechanics of Eng.*, Weisbach. Vol. ii., p. 67 for illustration.

PONCELET.—*Spons. Dic. Eng.*—To Prony's machine Poncelet added a rod at right angles to the end of the arm attached to the jaws, and pointing downwards. To the end of this rod the weights were attached. By this device if the coefficient of friction were to increase the weight would be carried into a new position, which would make its arm longer and its effect greater, and thus equilibrium would be restored.

APPOLD.—A pulley driven by the machine to be tested is embraced by a steel strap armed with wood blocks, which press against the pulley. The pressure of the strap is regulated by means of a lever, one end of which is fixed in a vertical line just under the axis of the pulley. To the other end of lever which hangs a little below the length of the strap the weighted side of the strap is attached by means of a short link. The other end of the strap is attached to the same lever at a point just within the length of the radius of the inner faces of the wood blocks. The effect of such a device is that if the coefficient of friction should increase, the weighted side of the strap is turned upwards. This causes the lever to be turned in the same direction and pressure to be taken off the strap. This at once restores equilibrium. The reverse takes place should the coefficient of friction decrease.

DEPREZ.—Two jaws are brought together by means of a similar lever to that used in the Appold machine, but the fixed point in Appold's becomes a weighted point placed in the line of the axis of the pulley on which the jaws act.

FROUDE.—*Proceedings of the Inst. Mech. Eng.*, July, 1877, p. 237. In this machine a turbine of peculiar construction takes the place of the pulley and wood jaws of the Prony machine. It will well repay the trouble of a close examination of the original description. *Spon's Dictionary of Engineering* gives a good history of it at page 513 supplement.

This is by no means an exhaustive list of the many forms of ergometers now used, but more have not been mentioned as they so nearly resemble some in this list, only differing in small details of construction.

A. HAMMETT, PRINTER, TAUNTON.