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Mackin

(54) **FOOT STRIKE ENERGY ABSORPTION METHOD FOR SHOES**

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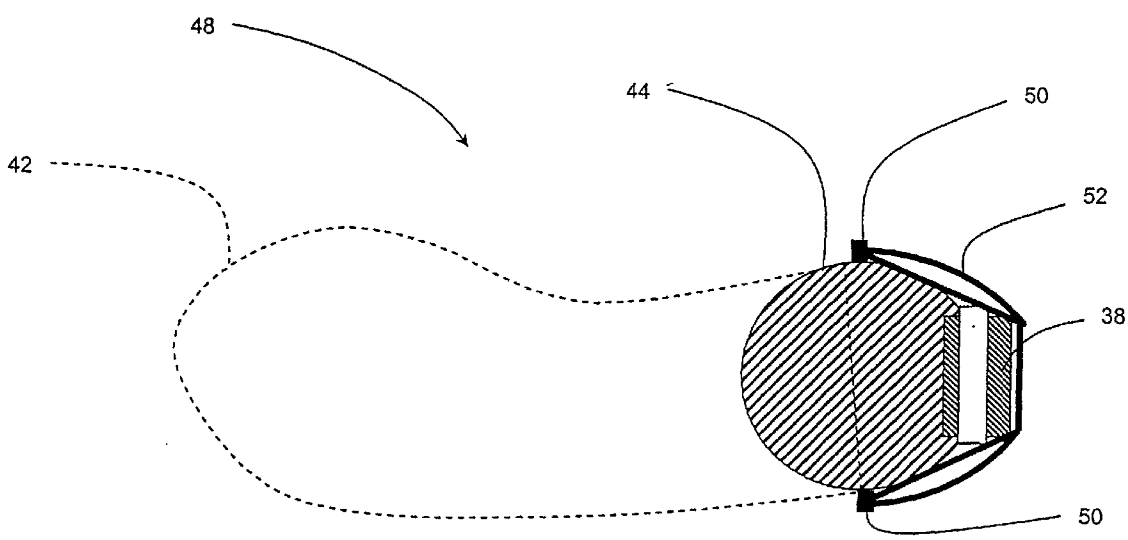
(57) **ABSTRACT**

A system and method for absorbing energy in shoes from an impact force. A variety of mechanical designs convert at least a portion of response of a first member in a direction of applied impact force, such as when a wearer's heel strikes a surface, to response of a second member in another direction. A mechanism absorbs at least some of the energy from the response in the other direction. A design method is also provided which allows a designer of shoes to select specific characteristics of the energy absorbing system, and precisely relate them to the impact load on the wearer. Modular components of the energy absorbing system can thus be produced having variations of the selected characteristic, for providing customizable selection of the energy absorbing system.



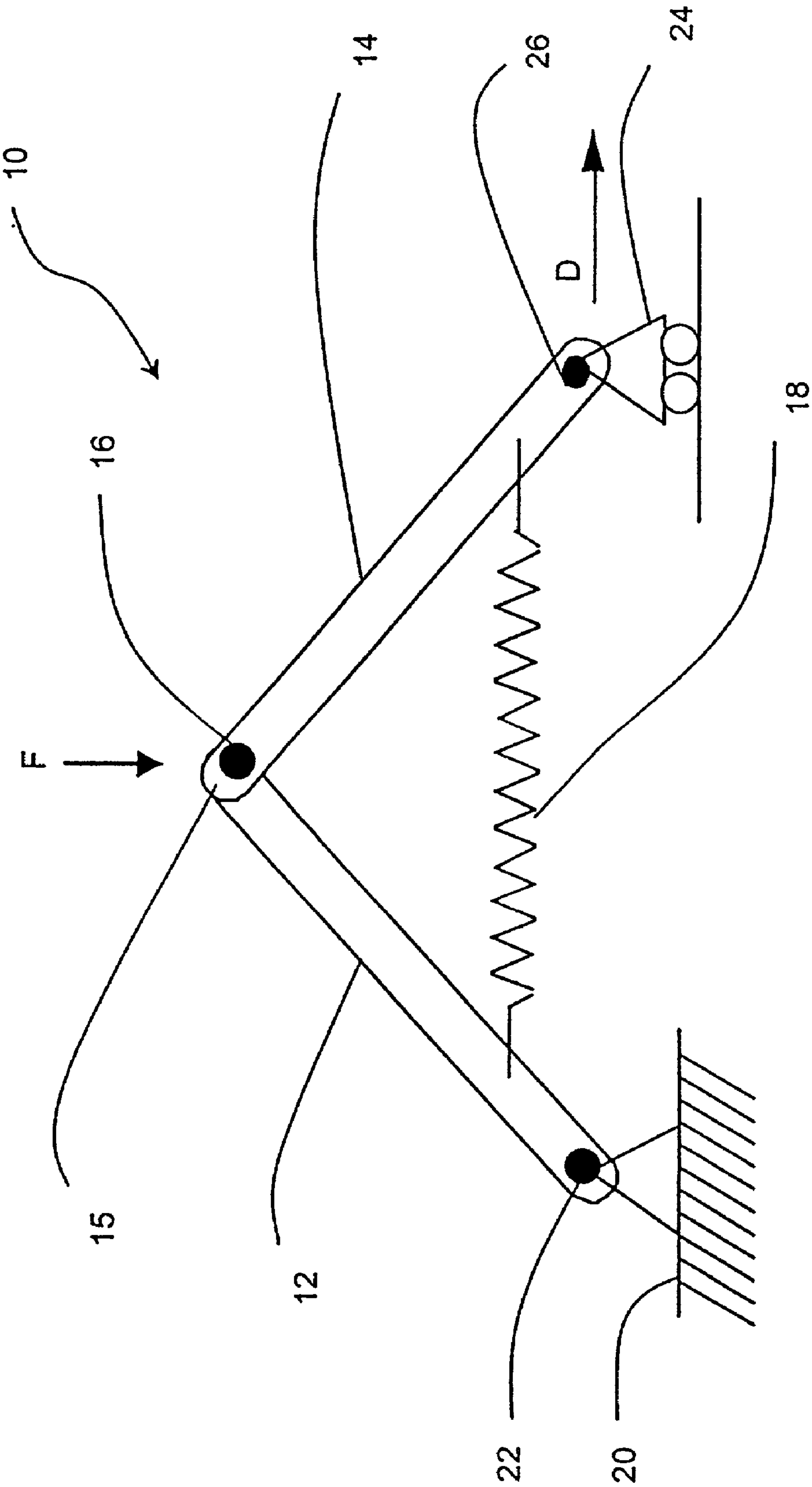


FIG.1

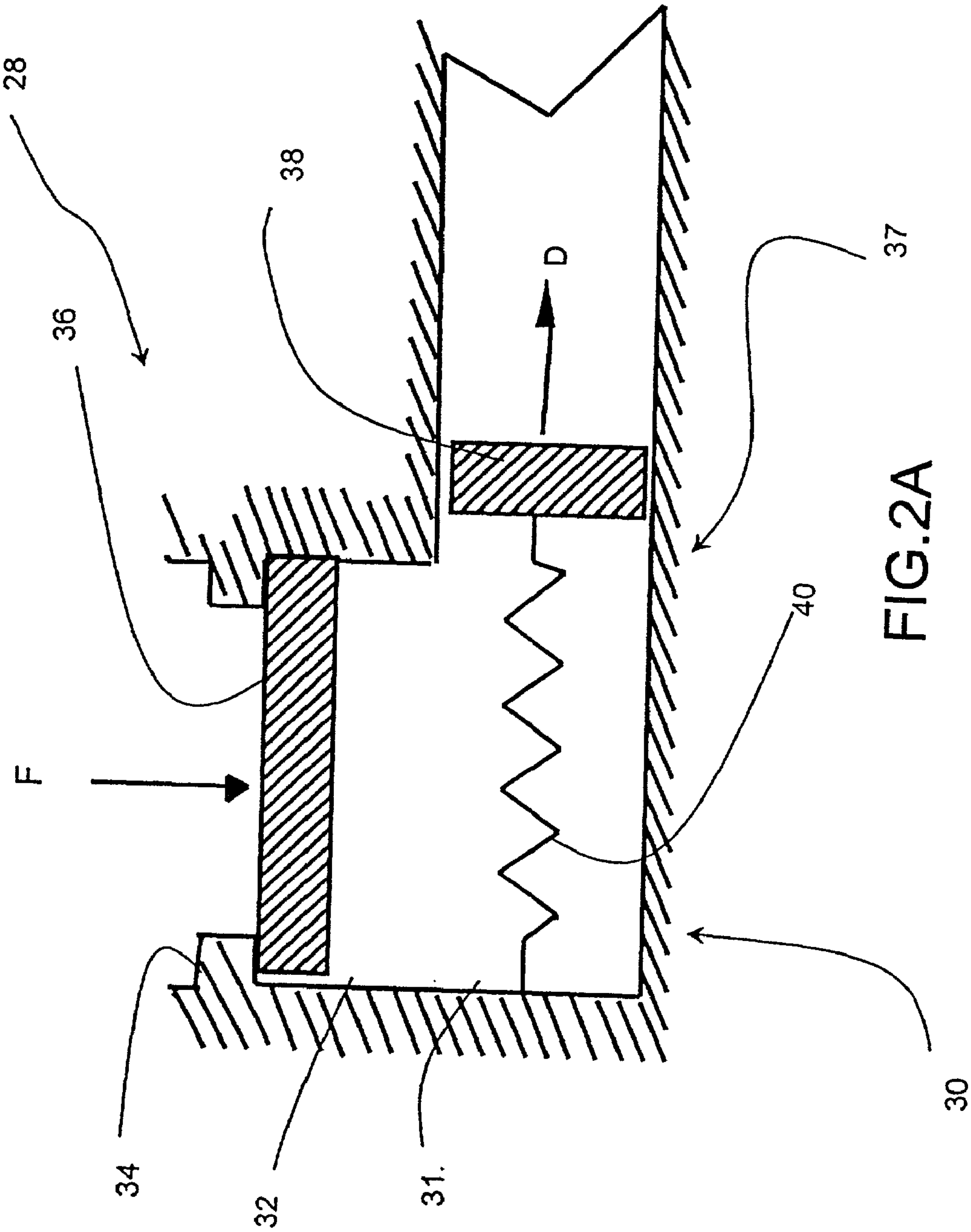


FIG.2A

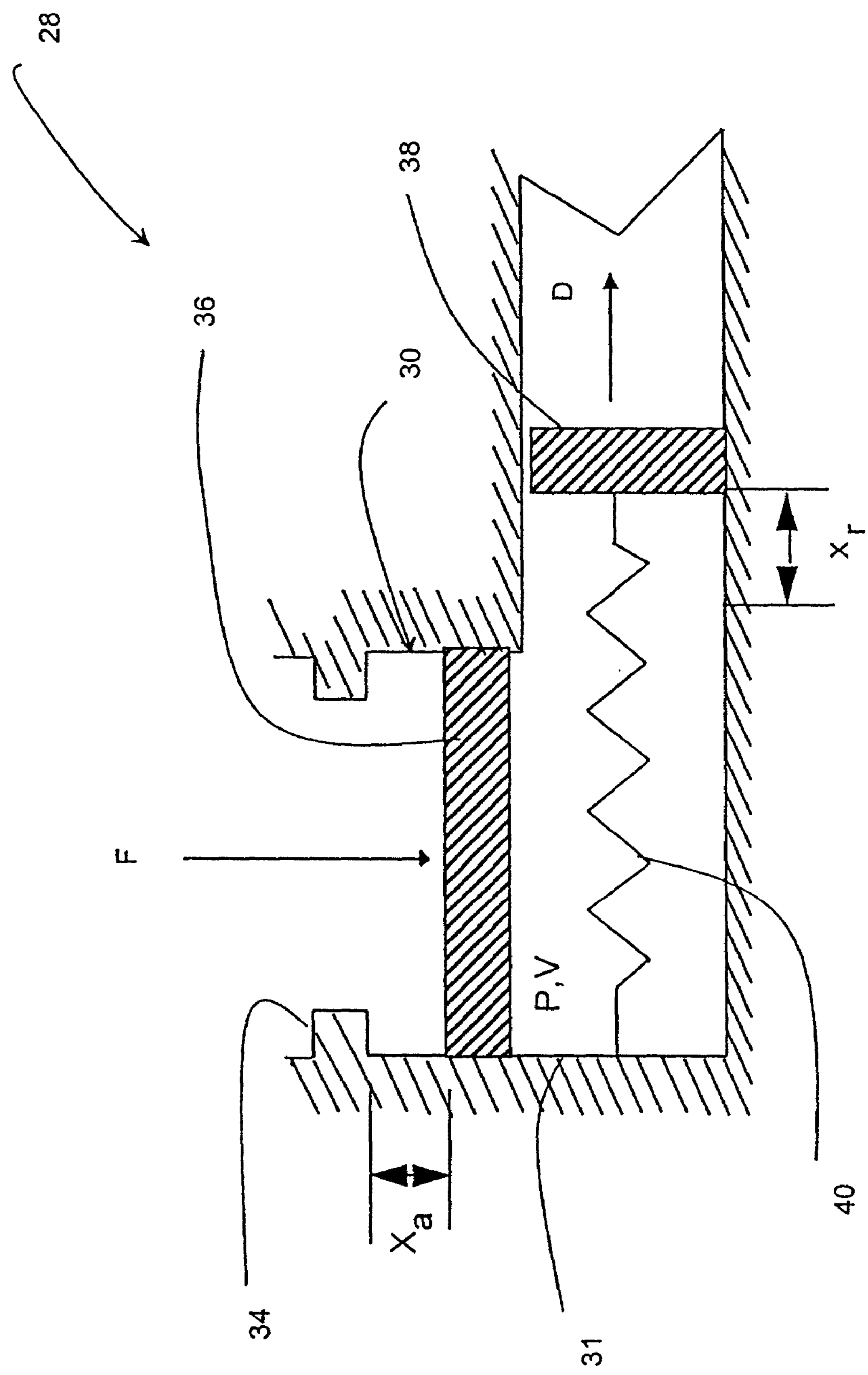


FIG.2B

FIG.3

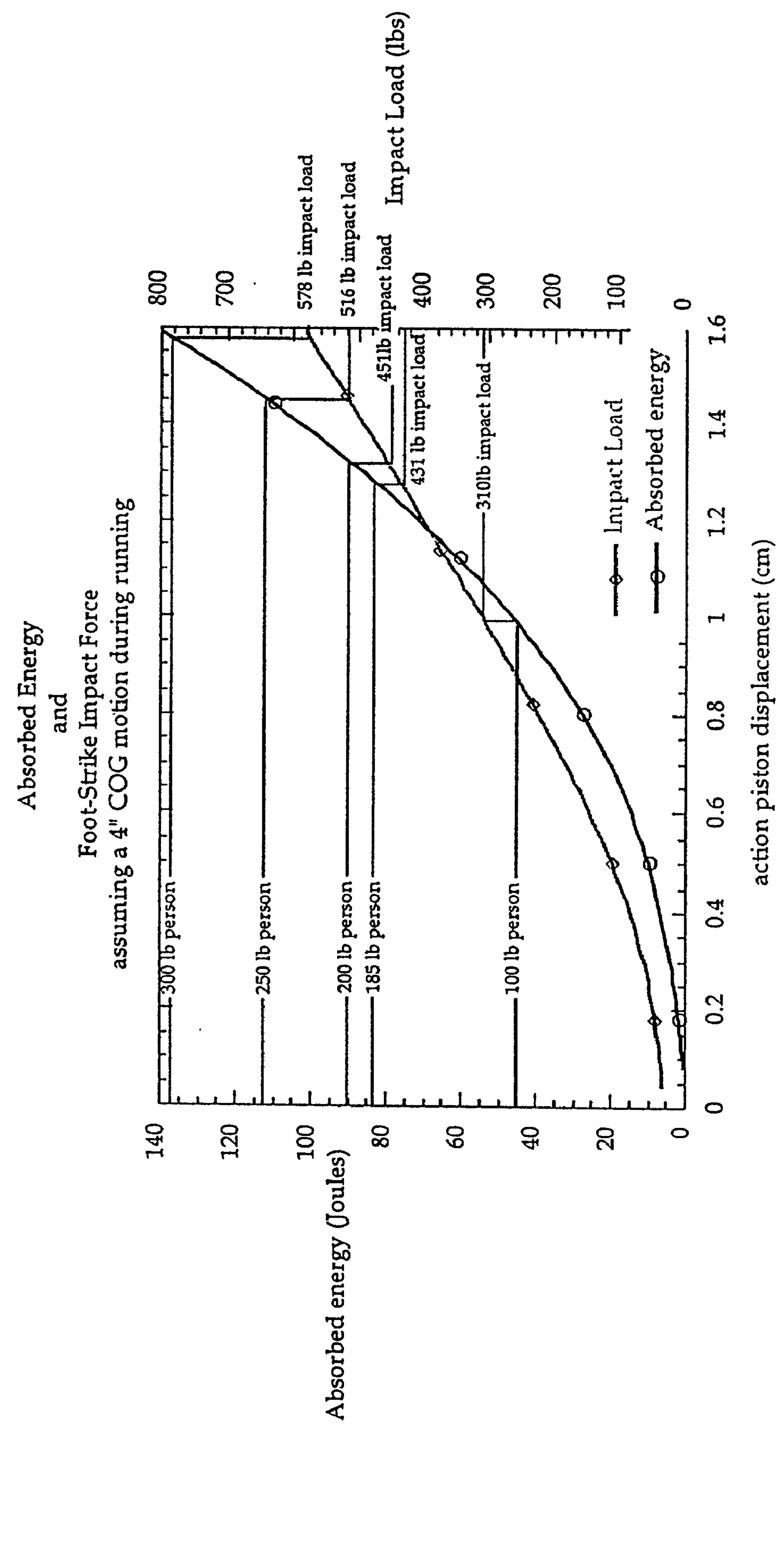

Absorbed Energy
and
Foot-Strike Impact Force
assuming a 4" COG motion during running
300 lb person
250 lb person
200 lb person
185 lb person
100 lb person
578 lb impact load
516 lb impact load
451lb impact load
431 lb impact load
310lb impact load
Impact Load
Absorbed energy
Absorbed energy (Joules)
Impact Load (lbs)
action piston displacement (cm)
0
20
40
60
80
100
120
140
100
200
300
400
700
800
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6

FIG.4

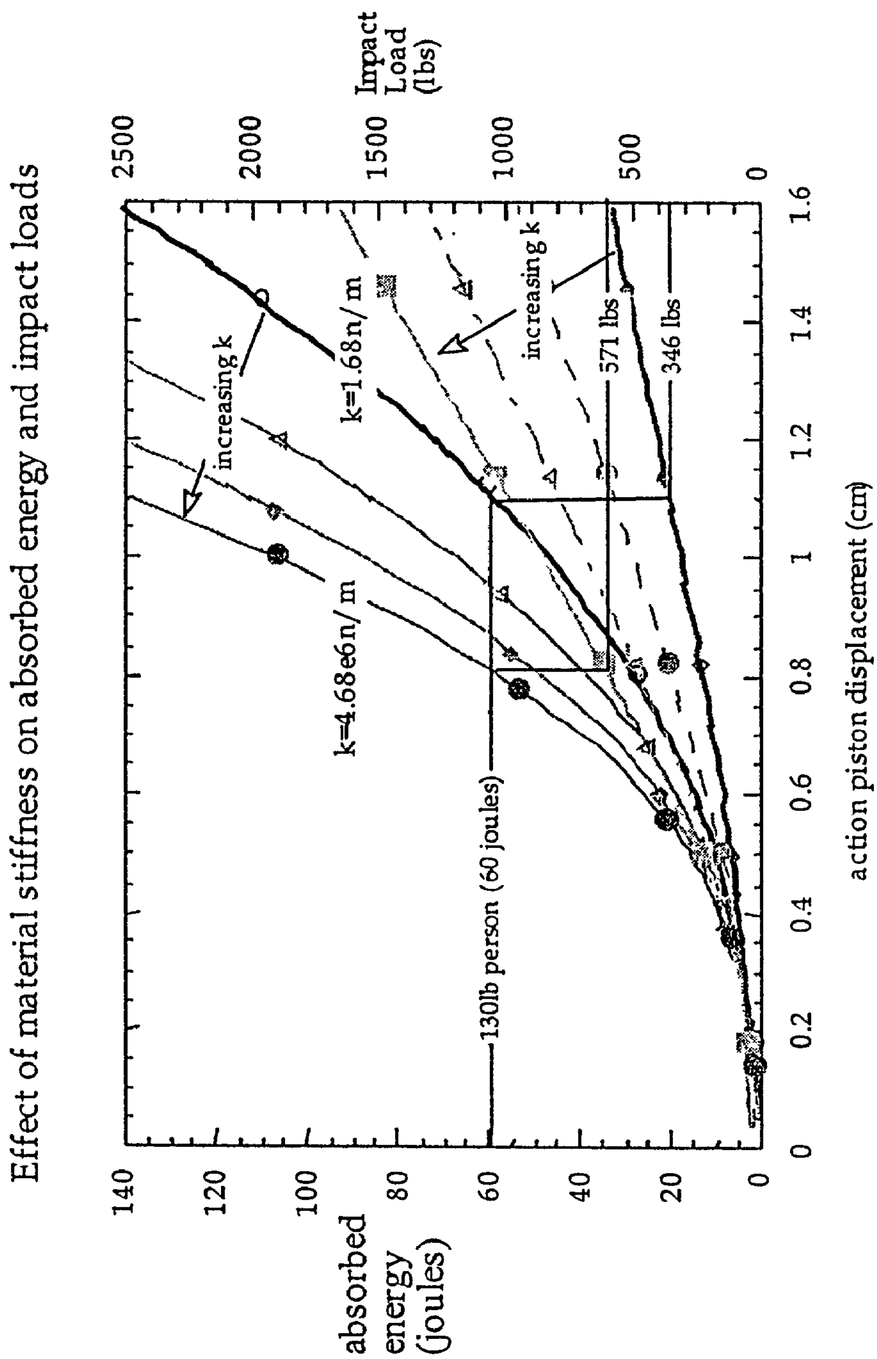

Effect of material stiffness on absorbed energy and impact loads
absorbed energy (joules)
140
120
100
80
60
40
20
0
Impact Load (lbs)
2500
2000
1500
1000
500
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
action piston displacement (cm)
k=4.68e6n/m
k=1.68n/m
increasing k
increasing k
130lb person (60 joules)
571 lbs
346 lbs

FIG.5

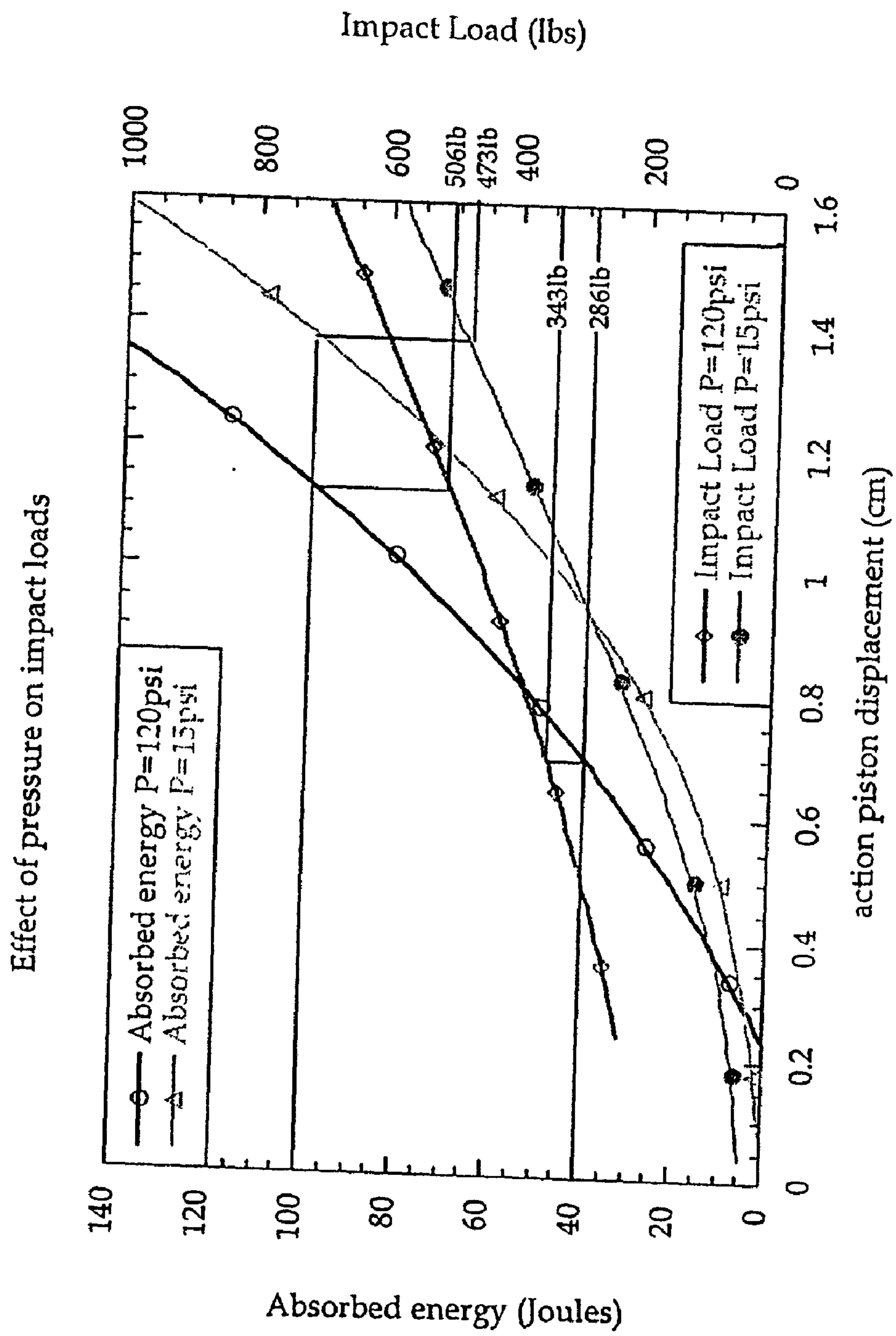
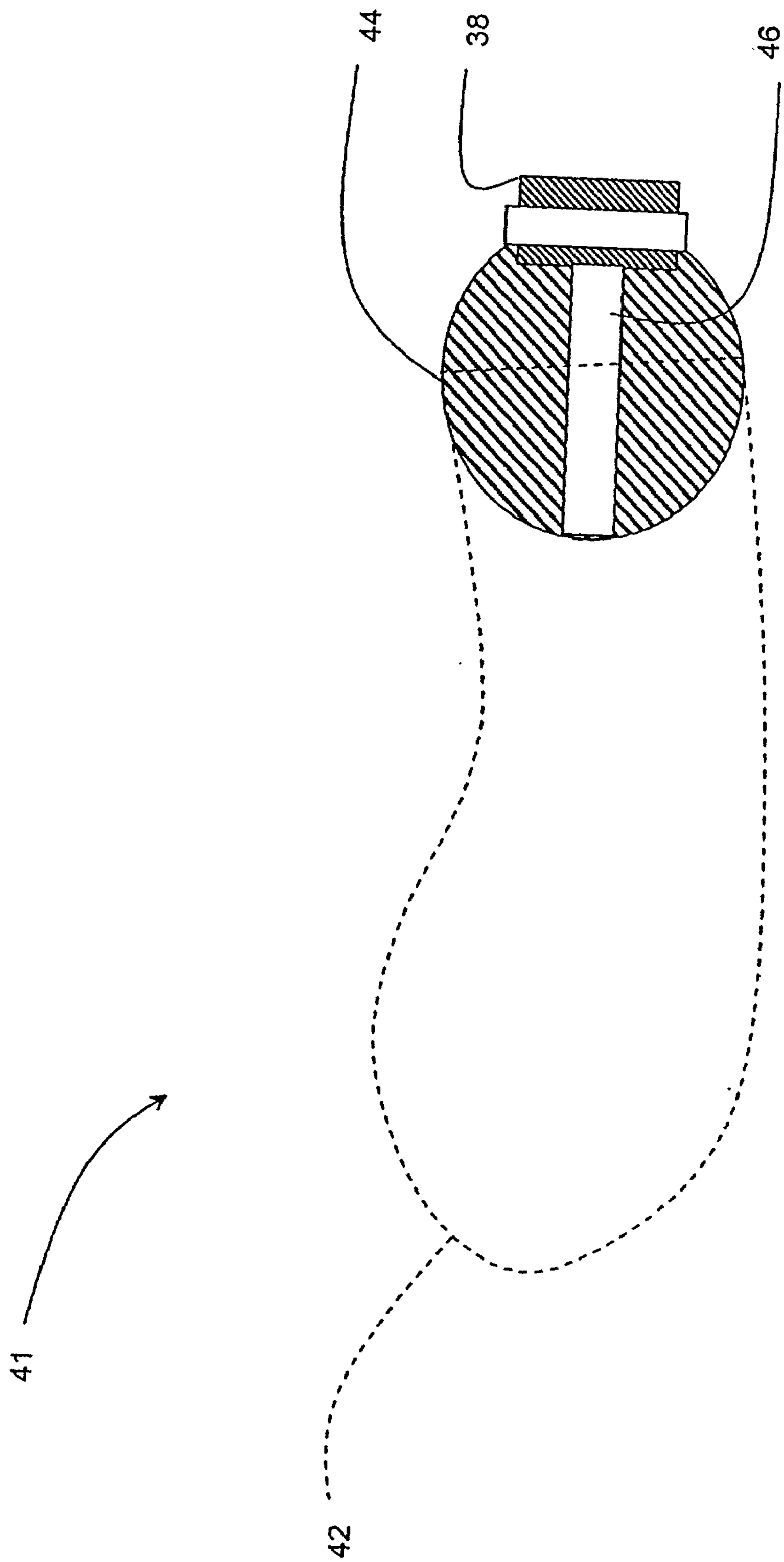

Effect of pressure on impact loads
Impact Load (lbs)
1000
800
600
506lb
473lb
400
200
0
343lb
286lb
Absorbed energy P=120psi
Absorbed energy P=15psi
Impact Load P=120psi
Impact Load P=15psi
140
120
100
80
60
40
20
0
Absorbed energy (Joules)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
action piston displacement (cm)

FIG.6



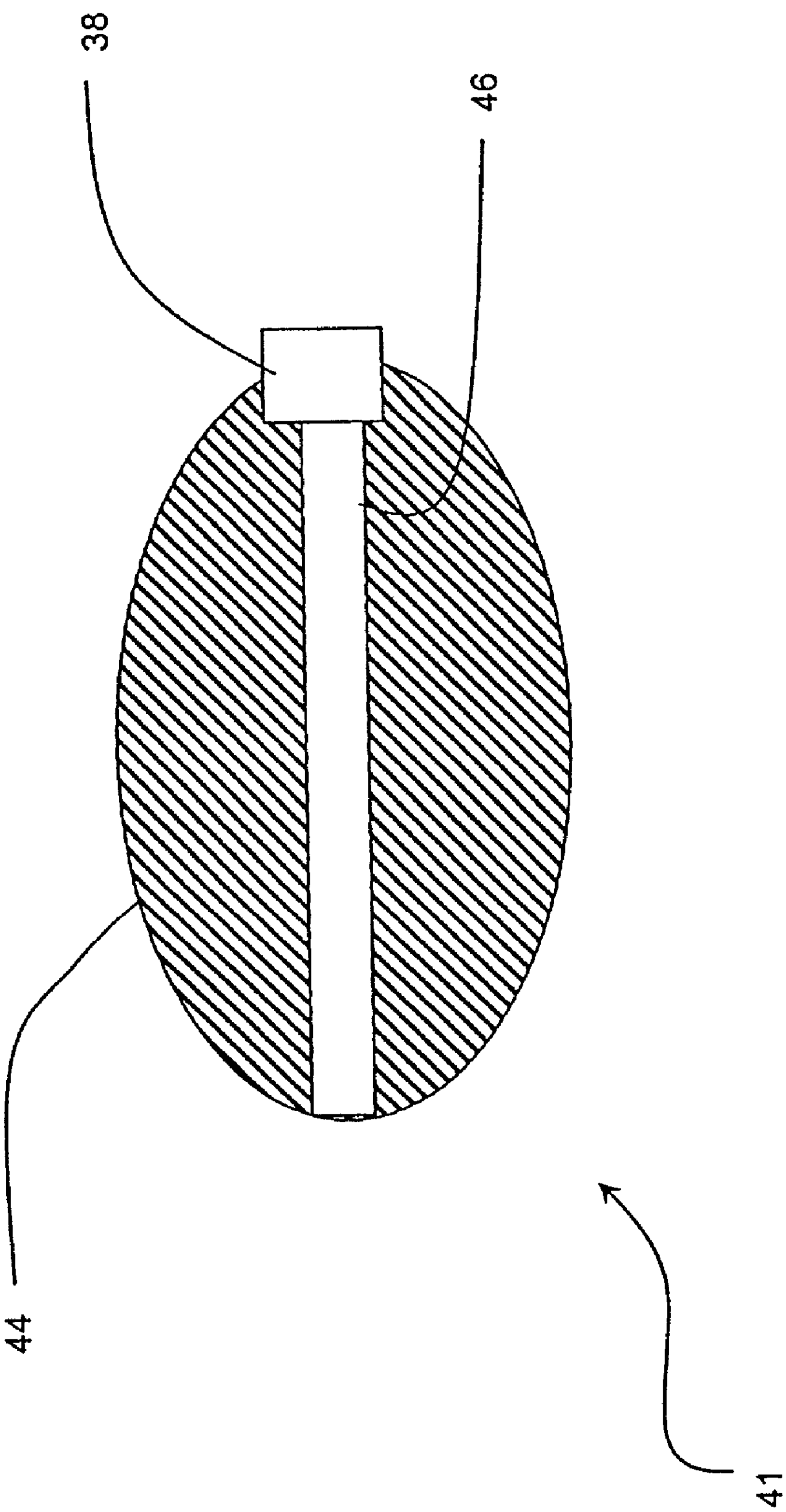


FIG.7

FIG.8

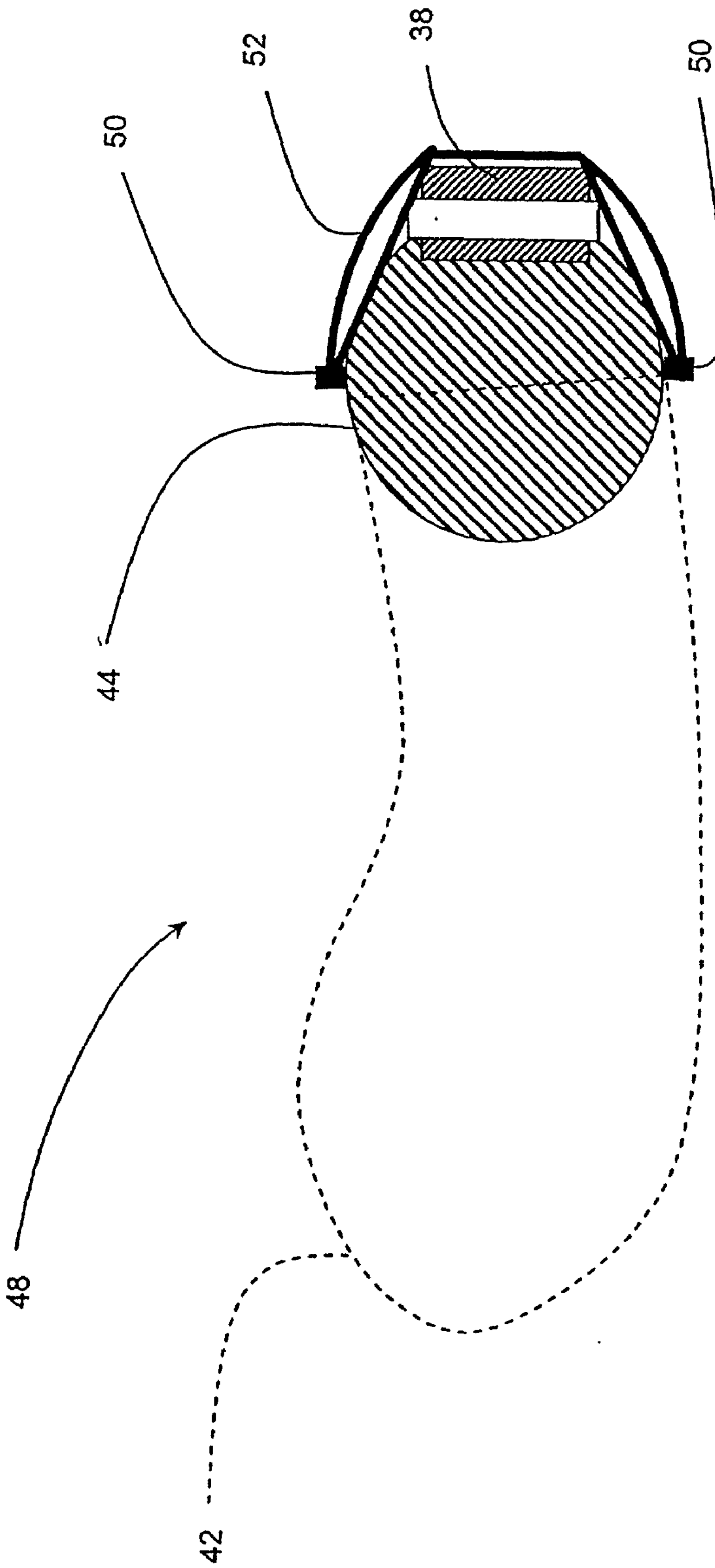
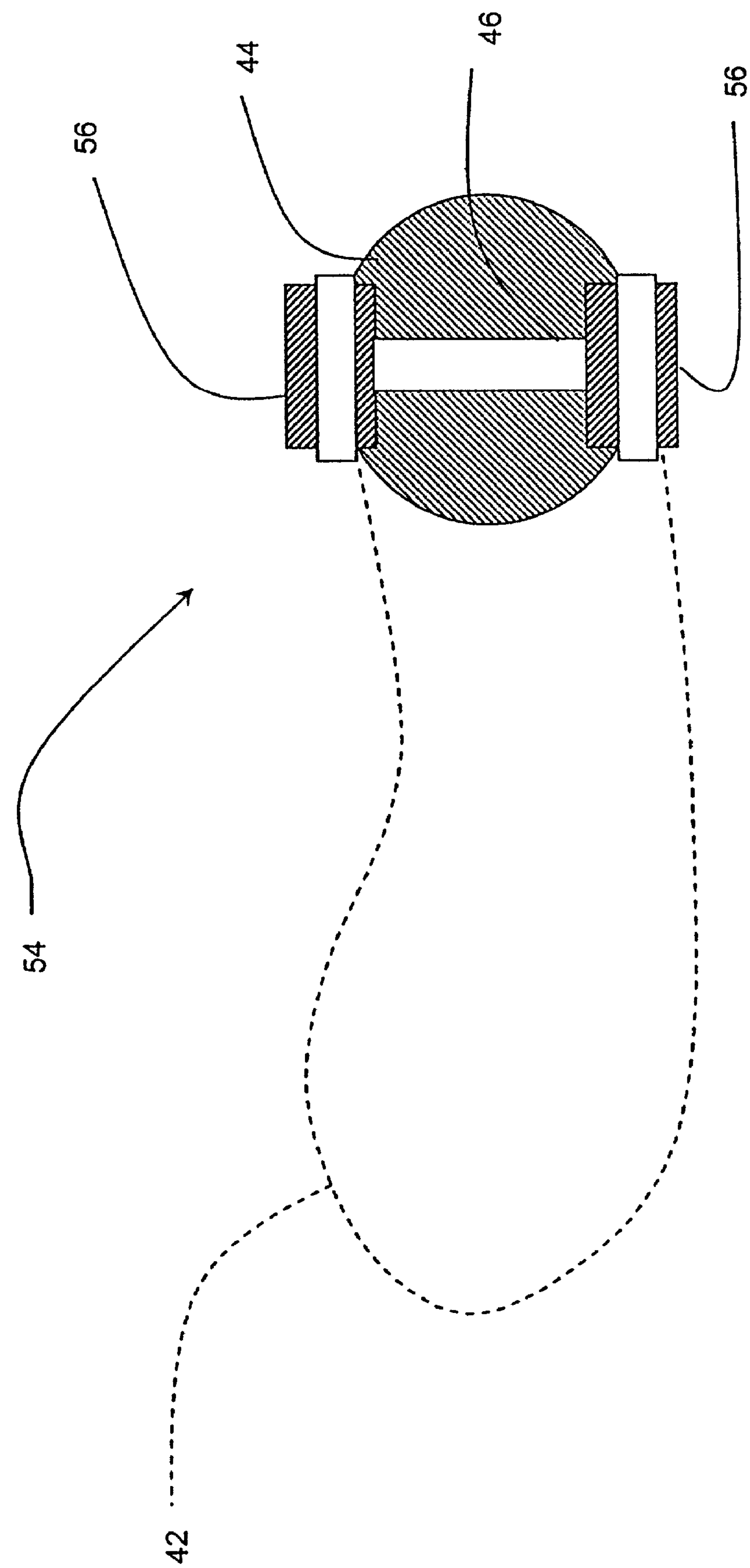


FIG.9



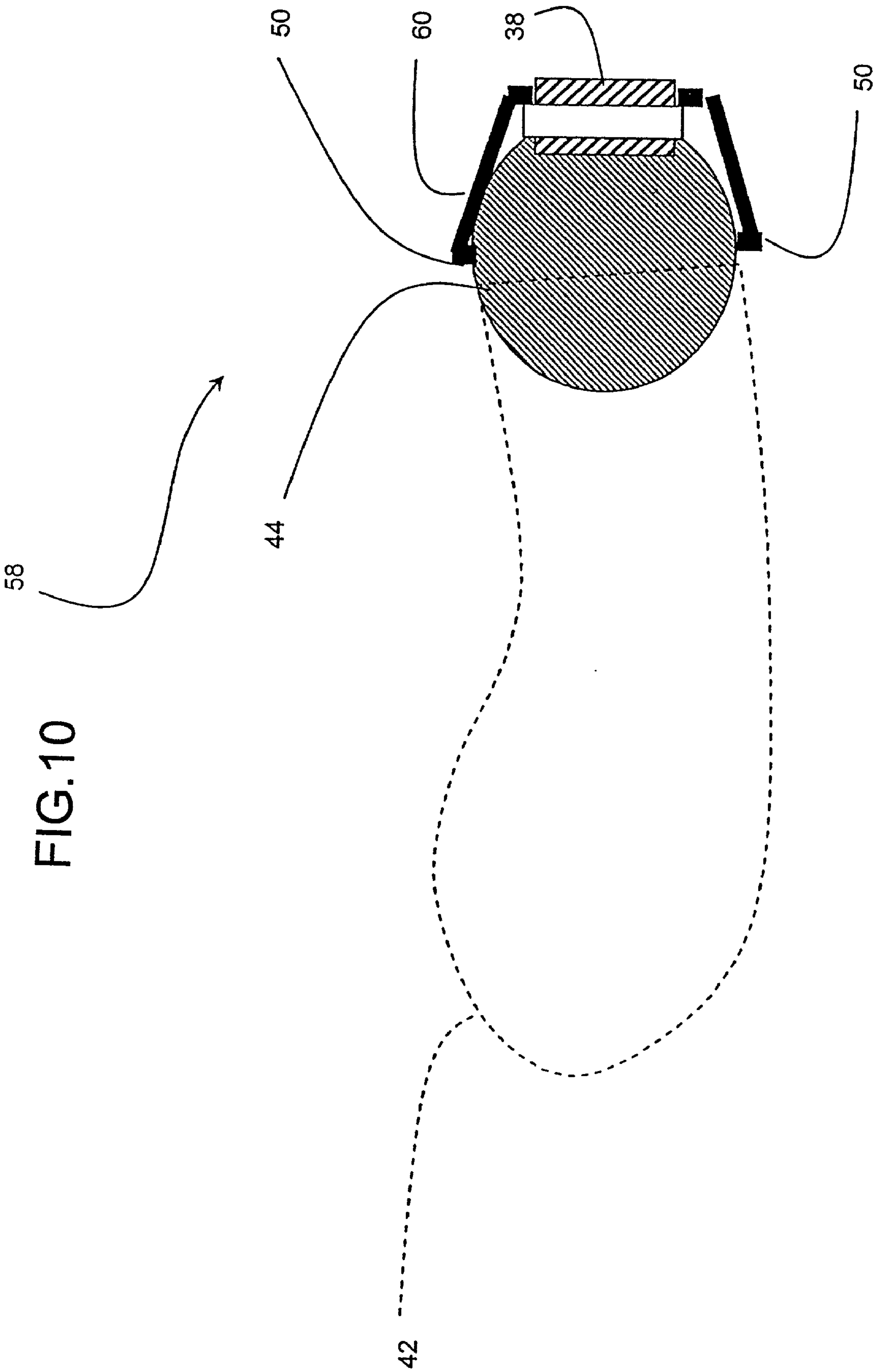
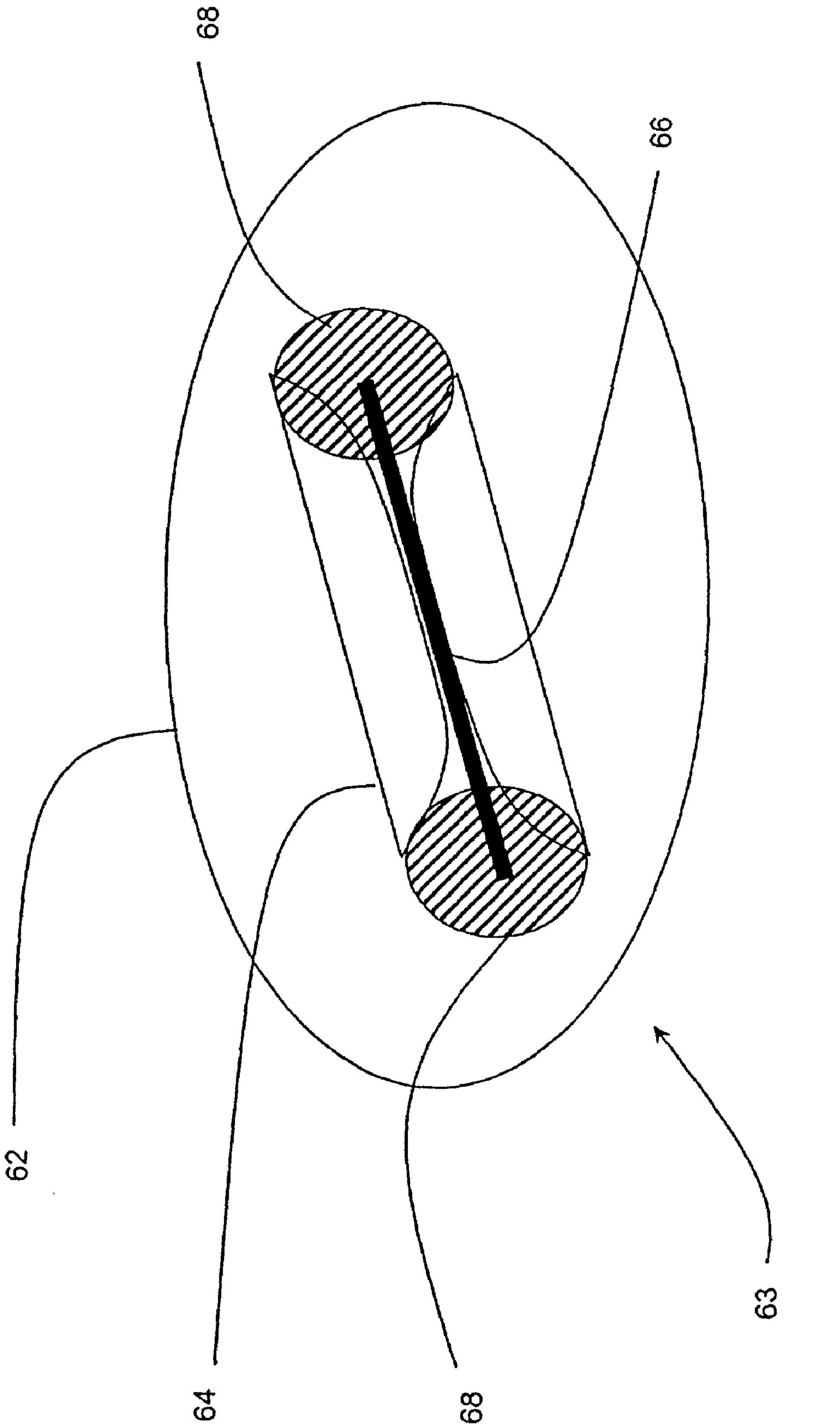


FIG.10

FIG.11



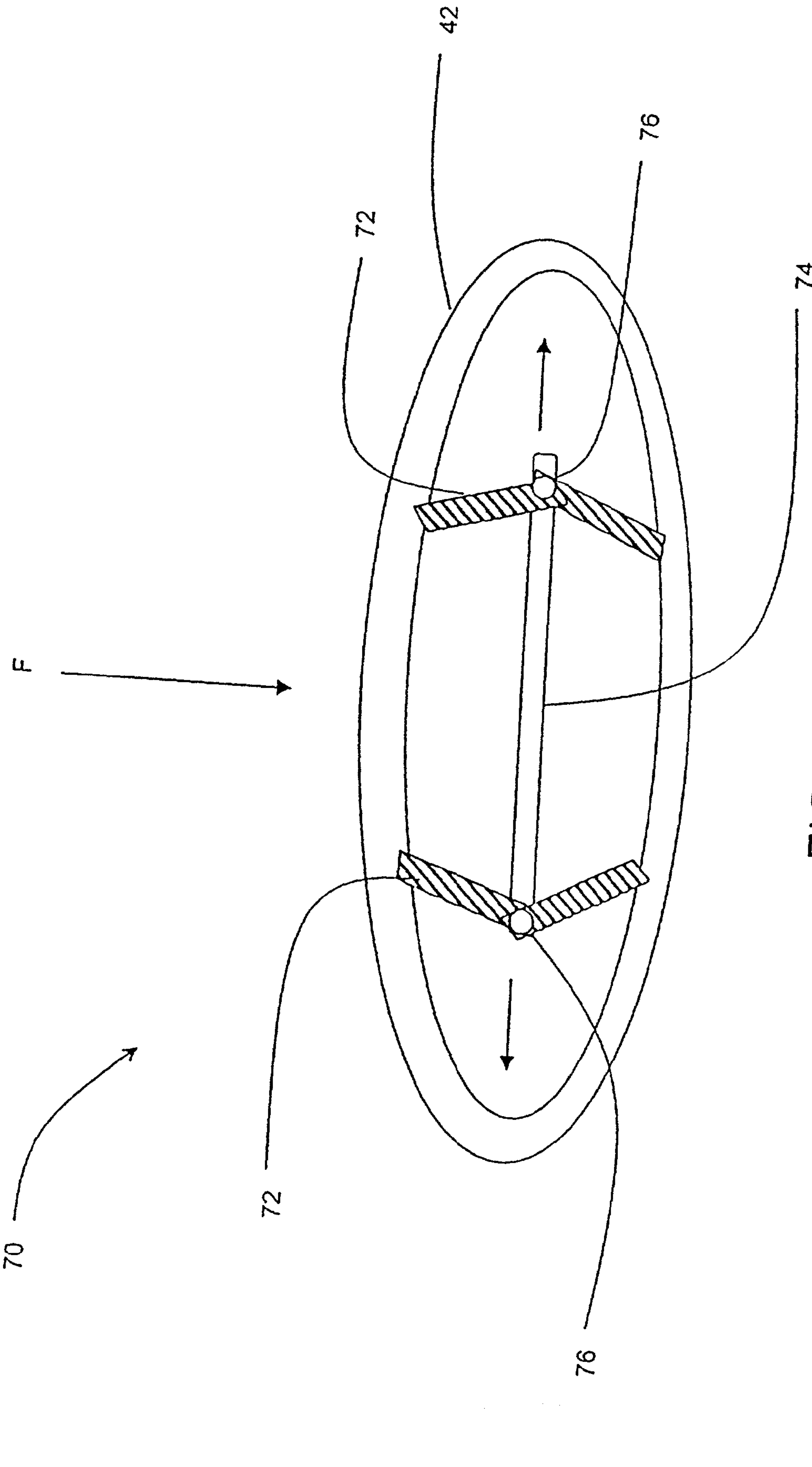


FIG.12

FOOT STRIKE ENERGY ABSORPTION METHOD FOR SHOES

FIELD OF THE INVENTION

[0001] The present invention is in the field of shoes. The invention is particularly useful in athletic shoes.

BACKGROUND OF THE INVENTION

[0002] Energy absorption is used in shoes, and particularly athletic shoes, to lessen the amount of impact force applied to the foot of a wearer from walking, running, and jumping. Shock absorbers and cushioning are widely used in running shoes, for example, to absorb energy. During running, the balls or heel of a wearer's foot impact a ground surface in a substantially normal direction to the ground surface, and the ground surface produces a corresponding force in the opposite, normal direction on the wearer's foot. This corresponding force is felt by the wearer as an impact load. Cushioning or shock absorbers are typically placed between the outsole and midsole of a shoe, typically in the area of the balls of the feet and the heel, to minimize the impact load on the wearer. However, cushions or shock absorbers in conventional shoes are designed to absorb the forces only in the normal directions, downward from the foot and upward from the ground. The present inventors have discovered that the basic paradigm for energy absorption in such conventional shock absorbers limits the design space for absorbing impact energy and tailoring the impact force felt by the wearer.

[0003] Recently, certain athletic shoes have included a liquid-filled or gas-filled bladder that receives the normal impact force and converts a portion of the impact force into a multitude of planes. In these systems some work is done compressing the liquid/gas in the bladder while the remaining work is received by the confining walls of the surrounding shoe. These liquid/gas-filled bladders, however, are not designed, as is the present invention, to precisely convert the normal impact force to a predetermined, preferably perpendicular direction. Furthermore, existing foot strike energy absorption systems partition the resulting energy absorption over a continuum of orientations that is not amenable to precise design control.

[0004] In addition, current designs of practical shoe energy absorption systems do not specifically account for a conversion of force into a non-normal plane. Accordingly, the design of conventional energy absorption systems involves a high degree of trial and error to tailor the system to the intended service environment and intended useful life. For at least this reason, it is difficult to tailor a shoe energy absorption system to particular wearers or environments away from a manufacturing facility (at a point of sale, for example).

SUMMARY OF THE INVENTION

[0005] The present invention provides an improved model for energy absorption in shoes. In a method for absorbing energy according to one aspect of the invention, a force is accepted in the direction of applied force by a first member, and response is permitted in the direction of applied force. At least a portion of the response in the direction of applied force is converted into response in another direction by a second member, by a conversion mechanism and at least a portion of the energy from the response of the second member is absorbed by a mechanism coupled to the second member.

[0006] By converting response of the first member in the direction of applied force to response of the second member in another direction, the present invention creates increased potential for energy absorption by providing a broad new array of energy absorbing systems, and isolates at least a portion of the displacement in the second direction for greater design control. Providing the energy absorption mechanism allows the response in the second direction, and the impact force on the wearer, to be precisely configured. A foot strike energy absorption system designed in this manner can also be customizable via selection among variants of particular components of the foot strike energy absorption system.

[0007] In a foot strike energy absorbing system according to the invention, a first member is configured to receive a force in a first direction normal to a ground surface and to respond in the first direction. A second member reactive to the response of the first member is configured to respond in a second direction generally perpendicular to the first direction, thereby transferring response from the first direction to response in the second direction. A mechanism coupled to the second member absorbs at least a portion of energy from the response of the second member in the second direction.

[0008] In yet another aspect of the invention, a method for designing a foot strike energy absorption system for shoes includes the steps of selecting a first mechanism type for converting at least a portion of response of a first member in a first direction to response of a second member in a second direction, selecting a second mechanism type for absorbing energy from the response in the second direction, selecting a characteristic of the second mechanism type having a plurality of possible variations, relating the variations of the selected characteristic to impact loads for the shoe, and producing a plurality of products of the second mechanism type, where each of the plurality of products has one of the variations of the selected characteristic. The method provides more freedom to generate a precisely designed force-displacement curve than conventional cushioning systems and methods, and creates a customizable energy absorption system that can be used to tailor the system to an individual wearer or environment, even at the point of sale.

[0009] In still another aspect of the invention, a method for customizing a foot strike energy absorption system for shoes includes the steps of providing a product of a first mechanism type for converting at least a portion of a response in a first direction to response in a second direction, providing a plurality of products of a second mechanism type for absorbing energy from the response in the second direction, each of the plurality of products of the second mechanism type having a variation of a characteristic correlating to impact load on a wearer, selecting one of the plurality of products of the second mechanism type, and combining the selected one of the plurality of products of the second mechanism type with the product of the first mechanism type to form the customized foot strike energy absorption system. According to this aspect of the invention, a component of a foot strike energy absorption system may be selected at an alternate location from a manufacturing facility (at a point of sale, for example) to optimize the system for a particular wearer or environment.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] Other features, objects and advantages of the invention will be apparent by reference to the drawings, of which:

[0011] **FIG. 1** is a schematic representation of a foot strike energy absorption system using direct mechanical actuation, which illustrates an energy absorption system utilized in a method of the invention;

[0012] **FIG. 2A** is a schematic representation of a foot strike energy absorption system using hydraulic actuation, which illustrates an energy absorption system utilized in a method of the invention, and is shown before displacement of an action piston;

[0013] **FIG. 2B** is a schematic representation of the foot strike energy absorption system of **FIG. 2**A, shown after displacement of the action piston;

[0014] **FIG. 3** is a graph showing plots of absorbed energy and resulting impact load as functions of displacement of an action piston in the hydraulic actuation foot strike energy absorption system of **FIGS. 2A and 2B**;

[0015] **FIG. 4** is a graph showing effects of changes in the material spring constant on energy absorption and impact load in the hydraulic actuation foot strike energy absorption system of **FIGS. 2A and 2B**;

[0016] **FIG. 5** is a graph showing effects of changes in internal pressure of a bladder in the hydraulic actuation foot strike energy absorption system of **FIGS. 2A and 2B** on energy and impact load;

[0017] **FIG. 6** is a schematic top view of a first preferred embodiment foot strike energy absorption system of the invention showing the function of an internal energy absorbing material ligament;

[0018] **FIG. 7** is a schematic side view of the foot strike energy absorption system shown in **FIG. 6**;

[0019] **FIG. 8** is a schematic top view of a second preferred embodiment foot strike energy absorption system of the invention showing the function of external energy absorbing material ligaments with a single, back-exit, working actuator;

[0020] **FIG. 9** is a schematic top view of a third preferred embodiment foot strike energy absorption system of the invention showing a lateral, internal energy absorbing ligament restraining 2 side-exit displacement actuators;

[0021] **FIG. 10** is a schematic top view of a fourth preferred embodiment foot strike energy absorption system of the invention;

[0022] **FIG. 11** is a schematic view of an alternate bladder for a fifth preferred embodiment foot strike energy absorption system of the invention using a lateral energy absorbing ligament; and

[0023] **FIG. 12** is a schematic rear view of an energy foot strike energy absorption system using direct mechanical actuation, and including a pair of flexible, buckled columns.

DETAILED DESCRIPTION OF THE INVENTION

[0024] Design Environment

[0025] Generally speaking, the present invention is directed to a foot strike energy absorption system for shoes that converts at least a portion of a response from a first member from an impacting body (such as a ground surface contacting a sole of a shoe as it strikes the ground surface) into a response of a second member in another direction, typically a direction generally perpendicular to the direction of initial response, and absorbs at least a portion of the energy from the response in the other direction. As used herein, the term "response" refers to displacement of a member, or displacement of a portion of a member (such as during deformation or deflection of the member, for example, a bladder), in a direction due to a force acting upon the member.

[0026] Typically, as a shoe impacts a surface (as its wearer is running, for example), the wearer's foot inside the shoe deforms the sole of the shoe in a direction normal to the surface and downward, while at the same time the surface naturally imparts an upward counterforce on the shoe, deforming the shoe in a direction similarly normal to the plane of the ground.

[0027] Conventional shock absorption or mediation systems for shoes absorb impact energy from an impacting body through material compression in the direction of the impact force. While a certain degree of cushioning is provided for the wearer, controlling energy absorption only in this normal direction limits the amount of energy that can be absorbed and thus limits the cushioning of impact force felt by the wearer, and also limits the universe of possible designs for shoe energy absorption systems.

[0028] Though some recent foot strike energy absorption systems have included a liquid-filled bladder to generally distribute portions of an impact force in various directions, they do not provide a precise conversion of response in the normal direction to response of a second member in a substantially perpendicular direction, and a mechanism to absorb energy from the response of the second member in the substantially perpendicular direction, as does the present invention. Accordingly, the conventional bladder foot strike energy absorption systems cannot configure or tailor the response in the substantially perpendicular direction as precisely as the foot strike energy absorption system of the present invention. The present system, by contrast, allows one to precisely design the foot strike energy absorption system and enables point-of-sale custom cushioning to match particular characteristics of the user.

[0029] Theoretical Models

[0030] Turning now to the drawings, and particularly **FIG. 1, a** model of a foot strike energy absorption system for illustrating a method of the present invention is shown using direct mechanical actuation to convert displacement of a first member in a first direction from an impact force, to displacement of a second member in a second direction. A first model foot strike energy absorption system **10**, using direct mechanical actuation, includes a first shaft **12** and a second shaft **14** hinged to one another at a junction **15** of respective ends using a first pin **16**, and also connected to one another at respective intermediate points with a spring **18**. The first shaft **12** is rotatably secured to a first surface **20** at a second pin **22**, which is above the first surface. The second shaft **14** is rotatably secured to a roller **24** by a third pin **26**, the roller having a height so that the third pin is approximately vertically even with the second pin **22**. The spring **18** connects intermediate portions of the first and second shafts **12**, **14** and extends in a direction parallel to the first surface **20**. The spring represents any material system that is used to restrain the separation of second pin **22** and third pin **26**.

[**0031**] As an impact force F in a first, vertical direction is applied to the junction **15** of the first and second shafts **12**, **14** near the first pin **16**, displacing the junction in the direction of the impact force, the roller **24** attached to the third pin **26** of the second shaft is displaced in a second direction D substantially perpendicular to the impact force, against the retention force of the spring **18**. The spring **18** absorbs a portion of the energy from the displacement of the roller **24**, and thus absorbs a portion of the impact force F.

[**0032**] FIGS. 2A-2B show a second model foot strike energy absorption system **28**, using hydraulic actuation. The second model foot strike energy absorption system **28** includes an L-shaped chamber **30** having a set of walls **31** for containing a fluid, such as a gas, the walls preferably being at least partially deformable. A first section **32** of the chamber **30** features a retaining device, such as an inwardly extending flange **34**, for retaining a first piston **36** (also referred to as an "action piston") within the chamber, the first piston being displaceable in a first (vertical) direction. Other retaining mechanisms, such as stops, may be used. A second section **37** of the chamber **30** extending substantially perpendicularly to the first section **32** includes a second piston **38** (also referred to as a "reaction piston"), which is displaceable in a second (horizontal) direction substantially perpendicular to the first direction. The second piston **38** is attached to the wall **31** of the chamber by a second spring **40** extending in a direction of motion of the second piston, i.e. the second direction. The term "piston" is intended to broadly include any suitable piston-like member.

[**0033**] In this configuration, when the impact force F is applied to the first piston **36** in the first (vertical) direction, the second piston **38** is displaced in the second direction D, as shown in **FIG.** 2B, due to the pressure provided by the fluid within the chamber **30**, and against the resistance of the second spring **40**, which absorbs a portion of the applied force. Thus, as in the first model foot strike energy absorption system **10**, at least a portion of the applied force F is converted to displacement in a direction D perpendicular to that of the applied force, and absorbed by an absorption mechanism, such as the second spring **40**.

[**0034**] By providing foot strike energy absorption systems according to the illustrative model foot strike energy absorption systems **10**, **28** described above, which convert at least a portion of the applied force and displacement of a first member in a first direction F to displacement of a second member in the second direction D, and provide a mechanism (such as the spring **40**) that absorbs energy in the second direction, the displacement in the second direction can be precisely controlled to control impact force felt by a wearer.

[**0035**] The second model foot strike energy absorption system **28** is an exemplary embodiment of a two-piston model for enabling a closed-form analysis of a gas or liquid filled shock absorption system with a deformable wall, and may be used to model more complicated systems. Though the working fluid may absorb energy, the bulk of the energy absorption is in the restraining (absorption) mechanism (in FIGS. 2A-2B, the second spring **40**). The actual system need not consist of the first and second pistons **36**, **38** and the second spring **40**, but may be alternatively constructed with localized or generally deformable walls, for example.

[**0036**] While the examples of **FIGS. 1 and** 2A-2B show a direct mechanical actuation system having a conversion mechanism using the pinned shafts **12**, **14**, and a hydraulic/pneumatic piston system a fluid, respectively, various other converting mechanisms for converting response of a flat member in one direction to response of a second member and energy absorption in another direction are contemplated by the present invention, such as, but not limited to, arched beams, rolling bladders, deformable bodies, controlled buckling, etc.

[**0037**] Although the spring **18** or second spring **40** is shown to demonstrate particular embodiments of an absorption mechanism, any number of alternate absorption mechanisms may also be used, such as the deformable walls **31** of the chamber **30**, a material strip, a spring/dashpot mechanism, or others. Each of these embodiments of the absorption mechanism absorbs energy from response of a second member in a second direction, reacting from response of a first member in a first direction.

[**0038**] Also, while it is preferred that the second direction of response or absorption is substantially perpendicular to the first direction of response (and that of the initial impact force F), it is contemplated that the impact force may generally be converted to response and absorption in various specific directions other than the first direction of the impact force.

[**0039**] Shoe Energy Absorption Mechanism Design Model

[**0040**] In a preferred aspect of the present invention, the theoretical model foot strike energy absorption systems and methods described above are employed to produce an inventive model for designing and customizing a shoe foot strike energy absorption system. This unique design model allows various design choices and parameters for components of the system.

[**0041**] Preferably, this model is embodied in software or tables that may be used to design precise force-displacement curves, and produce and select customizable, modular components for shoe absorption mechanisms according to the present invention.

[**0042**] There are numerous design choices provided based upon the method of the present invention exemplified by the first model foot strike energy absorption system **10** as well as the second model foot strike energy absorption system **28**. Using the second model foot strike energy absorption system **28** as an example, and referring again to FIGS. **2**A-**2**B, design choices may include, but are not limited to: the nature of the restraining spring **40** (or other absorbing mechanism); the nature of the working fluid that fills the chamber **30**; the pressure inside the chamber; the ratio of the areas of the first and second pistons **36**, **38**; the available displacement; the temperature; the time dependent response; material creep or fatigue, etc.

[0043] By controlling one or more of these parameters, individual components can be designed to optimize particular foot strike energy absorption systems for a particular wearer, for example, or for a different environment.

[0044] For example, by controlling only the working fluid or gas, a hydraulic/pneumatic foot strike energy absorption system can be designed so that the energy stored in the working fluid or gas is small compared to that of the spring, or the working fluid can be chosen to afford comparable or greater compressibility. The working fluid can be modified to this end in one of several ways, for example: (1) the working fluid can be chosen from several available gases/liquids/suspensions, each of which have different compressibility; (2) the working fluid can be over-saturated with a gas to enable a deformable suspension of gas bubbles; or (3) the working fluid can be filled to a specific volume fraction of deformable microcapsules that allow for a precisely controlled degree of compressibility in the working fluid. By providing a number of working fluids, each having a different compressibility, for example, a shoe foot strike energy absorption system can be customized by selecting one of the number of working fluids for the system having an optimal compressibility for a particular wearer.

[0045] The general approach of the double piston, dual actuation model from the second model foot strike energy absorption system **28** presents a broad range of mechanistic options for impact cushioning. A basic, exemplary theory for modeling a system based on this particular type of embodiment is shown and described herein, as well as an illustration of the design methodology for using the theory. By applying the basic theory, characteristics of particular components are isolated and variations of these characteristics are related to impact force on a wearer. In this way, a plurality of the components each having a variation of the characteristic(s) can be designed or manufactured, and provided for customization of the system by selection of one of the plurality of components at a point of sale, for example.

[0046] Additionally, several exemplary embodiments of foot strike energy absorption systems designed using the theory are shown. It should be understood that similar system modeling and design is also possible using the first (direct mechanical actuation) model foot strike energy absorption system 10, as well as other designs that convert impact force and response in one direction to response and absorption in another direction, and these are contemplated by the present invention. It will be appreciated by one skilled in the art that the analysis and results provided herein are broadly applicable to the problem of foot strike energy absorption and impact force, and may be used to design any impact cushioning systems.

[0047] Referring again to **FIG. 2**B, the second model foot strike energy absorption system **28** is considered under the action of an external stress, $\sigma_{applied}$. The first piston **36** (action piston) displaces by an amount x_a in the direction of the impact force F while the second piston **38** (reaction piston) displaces by some different amount x_r in the displacement direction D. It is assumed in this example for simplicity that the gas used in the chamber **30** is an ideal gas at an initial pressure and volume, P_i and V_i. If the second model foot strike energy absorption system **28** is modeled as isothermal, then the pressure and volume P;, V; at any subsequent position of the first and second pistons **36**, **38** is related to that of the initial pressure and volume by:

$$P_i V_i = P_j V_j \tag{1}$$

[0048] Furthermore, the volume of the chamber **30** after application of the applied stress $\sigma_{applied}$ is related to the displacements of the first and second pistons **36**, **38** having respective impact and reaction areas A_a, A_r by:

$$V_j = V_i - A_a x_a + A_r x_r \tag{2}$$

[0049] Using (2) in (1) results in:

$$P_i V_i = P_j V_i + P_j A_r\left(x_r - \frac{A_a}{A_r} x_a\right) \tag{3}$$

[0050] Modeling the spring **40** as linear with a spring constant k, the force generated by the spring for a displacement x_r is:

$$F_{spring} = k x_r \tag{4}$$

[0051] If the stress is applied quasi-statically, then the pressure, P_j, acting on both the first and second pistons **36**, **38** is balanced by the force in the spring **40**, so that:

$$P_j = \frac{k x_r}{A_r} \tag{5}$$

[0052] By substituting (5) into (3) an equation is constructed that relates the displacement of the second piston **38**, x_r, to the imposed displacement of the first piston **36**, x_a:

$$x_r^2 - x_r\left(x_a \frac{A_a}{A_r} - \frac{V_i}{A_r}\right) - \frac{P_i V_i}{k} = 0 \tag{6}$$

[0053] Equation (6) allows prediction of the displacement of the second piston **38** (reaction piston) for an imposed displacement of the first piston **36** (action piston) as functions of the cross sectional areas of the first and second pistons, the initial volume and pressure of the chamber **30** and the stiffness of the spring **40**. Energy absorption is computed by integrating the work done in stretching the spring **40** and compressing the gas:

$$E = \frac{1}{2} k x^2 + \int_{V_i}^{V_j} P\,dV \tag{7}$$

[0054] resulting in:

$$E = \frac{1}{2} k x_r^2 + P_i V_i \ln\left(1 + \frac{A_r}{V_i}\left(x_r - \frac{A_a}{A_r} x_a\right)\right) \tag{8}$$

[0055] Foot Strike Energy Absorption System Design Example

[0056] For the sake of illustration only, reasonable values for the impact areas of the first piston **36**, reaction areas of the second piston **38**, volume of the chamber **30**, spring constant for the spring **40**, and initial gas pressure in the chamber, are assumed to be as follows:

$$A_a=4054\times10^{-6}m^2$$

$$A_r=11{,}827\times10^{-6}m^2$$

$$V_i=46\times10^{-6}m^3$$

$$k=1.68\times10^{6}N/m^2$$

$$P_{i=}15\ psi(0.103\ MPa)$$

[**0057**] Furthermore, the energy generated by a running person is related to the motion of the center of gravity of that person. Assuming a 4" excursion in the center of gravity (though of course other distances may be used), the energy absorption mechanism should be able to absorb the energy associated with a 4" drop of a wearer of weight W=mg. That is:

$$E=mgh$$

[**0058**] where h=4"

[**0059**] Using equations (6) and (8), determined (or assumed) values for the constants listed above, and the required energy absorption, one can plot the absorbed energy as a function of displacement of the first piston **36**. Furthermore, one can also plot the reaction force generated at the first piston **36**, which the wearer would feel as the impact load during running.

[**0060**] **FIG. 3** plots energy absorption and impact load as functions of displacement of the first piston **36** (action piston). A number of lines are overlaid on the plot to illustrate how the designer can use these curves to determine the impact loads for a wearer of a specific weight. Lines are drawn for wearers weighing in at 100 lb, 185 lb, 200 lb, 250 lb, and 300 lb. Note that the impact loads are on the order of 3 times the body weight of the wearer. These impact loads are precisely what the wearer feels as a heel strike load during running.

[**0061**] The model allows a designer to vary particular model parameters and determine the changes in the impact loads. **FIG. 4** illustrates the effect of changing the stiffness of the spring **40**. For example, increasing the stiffness of the spring **40** by a factor of 2.78 increases the heel strike load by a factor of 1.65 for a 130 lb wearer.

[**0062**] As further illustration of the utility of the model, consider the effect of internal pressure on the resulting impact load, as shown in **FIG. 5**. An increase in the internal pressure from 15 to 120 psi, for example, increases the heel strike force by a factor of 1.19 for a 100 lb wearer.

[**0063**] These figures illustrate that the proposed model can be used to design a hydraulic/pneumatic foot strike energy absorption system **28**. Similar types of models can be used to design direct mechanical actuation foot strike energy absorption system **28** systems, as will be apparent to one skilled in the art. The designer can overlay a broad range of plots and select the desired combination of areas, volume, spring stiffness and pressure to achieve the target impact response. As such, the model affords a new design tool for developing foot strike energy absorption system **28** systems that perform a method according to the present invention.

[**0064**] As stated above, this model can be implemented in software, using real-time calculations or look-up tables to determine particular design parameters for one or more components of the shoe foot strike energy absorption system and produce tables, charts, etc., that relate variations of particular characteristics of one or more system components to impact loads on a wearer. Accordingly, an optimal design may be chosen, either at the factory or in the field, by selecting a component having a variant of the particular design parameter or parameters that is optimal for the particular wearer. Once appropriate models are developed for a particular shoe design, it becomes a relatively simple matter for storing a model either in software or in a number of tables or charts for access by, for example, a salesperson in the field to determine appropriate designs for a particular wearer. If, for instance, a number of materials, for example, springs, are provided, each having particular spring stiffness, under the example model developed above, a wearer, salesperson, manufacturer, etc. can select a spring having optimal stiffness for particular biomechanics of the wearer, such as weight or excursion in center of gravity. In preferred embodiments of shoe foot strike energy absorption system designs according to the present invention, the modular component can be chosen and incorporated into the foot strike energy absorption system in the field. For example, a salesperson may select a spring and attach it to the foot strike energy absorption system to customize the system.

[**0065**] Exemplary Embodiments

[**0066**] **FIGS. 6 and 7** show a first back-exit two-piston system **41** relating to the second model foot strike energy absorption system **28** (two-piston system), which is implemented in a shoe **42**. A bladder **44** between a midsole and outsole of the shoe **42**, typically in the area of the balls of the feet and/or the heel acts similarly to the first piston **36** and also as the chamber **30**. The second piston **38** is a back-exit piston, attached to the bladder **44** by an internal tensile cushioning ligament **46**. Preferably, the materials for the first and second pistons **36**, **38**, the bladder **44**, and the cushioning ligament **46** are polymers because they are inexpensive, easy to fabricate, and lightweight. The bladder **44** may be a stationary, deformable bladder, a rolling bladder, etc.

[**0067**] As the wearer's heel, for example, depresses the bladder **44**, displacing at least a portion of the bladder in a direction substantially normal to the ground surface, the second piston **38** is displaced outwardly (as pictured in **FIGS. 6 and 7**, to the right) due to pressure from an inner fluid within the bladder **44**. The displacement of the second piston **38** in this embodiment is in a plane substantially perpendicular to that of the impact force on the bladder **44**, and is against the resistance of the cushioning ligament **46**, which absorbs a portion of the displacement energy, and thus the impact force. When the heel eases or is removed from the bladder **44**, the second piston **38** returns to its original position.

[**0068**] In another embodiment of the second model foot strike energy absorption system **28**, a second back-exit two-piston system **48** is shown in **FIG. 8**. The bladder **44** acts similarly to the first piston **36**, as in the first back-exit two-piston system **41**. However, the second piston **38** is flexibly connected to a pair of posts **50** (which in turn may be coupled to the shoe **42**) via an external band ligament **52**. Preferably, the posts **50** and the ligament **52** are of polymeric material. The external band ligament **52** stretches laterally across and over the second piston **38**, for resisting outward and backward (as pictured in **FIG. 8**, to the right) movement of the second piston during depression of the bladder **44**.

Again, impact force on the bladder **44** and displacement of the bladder in a first direction results in displacement of the second piston **38** in a second direction different than the first direction, and absorption of at least a portion of the displacement energy and thus the impact force (by the external band ligament **52**).

[**0069**] In addition, by placing the energy-absorbing link (in **FIG. 8**, the external band ligament **52**) externally among the components of the second mechanical energy absorption system **28** (and possibly external to the shoe **42**), the link can be a modular component having selectable characteristics (such as stiffness or durability) to match the biomechanics of the wearer, for example, at the point of sale. As one possible embodiment of this type, the external band ligaments **52** are categorized according to suitability for wearers having a particular weight, excursion height, etc. (according to a design model similar to that described above), and referenced in any suitable way, such as by number, letter, and/or color combinations. A 170-pound wearer with a 4" excursion may select an external band ligament **52** having a particular variant (labeled such as "No. 10", or "blue") optimized for his or her biomechanics. The selected ligament **52** can be attached to the posts **50** to assemble the customized system.

[**0070**] Turning now to **FIG. 9, a** lateral exit 3-piston system **54** is shown in which the bladder **44** contains a pair of lateral pistons **56**, which alone or in combination operate similarly to the second piston **38** of earlier-described embodiments. The internal ligament **46** extends laterally across the bladder **44**, connecting the pair of lateral pistons **56**. As the bladder **44** is depressed, the pair of lateral pistons **56** is displaced outwardly and laterally (as pictured in **FIG. 9**, in upper and lower directions, respectively), resisted by the internal ligament **46**. The directions of displacement of each of the pair of lateral pistons **56** are substantially perpendicular to the direction of the impact force on the bladder **44**, and the internal ligament **46** absorbs a portion of the displacement energy from the pair of lateral pistons.

[**0071**] **FIG. 10** shows a third back exit two-piston system **58** similar to that of the second back-exit two-piston system **48** (shown in **FIG. 8**), except that the external band ligament **52** is replaced with a pair of flexible restraining straps **60** on lateral sides of the second piston **38**. The pair of flexible restraining straps **60** is connected to the posts **50** and to suitable portions of the second piston **38**. Preferably, the components are made of polymeric material. As in the second back two-exit piston system **48**, the presence of an external energy-absorbing link (the pair of flexible restraining straps **60**) allows the third back exit two-piston system **58** to be tailored, for example, by selection of the flexible restraining straps **60**, to meet the biomechanical requirements of the buyer at the point of sale.

[**0072**] Referring now to **FIG. 11**, an alternate bladder **62** is shown for an adaptable foot strike energy absorption system **63**. The alternate bladder **62**, which is preferably of polymeric material and may be filled with liquid, features a transverse hole **64** through its center, which preferably is similar to the geometry of a mathematical construction known as a Klein bottle. A (preferably polymeric) restraining ligament **66** is pre-stretched to traverse through a length of the transverse hole **64**, and is anchored to the alternate bladder **62**, preferably using a pair of platens **68**, one at each end of the transverse hole. In operation, the restraining ligament **66** modifies the deflection of the alternate bladder **62**, thus converting a portion of the impact force on, and displacement of, the alternate bladder in the first direction to displacement of the platens **68** in second and third directions substantially perpendicular to the first direction. The restraining ligament **66** absorbs energy from the displacement of the platens **68**. By producing a model relating the characteristics of the restraining ligament **66** to the impact load on the wearer, the restraining ligament having optimum characteristics can be selected to customize the adaptable foot strike energy absorption system **63** to the wearer.

[**0073**] **FIG. 12** shows an exemplary embodiment similar to the first model foot strike energy absorption system **10** utilizing direct mechanical elements to convert impact force in one direction to displacement and/or absorption in another direction. A flexible column system **70** includes a pair of flexible columns **72** substantially vertically disposed within a shoe **42**, typically near the area of the heel, separated and connected at respective central portions by a second restraining ligament **74** at a pair of pins **76**. The second restraining ligament **72** extends laterally across the shoe, preferably perpendicularly to both the length of the shoe and the substantially vertical length of the flexible columns. The flexible columns **72** are configured to buckle in directions perpendicular to the impact force direction F as the wearer's heel strikes the surface, against the resistance of the second restraining ligament **74**. Therefore, as upper portions of the flexible columns **72** are displaced in a first direction, central portions of the flexible columns (near the pins **76**) are displaced in second and third, perpendicular directions, and a portion of the displacement energy is absorbed by the second restraining ligament **74**. The flexible columns **72** are preferably perturbed for controlled buckling. The second direct mechanical energy absorption mechanism **70** thus provides displacement and absorption in a direction substantially perpendicular to the impact force direction F. By controlling the stiffness of the second restraining ligament **74** and/or the flexible columns, the flexible column system **70** is customizable.

[**0074**] The precise design and control, modularity of components, and field (such as point-of-sale) optimization for a shoe energy absorption system are important and unique aspects of several types of embodiments of the present invention. Many variations of types of embodiments are available according to the present invention that convert impact force in one direction to response and absorption in another, preferably perpendicular direction. These variations preferably allow creation of a model for designing components of energy absorption systems that provide force conversion, responsive displacement, or energy absorption and contain characteristics that can be optimized in the field. Such variations providing customizable parts for out of plane force conversion, responsive displacement and/or energy absorption design are contemplated by the present invention.

[**0075**] From the above description, artisans will appreciate that the foot strike energy absorption method for shoes of the present invention provides many advantages. The full scope of the invention is not limited to the illustrated embodiments, however, but is determinable with reference to the appended claims and their legal equivalents.

What is claimed is:

1. In a shoe, a method for absorbing energy imparted in a direction of applied force from a foot strike as the result of a foot strike, the method comprising steps of:

accepting force in the direction of applied force by a first member;

permitting response of said first member resulting from the applied force in said direction of applied force;

converting at least some of said response of said first member in said direction of applied force to response of a second member in a second direction;

absorbing energy of said response of said second member in said second direction by an absorption mechanism.

2. The method according to claim 1, wherein said response of said second member comprises displacement in said second direction.

3. The method according to claim 1, wherein said step of converting utilizes a mechanical actuator.

4. The method according to claim 1, wherein said step of converting utilizes a buckling element.

5. The method according to claim 1, wherein said step of converting utilizes pressure provided by a working gas.

6. The method according to claim 1, wherein said step of converting utilizes pressure provided by a working fluid.

7. In a shoe, an energy absorption system disposed between a midsole and outsole of the shoe, the system comprising:

a first member reactive to force applied in a first direction generally perpendicular to the midsole and outsole as the result of a foot strike and responsive in said first direction;

a second member reactive to displacement of said first member and responsive in a second direction substantially perpendicular to said first direction, said second member serving to accept and thereby transfer response from said first member in said first direction to response of said second member in said second direction;

an absorption mechanism coupled to said second member to absorb and thereby dissipate energy from said response of said second member.

8. The system of claim 7 wherein said second member comprises a piston-like mechanism.

9. The system of claim 8 wherein said first member comprises a bladder operatively coupled to said piston-like mechanism.

10. The system of claim 7 wherein said first and second members each comprise a piston-like mechanism operatively coupled to one another.

11. The system of claim 7 further comprising:

a conversion mechanism operatively coupled to said first and second members for converting at least a portion of said response of said first member in said first direction to response of said second member in said second direction.

12. The system of claim **111** wherein said conversion mechanism comprises a direct mechanical linkage between said first and second members.

13. The system of claim 11 wherein said conversion mechanism comprises a fluid chamber.

14. The system of claim 11 wherein said conversion mechanism comprises a bladder.

15. The system of claim 7 wherein said absorption mechanism comprises a spring.

16. The system of claim 7 wherein said absorption mechanism comprises an internal ligament coupled to said second member.

17. The system of claim 7 wherein said absorption mechanism comprises an external ligament coupling said second member to a portion of the energy absorption system.

18. The system of claim 7 wherein said absorption mechanism is coupled to said second member to at least partially restrain displacement of said second member in said second direction.

19. The system of claim 7 further comprising:

a third member reactive to response of said first member and responsive in a third direction substantially perpendicular to said first direction.

20. The system of claim 19 wherein said third member comprises a piston-like mechanism.

21. The system of claim 19 wherein said absorption mechanism is coupled to said second member to at least partially restrain response of said second member in said second direction and to said third member to at least partially restrain response of said third member in said third direction.

22. The system of claim 19 wherein said first member comprises a bladder having an internal lateral opening, wherein said second and third members each comprise platens coupled to lateral ends of said lateral opening, and wherein said absorption mechanism comprises a ligament operatively coupled to said platens, whereby response of said bladder in said first direction displaces said platens in said second and third directions, and whereby said ligament absorbs energy from said displacement of said second and third members.

23. In a shoe, an energy absorption system disposed between a midsole and outsole of the shoe, the system comprising:

a set of flexible columns coupled to inner portions of the shoe and generally perpendicular to the midsole and outsole, said columns being shaped to deform in a direction generally perpendicular to the midsole and outsole in response to force applied in a plane generally perpendicular to the midsole and outsole as the result of a foot strike;

an energy absorption mechanism connected to said columns to absorb energy and thereby dissipate energy from deformation of said columns.

24. For a shoe, a method for designing a customizable cushioning system, the method comprising steps of:

selecting a first mechanism type for converting at least a portion of response of a first member in a first direction of applied force to response of a second member in a second direction;

selecting said first and second members;

selecting a second mechanism type for absorbing energy of said response in said second direction;

selecting at least one characteristic of said second mechanism type, said selected characteristic having a plurality of possible variations;

relating said variations of said selected characteristic to a plurality of impact load measurements for the shoe; and

designing a plurality of products of said second mechanism type, each of said plurality of products having said selected characteristic in one of said variations.

25. A method according to claim 11 further comprising the step of:

selecting one of said plurality of products according to at least one biomechanical characteristic of a potential wearer of said shoe.

26. For a shoe, a method for customizing a cushioning system, the method comprising steps of:

providing a product of a first mechanism type for converting at least a portion of response of a first member in a first direction of applied force to response of a second member in a second direction;

providing said first and second members;

providing a plurality of products of a second mechanism type for absorbing energy of said response of said second member in said second direction, each of said plurality of products of said second mechanism type having a variation of a characteristic correlating to impact load on a wearer;

selecting one of said plurality of products of said second mechanism type.

27. The method of claim 26, further comprising the step of:

combining said selected one of said plurality of products of said second mechanism type with said product of said first mechanism type and said first and second members to assemble the customizable cushioning system.

28. The method of claim 25, wherein said at least one biomechanical characteristic is at least one of weight of said wearer and running excursion of said wearer.

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