

[54] ERGOMETER DEVICE

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1971, abandoned.

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272/DIG. 6

[51] Int. Cl. **A61b 5/04**

[58] Field of Search ... 128/2 R, 2 S, 2.05 R, 2.05 T,
128/2.06 F, 2.06 R; 272/69, 73, DIG. 6;
73/379 R

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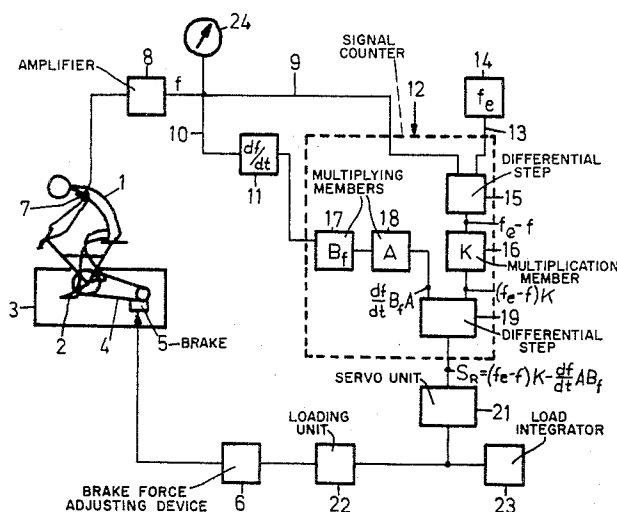
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[57]

ABSTRACT

An ergometer device consists of an exercise machine such as a pedalling device, braking means to control the force exerted by the operator upon the pedalling device, and control means to control the amount of application of the braking means. The control means are adjusted by means of a control signal which is developed by a continuous comparison of the pre-selected heartbeat rate as against the actual rate of the subject's heartbeat together with the alteration of the rate during the time period of use of the device.

4 Claims, 3 Drawing Figures



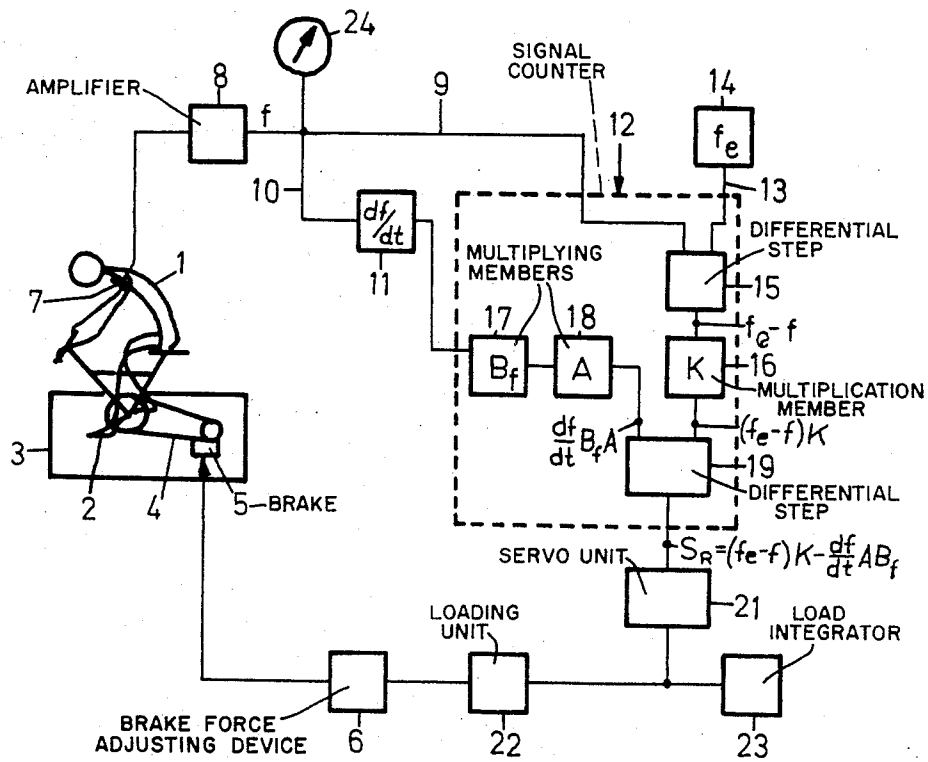


Fig.1

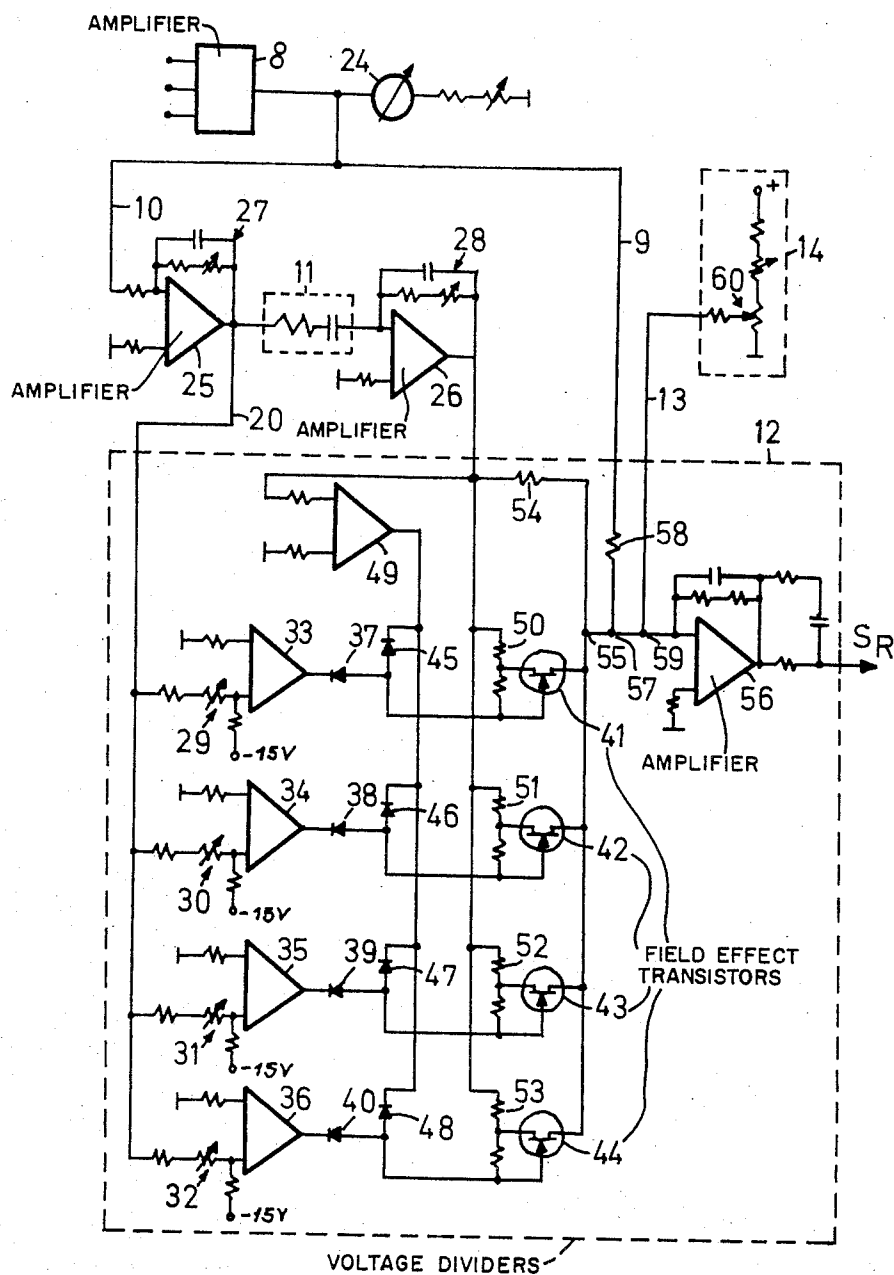


Fig. 2.

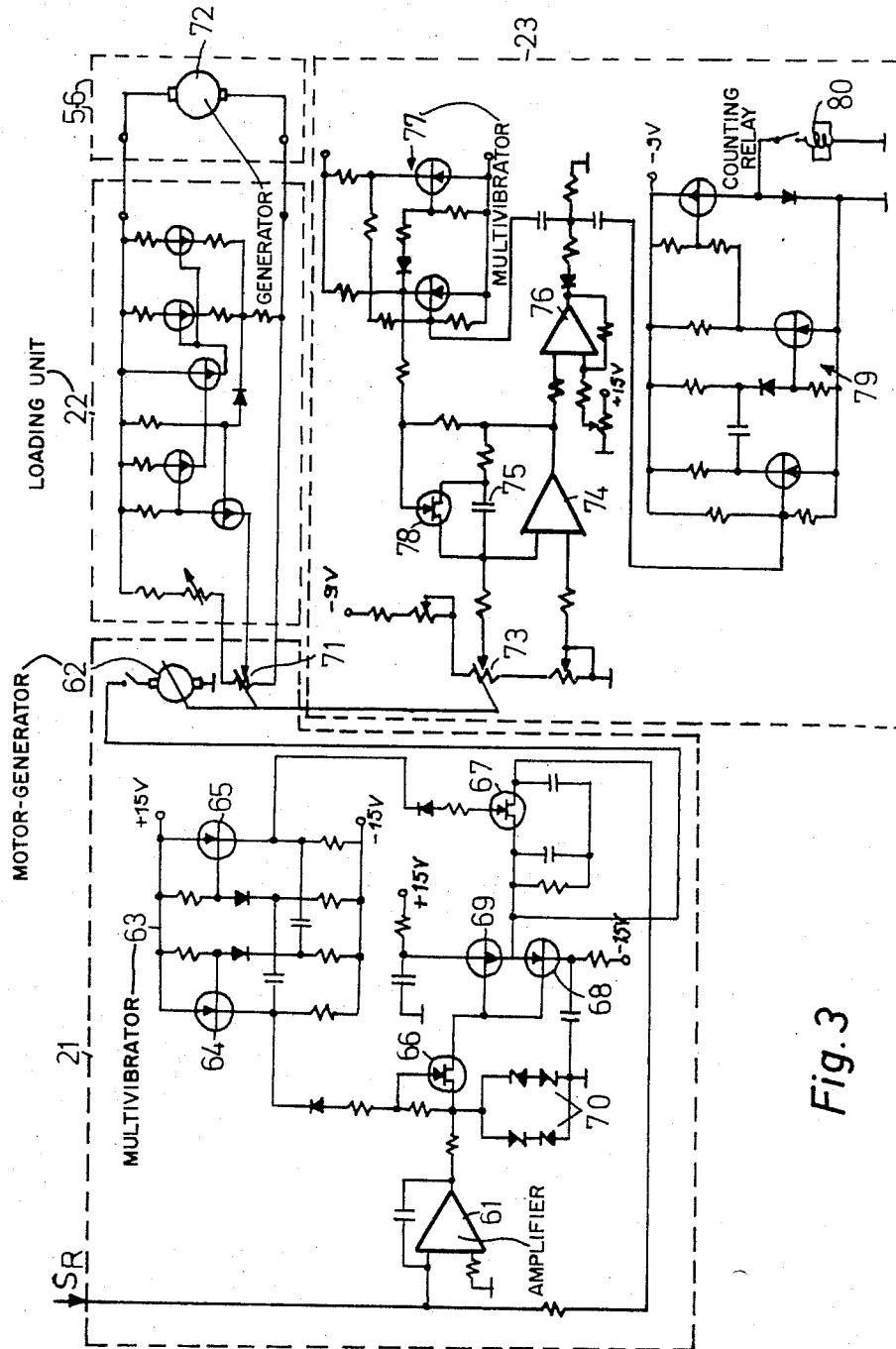


Fig. 3

ERGOMETER DEVICE

The present application is a continuation in part of an earlier patent application filed Sept. 29, 1971, Ser. No. 184,391. This earlier patent application is now abandoned.

This invention relates to an ergometer wherein the work to be applied by the person being examined is regulated depending upon a selected heart frequency value to a value corresponding to this selected frequency value.

An ergometer is a device utilized in various therapies particularly in recovery therapy of a patient after a heart attack or determination of the physiological performance capacity of a subject. The devices generally include a force exerting device (such as a pedalling device known as an ergometer bicycle), a braking device to permit application of differential forces upon the force exerting device, and control means to selectively apply the braking device.

In conventional devices of this type the work which is to be applied is not dependent upon the pedalling frequency of the user. Thus bicycles are so constructed that with increasing pedalling frequency the braking action is diminished while with diminishing pedalling frequency the braking action is increased. The patient can be then provided with predetermined constant work and his physiological operating capacity can be then determined by his actual heart frequency.

An ergometer of this type is not set to a constant work magnitude, rather the work is measured which the subject is capable of rendering at a given pre-selected heartbeat rate. The use of such ergometers affords notable benefits. For example, it is of decisive importance in rehabilitation after a heart attack that subject's heart may be subjected to a precise preselected workload, i.e. that the heart shall function at a pre-selected rate, and that the rate, for the subject's safety (against overload), shall not be exceeded, or shall not be exceeded in order to assure an optimum rehabilitation result. The ergometer can be operated without any additional medical supervision, as it is automatically provided that subject proper is never overloaded in a manner to threaten subject's health even in case of extremely low physiological performance capacity; consequently it is especially well suited for use in en masse examinations. The ergometer bicycle can also be used in work-physiological examinations in order to determine the bodily labor involved in a given type of activity. For this purpose it is only requisite that in the performance of such activity the rate of heart pulsation of subject be determined and the work to be done on the ergometer be adapted accordingly.

In heretofore utilized ergometers of the described type the regulation of the work to be accomplished to a value corresponding to the preselected heart frequency value, takes place solely by a regulating signal dependent upon the discrepancy between the desired and actual value of the subject's heart frequency. Practice has demonstrated that in a control process of this kind based merely upon the difference between the theoretical and the actual, the heart rate does not approach the pre-selected ideal FIGURE asymptotically, but that, rather, it builds up to such ideal rate for oscillating above and below it several times. When the ideal rate is exceeded, heart rates occur which can affect subject's circulation, especially when subject has poor

circulation, to an extent that could endanger the health and in extreme cases the life of the subject.

An object of the present invention is to avoid these drawbacks of existing devices.

Another object is the provision of an ergometer wherein dangerously high heart frequencies produced by exceeding the theoretical rates cannot occur.

Other objects of the present invention will become apparent in the course of the following specification.

In the accomplishment of the objectives of the present invention it was found desirable to affect the control by means of a control signal (S_R) produced by a continuous comparison between the pre-selected heart rate (f_e) and both the subject's actual rate at any given moment (f) and the temporary alteration (df/dt) of such actual rate.

In the ergometer according to the present invention, the strength of the control signal is not only affected, as in the known ergometers, by the ideal rate/actual rate discrepancy, but in addition also by any momentary alteration of the actual rate. If the effect of the actual rate alteration upon signal strength is such that the signal at any time is, in response to the degree of the actual rate alteration, more or less markedly diminished, (marked decline when there is a rapid increase in heart rate, slight decline when heart rate increase is less rapid), it is possible to bring it about that subject's actual heart rate shall approach subject's pre-selected heart rate asymptotically. The dangerously high rates far exceeding the theoretical or ideal, cannot then, as a matter of course, any longer set in.

In an advantageous embodiment of the invention, the control signal (S_R) is obtained by formation of the difference between a deviation signal proportional to the difference ($f_e - f$) between subject's ideal and actual rate and the rate-alteration signal that is proportional to the first heart rate differential. Thus the control signal is suitably formed pursuant to the equation:

$$S_R = (f_e - f) \cdot K - (df/dt) \cdot A \cdot B_f$$

where K and A are constants, and B_f represents a variable proportionality factor dependent upon the heart rate and the heart rate alteration polarity. Given positive polarity of the heart rate variation ($df/dt > 0$) the factor B_f should increase as rates increase and remain constant when polarity is negative ($df/dt < 0$), for all rates. Selection of such variable B_f factor will take into account the fact that like any other motor the heart accelerates less as load increases, that is, as the heart rate increases a further increase in rate within a given time period declines.

The B_f factor can be continuously altered. It will be sufficient however if factor B_f holds within definite rate levels to a constant figure. Sufficiently satisfactory results are obtained when factor B_f , ion function of heart rate f and the heart rate alteration sign df/dt , is established as:

60 a)	$df/dt > 0$		
	$B_f = 1$	at $f < 110$	beats/min
	$B_f = 2$	at $f = 110$ to 130	do.
	$B_f = 3$	at $f = 130$ to 150	do.
	$B_f = 4$	at $f = 150$ to 170	do.
b)	$df/dt < 0$		
	$B_f = 1$	for all heartbeat rates.	do.

An especially desirable asymptotic behavior of the heartbeat frequency is obtained when the control signal

(S_R) already at an ideal rate/actual rate variation ($f_e = f$) of 10 beats/min drops to zero. To this purpose it has been found advisable so to establish the constants K and A (with a corresponding B_f selection) of the variation or frequency alteration signal, that the zero position of the control signal is reached at the moment that

a)	$df/dt = +90$	beats/min ²	when $f < 110$	beats/min
	$df/dt = +45$	do.	do. $f = 110$ to 130	do.
	$df/dt = +30$	do.	do. $f = 130$ to 150	do.
	$df/dt = +22.5$	do.	do. $f = 150$ to 170	do.
	$df/dt = +18$	do.	do. $f > 170$	do.
b)	$df/dt = -90$	do.	for all heartbeat rates.	

The invention will appear more clearly from the following detailed description when taken in connection with the accompanying drawings showing by way of example only, a preferred embodiment of the invention idea.

In the drawings:

FIG. 1 is a basic diagram of the circuit of the present invention.

FIGS. 2 and 3 are detailed switch circuits of the diagram of FIG. 1.

The same structural parts are indicated with the same numerals throughout the FIGURES.

FIG. 1 shows a subject 1, who treats the pedals 2 of an ergometer bicycle 3. The tread motion of subject 1 can, by means of a brake 5 which engages transmission chain 4 of the wheel 3, be more or less forcefully braked. Setting of the desired brake force is then done by means of a brake force adjusting device 6.

An EKG electrode 7 applied to subject's body is used to taking the subject's heart signals. The signals are fed to a heartbeat frequency amplifier, which at its output produces an electric signal corresponding to the actual frequency rate at the time.

The output signals of the frequency amplifier 8 are carried over the line 9 direct and over line 10 via a differential stage 11 to a control signal counter 12. Over an additional line 13 there is attached to signal counter 12 additionally a frequency transmitter 14 for the ideal frequency f_e .

The control signal counter 12 consists essentially of a first differential step 15 for the formation of a signal corresponding to the ideal rate/actual rate deviation ($f_e - f$), with an after-attached multiplication member 16 for multiplication of the signal by the constant factor K , the signal being formed from either multiplying member 17 and 18 for multiplication of the output signal of differential step 11 by the factor B_f , and from the constant factor A and a second differential step 19 for the formation of the difference $S_R = (f_e - f) \cdot K - (df/dt) \cdot A \cdot B_f$. Factor B_f can be set manually, or automatically via control line, in function of the frequency f , to the previously described magnitudes.

The output signal S_R (control signal) of the control signal calculator 12 is conveyed to a motor servo unit 21, which, via a loading unit 22, controls the brake force regulating device 6 in function of the signal strength at the time prevailing. There is further connected up with motor servo unit 21 a load integrator 23 to calculate the work done by subject 1 during a pre-set time.

Construction element 24 represents a frequency indicator device that indicates the actual heartbeat frequency.

The described embodiment of the present invention operates in such a manner that every dangerously rapid

rate increase in the subject is, thanks to the thereby induced immediate debilitation of the control signal, via a corresponding reduction or fixing of the braking power of brake 5, picked up directly on transmission chain 4. As a result, subject's heart is never, not even briefly, over-strained, and instead subject's heart beat

rate asymptotically approaches the desired ideal count. If the timed duration with retained approximation of the actual to the ideal rate is to be reduced to a minimum, this can suitably be brought about by in addition connecting up the second differential counter to the first heart-rate differential.

According to FIG. 2 the outgoing signals of the heart frequency amplifier 8 are transmitted to the differentiating stage 11 (RC-member) through an operational amplifier 25 operating as an impedance changer. The differentiated signal (df/dt) is amplified in a further operational amplifier 26. Each of the operational amplifiers 25 and 26 has an RC-circuit 27, 28 for flattening the available outgoing signal.

The outlet of the operation amplifier 25 is connected through voltage dividers 29 to 32 (ohmic resistances) with the operational inlets of operation amplifiers 33 to 36 in the regulated signal calculator 12. The voltage dividers 29 to 32 are then so set that for heart frequencies $f < 100$ beats/min. all operational amplifiers 33 to 36 have a negative outgoing potential. However from 110 beats/min. the operational amplifier 33 is switched to a positive outgoing potential, from 130 beats/min. the operational amplifier 34 is switched to a positive outgoing potential, from 150 beats/min. the operational amplifier 35 and from 170 beats/min. the operational amplifier 36 are switched to a positive outgoing potential. Each switching of an operational amplifier 33 to 36 to positive outgoing potential results in the connection of a corresponding field effect transistor 41 to 44 through a rearwardly switched diode 37 to 40.

The operational inlets of transistors 41 to 44 are connected by further diodes 45 to 48 with the outlet of an operational amplifier 49. This operational amplifier is concerned with the existing polarity of the change in heart frequency. When the change in heart frequency has a negative polarity ($df/dt < 0$), the amplifier produces a negative outgoing signal which via diodes 45 to 48 prevents an actuation of transistors 41 to 44 through the operational amplifier 33 to 36. On the other hand, when the change in heart frequency has a positive polarity ($df/dt > 0$) the now positive outgoing voltage of the operational amplifier 49 frees the transistors 41 to 44 for actuation through the operational amplifiers 33 to 36.

Each actuation of a transistor 41 to 44 by an operational amplifier 33 to 36 causes the corresponding transistor to become conducting. This again results in a parallel connection of an ohmic resistance 50 to 53 connected in series with the corresponding transistor 41 to 44, with an ohmic resistance 54 switched at the outlet of the operational amplifier 26. The ohmic resistances 50 to 54 are selected to be equal to each other, so that in point 55 there is an amplification of the signal (df/dt)

in the ratio 1:2:3:4:5 for the individual heart frequency ranges of < 110, 110 to 130, 130 to 150, 150 to 170, > 170 beats/min.

The frequency changing signal produced in point 55 is transmitted to an operational amplifier 56. The operational amplifier 56 receives in point 57 the actual value signal of the heart frequency amplifier 8 via an ohmic resistance 58 and also receives in point 59 the desired value signal of the desired value giver 14 (setting of the desired value by the resistance potentiometer 60). The frequency change signal and the actual value signal are opposed to the desired value signal. Thus at the outlet of the operational amplifier 56 the desired regulating signal S_R is produced.

As shown in FIG. 3 the regulating signal S_R is transmitted to the inlet of an operational amplifier 61 in the motor servo unit 21. The motor servo unit is provided with a motor generator 62 operating alternately as a motor or as a generator. When the motor-generator operates as a generator, its speed is tested and a signal is produced corresponding to this speed. This signal is transmitted as counter coupling signal to the operational amplifier 61 switched as an integrator.

The outgoing signal of the operational amplifier 61 is broken up by a multivibrator 63 which consists in the usual manner of transistors 64 and 65, as well as ohmic resistances, diodes and condensers. The multivibrator 63 has on the outlet side field effect transistors 66 and 67 one of which is always closed while the other is conducting. When the transistor 66 is conducting the motor-generator 62 receives current through the transistors 68 and 69 for motor operation. When the transistor 67 is conducting the voltage is tested at the motor-generator 62, so that then the motor-generator 62 operates as a generator. A group of zener diodes 70 is used for limiting the speed of the motor-generator 62.

The motor-generator 62 drives mechanically the inlet potentiometer 71 of the loading unit 22. The loading unit 22 operates as an impedance changer and is used for adapting a direct current generator 72 acting as a regulatable brake 5 the outgoing output of which can go up to 400 watts, to the potentiometer 71. The loading unit consists of a differential amplifier which regulates the current of the generator 72 in such manner that this current is proportional to the setting of the potentiometer 71. The generator 72 is regulated to a constant voltage by the foot movements of the subject 1 and transmits, for example, a voltage of 85 volts.

The motor-generator 62 also drives the loading integrator 23 a second potentiometer 73 mechanically coupled with the potentiometer 71. The potentiometer 73 is located at the inlet of an operational amplifier 74 with an integrating condenser 75. Thus the inlet of the operational amplifier 74 receives via the potentiometer 73 a current proportional to the load of the subject.

A further operational amplifier 76 is switched after the amplifier 74 and is used to supply an outgoing impulse at a predetermined outgoing voltage value of the amplifier 74 produced on the basis of integration. The outgoing impulse starts a multivibrator 77 which discharges the integrating condenser 75 through a field effect transistor 78 and thus releases any further integration. Each outgoing impulse produced by the operational amplifier 76 is also transmitted through a transis-

tor amplifier 79 to a counting relay 80 which counts the impulses and the indication of which at the end of the measured time period constitutes a direct measure of the work carried out by the subject.

I claim:

1. An ergometer comprising, in combination, force exerting means adapted to be operated by a subject, braking means controlling the force to be exerted upon the force exerting means, and control means for determining the amount of braking force to be applied, a heart frequency measuring means enclosing electrodes connectable to the subject for producing an electrical signal corresponding to the real heart frequency f of the subject, an ideal heart frequency generating means for setting an ideal heart frequency f_e and producing an electrical signal corresponding to this ideal heart frequency f_e , a differentiator connected to the output of the heart frequency measuring means for producing the first derivative df/dt of the real heart frequency signal, and further comprising an electronic control signal calculator means connected to the outputs of said heart frequency measuring means, said ideal heart frequency generating means and said differentiator for calculating from the outgoing signals of said heart frequency measuring instrument, said ideal heart frequency generator and said differentiator a control signal S_R pursuant to the equation

$$S_R = (f_e - f) \cdot K - (df/dt) \cdot A \cdot B_f,$$

where K and A are constants and B_f is a variable proportionality factor, said calculator means including means to provide said proportionality factor as a function of both the real heart frequency f and the polarity of the real heart frequency alteration df/dt , which factor B_f in the presence of a positive polarity of the heart frequency alteration ($df/dt > 0$) increases with higher real heart frequencies, remains constant in the presence of negative polarity ($df/dt < 0$), said control signal S_R is connected to the input of said brake control means for controlling said brake control means to produce a higher amount of braking force when the strength of the control signal increases, and a lower amount of braking force when the strength of the control signal decreases.

2. An ergometer as described in claim 1, wherein the said producing means includes control means connected to the outputs of said heart frequency measuring instrument and said differentiator for automatically controlling the factor B_f in function of the real heart frequency f and the polarity of the heart frequency alteration df/dt as follows:

a)	$df/dt > 0$		
	$B_f = 1$	at	$f < 110$
	$B_f = 2$	do.	$f = 110$ to 130
	$B_f = 3$	do.	$f = 130$ to 150
	$B_f = 4$	do.	$f = 150$ to 170
	$B_f = 5$	do.	$f > 170$
b)	$df/dt < 0$		
	$B_f = -1$	for all real heart frequency rates.	

3. An ergometer as described in claim 1, wherein said electronic control signal calculator means includes calculating means for calculating the constants K , A so that the frequency alterational signal ($df/dt \cdot A \cdot B_f$) corresponds in strength to a variation signal $(f_e - f) \cdot K$ of 10 beats/min when

a)	$df/dt = + 90$	beats/min ² at	$f < 110$	beats/min
	$df/dt = + 45$	do.	$f = 110$ to 130	do.
	$df/dt = + 30$	do.	$f = 130$ to 150	do.
	$df/dt = + 22.5$	do.	$f = 150$ to 170	do.
	$df/dt = + 18$	do.	$f > 170$	do.
b)	$df/dt = - 90$	beats/min ² for all real heart frequency rates.		

4. An ergometer as described in claim 2, wherein said providing means of said electronic control signal calculator means for controlling the factor B_f comprising in combination first circuit means, operational amplifiers, connected to the output of the real heart frequency measuring instrument, and producing one output signals when the real heart frequency f increases in said steps $f < 110$, $f = 110$ to 130 , $f = 130$ to 150 , $f = 150$ to 170 , $f > 170$ beats/min, and second circuit means connected to the output of said differentiator for producing an output signal corresponding to the polarity of the signal df/dt , third circuit means connected to outputs of the first and second circuit means and connect-

ing the output signals of the first circuit means to switching means, such as switching transistors only in that case when at the same time, at the output of the second circuit means exists an output signal corresponding to a positive polarity of df/dt , said switching means setting amplifying means connected to the output of said differentiating device for an amplification of the signal df/dt in the ratio 1:2:3:4:5 corresponding to the appearance of outgoing signals of the first circuit means in the steps $f < 110$, $f = 110$ to 130 , $f = 130$ to 150 , $f = 150$ to 170 , $f > 170$ beats/min.

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