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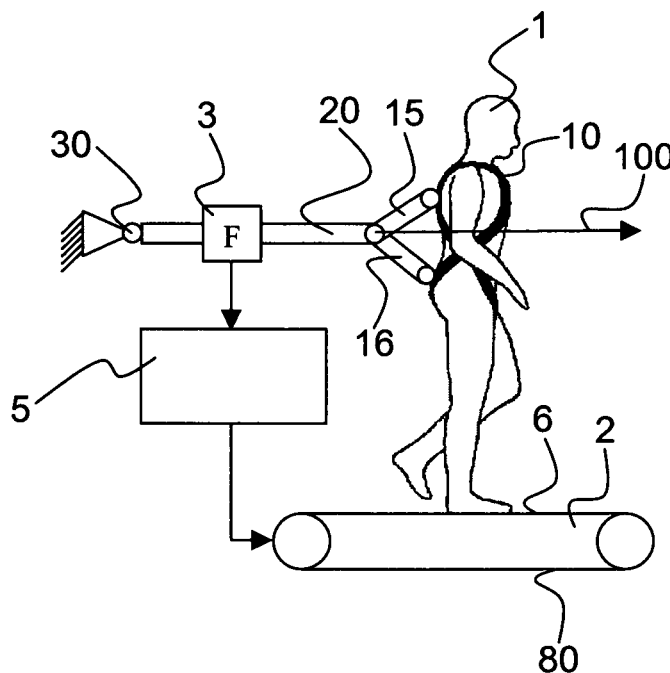
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• **Riener, Robert****81929 München (DE)**(54) **Device and method for an automatic treadmill therapy**

(57) A method to control the velocity of a treadmill according to the walking velocity of the person that is using the treadmill. A reaction force is measured, which occurs when a longitudinal repulsion force is created be-

tween the treadmill (2) and the person (1). A signal representation for said reaction force is transmitted to a control unit. The control unit is used to control the velocity of the treadmill.

**Fig. 1**

Description

Field of the invention

[0001] The invention relates to a device for adjusting the speed of a treadmill, which is used for the therapy of paraplegic or hemiplegic patients and other neurological as well as orthopaedical patient groups as well as for the (fitness) training of healthy or elderly subjects.

Prior Art

[0002] Treadmills are known by prior art for example from EP 0 002 188. The speed of the treadmill varies according to the heart frequency of the patient. If the heart frequency reaches an upper limit, the speed of the treadmill decreases. The heart frequency is a parameter that is not applicable in the therapy of paraplegic patients, since the purpose of the therapy is the ability of a proper motion sequence and the heart frequency does not change in a manner that is usable for this purpose.

[0003] US 5,707,319 discloses a treadmill with two lever to pull in order to adjust the belt speed. For patients this is not usable because the patient has to concentrate on the motion sequence.

[0004] US 6,179,754 discloses a treadmill equipped with detectors in order to detect the position of the feet of the runner. According to the measured position, the running belt will be accelerated or decelerated. This device cannot be used, when the runner does not move relatively to the treadmill, e.g. when a patient is fixed to the surrounding for therapeutical reasons so that his horizontal position relatively to the treadmill does not change.

[0005] Another attempt in order to control the velocity of the treadmill is to detect the load of the motor, as disclosed in US 6,416,444. The disturbance variables such as frictional influences are rather big. Due to this inaccuracy it is difficult to use this device for therapeutical purposes with variable treadmill speed.

Summary of the invention

[0006] An object of the present invention is to provide a method and a device, which gives a person the possibility for automatic treadmill training with variable treadmill speed.

[0007] According to the invention there is provided a method to control the velocity of a treadmill according to the walking velocity of the person that is using the treadmill. The person's trunk is connected to the environment via a rigid mechanical frame (or an elastic band). A reaction force is measured within this frame (or band), which occurs when the person intends and tries to increase or decrease his walking velocity. A signal represents said reaction force. The signal is transmitted to a control unit, which is used to control the velocity of the treadmill.

[0008] This will provide realistic conditions for a person who relearns walking with such a method.

[0009] In order to control the velocity of the treadmill the component of the reaction force, which is parallel to the surface of the treadmill and in running direction of the running belt of the treadmill has to be determined.

[0010] The person is harnessed with a hip and possibly with a leg orthotic device. The reaction force is measured from force sensors that can be positioned in various positions.

Brief description of the drawings

[0011] The drawings will be explained in greater detail by means of a description of an exemplary embodiment, with reference to the following figures:

- Fig. 1 shows a schematic arrangement of a first device according to the present invention
- Fig. 2 shows a further schematic arrangement of a second device according to the present invention
- Fig. 3 shows another schematic arrangement of a third device according to the present invention
- Fig. 4 shows another schematic arrangement of a fourth device according to the present invention in combination with an orthotic device.
- Fig. 5 shows a mechanical arrangement to determine a horizontal and longitudinal force.
- Fig. 6 shows a further mechanical arrangement to determine a horizontal and longitudinal force.
- Fig. 7 shows the control circuit that may be used to control the velocity of a treadmill according to the present invention.
- Fig. 8 shows schematically a block diagram of a general impedance controller in order to allow a patient-cooperative motion strategy.
- Fig. 9 shows a block diagram of an adaptive control strategy.
- Fig. 10 shows the idea of Patient-Driven Motion Reinforcement.
- Fig. 11 shows the velocity characteristics of the center of gravity of a human body when starting walking, walking and stopping with certain velocities.
- Fig. 12 shows the control circuit that may be used to control the velocity of a treadmill according to the present invention, when a training person is walking on inclines.
- Fig. 13 shows schematically the force relations for a person leaning forward as for walking up a hill.

Detailed description of the preferred embodiments

[0012] Fig. 1 shows a schematic view of a first device for measuring the reaction force, which occurs when a longitudinal repulsion force is created between a treadmill 2 and a person 1, wherein the person trains on the

treadmill 2 according to one embodiment of the present invention.

[0013] The device comprises at least a treadmill 2, measure means 3, a controller 5 and fixation means 10. The treadmill may be a treadmill as known from prior art i.e. WO 0028927 and comprises at least a running belt 80 and an adjustable motor. The surface of the treadmill comprises an essential horizontal base plane 6, on which the patient is walking. For definition reasons: the running direction of the running belt 80 is designated as longitudinal direction and the direction that lies orthogonal to the horizontal base plane 6 is designated as vertical direction. The direction orthogonal to these two directions will be called transversal or lateral direction.

[0014] A person 1 may be a patient who needs a therapy in order to relearn walking, walks on a treadmill and is rigidly connected to his surroundings especially by a pelvis or trunk harness. The treadmill is powered by an adjustable motor and initially runs with a treadmill velocity v . The velocity v can be adjusted continuously starting at 0 m/s.

[0015] The patient 1 is connected by fixation means 10 to mechanical rods 15, 16. Fixation means may be a harness that the patient 1 is wearing on his upper part of the body. The two mechanical rods 15, 16 are connected to a first end of a further rod 20. The second end of the rod 20 is connected to a bearing point 30 being in fixed relationship to the bearing of the treadmill. Since the bearing point 30 allows pivoting movements only, the movement of the patient 1 is restricted to vertical movements. Lateral (transversal) and longitudinal movements are not possible. Thus, the patient's position remains on the running belt 80 of the treadmill and especially at the same place. This makes it possible to provide a lesser length of the treadmill, e.g. only having a length being in the range of the step length of a person with a great body height.

[0016] Rod 20 can be a rigid bar or an elastic rubber band or rubber bar. In case of an elastic connection the patient's position can vary also in lateral (=transversal) and longitudinal directions. However, elastic forces are acting in such way that the patient remains on the treadmill.

[0017] When the patient 1 wants to accelerate or decelerate his body in order to change the walking-velocity v , he will produce a longitudinal force in backward or forward direction, respectively. Due to the rigid mechanical connection of the patient to the surrounding, this force results in a mechanical reaction force acting onto the mechanical rods 15, 16, 20. Force measure means 3 are arranged on the mechanical rods, in order to measure the reaction force. A force measure mean 3 may be a force sensor, for example based on a strain gauge measurement principle. The measured reaction force is processed in a controller 5 in order to adjust the velocity of the treadmill v to the intended walking-velocity of the patient 1. If the velocity adjustment is optimal, the patient will have the feeling that he is changing the treadmill

speed with his own voluntary efforts. This method is also designated as force-based adjustment of the treadmill velocity. This principle also works if an orthosis such as in WO 0028927 is attached to the legs of the patient.

[0018] For the force-based adjustment of the treadmill velocity, only a force component 100 has to be considered in the controller 5. The force component 100 is longitudinal, whereas longitudinal is horizontal. Several different concepts are possible to measure that force component 100 and are described by means of the following figures.

[0019] The force measure means 3 generate a signal according to the value of the reaction force. The signal is submitted to a controller 5 to provide input data for the control circuit. The control circuit will be explained by means of figure 7.

[0020] Fig. 2 shows a second embodiment according to the present invention. The patient is fixed to a plate 43 by the fixation means 10 as already described. On one end, the two rods 40 are connected to the plate 43 with bearings 42. The plate 43 may provide the possibility to fix the orthosis. On the other end the two rods 40 are connected to the bearings 30. The distance from one bearing 30 to another bearing 30 is the same as the distance from one bearing 42 to the other bearing 42. Since the two rods 40 have the same length, a parallelogram is formed. The parallelogram lies with an angle β to the horizontal base plane 6. The angle β depends on the height of the patient 1 and it varies with the up and down movement of the patient 1. The bearings 30 are hinge bearings that allow only pivoting movements in the sagittal plane.

[0021] The axial forces in rods 40 are measured by measure means 3, 4.

[0022] This arrangement of rods, bearings, and force sensors allows an easy determination of the longitudinal forces 100, whereas it remains independent from the vertical force 102. The horizontal force 100 in walking direction can be computed by the two forces F_1 and F_2 from the sensors 3 and 4, respectively:

$$F_{\text{longitudinal}} = (F_1 - F_2) \cos \beta$$

[0023] The vertical load 102 results from gravitation but also from inertial effects. As this force act in both rods 40 with the same strength but different directions, above-mentioned equation automatically compensates for the vertical force in such way that only the horizontal component 100 remains after correcting the term $F_1 - F_2$ with factor $\cos \beta$.

[0024] Due to forces that act also in the transversal (lateral) direction, the measure means 3, 4 have to be chosen accordingly in order to avoid erroneous force sensor output. In particular, this requires a sensor that is able to detect a force in one direction only, which is in that case the direction of the rod. Another possibility is the

use of a sensor that measures in two directions, which are in that case in the rod direction and in the transversal (lateral) direction. Note that there is no force acting in the third direction orthogonal to the rods, when assuming that bearings 30 and 42 are frictionless hinge joints.

[0025] The angle β can be measured by an angle measurement device as it is known or it can be determined by height measurements of the plate 43 over the base plane 6.

[0026] Figure 3 shows a further third embodiment according to the present invention. The patient 1 is connected to the mechanical rod system as described in figure 1. The rod 20 as introduced in figure 1 is now replaced by rod 51 which is one of the horizontal rods of a linkage 50. The linkage 50 comprises two horizontal rods 51 and two vertical rods 52 that are arranged in a rectangle. The horizontal rod 51 is longer than the other horizontal rod 51' and both are arranged in a way that one end protrudes the vertical rod 52. A diagonal rod 58 connects a first corner 53 of the parallelogram to a second corner 54 of the parallelogram. The diagonal rod 52 is equipped with a force sensor 55. The horizontal rod 51' and the linker rod 56 are rigidly connected to each other, for example welded. Via the horizontal rod 51' and a linker rod 56 the linkage 50 is connected to main rods 57. The two main rods 57 are supported by the bearings 30.

[0027] Due to the arrangement of the linkage, the vertical force components 102 are carried by the vertical rods 52. Therefore the force sensor 55 measures only the horizontal component 100 of the reaction force (in longitudinal direction).

[0028] In a further arrangement it may be possible that the rod 51 and the rod 51' have an equal length. Therefore the welding point which connects the horizontal rod 51' and the linker rod 56 is located on one the edge of the linkage 50.

[0029] Figure 4 shows a fourth embodiment similar to the embodiment of figure 1. Additionally to figure 1 a driven orthotic device 60 provides aid to the patient in order to learn a proper motion sequence. The orthotic device 60 may be according to the device as described in WO 0028927, which may also be designated as gait-robot or lokomat. The orthotic device 60 is connected via a plate 61 to the rod system as already described.

[0030] During the training a repulsion force between the treadmill 2 and the person 1 occurs. Force measure means 3 measure a reaction force that occurs due to the longitudinal repulsion force.

[0031] Additionally to the orthotic device 60 the patient may be supported by a relieve mechanism 80. A suspended weight 81 is arranged on one end of a cable 83. The cable 83 is diverted over two pulleys 82. On the other end the cable 83 is attached to the harness 10 of the patient 1. Due to the weight 81 on one end the patient 1 will be relieved from a part of his own weight. The mass of the weight 81 has to be chosen in accordance of the weight of the patient 1 and in view of his physical condition. An adjustment of the length of the cable 83 is also

necessary, but not shown in the drawings.

[0032] Figure 5 shows schematically a top view of a preferred embodiment to determine the longitudinal component 100 of the resulting force 101 produced by the patient explicitly, when the patient is fixed in an orthosis. Thereby sensors 70,71 are arranged in an asymmetric arrangement. Arrow 110 indicates the walking direction of the patient.

[0033] The mechanical system as shown in figure 5 may be a door-like frame, that is pivoting around a vertical axis. The door-like frame is arranged at the back of the patient 1. One side of the door-like frame is connected to a bearing point 75, the other side is blocked by a sensor 70 and a rod 78 to a bearing point 77. In this arrangement transversal (lateral) movements of the pelvis are blocked. The restriction of this degree of freedom results in a lateral force 103, orthogonal to the measure direction and in a bending moment in the frame. Due to the asymmetric arrangement with only one sensor 71 on only one side of the door-like frame, the bending moment resulting from lateral forces appears also in the force signal of sensor 71. Therefore, an additional sensor 70 is arranged to measure lateral forces, in order to compensate the influences of the bending moment.

[0034] The force 101 is applied to the rod system. The patient 1 is connected via the harness 10 to a cropped rod 73. The cropped rod 73 is connected to a longitudinal rod 74. A sensor 70 is mounted on the cropped rod 73, this sensor measures the lateral (transversal) component 103 of the force 101, also designated as F_2 . A longitudinal rod 74 is connected to a transversal rod 72. On one end the transversal rod 72 is connected to a bearing 75, whereas on the other end a sensor rod 78, which lies in longitudinal direction, leads to a further bearing 77. The sensor rod 78 is equipped with a force sensor 71 to measure the horizontal force, also designated as F_1 . The longitudinal force 100 is determined with the aid of F_1 and F_2 :

$$F_{longitudinal} = \frac{-F_1 \cdot (a+b) + F_2 \cdot l}{b}$$

[0035] The algebraic sign is chosen in such way that pressure forces on the fixation system (patient decelerates) result in negative and tractive forces (patient accelerates) result in positive signals. If the lateral forces measured by sensor 70 are unaccounted for the horizontal and longitudinal force 100, the lateral (transversal) component of the reaction force would be wrongly considered as the longitudinal force 100.

[0036] Figure 6 shows a further top view of an asymmetric arrangement, provided to determine the longitudinal force 100. A linker rod 79 connects one end of the transversal rod 72 to the bearing point 75. At the other end, the transversal rod 72 is connected to a further linker rod 91 by a joint 90. The linker rod 91 is connected to a bearing point 92. This newly built degree of freedom is

compensated by the sensor rod 78. The sensor rod 78 is orthogonally connected to the linker rod 91. However the sensors may be placed at any of the rods 72, 79 and 91. With such a rod arrangement, the sensor measures only the horizontal and longitudinal force 100.

[0037] Figure 7 shows a control circuit according to the present invention. The controller 5 (see figures 1, 2, and 4) comprises a control circuit, that integrates the physical determination of the velocity from the longitudinal component of the reaction force. The control circuit is preferably an admittance control circuit, but also an impedance control circuit may be used.

[0038] The reaction force that occurs due to the mechanical fixation of the patient 1 is measured by a sensor 201. An electrical signal that may be linear or non-linear to the reaction force is provided by the sensor 201.

[0039] The measured force will then be divided by a mass. This is conducted by a divider 202. After the divider a signal $\ddot{x}_1$ results. The value of the mass may be chosen according to the patient's physical condition. When the patient's physical condition is good, the parameter is equal to the body mass in order to provide a realistic situation and walking feeling for the patient. If the patient's motor system is weakened, for example after a surgery, injury or neuromuscular disease, a mass with a value lower than the body mass may be chosen. This will make it easier for the patient, because the force that is required to accelerate and walk will be smaller.

[0040] However, if the present invention is used for endurance training or rehabilitation of professional athletes it is possible to adjust the mass in an other range. Preferably a value will be used that is between 1 and 1.5 and especially between 1.2 and 1.5 of the body mass. This relieves the joints of the patient, namely the joints in the persons under part of the body, compared to the training method of fixing additional weights on the person's body.

[0041] $\ddot{x}_1$ is integrated by an integrator 203 and a velocity input signal $\dot{x}_1$ results. The actual velocity of the treadmill 2 is $\dot{x}$. $\dot{x}_1 - \dot{x}$ is fed into a PD velocity controller 204 that controls the treadmill 2 to provide equal velocities. A PID controller or any other control law may also be used.

[0042] The force-based velocity adjustment of the treadmill can be used together with an orthotic device such as the gait-robot according to WO 0028927.

[0043] In the most cases the device according to WO 0028927 is being used in a position-control mode, where the legs of the patient are moved along a predefined, desired trajectory. Figure 11 shows such a characteristic. During this fully guided movement the velocity of the feet may not fully correspond to the velocity of the treadmill due to inaccurate fixation between patient and orthosis or due to different leg anthropometries among the patients. During the swing phase 301, this speed deviation is not a problem. However, during the stance phase, when one foot or both feet are touching the treadmill, the

speed differences result in mechanical stress acting between treadmill and lokomat onto the legs and feet of the patient. As this stress acts as a horizontal force in longitudinal direction, the force is measured by the sensor arrangements presented and the speed of the treadmill is adjusted in such a way that the force and, thus, the stress acting on the patient's legs and feet is minimized.

[0044] The velocity characteristics as shown in Figure 11 will now be explained in greater detail. A curve 308 shows velocity characteristics of the center of gravity of a human body when walking with a certain velocity. In a first section of the movement, the patient accelerates, this is designated as the development phase 300. The first bend 303 in the development phase 300 shows the first step of the patient. The second bend 304 shows the second step of the patient. After another step, the patient reaches his average speed, which is indicated by a horizontal line 305, since the patient walks with a constant velocity. But even when patient walks with a constant velocity, the velocity of the center of gravity of the body oscillates around that line 305. With each step the center of gravity is accelerated and decelerated respectively, this is shown by the rhythmic phase 301. If the patient accelerates or decelerates the line 305 changes the slope. Acceleration is indicated by line 306, deceleration is indicated by line 307. However the oscillation of the center of gravity will be similar as if the patient walks at a constant velocity. During treadmill training the acceleration and deceleration is recognizable in an orthogonal plane of the walking direction as an alternating relative movement. While a device e.g. according to WO 0028927 is used, this relative movement is not possible, thus, it results in a reaction force at the fixation. The reaction force is measured as described and the velocity of the treadmill is controlled accordingly, i.e. the velocity of the running belt "oscillates" around the mean velocity. This gives the advantage to this device that a patient has the impression that his feet are touching the running belt in a natural way and there is no sliding of the feet on the belt. Additionally the control unit 5 can anticipate the "oscillating" reaction force and discern this intra-step movement from voluntary accelerations or decelerations. The decay phase 302 represents the end of the treadmill training session. The patient decelerates slowly, until the velocity reaches 0 m/s. Bends 310 and 311 show the last two steps. All the controllers as described in that application are able to control such a velocity characteristic.

[0045] It is noted that the force acting on the patient positioned within his harness is not coming from the harness as such, staying at the same place, but through the movement of the treadmill belt.

[0046] The force-based treadmill speed adjustment can also be applied, when the gait-robot according to WO 0028927 is being used in so-called patient-cooperative modes. Here, voluntary intentions and muscular efforts of the patient are detected within the gait-robot system in order to adjust the gait-robot assistance to the patient. Thus, walking pattern and speed are controlled

by the patient. Therefore, patient-cooperative strategies require the possibility to automatically adjust the treadmill speed to the patient effort or intention. Treadmill speed adjustment must occur in real-time with minimal delay times.

[0047] In Figures 8, 9, and 10 patient-cooperative strategies are presented that record the patient's movement efforts in order to make the robot behavior flexible and adaptive. Three different technical concepts are presented, which were applied to the gait-robot according to WO 0028927. It is clear that they can be used in connection with a number of different gait-robots.

[0048] The three strategies comprise, first, impedance control methods that make the gait-robot soft and compliant, second, adaptive control methods that adjust the reference trajectory and/or controller to the individual subject, and, third, a motion reinforcement strategy that supports patient-induced movements.

[0049] Figure 8 shows schematically a block diagram of a general impedance controller in order to allow a patient-cooperative motion strategy. Impedance controllers are well established in the field of robotics and human-system interaction. The basic idea of the impedance control strategy applied to robot-aided treadmill training is to allow a variable deviation from a given leg trajectory rather than imposing a rigid gait pattern. The deviation depends on the patient's effort and behaviour. An adjustable moment is applied at each joint in order to keep the leg within a defined range along the trajectory. The moment can be described as a zero order (stiffness), or higher order (usually first or second order) function of angular position and its derivatives. This moment is more generally called mechanical impedance. The deviations from the desired trajectory results in variations of the gait speed, which requires the treadmill to be adjustable.

[0050] Figure 9 shows the idea of a Patient-Driven Motion Reinforcement (PDMR) strategy for the control of patient-induced walking movements. Here, the actual movement initiated by the patient is recorded and fed into an inverse dynamic model of the patient in order to determine the robot moment contribution that maintains the movement induced by the patient. This means that the patient has to apply some own voluntary efforts in order to obtain a movement at all. This movement is then supported by the robot. A scaling factor K can be introduced in order to vary the supporting moment.

[0051] Figure 10 shows a block diagram of an adaptive control strategy. The main disadvantage of the impedance control strategy presented above is that it is based on a fixed reference trajectory. In comparison, the adaptive controller changes its reference trajectory as function of the patient efforts. In this way the desired trajectory adapts to the individual patient. Therefore, not only gait pattern but also gait speed are changing, thus, requiring an online treadmill speed adjustment function.

[0052] The PDMR controller enables the subjects to walk with their own walking speeds and patterns. The device according to WO 0028927 as well as the treadmill

speed adapts to the human muscle efforts and supports the movement of the subject's leg, e.g. by compensating for the gravity and velocity dependent effects. Prerequisite for this controller is that the subject has sufficient voluntary force to induce the robot-supported movement.

[0053] It has to be anticipated, that running belts are usually reacting with a time delay. Therefore the control unit anticipates these delays within the frame of the control of the drives of the running belt 80.

[0054] Due to controlling the treadmill in the way as described above, it is possible to provide a very realistic sensation of walking as the forces that occur during acceleration and deceleration as well as during the decay phase are similar to the forces that occur when the person walks on a fixed ground. The person has to overcome the inertia when changing speed on fixed ground. This inertia does not occur, if the person is not fixed and the treadmill is not controlled as shown in fig. 7, because it is the running belt and not the person's center of mass that changes speed.

[0055] Fig. 12 shows the control circuit that may be used to control the velocity of a treadmill according to the present invention, when walking on an incline is simulated. The main parts of the control circuit according to Fig. 12 are similar to the circuit according to Fig. 7. The reaction force that occurs due to the mechanical fixation of the patient 1 is measured by a sensor 201. This reaction force F_{patient} is submitted to an adder 210. An additional offset force F_{offset} corresponding to the virtual inclination of the virtual slope is added within this adder 210, being dependent on the weight of the person 1 and the inclination to be simulated.

[0056] The sum force will then be divided by a mass by a divider 202. The value of the mass may - as within the embodiment shown in Fig. 7 - be chosen according to the patient's physical condition. The resulting value $\ddot{x}_1$ is integrated by an integrator 203 and a velocity input signal $\dot{x}_1$ results. For safety reasons the velocity input signal $\dot{x}_1$ can be passed through a saturation block 211, which limits $\dot{x}_1$ to positive values. This prevents the treadmill from running in negative running direction when the situation of walking uphill is simulated but the person does not generate any longitudinal force.

[0057] The actual velocity of the treadmill 2 being $\dot{x}_1$, the difference value of $\dot{x}_{1s} - \dot{x}$ is fed into a PD velocity controller 204. A PID controller or any other control law may also be used.

[0058] Fig. 13 A&B show schematically the force relations for a person leaning forward as for walking up a hill. Fig. 13A shows a person 1 going uphill, the hill having an inclination of α . The person's mass force G, the normal force N and the friction force F_R are depicted, wherein $F_R = G \cdot \sin\alpha$.

[0059] Fig. 13B shows the person 1 according to Fig. 13A going virtually uphill and positioned in an harness with a longitudinal rod 20, a force sensor 3 and a bearing 30. The relative angle β between the surface of the tread-

mill and the person is defined as $\arctan(l/h)$. h is the vertical distance between the running belt and the person's center of mass and l is the longitudinal distance between the line of action of G and N for the static loading case of $F_R = F_{\text{offset}}$. The friction force for a person positioned on a running belt is therefore

$$F_R = G \cdot \frac{l}{h} = G \cdot \tan \beta .$$

An inclination of 20 % corresponds to $\alpha = 11,31^\circ$. An angle of 11° results in an angle $\beta = 10,8^\circ$. This is due to the fact that $\beta = \arctan(\sin \alpha)$.

Therefore a person starting to walk on such a running belt, will first lean forward to create the angle of the slope. This is enabled through the fixed position of the center of gravity of the person within its harness.

Reference numerals

[0060]

1	Patient
2	Treadmill
3	Force sensor
4	Force sensor
5	Controller
6	Base plane
10	Fixation means
15	Rod
16	Rod
20	Rod
30	Bearing
40	Rod
41	Angle of parallelogram
42	Bearing
43	Plate
50	Linkage
51	Horizontal rod
52	Vertical rod
53	First corner
54	Second corner
55	Force sensor
57	Main rod
58	Diagonal rod
60	Orthotic device
70	Force sensor
71	Force sensor
72	Transverse rod
73	Cropped rod
74	Longitudinal rod
75	Bearing point
77	Bearing point
78	Sensor rod
79	Linker rod
80	Relieve mechanism
81	Weight
82	Pulley
83	Cable

90	Joint
91	Linker rod
92	Bearing point
100	Longitudinal force
5 101	Force generated by patient
102	Vertical force
103	Lateral (transversal) force
110	Walking direction
201	Force sensor
10 202	Divider
203	Integrator
204	PD-Controller
210	Adder
211	Saturation block
15 300	Development phase
301	Rhythmic phase
302	Decay phase
303	First step
304	Second step
20 305	Average velocity
306	Acceleration
307	Deceleration
308	Velocity characteristic
310	Penultimate step
25 311	Ultimate step

Claims

- 30 1. A method to control a treadmill according to the walking velocity of a person that is using the treadmill (2), **characterized in that** a reaction force is measured (3), which occurs when a longitudinal repulsion force is created between the treadmill (2) and the person (1), and **in that** a signal representation for said reaction force is transmitted to a control unit (5), which is used to control the velocity of the treadmill (2).
- 35
- 40 2. Method to control a treadmill according to claim 1 **characterized in that** the reaction force of a person (1) harnessed in an orthotic device is measured wherein a signal representation for said orthotic reaction force is transmitted to the control unit (5), which is used to control the orthotic device.
- 45
- 50 3. Method to control a treadmill according to the walking velocity of the person that is using the treadmill (2), **characterized in that** a reaction force is measured (3), which occurs when a person (1) harnessed in an orthotic device walks with a different velocity than the running belt of the treadmill (2) is moving, and **in that** a signal representation for said reaction force is transmitted to a control unit (5), which is used to control the orthotic device or optionally the treadmill.
- 55
4. The method as claimed in claims 1 to 3, **characterized in that** the signal representative for said reaction force only comprises the component of the force,

which is parallel to the surface of the treadmill (2) and in running direction of the running belt (80).

5. Method as claimed in claims 1 to 4, **characterized in that** the person (1) is harnessed with a body or hip device and optionally a leg orthotic device, wherein the signal representative for said reaction force is taken from a force sensor or from force sensors positioned:

- on a single rod (20), or
 - on two rods (40), which are arranged in a parallelogram, or
 - on a diagonal rod (58) of a linkage (50);
- all above mentioned rods oriented in the direction of the running belt (80) attached to the harness of the person and fixing the person (1) in view of the running belt, or
- on a door-like rod arrangement, or
 - within a hip or leg orthosis.

6. Method as claimed in one of claims 1 to 5, **characterized in that** the velocity of the treadmill is adjusted to a natural motion, when a foot executes a rolling motion on the running belt (80).

7. Method as claimed in one of claims 1 to 6, **characterized in that** an offset force is added to the measured patient force to simulate a virtual slope.

8. A device to control a treadmill according to the walking velocity of the person that is using the treadmill, **characterized in that** it comprises at least:

- a treadmill (2) with an adjustable motor to drive the running belt,
- a mechanical system to fix the person (1) against movements in longitudinal direction above and or on the running belt,
- force measure means (3,4) arranged between the mechanical systems and the treadmill in order to measure a reaction force,
- a control circuit to analyse the signals provided by the force measure means and to control the velocity of the treadmill (2) and/or the movement of an orthotic device.

9. A device according to claim 8, wherein the mechanical system to fix the person comprises a harness (10) and a rod system (20, 40, 50, 51, 52, 56, 57, 58).

10. A device according to claim 8, **characterized in that** measured horizontal and longitudinal force is represented by an electrical signal that is used as a basic parameter to control the rotational speed of the motors of the treadmill (2) and/or the actuators of an orthotic device.

11. A device according to claim 10, **characterized in that** the control circuit comprises an impedance or an admittance control circuit.

12. A device according to claim 8, **characterized in that** the device comprises additional supporting means (60, 80) for the person (1).

13. A device according to claim 12, whereas additional supporting means are a relief mechanism (80) to relieve the person (1) from its own weight or a driven orthotic device (60) to provide guidance of the motion sequence.

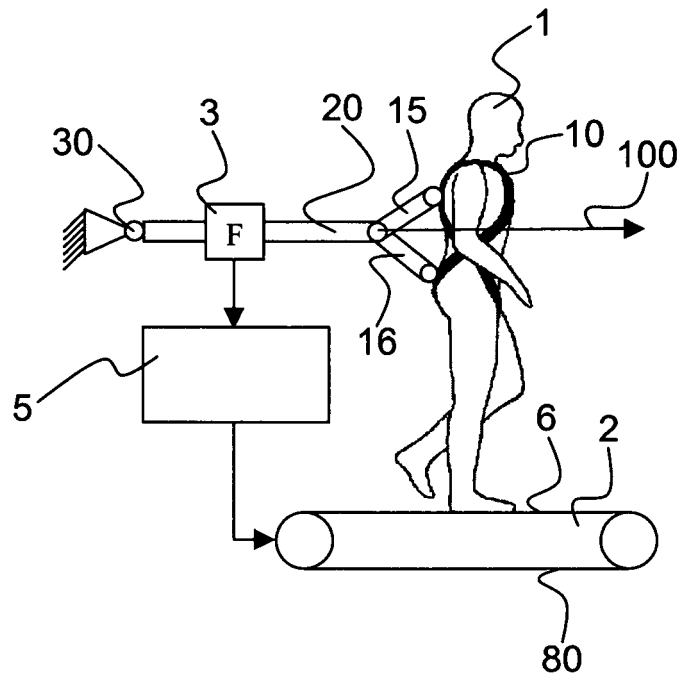


Fig. 1

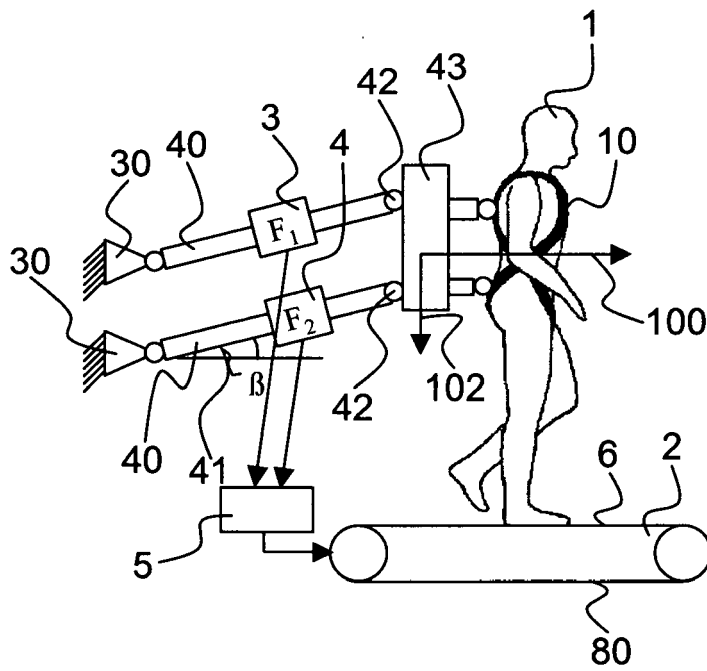


Fig. 2

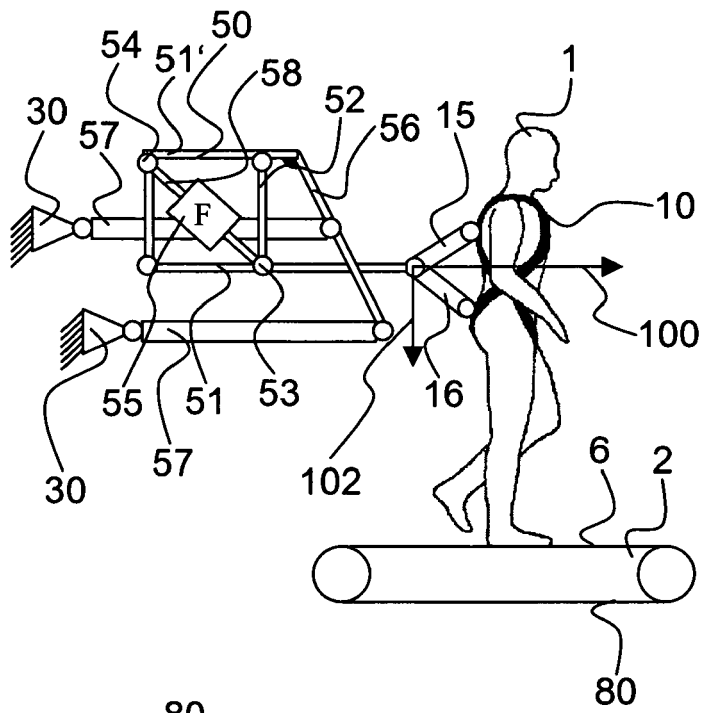


Fig. 3

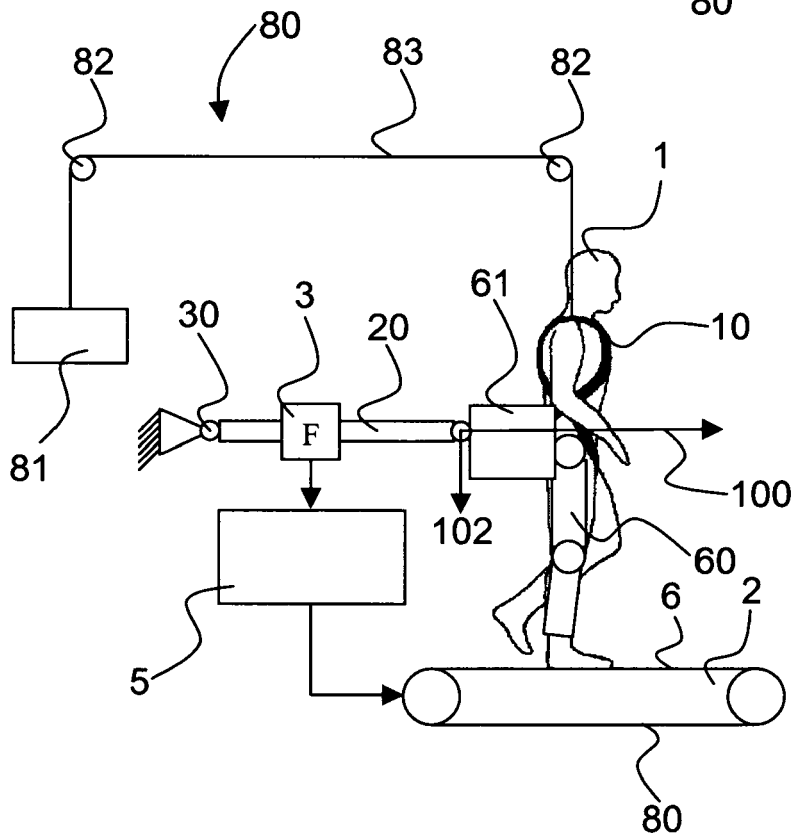


Fig. 4

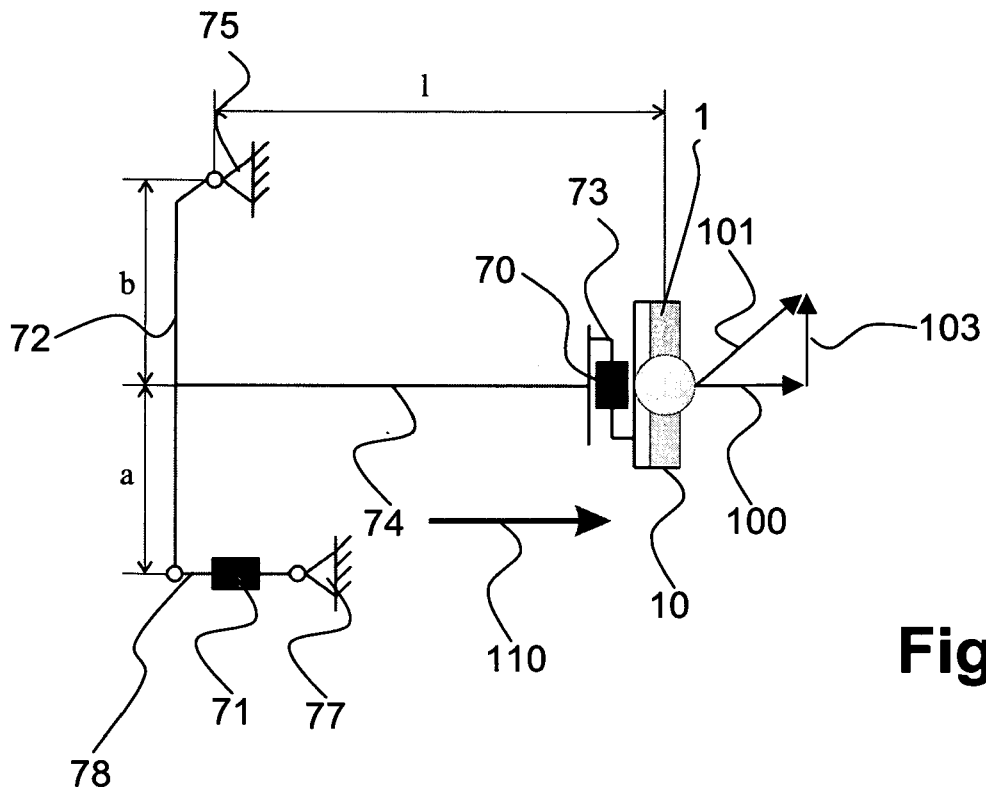


Fig. 5

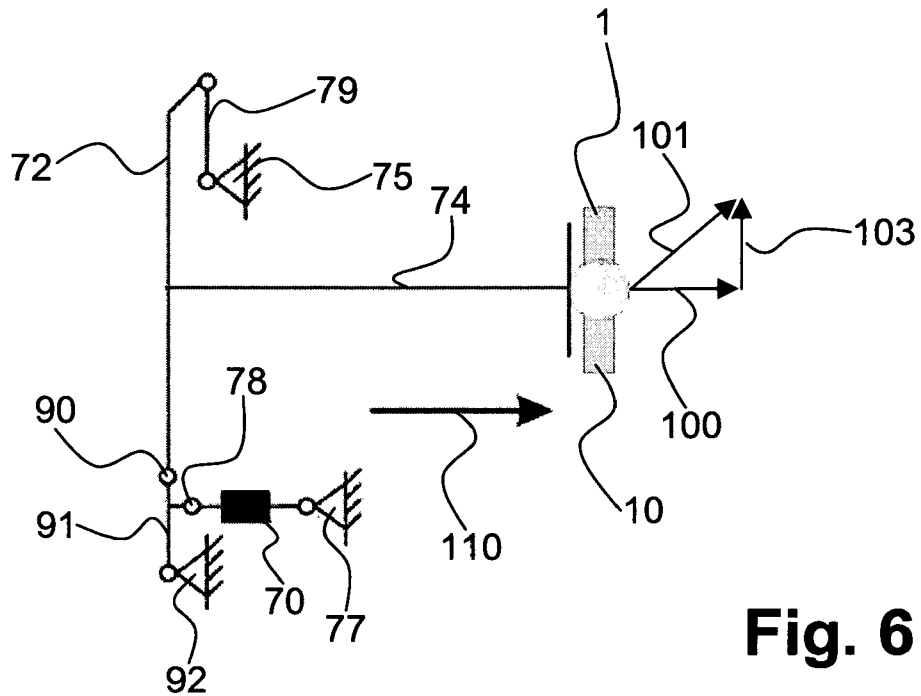


Fig. 6

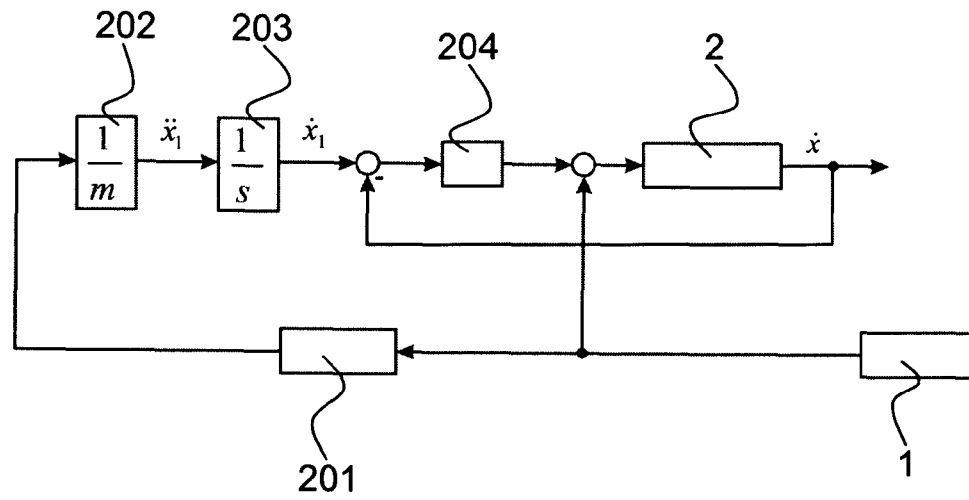


Fig. 7

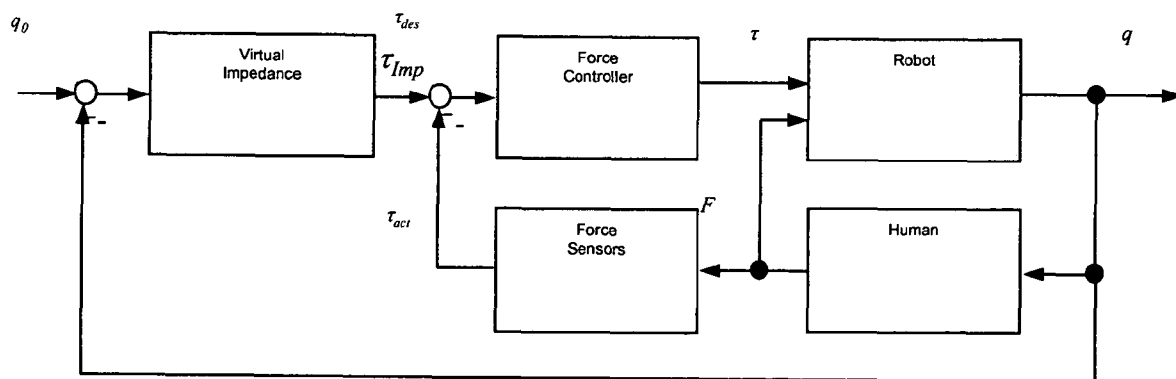


Fig. 8

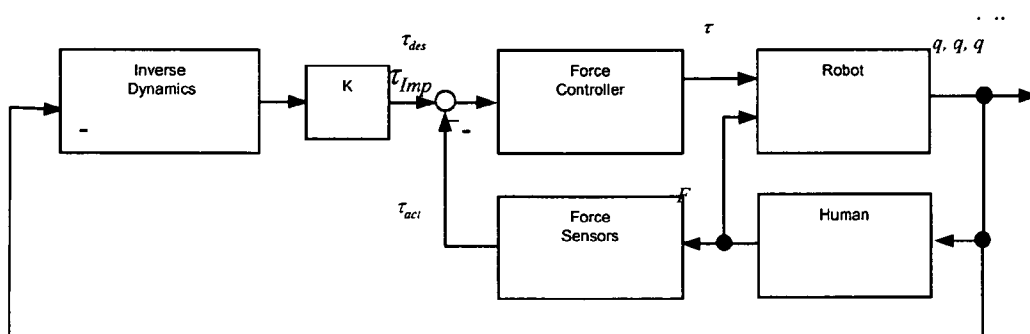


Fig. 9

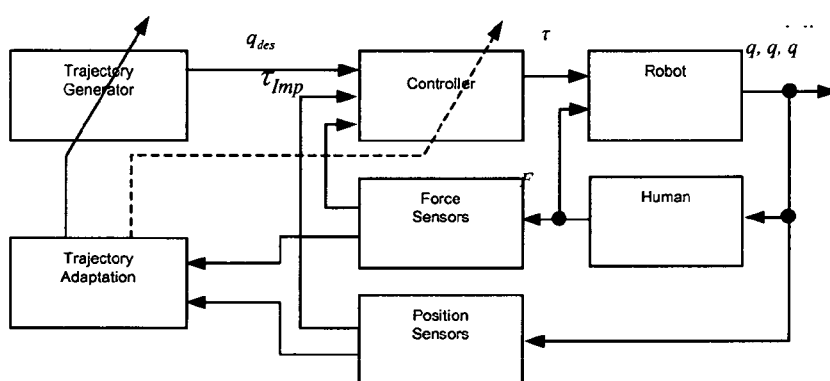


Fig. 10

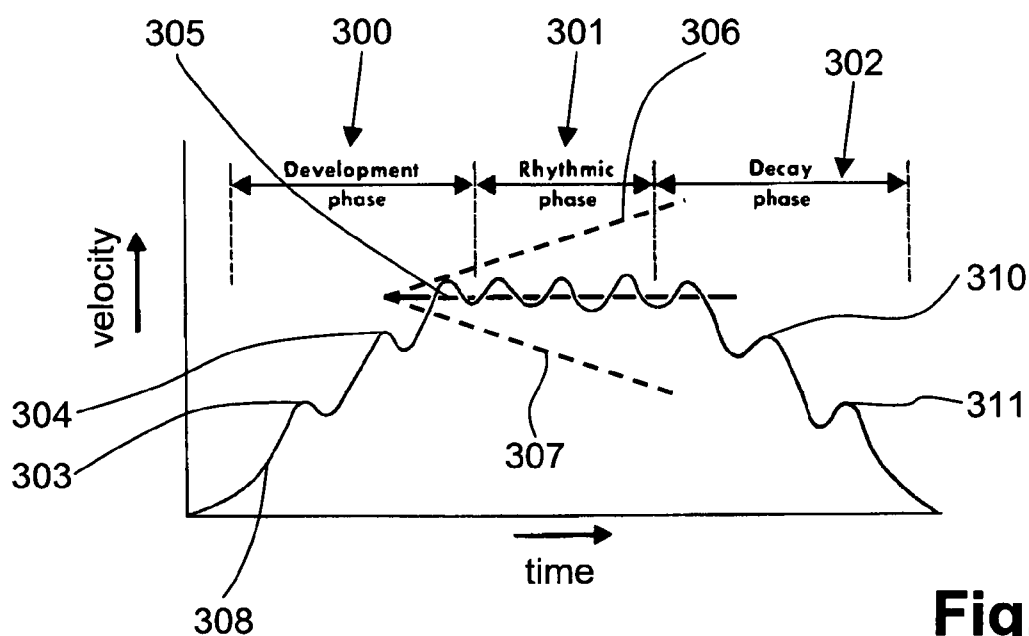


Fig. 11

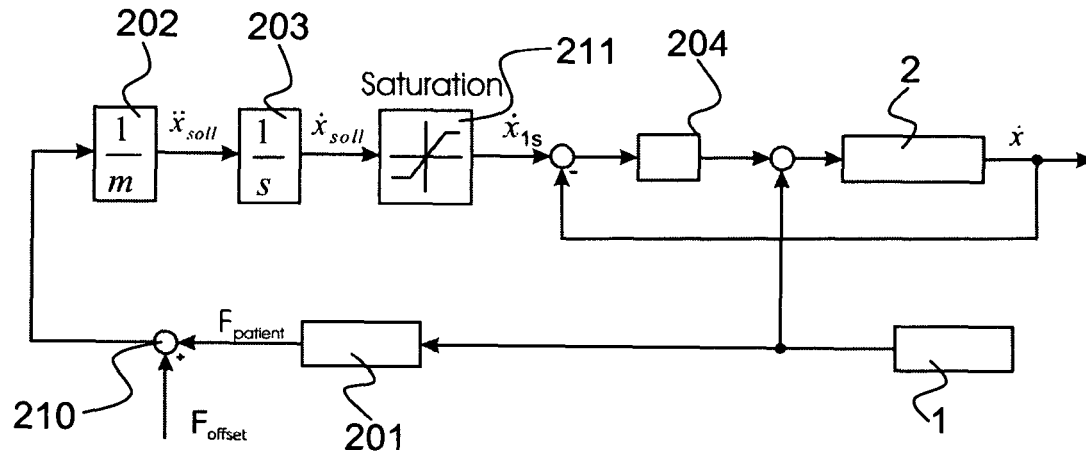


Fig. 12

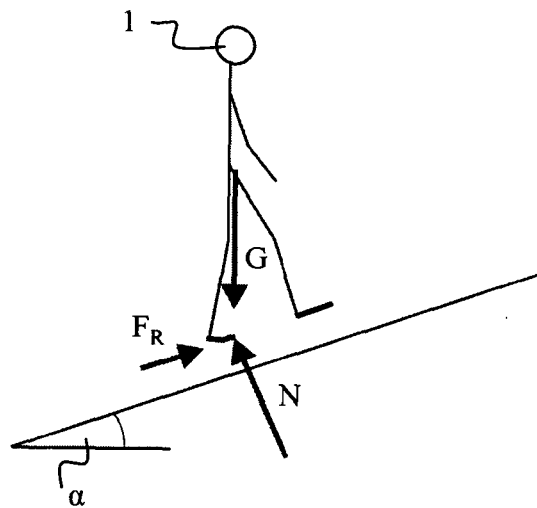


Fig. 13A

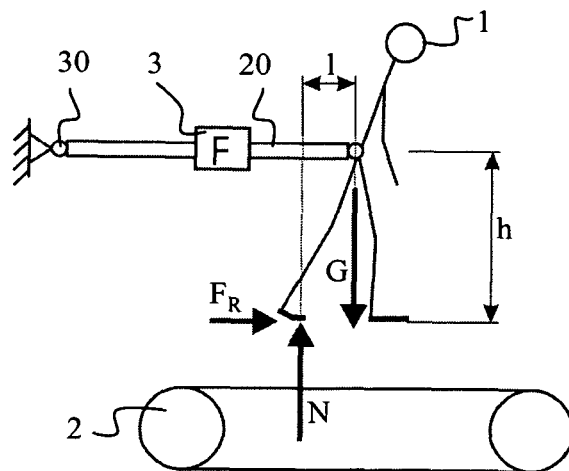


Fig. 13B



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X	US 5 242 339 A (THORNTON ET AL) 7 September 1993 (1993-09-07) * column 5, line 15 - column 12, line 10; figures 1-11 *	1,3-12	
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Place of search The Hague		Date of completion of the search 1 March 2006	Examiner Oelschläger, H
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