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A MODIFIED KROGH'S BICYCLE ERGOMETER.

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THE ergometer here described is the same in principle as that of Krogh [1913], but certain modifications and additions have been made which extend the usefulness of the machine for physiological purposes.

The modified ergometer has the following capabilities.

(1) Since it is built as a separate unit, it may be attached to any machine with a rotary motion.

(2) It may be made to function (like Krogh's) as a machine which will maintain a constant resistance under wide variations of speed.

(3) It may also be arranged so that the subject must work at a predetermined speed, the resistance being automatically increased if the subject tends to pedal too fast, and diminished if his speed tends to fall. Since, under these conditions, the load is constantly varying, the work done is recorded graphically on a kymograph.

The ergometer is chain driven from a bicycle or other apparatus. Its flywheel, 42·5 cm. in diameter and weighing 22·5 kg., consists of a copper disc with a peripheral lead rim, fixed to a shaft running in ball bearings. To one side of the hub of the wheel is fixed an eccentric. A roller, kept lightly in contact with this eccentric, actuates a veeder counter through suitable links. This method ensures accurate recording at high speeds.

To the other side of the hub is attached a fibre ring with a metal plate let into it over half of its circumference. Pressing on this ring are two small carbon brushes, from which leads may be taken to operate an electrical counter at a distance.

Mounted on ball bearings, coaxially with the flywheel, is a wrought iron rectangular frame to which are bolted four electromagnets, two on either side of the copper disc. The pole pieces of these electromagnets are brought as close as possible to the disc without actually touching it. A light girder, fixed to the frame, carries a scale pan supported on a knife edge $1/\pi$ metre from the axis of the flywheel. Attached to the under side of the frame is a large damping vane dipping into a tank containing syrup or other viscous fluid. The whole mass of the frame is counterpoised and is sensitive to 5 g. at the scale pan.

The electromagnet coils are connected in series, and derive their current from a potentiometer connected across the D.C. supply mains (Fig. 1).

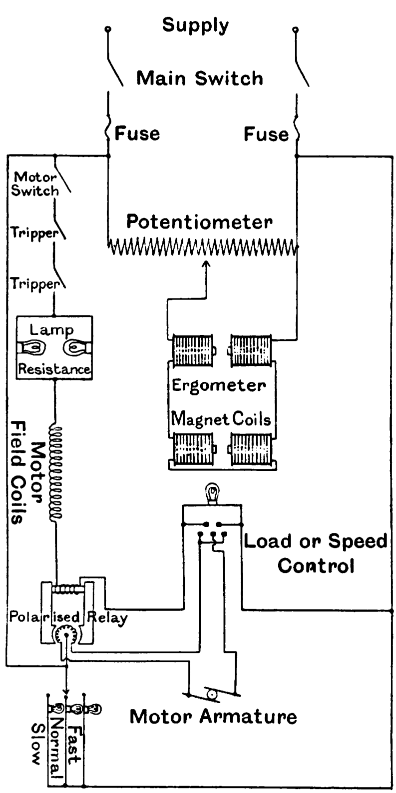

Fig. 1.

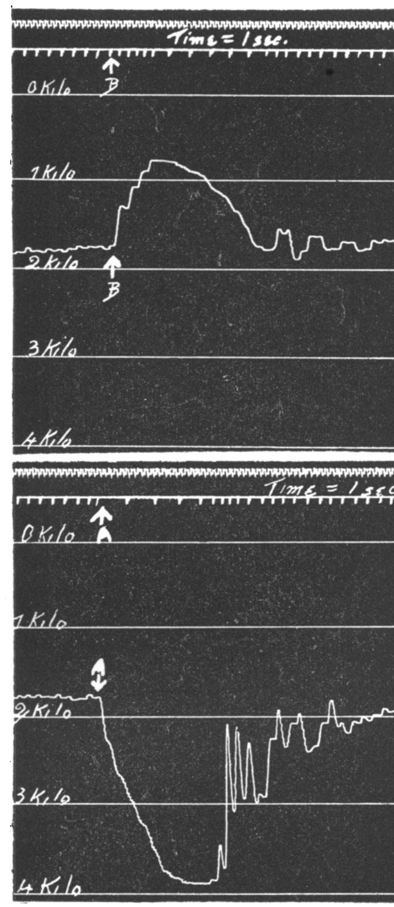

Fig. 2.

Fig. 2. Upper tracing: At *B*, subject voluntarily slowed down—load is immediately lightened until previous speed is regained. Lower tracing: At *A*, subject voluntarily speeded up—machine increases load and subject has to slow down to his previous speed.

The current passing through the electromagnets is controlled by the position of the movable contact on the potentiometer. This contact is mounted on a long screw, and may be driven in either direction by a small reversible electric motor. On one side of the top of the rectangular frame is fixed a slate piece with three contact studs. Over these three studs, which move with the frame, travel two roller contacts fixed to the ergometer stand. This arrangement forms a reversing switch for the electric motor and hence controls the direction in which the movable finger of the potentiometer travels.

Operation with load constant at any speed.

The switching mechanism described above serves to maintain the resistance applied to the ergometer flywheel constant, whatever the speed of rotation. If the latter increases, the production of stronger eddy currents in the copper disc makes the electromagnet frame rotate slightly in the same direction as the disc. This almost immediately, by bringing the appropriate contacts into operation, causes the electric motor so to move the potentiometer finger as to diminish the strength of the magnetic field in which the disc is spinning, and the frame returns to its original position. If the speed of rotation of the flywheel becomes slower, the weighted scale pan overcomes the weakened eddy currents, and the frame is pulled in a direction opposite to that of the flywheel's rotation. The electric motor is then actuated and moves the potentiometer finger so as to strengthen the magnetic field and to return the frame to its original position. The net result is that, whatever the speed, the electromagnet frame is maintained practically steady, the strength of the magnetic field being automatically kept so adjusted that the tendency of the frame to rotate with the disc is just balanced by the weight in the scale pan. The ergometer flywheel is thus rotated against the constant resistance of the weight in the scale pan. As in Krogh's design, the suspension of the scale pan is placed exactly $1/\pi$ metre from the axis of rotation of the disc, so that, if the load be in kilos, the work done per revolution of the flywheel is numerically equivalent to twice the load.

At either end of the potentiometer is fixed a tripper switch, automatically opened by an arm fixed to the travelling finger of the potentiometer. These prevent the travelling finger overrunning the screw in case of either a sudden stoppage or an excessive spurt of speed on the part of the subject.

Operation at constant speed, the load varying.

With the following modification of the apparatus, it is possible to keep the subject working at a constant speed, the machine automatically adjusting the load to the maximum which the subject can do at that speed.

In place of a fixed weight on the scale pan, the latter is attached to one end of a spring balance, the other end of the balance being fixed to the ergometer base-board. The balance is so arranged that it is extended and a greater load applied, the more the electromagnet frame tends to rotate with the copper disc. The wiring plan is similar, but the switching device is replaced by a similar one operated by a speed governor. This, originally an ordinary gramophone governor, has been modified and improved by one of us (A. R. S.), as follows. The original device has been replaced by a toggle-jointed governor, belt driven from a pulley on the flywheel axle. The switching mechanism consists of an ebonite block with six mercury pools recessed in it. Pivoted centrally above this is an ebonite beam having two strips of copper fixed parallel to its long axis. Each strip carries three dipping wires, the central pair being constantly immersed in the central mercury pools, and the two outer pairs, in the horizontal position of the beam, being held just clear of the outer mercury pools. These four outer pools are cross-connected, the whole arrangement acting as a sensitive reversing switch for the potentiometer control motor. A steel roller bears on the upper side of the beam, and is linked by levers to the sliding member of the governor, which acts against the pull of an adjustable spring. By means of an adjusting screw, the reversing switch can be moved nearer to, or farther from, the governor. The mechanism is set so that the roller is at the centre of the beam when the flywheel is rotating at the desired speed. If the speed alters, the governor moves the roller off the point of balance of the beam, thus bringing into operation one or other set of mercury contacts.

If the subject's speed becomes faster than that for which the governor is set, the switching mechanism actuates the electric motor, and through it the potentiometer contact, so as to increase the magnetic field. The electromagnet frame, being pulled in the direction of rotation of the disc, extends the spring balance and overloads the subject, thus reducing his speed. The converse occurs when his speed falls below that for which the governor is set.

Under these conditions the load is a varying one and has to be recorded graphically. This is done by fixing to the electromagnet frame a thread attached to a writing point recording on a smoked drum. The drum is driven from the ergometer flywheel itself, so that the horizontal movement of the writing point is a record of the flywheel revolutions, while its vertical movement records the load. The area enclosed between the actual load line and the zero load abscissa is thus a record of the work done. This area can readily be measured with a planimeter.

The tracing (Fig. 2) has been made to show how, when the subject has voluntarily attempted to vary his speed, the machine adjusts the load so as to force him back to the set speed. In an actual experiment, of course, such wide fluctuations in load do not occur; in the tracing shown, a purposely strong effort has been made to alter the speed in order to demonstrate the capabilities of the machine.

As shown in Fig. 1, a polarized relay may be introduced, if desired, to give visual indication to the subject of his speed variations.

Calibration of ergometer.

The power necessary to drive the ergometer unloaded, both with and without the constant speed governor, was determined as follows. The field and armature windings of a small electric motor were disconnected from one another and reconnected in separate circuits with the supply mains. In the field winding circuit was placed a milliammeter and a variable resistance; in the armature circuit, a second variable resistance, a voltmeter, and an ammeter. The electric motor drove the ergometer through its usual driving chain. An ordinary motor-car speedometer, friction driven from the ergometer flywheel, recorded the speed of rotation. By varying the resistances, the motor was set to drive the ergometer at a fixed speed. When the latter was constant, readings of all meters were taken.

The ergometer drive was now disconnected and a small brake-band dynamometer applied to the pulley of the electric motor, the tension of the brake band being adjusted until all the meters read as before. The work output of the electric motor was then calculated in the usual way from (dynamometer load × circumference of pulley × revs. of pulley per min.).

The following table gives the results of these calibration tests.

Revolutions of ergometer flywheel per min.	Energy required to rotate ergometer and cycle			
	Speed governor disconnected		Speed governor rotating	
	Kg.m. per min.	Cal. per min.	Kg.m. per min.	Cal. per min.
263	36·85	0·086	59·05	0·139
218	26·50	0·062	46·12	0·108
170	18·80	0·044	34·75	0·082
124	12·60	0·030	22·34	0·052
81	6·10	0·014	13·76	0·032

Summary.

A modification of Krogh's bicycle ergometer is described, which allows of work being done, not only at constant load as in the original design, but alternatively at a constant pre-determined speed, the load then being automatically adjusted by the machine itself to the capacity of the subject.

REFERENCE.

Krogh, A. (1913). *Skand. Archiv f. Physiol.* **30**, 375.