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(54) **EXERCISE APPARATUS WITH AUTOMATICALLY ADJUSTABLE FOOT MOTION**

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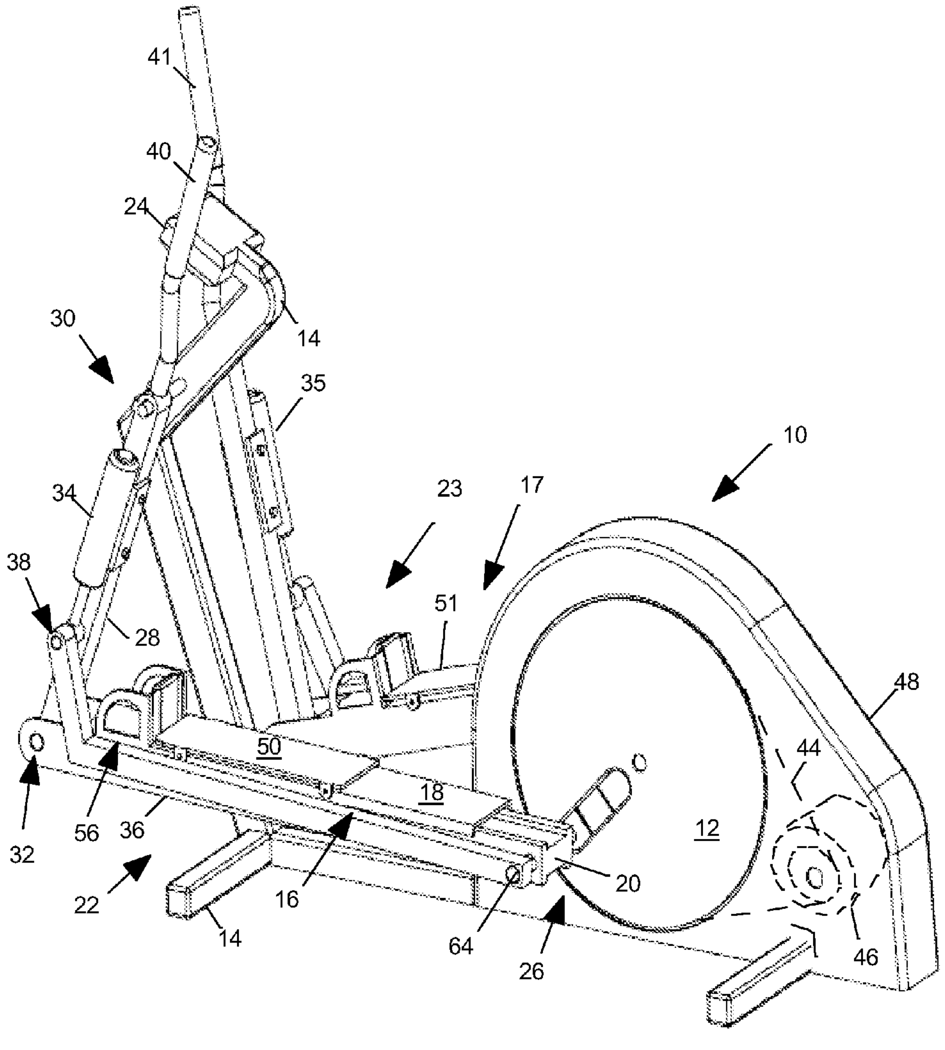
(57) **ABSTRACT**

An elliptical exercise apparatus includes a frame, a pair of footpads, and a linkage coupling the footpads to the frame and for guiding the footpads in closed paths when a user's feet apply forces to the footpads. The linkage, which includes a rotatable member having an angular position indicative of the positions of the footpads within their closed paths, responds to input control signals by adjusting length and height dimensions of the closed paths. A control system senses the angular position of the rotatable member, senses the forces the user applies to the footpads, and generates the control signals to increase or decrease the path dimensions when it senses particular combinations of angular position and user forces, thereby permitting the user to control the path dimensions by controlling the forces applied to the footpads.



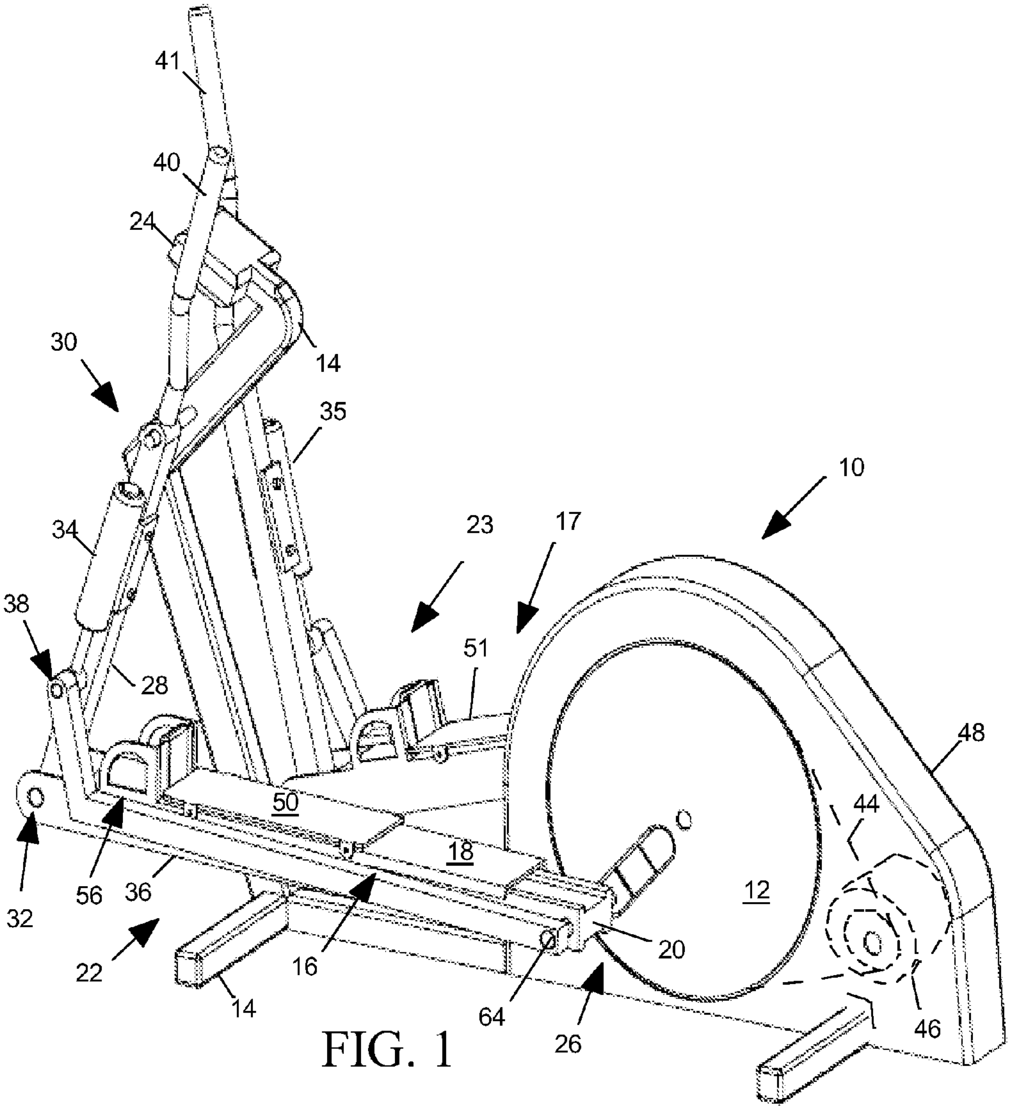


FIG. 1

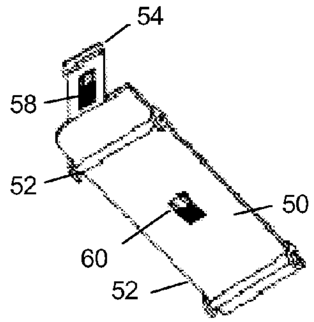


FIG. 2A

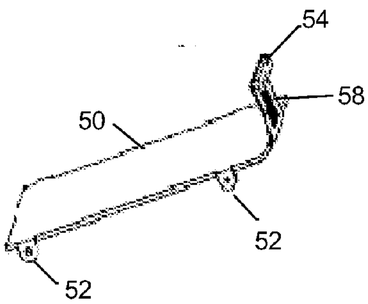


FIG. 2B

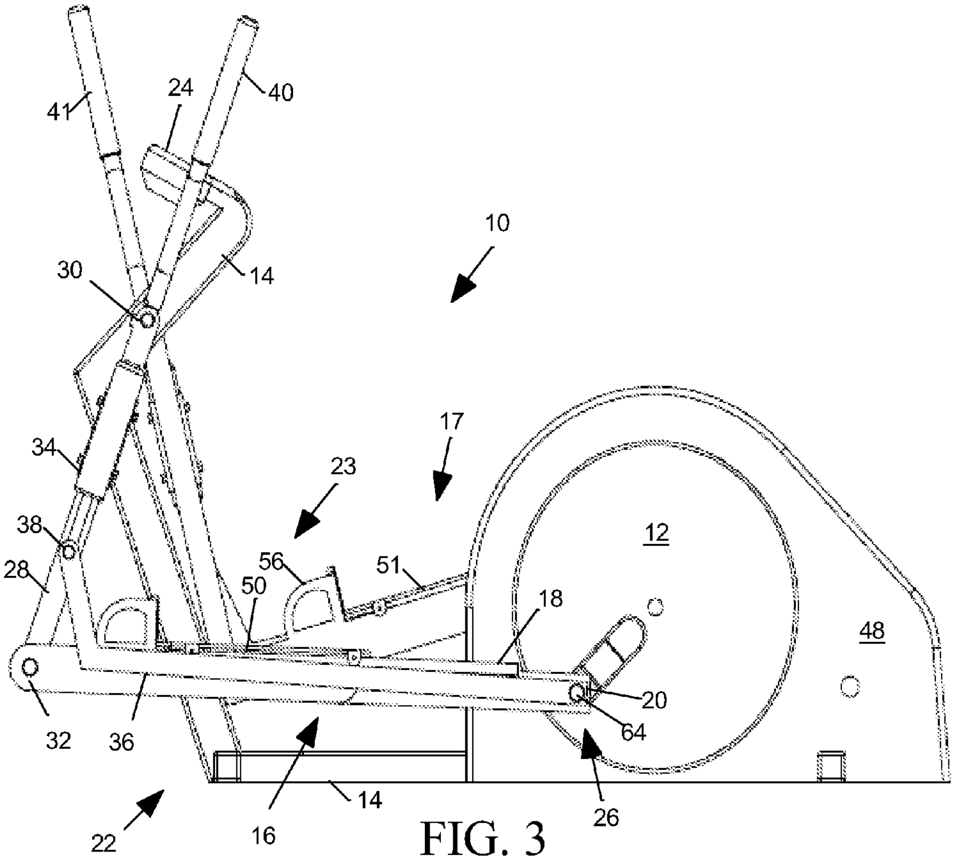


FIG. 3

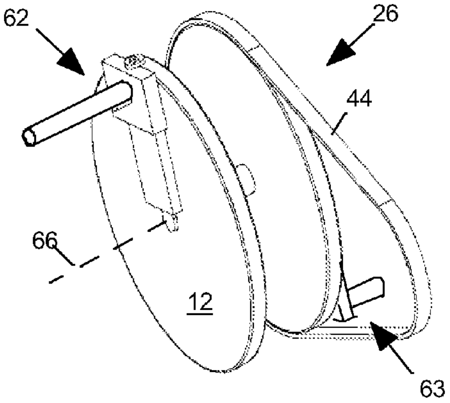


FIG. 4

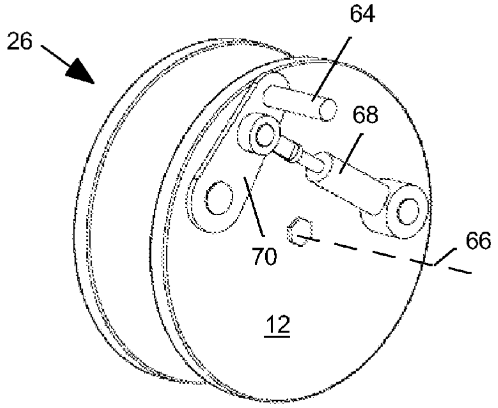


FIG. 5

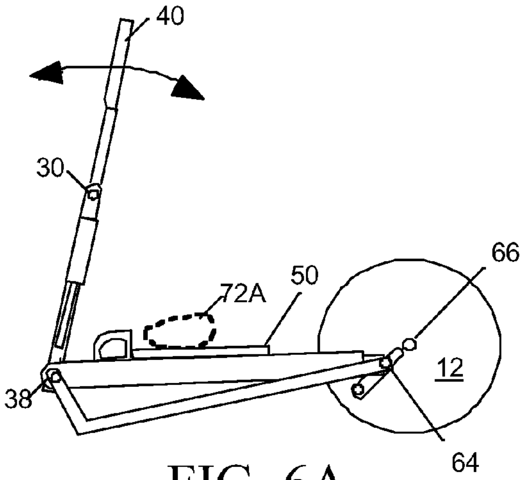


FIG. 6A

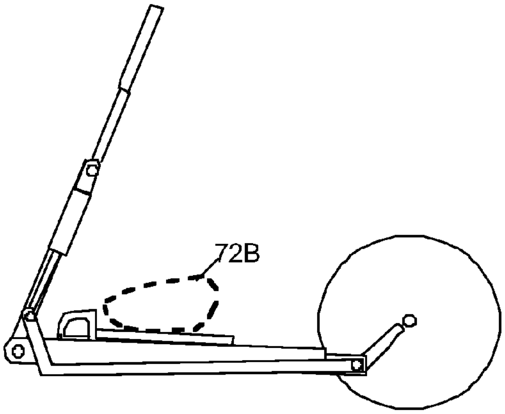


FIG. 6B

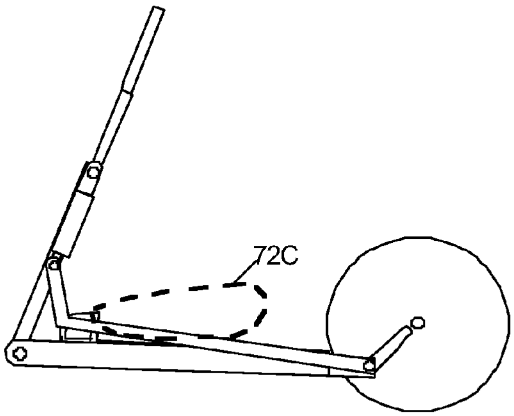


FIG. 6C

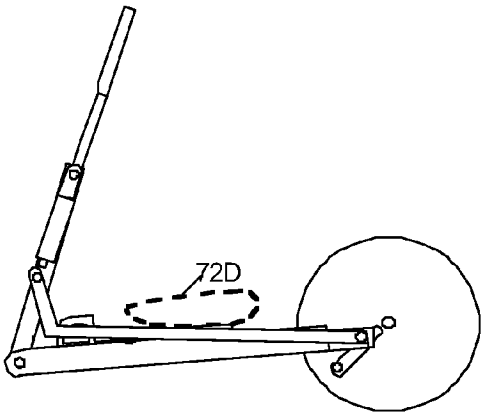


FIG. 6D

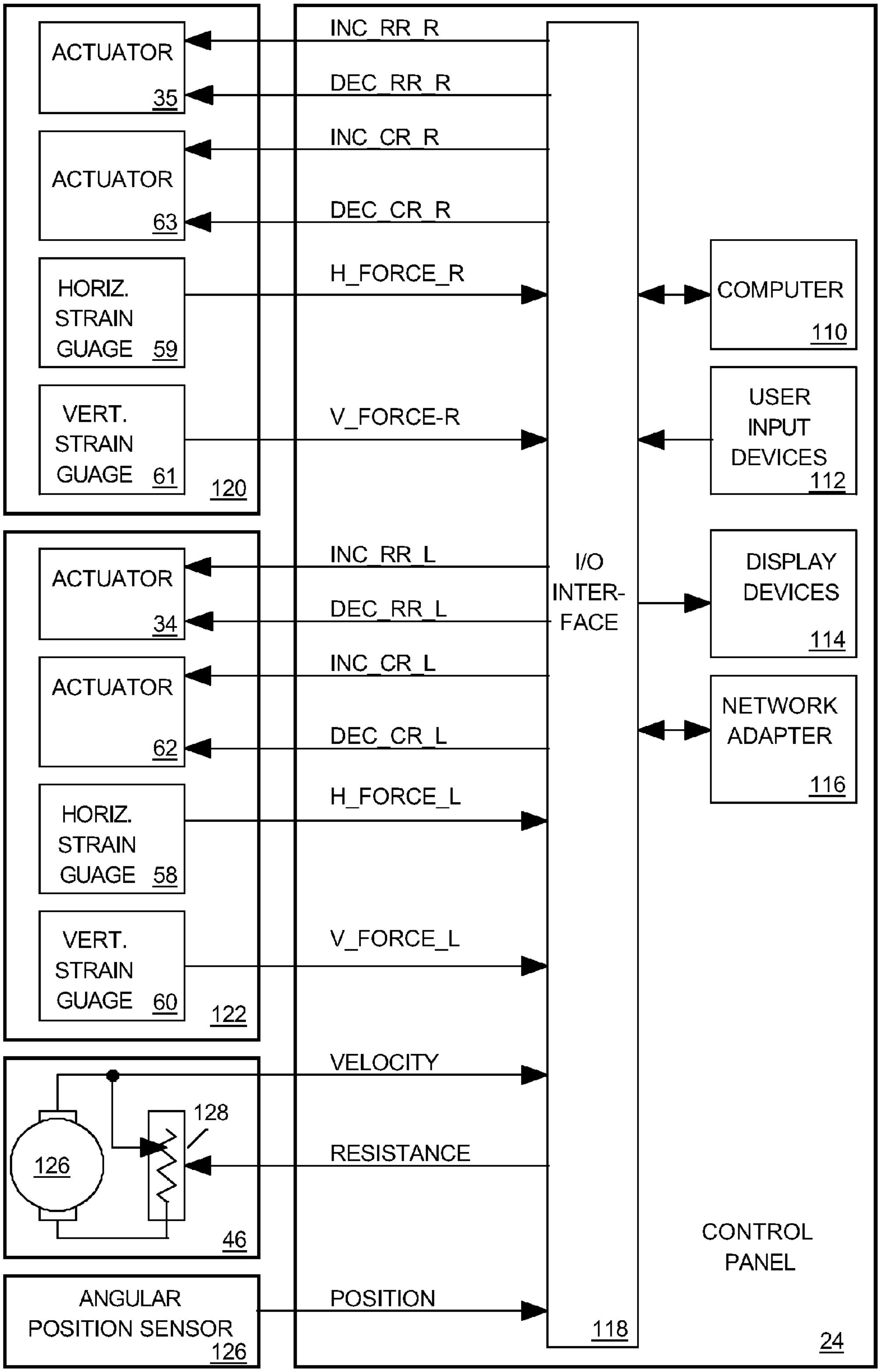

ACTUATOR
35
ACTUATOR
63
HORIZ. STRAIN GUAGE 59
VERT. STRAIN GUAGE 61
120
ACTUATOR
34
ACTUATOR
62
HORIZ. STRAIN GUAGE 58
VERT. STRAIN GUAGE 60
122
126
128
46
ANGULAR POSITION SENSOR
126
INC_RR_R
DEC_RR_R
INC_CR_R
DEC_CR_R
H_FORCE_R
V_FORCE-R
INC_RR_L
DEC_RR_L
INC_CR_L
DEC_CR_L
H_FORCE_L
V_FORCE_L
VELOCITY
RESISTANCE
POSITION
I/O INTER-FACE
118
COMPUTER
110
USER INPUT DEVICES
112
DISPLAY DEVICES
114
NETWORK ADAPTER
116
CONTROL PANEL
24

FIG. 7

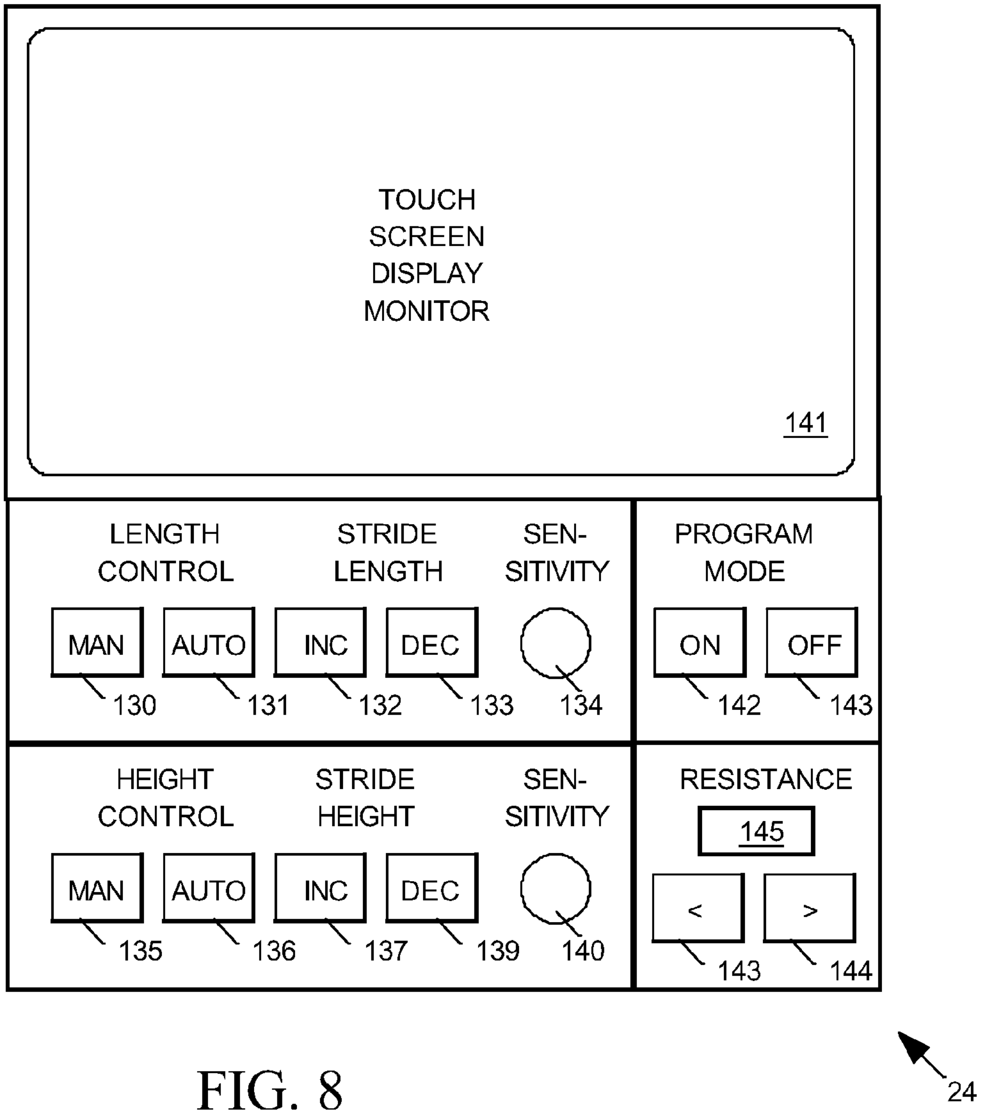

TOUCH
SCREEN
DISPLAY
MONITOR
141
LENGTH
CONTROL
STRIDE
LENGTH
SEN-
SITIVITY
PROGRAM
MODE
MAN
AUTO
INC
DEC
ON
OFF
130
131
132
133
134
142
143
HEIGHT
CONTROL
STRIDE
HEIGHT
SEN-
SITIVITY
RESISTANCE
145
MAN
AUTO
INC
DEC
<
>
135
136
137
139
140
143
144
24

FIG. 8

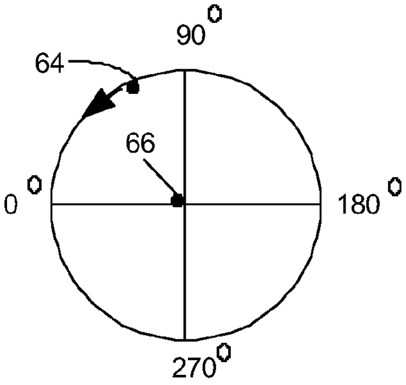

90°
64
66
0°
180°
270°

FIG. 9

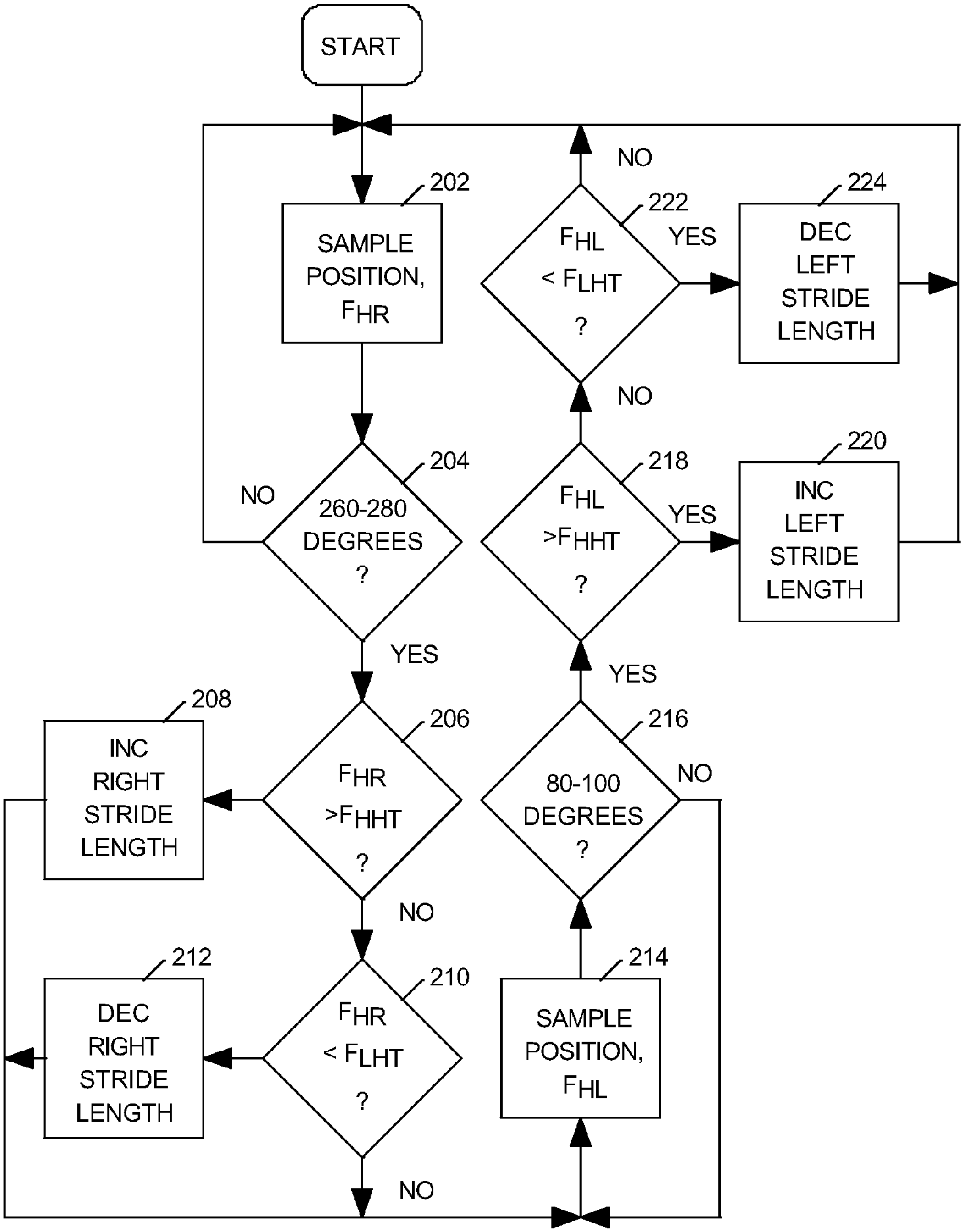

START
202
SAMPLE POSITION, F_{HR}
204
260-280 DEGREES ?
NO
YES
206
F_{HR} $>F_{HHT}$?
208
INC RIGHT STRIDE LENGTH
NO
210
F_{HR} $< F_{LHT}$?
212
DEC RIGHT STRIDE LENGTH
NO
214
SAMPLE POSITION, F_{HL}
216
80-100 DEGREES ?
NO
YES
218
F_{HL} $>F_{HHT}$?
YES
220
INC LEFT STRIDE LENGTH
NO
222
F_{HL} $< F_{LHT}$?
YES
224
DEC LEFT STRIDE LENGTH
NO

FIG. 10

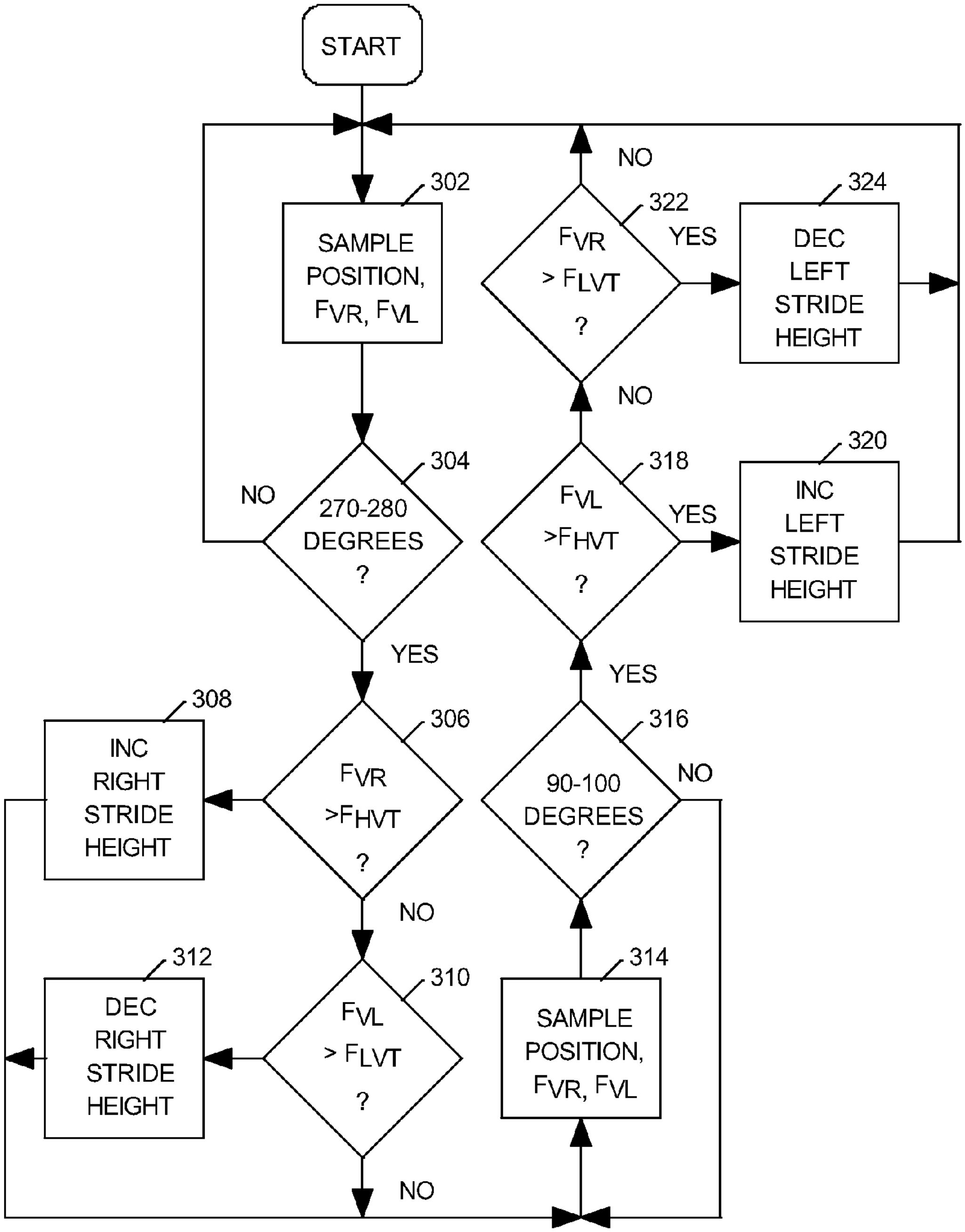

START
302
SAMPLE POSITION, FVR, FVL
304
270-280 DEGREES ?
NO
YES
306
FVR >FHVT ?
308
INC RIGHT STRIDE HEIGHT
NO
310
FVL > FLVT ?
312
DEC RIGHT STRIDE HEIGHT
NO
314
SAMPLE POSITION, FVR, FVL
316
90-100 DEGREES ?
NO
YES
318
FVL >FHVT ?
YES
320
INC LEFT STRIDE HEIGHT
NO
322
FVR > FLVT ?
YES
324
DEC LEFT STRIDE HEIGHT
NO

FIG. 11

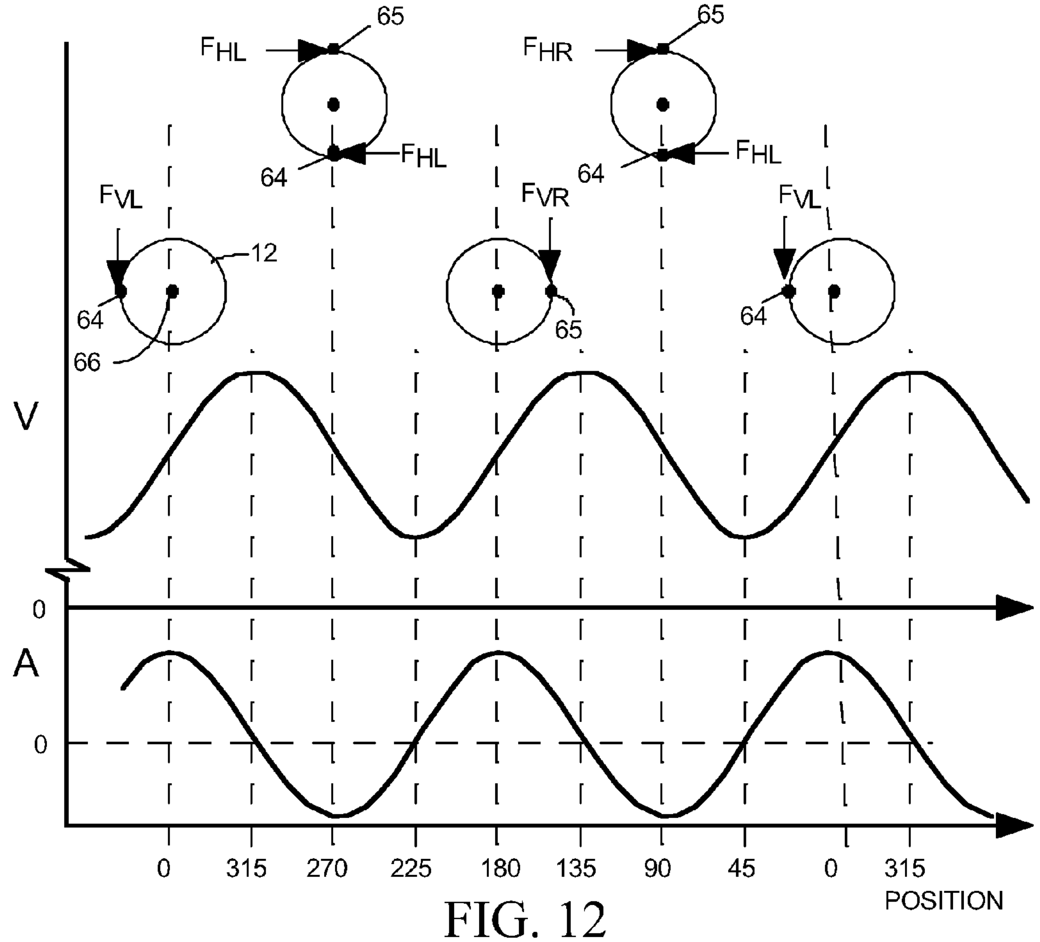

65
F_HL
64
F_HL
65
F_HR
64
F_HL
F_VL
12
64
66
F_VR
65
F_VL
64
V
0
A
0
0
315
270
225
180
135
90
45
0
315
POSITION

FIG. 12

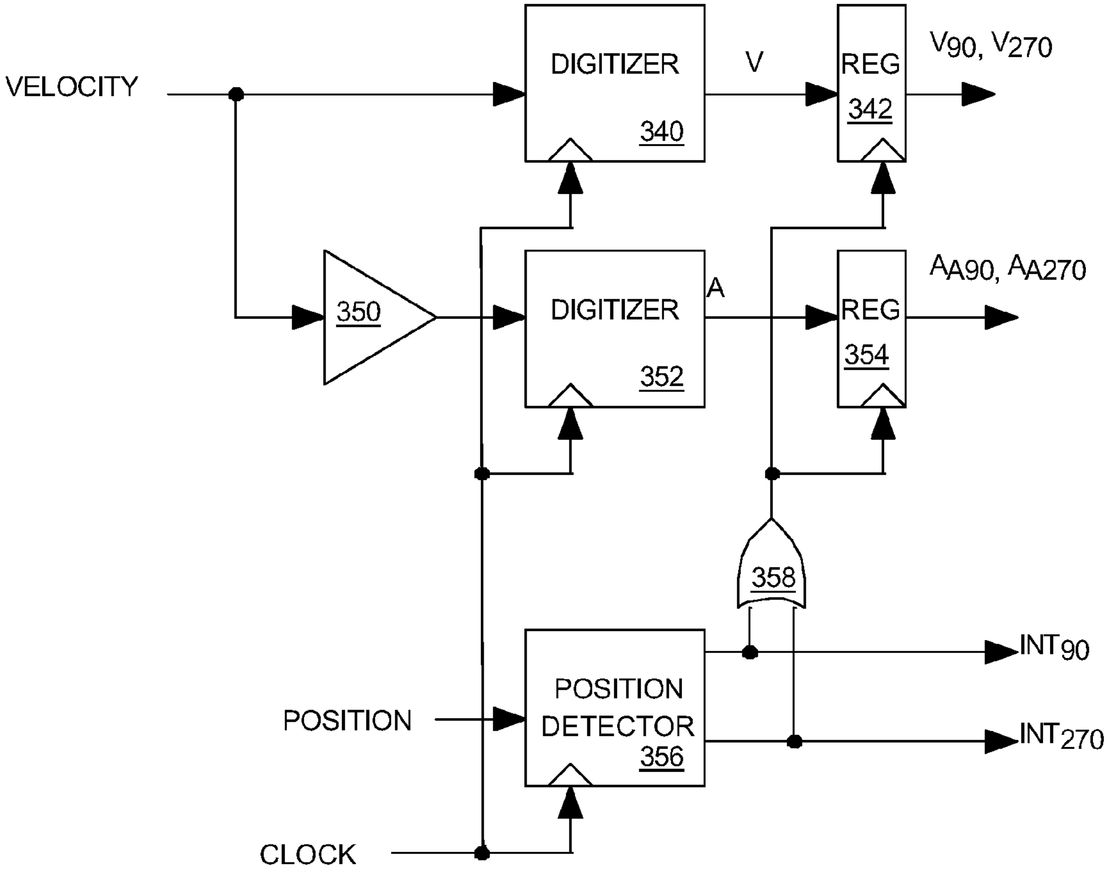

VELOCITY
DIGITIZER
340
V
REG
342
V90, V270
350
DIGITIZER
352
A
REG
354
AA90, AA270
358
INT90
POSITION
POSITION DETECTOR
356
INT270
CLOCK

FIG. 13

EXERCISE APPARATUS WITH AUTOMATICALLY ADJUSTABLE FOOT MOTION

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to exercise apparatus, and more specifically to an exercise apparatus that guides a user's feet through automatically adjustable paths of motion.

[0003] 2. Description of Related Art

[0004] Running on treadmills remains a popular form of indoor aerobic exercise even though it can lead to injuries. A runner hops from foot-to-foot, stressing his or her lower extremities with repetitive impact forces of each footfall that can eventually injure joints and tendons. Running the equivalent of only ten miles per day on a treadmill can expose each leg to 200,000 impacts per year. Many other kinds of exercise apparatus, including stationary bicycles, steppers, climbers, gliders and skiers, provide indoor aerobic exercise that allow a user's feet to follow a closed path without the impact stress associated with treadmills, however despite the advantages of these apparatus, running on treadmills remains popular. Since people are structurally better adapted to run rather than to pedal, climb steps, glide or ski, they often feel more comfortable running.

[0005] Elliptical exercise apparatus include foot support or pedals following closed paths designed to mimic the non-circular paths a user's feet trace out when running on a treadmill, but since the user's feet do not leave the foot supports, the user can engage in a running style of exercise without experiencing the repetitive impacts associated with running on a treadmill. Since the user's feet follow paths that are neither linear nor circular, they are commonly called "elliptical" paths to distinguish them over the circular closed paths provided stationary bicycle apparatus and the linear or arcuate closed paths associated with steppers and skier, gliders and climbers, even though an elliptical exercise apparatus normally does not provide a truly elliptical foot path.

[0006] A typical elliptical exercise apparatus includes a crank moving in a circular motion and a linkage mechanism coupling the crank to its foot supports for converting the circular motion of the crank into the "elliptical" motion of the foot supports. The linkage also includes a resistance device such as a regenerative or eddy current brake coupled to the crank for providing an adjustable resistance to the foot motion for controlling the amount of work the user must expend to move the foot supports. Examples of elliptical exercise apparatus are disclosed in U.S. Pat. No. 4,185,622 to Swenson; U.S. Pat. No. 5,278,529 to Eschenbach, U.S. Pat. No. 5,383,829 to Miller; U.S. Pat. No. 5,540,637 to Rodgers, Jr.; U.S. Pat. No. 6,196,948 to Stearns et al.; and U.S. Pat. No. 6,468,184 to Lee, all of which are incorporated herein by reference.

[0007] The height and length of a runner's stride varies depending on running speed, on the terrain and on the runner's preferences. While early elliptical exercise apparatus designs allowed a user to engage in a running style of motion while avoiding the impact stress associated with treadmills, the shape of the path the user's foot followed was fixed and the user was not able to adjust either the height or length of stride. Later elliptical exercise apparatus designs allowed a user to adjust stride length. For example U.S. Pat. No. 5,893,820 issued Apr. 13, 1999 to Maresh et al. describes an elliptical apparatus allowing a user to adjust the shape of an elliptical footpath by manually changing the linkage between the crank and the foot supports. U.S. Pat. No. 5,919,118 issued Jul. 6, 1999 to Stearns et al. teaches to incorporate a linear actuator into the linkage that can expand or contract to change the shape of the linkage in response to a signal controlled by a user-operable button on a control panel, thereby to change stride length. Although these apparatuses allow a user to adjust stride length, they required the user to stop the apparatus and manually alter the linkage, or to operate a control knob or button while exercising, either of which is inconvenient.

[0008] Still later designed elliptical exercise apparatuses automatically adjust stride length or height. U.S. Pat. No. 6,206,804 issued Mar. 27, 2001 to Maresh describes an elliptical exercise including dampers or springs in the linkage assembly defining the user's footpath that automatically vary the path shape in response to forces applied by the user's foot. U.S. patent application 20050181911, filed Aug. 18, 2005 by Porth teaches an elliptical exercise apparatus that senses the speed at which the crank rotates in which the crank rotates and adjusts an actuator in the linkage so that both stride length and height change with speed and pedaling direction. While the apparatus automatically adjusts stride length or height, there is no assurance that stride length or height that is adjusted as a function of speed or direction will match the user's desired stride length or height.

SUMMARY OF THE INVENTION

[0009] An elliptical exercise apparatus in accordance with the invention includes frame, a pair of footpads for supporting the user's feet, and a linkage coupling the footpads to the frame for guiding the footpads in a closed paths when the user's feet apply forces to the footpads. The linkage includes actuators that respond to control signals by adjusting length and height dimensions of the closed paths. The linkage also includes a rotatable member having an angular position that is indicative of the positions of the footpads within their closed paths.

[0010] The exercise apparatus further includes a control system that senses the angular position of the rotatable member and, for each footpad, senses the forces applied to the footpad and generates the control signals for controlling the length and height dimensions of the closed path as functions of the sensed angular position and forces. The control system increases or decreases the length and height dimensions of the closed path of each footpad when the user-applied force on the footpad is outside a particular magnitude range while the angular position of the rotatable member is within a particular angular position range. The exercise apparatus thus enables the user to independently control stride height and length of each footpad by controlling magnitudes of the forces the user applies to each footpad as it passes through a particular section of its closed path.

[0011] In one embodiment of the invention, the control system includes strain gauges attached to the footpads that sense user applied forces. In another embodiment of the invention, the controller determines user applied forces as functions of the acceleration of the rotatable member.

[0012] The claims appended to this specification particularly point out and distinctly claim the subject matter of the invention. However those skilled in the art will best understand both the organization and method of operation of what the applicants consider to be the best modes of practicing the invention by reading the remaining portions of the specification in view of the accompanying drawings, wherein like reference characters refer to like element

BRIEF DESCRIPTION OF THE DRAWING

[0013] FIG. **1** is a perspective view an exercise apparatus constructed according to the principles of the present invention.

[0014] FIGS. **2**A and **2**B are perspective views of a footpad of the exercise apparatus of FIG. **2**.

[0015] FIG. **3** is a left side elevation view of the exercise apparatus of FIG. **1**.

[0016] FIGS. **4** and **5** are perspective views of alternative versions of a crank assembly for the exercise apparatus of FIG. **1**.

[0017] FIGS. **6**A-**6**D are simplified side elevations views of portions of the exercise apparatus of FIG. **1**.

[0018] FIG. **7** is a block diagram an exercise control, monitoring and display system for the exercise apparatus of FIG. **1**.

[0019] FIG. **8** is a plan view of the control panel of FIG. **1**.

[0020] FIG. **9** is a diagram defining position of the crank member of FIG. **1**.

[0021] FIG. **10** depicts a software routine executed by the computer of FIG. **7** for automatically controlling stride length.

[0022] FIG. **11** depicts a software routine executed by the computer of FIG. **7** for automatically controlling stride height.

[0023] FIG. **12** graphically depicts the angular velocity and acceleration of the crank member of the apparatus of FIG. **1** as functions of angular position.

[0024] FIG. **13** is a block diagram depicting a subcircuit of I/O circuit **118** of FIG. **7**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0025] The present invention may be implemented in connection with exercise apparatus having a frame, user-operable footpads and a linkage for coupling the footpads to the frame and for guiding the footpads in closed paths. The invention relates in particular to a method for automatically responding to user forces applied to the footpads by adjusting one or more dimensions of the closed path each foot support follows. Although the invention is illustrated below as being used to control path dimensions in an elliptical exercise machine, the invention may be used to control path dimensions in other types of exercise machines having adjustable path dimensions. Although there are many possible modes of practicing the invention defined by the claims appended to this specification, the following specification and drawings describe in detail only preferred embodiments of practicing the invention. Since not all implementation details described below are necessary to practice the invention as recited in the claims, it is intended that the invention be limited only by the claims.

Mechanical System

[0026] FIGS. **1**-**5** depict an elliptical exercise apparatus **10** in accordance with the invention including a frame **14**, a left footpad **50** and a right footpad **51** for supporting a user's left and right feet. Left and right linkage assemblies **22** and **23** for a linkage for coupling the left and right footpads **50** and **51** to frame **14** and for guiding the footpads in closed paths when the user's feet apply forces to the footpads. As discussed below, each linkage assembly **22** and **23** includes actuators that respond to control signals by adjusting length and height dimensions of the closed path its corresponding footpad follows. Each linkage assembly also includes a rotatable member, suitably a crank member **12** rotatably mounted on a frame **14**, having an angular position that is indicative of the positions of the footpads within their closed paths. A control system, including a control panel **24** mounted on frame **14**, senses the angular position of the rotatable member and, for each footpad, senses the forces applied to the footpad and generates the control signals for controlling the length and/or height dimensions of the closed path as functions of the sensed angular position and forces. The control system increases or decreases the length and height dimensions of the closed path of a footpad when the user-applied force on the footpad is outside a particular magnitude range while the angular position of the rotatable member is within a particular angular position range. Exercise apparatus **10** thus allows the user to control stride height and length by controlling magnitudes of the forces the user applies to the footpads as they pass though particular sections of their closed paths.

[0027] Left linkage assembly **22** also includes a telescoping left foot member **16** having an upper channel member **18** supporting left footpad **50** and slidably engaging a lower channel member **20**. Left linkage assembly **22** further includes an adjustable length crank assembly **26** pivotally coupling lower channel member **20** to crank member **12**, a left rocker arm **28** pivotally coupled to frame **14** through a bearing pin **30** and pivotally coupled to upper channel member **18** through a bearing pin **32**, a left linear actuator **34** attached to rocker arm **28**, and a left drawbar **36** pivotally coupled to crank member **12** and lower channel member **20** through bearing pin **26** and pivotally coupled to actuator **34** through a bearing pin **38**. An upper end of rocker arm **28** forms a handlebar **40**.

[0028] Right linkage assembly **23** is generally similar to left linkage assembly **22** and includes a telescoping right foot member **17** for supporting the right footpad **51**, a right side actuator **35** similar to left side actuator **34**.

[0029] In addition to the right and left linkage assemblies **22** and **23**, the linkage also includes a regenerative brake **46** mounted inside frame housing **48** and a crank member **12** connected through a belt **44** to the regenerative brake's rotor that rotates with crank member **12**. Brake **46** provides an amount of resistance to crank member rotation that is adjusted by a control signal from control panel **24**.

[0030] As shown in FIGS. **2**A and **2**B, left footpad **50**, includes a set of rollers **52** for rollably engaging upper channel member **18** and a flexible hook member **54** for grasping an upright member **56** attached to an upper channel member for limiting horizontal motion of footpad **50** along upper channel member **18**. A strain gauge **58** mounted on hook member **54** supplies control panel **24** with an indicating signal of magnitude that varies as hook member **54** flexes. Strain gauge is **58** is biased so that its output signal magnitude is at a maximum when a user forces footpad **50** to the most forward position (toward rocker link **28**) along channel member **18** allowed by hook member **54** and is at a minimum when the user forces footpad **50** the most rearward position (toward crank member **12**) along channel member **18** allowed by flexible hook member **54**. The magnitude of the output signal of strain gauge **58** is a measure of the horizontal force a user applies to footpad **50**. Footpad **50** flexes as the user applies a downward force on the footpad, and another strain gauge **60**, attached to the underside of footpad **50**, provides control panel **24** with an output signal of magnitude that varies with the amount by which footpad **50** flexes. Thus the output signal of strain gauge **60** is a measure of the magnitude of the downward-directed vertical force a user applies to footpad **60**. Flexible conductors (not shown) convey the output signals of strain gauges **58** and **60** to control panel **24**. Right footpad **51** is similar to left footpad **50** and includes similar strain gauges.

[0031] FIG. **4** depicts an example implementation of left side adjustable crank assembly **26** as including a linear actuator **62** attached to crank member **12** for adjustably controlling a distance between a crank rod **64** and the crank member's rotational axis **66**. Crank rod **64** is coupled through bearings to footpad lower member **20** and drawbar **36**. Linear actuator **62** includes a stepper motor controlled by signals from control panel **24** that are delivered to the stepper motor through wires coupling control panel **24** to brush contacts (not shown) on crank member **12**. A similar adjustable crank assembly, including a linear actuator **63** is mounted on the right side of crank member **12** to form a portion of left side linkage assembly **23** of FIG. **1**.

[0032] FIG. **5** shows an alternative version of left crank assembly **26** including a linear actuator **68** pinned to crank member **12** for adjustably rotating a lever arm **70** also rotatably pinned to crank member **12**, thereby to adjust the distance between crank rod **64** attached to level arm **70** and crank member rotational axis **66**. Linear actuator **68** includes a stepper motor controlled by signals from control panel **24** that are delivered to the stepper motor through wires coupling control panel **24** to brush contacts (not shown) on crank member **12**. A similar adjustable right crank assembly mounted on the right side of crank member **12** forms a portion of right side linkage assembly **23** of FIG. **1**.

Elliptical Motion

[0033] A user standing on right footpad **50** applies forces to footpad **50** and handlebar **40** that cause foot member **16** to follow an elliptical path defined by linkage assembly **22** and cause handlebar **40** to oscillate about bearing pin **30**. We refer to the length of the elliptical path in the generally horizontal direction as the "stride length" and refer to the length of the elliptical path in the generally vertical direction as the "stride height". Actuators **34** and **62** of FIGS. **3** and **4** control the stride height and stride length by adjusting the shape of the elliptical path. The left side actuators **35** and **63** similarly control the stride length and stride height of the elliptical path followed by left footpad **51**.

[0034] The "crank radius", the distance between pin **64** and the rotational axis **66** of crank member **12** controlled by actuator **62** of FIG. **4**, influences the both stride height and stride height; as the crank radius increases, so too do stride height and stride length, The "rocker radius", the distance between bearing pins **30** and **38** controlled by linear actuator **34** also influences stride height but does not substantially influence stride height; as rocker radius increases, stride length decreases.

[0035] FIGS. **6A-6D** show four example elliptical paths **72A-72D** followed by a point on left footpad **50**. In FIG. **6A**, the crank radius is relatively small and rocker radius is relatively long, so both stride height and stride length of path **72A** are small. In FIG. **6B**, both crank radius and rocker radius are relatively large, so both stride length and stride and stride of path **72B** are larger than in path **72A**. In FIG. **6C**, the rocker radius is relatively small and the crank radius is relatively large, so the stride length of path **72C** is longer than in paths **72A** and **72B** and stride height is as large as in path **72B**. In FIG. **6D**, both rocker radius and crank radius are small, so stride length of path **72D** is long, about the same as for path **72B**, but stride height is small, about the same as in path **72A**.

[0036] Thus the control system can adjust actuators **34** and **62** to provide a stride length ranging from the short stride length of path **72A** to the long stride length of path **72C** and to provide a stride height ranging from the short stride height of path **72A** to the high stride height of path **72C**. Although the crank radius controlled by actuator **62** influences both stride height and stride length, the control system can independently adjust stride height and stride length. For example, to increase or decrease stride length without affecting stride height, the control system can signal actuator **34** to decrease or increase the rocker radius without signaling actuator **62** to change crank radius. To increase stride height without affecting stride length, the control system can signal actuator **62** to increase the crank radius and can signal actuator **34** to increase the rocker radius. The increase in crank radius not only increases stride height, but also tends to increase stride length, the control system can offset the increase in stride length by appropriately increasing rocker radius so that there is no net increase in stride length. Conversely, to decrease stride height without affecting stride length, the control system can signal actuator **62** to decrease the crank radius and signal actuator **34** to appropriately decrease the rocker radius.

[0037] As discussed below, when exercise apparatus **10** is in a manual stride height or length adjustment mode, the control system adjusts stride height or length in response to use-operated pushbuttons mounted on control panel **24**. When the exercise apparatus **10** is in an automatic stride height or length adjustment mode, the control system adjusts stride height or length in response to forces the user applies to footpads **50** and **51** which are sensed by strain gauges **58** and **60** of FIGS. **2A** and **2B** or by alternative means described below.

Control System

[0038] FIG. **7** is a block diagram showing a control system for exercise apparatus **10** of FIGS. **1-5** including a conventional computer **110** residing within control panel **24** and an I/O interface circuit **118** interfacing computer **100** to user input devices **112** and display devices **114** mounted on control panel **24**, and a network adapter **116**. User input devices **114** allow the user to input commands to computer and may include, for example, pushbuttons, control knobs, a keyboard and/or a touch screen. Display devices **114**, which may include, for example, pushbutton lights, light emitting diodes, alphanumeric display panels, and/or a video monitor, allow computer **110** to present various kinds of information to the user. Network adaptor **116**, which may be wireless, allows computer **110** to communicate with other computers via conventional network and Internet protocol for uploading programs and downloading or uploading data.

[0039] The control system also includes various sensor and control devices coupled to computer **110** via I/O interface circuit. Right side control devices and sensors **120** include actuators **35** and **63** and strain gauges **59** and **60**. Left side control and sensor devices **122** include actuators **34** and **62** and strain gauges **58** and **60**. Strain gauges **58-61** produce signals H_FORCE_R, H_FORCE_L, VFORCE_R and VFORCE_L, respectively, indicating the magnitudes of horizontal and vertical forces the user applies to footpads **50** and **51**.

[0040] Regenerative brake **46** includes a generator **126** coupled for rotation with crank member **12** of FIGS. **1-4**. Generator **126** generates an output voltage across a variable resistor **128** that increases with the generator's rotational velocity producing a current through resistor **128**. Resistor **128** dissipates in the form of heat the rotational energy the user expends rotating generator **126**. Under control of computer **110**, I/O interface **118** transmits a signal RESISTANCE to resistor **128** that controls the electrical resistance of resistor **128**, thereby controlling the mechanical resistance regenerative brake **46** provides to crank rotation. The voltage across resistor **128** is proportional to the angular velocity of crank rotation and is provided as a VELOCITY signal input to I/O interface circuit **118**, which includes an analog-to-digital converter for converting the analog VELOCITY signal into digital data input to computer **110** indicting rotational velocity.

[0041] An angular position sensor **126** mounted within frame housing **48** of FIG. **1** provides a POSITION signal to I/O interface **118** indicating the angular position of crank member **12**. In some embodiments of the invention, the VELOCITY signal may be omitted since computer **110** can alternatively compute velocity from changes in angular position indicated by the POSITION signal. Devices and circuits capable of carrying out the interface functions of I/O interface circuit **118** are well known to those of ordinary skill in the art.

[0042] Under control of computer **110**, I/O interface circuit **118** transmits control pulses to actuators **34**, **35**, **62** and **63** via the following control signals. Each control signal pulse tells the receiving actuator to increment or decrement its length by a unit amount:

[0043] INC_CR_R to tell actuator **35** to increment right side crank radius,

[0044] DEC_CR_R to tell actuator **35** to decrement right side crank radius.

[0045] INC_RR_R to tell actuator **63** to increment right side rocker radius,

[0046] DEC_RR_R to tell actuator **63** to decrement right side rocker radius.

[0047] INC_CR_L to tell actuator **34** to increment left side crank radius,

[0048] DEC_CR_L to tell actuator **34** to decrement left side crank radius,

[0049] INC_RR_L to tell left actuator **62** to increment left side rocker radius, and

[0050] DEC_RR_L to tell actuator **62** to decrement left side rocker radius.

[0051] Actuators **34**, **35**, **62** and **63** include internal limit switches to prevent computer **110** from signaling them to drive rocker radius or crank radius beyond their maximum or minimum limits. During system startup, computer **110** sends a sufficient number of pulses to each actuator to ensure that crank radius is at a minimum and rocker radius is at a maximum. Thereafter, computer **110** keeps track of the number of increment and decrement pulses it sends to each actuator in order to keep track of each crank and rocker radius. Computer **110** maintains a lookup table in its memory that relates crank and rocker radius to stride length and stride height. Whenever computer **110** needs to increment or decrement stride height or stride length, it uses the lookup table to determine the amount by which it must increment or decrement rocker radius and/or crank radius in order to achieve the desired change in stride height or length.

Stride Length Adjustment

[0052] The user can command computer **110** to operate in either a manual stride length adjustment mode wherein computer **110** and I/O interface circuit **118** control right and left stride length as a function of user input supplied via user input devices **112** or in an automatic stride length adjustment mode in which computer **110** and I/O interface circuit **118** automatically control right and left stride length based on sensor output.

[0053] As shown in FIG. **8**, the user input devices **112** on control panel **24** may include, for example, separate lighted pushbuttons **130** and **131** enabling the user to select between manual and auto stride length adjustment modes, with pushbutton **130** or **131** being illuminated to indicate the current mode of operation. When in the manual stride length adjustment mode, computer **110** signals I/O interface circuit to increase or decrease stride length in response to user input via separate pushbuttons **132** and **133** and a stride length sensitivity knob **134** allows the user control the amount by which computer **110** signals actuators **34**, **35**, **62** and/or **63** to increase or decrease stride length each time the user presses button **132** or **133**.

[0054] In the automatic stride length adjustment mode, computer **112** adjusts left and right stride length in response to a combination of information contained in the H_FORCE_R and H_FORCE_L output signals of the right and left horizontal strain gauges **58-61** and the POSITION output signal of angular position sensor **126** of FIG. **7** indicating the angular position of crank rod **64** of FIG. **1**. As discussed above, left drawbar link **36** of linkage mechanism **22** is rotatably connected to crank member **12** via crank rod **64**, and as crank rod **64** rotates about the axis **66** of crank member **12**, linkage mechanism **22** causes right left member **36** and left footpad **50** to oscillate back and forth through a horizontal distance controlled by actuators **34** and **62**.

[0055] FIG. **9** depicts the circular path of crank rod **64** about the axis **66** of crank member **12**. When crank rod **64** is at its maximum forward position, left footpad **50** has reached its maximum forward position, right footpad **51** has reached its maximum rearward position, and the POSITION signal output of position sensor **126** indicates that crank rod **64** is at 0 degrees. Conversely, when crank rod **64** reaches its maximum rearward position, left footpad **50** reaches its maximum rearward position, right footpad **51** reaches its maximum forward position, and the POSITION signal output of position sensor **126** indicates crank rod **64** is at 180 degrees.

[0056] A user rotates crank member **12** by shifting most of his or her weight to left side footpad **50** while crank rod **64** is moving counterclockwise from 90 to 270 degrees, and by shifting most of his or her weight to right side footpad **51** when crank rod **64** is moving counterclockwise from 270 to 90 degrees. The percentage of the user's weight allocated to the right and left during each half cycle of crank rotation controls the downward vertical forces the user applies to footpads **50** and **51** and affects the rotational velocity of crank member **12**. Vertical stain gauges **60** and **61** sense the vertical forces on the footpads. The user's leg muscles can also apply forward and rearward directed horizontal forces to footpads **50** and **51** that are sensed by left and right horizontal strain gauges **58**-**61**. The horizontal forces on footpads **50** and **51** also affect rotational velocity, but normally to a lesser extent than the vertical forces.

[0057] In the automatic stride length adjustment mode, computer **110** automatically increases or decreases stride length by increasing or decreasing the lengths of actuators **34**, **35**, **62** and **63** in response to the H_FORCE_L and H_FORCE_R signals produced by horizontal strain gauges **58** and **59** and the POSITION signal produced by position sensor **126**. We define the following horizontal forces as being positive in the forward direction from the user's point of view:

[0058] F_{HL}: horizontal force on left footpad **50**,

[0059] F_{HR}: horizontal force on right footpad **51**,

[0060] F_{HHT}: a high horizontal threshold level force, and

[0061] F_{LHT}: a low horizontal threshold level force,

[0062] Computer **110** stores parameters indicating the high and low horizontal threshold forces F_{HHT} and F_{LHT} as user adjustable constants in its memory. In the automatic stride length adjustment mode, computer **110** signals interface circuit **118** to carry out the following operations:

[0063] Increment left side stride length when $F_{HL}>F_{HHT}$ and crank rod **64** resides between 80 and 100 degrees,

[0064] Increment right side stride length when $F_{HR}>F_{HHT}$ and crank rod **64** resides between 260 and 280 degrees,

[0065] Decrement left side stride length when $F_{HL}<F_{LHT}$ and crank rod **64** resides between 80 and 100 degrees, and

[0066] Decrement right side stride length when $F_{HR}<F_{LHT}$ and crank rod **64** resides between 260 and 280 degrees.

[0067] When computer **110** follows the above rule, a user quickly learns that sufficiently increasing or decreasing the horizontal forces of a footpad when the footpad is at the top of its forward stride will cause an increase or decrease in stride length. Although the position ranges for crank rod **64** suggested above are provided for illustrative purposes, those of skill in the art will appreciate that in other embodiments of the invention, the computer may employ position ranges that vary from those indicated above when testing for the user's desire to increase or decrease stride length.

[0068] FIG. **10** is a flow chart for a program executed by computer **110** when in the automatic stride length adjustment mode. Computer **110** initially iteratively samples the right horizontal force data F_{HR} and the POSITION data provided by interface circuit **18** (step **202**) until it determines from the POSITION data that crank rod **64** resides between 260-280 degrees (step **204**). If the last sampled value of right horizontal force data F_{HR} exceeds the high horizontal threshold level force F_{HHT} (step **206**), computer **110** signals interface circuit **118** to increment the right stride length (step **208**). If the last sampled value of right horizontal force data F_{HR} is less than the low horizontal threshold level force F_{LhT} (step **210**), computer **110** signals interface circuit **118** to decrement the right stride length (step **212**). After step **208** or **212**, or after step **210** if the last sampled value of right horizontal force data F_{HR} is between the low horizontal threshold level force F_{LHT} and the high horizontal level threshold force F_{HHT}, computer **110** begins iteratively sampling the left horizontal force data F_{HL} and the POSITION data supplied by interface critic **118** (step **214**) until it determines from the POSITION data that crank rod **64** resides between 80 and 100 degrees (step **216**). If the last sampled value of left horizontal force data F_{HL} exceeds the high threshold level force F_{HHT} (step **218**), computer **110** signals interface circuit **118** to increment the left stride length (step **220**). If the last sampled value of left horizontal force data F_{HL} is less than the low threshold level force F_{LHT} (step **222**), computer **110** signals interface circuit **118** to decrement the left stride length (step **224**). After step **220** or **224**, or after step **222** if the last sampled value of left horizontal force data F_{HL} is between the low horizontal threshold level force F_{LHT} and the high horizontal level threshold force F_{HHT}, computer **110** returns to step **202**. Note that computer **110** increments or decrements right or left stride length at most only once during each rotational cycle. The amount by which computer **110** increases left or right stride length at step **208** or **220** increases with the amount by which the last sampled horizontal force F_{HR} or F_{HL} exceeds the high threshold level F_{HL}. Similarly, the amount by which computer **110** decreases left or right stride length at step **212** or **224** increases with the amount by which the low threshold level F_{HL} exceeds the last sampled horizontal force F_{HR} or F_{HL}.

[0069] Thus in the automatic stride length adjustment mode, the user can maintain a constant stride right and left stride lengths by keeping the horizontal forces on the left and right footpads **50** and **51** between the high and low horizontal threshold levels F_{HHT} and F_{LHT} while the left or right footpad is near its high point and moving forward, and can increase or decrease left or right stride length by increasing or decreasing the horizontal force on right or left footpad **50** or **17** above or below the high or low threshold levels while the footpad is near its high point and moving forward. The particular ranges of positions employed at decision steps **204** and **216** are a matter of design choice and can vary from those shown in FIG. **10**. For example at step **204** computer **110** could determine whether crank rod **64** is within a range of 90-120 degrees and at step **216** computer **110** could determine whether crank rod **64** is in a range of 270-300 degrees. In the automatic stride length adjustment mode, the user can adjust the values of the two threshold level force constants F_{LHT} and F_{HHT} up or down using stride length sensitivity knob **134**. Computer **110** displays the current stride height and length and the current threshold levels F_{LHT} and F_{HHT} on display monitor **114**. In the preferred embodiment of the invention, right and left stride paths, including their lengths and heights, are independently adjustable, which is advantageous because users having non-symmetric leg strengths sometimes prefer slightly differing right and left strides. In other embodiments of the invention, computer **110** automatically adjusts right and left stride height and/or length concurrently so they are always similar. This could be implemented, for example, by changing the algorithm of FIG. **10** so that at steps **208** and **220** both right and left stride lengths are incremented and so that at steps **212** and **224** both right and left stride lengths are decremented.

[0070] In the preferred embodiment of the invention, pushbuttons and knobs **132**-**134** allow the user to control right and left stride lengths concurrently when the computer is operating in the manual stride adjustment mode so that they are always similar.

[0071] However additional pushbuttons can be provided on control panel **24** to allow the user to independently increment and decrement right and length stride length when computer **110** is operating in the manual stride length adjustment mode.

Stride Height Adjustment

[0072] The user can also command computer **110** to operate in either a manual stride height adjustment mode wherein the user directly controls stride height via user input devices

112 or in an automatic height length adjustment mode in which the computer automatically controls stride height based on sensor input.

[0073] As shown in FIG. **8**, the user input devices **112** on control panel **24** may include, for example, separate lighted pushbuttons **135** and **136** enabling the user to select between manual and auto stride height adjustment modes, with pushbutton **135** or **136** being illuminated to indicate the current mode of operation. When in the manual stride height adjustment mode, computer **110** signals I/O interface circuit to increase or decrease stride height in response to user input via separate pushbuttons **137** and **138** and a stride height sensitivity knob **140** allows the user control the amount by which computer **110** increases or decreases stride length each time the user presses button **137** or **138**. While the preferred embodiment of the invention provides switches and knobs **130-140** for the above-described user input functions, one of skill in the art will appreciate that input devices **112** provided for these function are a matter of design choice and can be implemented by any of a variety of devices including, for example, keyboards, keypads, touch screens, and the like.

[0074] In the automatic stride height adjustment mode, computer **112** adjusts left and right stride height in response to a combination of information contained in the V_FORCE_R and V_FORCE_L output signals of the right and left horizontal strain gauges **100** and **101** and the POSITION output signal of angular position sensor **126** of FIG. **7**. We define the following vertical forces on the footpads as being positive in the upward direction and negative in the downward direction from the user's point of view:

[0075] F_{VR}: vertical force on right footpad **51**,

[0076] F_{VL}: vertical force on left footpad **50**,

[0077] F_{HVT}: a high vertical threshold level force, and

[0078] F_{LVT}: a low vertical threshold level force.

[0079] Interface circuit **118** converts the V_FORCE_R and V_FORCE_L output signals of the right and left horizontal strain gauges **100** and **101** into data representing the vertical forces F_{VR} and F_{VL} the user applies the left and right footpads **50** and **51** and permits computer **110** to read access that data. Computer **110** stores the high and low vertical threshold forces F_{HVT} and F_{LVT} as user adjustable constants in its memory.

[0080] Assuming upward directed vertical forces are positive, the vertical forces F_{VR} and F_{VL} the user applies to the left and right footpads **50** and **51** are negative (downward directed) and vary as the user rotates crank member **12** by shifting his or her weight from one footpad to the other during each rotation cycle. When crank rod **64** resides between 90 and 100 degrees, most of the user's weight will be on right footpad **51** but the user will normally continue to apply a modest downward force on left footpad **50**. However it is possible for the user to shift all or almost all of his or her weight to right footpad **51** when crank rod **64** is between 90 and 100 degrees thereby causing vertical force F_{VL} on left footpad **50** greater (less negative) than a small negative threshold force F_{HVT}. In the automatic stride height adjustment mode, computer **118** increases left side stride height when F_{VL} is greater (less negative) than F_{HVT} when crank rod **64** is between 90 and 100 degrees. Thus the user can signal computer **110** to increase left side stride height by removing most of all of his or her weight from footpad **50** when crank rod **64** is between 90 and 100 degrees. Similarly, computer **118** increases right side stride height when F_{VL} is greater (less negative) than F_{HVT} when crank rod **64** is between 270 and 280 degrees. Thus the user can signal computer **110** to increase left side stride height by removing most of all of his or her weight from footpad **51** when crank rod **64** is between 270 and 280 degrees.

[0081] In the automatic stride height adjustment mode, computer **118** decreases left side stride height when F_{VR} is less than (more negative) than a low vertical threshold level F_{LVT} when crank rod **64** is between 90 and 100 degrees. Thus the user can signal computer **110** to decrease left side stride height by shifting a sufficient amount of all of his or her weight to left footpad **50** when crank rod **64** is between 90 and 100 degrees. Similarly, computer **118** decreases right side stride height when $F_{VK\backslash L}$ is less (more negative) than F_{VT} when crank rod **64** is between 270 and 280 degrees. Thus the user can signal computer **110** to decrease right side stride height by a sufficient amount of his or her weight to right footpad **51** when crank rod **64** resides between 270 and 280 degrees. In the automatic stride height adjustment mode, the user can adjust the magnitude of low vertical threshold level F_{LVT} using stride height sensitive control knob **140** and computer **110** signals interface circuit **118** to carry out the following operations:

[0082] Increment left side stride height when $F_{VL}>F_{HVT}$ and crank rod **64** resides between 90 and 100 degrees,

[0083] Increment right side stride height when $F_{VR}>F_{HVT}$ and crank rod **64** resides between 270 and 280 degrees,

[0084] Decrement left side stride height when $F_{VL}<F_{LVT}$ and crank rod **64** resides between 90-100 degrees, and

[0085] Decrement right side stride height when $F_{VR}<F_{LVT}$ and crank rod **64** resides between 270 and 280 degrees.

[0086] The position ranges for crank rod **64** discussed above are provided for illustrative purposes. Those of skill in the art will appreciate that in other embodiments of the invention, the computer may employ position ranges that vary from those indicated above when testing for the user's desire to increase or decrease stride height and the user will learn to apply the appropriate vertical forces to the footpad at the appropriate points along their paths as needed to initiate desired changes in stride height.

[0087] FIG. **11** is a flow chart for a program executed by computer **110** when in the automatic stride height adjustment mode. Computer **110** initially iteratively samples the right and left vertical force data F_{VR} and F_{VL} and the POSITION data provided by interface circuit **18** (step **302**) until it determines from the POSITION data that crank rod **64** resides between 270 and 280 degrees (step **304**). If the last sampled value of right vertical force data F_{VR} exceeds the positive high threshold level force F_{HVT} (step **306**), computer **110** signals interface circuit **118** to increment the right stride height (step **308**). If the last sampled value of left vertical force data F_{VL} exceeds low threshold level force F_{LVT} (step **310**), computer **110** signals interface circuit **118** to decrement the left stride height (step **312**). After step **308** or **312**, or after step **310** if results of both steps **306** and **310** are "NO", computer **110** resumes iteratively sampling the right and left vertical force data F_{VR} and F_{VL} and the POSITION data (step **314**) until it determines from the POSITION data that crank rod **64** resides between 260 and 280 degrees (step **316**). If the last sampled value of left vertical force data F_{VL} exceeds the high threshold level force F_{HVT} (step **318**), computer **110** signals interface circuit **118** to increment the left stride height (step **320**). If the last sampled value of left vertical force data F_{HL} exceeds the low threshold level force F_{LVT} (step **322**), computer **110** signals interface circuit **118** to decrement the left stride height (step **324**). After step **320** or **324** or after step **322** if the result of both steps **318** and **322** is “NO”, computer **110** returns to step **302**. Note that computer **110** increments or decrements right or left stride height at most only once during each rotational cycle. The amount by which computer **110** increases or decreases left or right stride height at step **308**, **312**, **320** or **324** increases with the amount by which the last sampled vertical force F_{HR} or F_{HL} exceeds the high or low threshold level F_{VHT} or F_{VHT}.

[0088] Thus in the automatic stride height adjustment mode, the user can maintain a constant right and left stride height by keeping the vertical forces on the right and left footpads **50** and **51** between the high or low threshold levels F_{VHT} or F_{VHT} while the footpads are approaching their high points. The user can increase right or left stride height by lifting his right or left foot off the right or left footpad **50** or **17** as it nears its high point and can decrease right or left stride height by pushing down sufficiently hard on the right or left footpad **50** or **17** as it nears its high point.

[0089] In the preferred embodiment of the invention, right and left stride height are independently adjustable in the automatic mode, which is advantageous because users having non-symmetric legs sometimes prefer slightly differing right and left stride heights. In other embodiments of the invention, computer **110** can automatically adjust right and left stride height concurrently so they are always similar. This could be implemented, for example, by changing the algorithm of FIG. **10** so that at steps **308** and **320** both right and left stride heights are incremented and so that at steps **312** and **324** both right and left stride heights are decremented.

[0090] In the preferred embodiment of the invention, pushbuttons and knobs **137**-**140** allow the user to control right and left stride height concurrently when the computer is operating in the manual stride adjustment mode so that they are always similar. However additional pushbuttons can be provided on control panel **24** to allow the user to signal computer **110** to independently increment and decrement right and stride height when computer **110** is operating in the manual stride height adjustment mode.

[0091] Those of skill in the art will also appreciate that the particular ranges of positions employed at decision steps **304** and **316** are a matter of design choice and can vary from that shown in FIG. **10**. For example at step **304** computer **110** could determine whether crank rod **64** is within a range of 90-120 degrees and at step **316** computer **110** could determine whether crank rod **64** is in a range of 270-300 degrees.

[0092] Stride Length Control Based on Angular Velocity and Position

[0093] In the automatic stride length control mode, computer **110** determines when to increase or decrease stride length base as a function of the POSITION signal output of angular position sensor **126** and of the H_FORCE_R and H_FORCE_L output signals of horizontal strain gauges **59** and **60**. In an alternative embodiment of the invention, computer **110** determines when to change stride length as a function of the POSITION signal and the VELOCITY signal output of regenerative brake **46**, thereby eliminating the need for horizontal strain gauges **59** and **60**. This is particularly advantageous in an exercise apparatus that does not provide automatic stride height control mode and therefore does not require vertical strain gauges **60** and **61**. Eliminating the need for all strain gauges **98**-**101** reduces the complexity of footpads **50** and **51** and allows them to be formed as integral parts of foot members **16** and **17** and the wiring needed to deliver the strain gauge output signals to control panel **24** can be eliminated.

[0094] FIG. **12** plots the magnitude V of the VELOCITY signal as a function of both time and crank position as the user moves footpads **50** and **51** through a full rotation cycle of crank member **12** as indicated by the POSITION signal output of angular position sensor **128**. FIG. **13** plots the acceleration A of crank member **12** as a function the angular position of crank rod **64**. FIG. **12** also graphically depicts at angular positions 0, 270, 180 and 90 degree positions of crank rod **64** of FIG. **1** as it rotates about crank axis **66** as indicated by the POSITION signal and shows the direction of the horizontal and vertical forces on crank. crank resulting from user forces applied to the footpads.

[0095] At 0 degrees, the user applies the majority of his or her weight on footpad **50** to apply a net downward force F_{VL} on crank rod **64** which accelerates crank rotation by overcoming resistive forces applied by regenerative brake **46**. Since at 0 degrees, crank rod **64** is at its maximum horizontal distance from crank axis **66** of cranks **20** the net vertical force F_{VL} on crank rod **64** maximally accelerates crank member **12** as indicated by the rapidly increasing magnitude V of the VELOCITY signal at the 0 degree position. As crank rod **64** approaches 270 degrees, crank acceleration declines due to the decreasing leverage afforded by the declining horizontal distance between crank rod **64** and crank axis **66** and because the user has begin shifting his or her weight between footpads **50** and **51** so that the forces on left crank rode **64** and its right crank rod counter part **65** tend to cancel one another with respect to accelerating crank member **12**. Angular velocity peaks at about 315 degrees when the rotational forces provided by the user fall below the resistive forces provided by regenerative brake **14**. As crank rod **64** reaches its 270 degree position, the vertical forces on crank rods **64** and **65** have no effect on acceleration and crank deceleration is at a maximum, as indicated by the large negative slope of VELOCITY signal magnitude V. Velocity continues to decline to a minimum when crank rod **64** reaches its 225 degree position. Maximum rotational acceleration is again achieved when crank rod **64** reaches 180 degrees due to the large net vertical force on pin **45** at a maximum horizontal distance from crank axis **66**.

[0096] FIG. **12** plots angular velocity V and acceleration of crank rod **64** of FIG. **1** as a function of the angular position of crank rod **64** during one cycle of pin rotation and also graphically depicts the net vertical forces F_{VR} and F_{VL} the user applies to pins **64** and **65** **4** and the horizontal forces F_{HR} and F_{HL} the user applies to points **44** and **45**. FIG. **12** is drawn with the assumption that the user is maintaining a steady pace and that F_{HL} and F_{HR} are zero because the user is applying no horizontal forces to footpads **50** and **51**.

[0097] Even when the user pedals at a constant rate to provide a constant average angular velocity, the instantaneous angular velocity V will vary as shown in FIG. **12** during each cycle of rotation. At the 0 and 180-degree positions, acceleration A is at its positive maximum positive because F_V, being maximally horizontally displaced from crank member axis **66**, rapidly accelerates the crank. At the 90 and 270 degree positions, acceleration is at its negative minimum because F_V, having no horizontal displacement from crank member axis **66**, has no effect on crank acceleration and the crank rapidly decelerates due to the resistive force on crank member **12** provided by brake **46**. The “net vertical force” F_V is defined as the difference between the vertical forces F_{VR} and F_{VL} via crank rods **64** and **65** and is directed at the point receiving the larger of the two forces

[0098] The user could increase his or her pace by increasing the net force F_V applied to applied to crank rods **64** and **64**, and in such case, both the velocity and acceleration curves of FIG. **12** would trend upward until the resistance provided by regenerative brake **46**, which increases with rotational velocity, balances the increased cranking force provided by the user. At that point the velocity curve would look similar to that of FIG. **12**, but would be shifted upward.

[0099] Acceleration A at any given position P of crank rod **64** is a function of the net vertical force F_V on the crank rods **64** and **65** applied via lifter links **70** and **71** of FIG. **1**, the net horizontal forces F_H on crank rods **64** and **65** and the resistive force F_R provided by regenerative brake **46**, and the angular position P of crank rod **64**.

$$A=f(F_V,F_{HR},F_{HL},F_R,P)$$

[0100] The resistive force F_R provided by regenerative brake **46** is a function of the rotational velocity V of the crank member **12** and the magnitude of the resistance R of resistor **128** of FIG. **7**. Thus

$$A=g(F_V,F_{HR},F_{HL},V,R,P)$$

[0101] When the user applies no horizontal forces F_{HL}, F_{HR} to footpads **50** and **51**, then the negative crank acceleration at the 270 degree position of crank rod **64** arises only from resistive force F_R due to V and R because the net vertical force F_V is zero when P=270 degrees. Thus the expected acceleration A at the 270 degree position when net horizontal forces are 0,

$$A=g(0,0,0,V,R,270)$$

[0102] We define a variable A_{E270} as an "expected" crank acceleration for a given velocity at the 270 degree pin position when horizontal forces F_{HL}, F_{HR} on crank rods **64** and **65** are zero. The expected 270 degree position crank acceleration A_{E270} is a function only of V and R.

$$A_{E270}=h(V,R)$$

[0103] The expected acceleration A_{E90} at the 90-degree position of crank rod **64** is a similar function of V and R when horizontal forces on crank rods **64** and **65** are zero.

$$A_{E90}=h(V,R)$$

[0104] During each crank cycle, computer **110** samples the POSITION and VELOCITY signals to determine the magnitude V of crank velocity whenever the POSITION signal indicates crank rod **64** is at either the 90 or 270 degree position. Knowing the value to which it most recently set resistance R, computer **110** then computes A_{E90} and A_{E270} based on a stored equation or lookup table model of the above function h(V,R). The function is experimentally determined at the factory at the time the exercise apparatus is built and then stored in non-volatile memory of computer **110**.

Stride Height and Length Control for Backward Mode Operation.

[0105] Referring to FIG. **1**, when the user operates exercise apparatus **10** in a "forward mode" as described above such that crank rod **64** rotates counter-clockwise about the axis of crank member **12** as viewed from the left side of the apparatus, the user's feet will move in much the same way as the would if the user were walking forward on a flat surface. However the user can alternatively operate exercise apparatus **10** in a "backward mode" by rotating crank rod **64** in a clock-wise direction, thereby moving his or her feet in a manner similar to walking backwards. Computer **110** determines whether the user is operating the apparatus in the forward or backward mode based on how the POSITION signal output of angular position sensor **126** changes with time. During backward mode operation, when the user has selected automatic stride height and/or length control, computer **110** automatically adjusts stride height and/or length based on user applied forces using algorithms substantially similar to the forward walking mode algorithms described above, except that the angular positions at which user forces are sensed differ in the reverse mode. In the backward mode computer **110** will carry out the following actions:

[0106] Increment left side stride height when $F_{VL}>F_{HVT}$ and crank rod **64** resides between 80 and 90 degrees,

[0107] Increment right side stride height when $F_{VR}>F_{HVT}$ and crank rod **64** resides between 280 and 10 degrees,

[0108] Decrement left side stride height when $F_{VL}<F_{LVT}$ and crank rod **64** resides between 80 and 90 degrees, and

[0109] Decrement right side stride height when $F_{VR}<F_{LVT}$ and crank rod **64** resides between 280 and 10 degrees.

Interface Circuit

[0110] Interface circuit **118** and computer **110** determine the "actual crank accelerations" A_{A90} and A_{E270} at crank rod **64** positions 90 and 270 by differentiating the VELOCITY signal and sampling the result whenever the POSITION signal indicates crank rod **64** is at either the 90 or 270 degree position. FIG. **13** depicts a circuit within interface circuit **118** for providing computer **110** with data V**90**, V**270** representing rotational velocity at the 90 and 270 degree positions, data AA**90** and AA**270** representing actual acceleration at the 90 and 270 degree positions, and a data sequence V representing instantaneous rotational velocity. A digitizer **340** digitizes the VELOCITY signal many times during each rotational cycle in response to a CLOCK signal to produce the V data sequence. A differentiating amplifier **350** differentiates the VELOCITY signal and a digitizer **352** also clocked by the CLOCK signal, digitizes the result to produce another data sequence representing the angular crank acceleration A. Position detector **356** checks the POSITION signal on each pulse of the CLOCK, supplying an interrupt signal INT_{90} to computer **110** whenever crank rod **64** is at the 90 degree position and supplying an interrupt signal INT_{270} to computer **110** whenever crank rod **64** is at the 270 degree position. An OR gate **380** Ors the INT_{90} and INT_{270} signals to produce a signal for clocking a pair of registers **342** and **354** for storing the V and A outputs of digitizers **340** and **352**, respectively. Interrupt signals INT_{90} and INT_{270} tell computer **110** to read the contents of registers **342** and **354**. When INT_{90} is asserted, computer **110** assumes the contents of registers **342** and **354** are V_{90} and A_{A90}, and when INT_{270} is asserted, computer **110** assumes the contents of registers **342** and **354** are V_{270} and A_{270}. Since those of skill in the art will appreciate that there are many other possible ways to carry out the function of the circuit of FIG. **13** and that the approach used is a matter of design choice.

[0111] The difference between the expected and actual accelerations at the 90 and 270-degree positions of crank rod

64 is a function of the amount and direction of net horizontal force F_H the user is applying to pins.

$$F_{H90}=m(A_{A90}-A_{E90})$$

$$F_{H270}=m(A_{A270}-A_{E270})$$

The constant m is the mass of the system the horizontal forces F_{HR} and F_{HL} must move when accelerating the crank at the 90 and 270-degree positions.

[0112] In the alternative embodiment of the invention, computer **110** determines $(A_{A90}-A_{E90})$ and $(A_{A270}-A_{E270})$ each time crank rod **64** arrives at it 90 or 270 degree position, and determines whether to increase or decrease stride length depending on the magnitude of the difference. When $(A_{A90}-A_{E90})$ or $(A_{A270}-A_{E270})$ is larger than a high threshold value, computer **110** increases both right and left side stride length. When $(A_{A90}-A_{E90})$ or $(A_{A270}-A_{E270})$ is less than a low threshold value, computer **110** decreases both right and left side stride length.

[0113] Referring to FIGS. **1** and **2**, note that the user can also apply horizontal forces to crank rods **64** and **65** through linkages **22** and **23** by pushing and pulling on handle bars **40** and **41**. Since in the alternative embodiment of the invention stride length is adjusted in response to horizontal forces on crank rod **64** regardless of whether they originate from user forces applied to pads **16** or **17** to hand grips **40** and **41**, the user can increase or decrease stride length by increasing or decreasing forces he or she applies to hand grips **40** and **41** when crank rod **64** is at the 90 or 270 degree position.

Resistance Control

[0114] Referring to FIGS. **1**, **7** and **8**, control panel **24** includes a pair of pushbuttons **142** and **142** enabling the user to command computer **110** to increase or decrease the resistance to rotation of cranks **121** and **122** provided by regenerative brake **46** by signaling I/O interface circuit **118** to increase or decrease the resistance of resistor **128**. Display devices **114** of FIG. **7** include a numeric display panel **143** for indicating the current resistance level.

Programmed Exercise

[0115] Computer **110** can operate in a "Program Mode" in which it automatically varies the resistance of brake **46**, stride length, and/or stride height at various times during exercise. Referring to FIG. **8**, the user presses either of a pair of pushbuttons **142** on control panel **24** to tell computer **110** whether it is to turn the program mode on or off.

[0116] Referring to FIGS. **7** and **8**, display devices **114** and user input devices **112** within control panel **24** include in addition to control buttons and knobs **142** include a display monitor **141** for presenting data and other displays under control of computer **110**. Display monitor **141** includes a conventional touchscreen for signaling computer **110** whenever the user has touched the surface of the display monitor and for indicating the area of the monitor the user has touched. Computer **110** displays push button icons and menu items the user can touch to provide input commands to computer **110**. In the program mode, computer **110** generates a video of terrain on monitor **141** to simulate what the user might see if the user were running in such a terrain and also changes resistance, stride length, and/or stride height to simulate the effects of changes in the slope of the terrain viewed on display monitor **141**. For example, resistance and stride height are increased and stride length is decreased when the display shows the user is traveling uphill while resistance and stride height are decreased and stride length is increased when the display shows the user is traveling downhill. Network adapter **116** suitably allows computer **110** to download various programs via the Internet in response to commands from the user via the touchscreen monitor **141**. The user selects from among stored exercise programs listed as menu items on display monitor by using the touchscreen to select the appropriate menu item.

[0117] Computer **110** can use the touchscreen of monitor **141** to receive user input allowing the user, for example, to

[0118] (a) Log in as a user or log out
[0119] (b) Select exercise parameters being displayed.
[0120] (c) Select an exercise program,
[0121] (d) Download a new exercise program.

[0122] Computer **110** also uses display monitor **141** to display a variety of data regarding user exercise in graphical or numeric form including, but not limited to:

[0123] (a) Current resistance level,
[0124] (b) Elapsed exercise time,
[0125] (c) Current speed of exercise,
[0126] (d) Average speed of exercise,
[0127] (e) Number of calories burned during exercise
[0128] (f) Simulated distance traveled during exercise
[0129] (g) Simulated elevation gains and losses during exercise,
[0130] (h) User's weight,
[0131] (j) Available exercise programs,
[0132] (k) Currently selected exercise program,
[0133] (l) Current stride height and length
[0134] (m) Historical exercise data for each user.

[0135] Those of skill in the art will appreciate that computer **110** can be programmed to determine and display exercise speed, calories burned, distance traveled, and user weight from information provided by I/O interface **118** in response to signals it receives representing forces on the footpads, rotational velocity and position. Stride height, stride length and resistance are directly controlled by computer **110** and therefore known the computer. Historical exercise data for each user which may be displayed in tabular or graphical form, can include, for example, daily number of calories burned, distances traveled, exercise programs completed and times required to complete them.

[0136] The present invention has been described with the understanding that persons skilled in the art will recognize additional embodiments, improvements, and/or applications that nonetheless fall within the scope of the invention. For example, while the invention has been illustrated in connection with an elliptical exercise machine having a particular type of linkage for coupling each footpad to the frame and for controlling the path that the footpad follows, the invention in its broadest sense can be practiced in connection with exercise with any kind of linkage that can respond to input signals by adjusting one or more dimensions of that path. Therefore, the scope of the present invention as defined in any one the claims appended hereto is not intended to be limited to the particular linkage described in the specification and drawings except to the extent the claim recites details of such linkage. Also while the drawings and specification have described alternative methods and apparatuses for monitoring user forces on the footpad, including the use of strain gauges on the foot pad and processing the angular velocity signal to determine crank member acceleration, those of skill in the art will appreciate that the invention can be practiced using other methods and apparatuses for monitoring those forces. Therefore, the scope of the present invention as defined in any one of the claims appended hereto is not intended to be limited to any particular method of monitoring such forces described in the specification and drawings except to the extent that the claim may recite details of such method or apparatus. Those of skill in the art will also appreciate that any of a variety of methods and apparatuses for sensing the angular position of a rotatable member are known in the art and could be employed for that purpose when practicing the invention. Therefore, the scope of the present invention as recited in any one of the claims appended hereto is not intended to be limited to any particular method for sensing forces described in the specification and drawings except to the extent the claim may recite specific details of such method or apparatus. While the invention has been illustrated as being used in an elliptical exercise machine that guides a user's feet in an elliptical type of closed path, the principles of the invention can be used to automatically control path dimensions in other exercise machines such as, for example, steppers, gliders, skiers and climbers, that guide a user's feet in other types of closed paths including, for example, linear and/or arcuate paths that can be adjusted in one or more dimension.

1. An exercise apparatus comprising:

a frame;

a footpad for supporting a user's foot;

a linkage for coupling the footpad to the frame and for guiding the footpad in a closed path in response to a force applied to the footpad by the user's foot, the linkage including a rotatable member having an angular position indicative of a position of the footpad within the closed path, wherein the linkage adjusts a dimension of the closed path in response to an electrical control signal supplied as input to the linkage; and

a control system for monitoring the angular position of the rotatable member, for monitoring the force applied to the footpad, and for generating the control signal such that the linkage adjusts the dimension as a function of the monitored force on the footpad and of the angular position of the rotatable member.

2. The exercise apparatus in accordance with claim **1** wherein the control system generates the control signal to cause the linkage to increase and decrease the path dimension when it senses particular combinations the force and the angular position, thereby permitting the user to control the path dimension by controlling the force applied to the footpad.

3. The exercise apparatus in accordance with claim **2**

wherein the control system controls the control signal such that the linkage alters the dimension when a magnitude of the force is outside a magnitude range while the angular position of the rotatable member is within a position range,

such that the linkage refrains from adjusting the dimension when the magnitude of the force is outside the magnitude range, and

such that the linkage refrains from adjusting the dimension when the angular position of the rotatable member is outside the position range.

4. The exercise apparatus in accordance with claim **1** further comprising:

a strain gauge coupled between the footpad and the linkage for generating a force indicating signal indicative of the magnitude of the force,

wherein the control system monitors the force by monitoring the force indicating signal.

5. The exercise apparatus in accordance with claim **1** wherein the force and the dimension are in substantially parallel directions.

6. The exercise apparatus in accordance with claim **1** wherein the control system monitors the force by monitoring a rotational velocity of the rotatable member, and based on the monitored rotational velocity, determining a rotational acceleration of the rotatable member that is indicative of the magnitude of the force when the angular position of the rotatable member is within the position range.

7. The exercise apparatus in accordance with claim **1** wherein the dimension of the closed path defines a stride length of the user's foot.

8. The exercise apparatus in accordance with claim **1** wherein the dimension of the closed path defines a stride height of the user's foot.

9. An exercise apparatus comprising

a frame;

a footpad for supporting a user's foot;

a linkage for coupling the footpad to the frame and for guiding the footpad in a closed path in response to first and second forces applied in first and second directions, respectively, to the footpad by the user's foot, wherein the linkage includes a rotatable member having an angular position that changes with a position of the footpad within the closed path, and wherein the linkage adjusts first and second dimensions of the closed path in response to electrical control signals supplied as inputs to the linkage; and

a control system for monitoring the angular position of the rotatable member, for monitoring magnitudes of first and second forces, and for generating the control signals such that the linkage adjusts the first and second dimensions as functions of the monitored first and second forces and of the monitored angular position of the rotatable member.

10. The exercise apparatus in accordance with claim **9** wherein the control signals cause the linkage to increase and decrease the path dimensions when it senses particular combinations of the angular position and first and second forces, thereby permitting the user to control the path dimensions by controlling the force applied to the footpad.

11. The exercise apparatus in accordance with claim **10**

wherein the control system controls the first and second control signals such that the linkage alters the first dimension when a magnitude of the first force is outside a first magnitude range while the angular position of the rotatable member is within a first position range, such that the linkage refrains from adjusting the first dimension when the magnitude of the first force is outside the first magnitude range, and such that the linkage refrains from adjusting the first dimension when the angular position of the rotatable member is outside the first position range, and

such that the linkage alters the second dimension when a magnitude of the second force is outside a second magnitude range while the angular position of the rotatable member is within a second position range, such that the linkage refrains from adjusting the second dimension when the magnitude of the second force is outside the second magnitude range, and such that the linkage refrains from adjusting the second dimension when the angular position of the rotatable member is outside the second position range.

12. The exercise apparatus in accordance with claim **9** further comprising:

a first strain gauge coupled between the footpad and the linkage for generating a first force indicating signal indicative of the magnitude of the first force, and

a second strain gauge coupled between the footpad and the linkage for generating a second force indicating signal indicative of the magnitude of the second force,

wherein the control system monitors the first and second forces by monitoring the first and second force indicating signals.

13. The exercise apparatus in accordance with claim **9** wherein the first dimension of the closed path defines a stride length of the user's foot, and

wherein the second dimension of the closed path defines a stride height of the user's foot.

14. A method for controlling an exercise apparatus having a frame, a footpad for supporting a user's foot, and a linkage for coupling the footpad to the frame and for guiding the footpad in a closed path in response to a force applied to the footpad by the user's foot, wherein the linkage includes a rotatable member having an angular position that changes with a position of the footpad within the closed path, and wherein the linkage adjusts a dimension of the closed path in response to an electrical control signal supplied as input to the linkage, the method comprising the steps of

a. monitoring the angular position of the rotatable member,

b. monitoring a magnitude of the force, and

c. controlling the control signal such that the linkage adjusts the dimension as a function of the monitored force on the footpad and of the monitored angular position of the rotatable member.

15. The method in accordance with claim **14** wherein the control signals cause the linkage to increase and decrease the path dimension when it senses particular combinations of the monitored angular position and the monitored force, thereby permitting the user to control the path dimension by controlling the force applied to the footpad.

16. The method in accordance with claim **14**

wherein the exercise apparatus includes a strain gauge coupled between the footpad and the linkage for generating a force indicating signal indicative of the magnitude of the force, and

wherein step b comprises monitoring the force indicating signal.

17. The method in accordance with claim **14**

wherein step c comprises controlling the control signal

such that the linkage alters the dimension when a magnitude of the force is outside a magnitude range while the angular position of the rotatable member is within a position range,

such that the linkage refrains from adjusting the dimension when the magnitude of the force is outside the magnitude range, and

such that the linkage refrains from adjusting the dimension when the angular position of the rotatable member is outside the position range.

18. The method in accordance with claim **17** wherein the force and the dimension are in substantially parallel directions.

19. The method in accordance with claim **14** wherein step b comprises the substeps of:

b1. monitoring a rotational velocity of the rotatable member, and

b2. based on the monitored rotational velocity, determining a rotational acceleration of the rotatable member indicative of the magnitude of the force when the angular position of the rotatable member is within the position range.

20. The exercise apparatus in accordance with claim **14** wherein the dimension of the closed path defines a stride length of the user's foot.

21. The method in accordance with claim **14** wherein the dimension of the closed path defines a stride height of the user's foot.

22. A method for controlling an exercise apparatus having a frame, a footpad for supporting a user's foot, and a linkage for coupling the footpad to the frame and for guiding the footpad in a closed path in response to first and second forces applied in differing directions to the footpad by the user's foot, wherein the linkage includes a rotatable member having an angular position that changes with a position of the footpad within the closed path, and wherein the linkage adjusts first and second dimensions of the closed path in response to a plurality of electrical control signals supplied as inputs to the linkage, the method comprising the steps of

a. monitoring the angular position of the rotatable member,

b. monitoring magnitudes of first and second forces, and

c. controlling the control signals such that the linkage adjusts the first and second dimensions as functions of the monitored first and second forces and the monitored angular position of the rotatable member.

23. The method in accordance with claim **22** wherein the control signals cause the linkage to increase and decrease the path dimensions when it senses particular combinations of the monitored angular position and first and second forces, thereby permitting the user to control the path dimensions by controlling the force applied to the footpad.

24. The method in accordance with claim **22**

wherein the exercise apparatus includes a first strain gauge coupled between the footpad and the linkage for generating a first force indicating signal indicative of the magnitude of the first force,

wherein the exercise apparatus includes a second strain gauge coupled between the footpad and the linkage for generating a second force indicating signal indicative of the magnitude of the second force, and

wherein step b comprises monitoring the first and second force indicating signals.

25. The method in accordance with claim **22**

wherein step c comprises controlling the first and second control signal

such that the linkage alters the first dimension when a magnitude of the first force is outside a first magnitude range while the angular position of the rotatable member is within a first position range, such that the linkage refrains from adjusting the first dimension when the magnitude of the first force is outside the first magnitude range, and such that the linkage refrains from adjusting the first dimension when the angular position of the rotatable member is outside the first position range, and

such that the linkage alters the second dimension when a magnitude of the second force is outside a second magnitude range while the angular position of the rotatable member is within a second position range, such that the linkage refrains from adjusting the second dimension when the magnitude of the second force is outside the second magnitude range, and such that the linkage refrains from adjusting the second dimension when the angular position of the rotatable member is outside the second position range.

26. The method in accordance with claim **22** wherein the first and second forces are applied to the footpad in substantially orthogonal directions.

27. The method in accordance with claim **22** wherein the first and second dimensions are in substantially orthogonal directions.

28. The method in accordance with claim **22** wherein the first dimension of the closed path defines a stride length of the user's foot, and

wherein the second dimension of the closed path defines a stride height of the user's foot.

29. An exercise apparatus comprising:

a frame,

a right footpad for supporting a user's right foot,

a left footpad for supporting the users left foot,

a linkage for coupling the right and left footpads to the frame and for guiding the right and left footpads in a closed pats in response to forces applied to the right and left footpads by the user's right and left feet, the linkage including a rotatable member having an angular position indicative of positions of the right and left footpads within their closed paths, wherein the linkage adjusts dimensions of the closed paths of the right and left footpads in response to electrical control signals supplied as inputs to the linkage, and

a control system for monitoring the angular position of the rotatable member, for monitoring the forces applied to the right and left footpads, and for generating the control signals such that the linkage adjusts at least one dimension of the right footpad as a function of monitored force on the right footpad and of the angular position of the rotatable member, and independently adjusts at least one dimension of the left foot pad as a function of monitored force on the left footpad and of the angular position of the rotatable member.

30. The exercise apparatus in accordance with claim **29** wherein the control system generates the control signals to cause the linkage to increase and decrease the path dimensions of the right and left footpads when it senses particular combinations the angular position and the monitored forces, thereby permitting the user to independently control the dimensions of the paths followed by the right and left footpads by controlling the forces applied to the right and left footpads.

31. The exercise apparatus in accordance with claim **30**

wherein the control system controls the control signals such that the linkage alters the dimension of the closed path of the right footpad when a magnitude of the force on the right footpad is outside a first magnitude range while the angular position of the rotatable member is within a first position range and otherwise refrains from adjusting the dimension of the closed path of the right footpad; and

such that the linkage alters the dimension of the closed path of the left footpad when a magnitude of the force on the left footpad is outside a second magnitude range while the angular position of the rotatable member is within a second position range and otherwise refrains from adjusting the dimension of the closed path of the left footpad,

32. A method for controlling an exercise apparatus having a frame,

a right footpad for supporting a user's right foot,

a left footpad for supporting the users left foot, and

a linkage for coupling the right and left footpads to the frame and for guiding the right and left footpads in a closed pats in response to forces applied to the right and left footpads by the user's right and left feet, the linkage including a rotatable member having an angular position indicative of positions of the right and left footpads within their closed paths, wherein the linkage adjusts dimensions of the closed paths of the right and left footpads in response to electrical control signals supplied as inputs to the linkage,

the method comprising the steps of

a. monitoring the angular position of the rotatable member,

b. monitoring the forces applied to the right and left footpads, and

c. generating the control signals such that the linkage adjusts at least one dimension of the right footpad as a function of monitored force on the right footpad and of the angular position of the rotatable member, and independently adjusts at least one dimension of the left foot pad as a function of monitored force on the left footpad and of the angular position of the rotatable member.

33. The method in accordance with claim **1** wherein the control signals cause the linkage to increase and decrease the path dimensions of the right and left footpads when in response to particular combinations the angular position and the monitored forces, thereby permitting the user to independently control the dimensions of the paths followed by the right and left footpads by controlling the forces applied to the right and left footpads.

34. The method in accordance with claim **33**

wherein the control signals cause the linkage alter the dimension of the closed path of the right footpad when a magnitude of the force on the right footpad is outside a first magnitude range while the angular position of the rotatable member is within a first position range and otherwise to refrain from adjusting the dimension of the closed path of the right footpad, and

wherein the control signals cause the linkage alter the dimension of the closed path of the left footpad when a magnitude of the force on the left footpad is outside a second magnitude range while the angular position of the rotatable member is within a second position range and otherwise to refrain from adjusting the dimension of the closed path of the left footpad.

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