No 3589193

THE UNITED STATES OF AMERICA

TO ALL TO WHOM THESE PRESENTS SHALL COME:

Whereas, THERE HAS BEEN PRESENTED TO THE

Commissioner of Patents

A PETITION PRAYING FOR THE GRANT OF LETTERS PATENT FOR AN ALLEGED NEW AND USEFUL INVENTION THE TITLE AND DESCRIPTION OF WHICH ARE CONTAINED IN THE SPECIFICATION OF WHICH A COPY IS HEREUNTO ANNEXED AND MADE A PART HEREOF, AND THE VARIOUS REQUIREMENTS OF LAW IN SUCH CASES MADE AND PROVIDED HAVE BEEN COMPLIED WITH, AND THE TITLE THERETO IS, FROM THE RECORDS OF THE PATENT OFFICE IN THE CLAIMANT (S) INDICATED IN THE SAID COPY, AND WHEREAS, UPON DUE EXAMINATION MADE, THE SAID CLAIMANT (S) IS (ARE) ADJUDGED TO BE ENTITLED TO A PATENT UNDER THE LAW.

NOW, THEREFORE, THESE **Letters Patent** ARE TO GRANT UNTO THE SAID CLAIMANT (S) AND THE SUCCESSORS, HEIRS OR ASSIGNS OF THE SAID CLAIMANT (S) FOR THE TERM OF SEVENTEEN YEARS FROM THE DATE OF THIS GRANT, SUBJECT TO THE PAYMENT OF ISSUE FEES AS PROVIDED BY LAW, THE RIGHT TO EXCLUDE OTHERS FROM MAKING, USING OR SELLING THE SAID INVENTION THROUGHOUT THE UNITED STATES.

In testimony whereof *I have hereunto set my hand and caused the seal of the* Patent Office *to be affixed at the City of Washington this* twenty-ninth *day of* June, *in the year of our Lord one thousand nine hundred and* seventy-one, *and of the Independence of the United States of America the one hundred and* ninety-fifth.

Attest:

Edward M. Fletcher, Jr.
Attesting Officer.

William E. Schuyler, Jr.
Commissioner of Patents.

FORM PO 377A
(10-65)

ERGOMETER

BACKGROUND OF THE INVENTION

There is a wide variety of different types of such ergometers known to the art, the most common type being the externally powered tread mill, as well as units incorporating various types of weights, and the bicycle or pedal type of ergometer.

The usual prior art ergometer exhibits certain deficiencies. The most serious shortcoming is the fact that the forces presented to the muscles are not properly defined. It is known, for example, that the "efficiency" of a muscle is directly related to the nature of the load imposed on it. For example, a large pure resistance force rapidly tires the muscle.

Since a frequent present day medical use of the ergometer is to achieve high physiological workloads for prolonged periods, it is essential that the ergometer be a type which may be operated for such prolonged period without excessively tiring the patient. A feature of the ergometer of the present invention is that it can be used without excessive tiring for prolonged periods, so as to improve the efficiency of the cardiovascular system, a procedure known to the medical art as cardio-vascular conditioning.

It has been found that in order to maintain a relatively large workload on the patient for a prolonged period, as required, the muscles must be coupled to a load which will not tire them rapidly. The types and magnitudes of the forces applied to the muscles then become critical. It has also been found, in a manner analogous to mechanical engines, that the muscles require an inertial flywheel effect in some minimum ratio to other forces in order for them to function efficiently.

Specifically, the electrical ergometer of the present invention is particularly advantageous in that the various forces may be applied separately to the muscles in any desired magnitude in order to study muscle action. In addition, improved controls and instrumentation may easily be provided in conjunction with the electrical ergometer of the present invention to create, sense, display and record, rapid changes in forces, powers and work, as will be described.

The type of forces that may be applied to the muscles of the user by the improved ergometer of the invention may include the following:

$$F_1 = K (X \neq 0) \quad (1)$$

Where:

F_1 is a first type of force
X is the displacement
K is a constant.

The first type of force F_1 is exemplified by gravitational force or weight. In this case, X will be the vertical displacement of the weight above its resting position. It should be noted that the force F_1 is always mixed with inertia in nature.

$$F_2 = M \times A \quad (2)$$

Where:

F_2 is a second type of force
M is a mass
A is acceleration.

The second type of force is inertial force and is rarely encountered in pure form, except in freely falling bodies.

$$F_3 = R \times V^n \quad (3)$$

Where:

F_3 is a third type of force
R is resistance
V is velocity
n is a power depending on the source.

The third force may be considered a family of forces depending upon the value of n. The value of n may typically vary from $n=2$ in viscous drag type of devices; through $n=1$ in some types of eddy-current brakes, to $n=0$ X in sliding friction after a starting transient.

$$F_4 = K_2 \times AX \quad (4)$$

Where:

F_4 is a further type of force
K_2 is a constant
X is a constant.

This latter force F_4 is a spring force and is rarely encountered in nature.

As mentioned previously herein, the improved ergometer of the invention is constructed so that a variety of different forces, such as those described above, may be exerted on the muscles of the user, each in a controlled manner, so that any desired force balance may be achieved. The actual mechanisms embodying the invention may be of the linear type, or may be of the pedal type, as mentioned above.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1, 2, 3, 4A and 4B are schematic representations of instrumentalities by which the various types of forces described above may be exerted on the muscles of the user;

FIG. 5 is an electrical diagram, in conjunction with certain elements, and illustrating appropriate feedback loops for a torque motor so as to achieve the different types of forces developed in the electrical ergometer of the present invention; and

FIG. 6 is a circuit by which the various analogs of force, velocity, displacement, power and work, for example, are produced for recording purposes.

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENT

As mentioned above, FIGS. 1—3, 4A and 4B are schematic representations of elementary means for achieving the forces described above. For example, with respect to equation (1), i.e., $F_1=K$, this force may be achieved by constant force springs, such as the illustrated Negator spring assembly 10 in FIG. 1.

An elastic flat and set spring 11 is wound on a reel 12, and the end of the spring is coupled to a second reel 14. The second reel is mounted on a shaft 16 with a pulley 18. Then, as a force F_1 is applied to a belt 20, for example, wrapped around the pulley 18, the resulting rotation of the pulley causes the shaft 16 to rotate which, in turn, rotates the reel 14. When the reel 14 is rotated, it is resisted by the elastic set of the spring 11. The magnitude of the constant force F_1 may be controlled by the spring size, or by varying the radii of the reels 12 and 14, and of the pulley 18.

The second force, as represented by $F_2=M \times A$ in equation (2), is represented in FIG. 2 by a flywheel 30 which is mounted for rotation on a shaft 32, and which includes a pulley 34 on the shaft. Then, when the force F_2 is applied to a belt 36 around the pulley, the rotation of the pulley causes the flywheel to rotate so as to obtain a torque which is equal to the moment of inertia of the flywheel I multiplied by its angular acceleration $\ddot{\omega}$.

A simple mass supported on a low friction support could be used to achieve the force of equation (2), but it is simpler to use rotating masses, which may be mounted on ball or other low friction bearings, and subsequently translating the resulting torques into linear forces through a pulley and belt assembly, such as described above. The magnitude of the force F_2 may be controlled by selecting the mass and configuration of the flywheel 30, by varying its mass distribution or by selecting different radii for the pulley 34, or even by using a gear arrangement.

The force F_3 of equation (3) may be produced by the eddy-current brake 40 illustrated in FIG. 3. This particular eddy-current brake is a Faraday disc arrangement, and it comprises a highly electrically conductive disc 42 which is composed for example, of an appropriate nonmagnetic material, such as copper, aluminum or the like, and which is mounted for rotation within a U-shaped permanent magnet 44. The resulting force $F_3=R \times V^n$ which, in this case is $F_3=R \times V^1$, may be conveniently developed b the assembly shown in FIG. 3.

As before, a pulley **46** is mounted on a shaft **48** with the disc **42**, so that the torque may be converted to the linear force F_3 by means of an appropriate strap **50** which is wrapped around the pulley.

The magnitude of the force F_3 may be adjusted by selecting the strength of the U-shaped permanent magnet **44**, or by relative positioning of the poles, or by varying the gap between its poles. Also, the magnitude of the force is a function of the speed of the disc **42** and of its configuration.

The force $F_4=K_2 \times X$ set forth in equation (4) may be generated by a simple linear spring **52** such as shown in FIG. 4A, or by a coiled spring **54**, such as shown in FIG. 4B. In the latter instance, the coil spring **54** exerts an angular force on a shaft **56**, and a pulley **58** is mounted on the shaft. A belt **60** is wrapped around the pulley, so that the force F_4 is developed as the belt is pulled so as to rotate the pulley **58** and the shaft **56**. Magnitude of this latter force F_4 may be determined by the spring constants, or by the pulley ratio in FIG. 4B.

Although, as mentioned above, the mechanical ergometers described in the prior art are simple and reliable, and although they are self-contained units, they do not possess any high degree of flexibility insofar as the setting and adjustment of the various types of forces are concerned. For research purposes, for example, the electrical ergometer of the present invention, an embodiment of which is shown in FIGS. 5 and 6, has certain advantages.

For example, torque motors are rotary devices which have an output torque directly proportional to input current, with a sine wave response which is flat to $8-10^{13}$ seconds or less. Furthermore, torque motors have an appreciable torque at reasonable size and currents, and are capable of providing useful loads for ergometer purposes without the requirement for large gear ratios.

For that reason, the torque motor is used as a component of the embodiment of the electrical ergometer shown in FIG. 5. By means of appropriate feedback loops, as will be described, in a closed servo system, the various forces described above may be simulated. Also, the magnitude of the individual forces may be readily controlled electrically.

The electrical ergometer shown in FIG. 5, for example, includes a torque motor **10** which, for example, has a pulley **12** mounted on its drive shaft **14**, the pulley being driven by a pedal assembly **16** which comprises a further pulley **18** coupled to the pulley **12** by means of a belt **20**. The pulley **18** is rotated by pedals **22**, the assembly **16** being mounted in an appropriate frame, as is the torque motor **10** and its pulley **12**. The pulleys **12** and **18** may be toothed, and the belt **20** may be toothed for a more positive drive.

A linear tachometer generator **30** is mechanically coupled to the torque motor **10**, and the tachometer develops a signal E' which may be considered to be equal to the angular velocity of the torque motor $\dot{\omega}$. The torque motor **10** is energized by a constant current generator **32** which provides a constant current through the torque motor **10** for a given feedback load, regardless of speed. The current generator **32** energizes the torque motor and causes it to tend to turn in one direction. When the user operates the pedals **20**, he turns the torque motor in the opposite direction, causing the linear tachometer generator **30** to generate the signal E'.

A voltage E_0 is applied to the the current generator **32**, and this voltage is the sum of three separate voltages E_1, E_2 and E_3, the latter voltages being intended to represent the various forces described above. For example, the voltage E_1 is developed at the output of an operational amplifier **34**, whose input is connected to a constant voltage source E_k.

The operational amplifier **34** is shunted by a potentiometer R_1, and this potentiometer may be adjusted, so that the voltage E_1 has any desired constant value, with the operational amplifier **34** providing a low impedance source for the constant voltage. Also, the constant voltage E_1 may be set to any desired value, by an appropriate adjustment of the potentiometer R_1. The voltage E_1 is the electrical analog of the force F_1 of equation (1) which is a constant force. Also, this force may have any desired value, as determined by the setting of the potentiometer R_1.

The system of FIG. 5 also includes a multiple channel feedback loop. A first channel in the feedback loop includes an operational amplifier **36** which is shunted by a potentiometer R_2, and which is connected directly to the output of the linear tachometer generator **30**. The operational amplifier **36** produces the voltage E_2 which is the electrical analog of the force F_3 of equation (3). That is, the voltage E_2 varies with the velocity $\dot{\omega}$ as represented by E' applied to the input of the operational amplifier **36**. Therefore, the electrical analog of the force F_3 is also applied to the input of the current generator **32**.

The feedback loop includes a second channel incorporating a first operational amplifier **38** having its input coupled to the output of the generator **30** through a capacitor **40**, and shunted by a resistor **42**. The operational amplifier **38** produces a voltage E'' at its output which, due to the differentiating action of the circuit element **40** and **42** is equal to $d\dot{\omega}/dt$ which equals $\ddot{\omega}$. This latter voltage is translated by a second operational amplifier **44**, the latter amplifier being shunted by a potentiometer R_3. The operational amplifier **44** develops a voltage E_3 at its output, which is the electrical analog of the force F_2 of equation (2). That is, the voltage E_3 is proportional to the acceleration $\ddot{\omega}$ of the torque motor **10**.

The constant current generator **32** is activated by the voltage E_0, which is the sum of the voltages E_1, E_2 and E_3. This latter generator, therefore, causes the torque motor to exhibit forces when the pedals **20** are operated, and which are of different types, as represented by the equations (2), (3) and (4) set forth previously herein. Also, merely by adjusting the potentiometers R_1, R_2 and R_3, the different types of forces may have any desired magnitude.

Specifically, the rate of rotation of the torque motor **10** is converted to an analog voltage E' which is proportional to the angular velocity of the torque motor, and which becomes the signal which drives the inertia and resistance legs of the force generator. Specifically, the output torque T of the torque motor **10** is converted into a force F_S which is related as follows:

$$F_S \alpha T \alpha I A a E' =_0 = E + E_2 \mathrm{az} E_3 \quad (5)$$

$$= K_1 + R\dot{\omega} M\ddot{\omega} \quad (6)$$

The foregoing is analogous to:

$$F_S = F_1 +_2 + FA3$$

$$= K_1 + RV^1 \mathrm{ahz} MA \quad (7)$$

The spring force of FIGS. **4A** and **4B** is not included in the electrical ergometer of FIG. **5** because that force is seldom used. However, it could be added if so desired. Also, the resistance force could be changed to a viscous resistance RV^2, for example, by adding a multiplier for the voltage E_0. Since the potentiometers R_1, R_2 and R_3 may be easily adjusted to any selected value, the magnitudes of the various voltages E_1, E_2 and E_3 may be readily controlled and varied.

To make full use of the electrical ergometer of FIG. 5, for example, a record should be made of the instantaneous forces, displacements, power and work performed by the user. In mechanical devices, such as those described in the prior art, these records may be obtained, for example, from a strain gauge, and if the forces are converted to linear motion, they may be obtained by a velocity pickup. In the electrical ergometer of FIG. 5, for example, the desired records may be obtained in a simplified manner, and by a simple network, such as shown in FIG. 6.

In the circuit of FIG. 6, only the elementary analog computation is required to yield the needed analogs of force, velocity, displacement, power and work, for recording purposes. The simplified versions for the pedal ergometer, such as shown in FIG. 5, for example, can use much simpler instruments since only averages are important. For example, a simple tachometer, and a Veeder Root counter may be used with a gauge to indicate the various loadings.

As shown in FIG. 6, for example, the pedal drive for the torque motor **10** may be replaced by a drum **100** and a handle **102** which is coupled to the drum by a line **104** reeled about the drum. The motor then is driven by the user drawing the handle, with an appropriate ratchet arrangement being provided (not shown) so that reciprocally pulling the handle **102** causes the motor **10** to achieve a certain speed with a particular loading, as established by setting the potentiometers R_1, R_2 and R_3 in the circuit of FIG. 5. A strain gauge **106** is provided in the line **104**, so that a voltage may be developed which is proportional to the force exerted. It will be appreciated, of course, that a similar arrangement may be provided in conjunction with the pedal assembly of FIG. 5, so that a similar voltage may be generated which is proportional to the voltage developed by the pedal assembly. The resulting voltage E_1 from the strain gauge **106** is amplified in an amplifier **108**, so that a voltage E_1 is developed which is proportional to force. It will be appreciated, therefore, that a suitably calibrated instrument may be connected to the output terminal **110**, and the instrument may designate force directly.

In addition, the output E' from the tachometer generator **30**, which is proportional to velocity $\dot{\omega}$ may be applied to an output terminal **112**, and an appropriately calibrated instrument, connected to the output terminal would provide a direct indication of velocity.

The voltage E' which is proportional to velocity $\dot{\omega}$ may be integrated in a network including an operational amplifier **114**, and an integrating network made up of a capacitor **116** at its input, and a shunting resistor **118**, to provide an output voltage E^{V}. The latter voltage may be applied to an output terminal **120**, and a suitable voltmeter, or recorder, connected to the output terminal **120** may be calibrated to provide a direct indication of acceleration.

Likewise, the voltage E' may be applied to an operational amplifier **122** and associated differentiating network including a resistor **124** at the input to the differential amplifier, and a shunting capacitor **126**, so that a voltage E^{IV} is produced. The latter voltage may be applied to an output terminal **128**, so that an appropriately calibrated meter connected to the output terminal may provide a direct reading of displacement.

A multiplier circuit **130** of any known type may be connected into the circuit to receive the voltages E' and E_1, so as to produce a voltage E'' representative of force multiplied by velocity which equals power. The latter voltage may be applied to an output terminal **132**, so that the power developed may be directly indicated by an appropriate meter, or recorder, connected to that output terminal.

The voltage E'' may be applied through a resistor **134** to an operational amplifier **136**, the operational amplifier being shunted by a capacitor **138** to form an integrating network, so that a voltage E''' applied to an output terminal **140** is a direct indication of the work done, and this value may be directly indicated by a suitably calibrated voltmeter, or recorder, connected to the output terminal **140**.

The electrical ergometer of the present invention, therefore, is most advantageous in that the desired forces may be simulated with any desired magnitude by a simple potentiometer adjustment. Moreover, the resulting voltages developed within the system itself may be used to provide appropriate instrumentation voltages, so that simple meters may be used to display on a direct basis, and by suitable calibrations, the various parameters described in FIG. 6.

What I claim is:

1. An electric ergometer for imposing measurable work loads on the muscles of a user, including: an electric motor having a drive shaft; circuit means for energizing said motor so as to cause said drive shaft to tend to rotate in a particular direction; manually operable means mechanically coupled to said drive shaft for rotating said drive shaft in the opposite direction; electric generating means coupled to said motor for generating an electric signal having a value related to the angular velocity of said drive shaft in said opposite direction; and electric feedback circuit means connected to said generating means and to said energizing circuit means for creating a force in said motor opposing such rotation in said opposite direction and which is a function of said angular velocity.

2. The electric ergometer defined in claim **1**, and in which said electric feedback circuit means includes a network for differentiating the signal from said electric generating means so as to create an additional force in said motor opposing such rotation in said opposite direction and which is a function of the angular acceleration of the drive shaft in said opposite direction.

3. The electric ergometer defined in claim **1** and which includes a network for introducing a constant signal to said energizing circuit means for creating a constant additional force in said motor opposing such rotation in said opposite direction.

4. The electric ergometer defined in claim **3** and which includes adjustable potentiometers in said last-named network and in said feedback circuit means for setting the aforesaid forces created in said motor to predetermined values.

5. The electric ergometer defined in claim **1** in which said manually operable means includes a rotatable pedal assembly.

6. The electric ergometer defined in claim **1** in which said manually operable means includes a linearly movable assembly.

7. The electric ergometer defined in claim **1** in which said manually operable means includes means developing an electric signal representative of the force exerted on said manually operable means; and circuitry coupled to said last-named means for developing an electric instrumentation signal indicative of said force.

8. The combination defined in claim **7** in which said circuitry includes a network coupled to said electric generating means for developing further instrumentation signals indicative of the work performed by the user.

9. The electric ergometer defined in claim **1** and which includes circuitry coupled to said electric generating means for developing instrumentation signals representative of the angular velocity of said drive shaft.

10. The combination defined in claim **9** in which said last-named circuitry further develops an instrumentation signal representative of the angular acceleration of said drive shaft.

United States Patent

[11] **3,589,193**

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5131 Lancelot Drive, San Antonio, Tex. 78218
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[45] Patented June 29, 1971

[54] **ERGOMETER**
10 Claims, 7 Drawing Figs.

[52] **U.S. Cl.** .... **73/379 R,** 73/133
[51] **Int. Cl.** **G01l 5/02**
[50] **Field of Search** 73/133, 379; 272/73, 79

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ABSTRACT: An electrical ergometer capable of imposing measurable work loads on the user's muscles for medical and/or physical therapy purposes. The ergometer includes a torque motor with a plurality of controllable feedback loops for causing the motor to develop different types of easily adjustable forces as it is driven by the user.

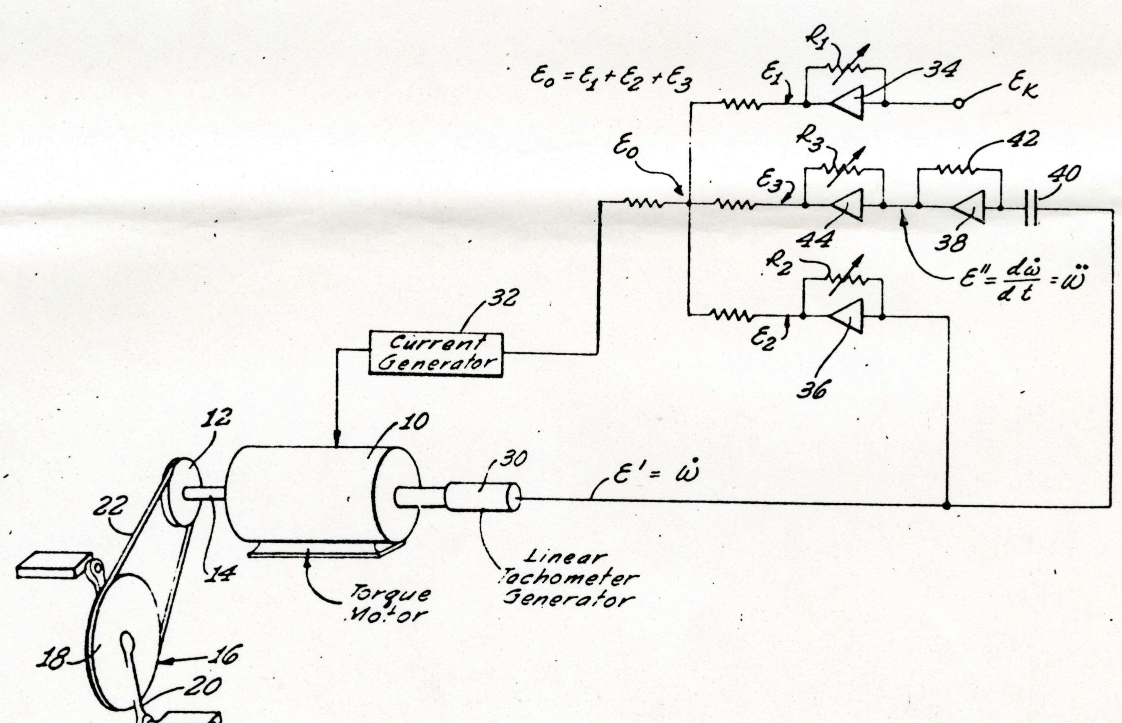

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Fig. 1

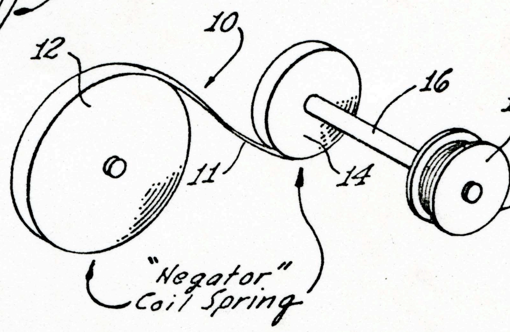


Fig. 2

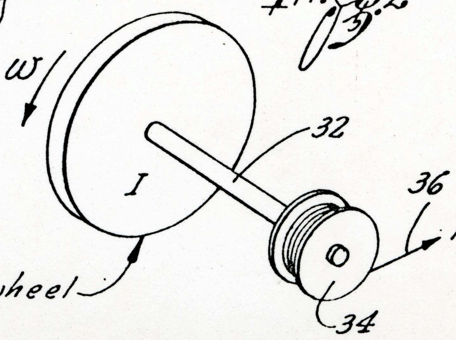


Fig. 3

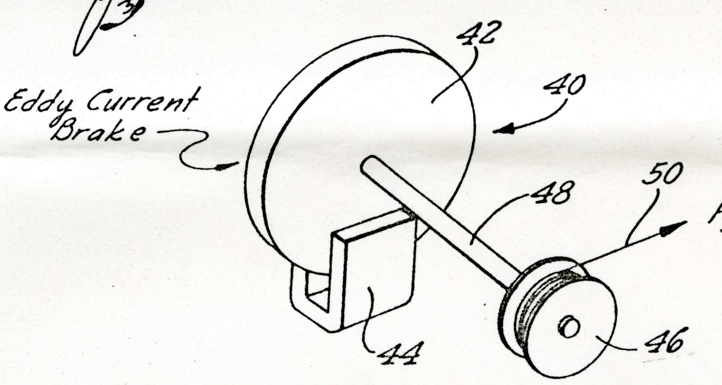


Fig. 4A

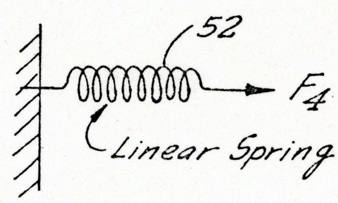
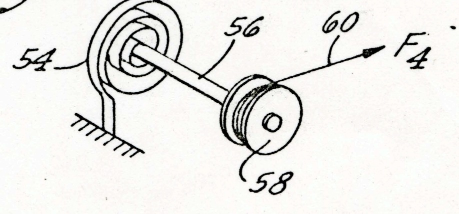


Fig. 4B



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[52] U.S. Cl.

[51] Int. Cl.
[50] Field of

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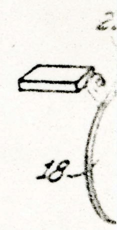

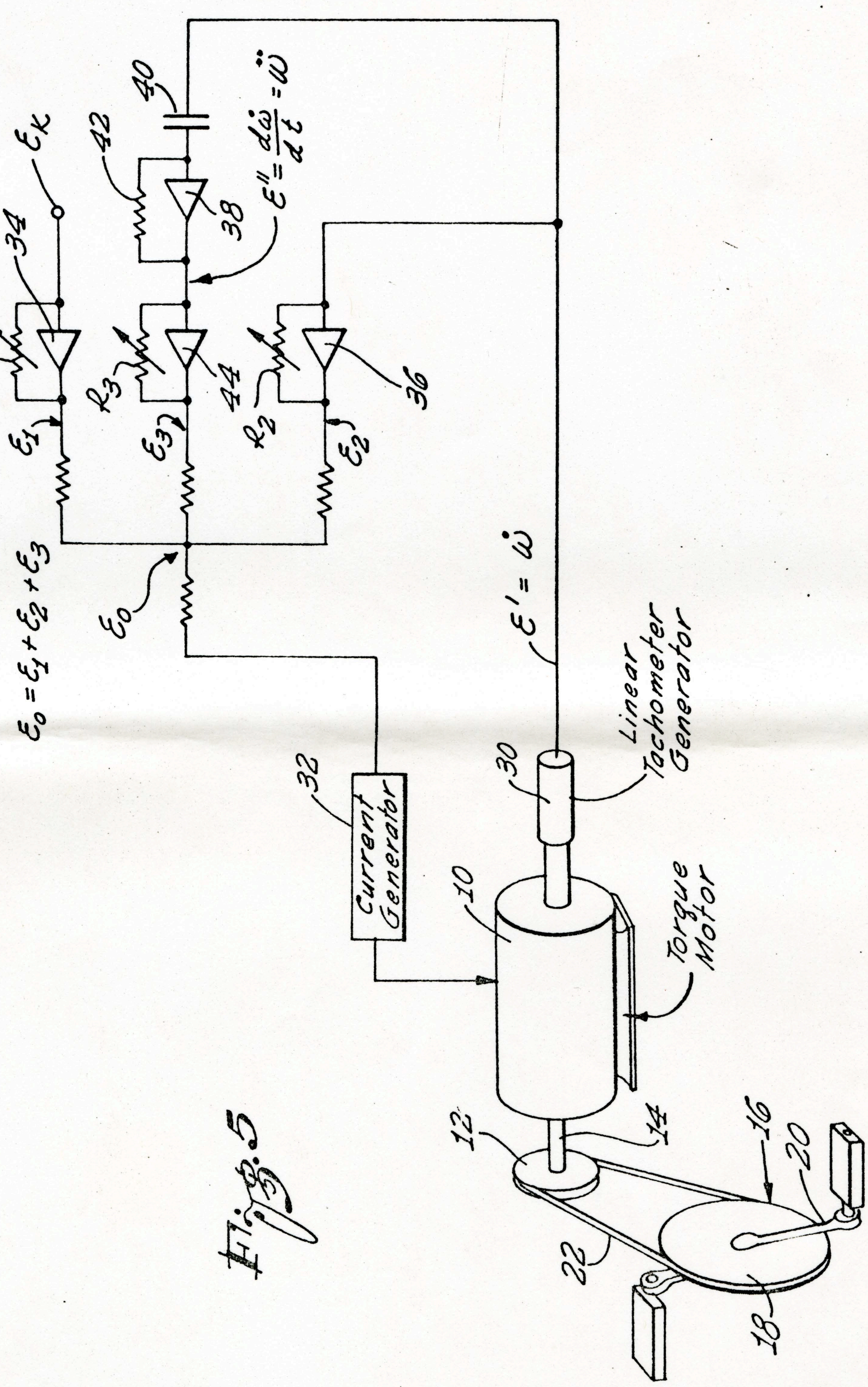

Fig. 5

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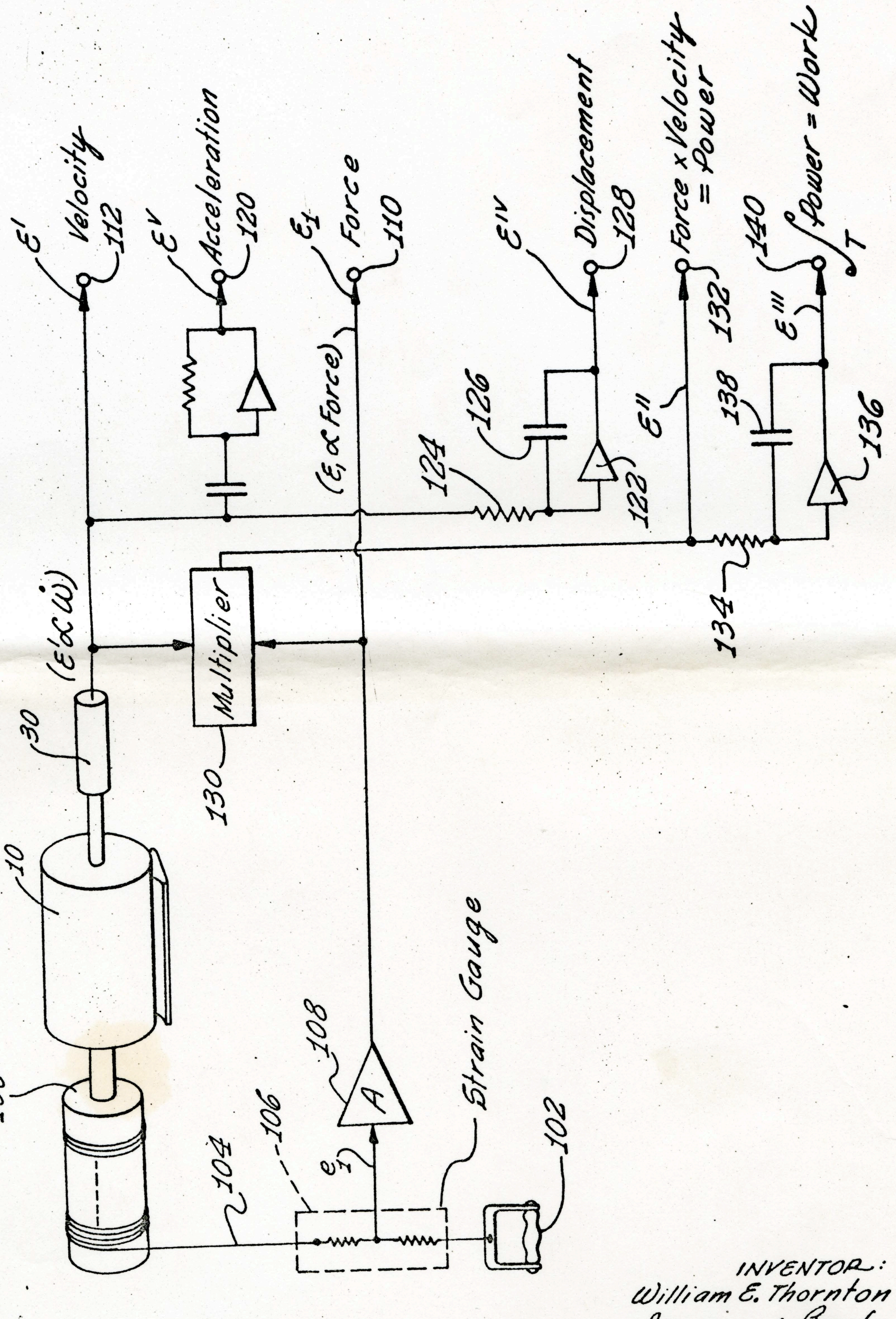

Fig. 6

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