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(54) **ENERGY-EFFICIENT RUNNING AID**

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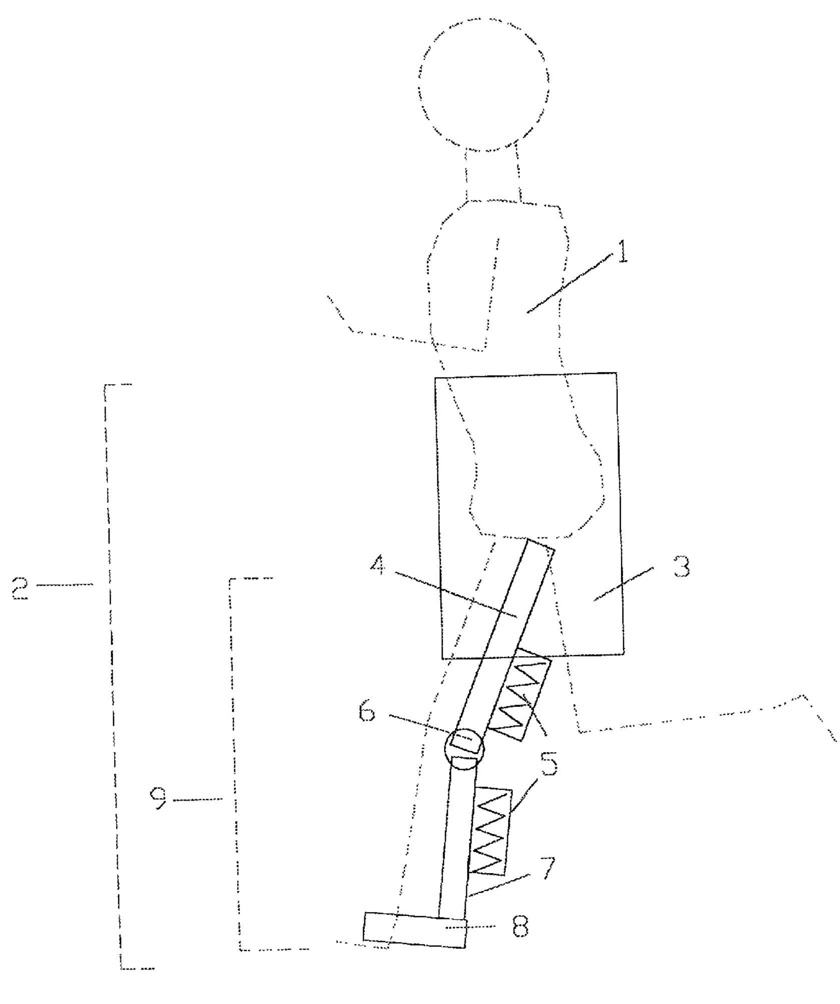
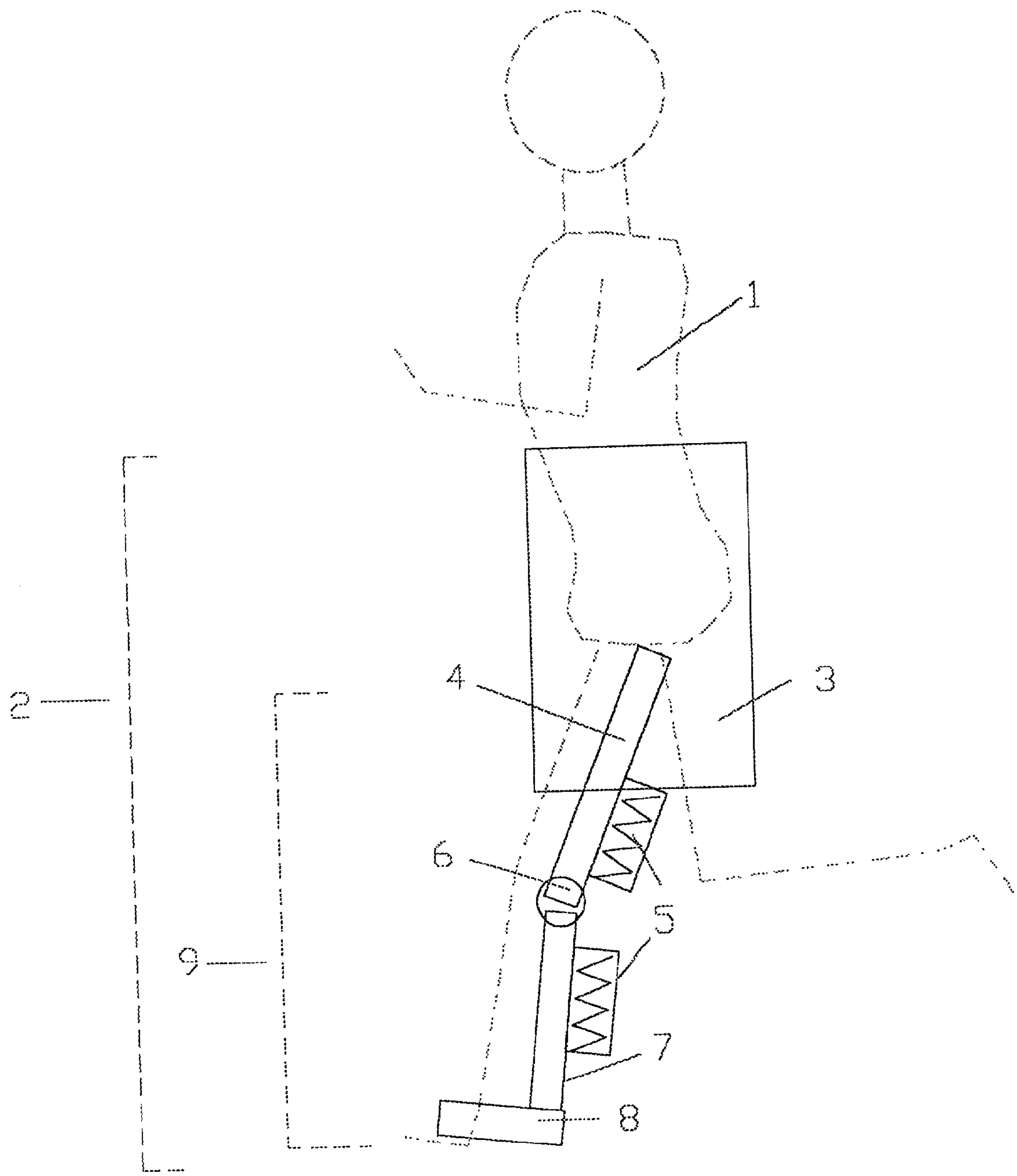
(51) Int. Cl.[7] **A63B 21/02**; A63B 71/00

(52) U.S. Cl. **482/124**; 482/74

(57) **ABSTRACT**

This invention, referred to as an Energy-Efficient Running Aid, relates to passive (spring-actuated) running/walking aids for ortheses, prostheses, and robots—to allow faster running using less energy. The full invention is an leg ortheses or an energy-efficient running brace. It is a running brace which acts in parallel with a runner's leg to support the runner during stance phase and to capture all foot-impact energy, preferably with the optimal constant-force curve, for use to thrust said runner back into the air during toe-off. Novel structural elements include a hyper-extending knee-lock, a variable-angle knee-lock, a kneeless adjustable-length brace, a self-guiding/constant force bow spring, a pulley-based/constant-force bow spring, a asymmetric brace foot, a load-tightening full harness, and a means to guarantee lock release at toe-off. The running brace eliminates impact injuries by absorbing the impact energy.





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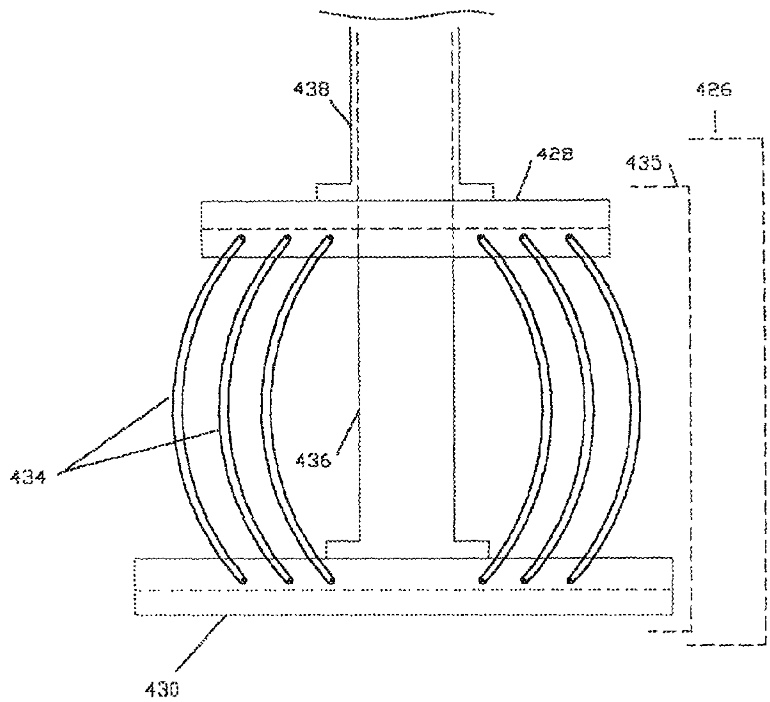

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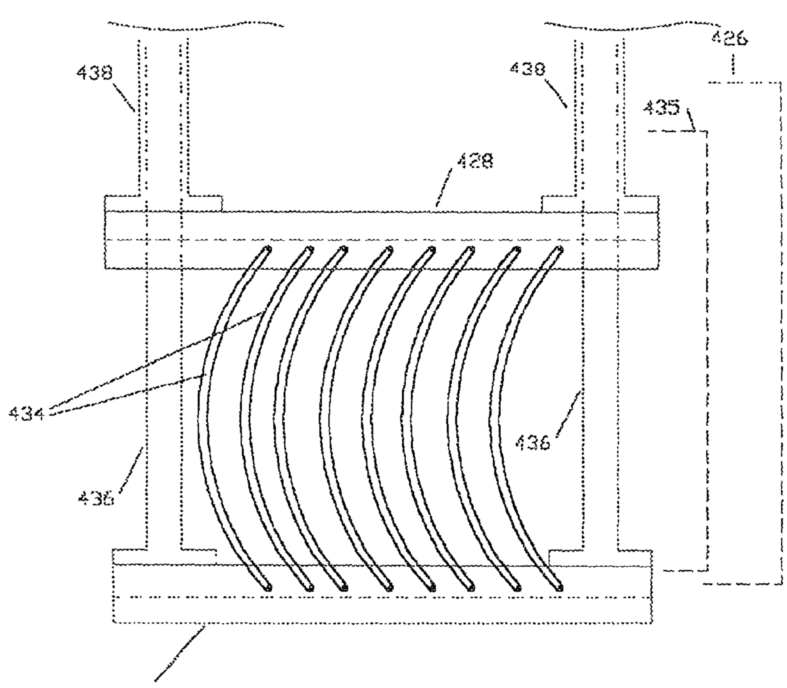

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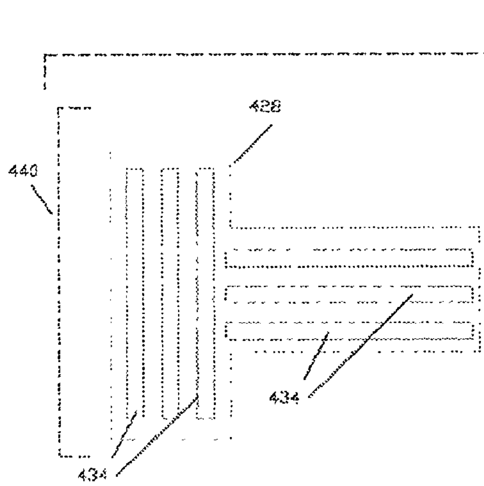

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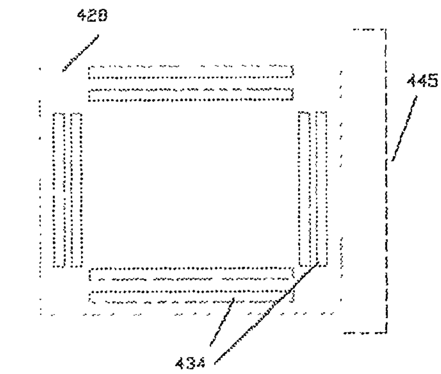

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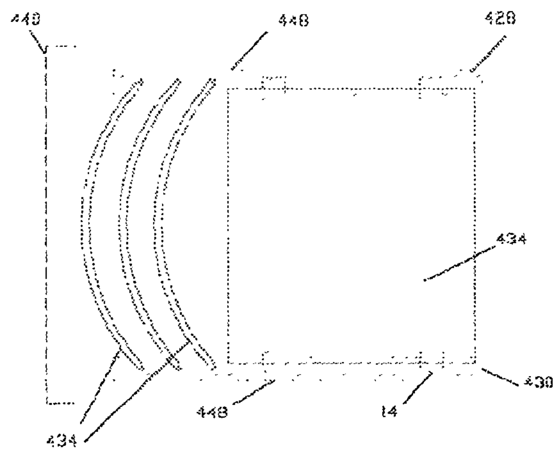

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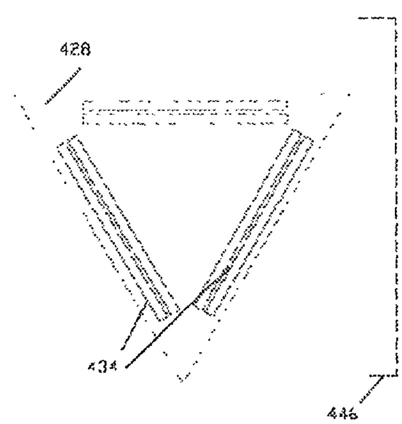

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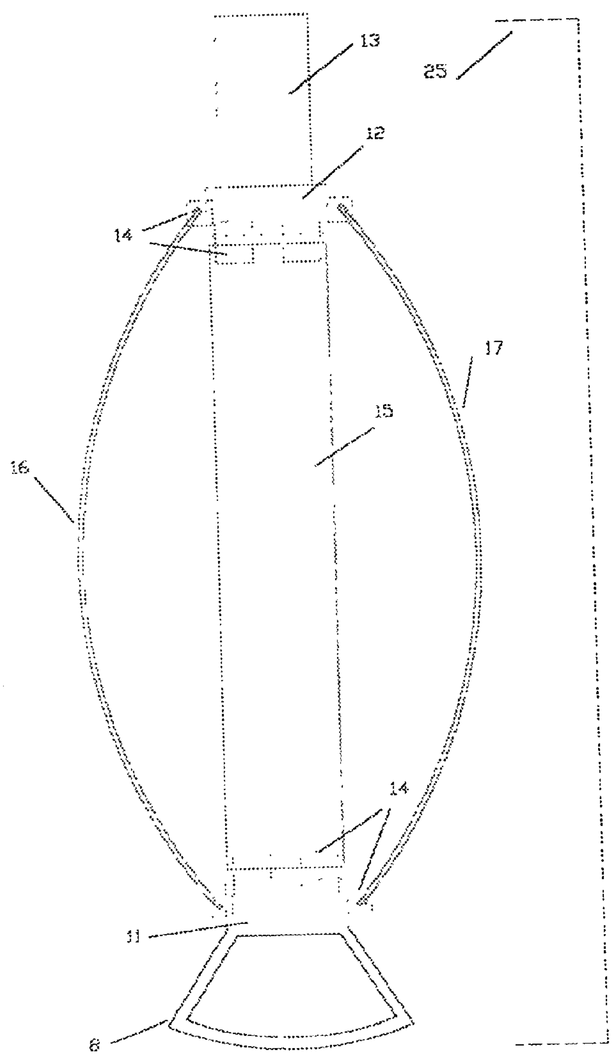

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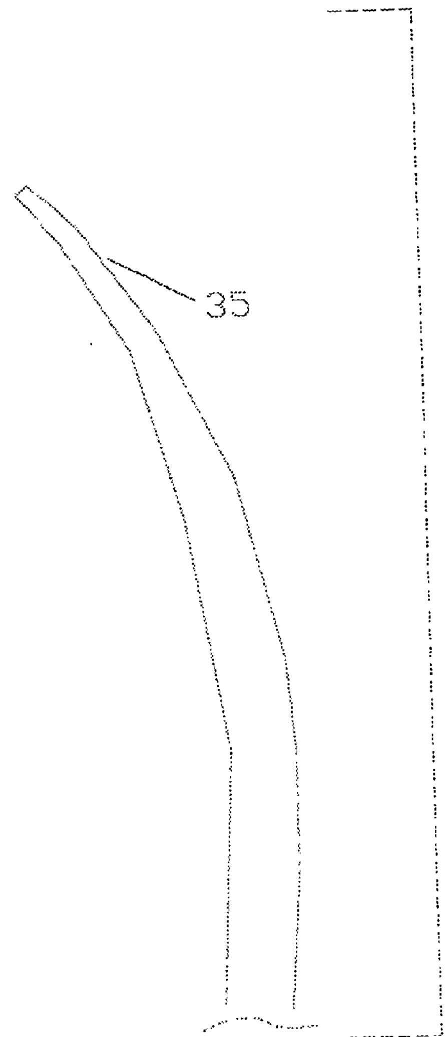

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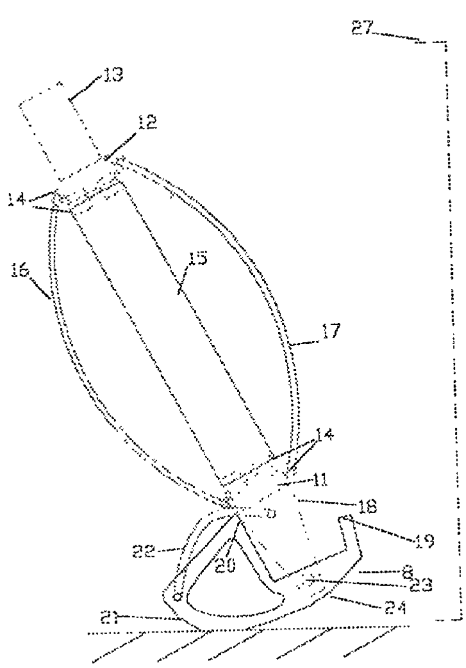

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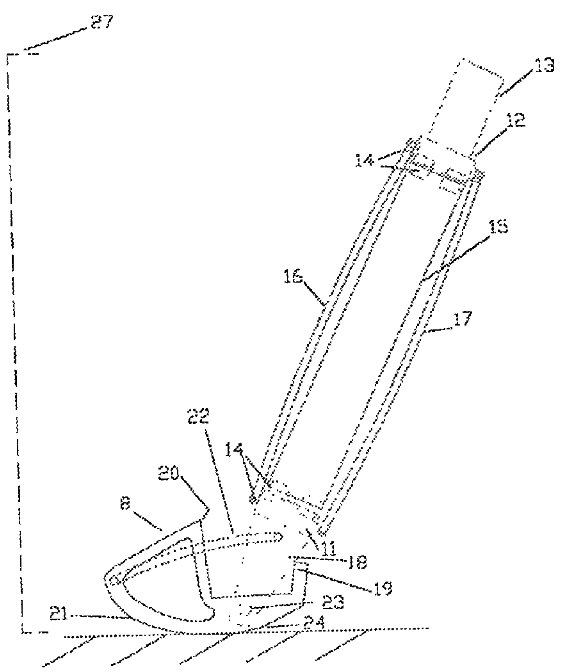

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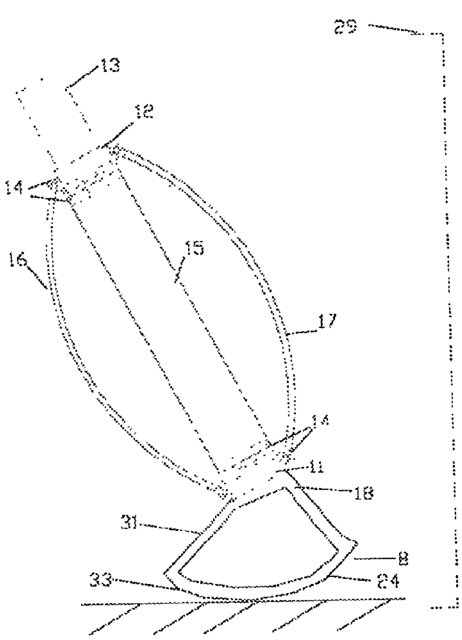

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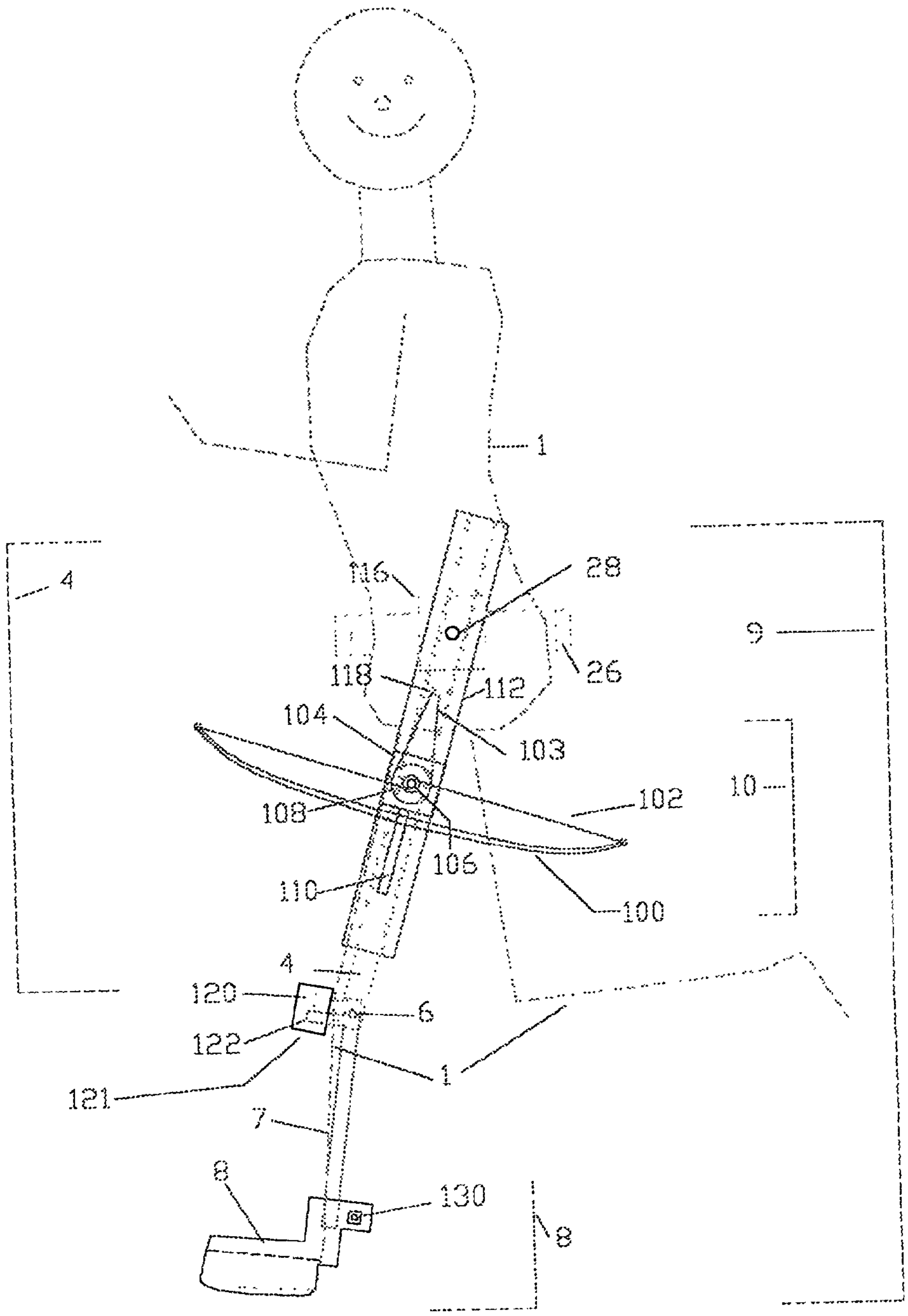
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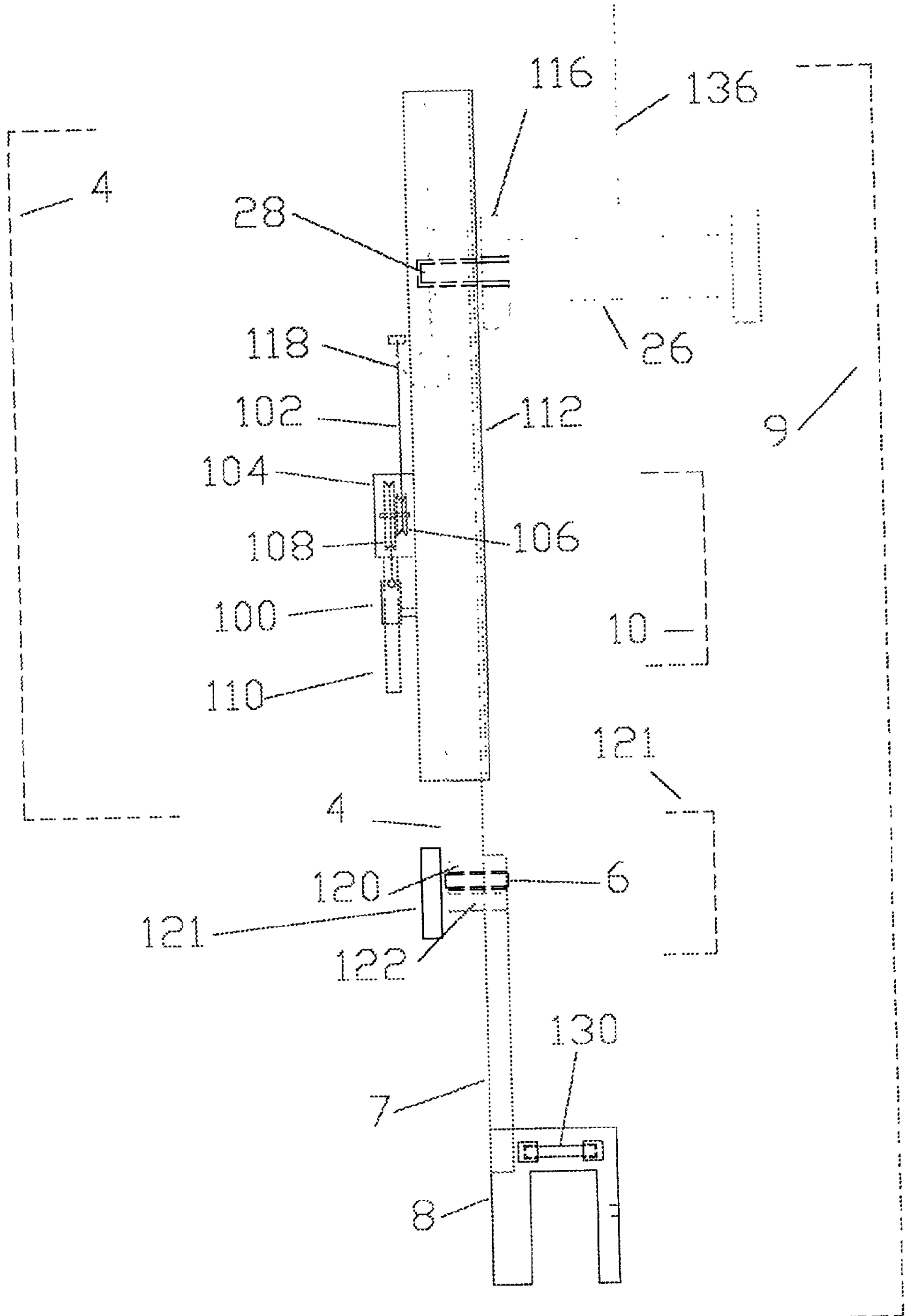
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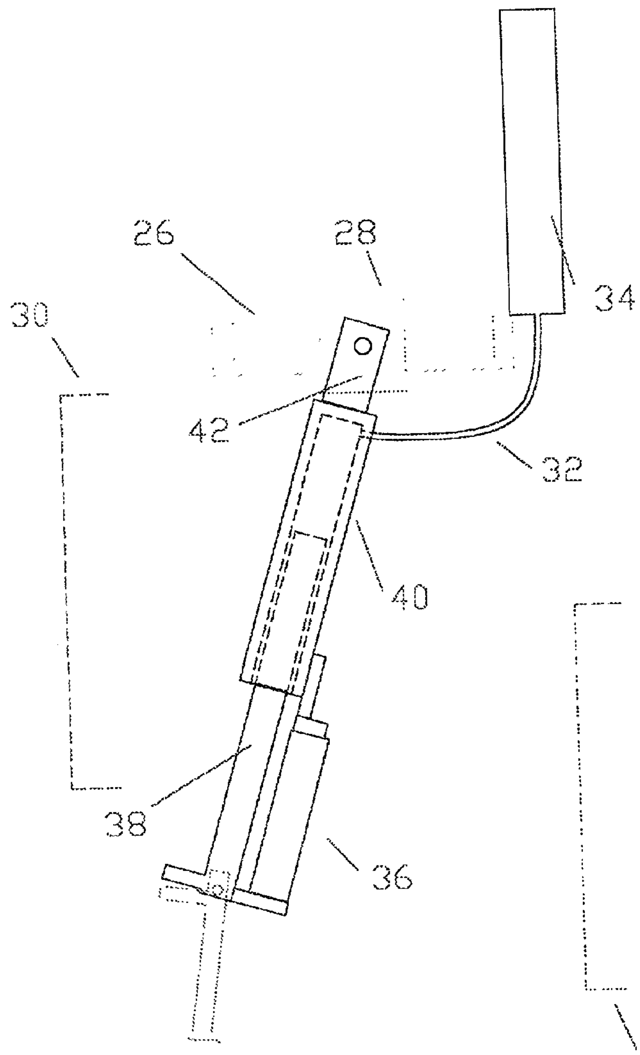

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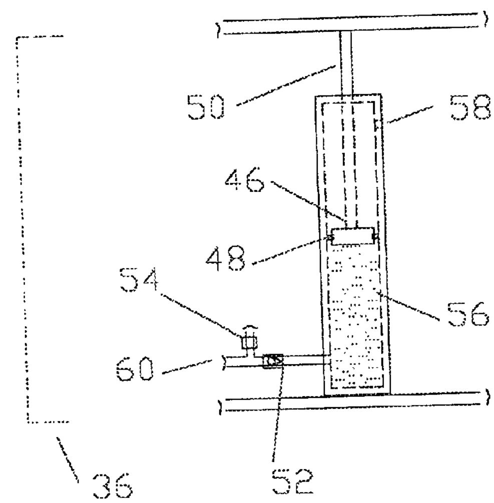

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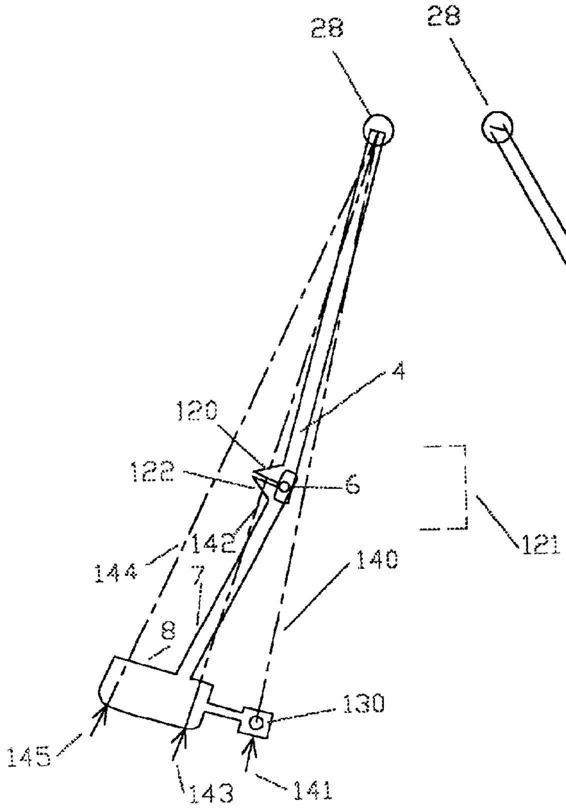

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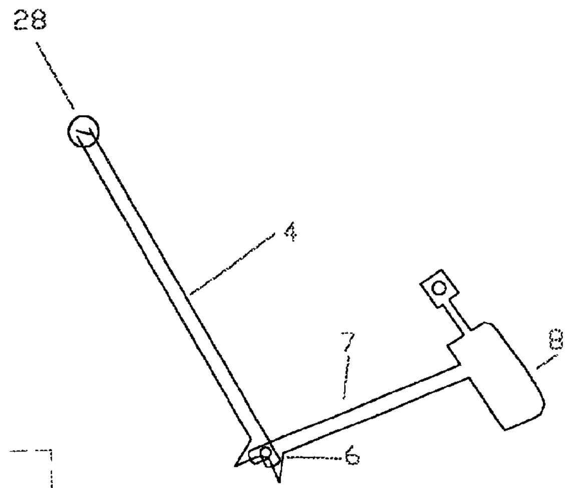

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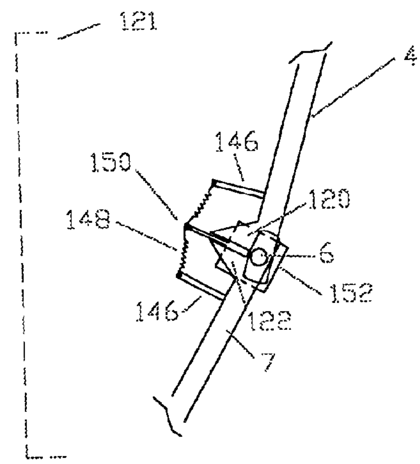

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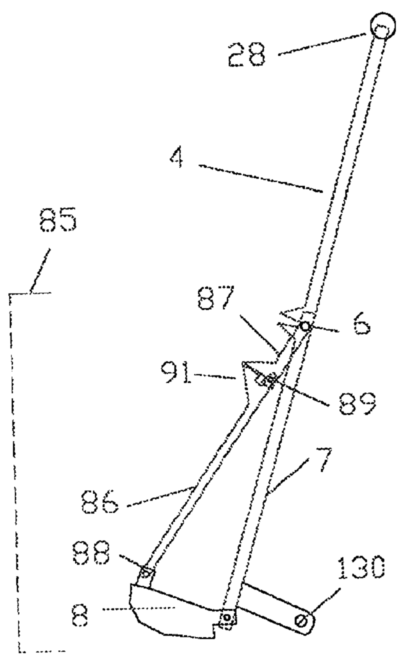

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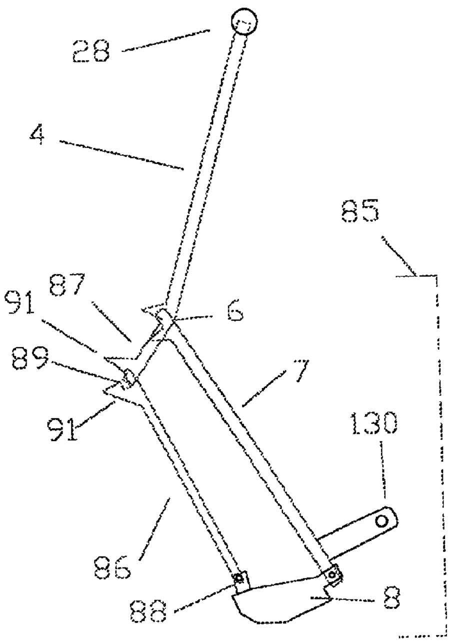

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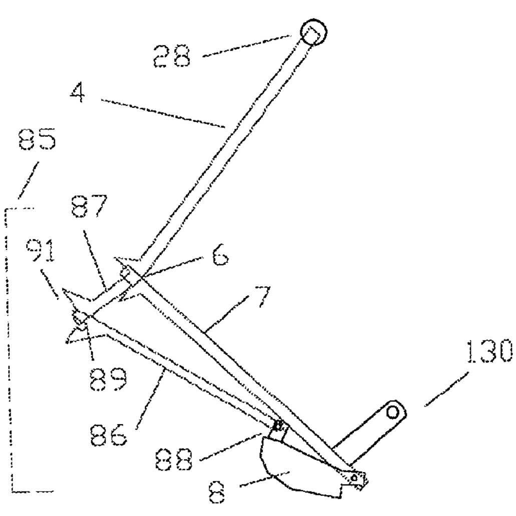

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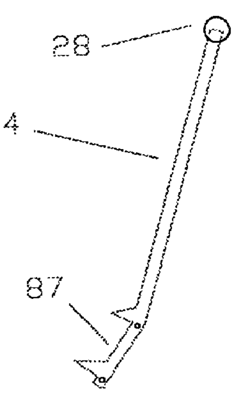

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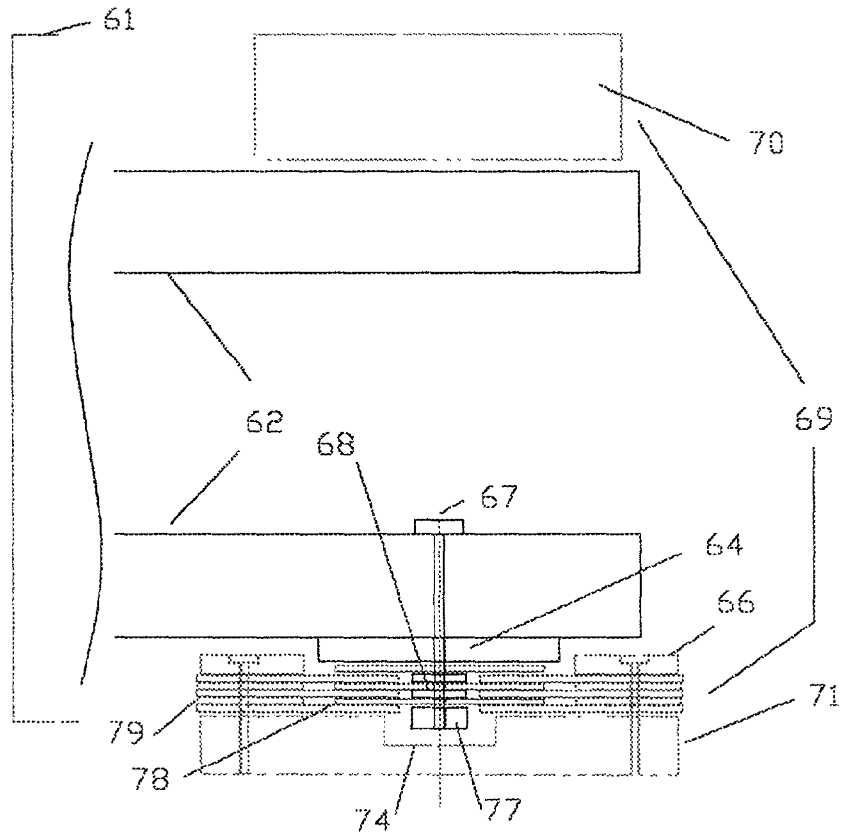

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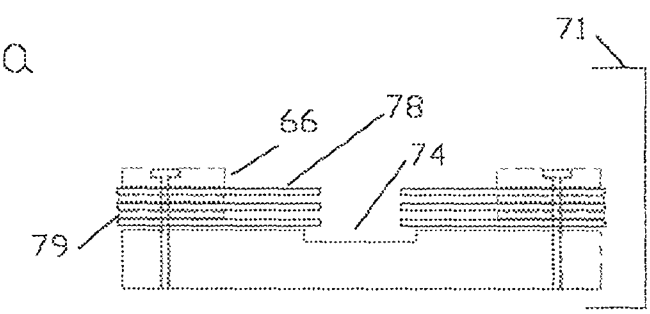

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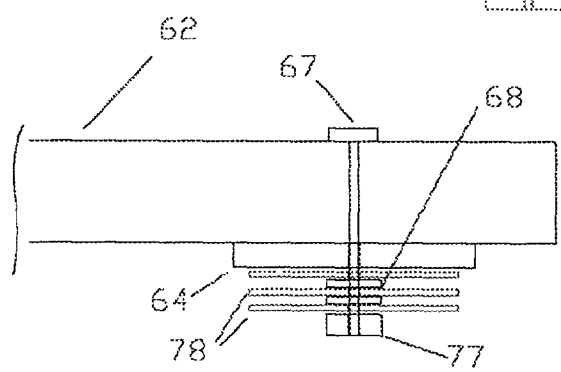

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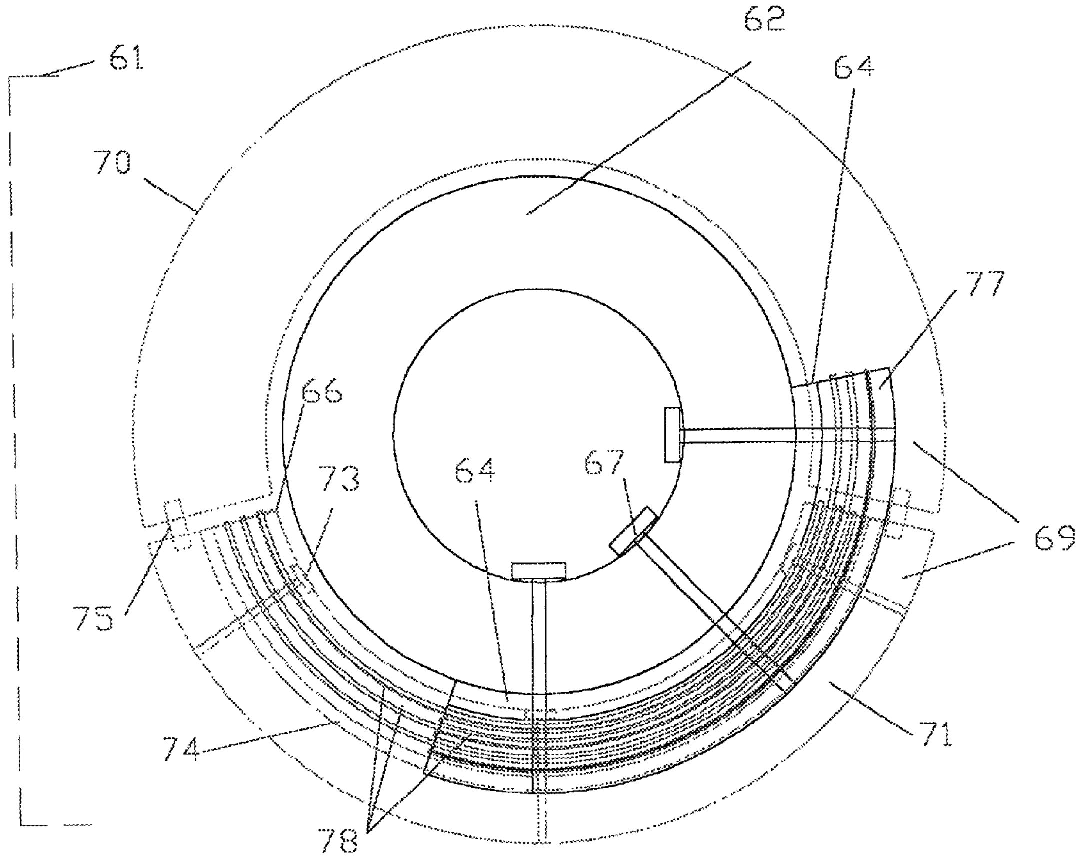

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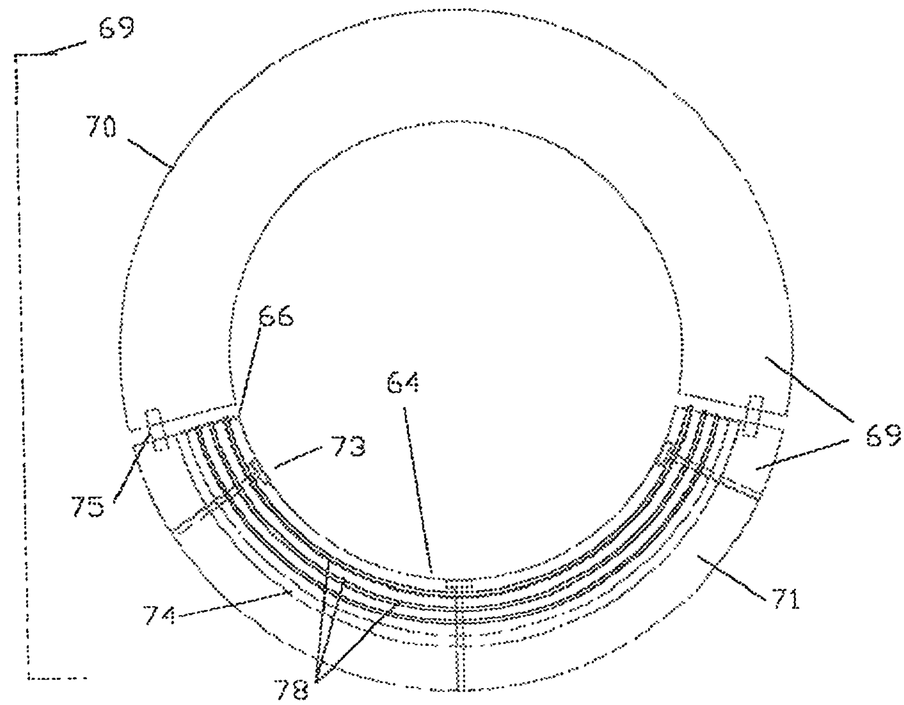

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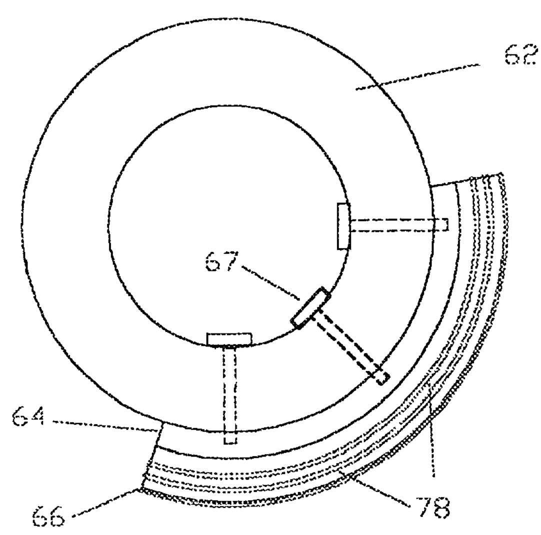

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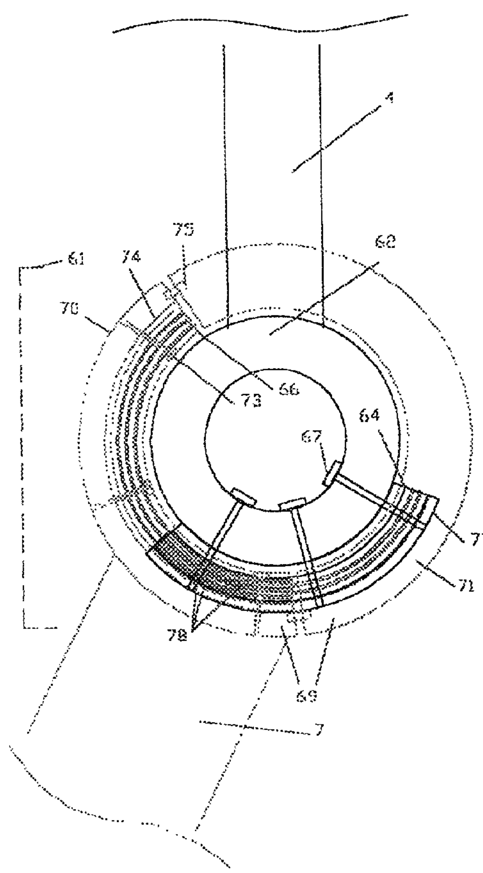

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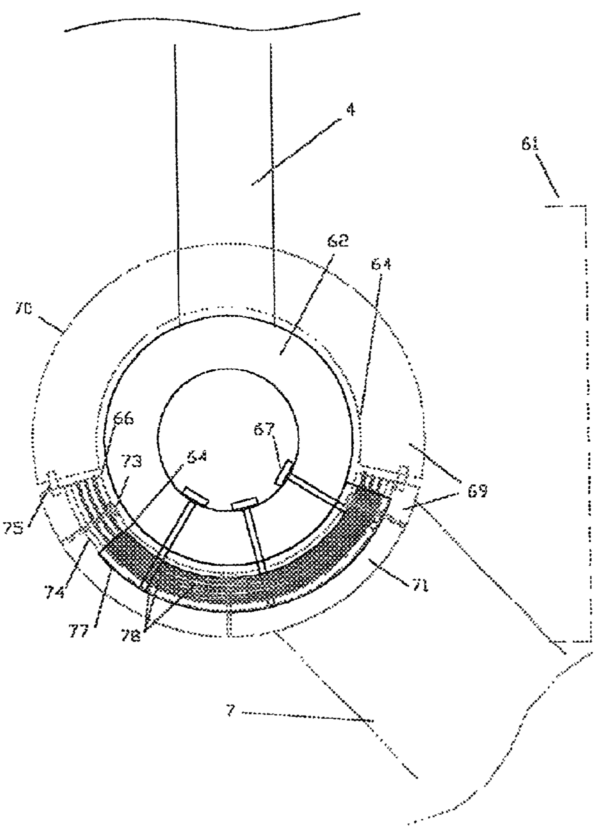

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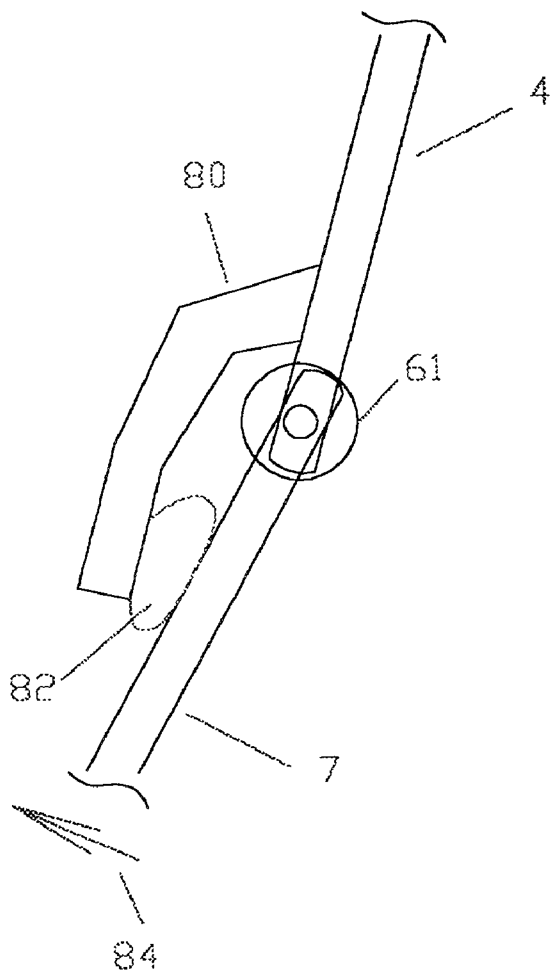

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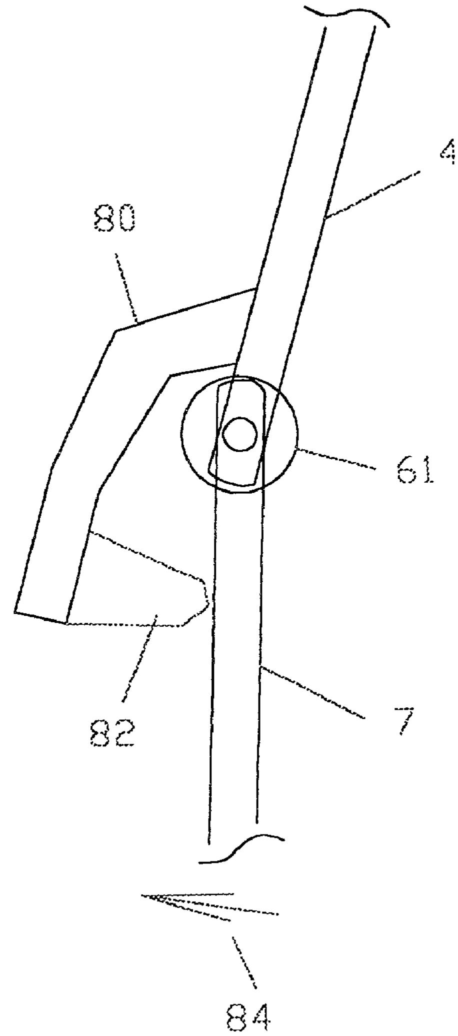

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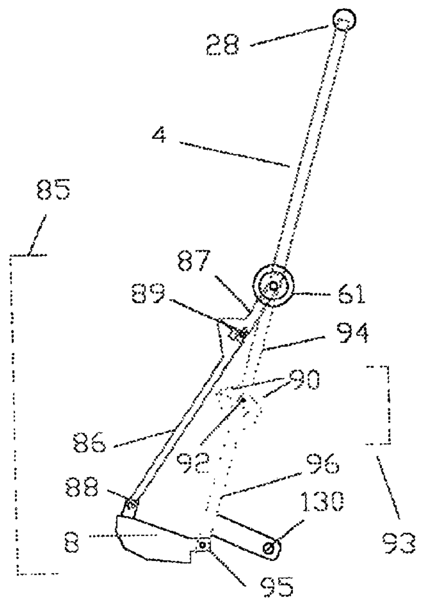

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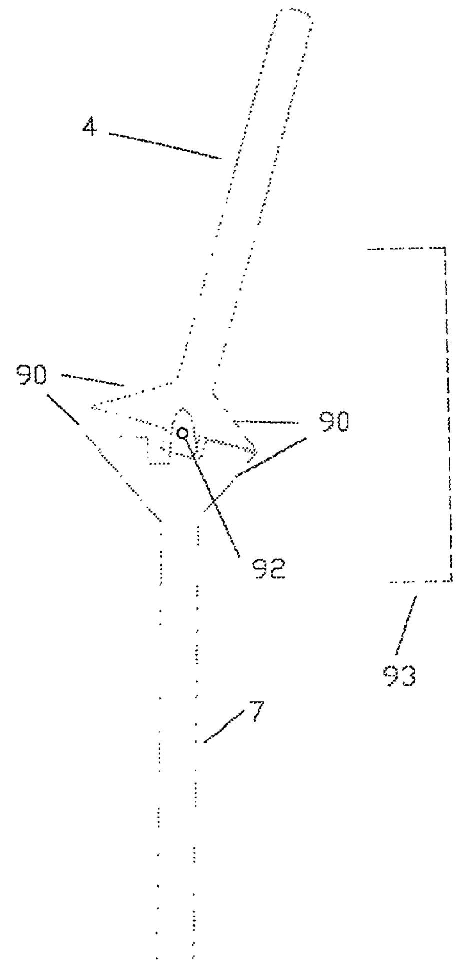

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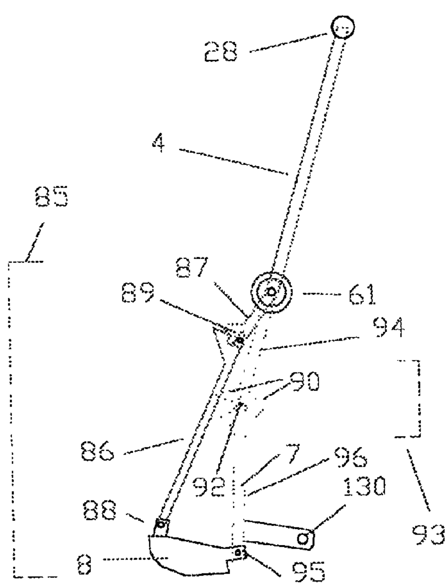

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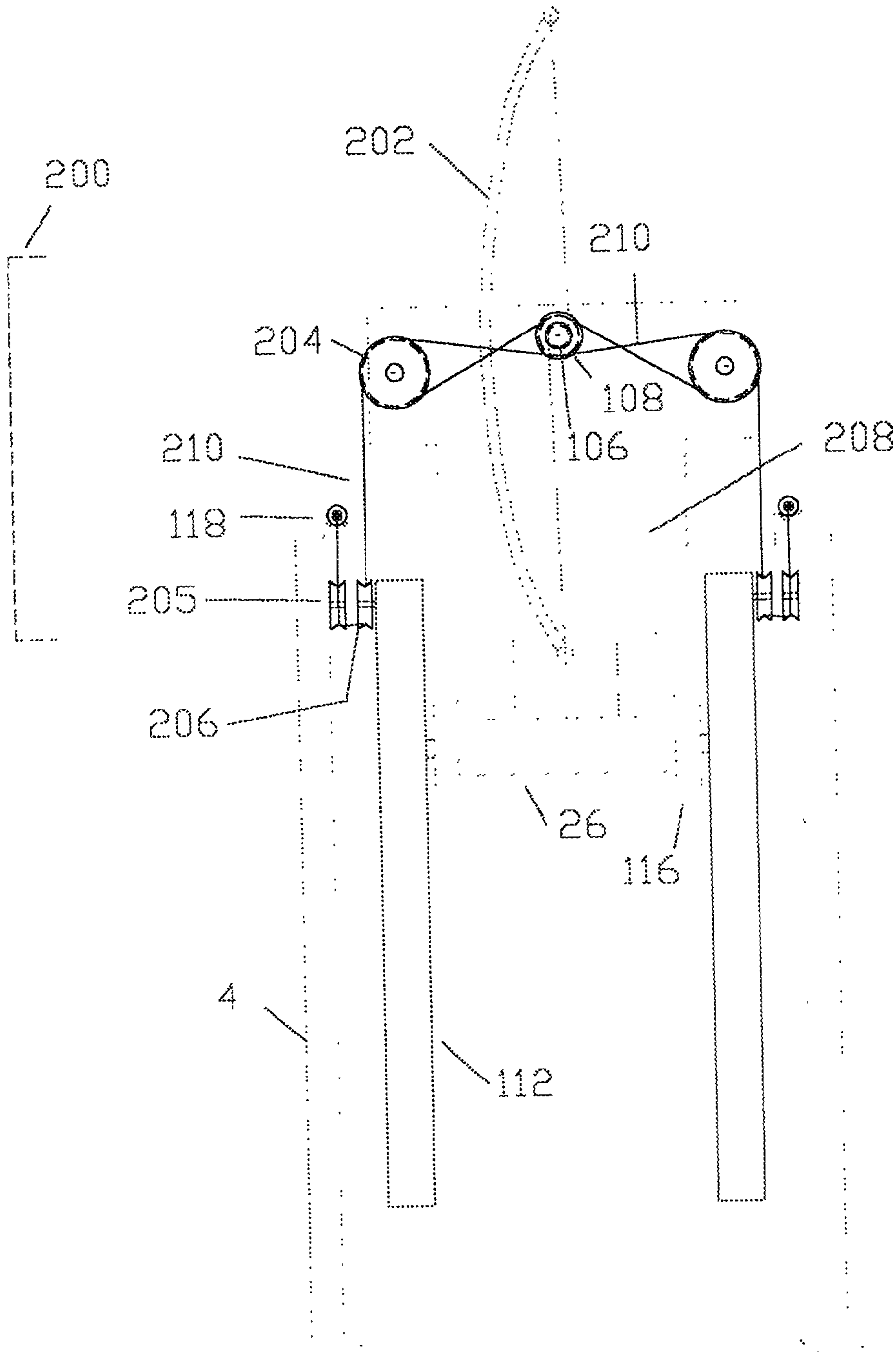

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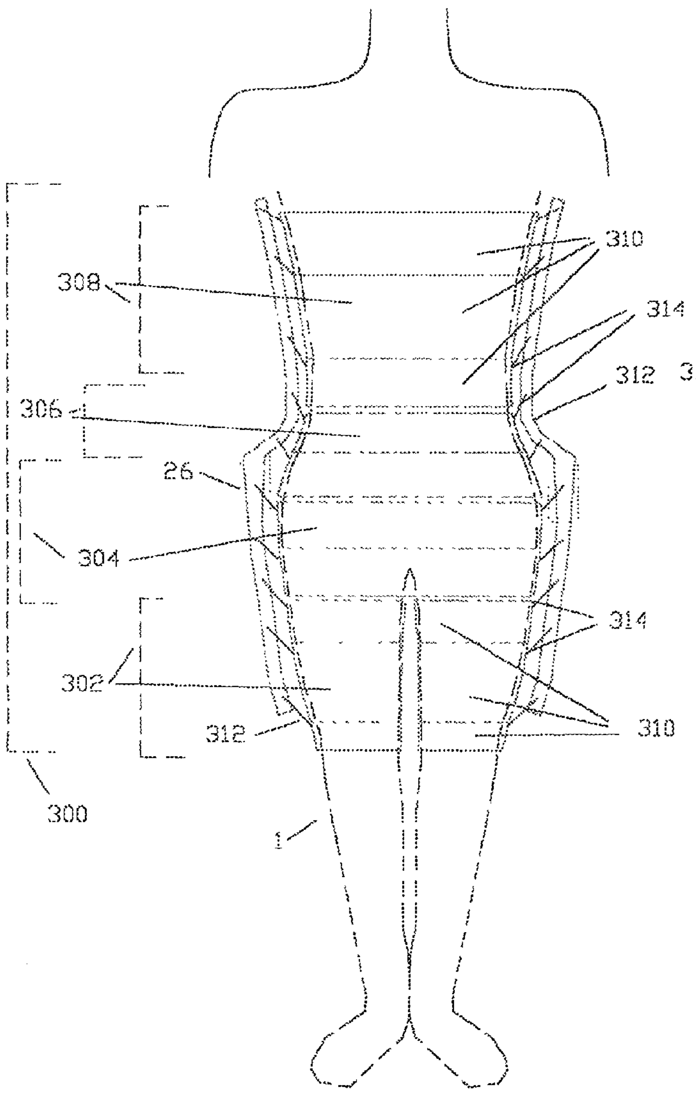

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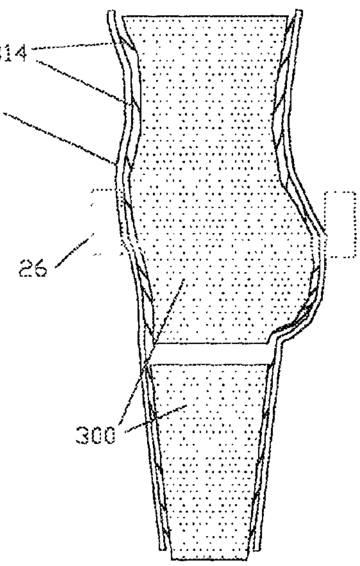

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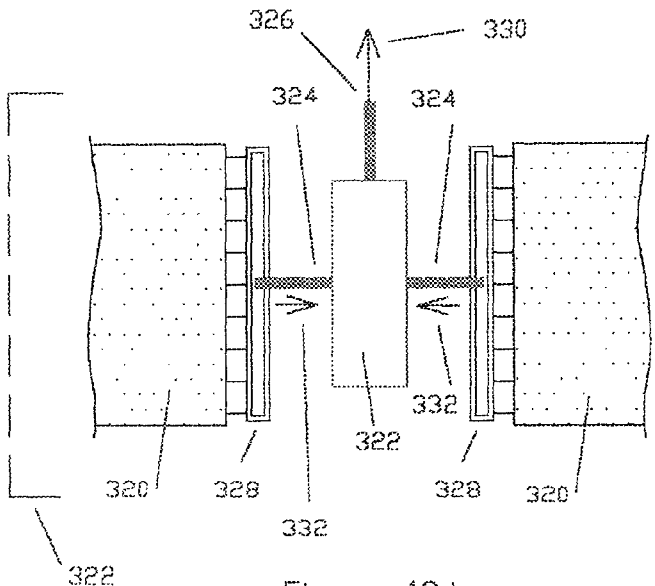

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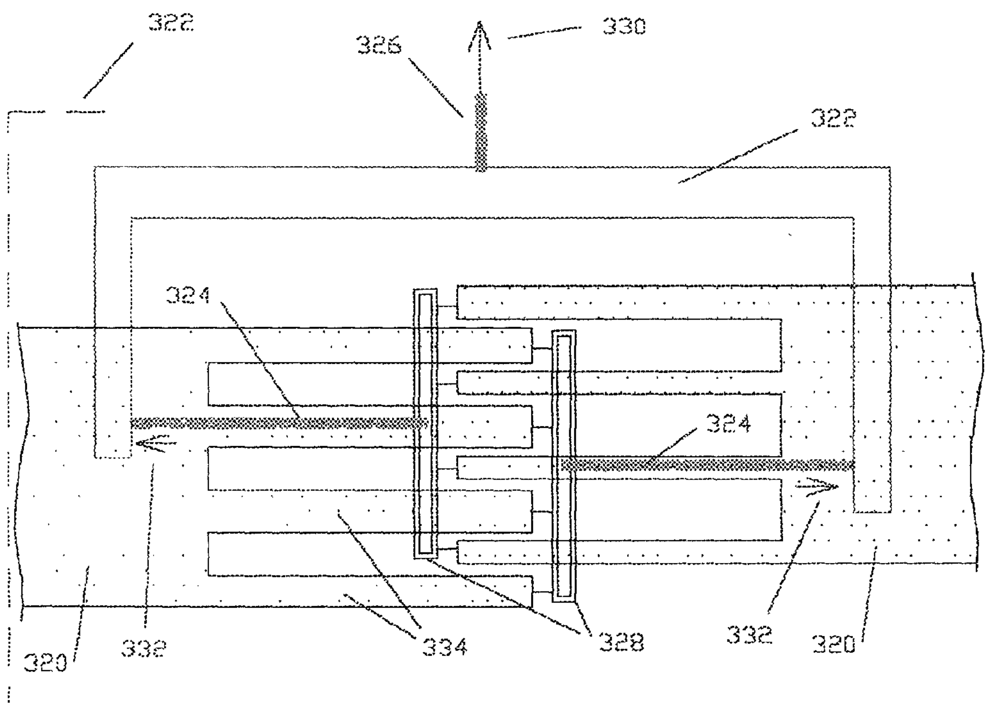

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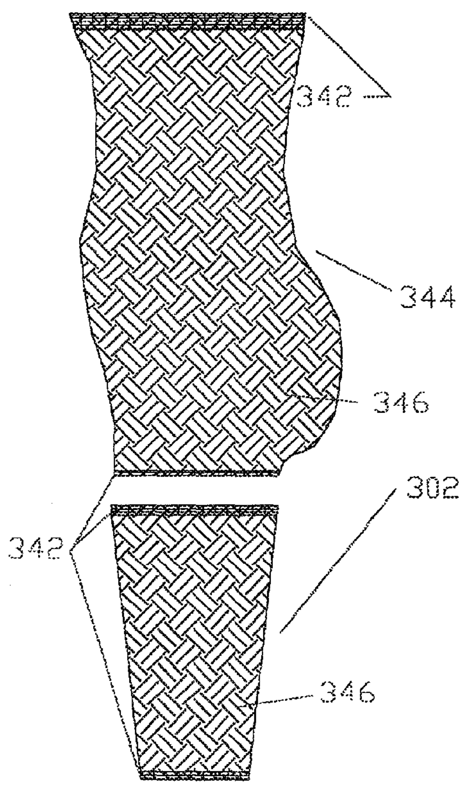

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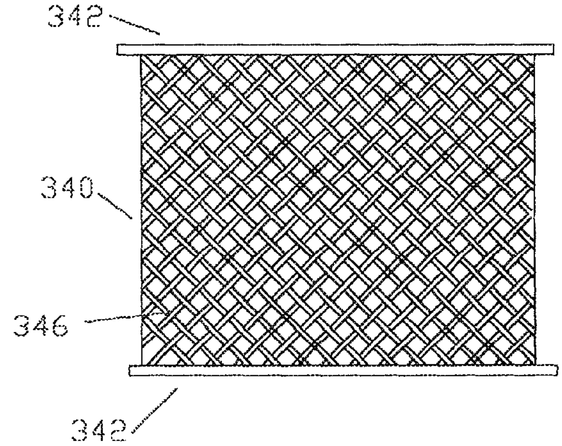

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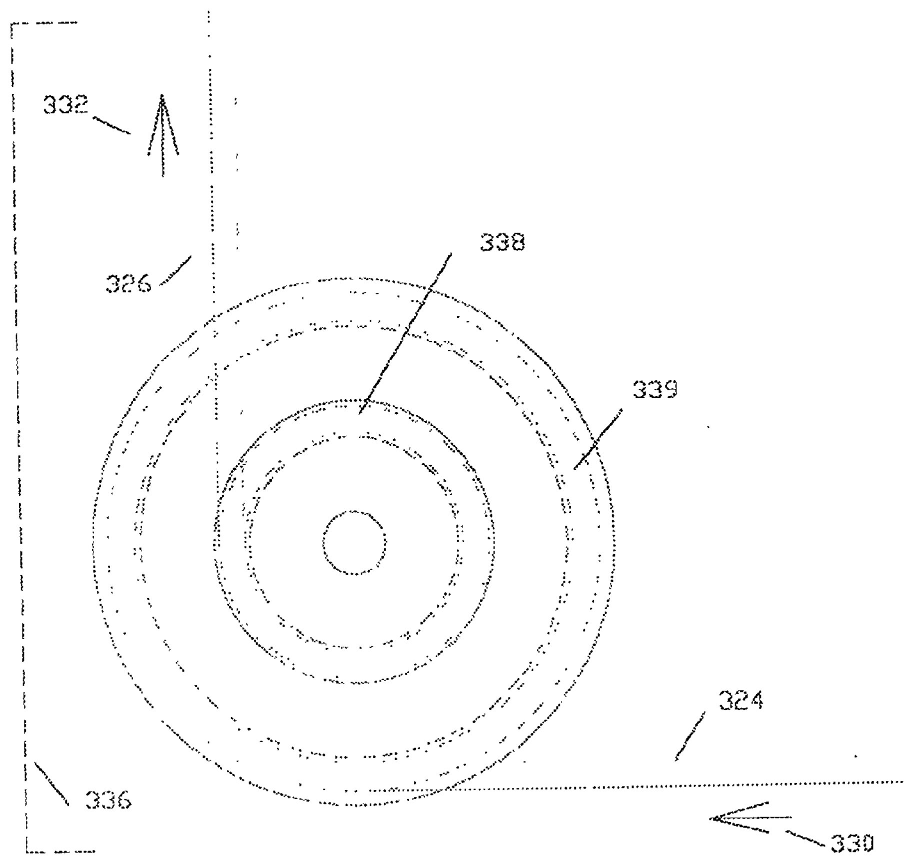

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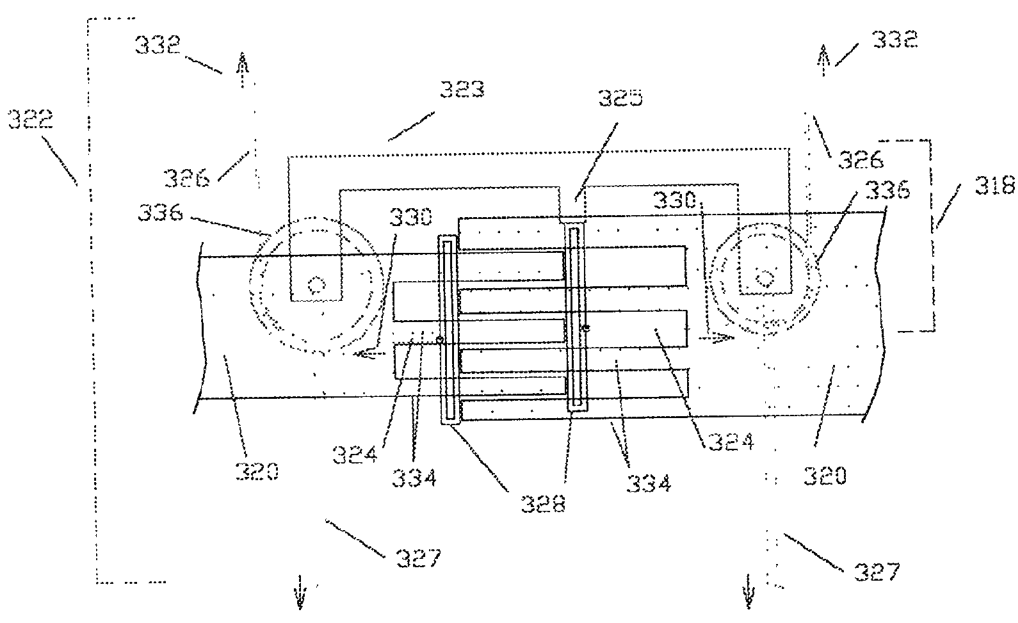

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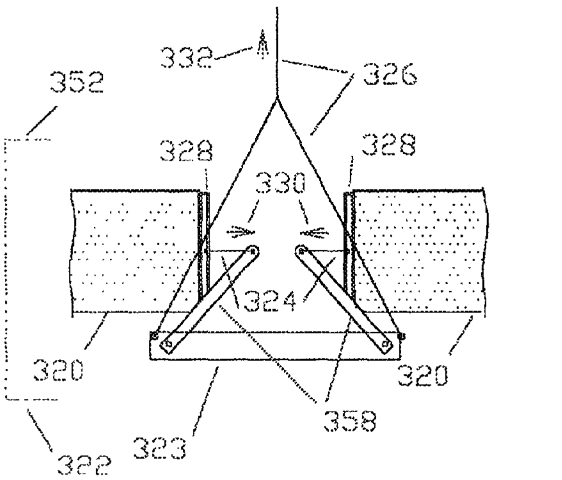

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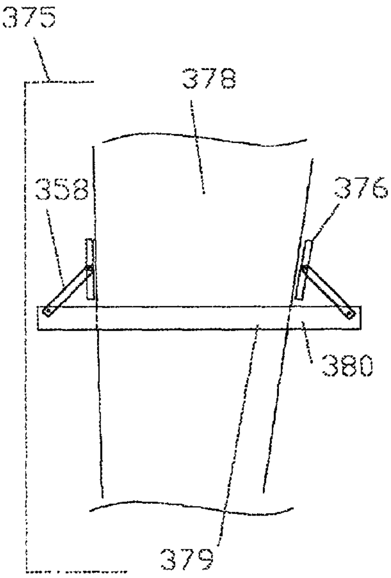

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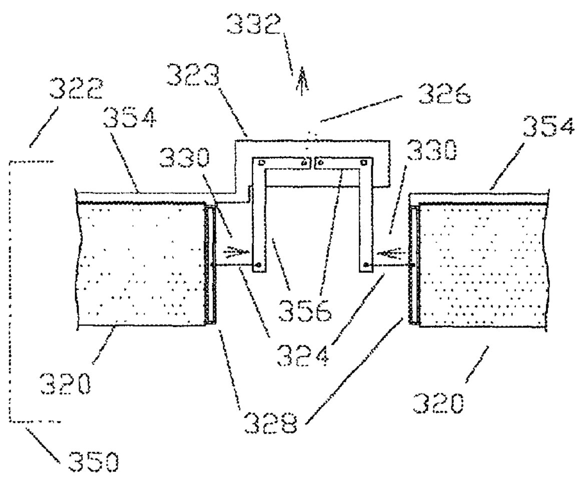

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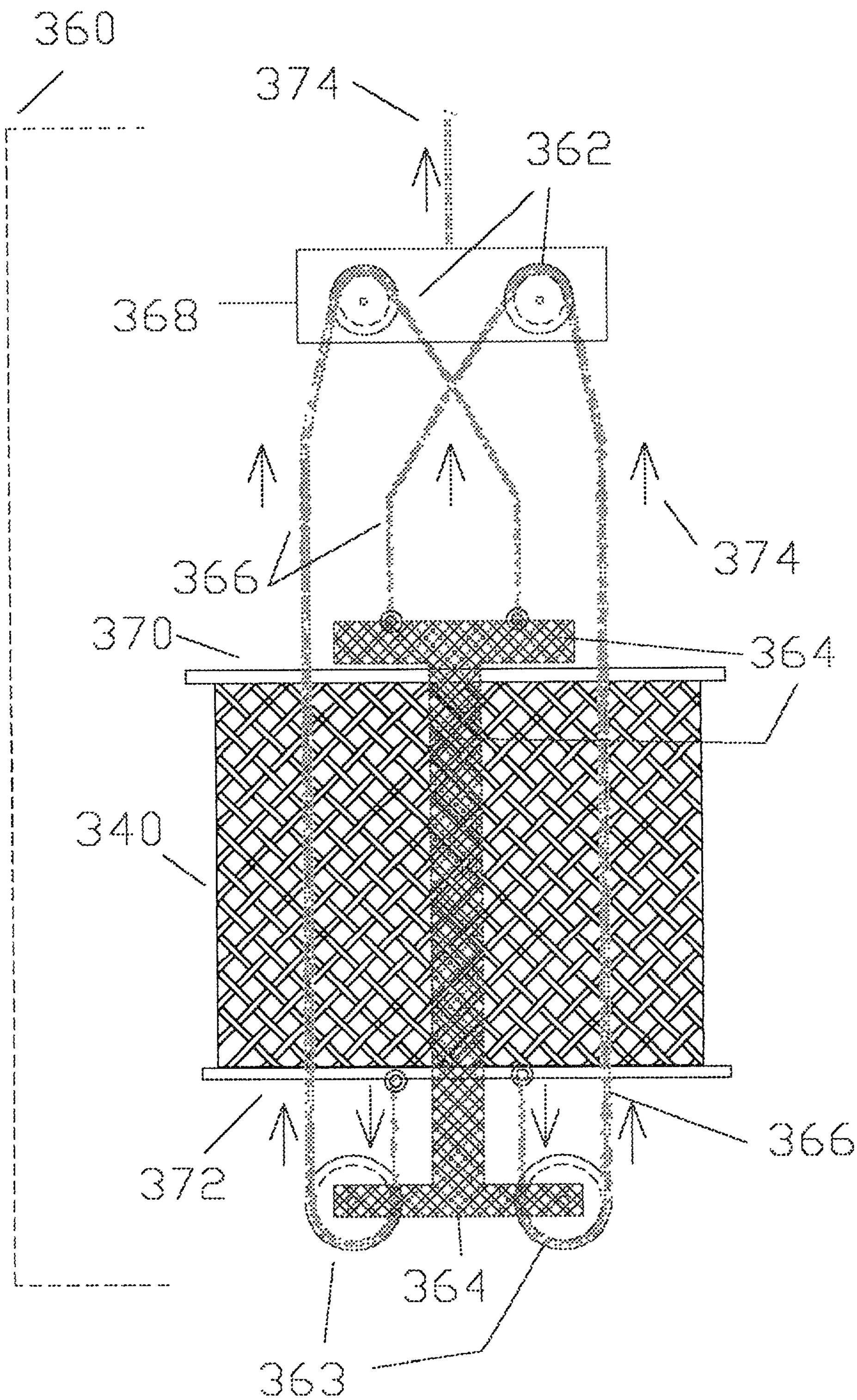

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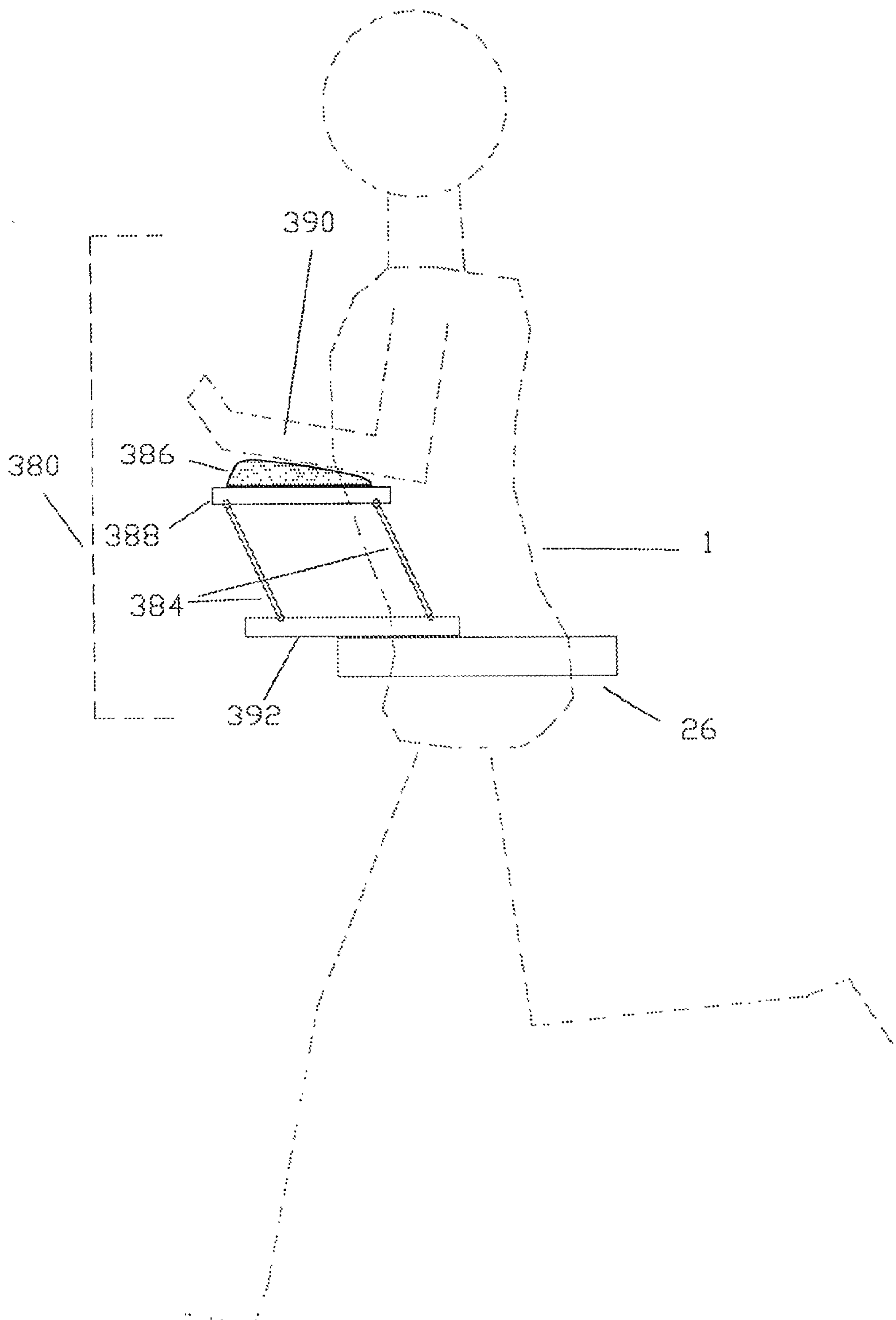

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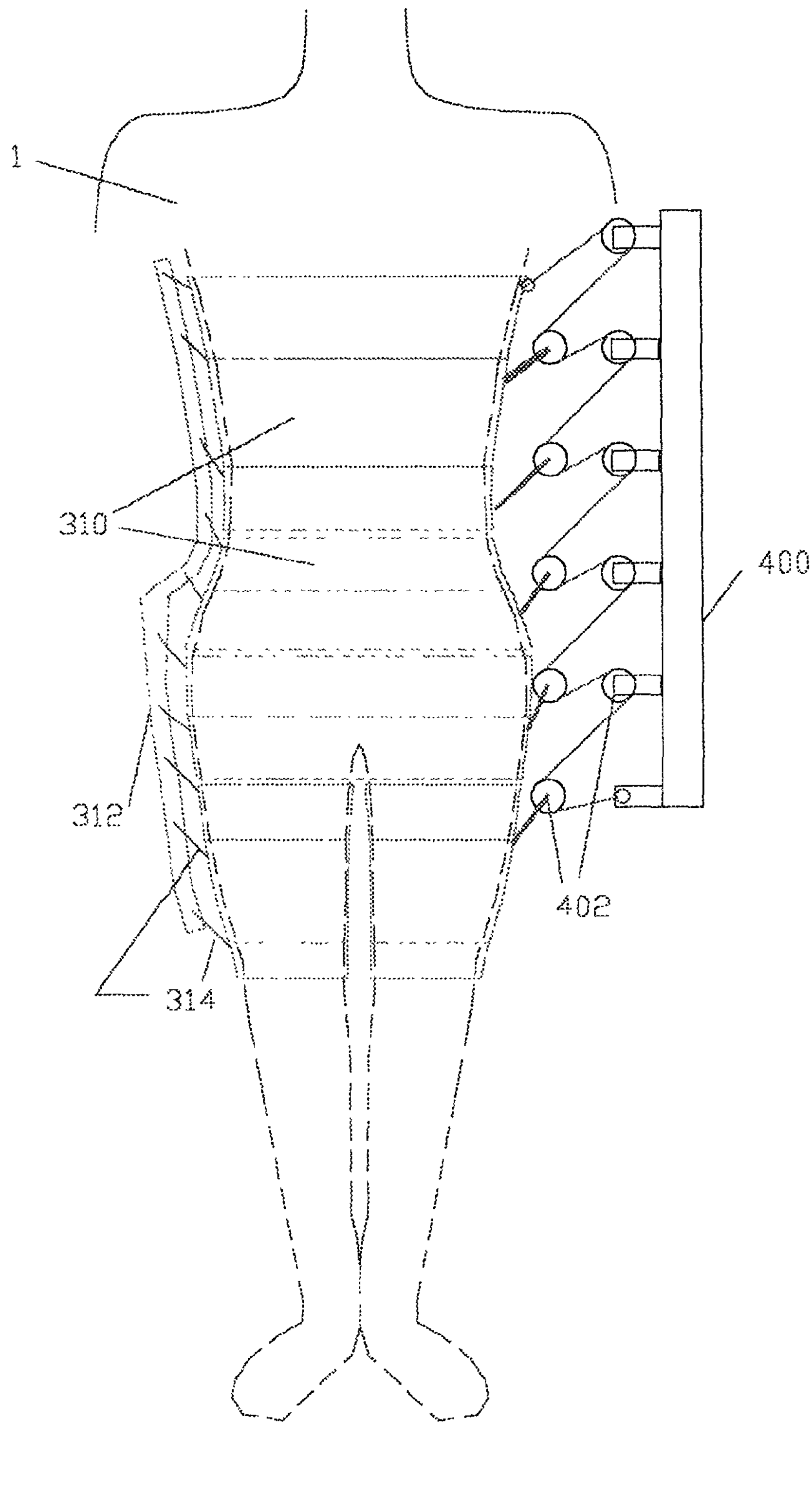

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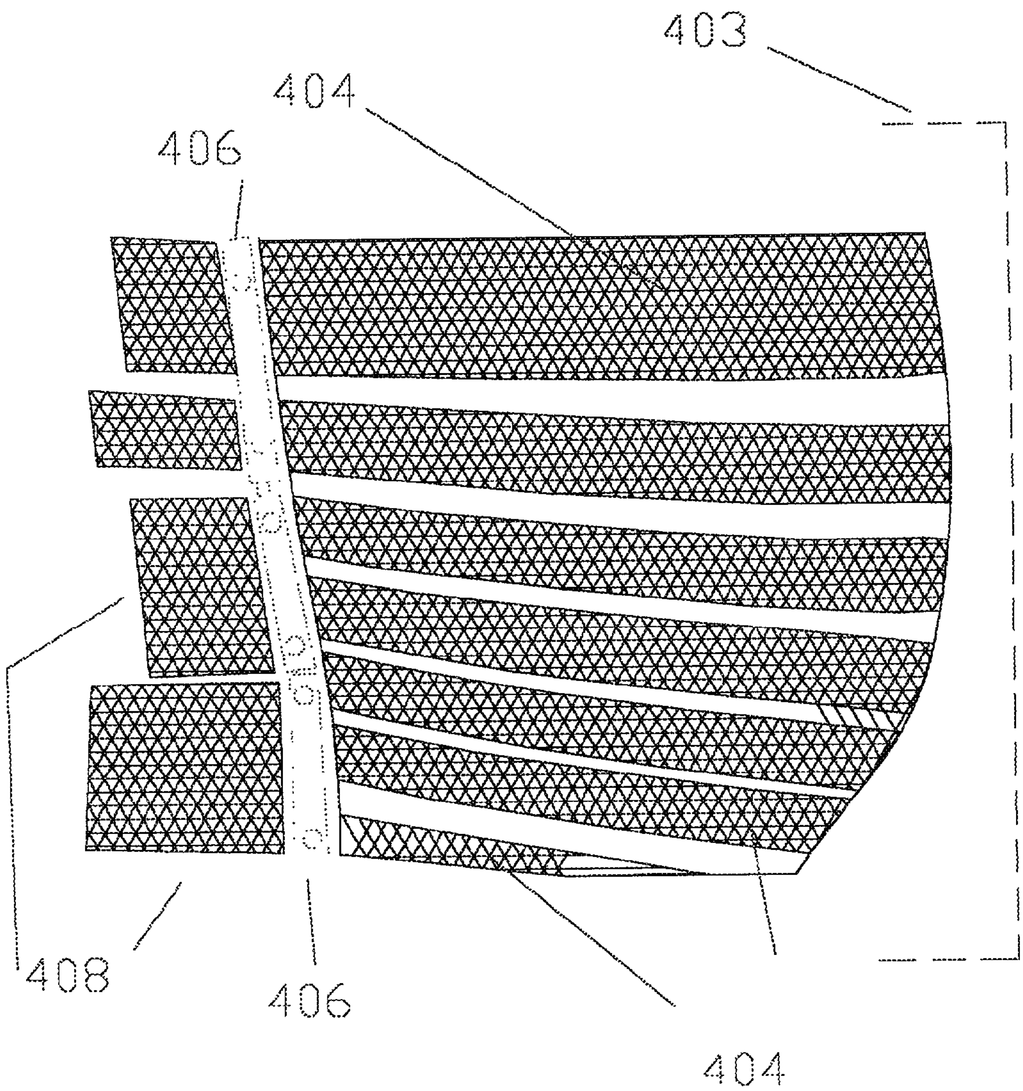

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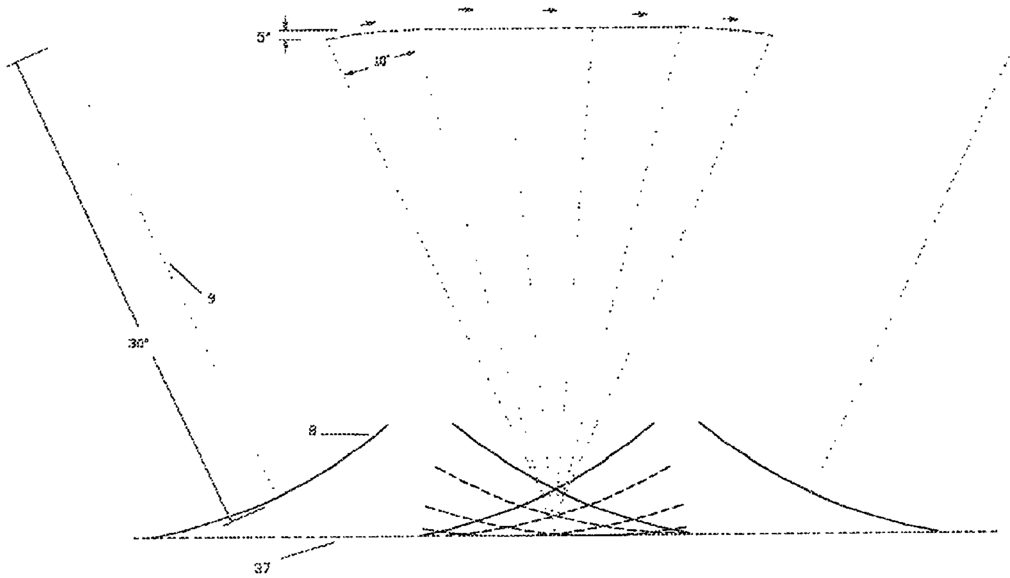

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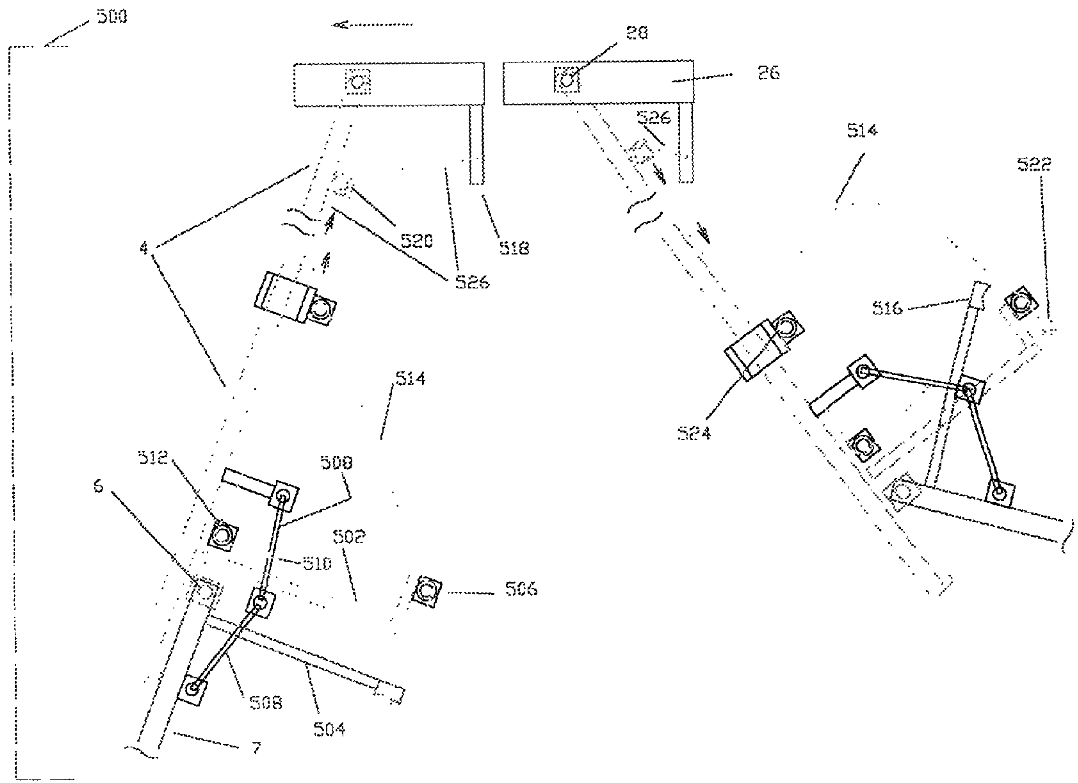
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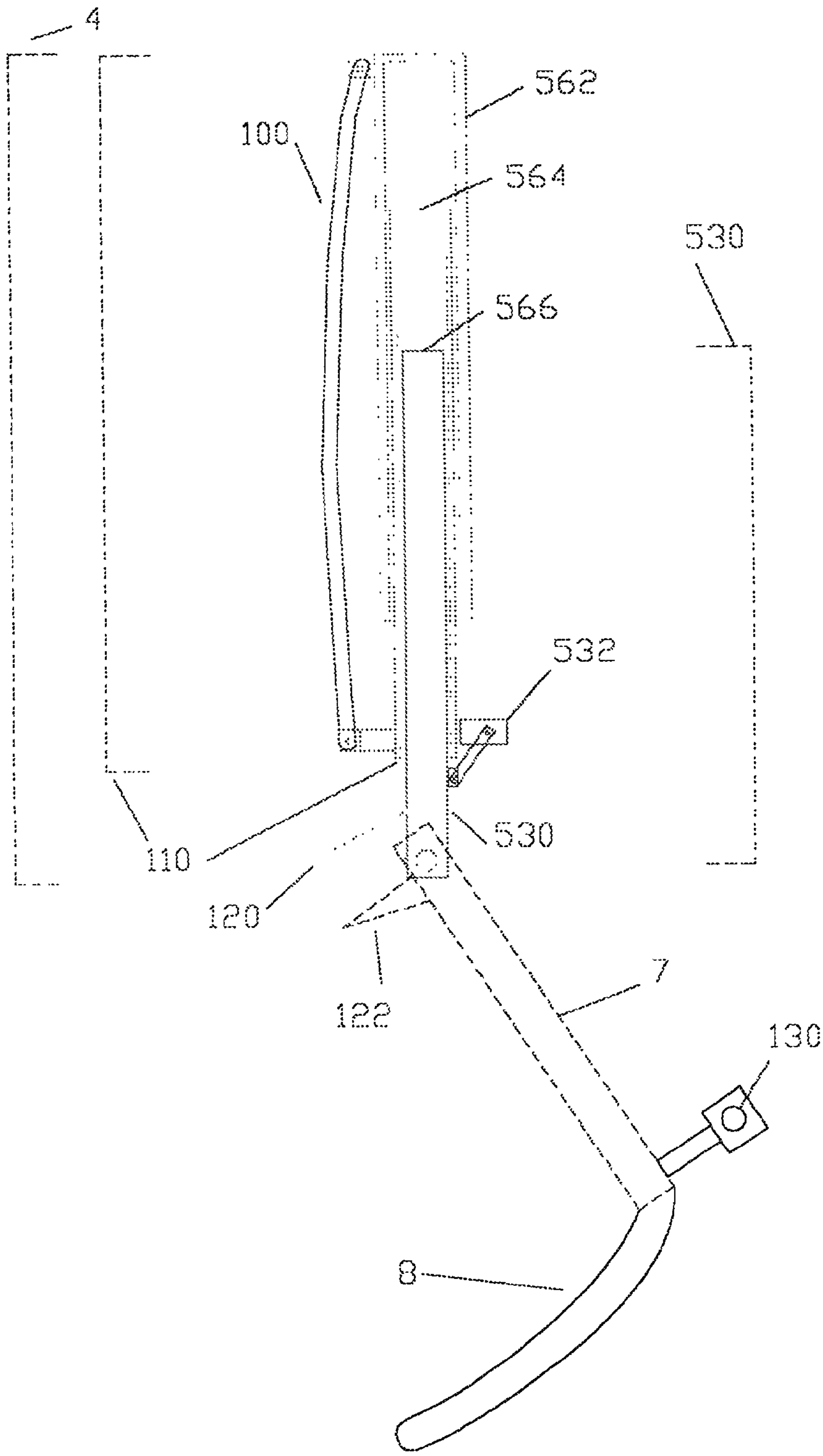

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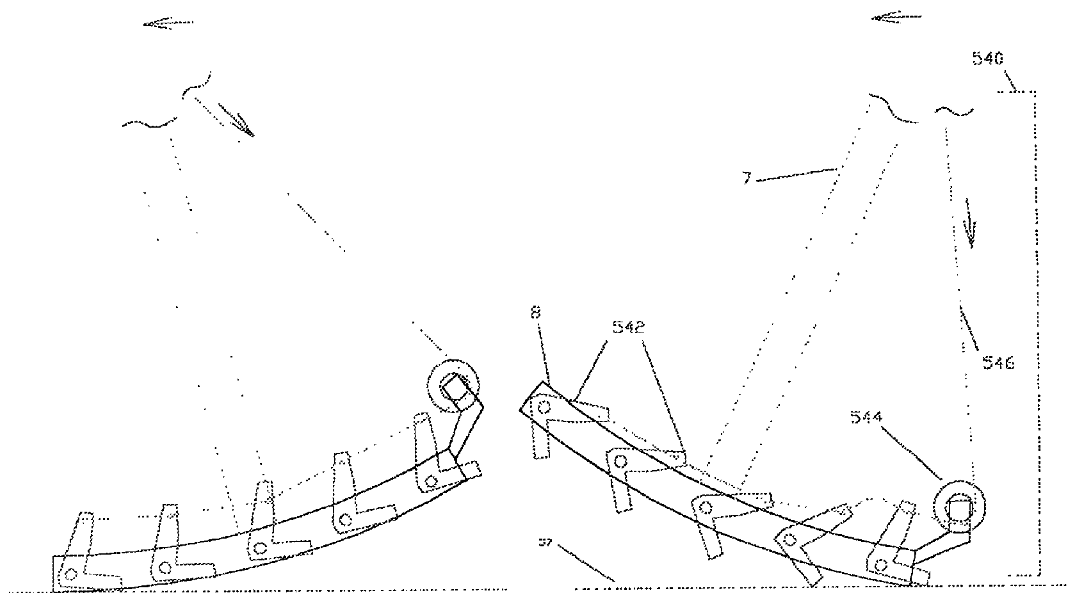

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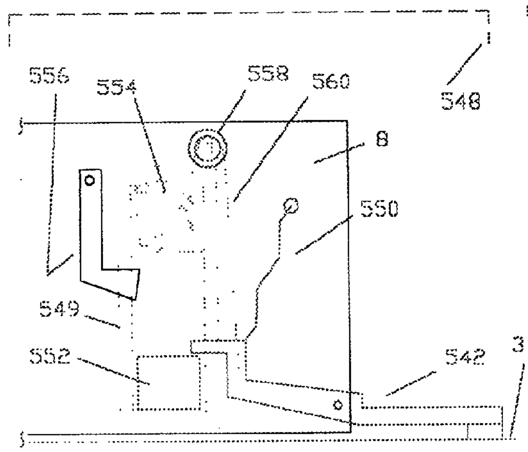

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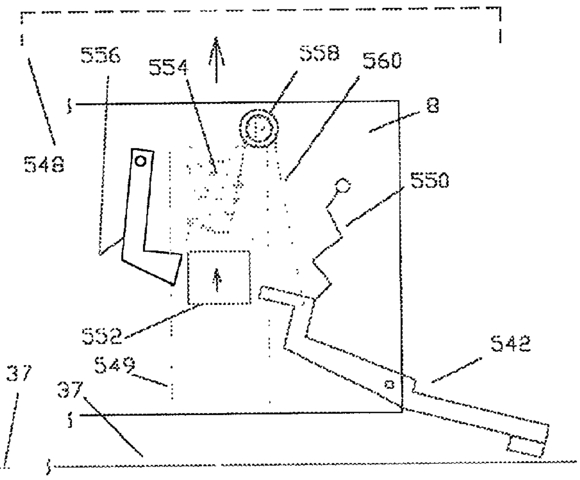

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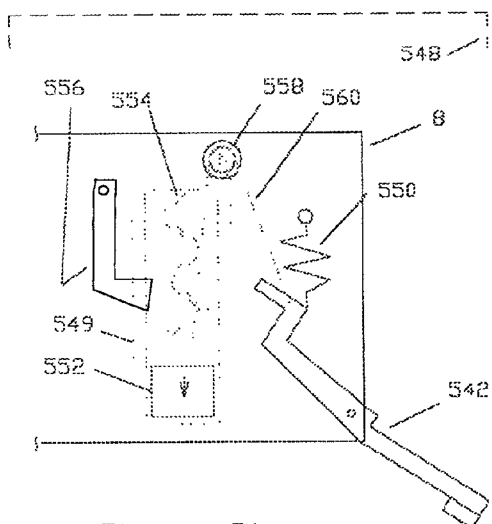

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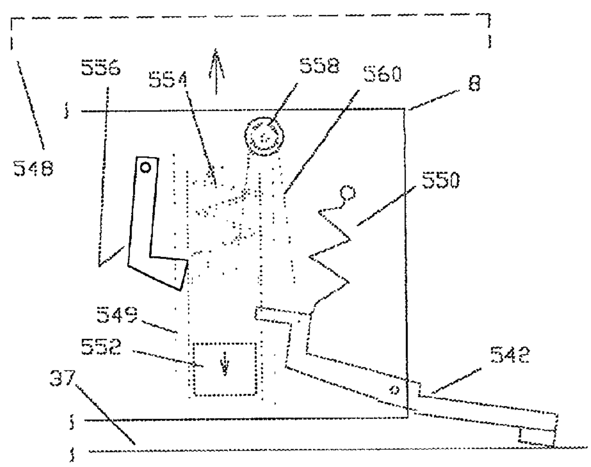

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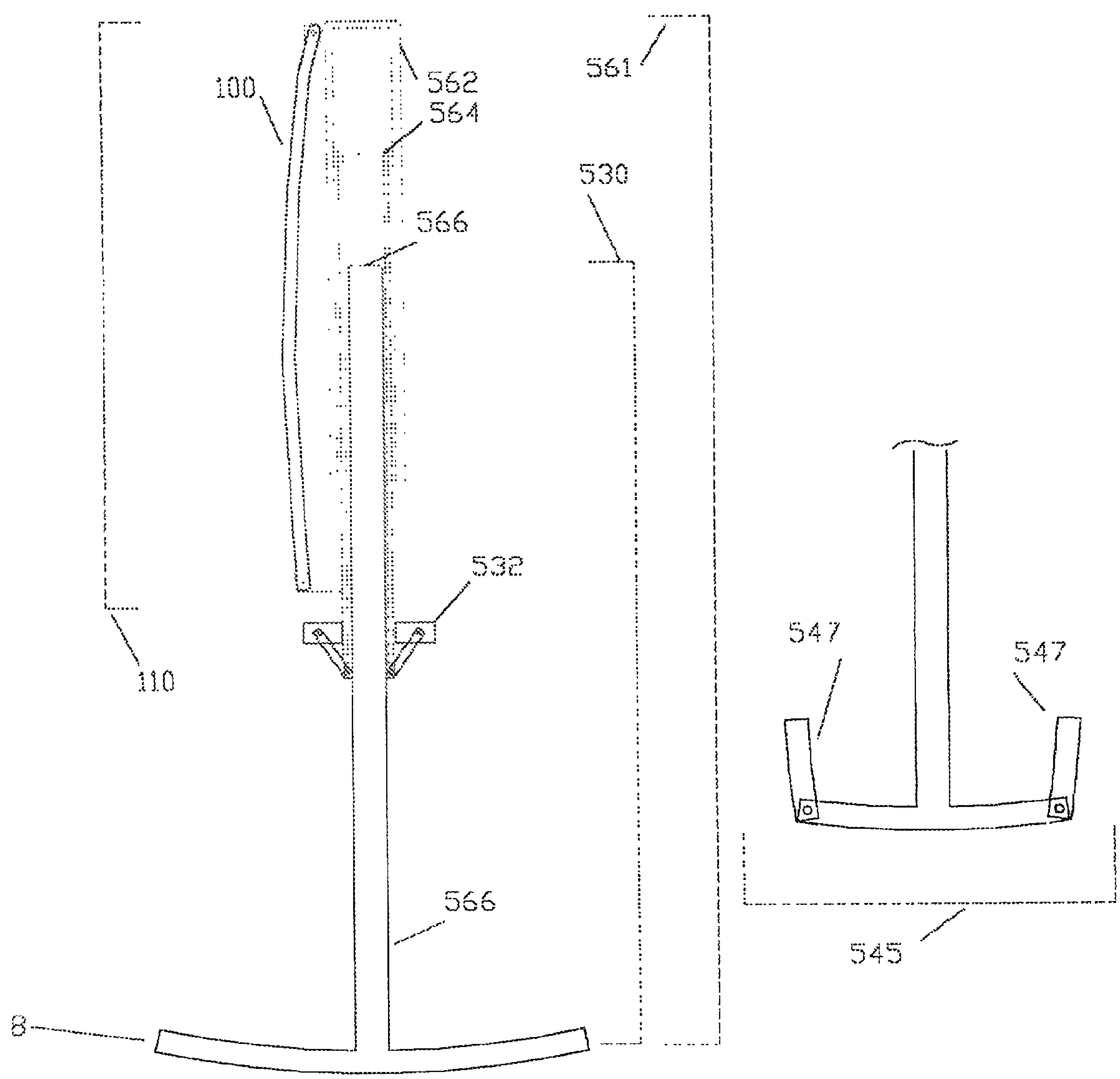

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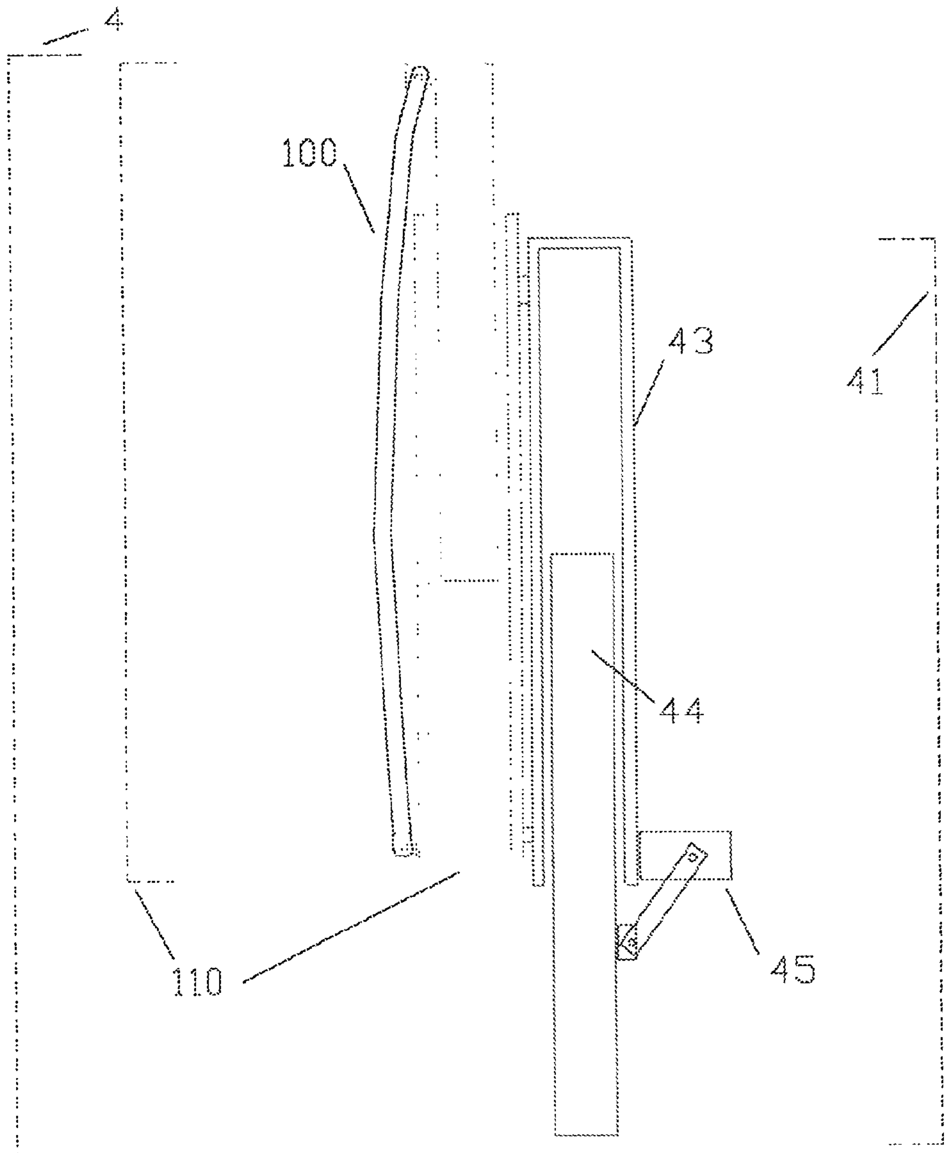

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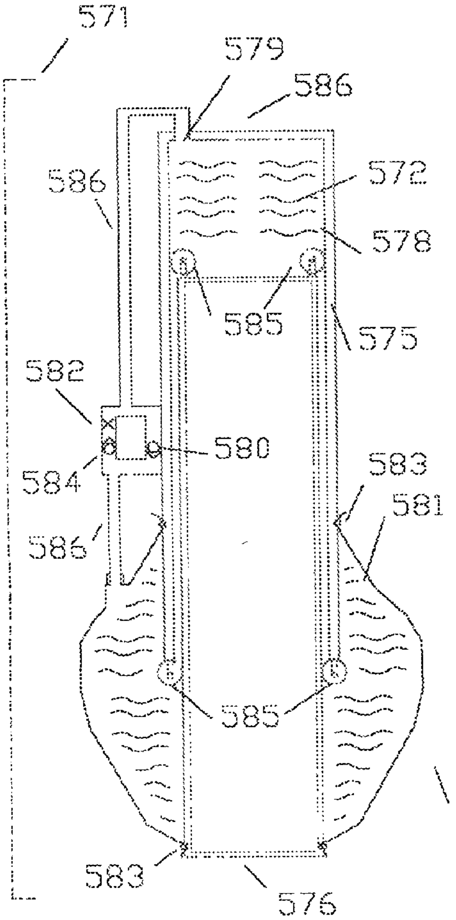

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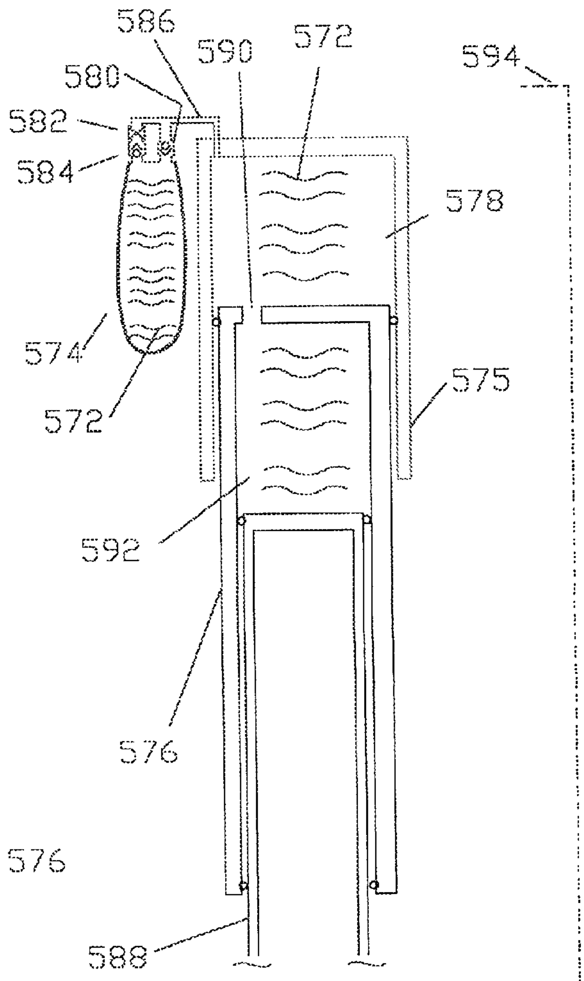

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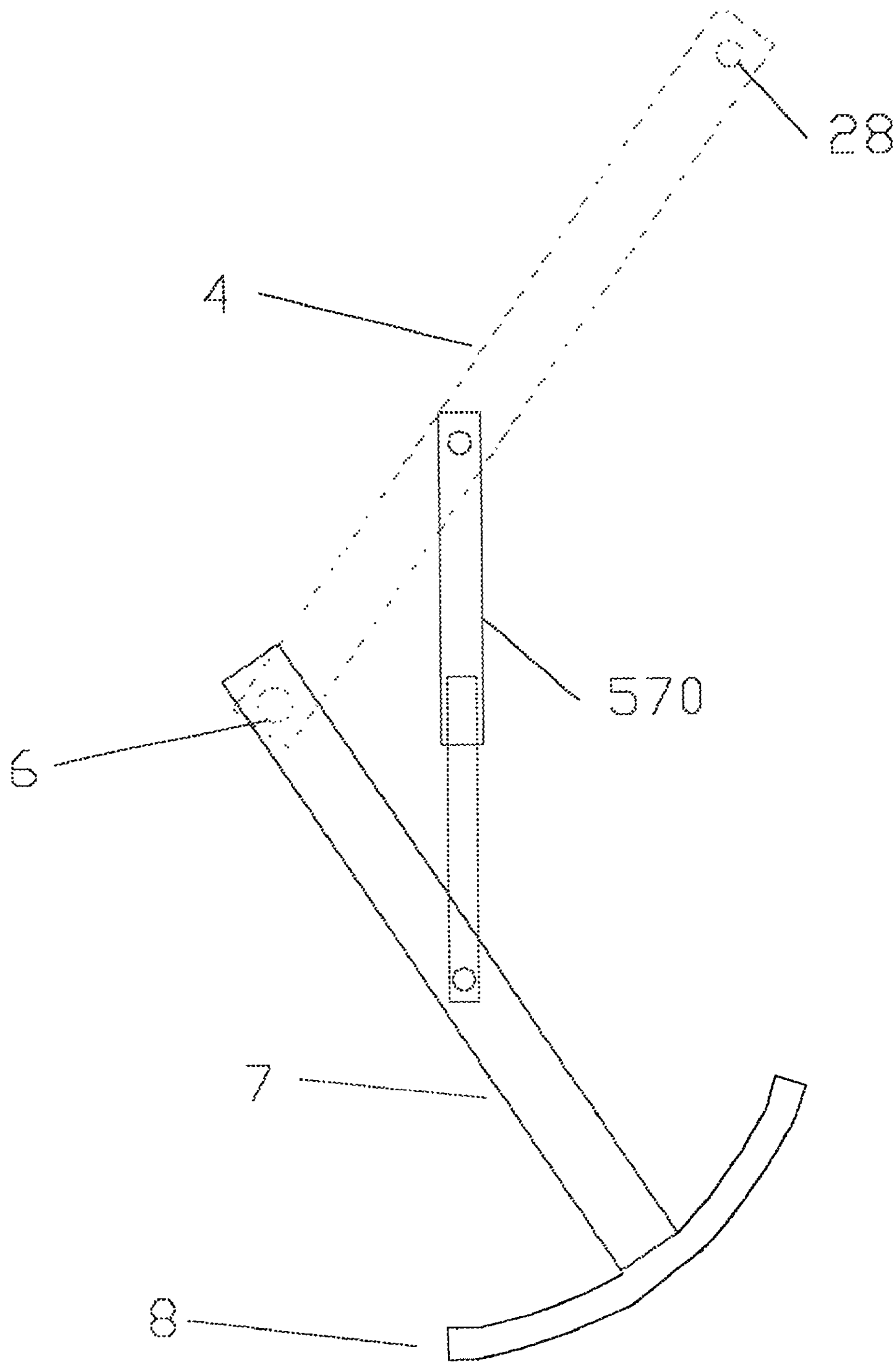

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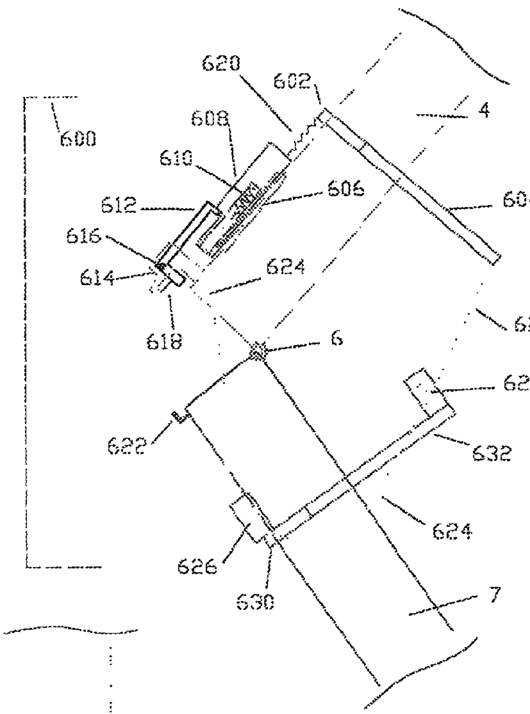

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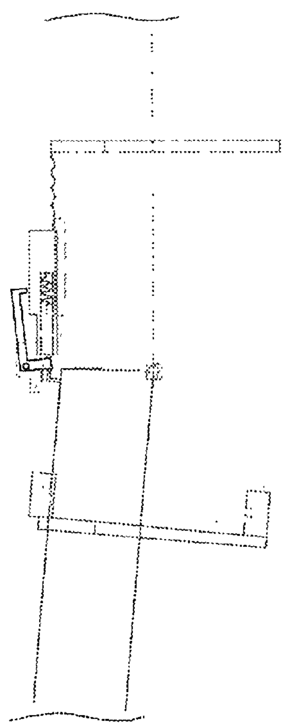

Figure 36c

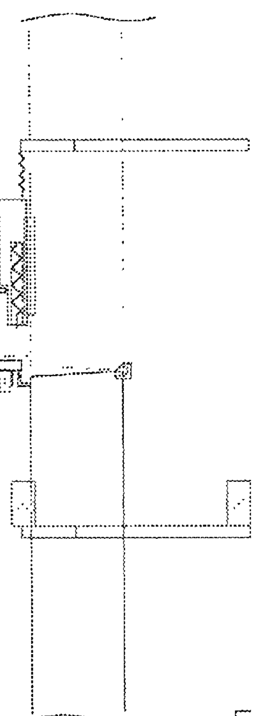

Figure 36b

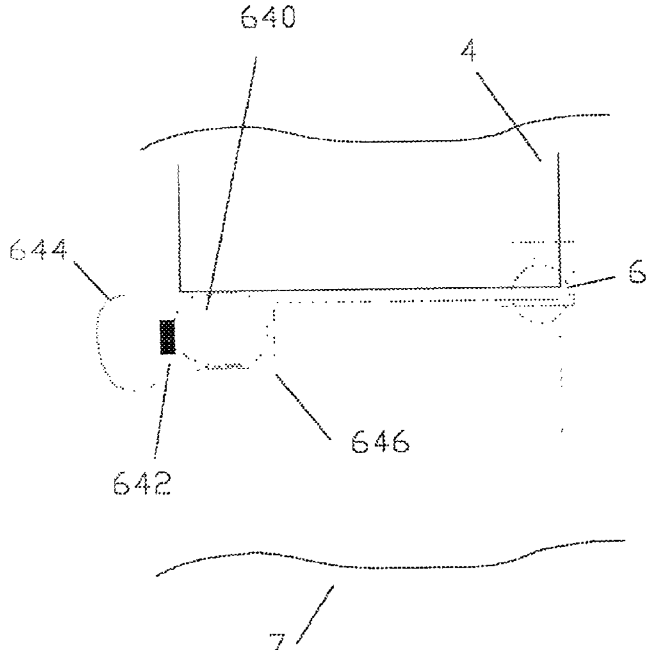

Figure 37 b

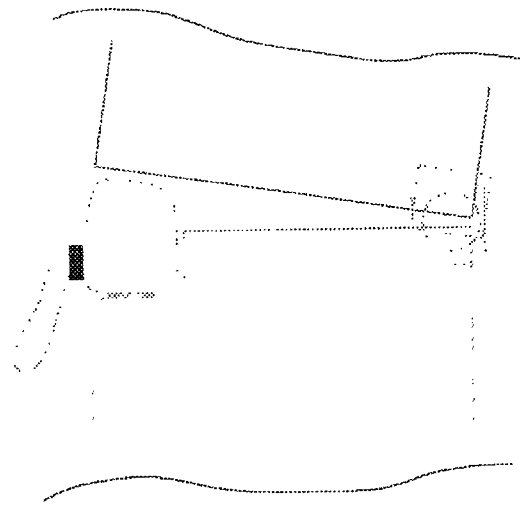

Figure 37 a

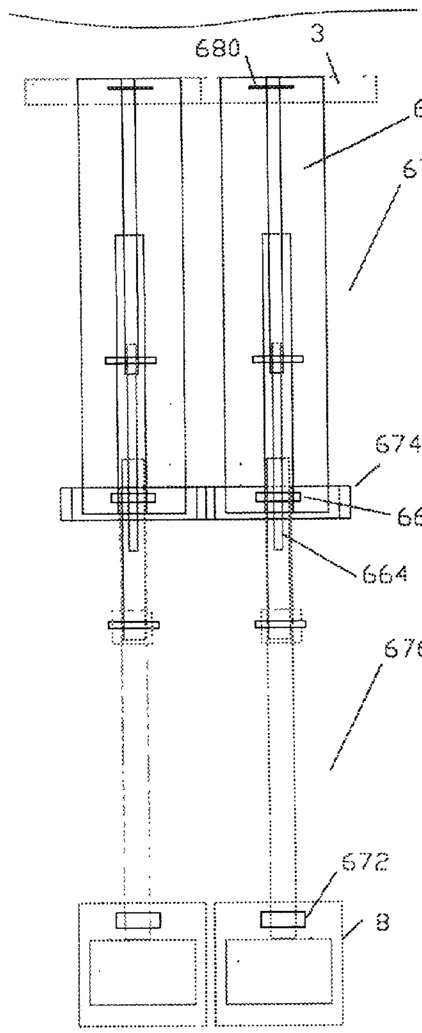

Figure 38 a

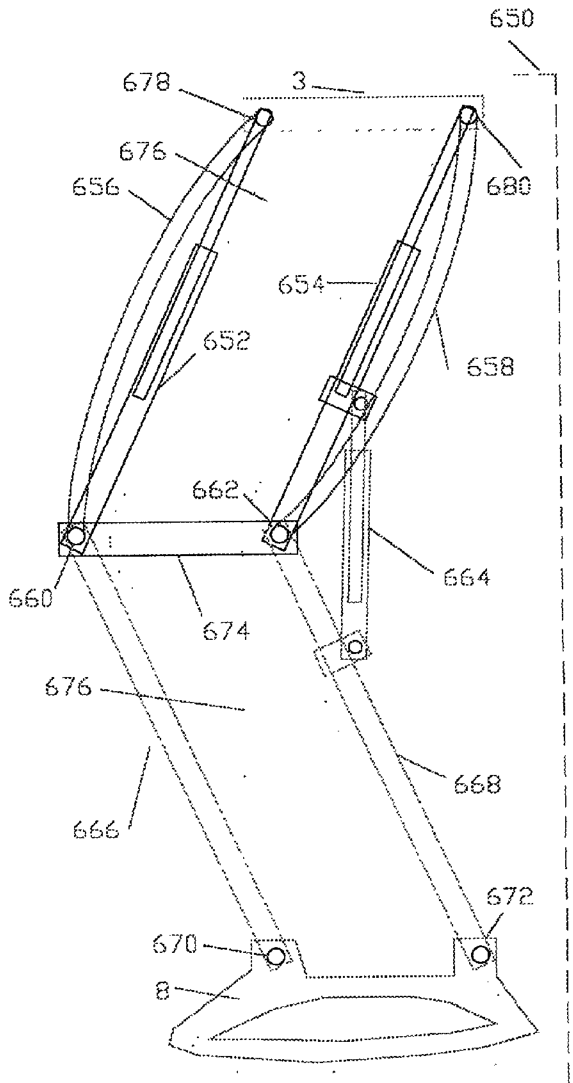

Figure 38 a

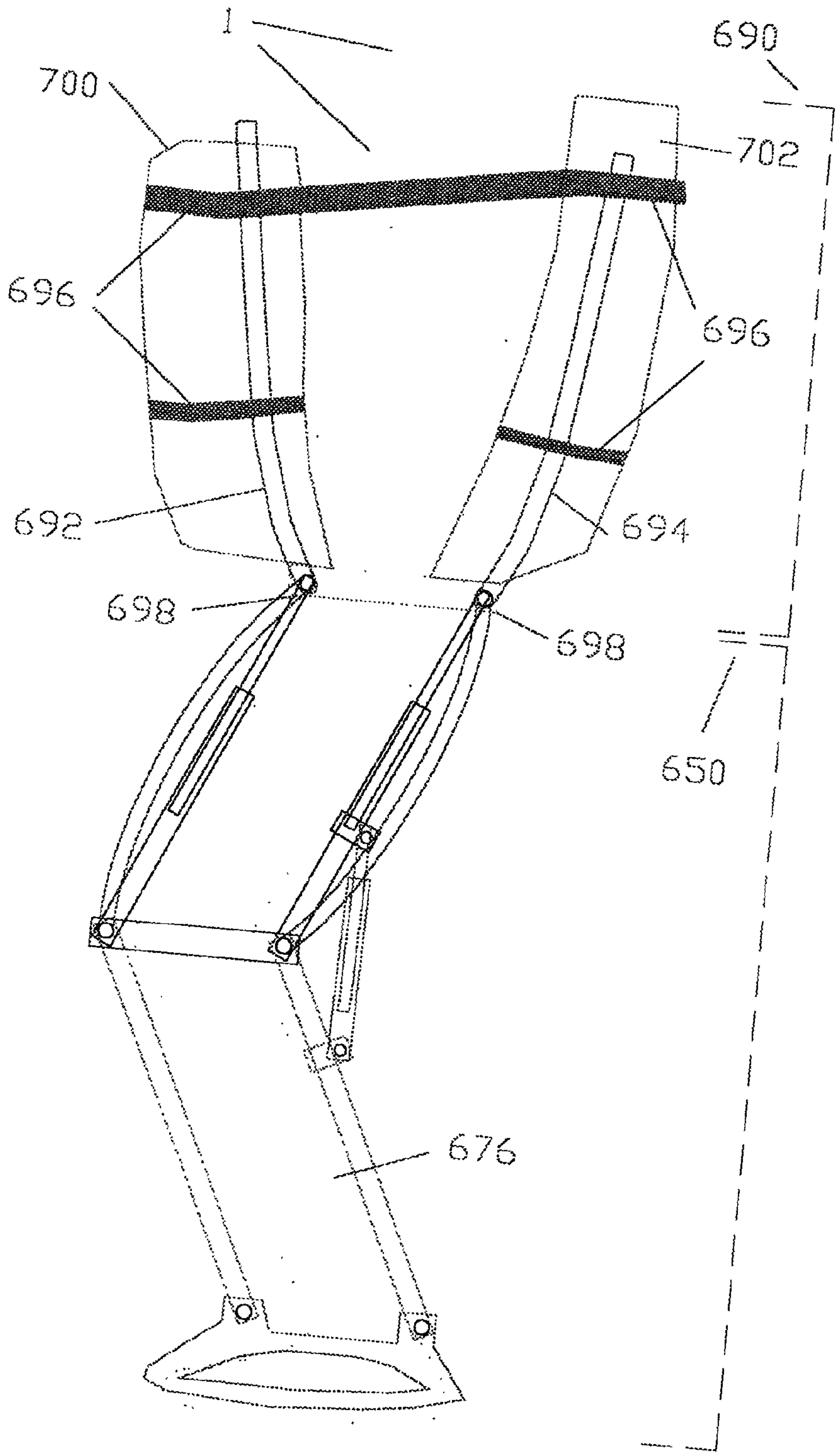

Figure 39

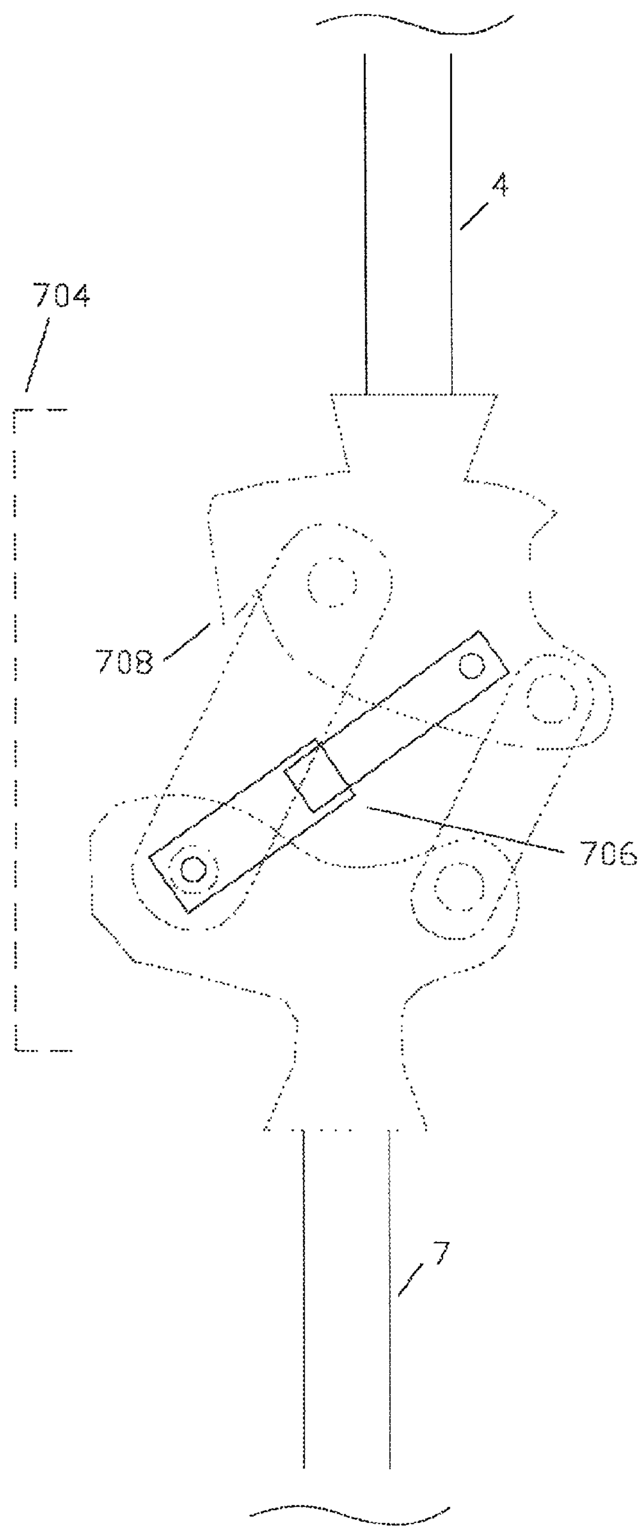

Figure 40

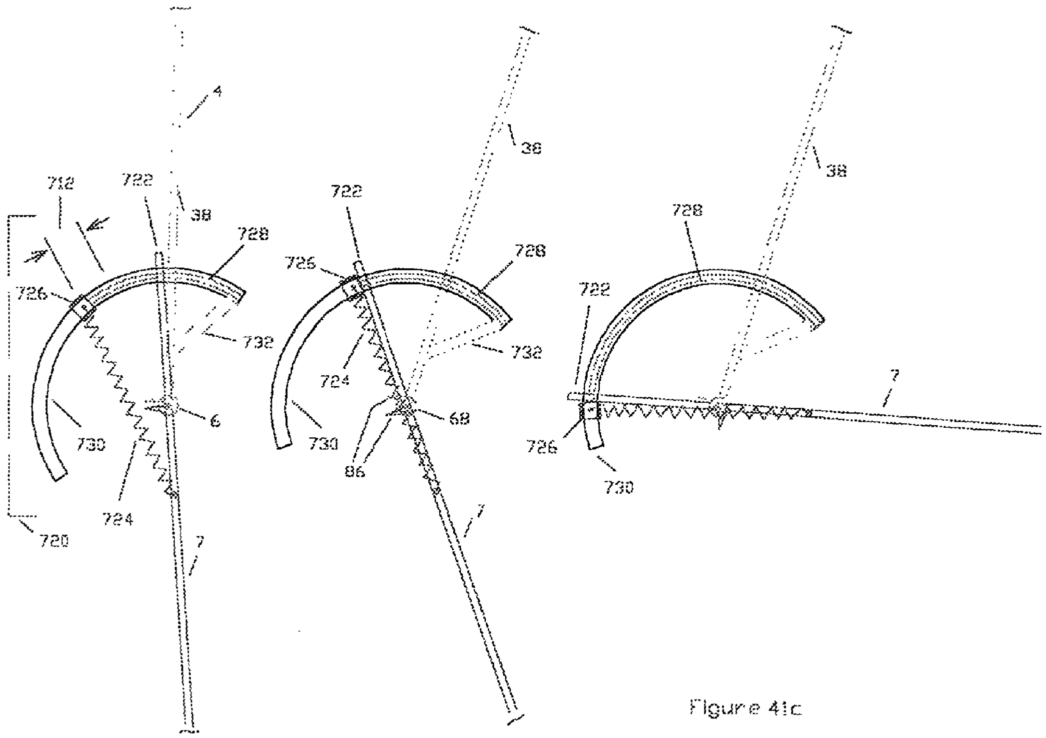

Figure 41a

Figure 41b

Figure 41c

ENERGY-EFFICIENT RUNNING AID

[0001] This application is a continuation in parts of application Ser. No. 09/621,238 filed on Jul. 26, 2000 by Brian Rennex.

BACKGROUND OF THE INVENTION

[0002] This invention, referred to as a running aid, relates to running braces and in particular to energy-efficient running braces. A running brace augments the effective spring constant of the leg by adding a resilient brace which supports the runner's weight in parallel with the leg. The invention combines the balance and control capabilities of the human foot/leg system with the strength and resilience features of a mechanical brace system.

[0003] Around 1890, four running brace patents were issued to Nicholas Yagn, a mechanical engineer in the army of the Emperor of Russia. The first two, U.S. Pat. Nos. 420,178 and 420,179, use bow springs, attached to the shoulder and the pelvis, respectively. The second of these incorporates a foot-lift means whereby the top of the bow spring can slide up a plate extending upwards from the runner's waist, during swing phase. However, there is no workable means to trigger this sliding. U.S. Pat. No. 438,830 was based on an unworkable design to fill a flexible tube with compressed gas to achieve a resilient brace. The fourth, U.S. Pat. No. 406,328 comprised telescopic springs and an unworkable telescopic release for leg lift in swing phase.

[0004] More recently, Chareire, U.S. Pat. No. 4,872,665, provides for a running brace comprising telescoping gas springs and a leg-lift means further comprising a ratchet joint. In principle, this invention should, in principle, work but it is exceedingly complex and it would be difficult and expensive to manufacture. In addition, it is doubtful that the trigger system for braking and releasing the rachet joint is versatile. Another drawback of the design is that compressive telescopic means necessarily entail friction losses, and this is especially the case with gas springs. Also, the travel of this running brace is limited by the requirements of telescopic overlap.

[0005] Dick, U.S. Pat. No. 5,016,869, discloses another complicated and heavy (50 lbs.) bipedal device which is intended to ensure a long travel and leg lift in swing phase, and it appears that the runner's weight is not supported in parallel with the runner's legs in which case the device is equivalent to a series-support running shoe and not a running brace. A number of links, cables and springs are incorporated in the involved design as to make the device rather cumbersome. Rennex disclosed an invention in U.S. Pat. No. 5,011,136 to provide for asymmetric leg-length travel in impact and thrust and to provide for high leg lift. It features a pair of telescopic springs and a trigger and ratchet system to achieve this asymmetry. The disadvantages of this design are its complexity and friction losses in the compressive telescopic design. Other provisions attempted to address the problem of optimized force curves to achieve high performance and high impact energies without Injury.

[0006] This inventor was not able to find prior art for harnesses specifically designed for coupling a running brace to the human body. One related example is disclosed by Petrofsky in U.S. Pat. No. 5,054,476, which uses support elements coming up the sides of a walker with cuffs attached at the thigh, waist , and armpit levels to give the walker support. This design does not provide for comfortable support for the brace loads of several gees needed for a running brace. A second example is disclosed by Spademan in U.S. Pat. No. 5,002,045, in which cuffs or straps attached to the limbs (or the waist) on either side of a joint are tightened as the limbs bend around that joint. The current patent is distinguished from both of these examples of prior art by virtue of the fact that the brace load is distributed in an adjustable manner over a substantial area of the human body for optimal comfort, and the automatic harness tightening is powered by the impact load on the brace, and not the relative motions of adjacent human limbs or elements. These features are adapted for the demanding requirements of running-brace support where load forces are large—several gees—and the human body is erect. Virtually all harnesses for high loads require the user to be sitting, and, hence, they are not useful for a running brace.

[0007] Regarding the prosthetic applications of the novel, tibia-located self-guiding springs of this invention, Phillips discloses in U.S. Pat. No. 5,458,656 a leaf spring guided by telescoping tubes and hingeably-attached to the top knee pylon. The drawback of this invention is that the telescoping guide is costly and the deflection of the single spring is limited. Kania discloses in U.S. Pat. No. 5,653,768 a pair of leaf springs fixedly attached to the top knee pylon and passing one through the other. The limitation of this design is that the spring deflection is limited because the leaf springs are not hingeably connected. Likewise Rappoport discloses in U.S. Pat. No. 5,509,936 a pair of leaf springs fixedly attached to the top knee pylon—with limited deflection. The advantage of the tibia spring in the current invention is that the vertical bow springs are hingeably attached, allowing optimization of the spring system in terms of ample deflection, constant force-curve, and low weight. Also, cost is reduced by eliminating the guide system.

SUMMARY OF THE INVENTION

[0008] This "running aid" invention relates to passive (spring-actuated) running aids for ortheses, prostheses, and robots. The full invention is an leg ortheses or an energy-efficient running brace. It is a running brace which acts in parallel with a runner's leg to support the runner during stance phase and to capture all foot-impact energy, preferably with the optimal constant-force curve, for use to thrust said runner back into the air during toe-off. Moreover, several structural components of the full invention also have applications for prostheses, robots, and robotic exoskeletons to enhance human performance. These structural elements include a novel variable-angle knee-lock, a novel self-guiding/constant force bow spring, a novel pulley-based/constant-force bow spring, a novel brace/ankle system, a novel front/back brace leg which couples to the runner's pelvis in the front and back of his pelvis, novel means to ensure hyper-extension for "constrained hyper-extension" knee locks (referred to as self-locking), a novel and very cheap means to prevent "bounce-back" with self knee locks, and a novel load-tightening full harness. In addition to allowing faster running with less energy, the running brace protects the legs, joints and feet from impact injury since it eliminates impact forces above a safe level. The running brace is coupled to the runner via a body harness. This coupling must be located above the leg to allow it to rest as much as possible during the stance phase.

[0009] This running aid provides an essential improvement over prior art in the following ways. The force curve of the leg spring is optimal for quick support and maximum energy storage. Tile problem of a lock—to switch the running brace from a stiff spring mode during stance to free bending mode during swing phase—is circumvented with self-locking designs, and it is solved with either a novel variable-angle knee lock or a slider lock. The problem of leg-length asymmetry is overcome with a shaped brace foot, and the comfort problem is addressed with a novel load-tightening pelvic/body harness which distributes the impact load over a substantial portion of the body above the knees.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] **FIG. 1** is a schematic side view of the running aid generic to the various embodiments of the invention.

[0011] **FIG. 2** shows side views of series bow springs for use in the first embodiment of the invention.

[0012] **FIG. 3** shows side and top views of perpendicular-bow self-guiding springs for use in the first embodiment of the invention.

[0013] **FIG. 4** shows a side view of a tibia perpendicular-spring/brace-foot assembly for use in the first embodiment of the invention.

[0014] **FIG. 5** shows side views of a tibia perpendicular-spring/hinged-brace-foot assembly.

[0015] **FIG. 6** is a side view of the decoupled-bow version of the running aid according to the second embodiment of the invention.

[0016] **FIG. 7** is a front view of the decoupled-bow version of the running aid according to the second embodiment of the invention.

[0017] **FIG. 8** is a side view of the running aid according to the third embodiment of the invention showing a gas spring with a reservoir.

[0018] **FIG. 9** is a side view of the support part of a self-locking knee mechanism of the running aid according to the fourth embodiment of the invention.

[0019] **FIG. 10** is a side view of the **4**-bar foot-lift assembly for maintaining clearance of the brace foot above the ground during swing phase according to the fourth embodiment of the invention.

[0020] **FIG. 11** is a front cross-sectional view of the running aid according to the fifth embodiment of the invention showing the variable-angle knee lock.

[0021] **FIG. 12** is a side cross-sectional view of the running aid according to the fifth embodiment of the invention showing the shaft/collar assembly of the variable-angle knee lock.

[0022] **FIG. 13** is a side cross-sectional view of the running aid according to the fifth embodiment of the invention showing the shaft and the collar of the variable-angle knee lock.

[0023] **FIG. 14** is a side cross-sectional view of the running aid according to the fifth embodiment of the invention showing rotation of the shaft with respect to the collar of the variable-angle knee lock.

[0024] **FIG. 15** is a side view of the running aid according to the fifth embodiment of the invention showing a damper for use with the variable-angle knee lock.

[0025] **FIG. 16** is a side view of the running aid according to the fifth embodiment of the invention showing a tibia lock-release for use with the variable-angle knee lock.

[0026] **FIG. 17** is a back view of the cable system allowing the use of a single bow spring in the sixth embodiment of the running aid.

[0027] **FIG. 18** shows schematic views of the full harness for the running aid.

[0028] **FIG. 19** is a side view of a generic mechanical design for a mechanical load-tightener used in the harness for the running aid.

[0029] **FIG. 20** shows examples of compressible woven harnesses for load-tightening sleeves of the harness for the running aid.

[0030] **FIG. 21** is a side view of an overlap double-pulley load tightener which is an example of a mechanical load-tightening cuff used in the harness for the running aid.

[0031] **FIG. 22** is a side view of a bent-lever load tightener, a jamming load tightener and an inward-force load tightener of the harness for the running aid.

[0032] **FIG. 23** is a side view of a combination mechanical/weave load-tightener of the harness for the running aid.

[0033] **FIG. 24** is a side view of an arm load-bearing harness for the running aid.

[0034] **FIG. 25** shows a schematic front view of a load-equalizer stay tree which distributes the brace load over various parts of the harness for the running aid.

[0035] **FIG. 26** shows an adjustable harness for the running aid.

[0036] **FIG. 27** shows a side view of a generic brace leg with a circular brace foot, demonstrating graphically how well the brace foot prevents vertical travel of the runner's center of mass throughout stance.

[0037] **FIG. 28** shows a hyperlocker mechanism to guarantee hyper-extension of the self-locking knee mechanism of the fourth embodiment of the invention of **FIG. 9**.

[0038] **FIG. 29** shows a slider for changing the length of a running aid according to the seventh embodiment of the invention.

[0039] **FIG. 30** shows a full-stance brace-foot trigger for locking a slider during stance.

[0040] **FIG. 31** shows a foot-coupling guaranteed release mechanism for release of the slider lock at toe-off.

[0041] **FIG. 32** shows a simple-slider running brace according to the eighth embodiment of the invention, wherein the knee pivot is no longer used.

[0042] **FIG. 33** shows a means to combine an active power source with a passive spring according to the ninth embodiment of the invention.

[0043] **FIG. 34** shows two lockable hydraulic sliders with two and three telescopic members.

[0044] **FIG. 35** shows a knee pivot locked by a lockable hydraulic slider according to the eleventh embodiment of the invention.

[0045] **FIG. 36** shows a self-hyper-locker for guaranteeing hyper-extension at foot strike.

[0046] **FIG. 37** shows a "hyper-extension bounce back" prevention means for prevention of folding of a hyper-extending knee lock at heel strike.

[0047] **FIG. 38** shows a front/back brace leg in which the pelvic coupling is made directly behind and in front of the runner's ischial tuberosity (buttock) rather on the side of the hip.

[0048] **FIG. 39** shows a front/back pack extension for comfortable and optimal pack load support.

[0049] **FIG. 40** shows a four-bar knee joint.

[0050] **FIG. 41** is a schematic side view of the bow shoe showing a low-eccentricity knee-joint straightener.

DESCRIPTION

[0051] **FIG. 1** is a schematic side view of running aid **2** with runner **1** shown in dashed lines to indicate the approximate location and extent of the various elements of the invention with respect to the runner who wears the invention. Running aid **2** comprises harness **3** and two brace legs **9**, one on the outside of each leg of runner **1**. Each brace leg **9** supports runner **1** when her adjacent foot is in contact with the ground during running, i.e. during the stance phase, as distinguished from the swing phase when that leg is not in contact with the ground. Harness **3** is attached to the runner's pelvis, and each brace-foot assembly **8** is attached to the adjacent runner's foot. Since running aid **2** supports the weight of runner **1** in parallel with her leg, she can rest her leg during the stance phase of the running stride cycle. Since running aid **2** can act as a spring to absorb the impact energy of running and to thrust runner **1** back into the air during leg thrust, runner **1** can both exert less energy while running and avoid in juries related to the impact of running. Later, each design component will be discussed in detail, but, first, here is a quick overview.

[0052] In order to be able to swing a brace leg forward and/or run uphill, a swing-phase length-change means is required. One option is knee pivot **6** of **FIG. 1**; another option is simple-slider running aid **561** of **FIG. 32**. In **FIG. 1**, thigh-link **4** is rotatably attached to harness **3** on the top and to knee pivot **6** on the bottom. Spring mechanism **5** is incorporated into thigh-link **4** in the second embodiment of the invention shown in **FIG. 6**, but is may be located elsewhere, e.g., on the back of runner **1** in the sixth embodiment of **FIG. 17** or in the tibia link **7** as an option of the second embodiment of **FIG. 6**. Or, there can be no spring at all in this running aid invention, in which case the running aid simply provides support and in which case the design features in the discussion of **FIG. 5** are crucial to provide the brace leg/foot length asymmetry to match the brace support to the runner's leg action. This "no-spring" variation will be referred to as the tenth embodiment of the invention. As will be seen in the more detailed description of the second embodiment in **FIG. 6**, thigh-link **4** includes a guide means which constrains an element rotatably connected to harness **3** to slide with respect to an element connected to knee pivot, under the action of bucky-bow spring mechanism **10**—to deliver an impulse to runner **1**. Knee pivot **6** connects thigh-link assembly **4** and tibia link **7**, and it incorporates the brace-link self-locking mechanism to be detailed later. The bottom of tibia link **7** is attached to brace foot **8** which contacts the ground. Each of these components has one or more specific functions essential to easy, efficient running. These functions will next be previewed in a general sense to prepare the reader for the more detailed discussion of the drawings.

[0053] Harness **3** must couple running aid **2** to runner **1** above his leg to ensure that running aid **2** acts in parallel with his leg. Since the g-force of running can be **2**-**3** g's, there is significantly more weight on harness **3** than would be the case with bicycle riding, for example. Since conventional harnesses actually require the user to sit, in which case most of the weight is borne by the backs of the thighs and the back of the waist loop, these conventional harnesses cannot be used for the running aid harness, as one cannot run and sit at the same time. Also, conventional, "above the knee" orthotics, which comprise a rigid, tapered thigh socket and a lip to receive the weight of the ischial tuberosity at the base of the buttocks, receive perhaps 40% of the load in the thigh tapered region. Since the thighs of able-legged runners change shape due to muscular and tendon activity, these conventional, thigh-socket orthotics cannot comfortably be used for running aid **2**. Therefore, the design discussion for harness **3** presents a means to spread the brace load over a substantial portion of the body. The area of harness support indicated in **FIG. 1** extends from the lower thigh to the chest, but it may also include the arms and shoulders.

[0054] Spring mechanism **5** should give runner **1** virtually instantaneous support. The optimal force curve is achieved with a bow spring with a buckling force curve in which the force changes virtually instantaneously to the critical-load value and continues at close to that value as the bow bends further. In the second embodiment of the invention of **FIGS. 6 and 7**, this buckling force curve is achieved by pulling the bow ends straight together. Since pulleys are used in this design, it is straightforward to achieve a mechanical advantage which allows, first, reduced bow flexing—an important feature since there is a tradeoff between flexibility and strength—and, second, a de facto changing of gears. Another advantage of the pulley/cable aspect of spring mechanism **5**, which becomes bucky-bow spring mechanism **10** in **FIG. 6**, is that it can be located anywhere, e.g., on the sides of the legs, behind the legs, or behind the back. Also, a single bucky-bow spring mechanism can be used for both legs of runner **1**. Although a variety of spring systems, such a helical springs with longitudinal, "piston-like" guides, may be used in this invention, the bucky-bow has the distinct advantage of the buckling force curve.

[0055] Knee pivot **6** allows the folding of thigh-link **4** and tibia link **7**. This, in turn, allows runner **1** to high-kick his leg during swing phase, when the leg is not in ground contact. However, there must be some way to lock knee pivot **6** during the stance phase, when the leg is in ground contact. The strength requirements of this locking are very high due to the leverage about knee pivot **6**. And, since runner **1** may sometimes land on a bent knee, e.g., when running uphill, this locking must work when thigh link **4** and tibia link **7** have not yet rotated to be aligned. These lock-design requirements have been the major design hurdle for running-brace prior art. The current invention circumvents this locking problem with a self-locking knee designs of **FIGS. 9 and 36**, and it solves it with the variable-angle knee lock of FIGS. **11-14** and with the hydraulic locks of **FIGS. 32 and 35**.

[**0056**] The purpose of brace-foot **8** is to give running aid **2** the same length asymmetry as is the case for the legs of runner **1**. The term length asymmetry refers to the fact that the effective length of the leg/foot system of runner **1** (e.g., the distance between the hip pivot and the effective point of contact of her foot with the ground) is several inches shorter for landing (heel-down) than for taking off (toe-off). This length asymmetry results from the presence of the human foot and ankle, and it serves to reduce the leg/foot angle of heel-down relative to that of toe-off, thereby improving running energy efficiency. If a running aid does not feature this same length asymmetry, the timing of brace thrust will be too early for optimal, efficient brace thrust. The just-mentioned self-locking requires that brace-foot **8** be rotatably attached to the runner's foot behind her heel. The drawback then is that brace-foot **8** may rotate so that its front portion will drop below the level of the runner's toe, leading to a tripping hazard. To avoid tripping, the brace foot must have the design of **FIG. 10** to lift the front of brace foot **8** during swing phase.

[**0057**] This completes the overview. Now the detailed components of the invention will be described. **FIG. 2***a* is a side view showing guided bow spring **426**. This first embodiment utilizes "series" bow springs which are almost straight when unloaded and which are loaded by pushing the ends of the bow springs toward each other—to achieve a buckling or constant spring force curve (versus deflection). Guided bow spring **426** and spring guide **435** comprise upper guide **438** which is slidingly corrected to lower guide **436**. Upper guide **438** is rigidly connected to top bowholder **428**, and lower guide **436** is rigidly connected to bottom bowholder **430**. One or more mini-bows **434** are hingeably connected between bottom bowholder **430** and top bowholder **428**. Accordingly, guided bow spring **426** is located in series with thigh link **4** and/or tibia link **7** (see **FIG. 1**), and the runner's impact force forces upper guide **438** to slide down into lower guide **436** and compress mini-bows **434**. In like manner, the design of **FIG. 2***b* is the same as that of **FIG. 2***a* except that there are two spring guides **435** located on either side of mini-bows **434**.

[**0058**] **FIG. 3** shows top and side views of perpendicular-bow self-guiding bows **444**. **FIG. 3***a* shows a top view and **FIG. 3***b* a side view of T-shaped perpendicular-bow system **440** in which one or more mini-bows **434** are oriented perpendicular to one or more other mini-bows **434**. The rationale is to take advantage of the resistance to bending in the plane of the wide dimension of a bow. In this case and in general, mini-bows **434** are substantially wider than they are thick. Since mini-bows **434** are hingeably attached to end-plates **448** via hinges **14**, if only one mini-bow **434** stack (all parallel to each other) is used, then end-plates **448** can rotate freely with one degree of freedom. As soon as another single one or stack of mini-bows **434** is connected between end-plates **448** with an orthogonal or a substantially orthogonal orientation, each orthogonal mini-bow **434** resists rotation of the orthogonal mini-bows **434** in the orthogonal degree of rotational freedom. The result is that T-shaped perpendicular-bow system **440** resists tilting of one end-plate **448** with respect to the other on the opposite end, and this gives a substantially self-guiding spring system. As mini-bows **434** bow over considerably, this self-guiding, or ability to resist non-axial loads is compromised, but in some applications it eliminates the need for a guide system longitudinal to the perpendicular-bow self-guiding bow **444**. **FIG. 3***c* shows square-shaped perpendicular-bow system **445** in which one or more stacks of mini-bows **434** are oriented to form a rectangular configuration, and **FIG. 3***d* shows triangle-shaped perpendicular-bow system **446** in which one or more stacks of mini-bows **434** are oriented to form a triangular configuration—the combination of which yields a substantially orthogonal configuration. These are just a few of the many configurations possible for perpendicular-bow self-guiding bow **444**.

[**0059**] The advantages of perpendicular-bow self-guiding bow **444** include the following. First and most importantly, a significant travel, i.e., 2-6 inches, of spring compression can be achieved with a bow the length of the thigh and/or tibia of the runner—due to the possibility of using very thin mini-bows **434**. Second, it is easy to manufacture, and the total spring stiffness can easily be varied to "tune the brace for a particular runner. Third, this ease in "changing gears" allows one to use a gear-changing mechanism to engage a variable number of mini-bows to "tune" a running aid for an individual or to "change gears" while running by utilizing a mechanism to engage a variable number of min-bows **434**.

[**0060**] **FIG. 4** shows a side view of a tibia perpendicular-spring/brace-foot assembly **25** for use in the first embodiment of the invention. Tibia perpendicular-spring/brace-foot assembly **25** can also be used for below-the-knee prostheses, the only difference being that tipper-tibia pylon **13** connects to the runner's stump instead of to the upper portion of tibia link **7** of **FIG. 1**. The function is the same, namely to absorb and return impact energy of running. Upper-tibia pylon **13** is rigidly attached to tipper-tibia end-plate **12**, and brace foot **8** is rigidly attached to brace-foot end-plate **11**. Front bows **16** bow to the front, side bows **15** bow to the outside, and back bows **17** bow to the back—of the runner, and all are hingeably attached to upper-tibia end plate **12** and brace-foot end plate **12**. It is still possible to use the configuration of **FIG. 3***c* since both stacks of side bows **15**, one on either side of the rectangle, can bow to the outside. This is necessary so as to not interfere with the runner's other foot. Tibia perpendicular-spring/brace-foot assembly **25** absorbs and returns the runner's impact energy without need for a separate, longitudinal guide system because of the self-guiding capability described above. Notice that the bottom of brace foot **8** is curved. The shape of this curve is critical to optimize running performance, and this point will be explained in the discussion of the next figure. **FIG. 4***b* shows tapered bow **35** which can be used for any of the bow springs discussed herein. Its purpose is to make the rise of the bow force curve to the constant buckling value more gradual in case this is needed for comfort concerns. The amount of taper controls the force curve very precisely and easily.

[**0061**] **FIG. 5** shows side views of tibia perpendicular-spring/hinged-brace-foot assembly **27**. **FIG. 5***b* shows the landing at heel-down, and **FIG. 5***a* shows the toe-off at take-off. Tibia perpendicular-spring/hinged-brace-foot assembly **27** is now hingeably connected to brace foot **8** via brace-foot end-plate **11**, rigidly attached to brace-foot end mount **18**, and ankle pivot **23**. Brace-foot return spring **22** tilts forward brace foot **8** against brace-foot rear stop **19** in swing phase. At heel-down brace heel **24** impacts the ground. During stance, as the runner continues forward, tibia perpendicular-spring/hinged-brace-foot assembly **27** rotates forward, like an inverted pendulum, until brace-foot end mount **18** impinges brace-foot front stop **20**—at which time brace-foot **8** rocks forward over brace forefoot curved bottom **21** until toe-of. Regarding the below-knee prosthesis application, the advantage of this design is that all of the impact energy is stored in perpendicular-spring/hinged-brace-foot assembly **27** with its constant-force curve, and this energy is returned to thrust at toe-off at the time when it is best utilized. Prior art prostheses which store energy in heel flat springs and flexing bow shins either give back the energy too soon, or they give it back with a linear force curve which does not couple well with the runner's push-off action. That is, the spring force is too weak at the end of take-off. Whereas, for a constant-force spring, the spring force is still optimally high at toe-off. Also, by using hinged, multiple bows, the spring deflection can easily be as large and optimal as is needed. Finally, perpendicular-spring/hinged-brace-foot assembly **27** can support sufficient torque for this application without need for a telescoping-tube guide system.

[0062] **FIG. 5***c* shows a side view of tibia perpendicular-spring/rigid-brace-foot assembly **29** which differs from the design of **FIGS. 5***a* and **5***b* in that brace-foot end-plate **11** is now rigidly attached to brace foot **8**. The intention here is to reap the benefits of a long brace foot, but this means that the pitch torque (in the front-back-vertical plane) must be resisted by the prosthesis. The shape of rigid-foot curved bottom **33** is designed to minimize this torque. The design benefits then are that the landing and take-off angles of the runner's leg are optimized, but these benefits must be traded off with the tolerable pitch torque. For the running aid application, brace foot **8** is even more important—to match the length asymmetry of a running brace to the natural length asymmetry of the runner's leg/foot system which results from the greater length of the toe-to-hip-joint distance at toe-off than the length of the heel-to-lip-joint distance at heel-down. Again, the design goal of length asymmetry for the running aid and the specific asymmetry achieved depend on the precise shape of the bottom of brace foot **8**. The length of brace foot **8** controls the amount of length asymmetry and the precise shape controls the rate (which should be steady) of forward motion of the effective contact point rate, i.e., the point around which there is no net torque due to the foot force—between the ground and the bottom of brace foot **8**. That is at toe-off, brace forefoot curved bottom **21** acts as a rolling pivot to limit the pitch torque on running aid **2** in **FIG. 1**. The design of the shape of brace foot **8** to achieve length asymmetry and to optimize performance during the rollover from heel to toe is referred to herein as the weight transfer structure.

[0063] **FIG. 6** is a side view of running aid **2** from **FIG. 1** according to the second embodiment of the invention; **FIG. 7** is a front view of the same. Here, the bow is decouple from the support. Only one side of brace leg **9** is shown in each figure, and harness center line **136** indicates the center of harness **3** in **FIG. 7**. Running brace harness **3** shown in **FIG. 1** is not shown in **FIG. 6**, but it is attached to hip-pivot rim **26** in the actual invention. Runner **1** is shown in **FIG. 6** as a dashed line.

[0064] Hip link **112** is rotatably attached to harness **3** via hip pivot **28** mounted in hip-pivot block **116**. There are three senses of rotation for pivots, with respect to runner **1**. "Pitch" refers to rotation about the side-to-side axis, "roll"—rotation about the front-to-back axis, and "yaw"—rotation about the vertical axis. Hip pivot cannot allow roll because of self-locking knee mechanism **121**, to be discussed below. Hip pivot **28** must allow pitch so that the runner's leg can swing back and forth, and it may optionally allow roll to allow knee turn-out—for runner **1** to change direction. Hip link **112** is a support member, and it serves to house bucky-bow spring mechanism **10** and to slidingly connect with thigh link **4** which slides along bearings within or beside hip link **112**. Bucky-bow spring mechanism **10** comprises pulley block **104** to which are mounted inner pulley **106** and outer pulley **108** (rigidly attached to inner pulley **106**). It further comprises bow spring **100** and bow strings **102** which extend from either end of bow spring **100** around inner pulley **106**. Draw strings **103** then extend around outer **108** to be caught by spring catch **118** upon impact, as thigh link **4** is forced upward through hip link **112**. Bucky-bow spring mechanism **10** further comprises thigh-link constraint **120** which allows bow spring **100** to bow, but which constrains the center of bow spring **100** to move straight down hip link **112**.

[0065] The function of bucky-bow spring mechanism **10** is to allow bow spring **100** to absorb the runner's impact energy as thigh link **4** slides up through hip link **112**, catching drawstring **103**. Drawstring **103** then turns outer pulley **108** which turns inner pulley **106**, pulling tie ends of bow spring **100** together. The mechanical advantage achieved with this double pulley system allows a greater travel of draw string **103**, and, hence, of bucky-bow spring mechanism **10**, for a given flexing of bow spring **100**. This allows a more lightweight bow for a given strength. For example, a bow spring 30 inches long and between one and two lbs in weight can give a constant force of 400 lbs with a draw-string **103** travel of six inches (same as the human center-of-mass travel). The use of pulleys also permits the possibility of changing tile stiffness of spring assembly **5**, which is analogous to changing gears on a bicycle. This change can be done simply with a conventional gear mechanism—to change the load-carrying pulley strings from one pulley to another. Finally, bow spring **100** can be inverted and attached to thigh link **4**, so that hip link **112** pulls down on draw string **103**, but it is preferable to have the weight of the lower brace support on hip link **112**.

[0066] In order for spring assembly **5** to carry out this function of bow-loading, self-locking knee mechanism **121** must be locked. That is, tibia link **7** must be loaded so that it exerts clockwise torque about knee pivot **6**, causing thigh-link constraint **120** to impinge against tibia-link constraint **122**—in which case self-locking knee mechanism **121** is self-locked. Looking now at brace foot **8**, tibia link **7** transmits the impact load to the ground via its rotatable (pitch) connection with knee pivot **6** on the top and its rigid attachment to brace foot **8**. Heel pivot **130** connects brace foot **8** to the runner's foot behind her heel guaranteeing the release of self-locking knee mechanism **121**, to be discussed with **FIG. 9**.

[0067] **FIG. 8***a* is a side view of gas spring **30** with gas reservoir **34** which is the third embodiment of the invention. This combination can be used to achieve a substantially constant spring force curve. This substantially constant force curve is achieved by pre-pressurizing the gas to get a high initial pressure or spring force and a low force-curve slope as gas spring **46** deflects. A working definition of a constant force curve is that the average force over the range of deflection is greater than 70% of the maximum value during that deflection. For example, if a force curve is linear, the average force is 50% of the maximum. Increasing the pre-pressure (unloaded) value and the reservoir volume results in an increase of this average force value with respect to the maximum force value, but there must be a trade-off with weight. Tile running impact force compresses gas spring **30** as chamber cylinder **40** slides down around piston **38**. Gas line **32** transmits the pressure to gas reservoir **34** located above lip pivot rim **26**. A single gas reservoir **34** can be used for both gas springs on both legs. The preferred gas in gas springs **30** is air, but it may be another gas.

[**0068**] **FIG. 8***b* is a schematic side view of gas pump **36** for replenishing lost gas in pressurized gas spring **30**. Gas pump **36** is mounted next to gas spring **30** so that, when gas spring **30** is compressed, the gas pressure in pressure chamber **56** increases as pump piston **46** and gas seal **48** are pushed down by piston shaft **50**. When the pressure in pressure chamber **56** exceeds the pressure in gas spring **30** to which it is connected via feeder tube **60**, gas leaks through check valve **52** into gas spring **30**. If the pressure there gets too high, pressure release valve **54** releases the pressure. On the return stroke, inlet hole **58** allows gas into pressure chamber **56** for the next pressure stroke.

[**0069**] **FIG. 9** is a side view of the support part of self-locking knee mechanism **121** of the running aid according to the fourth embodiment of the invention. It simplifies the picture of how this self-locking is achieved by showing only the components needed for this demonstration. The purpose of self-locking knee mechanism **121** is to ensure that the support elements, thigh-link assembly **4** and tibia link **7** are locked straight during stance phase and free to bend about knee pivot **6** during swing phase. As the runner's leg extends before foot strike, these support elements approach the straight orientation shown **FIG. 9***a*, from the folded orientation shown in **FIG. 9***b*.

[**0070**] Self-locking knee mechanism **121** is shown in **FIG. 9***c*, and its purpose is to ensure that thigh-link constraint **120** and tibia-link constraint **122** close completely before foot strike for the self-locking to occur. This closing can also be referred to as the hyper-extension force. Posts **146** are rigidly attached to tibia link **7** and thigh link **4**; center post **150** is rigidly attached to knee-pivot block **152**. Knee spring **148** is attached to posts **146** and passes over center post **150**, it acts to close thigh-link constraint **120** and tibia-link constraint **122** completely, and it is strong enough to ensure this closing, but weak enough to allow the runner's lifting leg to fold knee pivot **6** at toe-off. Note that by shortening posts **146** and/or center post **150** it is possible to reduce the hyper-extension force to any desired value after the knee pivot has folded beyond a particular angle, thereby reducing the force that the runner must exert in high kick.

[**0071**] At heel-down, the heel portion of aid foot **8** strikes the ground at the location of heel arrow **143**, and heel centerline **142** indicates the line of force between hip pivot **28** and the ground. Since heel centerline **142** passes to the left of knee pivot **6**, this impact force pushes thigh-link constraint **120** and tibia-link constraint **122** together, and self-locking knee mechanism **121** remains locked. As aid foot **8** rolls over forward until toe-off from the location of toe arrow **145**, the force curve indicated by toe centerline **144** still passes to the left of knee pivot **6**, and knee pivot **6** remains locked. immediately at toe-off, the runner lifts her foot which is rotatably connected to heel pivot **130**, at which time the force curve passes to the right of knee pivot **6**, as indicated by foot-coupling pivot center line **140**—between foot-coupling pivot arrow **141** and hip pivot **28**—causing tibia link **7** to fold about knee pivot **6** as seen **FIG. 9***b*. The advantage of self-locking knee mechanism **121** is that it circumvents the problem of a knee-pivot lock, which is a very difficult problem because of the weight and strength constraints in view of the large torques involved. This self-locking can also be achieved with a foot-aid coupling in front of the runner's foot, but this approach is not as convenient. Also, the device can be prevented from locking at all by walking on very bent knees, e.g., up a steep hill or up stairs, or a mechanical switch can be incorporated into self-locking knee mechanism **121** to prevent thigh-link constraint **120** from approaching close enough to tibia-link constraint **122** for the self-locking to take effect, thereby allowing the runner to walk or climb a steep hill.

[**0072**] **FIG. 10** is a side view of **4**-bar foot-lift assembly **85** for maintaining clearance of aid foot **4** above the ground during swing phase. Foot-lift link **86** hingeably connects the front of aid foot **8** via toe pivot **88** to thigh-link extension **87** via foot-lift pivot **89**. Thigh-link extension **87** extends rigidly from thigh link **4**. When knee pivot **6** folds, thigh-link extension **87** lifts aid foot **8** via foot-lift link **86**, thereby preventing aid foot **8** from dropping below the runner's foot and tripping him. **FIGS. 10***a*, **10***b* and **10***c* display **4**-bar foot-lift assembly **85** at various degrees of folding and straightening. **FIG. 10***a* shows that both foot-lift pivot **89** and knee pivot **6** have straightened to hyper-extend and lock against foot-pivot constraints **91** and tibia-link constraint **122** and thigh-link constraint **120**, thereby ensuring that both foot-lift link **86** and tibia link **7** transmit the running impact load to aid foot **8**. And, when heel pivot **130** lifts aid foot **8** and releases the locking of both foot-lift pivot **89** and knee pivot **6**, the runner can high kick his foot behind him. **FIG. 10***d* shows thigh link **4** and thigh-link extension **87** as a single rigid element. Both foot-lift pivot **89** and knee pivot **6** require closing mechanisms (not shown here for clarity) to ensure that they close at heel down, such as the spring system shown with self-locking knee mechanism **121** in **FIG. 9***c*.

[**0073**] **FIG. 11** is a front cross-sectional view of variable-angle knee lock **61** which is a more versatile and sophisticated alternative to self-locking knee mechanism **121** of **FIG. 9** and which is the fifth embodiment of the invention. The idea behind this device is to make a shaft/collar system which turns freely when loaded on one side and which locks very strongly when loaded on the other side. By interleaving a number of strips, alternating between strips attached to the shaft and strips attached to the collar, it is possible to magnify the friction force by the number of interfaces between alternating strips. This means that a very large lock force can easily be achieved with a number, perhaps five or ten, of very thin, light, cheap metal circumferential strips **78**. Also, the goal of this design is to load the lock radially rather than axially—as is done with conventional car disk brakes. This radial loading eliminates the need for a force re-direction mechanism.

[0074] **FIG. 11***a* shows hollow shaft **62** (optionally hollow) and split collar **69** assembled together. The top portion of hollow shaft **62** and upper collar **70** form a cylindrical bearing surface so that when hollow shaft **62** pushes up against upper collar **70**, they rotate freely. **FIG. 11***c* shows shaft boss **64** which is attached to the lower portion of hollow shaft **62** by boss screws **67**. Boss spacers **68** interleaf with circumferential strips **78**—all of which extend circumferentially around the bottom portion of hollow shaft **62**. This circumferential extension can been seen in **FIG. 12** which is a side view of variable-angle knee lock **61**. Boss screws **67** tighten boss stack plate **77** against boss spacers **68** interleaved with circumferential strips **78** and against shaft boss **64**. Thus, circumferential strips **78** are fixedly attached to hollow shaft **62**.

[0075] **FIG. 11***b* shows lower collar **71** with circumferential strips **78**—both of which are attached to shaft boss **64** by boss screw **67**. The attachment of circumferential strips **78** to lower collar **71** is accomplished in a similar manner to their attachment to hollow shaft **62**. Collar screws **73** tighten collar stack plate **66** against collar spacers **79** interleaved with circumferential strips **78** and against lower collar **71**.

[0076] **FIG. 11***a* shows in assembly that alternating circumferential strips **78** attached to shaft boss **64** and lower collar **71** interleaf between each other. Thus, when lower collar pushes up against hollow shaft **62**, a friction force is exerted between these alternating circumferential strips **78** attached to shaft boss **64** and lower collar **71**. Specifically, this upward pushing causes the portion of lower collar **71** radially external to the interleaf region to compress the stack of interleaved circumferential strips **78** against shaft boss **64**, thereby locking hollow shaft **62** from rotating in lower collar **71**. The radial dimensions of collar recess **74** and shaft boss **64** are chosen to ensure that this compression and locking is unimpeded. Again, the frictional force of this device is proportional to the number of circumferential strips **78** and can easily be magnified to a very large value.

[0077] The circumferential ranges of extension of lower collar **71** and shaft boss **64** can been seen in **FIG. 12** which is an assembly side view of variable-angle knee lock **61** and in **FIG. 13** which shows the shaft and collar components separately. This particular choice of angular ranges gives a locking range of over 70 degrees which is more than adequate for the range of bent-knee angles needed for natural running, as can be seen in **FIGS. 14***a* and **14***b* which show the rotation of lower collar **71** around shaft **62**. Lower collar **71** is fixedly attached to tibia shaft **7**, and shaft **62** is fixedly attached to thigh link **4**, Again, the upward force of lower collar **71** on shaft **62** will cause locking over the range of tibia **7** rotation shown in **FIG. 14**. Since thigh link **4** and tibia link **7** are approaching being aligned whenever foot impact occurs, it is likely that the jarring force transmitted up tibia link **7** to lower collar **71** will be sufficient to lock variable-angle knee lock **61**, as is the case with prior-art, above-the-knee prostheses. If more force is needed, a foot-contact trigger can be used to initiate the locking of variable-angle knee lock **61**. For example, a "brake cable" could transmit foot-impact force to close split-collar **69** by having collar attachments **75** provide a sliding connection between lower collar **71** and upper collar **70** rather than a fixed attachment provided by collar attachment **75**. It should be understood that if the bearing surfaces are located on the bottom side rather than the top side, thigh link **4** can be attached to split collar **69** and tibia link **7** to hollow shaft **62**. Finally, variable-angle knee lock **61** allows uphill running, and it results in an effective gear changing because the spring action is not as aligned with the thrust action when variable-angle knee lock **61** locks at a more bent position.

[0078] **FIG. 15** is a side view of variable-angle knee lock **61** showing damper **82** for use with variable-angle knee lock **61**. When tibia link **7** swings forward just before heel strike, it is important to prevent it from over-hyper-extending and from bouncing back off a stop. This is accomplished with damper **82** fixedly attached to damper arm **80** fixedly attached to thigh link **4**. **FIG. 15***b* shows tibia link **7** swinging forward in the direction indicated by arrow **84** and approaching the straight-leg position. **FIG. 15 a** shows that damper **82** absorbs the momentum of tibia **7** and stops it near the straight position. It should be understood that variable-angle knee lock **61** can optionally utilize a device to ensure that it opens to a straight orientation at heel-strike such as that shown in **FIG. 9***c*. Also, since variable-angle knee lock **61** locks over a range of angles, a simple damper such as a foam, gel or bladder can be used. This is an advantage over conventional knee locks used ill above-the-knee prostheses which use expensive and sophisticated hydraulic mechanisms to prevent bounce back over a range of gaits. And, it should be understood that variable-angle knee lock **61** has applications in robots and above-the-knee prostheses. Also, there are other ways obvious to one of ordinary skill in the machining and fabrication arts to construct variable-angle knee lock **61**—that do not depart from the device intent to radially load interleaving strips so as to magnify considerably the pivot lock force.

[0079] **FIG. 16** is a side view of **4**-bar foot-lift assembly **85** showing tibia lock-release **93** for use with variable-angle knee lock **61**. The purpose is to ensure knee-lock release at toe-off as was done in the example of self-locking knee mechanism **121** shown in **FIG. 9**. In this case the hyper-extended, constrained pivot lock is located near the middle of what was tibia link **7** in earlier figures. The **4**-bar foot-lift assembly **85** is the same as that shown in **FIG. 10**, but now tibia-link **7** comprises lower tibia-link **96**, tibia pivot **92** and upper tibia-link **94**. The ends of upper tibia-link **94** and lower tibia-link **96** connected to tibia pivot **92** have double constraints **90** which serve to lock tibia pivot **92** on the hyper-extending side and to limit the folding of tibia pivot **92** on the other side. The lifting of aid foot **8** by the runner's foot via heel-pivot **130** breaks the hyper-extended locking action of both tibia pivot **92** and foot-lift pivot **89** as shown in **FIG. 16***b*. **FIG. 16***c* shows a blow-up of the components of tibia lock release **93**.

[0080] **FIG. 17** is a back view of cable system **200** which allows the use of single bow spring **202** in the sixth embodiment of the running aid invention. That is, one bow, located behind the runner's back, is used for either leg instead of two (one on each leg) as shown in **FIG. 6**. This embodiment requires a system of pulleys to direct the force of single bow spring **202** to the runner's sides. For clarity, only the pulleys are shown, and the support attachments of the various pulleys are mentioned in this specification. Thigh link **4** transmits the impact force by pulling upward with pulley catch **118** on pulley cable **210** which passes around side pulley **205** (rotatably mounted to thigh link **4**; mounting not shown). Pulley cable **210** next transmits the force back to back-pulley **206**, mounted on back support **208**, and then up to up-pulley **204**, also mounted to back support **208**. Actually, side pulley **205** will be directly in front of back pulley **206**, but they are shown slightly offset here for clarity. Next, the force is transmitted to outer pulley **108** and to inner pulley **106**, which are mounted behind the runner to back support **208**, which is rigidly attached to hip pivot rim **26**. Single bow spring **202** is connected to and interacts with outer pulley **108** in a manner similar to that shown with bow spring **100** in **FIG. 6**, the difference being that single bow spring **202** can absorb impact force from the brace elements on either or both sides.

[0081] **FIG. 18** shows full harness **300** for the running aid with the front view on the left and the side view on the right. In the front view, runner **1** is shown in dashed lines, and the coupling between runner **1** and full harness **300** is made via pelvic rim **26** from **FIG. 6**. Full harness **300** can be subdivided into thigh harness **302**, pelvic harness **304**, waist harness **306**, and chest harness **308**, and each of these can be further subdivided into multiple cuffs **310**. Later, a figure will show a means to take some of the brace load on the arms of runner **1**, as well. Stays **312** are rigidly attached to pelvic rim **26** and extend upward and downward from it to support the elements of full harness **300** via cords **314**. Only the portion of pelvic rim **26** at either side is shown for clarity, but it encircles runner **1**. Only those stays **312** on either side are shown for clarity, but there may be multiple stays around pelvic rim **26**. Cords **314** can independently support each cuff to better distribute the brace load along the length of full harness **300**, and there may be one or more cuffs **310** in each harness subdivision. Finally, only a portion of the full harness **300** shown may be needed and used in this invention.

[0082] One very important feature of this extensive harness is that the harness portions which support and upward pull can be tightened down against the harness portions which support a downward pull. For example in **FIG. 18**, waist harness **306** can be cinched down to thigh harness **302** with straps, and vice versa. This allows the compliance of the underlying runner's flesh to shear to be reduced substantially.

[0083] It may be possible to comfortably support a runner with harnesses that are simply tight and extensive, but the following discussion gives designs for harness in which the load of the runner on the running brace tightens the harness. This load-tightening feature may be used with a portion or all of full harness **300**. The advantages are (1) that the harness tightens as the load increases, thereby increasing its load capability and (2) the harness loosens when not loaded, thereby improving blood circulation and comfort for the runner.

[0084] **FIG. 19** is a side schematic view of a generic mechanical design for . mechanical load-tightener cuff **322** used in full harness **300** for the running aid. In the bottom section of **FIG. 19**, load-tightening cuffs **320** overlap and in the top section they do not. Looking at the top section, the two ends of load-tightening cuffs **320**, which encircle a portion of the runner's body part, are attached to adjacent cuff buckles **328**, which, in turn, are attached to mechanical load tightener **322** via tightening cords **324**. When the brace load pulls up on mechanical load tightener **322** as indicated by load arrow **330**, mechanical load tightener **322** causes tightening cords **324** to pull inward as indicated by tightening arrows **330**, thereby tightening load-tightening cuffs **320**. Referring to the bottom section of **FIG. 19**, the same tightening occurs. The difference is that mechanical load tightener **322** must be wide enough to pull together either side of load-tightening cuffs **320** which now overlap by virtue of ending with cuff fingers **334**. The advantage of this overlapping is that the surface of load-tightening cuffs **320** is smooth in the vicinity of mechanical load tightener **322**, thereby providing greater comfort to the runner. In the following examples of load-tightening designs, only one will show this overlapping, but it should be understood that any of them can be adapted for overlapping.

[0085] Regarding the use of load-tightening cuffs **320** in general, these may comprise means for lacing or cinching to achieve a snug yet comfortable degree of pre-tightening. Further pre-tightening may be achieved by tightening different levels of the harness, one against the other. For example, waist harness **306** may be cinched down against pelvic harness **304** to reduce the compliance between the runner's flesh and the harness. Depending on how much soft tissue there is below the runner's skin, the skin may move a half-inch to an inch or more under shear. Pre-tightening can eliminate most of this compliance.

[0086] **FIG. 20** shows examples of compressible woven harness **340** for load-tightening sleeves of the harness for the running aid. On the left side thigh harness **302** and torso harness **344** are held at either end by hoops **342**. Braids **346** are interwoven about the shape of a pelvis and thigh. Provided their lower sections are sufficiently anchored, when the upper hoop **342** pulls upward, compressible woven harness **340** must shrink or compress, and this results in gripping of the underlying object, in this case the runner's body pails. In order for this gripping to occur, the individual braid material which composes compressible woven harness **340** must be inelastic to stretching, but flexible to bending over the shape of the underlying object. This idea is similar to that used for the finger traps known as Chinese hand cuffs, in which a number of bands (tapes, ribbons, strips) are inter-woven into a tube which traps the fingers of unwary children. On the right side of **FIG. 20** compressible woven harness **340** is composed of braids **346** in such a manner that there is substantial void space between braids **346**. This has several advantages: ventilation for the runner, a greater compression range, and improved traction of braids on the compressible human flesh underneath. The relative amount of contraction for a given extension between hoops **342** depends on the number, width, thickness and pitch angle of braids **346**, as well as on their friction coefficient with the underlying surface. If the underlying surface is irregular, it can also be seen that judicious locations of stays **312** and cords **314** in **FIG. 8** can improve the even distribution of load along the length of a harness.

[0087] An important feature of the woven mesh design is that the bottom portion of the sleeve must be sufficiently well anchored as to cause the higher regions to contract and thereby distribute the (upward) load up the entire sleeve length. This may be accomplished for thigh sleeve **20** with straps extending down and around the foot or with straps extending to a stuff around the runner's tibia below the knee.

Or, since the runner's thigh has a natural taper, keeping the lower portion of thigh sleeve **20** fairly tight may be sufficient in some cases to achieve this anchoring. Once sufficient bottom anchoring is achieved, the load is distributed up the length of compressible woven harness **340**, which is the overall goal.

[0088] **FIG. 21** is a side view of overlap double-pulley load tightener **318** which is an example of a mechanical load-tightener **322** used in the harness for the running aid. Tile discussion here is similar to the discussion of mechanical load-tightener **322** for **FIG. 9** except that mechanical load tightener **322** is shown in detail rather than schematically. Mechanical load-tightener **322** comprises load-tightening cuff **320** attached on either end to cuff buckles **328** and overlapping each other via cuff fingers **334**. It further comprises spreader bar **323** which is mounted to load-tightening cuff **320** at spreader bar tab **325** and which has rotatably mounted on either end tightening pulleys **336**. When the brace load pulls up on stay cords **326** at indicated by load arrows **332**, stay cords **326** pass around tightening pulleys **336** to pull tightening cords **324** as indicated by tightening arrows **330**, via cuff buckles **328**, thereby tightening load-tightening cuffs **320**. Spreader bar **323** is anchored below via anchor cords **327** as indicated by anchor arrows **329**. At first, it may seem self-defeating to require additional anchor cords for spreader bar **323** because the goal is to be able to pull up on load-tightening cuffs **320** with the brace load via stay cords **326** and the attachment to spreader bar **323** at spreader bar tab **325**. If load-tightening cuffs **320** are already tight enough, anchor cords **327** are not needed, but they provide back-up as the tightening begins. The top section of **FIG. 21** shows a blow-up of tightening pulley **336** which optionally may comprise inner tightening pulley **338** and outer tightening pulley **339**. In this case, there is a mechanical advantage whereby the travel of stay cord **326** is augmented by a factor equal to the mechanical advantage between these pulleys to create a greater travel of tightening cord **324**. This is an important feature because it reduces the slack or compliance needed to tighten mechanical load-tightener **322**. This means that the running aid can give substantial support to the runner quicker, and this is key to natural running.

[0089] **FIG. 22** is a side view of bent-lever load tightener **350**, jamming load tightener **352**, and inward-force load tightener **375** of the harness for the running aid. These are examples of the mechanical load tighteners **322** shown in **FIG. 9** and **FIG. 21**, and the first two function in a similar manner. Bent-lever load tightener **350** is shown in the bottom left of **FIG. 22**. Bent levers **356** are rotatably attached to spreader bar **323** which is attached to load-tightening cuff **320** via cuff hoop **354**. Cuff hoop **354** is slidingly attached to load-tightening cuff **320** so as to not impede its tightening. Provided load-tightening cuff **320** is well pre-tightened or provided spreader bar **323** is well anchored below, when stay cord **326** pulls up (see load arrow **332**) the top arms of bent levers **356**, then the bottom arms of bent levers **356** pull the ends of load-tightening cuff **320** inward via cuff buckles **328** (see tightening arrows **330**). A similar function occurs for jamming load tightener **352** in the top left of **FIG. 22** Here, as spreader bar **323** is pulled up, jamming links **358** tighten load-tightening cuff **320**. It should be understood that cuff hoop **354** can be used with any of the cuffs discussed herein, and it may be segmented or telescoping to allow cuff **20** tighten. Inward-force load tightener **375** is shown on the right of **FIG. 22**, and it functions slightly differently. Frame hoop **379** is rigidly attached to harness **3** of **FIG. 1** and encircles body part **378**, and it is strong enough to be rigid when the jamming links **358** on either side jam against pressure pads **376** on either side to grip body part **378** as a brace load force pushes up on frame hoop **379**—to clamp or grip body part **378** as it is supported. It should be understood that there may be a number of these elements distributed about the body harness, and there are a number of mechanisms known to one of ordinary skill in the art for accomplishing this gripping. Again, this last load-tightening mechanism is distinguished from the earlier ones by virtue of the fact that the clamping force is directed inward toward the body part instead of circumferentially around the part body tightening a cuff.

[0090] **FIG. 23** is a side view of combination mechanical/weave load-tightener **360** of the harness for the running aid. Its purpose is to lift and simultaneously apart spread compressible woven harness **340**. Vertical spreader bar **364**, attached to top hoop **370**, pulls upward on compressible woven harness **340**—attached at its top to top hoop **370** and its bottom to bottom hoop **372**. This upward pull is exerted by cables **366** which pass firm vertical spreader bar **364** around block pulleys **362**, and then all the way down to pass around spreader pulleys **363**—attached to the bottom of vertical spreader bar **364**—to finally pull down on bottom hoop **372**, thereby spreading compressible woven harness **340** and causing it to contract and grip the underlying body part. Block pulleys **362** serve to equalize the upward force on top hoop **370** with the downward force on bottom hoop **372**. Cable arrows **374** indicate the pull directions that achieve the spreading apart of compressible woven harness **340**. Tills spreading causes a quicker gripping of the body part, which eventually is lifted when the gripping force becomes sufficiently large.

[0091] **FIG. 24** is a side view of arm load-bearing harness **380** for the running aid. Runner **1** and runner's arm **390** are shown as a dashed line. Tile lower running aid is not shown bit is attached to pelvic rim **26** as is shown in earlier figures. Arms beam **392** is rigidly attached to pelvic rim **26**, and swing links **384** are rotatably attached to arm beam **392** to support arm rest **388** which supports runner's arm **390** via arm pad **386**. Accordingly, runner **1** can support a substantial portion of her weight on arm load-bearing harness **380** and still swing her arms.

[0092] **FIG. 25** shows a schematic front view of load-equalizer stay tree **400** which distributes the brace load over various parts of the harness for the running aid. On the left side of the figure stays **312** support cords **314** which attach to cuffs **310**, which make Up a body harness. In this case, the load will be distributed approximately evenly over each cord **314** and cuff **310**. If one wishes to vary the load on a particular cuff **310**, the elasticity of the attached cord **314** can be varied. In the event that one wishes to ascertain that there is an even load distribution without have to make all the cords **314** just the right length, load-equalizer stay tree **400** may be used. Here, cords **314** are attached at one end to the bottom of load-equalizer stay tree **400** and at the other end to the top cuff **310**. In between, cord **314** passes over stay pulleys alternately attached to cuffs **314** and load-equalizer stay tree **400**. The result is that load-equalizer stay tree **400** pulls up evenly on cuffs **310** via the attached pulleys. The detailed and workable design is more involved, but this figure demonstrates the principle.

[0093] **FIG. 26** shows adjustable harness **403** for the running aid. Adjustable bands **404** pass around a body part and through fitting clamps **406**. When adjustable bands **404** are pulled to fit tight about the underlying body part, a portion—namely leftover bands **408**—of their lengths stick out the other side of fitting clamps **406**. In this way a range of sizes and shapes can be snugly fit with adjustable harness **403**. The same device can be use to adjust braids **346** which make up compressible woven harness **340** in **FIG. 20**. This adjustability is important because a self-tightening harness material should have minimal elasticity.

[0094] **FIG. 27** shows a side view of a generic brace leg with a circular brace foot **8**, demonstrating graphically how well the brace foot prevents vertical travel of the runner's center of mass throughout stance. The figure depicts a stick leg, brace leg **9**, running from left to right. The stick figure on the left shows heel-strike and on the right shows toe-off. Tile center sequence shows the trajectory of the top of brace leg **9** throughout stance, at 10 degree intervals of rotation—with alternating positions being either solid or dashed. In the first 10 degrees, the brace top rises 0.5" (for a 30" leg); for the next 30 degrees, the brace top stays level because the radius of brace foot **8** is also 30", and for the last 10 degrees the brace top falls 0.5". The curved brace foot can be used with any of the embodiments for the running aid herein, or it can be used in the tenth embodiment with a straight rigid leg as shown in **FIG. 27**. In this case the "running aid" is actually a walking brace used for support.

[0095] **FIG. 28** shows hyperlocker **500**, a mechanism to guarantee hyper-extension of the self-locking knee mechanism of the fourth embodiment of the invention of **FIG. 9**. Thigh link **4** rotates about lip pivot **28**. Since the direction of running is from right to left on the page, the right side depicts the early stage of swing phase after toe-off The left side depicts the instant just before heel-strike when knee pivot **6** is hyper extended. The purpose of hyperlocker **500** is to force hyper-extension before heel-strike, while still being able to freely fold knee pivot **6** at toe-off. This is done by keying hyperlocker **500** to the position of thigh link **4**—either swung forward or backward. When thigh link **4** swings forward (leftward), slide-pulley cord **526** pulls slidable thigh pulley **524** up, via top thigh pulley **520** against rim beam **518**. Closer cord **514** runs from closer-link attachment **510** around thigh-link pulley **512**, up to slidable thigh pulley **524**, back down to and through beam pulley **506** (on the end of upper closer beam **502**, to end at cord ball **522**. When thigh link **4** is swung back, slidable thigh pulley **524** slides down thigh link **4**, and closer cord **514** has enough slack so as to allow closer links **508** to bend and knee pivot **6** to fold with no resistance from closer cord **514**.

[0096] However, when thigh link **4** swings forward (leftward, in swing phase), slide-pulley cord **526** pulls slidable thigh pulley **524** up thereby pulling closer cord **514** taut. Now, when tibia link **7** starts to move down to prepare for heel-strike, closer-cord catch **516** on the end of lower closer beam **504** catches cord ball **522**, causing closer-link attachment **510** to be pulled toward thigh-link pulley **512**, causing the hyper-extension of tibia link **7** about knee pivot **6**. By adjusting the various parameters, it is possible to choose the fold angle at which the hyper-extension action begins. Also, a spring can be incorporated in closer cord **514**.

[0097] **FIG. 29** shows slider **530** for changing the length of a running aid according to the seventh embodiment of the invention. Slider **530** comprises middle guide **564** and inner guide **566** (which may be telescoping tubes) as well as slider ratchet **532**. The purpose of slider **530** is to change the length of the running aid even when knee pivot **6** is hyper-extended, to allow uphill running. Slider **530** changes length freely during swing phase; at heel-strike, a foot-contact trigger, such as the one shown in **FIG. 30**, engages slider ratchet **532** to lock slider **530** throughout stance. When the total brace length can be changed in two ways, with a slider and a knee pivot, it is important to ensure that the hyper-extension of the knee-lock occurs. Hyperlocker **500** of **FIG. 28** ensures this. Note that bow guide **110**, comprising outer guide **562** and middle guide **564**, significantly overlaps slider **530**—allowing greater length for both elements.

[0098] **FIG. 30** shows full-stance brace-foot trigger **540** for locking slider **530** throughout stance. An array of ground levers **542** are rotatably attached to curved brace foot **8** along its length. The tops of these are fixably interconnected by ground trigger cord **546**, each of which pulls ground trigger cord **546** around ground pulley **544** and down the length of tibia length **7**, when that ground lever **542** is caused to rotate by contact with running surface **37**. This is true at heel-strike, shown on the right side of the figure, until toe-off, on the left side of the figure. That is, even though each particular ground lever is not always in contact with running surface **37**, there is always at least one ground lever **542** in ground contact. Since all ground levers **542** are interconnected at their tops, it only takes one ground lever **542** to pull on ground trigger cord **546**, ensuring that the force engaging slider ratchet **532** of **FIG. 29** is exerted throughout stance.

[0099] **FIG. 31** shows foot-coupling guaranteed release mechanism **548** for release of slider ratchet **532** of **FIG. 29** at toe-off. This can be used in place of the hyper-extended knee locks of **FIGS. 9, 10**, and **29** to prevent a knee lock or a slider lock from sticking due to premature lifting of his foot by a runner. Foot pivot square extension **552** extends from the shaft used for pivotable coupling between a runner's foot and brace foot **8**. The idea is for foot pivot square extension **552** to freely move up within down-spring slot **549** just at toe-off, thereby reducing any upward force exerted by the runner's foot on the brace foot for an instant, allowing any slider lock to release. During swing phase, foot pivot square extension **552** must be returned to the bottom of down-spring slot **552** to prevent brace foot **8** from hanging below the runner's foot and tripping him. This return to the bottom is accomplished with a spring cocked by the force of heel-strike and then released by the upward motion of foot pivot square extension **548**.

[0100] In detail, **FIG. 31***a* depicts the mechanism during stance. Ground lever **542** is rotated by ground contact to hold down foot pivot square extension **552**. Down spring **554** is cocked and held in place by down-spring pawl **556**. Down spring **554** was cocked by the rotation of grounded lever **542** at heel-strike, via the downward pull on cocking cord **560** which rums over cocking pulley **558** to pull up on down spring **554**. **FIG. 31***b* depicts the instant just after toe-off. Ground lever **542** is pulled upward by ground-lever return spring **550** releasing foot pivot square extension **552** to be lifted by the runner's foot, (This is when foot pivot square extension **552** freely moves up within down-spring slot **549**; this free motion allows slider ratchet **532** of **FIG.**

29 to release.) pushing down-spring pawl **556** to the side until it releases down spring **544** which pushes foot pivot square extension **552** back to the bottom of down-spring slot **549** (as shown in **FIG. 31***c*) where it stays until heel-strike. **FIG. 31***d* shows the beginning of heel-strike. Ground lever **542** is being rotated to pull down cocking cord **560** to pull Up and cock down spring **554** as it is pulled high enough for spring-loaded down-spring pawl **556** to rotate and catch it—at which time **FIG. 31***a* applies again.

[0101] **FIG. 32** shows simple-slider running aid **561** according to the eighth embodiment of the invention, wherein a knee pivot is no longer used. The elements of slider **530** and bow guide **100** have been explained in the discussion of **FIG. 29**. Instead of having a knee pivot connect to a tibia link below bow guide **100**, inner guide **566** extends straight down, all the way to brace foot **8**. This embodiment is simple in that it eliminates the knee pivot and all the related mechanisms, but its drawback is that it is not possible to high-kick as high. Full-stance ground trigger **540** of **FIG. 30** and foot-coupling guaranteed release mechanism **548** of **FIG. 31** can be incorporated in this embodiment. It is possible that the spring which causes slider ratchet to pull away from and disengage from inner guide **566** can be strong enough to guarantee slider lock release in which case foot-coupling guaranteed release mechanism **548** would not be needed. The top of outer guide **562** would be attached to hip pivot **28** in a manner similar to that shown in **FIG. 6**.

[0102] On the right side of **FIG. 32** there is shown retractable brace foot **545** with lockable hinged extensions **547** which can be locked for running or walking on relatively flat or shallow sloping terrain and which can be retracted for running or walking on steps or steep terrain.

[0103] **FIG. 33** shows a means to combine an active power source with a passive spring according to the ninth embodiment of the invention. In this case actuator piston **44** is propelled downward within actuator housing **43** during the active power stroke. This results in an upward force on actuator housing **43** and on bow guide **110** which compresses bow spring **100**. Even if the power stroke is of very short duration, the timing of the expansion of bow spring will be slow enough to appropriately couple with the runner's weight at the top of bow guide **10**. In effect, the active component extends the power stroke delivered by the bow spring, and the timing problem is solved by putting the active component in series with the passive component.

[0104] **FIG. 34***a* shows booted lockable hydraulic slider **571** and **FIG. 34***b* shows nested lockable hydraulic slider **594** both of which can be used for the various lockable sliders. The idea is to utilize the resistance of flow of fluid through a valve to lock, unlock, or control the length change of the two brace length-change means discussed herein: namely, knee pivot **6** of **FIG. 1** and slider **530** of **FIG. 32**. Referring to **FIG. 32***a*, booted lockable hydraulic slider **570** comprises hydraulic piston **576** which slides within hydraulic cylinder **575**. Fluid flows between hydraulic chamber **578** and bladder boot **581** through top orifice **579**, through fluid lines **586**, and through the following valve system. Fluid line **586** branches to go through return check valve **580** (allowing fluid to return to hydraulic chamber **578**) on one side and through exit valve **582** and exit check valve (allowing fluid to exit hydraulic chamber **578**) on the other side.

[0105] Exit valve **582** is triggered (by release of toe contact using the full-stance ground trigger **540** of **FIG. 30**) to open at toe-off—thereby allowing fluid **572** to move into reservoir **574** as hydraulic piston **576** moves tip during the runner's high kick after toe-off. Since there is no resistance to this opening of exit valve **582**, even if the runner's foot is prematurely lifting the brace foot, the release of lockable hydraulic slider **570** is guaranteed.

[0106] In swing phase, hydraulic piston **576** is now free to move both up and down as one check valve allows fluid to flow in and the other allows fluid to flow out. Just before heel-strike, exit valve **582** is triggered (by pre-strike heel contact) to close. At heel-strike, hydraulic piston **576** cannot move up because exit valve **582** is closed. Thus, lockable hydraulic slider **570** is locked. In view of the fact that some running brace designs require hydraulic sliders to resist considerable non-axial loads, piston sliding friction is reduced by not using o-rings. This is possible since bladder boot **581** receives any fluid that leaks through the small area between hydraulic piston **576** and hydraulic cylinder **575**; bladder boot **581** is sealed by ring seals **583**.

[0107] Cylinder rollers **585** resist any non-axial load in any design application where hydraulic piston **576** slides under load. For example, in order to walk down steps or to run downhill, exit valve **582** can be controlled to be partially open, allowing **576** hydraulic piston to move slowly upward and lockable hydraulic slider **570** to slowly compress. The size of the opening of exit valve **582** determines how fast the runner or walker can walk down steps, and the valve can be controlled manually by the runner.

[0108] **FIG. 34***b* shows that one telescoping element can be nested within another to achieve a higher "high-kick" by the runner just after toe-off. Also, conventional **0**-rings are used to prevent fluid leakage for this case where the bladder reservoir is not booted. Nested lockable hydraulic slider **594** further comprises inner piston **588** which telescopes within hydraulic piston **576**, which now has a hole, fluid opening **590**, to allow fluid to flow from inner hydraulic chamber **592** through hydraulic chamber **578** to reservoir **574**. The timing of the triggering is the same as that just discussed.

[0109] Again, nested lockable hydraulic slider **594** and booted lockable hydraulic slider **571** can be simply substituted for the sliders discussed elsewhere herein, or it can be used to lock a knee pivot. **FIG. 35** shows knee pivot **6** locked by lockable hydraulic slider **570** according to the eleventh embodiment of the invention. The triggering is the same as that just discussed. When booted lockable hydraulic slider **571** locks, knee pivot **6** also locks.

[0110] **FIG. 36** shows self-hyper-locker **36** for guaranteeing hyper-extension at foot strike. The idea is to route closer cord B **624** around a path which passes both on the front side and back side of folding knee pivot **6** in such a manner that the back part of the path (between top inside post **604** and inside pulley **628**) increases faster than the front part of the path (between top outside post **602** and outside pulley **626**) as tibia link **7** and thigh link **4** unfold about knee pivot **6**. By choosing a certain length of closer cord B **624**, closer cord B **624** becomes taut at a particular flexion angle as the unfolding occurs, causing closer cord B **624** to begin to pull on closing spring **610** which acts to accelerate the unfolding, especially if closing spring **610** is pre-loaded (which is easily accomplished with a plug (not shown) on closer cord B **624** just below the bottom of notched tube **608**). Top outside post **602** and top inside post **604** are fixably attached to thigh link **4**. Bottom outside post **630** and bottom inside post **632** are fixably attached to tibia link **7**—providing support for outside pulley **626** and inside pulley **628**. Notched tube **608** is attached to top outside post **602** by reset spring **620**. Closer cord B **624** is attached to notched tube **608** via closing spring **610** which is stronger than reset spring **620**. Notched tube **608** is slidably connected to thigh link **4** via notched-tube guide **606**. Pawl **612** is pivotly connected to thigh link **4** at pawl pivot **616** via pawl tab **614** (fixably attached to thigh link **4**). Pawl spring **618** bias pawl **612** to engage the notch in notched tube **608** when it is pulled upward in swing phase by reset spring **620**.

[0111] Accordingly, **FIG. 36***a* shows self-hyperlocker **600** in swing phase when closer cord B **624** is slack and there is no unfolding force—allowing the tibia link **7** to swing freely. Reset spring **620** has pulled notched tube **608** up so that pawl **612** can engage its notch. Again, at a particular flexion angle closing spring **610** slams tibia link **7** closed as seen in **FIG. 36***b*. Just after the joint becomes hyper-extended, pawl bumper **622** impinges the bottom of pawl **612** causing it to disengage from the notch of notched tube **608**, thereby releasing closing spring **610** from its folding force because notched tube **608** moves down notched-tube guide **606**—shortening the patch of closer cord B **624** (shown in **FIG. 36***c*) and causing it to become slack. Thus, there is no closing force later, at toe-off, to resist folding and high kick. Self-hyperlocker **600** is called "self" because it does not require any trigger from the foot or the hip to work. The release of closing force is keyed to hyper-extension at the knee pivot. Self-hyperlocker **600** can be used with simple-hinge knee pivots or with four-bar knee pivots (in which case it only needs to be located at one of the two knee pivots).

[0112] **FIG. 37** shows a "hyper-extension bounce back" prevention means for prevention of folding of a hyper-extending knee lock at heel strike. Pinched bladder **640** is glued to bladder step **646** in tibia link **7**. Pinch band **624** forms a portion of pinched bladder **640** exterior to bladder step **646**. And it allows only a small orifice connecting the main body of pinched bladder **640** with elastomer nipple **644**. When tibia link **7** closes to the point where hyper-extension of the joint begins, the bottom of thigh link **4** squeezes bladder fluid through the orifice made by pinch band **642** into elastomer nipple **646**, causing it to expand. The resistance to fluid flow through a small orifice absorbs the impact energy of the closing of the joint so it does not bounce back open. The force exerted by the expansion of elastomer **644** is too small to re-open the joint when it is loaded by a runner's weight, but this force is large enough to force the fluid back through the orifice during swing phase when pinched bladder **640** is no longer squeezed. This is a very cheap and simple way to eliminate bounce-back opening of the knee joint as compared with elaborate, expensive hydraulic devices used in conventional above-knee prostheses.

[0113] **FIG. 38***a* shows a rear view and **FIG. 38***b* a side view of front/back brace leg **650** in which the pelvic coupling is made directly behind and in front of the runner's ischial tuberosity (buttock) rather on the side of the hip. Front hip pivot **678** is pivotly attached to harness **3** directly above runner's leg **676** in front, and back hip pivot **680** is pivotly attached to harness **3** directly above runner's leg **676** in back. Front and back—hip pivots **678** and **680**, knee pivots **660** and **662**, and thigh links **652** and **654**—and knee cross link **674** form a four-bar system. Front and back—ankle pivots **670** and **672**, knee pivots **660** and **662**, and ankle links **670** and **672**—and knee cross link **674** form another four-bar system—with knee pivots **660** and **662** and knee cross link **674** being shared between these two four-bar systems. The runner's pelvis and/or harness **3** act as the cross link at the hip level for the upper four-bar system, and brace foot **8** acts as the cross link at the foot level for the lower four-bar system. These two four-bar systems are sufficiently distant from runnier's leg **676** throughout a stride as to not interfere with the same. Back hydraulic knee lock **664** is rotatably connected to a back thigh link **654** and back tibia link **668** so that when a foot trigger (not shown, but straightforward to implement for one of ordinary skill in the art) locks back hydraulic knee lock **664** as foot strike, flexion about back knee pivot **662** is locked. Another knee lock could be used for front knee pivot **660**, but this is not necessary because back knee pivot **662** is shared by both four-bar systems. That is, when back knee pivot **662** is locked, both the above-mentioned top and bottom four-bar systems are converted to three-bar systems, and both structures are locked. Folding of the upper and lower four-bar systems with respect to each other is realized as the runner's weight leans forward. This folding can be enhanced by tethering front and back knee pivots **660** and **662** to the runner's knee. The runner's foot can now be coupled to brace foot **8** anywhere along the length of the runner's foot. Front and back bows **656** and **658** store and return impact energy, and only one of these need be used. Finally, if the one or both knee pivots in **FIG. 38** are constrained from hyper-extending (see e.g. **FIGS. 16 and 36**), a separate knee lock, such as back hydraulic knee lock **664**, can be eliminated since the "constrained hyper-extension knee lock" naturally locks at heel-strike and naturally starts folding just before toe-off. Having a separate knee lock allows the runner to run uphill or to land with a more substantially pre-bent leg, but this capability is not needed in many applications. This is even more true for a running brace than for above-knee prostheses, since the runner's leg is there to prevent a fall.

[0114] **FIG. 39** shows front/back pack extension **690** for comfortable and optimal pack load support. The running/walking brace shown is front/back brace leg **650** of **FIG. 38**. Front pack frame **692** is pivotly attached to the top front of front/back brace leg **650** by pack-frame pivot **698**, and back pack frame **694** is pivotly attached to the top back of front/back brace leg **650** by pack-frame pivot **698**. Pack straps **696** attach front pack **700** to front pack frame **692**, and back pack **702** to back pack frame **694**. If the brace legs were not supporting the pack weight, there would be an uncomfortably high load on the runner's shoulders. Also, the front parts of front/back pack extension **690** can be eliminated, in which case runner **1** must lean forward at the waist to balance the pack.

[0115] **FIG. 40** shows four-bar knee joint **704** with hyper-extension stop **708** which prevents hyperextension of the joint. Optional four-bar hydraulic lock **706** can be used to lock four-bar knee joint **704** and which can be triggered to lock a foot-contact in a manner similar to that of booted lockable hydraulic slider **571** of **FIG. 34**.

[0116] **FIG. 41** is a schematic side view of a low-eccentricity knee joint straightener **720**. It resists folding about side knee pivot **6** with only a very small force (of circle spring **728**) beyond a chosen flexion angle so that the wearer is free to high kick. As tibia link **7** descends beyond this chosen flexion angle, low-eccentricity knee-joint straightener **720** acts to accelerate this straightening via close spring **724** with a force that increases proportional to eccentricity **712** of the spring force about knee pivot **6**. Thus, the greatest straightening force acts when full straightening occurs. The components are assembled as follows. Circle tube **730** is rigidly attached to thigh link **4** and circle brace **732** which extends rigidly from thigh link **4**. Slide ring **726** slides along circle tube **730** and it is connected both to close spring **724** which extends down to connect to tibia link **7** and to circle spring **728** which extends through circle rube to connect to its upper end. Slide ring **726** is constrained from sliding tip and to the right at a chosen location. Pivot stops **86** prevent hyper-extension about side knee pivot **68**. In **FIG. 41***a*, the configuration is straight, eccentricity **202** is at a maximum value, and the straightening force is at a maximum value. In **FIG. 41***b*, shin tube has folded to the point where shin-tube extension **722** impinges slide ring **726**, eccentricity **702** is very small, and the straightening force due to close spring **724** is very small. In **FIG. 41***c*, shin tube **64** has folded considerably. However, the straightening force due to close spring **724** is still very small because slide ring **726** is forced to slide around circle tube **730** by shin-tube extension **722** and eccentricity **702** remains very small. There is still a very small resistance to folding due to circle spring **730** which is much weaker than close spring **724**. Again, as straightening progresses beyond the configuration of **FIG. 41***b*, the straightening force increases rapidly.

[0117] This completes the discussion of the figures. Now a few general issues will be discussed. One of the key problems discussed in various parts of this patent is to guarantee the release of the lock of the swing-phase length change means, which can be the self-locking knee mechanism **FIG. 9**, the variable-angle knee lock of **FIG. 11**, the slider of **FIG. 29**, or the simple slider of **FIG. 32**. This lock release is necessary but not sufficient for guaranteed folding (about the knee pivot for the hyper-extended knee locks) which will be discussed afterward. Guaranteed lock release is necessary because a runner can lift the brace foot prematurely, thereby preventing a break in the loading of the lock, therefore preventing lock release; then the runner could fall flat on her face. For the hyper-extending design of **FIG. 9, a** simple spring between thigh-link constraint **120** and tibia-link constraint **122** might suffice. If more guarantee is needed the hyperlocker mechanisms of **FIG. 28** and **36** can be utilized. Also, a four-bar system such as that shown in **FIG. 38** will naturally fold as the runner's weight leans forward near the end of stance. For the variable-angle knee-lock, tibia lock-release **93** of **FIG. 16** can be used if a simple spring—to push down split collar **69** with respect to hollow shaft **62**, thereby disengaging circumferential strips **78**—does not suffice to release the lock at toe-off. For the slider of **FIG. 29** or the simple slider of **FIG. 32, a** spring to disengage slider ratchet **532** may be sufficient to release the lock at toe-off. If not, foot-coupling guaranteed release mechanism of **FIG. 31** can be used.

[0118] Guaranteed folding (about the knee pivot for the hyper-extended knee locks) is achieved with a heel coupling in **FIG. 9, a** knee tether (mentioned in the discussion of **FIG. 38** although it could be used in any of the hyper-extended knee locks), and as a natural consequence of a forward lean in the discussion of **FIG. 38** of a four-bar knee pivot. It simply means that the force exerted by the runner on the brace leg must fold the knee pivot rather than hyper-extend it.

[0119] In conclusion, the invention herein described comprises a variety of passive or spring running aids—most notably an energy efficient running aid or brace which provides optimally fast support of a runner's impact load by virtue of the buckling load force curve of the bucky-bow spring and by virtue of the load-tightening body harness with minimal compliance. In addition, the designs can also be used for walking or in conjunction with an active power source. The spring is lightweight and features an optimally long travel, along with an optimal constant force curve. In the second embodiment of **FIGS. 6 and 7**, since a cable system with pulleys is used, there is a "gear changing" feature, and a single bow spring can be used for either leg. The harness achieves a unique capability in that it provides for a uniform distribution of impact load over a substantial portion of the runner's body, even though the runner's body is vertical. Comfort is enhanced with a load-tightening feature of the harness. The daunting knee-lock problem is circumvented with a knee self-locking device of **FIG. 9** which solves the other difficult problem of guaranteed knee-lock release, and it is solved with the variable-angle knee locking device of FIGS. **11-14** and the lock-release devices of **FIGS. 16, 31, 34** and **36**. This variable-angle device allows uphill running, and it results in an effective gear changing because the spring action is not as aligned with the thrust action when the knee pivot locks at a more bent position. Finally, a shaped brace foot solves the problem of leg-length asymmetry. The overall design is lightweight, and this aspect is improved by minimizing the distill weight of the running aid.

[0120] It should be understood that the running aid described herein has many features which apply to robotic running as well as to a running brace. These include the spring mechanisms for energy return, the brace foot, and the self-locking pivot. The running aid invention uses either the pulley-bow or the series bucky bow, as well as the single pulley bow in the back, all can be easily adapted to robotic running. The brace foot should be used as well in robotic running to optimize the angles of leg/foot support while landing and taking off for greater performance and fuel economy. A slight adaptation would be needed to use the self-locking knee pivot because there is no runner's foot to lift Up the heel pivot to fold the knee pivot. Instead, a cable could be spring-loaded and triggered by toe-off to pull on the heel pivot to unlock the knee pivot for swing phase. And, the uphill running feature to allow the bow to engage and the knee pivot to lock when the runner's leg lands partially bent can also be use in robotic running. Also, the front/back brace leg of **FIG. 38** can be used for exo-skeleton applications which are active as well as passive. And, it can be used for above-knee prostheses and robots. Furthermore, separate four-bar systems can be used to allow articulation in the roll plane as well as the pitch plane.

[0121] The running aid designs herein also can be used for both walking even though the main thrust in the development of these designs has been for running. These running aid designs can also be used for carrying a backpack. The backpack can simply be attached to the pelvic rim of the harness in which case the running aid substantially supports the load of the backpack, and the harness is not needed—at least for support of the pack by the running brace. Or, as just described for **FIG. 39**, tile front/back brace leg of **FIG. 38** can be used to support pack weight both in front of and behind the runner via a front/back pack extension. This design provides for improved equilibrium of the runner/pack system, and it eliminates the uncomfortable backward force on the runner's Shoulders resulting from pack which is only in the back.

[**0122**] Since the preferred spring systems described herein provide an approximately constant force curve, they also provide for the maximum amount of absorption and return of impact energy—given a threshold level of force that the human body can safely tolerate. This means that these preferred spring systems, herein called bucky-bow springs or "series" bow springs, can be used for extreme landing protection such as with parachute landing or jumping from heights, and the full-body harness described herein can also be used for these applications. It is hoped that this invention will provide enjoyment and injury-free exercise for people who love to run.

[**0123**] The above description shall not be construed as limiting the ways in which this invention may be practiced but shall in inclusive of many other variations that do not depart from the broad interest and intent of the invention.

1. A running aid comprising

a harness attached to a runner's body,

one or more brace legs extending from said harness to the ground, wherein said brace leg supports a runner's weight while walking and running, wherein the runner can be a human or a robot,

one or more hip pivots for rotatable connection of said harness with said brace leg, and

one or more asymmetric-travel brace feet, called brace feet herein, attached to the bottom of said brace leg, wherein said brace foot is sufficiently long to provide the comparable brace length asymmetry to said running brace as pertains to the length asymmetry of said runner, wherein the distance between the hip joint and the heel of said runner at the beginning of heel strike is less than the distance between the hip joint and the toe of said runner at toe-off when his foot leaves the ground, and

one or more foot couplings for attaching said runner's foot with said brace foot, wherein said running aid must be shaped and positioned so as to not interfere with the running action of said runner, wherein tile elements of said running aid must extend around said runner's leg and foot.

2. The running aid of claim 1 wherein said brace leg comprises a spring mechanism for storage and return of running impact energy and a guide to resist the non-axial load of the impact force of said runner on said spring mechanism, wherein said spring mechanism connects in series with an upper pylon and a lower pylon of said brace leg.

3. The running aid of claim 2 wherein said spring mechanism comprises a series buckling-bow spring further comprising:

a top bow holder,

a bottom bow holder,

one or more mini-bows hingeably interconnecting said top bowholder to said bottom bowholder, wherein said top bow holder and said bottom bow holder make a rigid series connection with said upper pylon and said lower pylon, wherein said mini-bows are confined by said top and bottom bow holders so as to resist in parallel the compression of said top and bottom bow holders together, wherein said mini-bows are almost straight when not compressed to provide a buckling force curve when loaded, in which case their force curve is approximately a buckling load curve and is approximately constant as said mini-bows deflect under compression.

4. The running aid of claim 2 wherein said spring mechanism comprises a perpendicular-series buckling-bow spring further comprising:

a top bow holder,

a bottom bow holder,

one or more bow stacks each comprising one or more mini-bows aligned parallel to each other, wherein at least one pair of said bow stacks is oriented substantially orthogonal to at least one other said bow stack, wherein said top bow holder and said bottom bow holder make a rigid series connection with said upper pylon and said lower pylon, wherein said mini-bows are confined by said top and bottom bow holders so as to resist in parallel the compression of said top and bottom bow holders, wherein said mini-bows hingeably connect said top bowholder to said bottom bowholder, wherein said mini-bows are almost straight when not compressed to provide a buckling force curve when loaded, in which case their force curve is approximately a buckling load curve and is approximately constant as said mini-bows deflect under compression, wherein orthogonal orientation of one said bow stack with another provides a resistance to torque accompanying non-axial loading of said perpendicular buckling-bow spring and resultant tilting of said upper pylon with respect to said lower pylon, wherein said perpendicular buckling-bow spring also functions as said guide.

5. The running aid of claim 2 wherein said guide comprises a hip link rotatably connected to said hip pivot and a thigh link element slidingly connected with said hip link and rotatably connected with said knee pivot, wherein said spring mechanism comprises a pulley bucky-bow spring comprising:

a bow spring,

a bow pulley block,

a bow guide rigidly attached to said bow pulley block and slidingly connected to the center region of said bow spring,

a bow pulley system comprising one or more pulleys,

bow strings which are connected to either end of said bow spring and which pass around one or more pulleys in said pulley system,

a draw string catch, and

a draw string which is attached at one end to said draw string catch and which passes around one or more pulleys in said pulley system and which transmits the force of said bow spring to resist the sliding of said hip link with respect to said thigh link element, wherein said bow strings extend from either end of said bow spring inward toward each other and then around said pulley system so that the turning of one or more pulleys in said pulley system causes the ends of said bow spring to be pulled together, wherein said bow guide prevents said bow spring from rotating around said pulley block in the sense that an imaginary line connecting said bow ends does not rotate about said pulley block, wherein said bow spring may be almost straight when uncompressed to provide a buckling force curve when loaded, in which case the force curve is approximately constant as said bow spring is compressed.

6. The running aid of claim 5 wherein said pulley system comprises an inner pulley and an outer pulley for creating a mechanical advantage between the relative travel of said bow strings and said draw string, wherein the compression and force of said brace leg can be varied for a given compression of said bow spring.

7. The running aid of claim 6 wherein said harness further comprises a hip rim encircling said runner and a back support extending up and behind said runner's back, wherein said bow pulley block is rigidly attached to said back support, wherein said pulley system allows a single said bow spring to support one or both said brace legs during foot stance, wherein said pulley system further comprises a transfer system of pulleys to route said draw string from said bow pulley block to engage both of said thigh link elements at foot strike.

8. The running aid of claim 2 wherein said spring mechanism comprises a constant-force gas spring which comprises:

a gas spring,

gas tubes,

a gas reservoir connected to said gas spring by said gas tubes, and

a check valve, wherein the gas in said gas spring and said gas reservoir is pre-pressurized, wherein the ratio of volume of gas in said reservoir to volume in said gas spring is sufficiently high so that the pressure in said gas spring does not change substantially as said gas spring is compressed, wherein the force curve of said constant-force gas spring is substantially constant over its range of compression.

9. The running aid of claim 8 wherein said constant-force spring system further comprises a gas pump for replenishing pressurized gas in said gas spring lost during strokes of said gas spring.

10. The running aid of claim 2 wherein said brace leg comprises an active power source which acts in series with said spring system to impart thrust to said runner, wherein the force imparted by said active power source compresses said spring system which then thrusts with the combined energy from said active power source and impact energy stored in said spring system during impact of said runner's foot with the ground.

11. The running aid of claim 1 wherein said brace leg comprises a swing-phase length-change means to shorten the length of said brace leg during swing phase and a length-change lock to prevent any change of the length of said brace leg during stance.

12. The running aid of claim 11 wherein said length-change lock comprises a means for guaranteed release of said length-change lock at toe-off.

13. The running aid of claim 12 wherein said swing-phase length-change means comprises

a thigh-link rotatably coupled with said harness,

a knee pivot rotatably attached to said thigh-link and which further comprises a knee pivot lock corresponding to said length-change lock,

a tibia link rotatably attached to said knee pivot, wherein the engagement of said pivot lock prevents said tibia link from rotating about said knee pivot with respect to said thigh-link assembly during the foot-stance phase portion of a stride cycle, wherein the disengagement of said pivot lock allows said tibia link to rotate freely about said knee pivot with respect to said thigh-link assembly during the swing phase portion of a stride cycle, wherein said tibia link is rotatably attached to said brace foot.

14. The running aid of claim 13 wherein said knee pivot lock comprises a hyper-extended knee lock which further comprises:

a knee pivot block,

a thigh-link constraint at the bottom end of said thigh link, and

a tibia-link constraint at the top end of said tibia link, wherein said thigh-link constraint impinges against said tibia link constraint during the foot stance period when said brace foot is in contact with the ground, thereby ensuring that the structural support comprising said thigh link, said knee pivot lock and said tibia link is rigid, wherein said rigid state is called hyper-extension.

15. The running aid of claim 14 wherein said wherein said means for guaranteed release and said foot coupling comprise a heel pivot rotatably attached to the back of the foot of said runner and to the bottom of said tibia link, wherein the rearward location of said heel pivot ensures that said tibia link and said thigh link rotate freely so as to move said thigh link constraint away from said tibia link constraint when the foot of said runner lifts said heel pivot.

16. The running aid of claim 14 wherein said means for guaranteed release comprises a knee tether connecting said knee pivot with the knee of said runner.

17. The running aid of claim 14 wherein said tibia link comprises a four-bar foot-lift assembly comprising:

a thigh-link extension rigidly extending downward from said thigh link,

a foot-lift link hingeably connected to said thigh-link extension, a toe pivot at the front of said brace foot wherein said foot-lift link is hingeably connect to said brace foot via said toe pivot,

an ankle pivot located at the ankle of said brace foot,

a thigh-link-extension front constraint rigidly attached to and extending forward from the bottom of said thigh-link extension,

a foot-lift-link front constraint rigidly attached to and extending forward from the top of said foot-lift link, wherein said thigh-link-extension front constraint impinges said foot-lift-link front constraint to limit the hyper-extension of said foot-lift link with respect to said thigh-link extension at heel-down, wherein the rearward location of said heel pivot ensures that said foot-lift link and said thigh-link extension rotate freely so as to move said thigh-link-extension front constraint away from said foot-lift-link front constraint at toe-off, wherein said foot-lift link lifts the front of said brace foot via said front pivot during swing phase thereby preventing downward motion of the front of said brace foot during swing phase.

18. The running aid of claim 14 wherein said hyper-extended knee lock comprises a four-bar knee joint which comprises four bars hingeably interconnected and one side of which is fixably attached to one said bar and another side of which is fixably attached to another said bar.

19. The running aid of claim 14 wherein said hyper-extended knee lock comprises a hyperlocker to ensure hyper-extension before foot strike.

20. The running aid of claim 19 wherein said knee pivot self lock comprises a knee-lock hyper-extension means called a hyperlocker, wherein said hyperlocker accelerates the extension unfolding of said thigh link and said tibia link about said knee pivot to ensure that said knee pivot self lock is hyper-extended at heel-strike, wherein said hyperlocker comprises

a rim beam pulley rigidly attached to said harness,

a thigh-link pulley attached to said thigh-fink,

a slide-pulley cord attached to said rim beam, wherein the forward swinging of said thigh link causes the upward pulling on said slide-pulley cord through said thigh-link pulley,

a hyper-extension means keyed to the upward pull on said slide-pulley cord, wherein said tibia link is forced to hyper-extend about said knee pivot (with respect to said thigh link) during the latter part of swing phase, wherein said tibia link can be freely folded by the upward force of said runner's foot on said brace foot at toe-off.

21. The running aid of claim 19 wherein said hyperlocker comprises a self-hyperlocker further comprising

a closer cord,

a cord-path system which routes said closer cord through a path along both the back side and the front side of said thigh and tibia links about said knee pivot, wherein said closer cord is fixed at a first end to said brace leg, wherein the cord-path length on the back side of said knee pivot increases more rapidly than the cord-path length on the front side of said knee pivot during said extension unfolding,

a closing spring located on the front side of said brace leg so as to pull into hyper-extension said thigh and tibia links when engaged,

a spring release connected to said brace leg and to a second end of said closer cord, and

a pawl system, wherein the configuration of said cord-path system causes said closer cord to pull taut at a particular flexion angle, of said thigh link with respect to said tibia link, as said brace leg extends during swing phase—causing said closer cord to pull against said closing spring accelerating said extension unfolding, wherein said spring release is triggered to release said closing spring from acting against said closer cord as hyper-extension occurs, thereby allowing easy and force-free folding of said tibia link with respect to said thigh link at toe-off, and

a reset spring for re-engaging said closer cord with said closing spring during swing phase when said closer cord becomes slack, wherein said self hyperlocker is keyed to said flexion angle for guaranteed hyper-extension using said closing spring, and it is keyed to said hyper-extension for guaranteed release of said closing spring as folding begins.

22. The running aid of claim 14 wherein said knee pivot lock further comprises a "hyper-extension bounce back" prevention means to prevent the impact force of the closing of said knee pivot from causing said brace leg to bounce back out of hyper-extension wherein said "hyper-extension bounce back" prevention means also comprises

a bladder step, in the impinging surface of said tibia link that contacts said thigh link during said hyper-extension, wherein said bladder step forms a recessed region between said impinging surface and said thigh link when they are aligned,

a pinched bladder attached to said bladder step, filled with fluid, and protruding above the level said impinging surface,

a pinch band, and

an elastomer nipple, wherein said pinched band constricts said pinched bladder to form said elastomer nipple and to form an orifice between said elastomer nipple and said pinched bladder, wherein said elastomer nipple lies outside of said bladder step, wherein said fluid is free to flow through said orifice from said pinched bladder to said elastomer when said hyper-extension occurs—and during swing phase, wherein the restricted flow of said fluid through said orifice dissipates said impact force of closing.

23. The running aid of claim 12 wherein said knee pivot lock comprises a variable-angle knee lock comprising:

a shaft,

shaft spacers,

a shaft boss rigidly attached to and subtending a shaft locking angular range of said shaft, wherein said shaft boss further comprises a plurality of shaft circumferential strips rigidly attached to said shaft boss by a boss attachment structure, wherein said shaft circumferential strips are spaced apart one from another by said shaft spacers, wherein said shaft circumferential strips extend in the shaft longitudinal direction from their attachment location,

collar spacers,

a split-collar encircling said locking shaft wherein said split-collar further comprises a bearing collar section and a locking collar section, wherein said locking collar section further comprises a plurality of collar circumferential strips rigidly attached to said locking collar section by a collar attachment structure, wherein said collar circumferential strips are spaced apart one from another by said collar spacers, wherein said collar circumferential strips extend in the shaft longitudinal direction from their attachment location, wherein said bearing collar section forms a bearing surface with the portion of said shaft not subtended by said shaft locking angular range thereby allowing free pivoting of said split-collar about said shaft when said bearing surface is loaded, wherein said locking collar section subtends a collar locking angular range, wherein said shaft circumferential strips interleaf with said collar circumferential strips over an overlap longitudinal region, wherein said locking collar section has a collar recess for allowing said locking collar section to freely impinge said collar circumferential strips and said bearing circumferential strips at said longitudinal region without constraint by said boss attachment structure, wherein the radial extent of the inner portion of said shaft boss is sufficient to allow said locking collar section to freely impinge said collar circumferential strips and said bearing circumferential strips at said overlap longitudinal region without constraint by said collar attachment structure, wherein said locking collar section forms a locking surface with the portion of said shaft subtended by said shaft locking angular range thereby ensuring locking of rotation of said split-collar about said shaft when said locking surface is loaded.

24. The running aid of claim 23 wherein said tibia link comprises

an upper-tibia link hingeably connected to said knee pivot,

a lower-tibia link hingeably connected with said ankle pivot,

a tibia pivot for hingeably connecting said upper-tibia link with said lower-tibia link,

a lower-tibia-link front constraint rigidly attached to and extending forward from the top of said lower-tibia link,

an upper-tibia-link front constraint rigidly attached to and extending forward from the bottom of said upper-tibia link, wherein said upper-tibia-link front constraint impinges said lower-tibia-link front constraint to limit the hyper-extension of said lower-tibia link with respect to said upper-tibia link at heel-down, wherein the rearward location of said heel pivot ensures that said tibia link and said thigh link rotate freely so as to move said lower-tibia-link front constraint away from said upper-tibia-link front constraint at toe-off, wherein any residual loading of said variable-angle knee lock at toe-off is released due to the folding of said upper-tibia link with respect to said lower-tibia link,

a lower-tibia-link rear constraint rigidly attached to and extending backward from the top of said lower-tibia link,

an upper-tibia-link rear constraint rigidly attached to and extending rearward from the bottom of said tipper-tibia link, wherein said tipper-tibia-link rear constraint impinges said lower-tibia-link front constraint to limit the folding of said lower-tibia link with respect to said tipper-tibia link during swing phase, and

a closing mechanism to ensure that said lower-tibia-link front constraint impinges against said upper-tibia-link front constraint at heel-down, thereby ensuring that the structural support comprising said upper-thigh link, said tibia pivot and said lower-tibia link is rigid during stance phase.

25. The running aid of claim 12 wherein said swing-phase length-change means comprises a lockable slider comprising

a guide means comprising an upper and lower guide slidably interconnected,

wherein said guide means is a series component of said brace leg,

a slider lock corresponding to said length-change lock, and

a slider-lock trigger, wherein ground contact of said brace foot causes said slider lock to lock said lockable slider, wherein said lockable slider is a series component of either said thigh link or said tibia link.

26. The running aid of claim 25 wherein said knee pivot lock comprises a lockable hydraulic slider comprising

one or more hydraulic cylinders containing fluid and a fluid line,

one or more hydraulic pistons which slide within said hydraulic cylinders moving said fluid through said fluid line,

a reservoir connecting said fluid line to said reservoir via an exit branch and a return branch,

a triggered valve system which prevents or restricts said fluid from exiting said hydraulic cylinder during stance, thereby locking said lockable hydraulic slider, and which allows said fluid to freely exit and enter said hydraulic cylinder during swing phase, thereby allowing free compression and expansion of said lockable hydraulic slider, wherein said lockable hydraulic slider is rotatably attached to both thigh link and said tibia link, wherein the locking of said lockable hydraulic slider locks said knee pivot lock.

27. The running aid of claim 25 wherein said lockable slider comprises a lockable hydraulic slider comprising

one or more hydraulic cylinders containing fluid and a fluid line,

one or more hydraulic pistons which slide within said hydraulic cylinders moving said fluid through said fluid line,

a reservoir connecting said fluid line to said reservoir via an exit branch and a return branch, a triggered valve system which prevents or restricts said fluid from exiting said hydraulic cylinder during stance, thereby locking said lockable hydraulic slider, and which allows said fluid to freely exit and enter said hydraulic cylinder during swing phase, thereby allowing free compression and expansion of said lockable hydraulic slider.

28. The running aid of claim 12 wherein said swing-phase length-change means comprises a lockable slider comprising

a guide means comprising an upper and lower guide slidably interconnected,

wherein said guide means is a series component of said brace leg,

a slider lock corresponding to said length-change lock, and

a slider-lock trigger, wherein ground contact of said brace foot causes said slider lock to lock said lockable slider.

29. The running aid of claim 28 wherein said lockable slider comprises a lockable hydraulic slider comprising

one or more hydraulic cylinders containing fluid and a fluid line,

one or more hydraulic pistons which slide within said hydraulic cylinders moving said fluid through said fluid line,

a reservoir connecting said fluid line to said reservoir via an exit branch and a return branch,

a triggered valve system which prevents or restricts said fluid from exiting said hydraulic cylinder during stance, thereby locking said lockable hydraulic slider, and which allows said fluid to freely exit and enter said hydraulic cylinder during swing phase, thereby allowing free compression and expansion of said lockable hydraulic slider.

30. The running aid of claim 1 wherein said brace leg comprises a front/back brace leg further comprising

a front hip pivot, p**1** a back hip pivot,

a front thigh link pivotly attached to the front of said harness with said front hip pivot,

a back thigh link pivotly attached to the front of said harness with said back hip pivot,

an optional front bow attached to said front thigh link,

a optional back bow attached to said back thigh link,

a front tibia link pivotly attached to the front of said brace foot,

a back tibia link pivotly attached to the back of said brace foot,

a front knee pivot connecting said front thigh link and said front tibia link,

a back knee pivot connecting said back thigh link and said back tibia link,

one or more hyper-extending knee pivot locks at the locations of said front and back knee pivots to prevent pivot hyper-extension,

an optional back hydraulic knee lock pivotly attached to said back thigh link and said back tibia link,

an optional front hydraulic knee lock pivotly attached to said front thigh link and said front tibia link,

a front ankle pivot for the connection of said front tibia link to said brace foot,

a back ankle pivot for the connection of said back tibia link to said brace foot,

a knee cross link connecting said front knee pivot with said back knee pivot,

wherein said front and back hip pivots are located approximately above the center of each leg, wherein the front and back locations of said brace leg elements prevents interference with said runner's legs.

31. The running brace of claim 30 wherein said harness comprises a front/back pack extension further comprising

a front pack-frame pivot at the front of said harness,

a back pack-frame pivot at the back of said harness,

a front pack frame attached to the front of said harness via said front pack-frame pivot,

a back pack frame attached to the back of said harness via said back pack-frame pivot,

pack straps,

a front pack secured to said front pack frame be said pack straps, and

back pack secured to said back pack frame be said pack straps, wherein said brace legs continuously support said front and back packs as said runner walks or runs.

32. The running aid of claim 1 wherein said brace foot comprises a curved surface on the bottom of said brace foot.

33. The running aid of claim wherein said brace foot comprises one or more lockable hinged extensions in the front or back of said brace foot which can be locked for running or walking on relatively flat or shallow sloping terrain and which can be retracted for running or walking on steps or steep terrain.

34. The running aid of claim 28 wherein said slider-lock trigger comprises an array of ground levers rotatably attached along the bottom of said brace foot,

a ground pulley, and

a ground trigger cord fixably interconnecting each said ground lever with its neighbor and passing around said ground pulley and up to said slider lock, wherein ground contact of any one of said ground levers causes said ground pulley to engage said slider lock.

35. The running aid of claim 12 wherein said means for guaranteed release comprises a foot-coupling guaranteed release which allows a runner's foot to freely move up at toe-off without lifting said brace foot for a prescribed time and distance and which ensures that said brace foot is lifted that same distance with respect to said runner's foot during swing phase, wherein any force between said runner's foot and said brace foot is zero for said prescribed time—allowing said length-change lock to release, wherein said brace foot is not allowed to hang below said runner's foot and trip said runner as said brace foot approaches heel-strike.

36. The energy-efficient running brace of claim 1 wherein said harness comprises:

a plurality of harness sections wherein some harness sections are upward-pull sections which naturally support an upward pull and some sections are downward-pull sections which naturally support a downward pull,

vertical connectors between said upward-pull sections and said downward-pull sections, and p**1** a vertical tightening mechanism for cinching said upward-pull sections and said downward-pull sections against each other via said vertical connectors, wherein the compliance between said harness and said runner is reduced.

37. The running aid of claim 1 wherein said harness comprises a load-tightening mechanism to grip more tightly the body parts of a runner as the brace load of her weight between said support system and said harness increases, wherein the increased gripping force of the harness on said body parts is provided by said brace load, wherein a tightening distance is associated with said gripping and said tightening distance is the decrease in circumferential length of said harness due to said gripping.

38. The running aid of claim 37 wherein said load-tightening mechanism comprises one or more load-tightening cuffs encircling said body parts and a tightening mechanism to re-direct said brace load from an approximate vertical direction to an approximate horizontal direction to accomplish said gripping force to tighten said load-tightening cuffs.

39. The running aid of claim 37 wherein said load-tightening mechanism comprises a compressible woven harness, wherein said brace load pulls upward on the upper portion of said compressible woven harness causing said compressible woven harness to shrink in size, thereby increasing said gripping force, wherein said compressible woven harness comprises braids interwoven among themselves and extending along and around said body parts.

40. The running aid of claim 37 wherein said load-tightening mechanism comprises a mechanical-advantage mechanism wherein the distance or travel of the connection point between said brace leg and said harness is multiplied by a mechanical advantage to yield a greater value for said tightening distance, wherein the compliance between said brace leg and said harness under load is reduced by a factor approximately equal to said mechanical advantage.

41. The running aid of claim 1 wherein said harness comprises an arm-load harness to partially support said brace load with the arms of said runner.

42. The running aid of claim 1 wherein said harness comprises a load-equalizer means to distribute said brace load over all portions of said harness, wherein said load-equalizer means further comprises a system of pulleys and cables to evenly distribute said brace load over all portions of said harness.

43. The running aid of claim 1 wherein said harness comprises adjustable bands and fitting clamps wherein said adjustable bands are pulled through said fitting clamps and clamped to snugly fit said harness to said body parts.

44. The running aid of claim 38 wherein said tightening mechanism comprises:

a spreader bar,

cuff buckles,

one or more tightening pulleys,

tightening cords, and

stay cords, wherein said load-tightening cuffs are attached on either end to said cuff buckles, wherein said spreader bar is mounted to said load-tightening cuff near an end, wherein said tightening pulleys are mounted to said spreader bar, wherein said stay cords are connected to said brace leg and transmit said brace load to tighten said tightening cuff by passing around said tightening pulleys which re-direct said brace load direction from a vertical to a horizontal direction, wherein said tightening cords also pass around said tightening pulleys and attach to said cuff buckles to transmit said brace load to pull together the ends of said tightening cuff, thereby tightening said tightening cuff.

45. The running aid of claim 25 wherein said tightening mechanism comprises:

a spreader bar,

cuff buckles,

one or more tightening levers,

tightening cords, and

stay cords, wherein said load-tightening cuffs are attached on either end to said cuff buckles, wherein said spreader bar is mounted to said load-tightening cuff near an end, wherein said tightening levers are mounted to said spreader bar, wherein said stay cords are connected to said brace leg and transmit said brace load to tighten said tightening cuff by pulling on first ends of said tightening levers to re-direct said brace load direction from a vertical to a horizontal direction, wherein said tightening cords are connected both to second ends of said tightening levers and also to said cuff buckles—to transmit said brace load to pull together the ends of said tightening cuff, thereby tightening said tightening cuff.

46. The running aid of claim 39 wherein said compressible woven harness comprises combination mechanical/weave load-tightener comprising:

stay cords,

pulley block attached to stay cords,

one or more block pulleys mounted on said pulley block,

top hoop sliding mounted to the top of said compressible woven harness,

bottom hoop sliding mounted to the bottom of said compressible woven harness,

vertical spreader bar mounted to said top hoop,

one or more spreader pulleys mounted to the bottom of said vertical spreader bar, and

cables, wherein said vertical spreader bar pulls upward on said compressible woven harness via said top hoop, wherein this upward pull is exerted by said cables which pass from said vertical spreader bar around said block pulleys and then down to pass around said spreader pulleys to pull down on bottom hoop, thereby spreading said compressible woven harness and causing it to circumferentially contract and grip said body parts.

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