



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON, D.C. 20546

N73-27941

(NASA-Case-MFS-21109-1) ERGOMETER Patent
(NASA) 8 p CSCL 06B

00/05 Unclas
10039

REPLY TO
ATTN OF: GP

TO: KSI/Scientific & Technical Information Division
Attention: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General Counsel for
Patent Matters

SUBJECT: Announcement of NASA-Owned U.S. Patents in STAR

In accordance with the procedures agreed upon by Code GP and Code KSI, the attached NASA-owned U.S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No. : 3,744,480
Government or Corporate Employee : U.S. Government
Supplementary Corporate Source (if applicable) : _____
NASA Patent Case No. : MFS-21,109-1

NOTE - If this patent covers an invention made by a corporate employee of a NASA Contractor, the following is applicable:

Yes No

Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of column No. 1 of the Specification, following the words ". . . with respect to an invention of . . ."

Elizabeth A. Carter

Elizabeth A. Carter
Enclosure
Copy of Patent cited above

[54] **ERGOMETER** 3,518,985 7/1970 Quinton 128/2.06 R
 3,675,640 7/1972 Gatts 128/2.05 R
 [75] Inventors: **Raymond L. Gause; Bobby G. Bynum**, both of Huntsville, Ala. 3,505,992 4/1970 Jaeger 128/2 S
 3,323,366 6/1967 DeLorme, Jr. et al. 73/379
 3,189,344 6/1965 Swarts 272/73 X

[73] Assignee: **The United States of America as represented by the Administrator of the National Aeronautics and Space Administration**

Primary Examiner—Kyle L. Howell
Attorney—L. D. Wofford, J. R. Manning et al.

[22] Filed: **Nov. 29, 1971**

[21] Appl. No.: **202,769**

[52] U.S. Cl. **128/2.05 R, 73/379, 128/2.06 R, 272/73**

[51] Int. Cl. **A61b 5/02**

[58] Field of Search **128/2.05 R, 2.06 R, 128/2.06 F, 2.1 R, 2 R, 2 S; 272/73; 73/379**

[56] **References Cited**

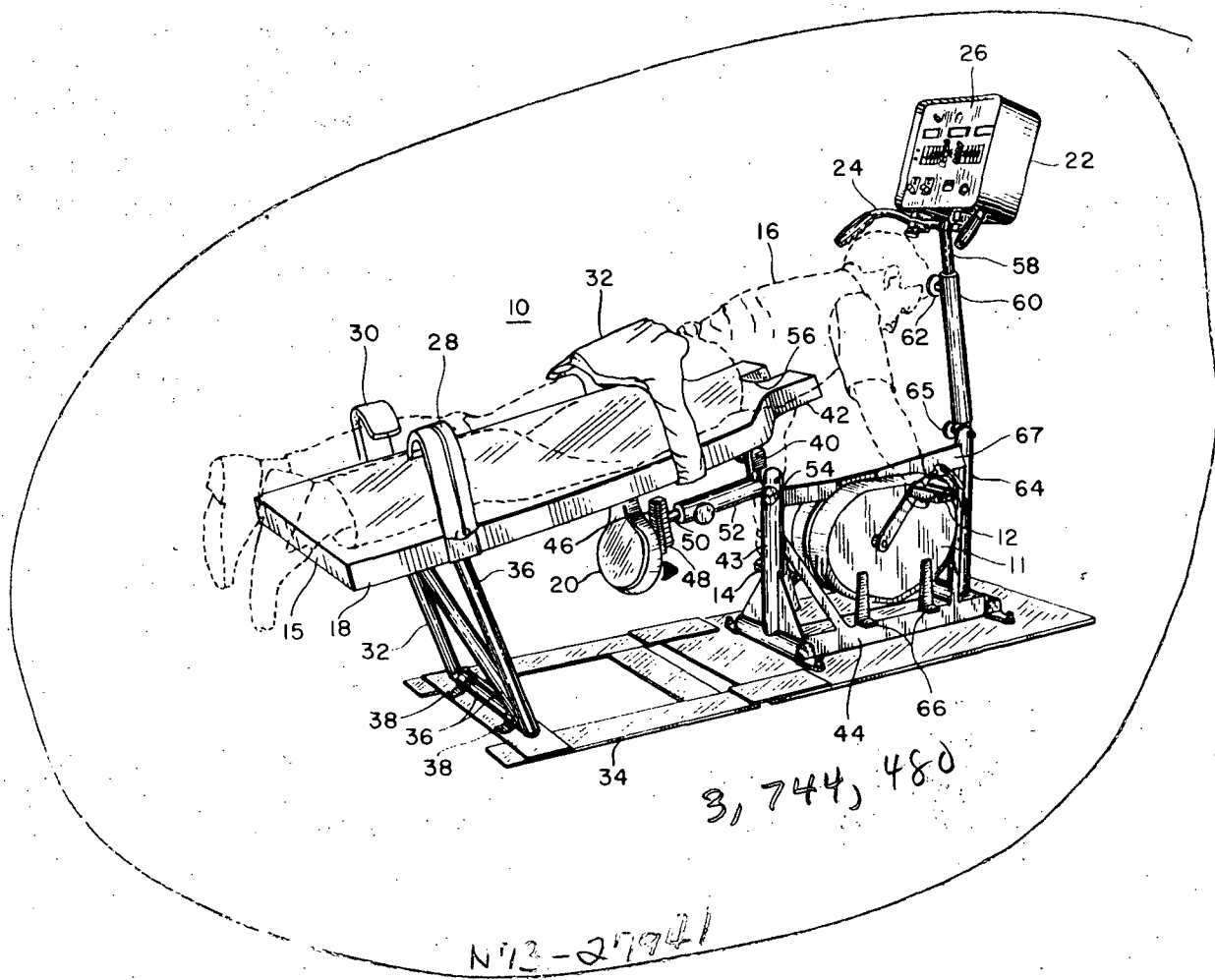
UNITED STATES PATENTS

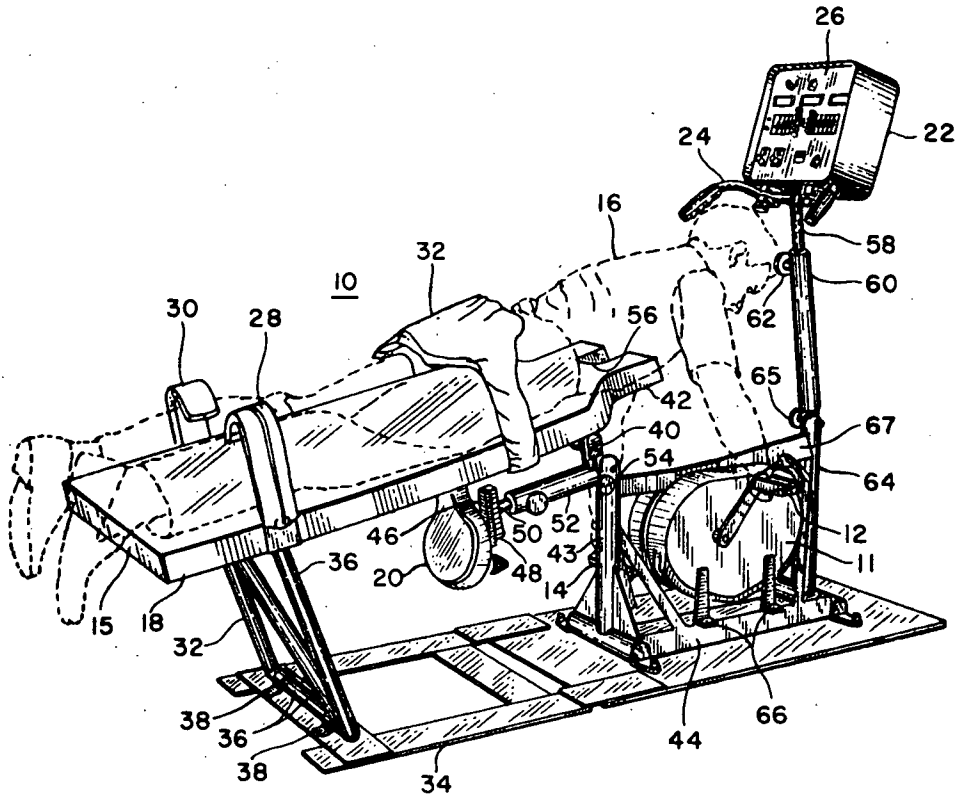
3,395,698 8/1968 Morehouse 128/2.05 R
 3,057,201 10/1962 Jaeger 73/379

[57] **ABSTRACT**

An ergometer including a pedal driven direct current motor as a load and including a frame for supporting the body of a person in either a sitting or a prone position whereby the pedals may be operated by either the feet or the hands and the electrical circuitry of the ergometer includes means for limiting the load applied to the pedals as a function of work being performed, heart rate, and increases in heart rate.

6 Claims, 3 Drawing Figures





N7327941

FIG. 1

RAYMOND L. GAUSE
BOBBY G. BYNUM
INVENTOR(S)

BY *George J. Porter*
ATTORNEY

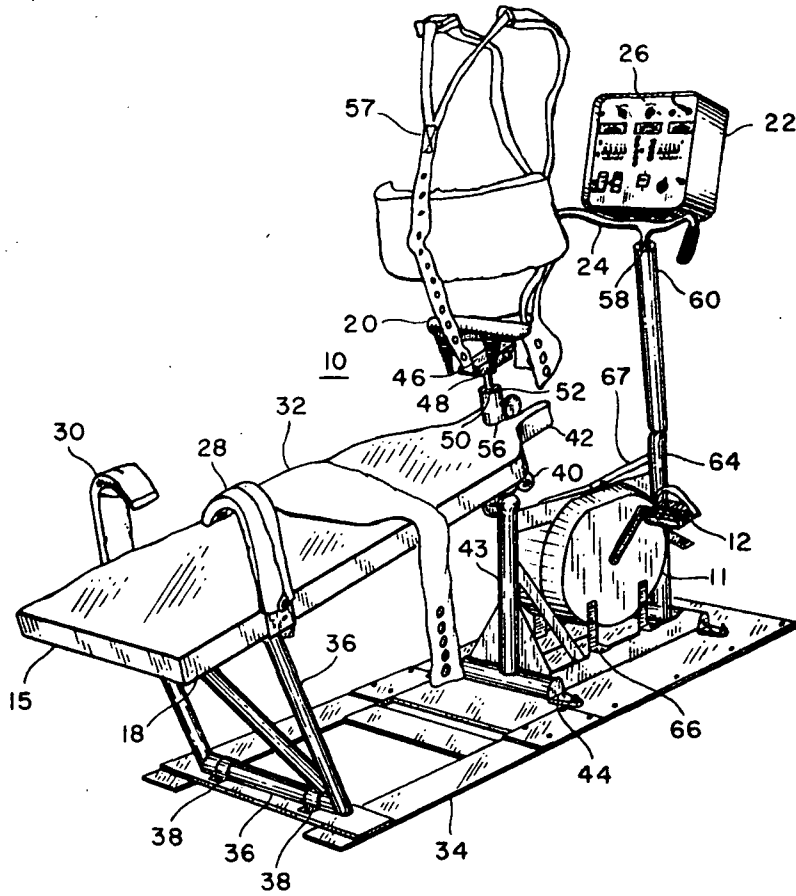


FIG. 2

RAYMOND L. GAUSE
BOBBY G. BYNUM
INVENTOR(S)

BY *George J. Porter*
ATTORNEY

ERGOMETER**ORIGIN OF THE INVENTION**

The invention described herein was made by employees of the United States and may be manufactured and used by or for the Government of the United States of America for Governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

This invention relates generally to physiological stressing and conditioning devices and systems and more particularly to a system in which there is provided enhanced versatility in operation and more effective control of the work load imposed upon the body undergoing the conditioning.

GENERAL DESCRIPTION OF THE PRIOR ART

Devices and systems for the controlled stressing, conditioning or exercising of a person are well known. They vary from simple mechanically loaded pedal structures to sophisticated electrically regulated systems. A sometimes critical parameter in the employment of conditioning devices is the effect on the heart. Further, it is believed clear that it is generally desirable to provide some regulation of the work load as a function of heart activity.

One prior art system shows the control of work load is achieved automatically by means of a comparison of programmed work with heart rate as an indication of work and thus varying loads until the heart rate of the person being exercised equals that of the programmed work. In addition there is provided for the removal of work load in the event that a dangerous condition of the person is sensed via an ECG (electrocardiogram), temperature or chemical sensor.

One difficulty with known previous systems has been the reliance upon the exercising operator to generally regulate the speed of exercise in that actual work performed was not included as a parameter of the control system. A further difficulty has been that systems have not provided for load compensation when system inputs called for a change in loading. Thus, for example, during an increase in loading, that is between the time that increased loading is indicated and the time that it is actually achieved, excessive loading is often applied to a person. A further deficiency has existed in prior systems in that they have failed to provide versatility insofar as exercise of different limbs of the body is concerned.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a new and improved ergometer which overcomes the aforesaid difficulties.

An ergometer in accordance with the present invention includes means for comparing actual work performed with a fixed indicated work rate to be performed, and actual work rate versus the difference between a programmed heart rate and actual heart rate. As another feature of the invention there is dual integration of heart rate signals employing different time constants and the combination and a comparison made of the outputs of the two integrators to derive a work reduction signal during periods when heart rate is accelerating. A still further feature of the invention is that of employing a DC torque motor connected in a gener-

ator mode as a load source thus simplifying and providing more effective control of the load which may be accomplished simply by variable duty cycle switching of resistance connected across the terminals of the motor. A still further feature of the invention is that of an exercise frame which includes readily convertible supports enabling one to apply work by use of feet or hands.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of the exercise frame of the invention adjusted for hand operation of the pedals.

FIG. 2 is a perspective view of the exercise frame adjusted for foot operation.

FIG. 3 is a schematic illustration of the electrical system of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Considering first the physical arrangement of components, principally exercise machine 10, reference is made to FIGS. 1 and 2. Load module 11 is driven by bicycle type pedals 12 and 14 and operator 16 may operate the pedals from either a prone position on table 18 (FIG. 1) or from a sitting position on bicycle seat 20 (FIG. 2) to react to a load effected by load module 11. In the prone position the pedals are hand operated, as shown, and in the sitting position they are, of course, foot operated. Electronic control circuitry elements are contained in console 22 which is mounted on handlebars 24. Front panel 26 of console 22 includes appropriate meters and controls sufficient to enable the operator to observe his performance and control the torque which he must oppose in operating load module 11.

Table 18 (FIG. 1) is rectangular and of a dimension generally adapted to support the body of an operator from about the ankles to the chest and is typically padded for comfort. Semi-rigid leg supports 28 and 30 are attached to table 18 and adapted to vertically support the legs of the operator and belt 32 is adapted to secure the buttocks of the operator to table 18. Table 18 is pivotally supported near end 15 by means of support assembly 32 upon flat base 34, this assembly being constructed of round tubular members 36 which are pivotally attached to base 34 and table 18 (attachment not shown) by brackets 38 to enable table 18 to be moved backward and lowered so that seat 20 may be raised or lowered to and from an operating position. This function is enabled by coupling assembly 40 which detachably secures the other end, end 42, of table 18 to vertical support 43 in turn supported by mounting frame 44 to base 34.

Seat 20 is attached to plate 46 which is adjustably movable on, and attached to, supporting plate 48 to provide fore and aft adjustment of seat 20. Supporting plate 48 is in turn supported by arm 50 which is adjustably locked in seat supporting column 52 to provide vertical adjustment of seat 20. Column 52 is pivotally mounted on vertical support 43 by bolt assembly 54 which selectively permits column 52 to assume an operating position, as shown in FIG. 2, or a stored position, as shown in FIG. 1. In a raised or operating position, seat supporting column 52 rests against the back of recess 56 of table 18 to provide a rear lateral support for seat 20, and the operator, when engaged in foot operation of load module 11. Harness 57 fastened to seat 20 by means not shown further secures the operator in an operating position. Handlebars 24 are adjustably

supported in height by arm 58 supported by tubular column 60 by bolt 62. Fore and aft adjustment of handlebars 24 is achieved by pivotal connection of column 60 to vertical support 64 by bolt assembly 65. Vertical support 64 is in turn supported by mounting base 34 through mounting frame 44.

Load module 11 is secured to mounting frame 44 by means of angle brackets 66 and arm 67 extending between vertical support 43 and vertical support 64.

Considering now the control system of the invention, shown in FIG. 3, load module 11 includes a permanent magnet torque motor 70 which functions as a generator and which is driven by pedals 12 and 14 of exercise machine 10 (FIG. 1). Variable loading to torque motor 70 is effected by electrical resistor 72 connected across the terminals of torque motor 70 through transistor 74, which is switched on and off in accordance with pulses of varying widths by switch driver 76. Tachometer 78 is coupled to torque motor 70 by a shaft diagrammatically illustrated by broken line 71 and provides a speed output signal to one input, input 80, of multiplier 82. Torque sensor 84, mechanically connected between torque motor 70 and its support by means diagrammatically illustrated by broken line 85, provides a torque signal representative of the torque applied by the operator of exercise machine 10 to a second input, input 86 of multiplier 82.

Multiplier 82 provides a direct current output representative of the rate of work being performed on exercise machine 10. The calibration of this output by the operator is such that an output of 5 volts is representative of a work rate of 300 watts. This output is indicated or read out by first converting it to a pulse frequency proportional to voltage by DC frequency converter 88 and then applying the thus converted output to counter 90, which counts pulses for a predetermined period, the second being chosen to provide a direct readout of counter 90 in watts.

The output of multiplier 82 is also applied to input 92 of differential amplifier 94 and a "work demand" signal is applied to the other input, input 96, of differential amplifier 94. This "work demand" signal is obtained through three-position selector switch 98 in accordance with the desired mode of operation of the system. In one mode, the work rate control mode, the mode is shown by the position of movable contact c of switch 98 there is provided a voltage from potentiometer 100 of 0 to 5 volts, again with 5 volts being representative of a work rate of 300 watts.

"Work demand" signals which are in terms of desired heart rate are obtained in two of the three modes of operation from heart rate circuit 102 and applied to contacts C2 and C3 in a manner which will be discussed below with respect to this circuit.

In all modes of operation of the system, differential amplifier 94 provides a work demand output whenever the work demand input signal on input 96 exceeds that of the actual work signal on input 92. The work demand output of differential amplifier 94 is applied to a variable width pulse modulator 104 which provides output pulses at a predetermined frequency but which vary in width in proportion to the amplitude of the work demand signal. Modulator 104 consists of a saw-tooth generator 106 which provides a saw-tooth voltage of constant frequency to one input, input 108, of comparator 110 and the work demand signal is applied to the other input, input 112, resulting in a variable cut-

off of the amplitude of the saw-tooth voltage and thus variable width output pulses 114 are a function of the work demand signal 112.

The output of modulator 104 is amplified in switch driver 76 and is employed to control transistor 74 of load module 11 turning transistor 74 on during the presence of a pulse and off when no pulse is present. In this fashion transistor 74 provides control of the loading of torque motor 70, effecting loading by closing an electrical path through resistor 72 during the presence of a pulse and closing this path in the absence of a pulse. Thus the average work extracted by load module 11 is proportional to the pulse "on-time" for the period averaged.

As stated above, two modes of operation of the system contemplate work requirement based upon heart rate. These modes are selected by positioning selector switches 98 and 116 with movable contact C in contact with fixed contacts C2 or C3. It is to be noted that switches 98 and 116 are mechanically linked for operation in unison. With the movable arm C of selector switch 116 in contact with fixed contact C2 and thus an input provided to differential amplifier 118 from potentiometer 120, potentiometer 120 is set to a position to provide an output voltage, again in the range of 0 to 5 volts, representative of the selected heart rate of 0 to 200 beats per minute.

Alternately, with selector switch 116 set with movable contact C in contact with fixed contact C3, differential amplifier 118 is connected to the output of programmer 122. Programmer 122 provides a plurality of selected voltages, corresponding to desired heart rate demands, which voltages are made available in a selected sequence and for selected periods. Such circuitry is believed well known and is not further described herein.

Actual heart rate signals are also provided as an input to heart rate circuit 102 to enable the limiting of work demand signals applied to input 96 of differential amplifier 94 during the period when there is a shift in the heart rate demand as called for by programmer 122 or potentiometer 120. Thus, sudden or too rapid a change in demand is avoided by heart rate circuit 102. This is accomplished as follows. An ECG, electrocardiogram, type signal is obtained by appropriate sensors from the body of operator 16. This signal is amplified and shaped by amplifier and shaper 124 to obtain a pulse output from ECG waveforms, thus corresponding to heart beats and this output is applied to one shot 126 which provides output pulses, one for each heart beat, of constant amplitude and width. Heart beat pulses from one shot 126 are applied to both short (approximately 3 seconds) and long (approximately 12 seconds) time-constant integrators 128 and 130. Long term integrator 130 provides a direct current output voltage which is continuous and proportional to heart rate. It is applied to input 132 of differential amplifier 118. As previously indicated, a desired heart rate voltage is applied to the other input, input 134 of differential amplifier 118. The output of differential amplifier 118, representing the error or difference between demanded heart rate and actual (average for several seconds) heart rate is applied to input 136 of summing circuit 138. A second input is applied to input 140 of summing circuit 138 from differential circuit 142 which provides a signal representative of the difference between the output of short time-constant integrator 128

and long time-constant integrator 130. The result is that the signal applied to input 140 is a signal representative of actual heart rate less a factor proportional to acceleration of heart rate or plus a factor proportional to deceleration of heart rate, as the case may be. Thus, summing circuit 138 computes a heart rate demand control signal which is the sum of the output of differential circuit 118 and differential amplifier 142 and wherein the sum would be expressed as $D_s = V_1 + V_2$ where

V_1 = a voltage proportional to actual heart rate minus desired heart rate.

V_2 = a voltage proportional to the first derivative of actual heart rate.

The output of summing circuit 138 is further integrated in integrator 144 to provide an output which averages and thus eliminates rapid changes in the "demand" signal. The sense of the "demand" signal is that of a signal which indicates that actual heart rate differs from desired heart rate and is of a magnitude to achieve a change in heart rate at a desired rate of change.

Differential amplifier 94, with a work rate signal applied to input 92 and a heart rate "demand" signal applied to input 96 provides an applied signal to pulse width generator 104 when the inputs to terminals 92 and 96 are not identical and causes pulse generator 104 to provide control pulses to operate switch driver 76 and thus cause a change in loading to effect the loading determined by the desired heart rate demand signal.

To examine operation of the ergometer, assume first that selector switch 98 is set in the indicated position and potentiometer 100 is set to provide an output voltage of 2.5 volts, corresponding to a desired work rate of 150 watts, and this voltage is applied to input 96 of differential amplifier 94. Prior to pedaling by the exerciser, there will be no feedback inputs to multiplier 82 and thus no input to input 92 of differential amplifier 94. The result will be that differential amplifier 94 will respond to the full input signal on input 96 to trigger pulse generator 104 to provide relatively wide modulating pulses to switch driver 76. It in turn will operate transistor 72 to complete a loading circuit through resistor 72 across torque motor 70 during each such pulses. Upon pedaling exercise machine 10, tachometer 78 and torque sensor 84 provide speed and torque signals to multiplier 82, and a product output, representative of the rate of work being performed, is applied to input 92 of differential amplifier 94 to oppose the input on input 96. When pedaling is accelerated to the point where the actual work rate is equal to the work rate setting of potentiometer 100, and the voltages at inputs 92 and 96 are equal, the output of differential amplifier 94 drops to zero and momentarily the pulse width output of pulse generator 104 diminishes to zero. Actually this zero pulse width condition exists only instantaneously since the result will be that there will be a like instantaneous drop in torque in the product input signal on input 86 causing a differential voltage, and thus pulsed loading of torque motor, to again occur. Thus, average loading is maintained at the work rate setting of potentiometer 100. Load switching effects when loading is near the selected load are minimal in view of the fact that with a small difference between the load demand signal on input 96 and actual load signal on input 92 there is provided a small output signal to pulse generator 104 to produce relatively narrow switching pulses. Accordingly, change from zero pulse

width to a discrete pulse width is of small magnitude.

The actual work rate as computed by multiplier 82 is indicated by counter 90 in the manner described above.

Assume next that it is desired to regulate the work request to operate exercise machine 10 in terms of desired heart rate. This is accomplished manually by the setting of potentiometer 120 to a level corresponding to heart rate for continuous loading or automatically by setting programmer 122 to provide a series of timed, discrete, heart rate voltages. Assuming that it is desired to operate the ergometer in the first of these two modes of operation, selector switch 116 is positioned with movable contact C in contact with fixed contact C2. Potentiometer 120 is then set to a preselected heart rate analog voltage of said 2.5 volts representative of 100 beats per minute and the voltage is applied to input 134 of differential amplifier 118. Assume further that the operator of ergometer 10 is pedaling and that his initial heart rate is 80 beats per minute and thus less than the desired heart rate. An actual heart rate signal is derived, as described above, by processing an ECG signal through amplifier and shaper 124 and one-shot 126 to provide pulse inputs to integrators 128 and 130 of a predetermined height and width.

Since the desired heart rate is significantly higher than the actual heart rate there is a requirement that there be a substantial increase in loading on the exerciser. On the other hand, as discussed above, it is not desirable to increase the loading, this heart rate, too rapidly. To prevent this, operation of circuitry is as follows. One set of the heart rate pulses are integrated by short time-constant integrator 128 to provide a direct current output to input 146 of differential circuit 142 which is a direct current but which with change in rate takes the form of stair steps, ascending or descending, depending upon whether there is an increase or decrease in heart rate. A second set of the heart rate pulses are subject to long time-constant integration in long time-constant integrator 130 and the resulting output reflects the generally long term average heart rate which is fed to input 132 of differential circuit 118 and to input 148 of differential amplifier 142. The output of differential circuit 142 is thus a signal which may be characterized as of a value proportional to average heart rate less a value proportional to increasing heart rate, or plus a value proportional to decreasing heart rate. The output of differential amplifier 118 is simply an error signal indicating the difference between desired heart rate and average heart rate, or required change in heart rate. The outputs of differential circuit 142 and differential circuit 118 are summed in summing circuit 138 to provide an output which is proportional to the difference in actual heart rate and desired heart rate and the rate of change of actual heart rate. The output of summing circuit 138 is integrated by integrator 144 to accomplish the smoothing of the signal to provide a gradual rather than stepped changes in the signal during heart rate changes. The result is that there is a demand signal from integrator 144 which is applied to input 96 of differential amplifier 94 which is of a desired value to produce the desired rate of increase in heart rate at a desired characteristic of increase and without abrupt changes in demand. The operation of differential amplifier 94 and the balance of the loading circuitry is the same as described above for the application of a load demand signal from potentiometer 100.

Thus loading is increased in accordance with the value of the signal on input 96 of differential amplifier 94, with feedback signals from speed tachometer 78 and torque sensor 84, respectively, to multiplier 82 limiting the force application to that described by the input signal on input 96 of differential amplifier 94.

In the programmed mode of operation, with movable contact C in contact with fixed contact C3, a series of programmed voltages are applied to input 134 of differential amplifier 118 for predetermined periods. Otherwise, the operation of heart rate circuitry 102 and load circuitry is identical to that just described.

What is claimed is:

- 1. An ergometer comprising:
 - exercise means adapted to be operated by limbs of the body and providing a mechanical output;
 - electrical load means connected to the said output of said exercise means for applying resistance to the operation of said exercise means;
 - load control means responsive to an input signal for varying said resistance applied to said exercise means;
 - work signal means responsive to the speed of operation of said exercise means and resistance force applied to said exercise means for providing a work output signal;
 - physiological monitoring means responsive to a condition of an operator of said exercise means for providing an electrical output corresponding to heart beats of said operator;
 - first and second integrating means responsive to the output of said physiological monitoring means, said first integrating means having a longer time constant than said second integration means;
 - first differential means responsive to the outputs of said first and second integrating means for providing a first difference signal of a value proportional to actual heart rate less a value proportional to increasing heart rate, or plus a value proportional to decrease in heart rate;
 - heart rate signal reference means for providing an output representative of a desired heart rate from said operator;
 - second differential means responsive to the outputs of said first integrating means and said heart rate signal means for providing an output corresponding to an error signal indicating the difference between desired heart rate and actual heart rate of said operator;
 - summing means responsive to the outputs of said first and second differential means for providing a heart rate demand signal which is proportional to re-

quired change in heart rate to achieve said desired heart rate less a value proportional to the presence of increasing heart rate or plus a value proportional to the presence of decreasing heart rate; and third differential means responsive to the output of said work signal means and said summing means for providing said input signal to said load control means;

whereby a work rate imposed upon an operator of said exercise means is determined by a desired heart rate activity of the operator as modified by rate of change of heart rate experienced by the operator during an imposed change from one heart rate to another.

2. An ergometer as set forth in claim 1 further comprising a work rate signal reference means and selection means for coupling either said heart rate demand signal or the output of said work rate signal reference means to said third differential means,

whereby said load control means may, selectively, be controlled as either a function of a selected work rate or a selected heart rate.

3. An ergometer as set forth in claim 2 wherein said heart rate signal reference means includes programming means for selectively applying in sequence, predetermined, discrete said outputs for predetermined periods of time.

4. An ergometer as set forth in claim 1 wherein said load control means includes pulse width modulation means responsive to the output of said third differential means for generating variable width control signals proportional to the output of said third differential means for controlling said electrical load means.

5. An ergometer as set forth in claim 4 wherein said pulse modulation means comprises:

- a comparator,
- a saw-tooth oscillator operating at a predetermined frequency and providing a first input to said comparator;
- said third differential amplifier provides a second input to said comparator,
- whereby said variable width pulses are obtained by coincidence of signal levels between said saw-tooth oscillator and said output of said third differential amplifier.

6. An ergometer as set forth in claim 4 further comprising integration means coupling said summing means to said third differential means for smoothing the coupled signal to provide gradual rather than step changes in the coupled signal during heart rate changes.

* * * * *

55

60

65

