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CA 2673399 C 2017/08/29

(11)(21) 2 673 399

(12) BREVET CANADIEN
CANADIAN PATENT

(13) C

(86) Date de dépôt PCT/PCT Filing Date: 2008/01/07
(87) Date publication PCT/PCT Publication Date: 2008/07/10
(45) Date de délivrance/Issue Date: 2017/08/29
(85) Entrée phase nationale/National Entry: 2009/06/26
(86) N° demande PCT/PCT Application No.: CA 2008/000011
(87) N° publication PCT/PCT Publication No.: 2008/080231
(30) Priorité/Priority: 2007/01/05 (US60/878,690)

(51) Cl.Int./Int.Cl. *A61F 2/68* (2006.01), *A61F 2/60* (2006.01), *A61F 2/64* (2006.01), *A61F 2/66* (2006.01), *A61F 5/01* (2006.01), *G01L 5/00* (2006.01)

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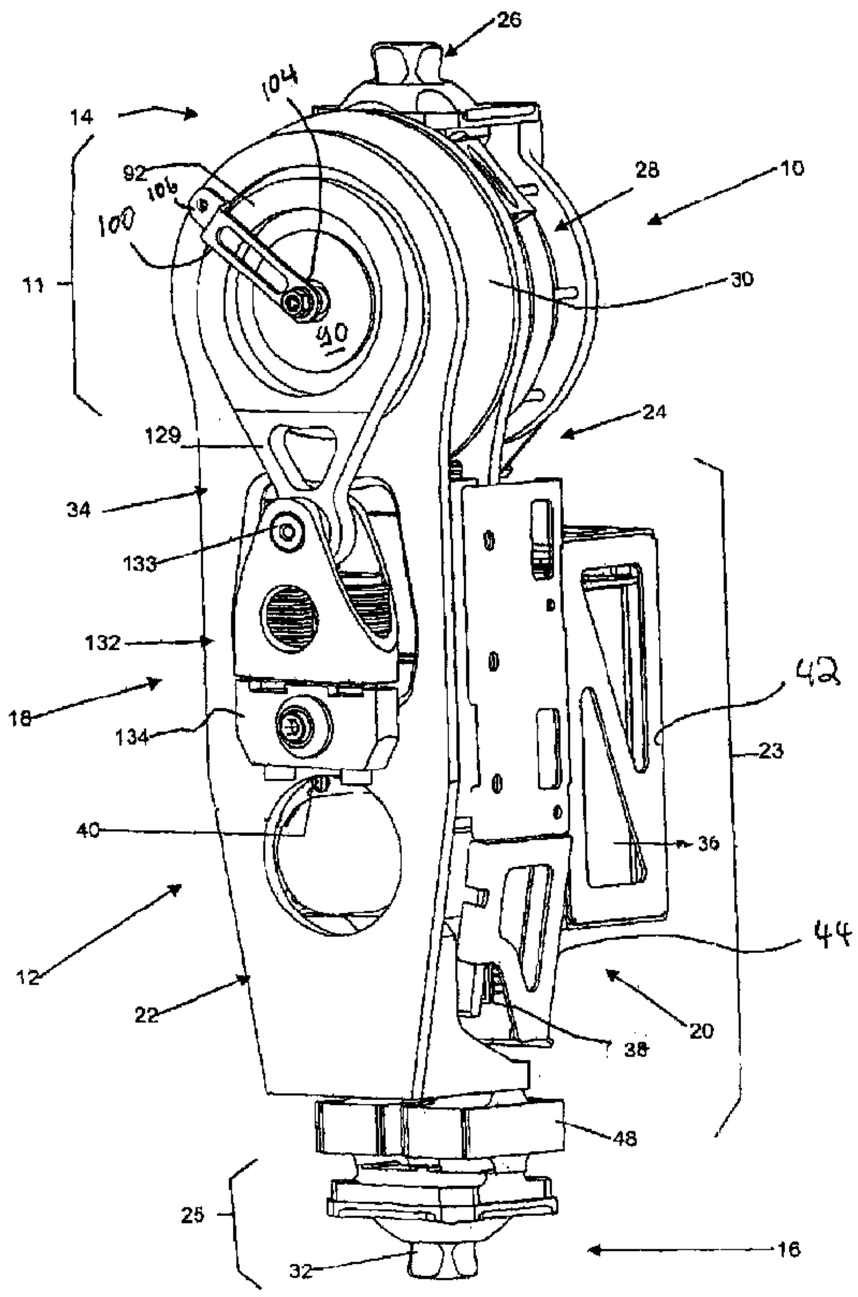
(54) Titre : MECANISME D'ACTIONNEMENT D'UNE ARTICULATION POUR DISPOSITIF PROTHETIQUE OU ORTHETIQUE A TRANSMISSION FLEXIBLE

(54) Title: JOINT ACTUATION MECHANISM FOR A PROSTHETIC AND/OR ORTHOTIC DEVICE HAVING A COMPLIANT TRANSMISSION



(57) Abrégé/Abstract:
Disclosed herein a prosthetic or orthotic device having a joint portion and a compliant transmission assembly in operational communication with the joint portion. The device restores the normal capabilities and natural dynamics of a healthy joint for

CA 2673399 C 2017/08/29

(11)(21) 2 673 399

(13) C

(57) Abrégé(suite)/Abstract(continued):
common activities. The compliant transmission assembly includes a compliant element. The compliant transmission assembly absorbs energy when a torque is applied between a prosthetic or orthotic device portion and another adjacent device portion or the adjacent limb segment of the user. The compliant element of the invention absorbs energy during flexion of a joint for the dampening thereof and releases this energy during extension of the joint for assistance thereof. Also disclosed herein is an actuator assembly, a torque sensor and an actuator locking device as well as a method for determining the torque of such prosthetic and orthotic devices.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
10 July 2008 (10.07.2008)

PCT

(10) International Publication Number
WO 2008/080231 A1

(51) International Patent Classification:
A61F 2/68 (2006.01) *A61F 2/66* (2006.01)
A61F 2/60 (2006.01) *A61F 5/01* (2006.01)
A61F 2/64 (2006.01) *G01L 5/00* (2006.01)

(21) International Application Number:
PCT/CA2008/000011

(22) International Filing Date: 7 January 2008 (07.01.2008)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/878,690 5 January 2007 (05.01.2007) US

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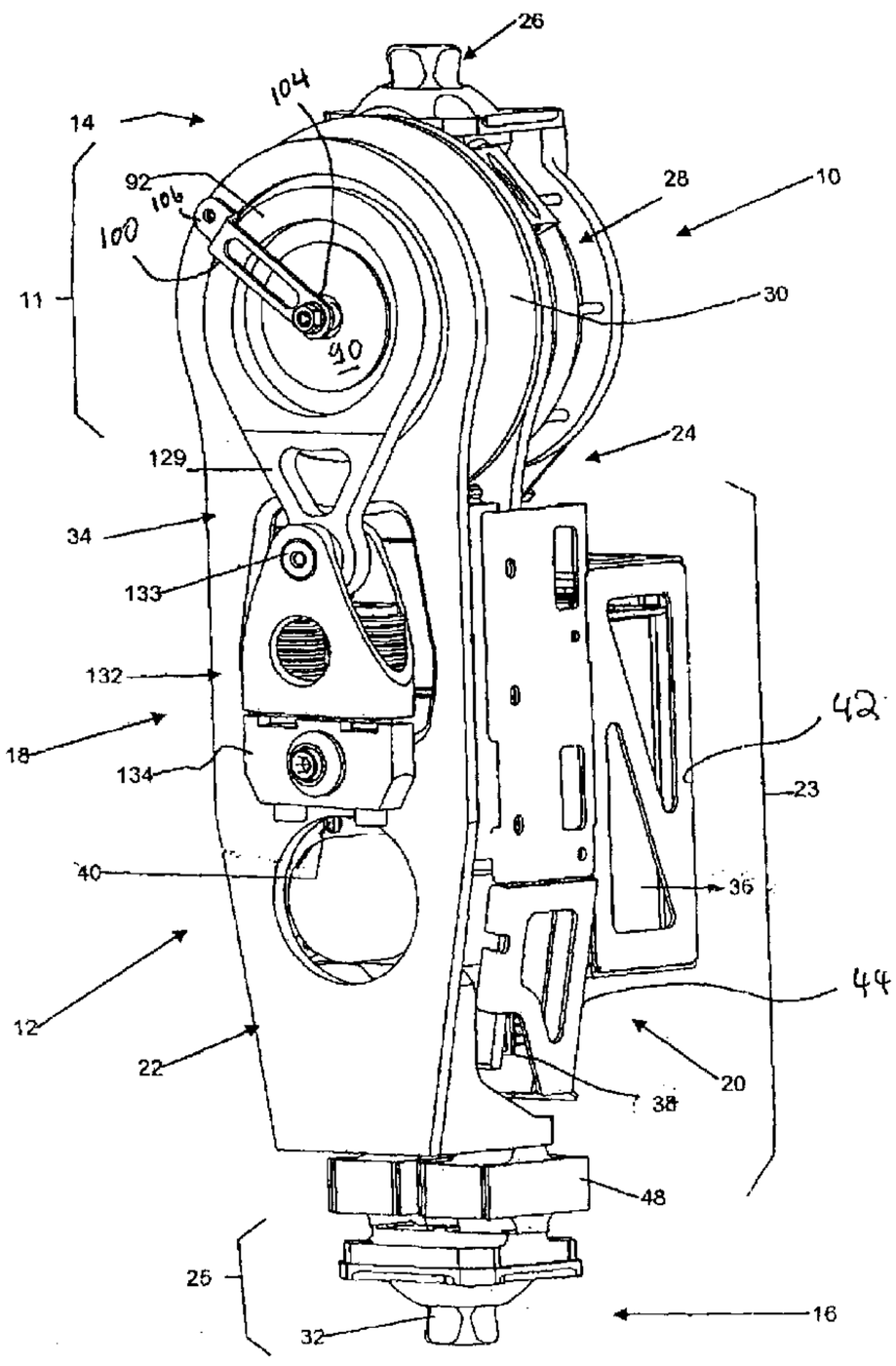
(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM),

[Continued on next page]

(54) Title: JOINT ACTUATION MECHANISM FOR A PROSTHETIC AND/OR ORTHOTIC DEVICE HAVING A COMPLIANT TRANSMISSION



(57) Abstract: Disclosed herein a prosthetic or orthotic device having a joint portion and a compliant transmission assembly in operational communication with the joint portion. The device restores the normal capabilities and natural dynamics of a healthy joint for common activities. The compliant transmission assembly includes a compliant element. The compliant transmission assembly absorbs energy when a torque is applied between a prosthetic or orthotic device portion and another adjacent device portion or the adjacent limb segment of the user. The compliant element of the invention absorbs energy during flexion of a joint for the dampening thereof and releases this energy during extension of the joint for assistance thereof. Also disclosed herein is an actuator assembly, a torque sensor and an actuator locking device as well as a method for determining the torque of such prosthetic and orthotic devices.

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WO 2008/080231 A1

European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

TITLE OF THE INVENTION

JOINT ACTUATION MECHANISM FOR A PROSTHETIC AND/OR ORTHOTIC DEVICE HAVING A COMPLIANT TRANSMISSION

FIELD OF THE INVENTION

[0001] The present invention relates to a joint mechanism for a prosthetic and/or orthotic device. More particularly, but not exclusively the present invention relates to a joint actuation mechanism for a prosthetic and/or orthotic device having a compliant transmission.

BACKGROUND OF THE INVENTION

[0002] A few types of joint actuation mechanisms for prosthetic or orthotic devices are known in the art and include joint actuation mechanisms. Usually, powered joint mechanisms form part of an orthotic device or a prosthetic device and include a housing for an actuator comprising a motor and a shaft in communication with a reducer which communicates with an output to cause the joint to rotate about an axis thereof.

[0003] A drawback of known joint actuation mechanisms include important electrical energy input to operate, affecting the autonomy of the device and requiring important battery capacity thereby affecting the weight of the device Another drawback of know joint actuation mechanisms is that they are heavy and voluminous, directly affecting the weight and size of the device.

[0004] Some drawbacks of known knee actuation mechanisms is that they do not provide real-time direct measurement of the torque and do not demonstrate compliance in any locomotion situation, consequently the prosthetic or orthotic device to which they are mounted does not smoothly respond to the commands of a user, to unexpected events nor does it easily adapt to the specific gait style of a user.

[0005] Still another drawback of conventional powered joint actuation mechanisms is that they are relatively noisy as causing embarrassment to the user in relatively quiet social settings.

OBJECT OF THE INVENTION

[0006] An object of the invention is to provide an actuation mechanism, designed for prosthetic and orthotic application, allowing mechanical energy storage through a compliant transmission.

SUMMARY OF THE INVENTION

[0007] In accordance with an aspect of the present invention, there is provided a prosthetic device for replacing the limb of a user comprising: at least one prosthetic portion; a joint portion interposed between said prosthetic portion and another adjacent prosthetic portion or an adjacent limb segment of the user, said joint portion comprising a joint actuator assembly configured to pivot said at least one prosthetic portion between flexion and extension movements relative to said another adjacent prosthetic portion or the adjacent limb segment of the user when mounted thereto; a compliant transmission assembly in operational communication with said joint portion and comprising a compliant member; and a torque sensor in communication with a controller of the prosthetic device, wherein said compliant member absorbs energy when a torque is applied between said at least one prosthetic portion and said another adjacent prosthetic portion or the adjacent limb segment of the user.

[0008] In accordance with another aspect of the present invention, there is provided an orthotic device for a limb of a user, said orthotic device

comprising: a proximal orthotic portion to be mounted to a proximal limb segment of the user; a distal orthotic portion to be mounted to a distal limb segment of the user; an orthotic joint portion interposed between said proximal and distal orthotic portions to be mounted to the joint of the user's limb for supporting the user's joint during flexion and extension thereof, said orthotic joint portion comprising a joint actuator assembly; a compliant transmission assembly in operational communication with said orthotic joint portion and comprising a compliant member; and a torque sensor in communication with a controller of the orthotic device, wherein said compliant member absorbs energy when a torque is applied between said proximal and distal portions.

[0009] In accordance with a further aspect of the present invention, there is provided a prosthetic/orthotic device comprising: at least one device portion; a joint portion configured to pivot said at least one device portion between flexion and extension movements relative to another adjacent device portion or an adjacent limb segment of the user; a compliant transmission assembly in operational communication with said joint portion, said compliant transmission assembly comprising a compliant member and a pivot interposed between said compliant member and said joint portion; and a torque sensor in communication with a controller of the prosthetic/orthotic device, wherein said compliant member absorbs energy when a torque is applied between said at least one device portion and said another adjacent prosthetic portion or the adjacent limb segment of the user.

[0010] In accordance with yet another aspect of the present invention, there is provided a compliant transmission assembly for a prosthetic/orthotic device comprising at least one device portion and a joint portion configured to pivot the at least one device portion between flexion and extension movements relative to another adjacent device portion or an adjacent limb segment of the user, said compliant transmission assembly comprising: a connector coupleable to the joint portion; a compliant member mountable to the device; a pivot interposed between said connector and said compliant

member; and a torque sensor in communication with a controller of the prosthetic/orthotic device, wherein said compliant member absorbs energy when a torque is applied between said at least one device portion and said another adjacent prosthetic portion or the adjacent limb segment of the user.

[0011] In accordance with yet a further aspect of the present invention, there is provided a prosthetic/orthotic device comprising: at least one device portion; and a joint portion interposed between said device portion and another adjacent device portion or an adjacent limb segment of a user, said joint portion comprising: a joint actuator assembly configured to pivot said at least one device portion between flexion and extension movements relative to said another adjacent device portion or the adjacent limb segment of the user when mounted thereto, said joint actuator assembly comprising an actuator in operational communication with a first hollow shaft, and a second sensor shaft coaxially mounted within said first hollow shaft and comprising a rotational axis sensor assembly.

[0012] In accordance with still another aspect of the present invention, there is provided a prosthetic/orthotic device comprising: at least one device portion; and a joint portion configured to be interposed between said device portion and another adjacent device portion or an adjacent limb segment of the user, said joint portion comprising: a joint actuator assembly configured to pivot said at least one device portion between flexion and extension movements relative to said another adjacent device portion or the adjacent limb segment of the user when mounted thereto, a harmonic transmission assembly in operational communication with said joint actuator assembly, and a sensor assembly mounted within said harmonic transmission assembly.

[0013] In accordance with still a further aspect of the present invention, there is provided a prosthetic/orthotic device comprising at least one device portion and a joint portion configured to be interposed between said device portion and another adjacent device portion or an adjacent limb segment of the user, said joint portion comprising: a joint actuator assembly configured to pivot said at least one device portion between flexion and extension movements relative to said another adjacent device portion or the adjacent limb segment of the user when mounted thereto; and an actuator locking device extending outwardly of said joint portion and being in operational communication with said joint actuator assembly configured to provide selective locking of said joint actuator assembly.

[0014] In accordance with still yet another aspect of the present invention, there is provided a method for determining a torque of a prosthetic/orthotic device having a joint portion thereof configured to enable flexion and extension movements of the device, said method comprising: providing a compliant member to be in operational communication with the joint portion; providing for a deflection between the compliant member and the joint portion during the flexion and extension movements; determining characteristics of the complaint member in operation; and determining the deflection.

[0014a] In accordance with an aspect of the present invention there is provided a prosthetic device for replacing the limb of a user comprising:

at least one prosthetic portion;

a joint portion interposed between said prosthetic portion and another adjacent prosthetic portion or an adjacent limb segment of the user, said joint portion comprising a joint actuator assembly configured to pivot said at least one prosthetic portion between flexion and extension movements relative to said another adjacent prosthetic portion or the adjacent limb segment of the user when mounted thereto;

a compliant transmission assembly in operational communication with said joint portion and comprising a compliant member;

and

a torque sensor in communication with a controller of the prosthetic device,

wherein said compliant member absorbs energy when a torque is applied between said at least one prosthetic portion and said another adjacent prosthetic portion or the adjacent limb segment of the user.

[0014b] In accordance with a further aspect of the present invention there is provided an orthotic device for a limb of a user, said orthotic device comprising:

a proximal orthotic portion to be mounted to a proximal limb segment of the user;

a distal orthotic portion to be mounted to a distal limb segment of the user;

an orthotic joint portion interposed between said proximal and distal orthotic portions to be mounted to the joint of the user's limb for supporting the user's joint during flexion and extension thereof, said orthotic joint portion comprising a joint actuator assembly;

a compliant transmission assembly in operational communication with said orthotic joint portion and comprising a compliant member; and

a torque sensor in communication with a controller of the orthotic device,

wherein said compliant member absorbs energy when a torque is applied between said proximal and distal portions.

[0014c] In accordance with a further aspect of the present invention there is provided a prosthetic/orthotic device comprising:

at least one device portion;

a joint portion configured to pivot said at least one device portion between flexion and extension movements relative to another adjacent device portion or an adjacent limb segment of the user;

a compliant transmission assembly in operational

communication with said joint portion, said compliant transmission assembly comprising a compliant member and a pivot interposed between said compliant member and said joint portion; and

a torque sensor in communication with a controller of the prosthetic/orthotic device,

wherein said compliant member absorbs energy when a torque is applied between said at least one device portion and said another adjacent prosthetic portion or the adjacent limb segment of the user.

[0014d] In accordance with a further aspect of the present invention there is provided a compliant transmission assembly for a prosthetic/orthotic device comprising at least one device portion and a joint portion configured to pivot the at least one device portion between flexion and extension movements relative to another adjacent device portion or an adjacent limb segment of the user, said compliant transmission assembly comprising:

a connector coupleable to the joint portion;

a compliant member mountable to the device;

a pivot interposed between said connector and said compliant member; and

a torque sensor in communication with a controller of the prosthetic/orthotic device,

wherein said compliant member absorbs energy when a torque is applied between said at least one device portion and said another adjacent prosthetic portion or the adjacent limb segment of the user.

[0014e] In accordance with a further aspect of the present invention there is provided s method for determining deflection of a prosthetic/orthotic device having a joint portion thereof configured to enable flexion and extension movements of the device, said method comprising:

providing a compliant member to be in operational communication with the joint portion;

providing for a deflection between the compliant member and the joint portion during the flexion and extension movements;

determining characteristics of the complaint member in operation; and

determining the deflection.

[0014f] In accordance with a further aspect of the present invention there is provided a prosthetic knee device comprising:

a knee joint interposed between a prosthetic shin and another adjacent prosthetic portion or an adjacent limb segment of a user, said knee joint comprising a joint actuator assembly configured to pivot said prosthetic shin between flexion and extension movements relative to said another adjacent prosthetic portion or the adjacent limb segment of the user when mounted thereto;

a compliant transmission assembly in operational communication with said knee joint via a rotatable connector mounted to a compliant member and said knee joint, the rotatable connector located between the joint actuator assembly and the compliant transmission assembly, wherein said compliant member absorbs energy and rotates relative to the prosthetic shin when a torque is applied between said prosthetic shin and said another adjacent prosthetic portion or the adjacent limb segment of the user;

a sensor that provides for torque measurement; and

a controller configured to use said torque measurement to control said joint actuator assembly,

wherein during a stance phase of the gait cycle the prosthetic knee device is configured so that the actuator assembly does not provide said pivot between flexion and extension and the compliant transmission assembly absorbs and returns energy, and

wherein during a swing phase of the gait cycle the prosthetic knee device is configured so that the controller causes the actuator assembly to adopt a force following behavior based on the torque measurement.

[0014g] In accordance with a further aspect of the present invention there is provided a prosthetic knee device comprising:

a prosthetic connector configured to be connected to a leg socket;

a knee joint actuator assembly comprising an actuator housing connected to the prosthetic connector and housing an actuator comprising a motor;

a rotatable shin structure configured to rotate about a pivot axis relative to the actuator housing, said rotation configured to be powered by the actuator to cause flexion and extension movements, wherein the actuator is mounted about the pivot axis;

a compliant transmission assembly connected between the rotatable shin structure and the knee joint actuator assembly, said compliant transmission assembly comprising a connector mounted to a compliant member and the knee joint actuator assembly, the compliant member being also mounted to the rotatable shin structure;

a sensor that provides for torque measurement based on deflection of the compliant member; and

a controller configured to use the torque measurement to control the actuator,

wherein during a stance phase of a gait cycle the prosthetic knee device is configured so that said compliant member first absorbs energy from ground contact and deflects relative to the rotatable shin structure, and then releases energy and moves back toward an undeflected position, and said motor of said actuator is immobilized, and

wherein during a swing phase of the gait cycle the prosthetic knee device is configured so that the controller causes the actuator to adopt a force following behavior, based on the torque measurement, in cooperation with energy released or absorbed by the compliant member.

[0014h] In accordance with a further aspect of the present invention there is provided a prosthetic device comprising:

at least one device portion;

a joint portion for providing for said at least one device portion to pivot about an axis between flexion and extension movements relative to another adjacent device portion or an adjacent limb segment of a user, the joint portion comprising two connectors on opposite sides of the joint portion for connection to the at least one device portion and the another adjacent device portion or the adjacent limb segment of the user, the joint portion further comprising a powered actuator configured to power pivoting between the at least one device portion and said another adjacent device portion or said adjacent limb segment of the user; and

a compliant transmission assembly in operational communication with said joint portion, said compliant transmission assembly comprising at least one compliant member and a pivot such that the compliant member is configured to pivot relative to said powered actuator about a pivot axis, the pivot axis between the compliant member and the powered actuator being located at a distance from a lower connector of the two connectors that is less than a distance of the axis of the joint portion from the lower connector, the compliant member comprising a deformable and resilient element,

wherein said compliant member absorbs energy when a torque is applied between said at least one device portion and said another adjacent prosthetic portion or the adjacent limb segment of the user.

[0014i] In accordance with a further aspect of the present invention there is provided a prosthetic/orthotic device comprising:

at least one lower device portion and a knee joint portion for providing for the at least one lower device portion to pivot between flexion and extension movements relative to another adjacent device portion or an adjacent limb segment of a user about an axis corresponding to a natural knee joint of the user, the knee joint portion comprising a powered actuator configured to power pivoting between the at least one lower device portion and said another adjacent device portion or said adjacent limb segment of the user; and

a compliant transmission assembly positioned to transmit the pivoting of the powered actuator from the knee joint portion between the at least one lower device portion and said another adjacent device portion or said adjacent limb segment of the user; the compliant transmission assembly comprising

a lever for being mounted to the knee joint portion and

a compliant member mountable to the at least one lower device portion, wherein said compliant member has a non-linear stiffness such that the compliant member is configured to be stiffer at a first torque value than at a second torque value, wherein said first torque value is larger than said second torque value, and wherein said compliant member is configured to pivot relative to said powered actuator about a pivot axis, the pivot axis being located at a distance from the lower device portion that is less than a distance of the axis of the joint portion from the lower device portion, and the compliant member comprises a deformable and resilient element.

[0014j] In accordance with a further aspect of the present invention there is provided an orthotic device comprising:

a joint portion for mounting directly to two adjacent limb segments of a user and providing for said two adjacent limb segments to pivot between flexion and extension movements relative to each other, the joint portion comprising two mounts on opposite sides of the joint portion for direct connection to the adjacent limb segments of the user, the joint portion further comprising a powered actuator configured to power pivoting between the adjacent limb segments of the user; and

a compliant transmission assembly in operational communication with said joint portion, said compliant transmission assembly comprising a compliant member and a pivot such that the compliant member is configured to pivot relative to said powered actuator, the compliant member comprising a deformable and resilient element,

wherein said compliant member absorbs energy when a torque is applied between the adjacent limb segments of the user.

[0014k] In accordance with a further aspect of the present invention there is provided an orthotic device comprising:

a joint portion for mounting directly to two adjacent body portions of a user separated by a natural joint of a user and providing for said two adjacent body portions to pivot between flexion and extension movements relative to each other about the natural joint, the joint portion comprising two mounts on opposite sides of the joint portion for direct connection to the adjacent body portions of the user, the joint portion further comprising a powered actuator disposed between the two mounts and configured to power pivoting between the adjacent body portions of the user; and

a compliant transmission assembly disposed between the two mounts and in operational communication with said joint portion, said compliant transmission assembly comprising a compliant member and a pivot such that the compliant member is configured to pivot relative to said powered actuator, the compliant member comprising a deformable and resilient element,

wherein said compliant member absorbs energy when a torque is applied between the adjacent body portions of the user.

[0014l] In accordance with a further aspect of the present invention there is provided an orthotic device comprising:

a joint portion for mounting directly to two adjacent body portions of a user separated by a natural joint of a user and providing for said two adjacent body portions to pivot between flexion and extension movements relative to each other about the natural joint, the joint portion comprising two mounts defining opposite sides of the orthotic device and providing for direct connection to the adjacent body portions of the user, the joint portion further comprising a powered actuator configured to power pivoting between the adjacent body portions of the user; and

a compliant transmission assembly in operational communication with said joint portion, said compliant transmission assembly

comprising a compliant member and a pivot such that the compliant member is configured to pivot relative to said powered actuator, the compliant member comprising a deformable and resilient element,

wherein said compliant member absorbs energy when a torque is applied between the adjacent body portions of the user.

[0015] In accordance with still yet a further aspect of the present invention there is provided a joint actuation mechanism for a prosthetic and/or orthotic device comprising a compliant transmission.

[0016] In accordance with yet still another aspect of the present invention there is provided a compliant transmission for a joint actuation mechanism for a prosthetic and/or orthotic device.

[0017] In accordance with yet still a further aspect of the present invention there is provided a knee actuation mechanism for a prosthetic and/or orthotic device comprising a compliant transmission.

[0018] In accordance with another aspect of the present invention there is provided a compliant transmission for a knee actuation mechanism for a prosthetic and/or orthotic device.

[0019] In accordance with further aspect of the present invention there is provided a prosthetic device comprising a joint actuation mechanism, the joint actuation mechanism comprising a compliant

transmission.

[0020] In accordance with still another aspect of the present invention there is provided an orthotic device comprising a joint actuation mechanism, the joint actuation mechanism comprising a compliant transmission.

[0021] In accordance with still a further aspect of the present invention there is provided a prosthetic knee device comprising a knee joint actuation mechanism, the knee joint actuation mechanism comprising a compliant transmission.

[0022] In accordance with still yet a further aspect of the present invention there is provided an orthotic knee device comprising a knee joint actuation mechanism, the knee joint actuation mechanism comprising a compliant transmission.

[0023] In an embodiment, the knee actuation mechanism of the invention comprises an actuator, a harmonic transmission assembly and a compliant torque transmission system used to serially connect the output stage (actuator and harmonic transmission) to the prosthesis structure (for example, the shank replacement part).

[0024] In an embodiment, the invention comprises a knee actuation mechanism intended to be utilized in a prosthetic device (for above-knee amputees) or an orthotic device (for users that lost control of their leg). The active device restores the normal capabilities and natural dynamics of

a healthy leg for common activities such as level and incline walking, stairs ambulation as well as sitting down and up.

[0025] In an embodiment, the invention substantially restores natural dynamics and adaptation to a user's gait.

[0026] In an embodiment, the energy storing capability of the compliant transmission assembly reduce the energy required by the joint actuation system when the user is walking.

[0027] In an embodiment, the compliant transmission assembly or mechanism provides substantially the same compliance as a healthy human leg during the stance phase of the walking gait.

[0028] In an embodiment, the foregoing is achieved through a compliant element properly configured and assembled to provide the desired behavior.

[0029] In an embodiment, the compliant element comprises an elastic element.

[0030] In an embodiment, the elastic element comprises deformable and resilient characteristics.

[0031] In an embodiment, the elastic element comprises a spring.

[0032] In an embodiment, as the compliant transmission

participates in providing natural dynamics, the actuator activity (which comprises an electric motor and a shaft in one example) is reduced during the stance phase, leading to reducing the power consumption for the joint actuation mechanism. In fact, the compliant transmission stores and very efficiently returns mechanical energy. Without the compliant transmission, the energy recycling process would be much less efficient as the process would involve many energy transformations (from mechanical to electrical and the opposite), thus reducing the efficiency. Therefore, the compliant transmission mechanism contributes to increasing the autonomy of the prosthetic/orthotic device and/or to reduce the dimensions and weight of the battery pack.

[0033] In an embodiment, the angular deflection of the compliant transmission is measured by means of a rotational sensor. The measurement of the deflection angle is used to provide a real-time measurement of the torque at the joint. The foregoing is possible due to the known characteristics of the elastic element of the compliant transmission. This measurement is useful for the device's controller to provide a smoother motion (through impedance control to give but one example). This type of control better reacts to a user's commands or to unexpected events and naturally adapts to the specific gait style of a user. The mechanical compliance also contributes in improving the comfort, as shocks and vibrations are greatly adsorbed instead of being transmitted to the limb.

[0034] In an embodiment, the compliant transmission attenuates noise-generating vibrations (induced by the motor and/or harmonic transmission assembly for example), thereby substantially avoiding

transmission of the vibrations to the prosthetic/orthotic device or structural elements thereof. The foregoing contributes in reducing the noise generated by the device.

[0035] In one embodiment, the center of mass of the prosthetic knee device of the invention is located proximal relative to the hip joint, the device will feel lighter by the user.

[0035a] In accordance with still yet another aspect of the present invention, there is provided a prosthetic knee device comprising: a knee joint interposed between a prosthetic shin and another adjacent prosthetic portion or an adjacent limb segment of a user, said knee joint comprising a joint actuator assembly configured to pivot said prosthetic shin between flexion and extension movements relative to said another adjacent prosthetic portion or the adjacent limb segment of the user when mounted thereto; a compliant transmission assembly in operational communication with said knee joint via a rotatable connector mounted to a compliant member and said knee joint, the rotatable connector located between the joint actuator assembly and the compliant transmission assembly, wherein said compliant member absorbs energy and rotates relative to the prosthetic shin when a torque is applied between said prosthetic shin and said another adjacent prosthetic portion or the adjacent limb segment of the user; sensor that provides for torque measurement; and a controller configured to use said torque measurement to control said joint actuator assembly, wherein during a stance phase of the gait cycle the prosthetic knee device is configured so that the actuator assembly does not provide said pivot between flexion and extension and the compliant transmission assembly absorbs and returns energy, and wherein during a swing phase of the gait cycle the prosthetic knee device is configured so that the controller causes the actuator assembly to adopt a force following behavior based on the torque measurement.

[0035b] In accordance with still yet another aspect of the present invention, there is provided a prosthetic knee device comprising: a prosthetic connector configured to be connected to a leg socket; a knee joint actuator assembly comprising an actuator housing connected to the prosthetic connector and housing an actuator comprising a motor; a rotatable shin structure configured to rotate about a pivot axis relative to the actuator housing, said rotation configured to be powered by the actuator to cause flexion and extension movements, wherein the actuator is mounted about the pivot axis; a compliant transmission assembly connected between the rotatable shin structure and the knee joint actuator assembly, said compliant transmission assembly comprising a connector mounted to a compliant member and the knee joint actuator assembly, the compliant member being also mounted to the rotatable shin structure, a sensor that provides for torque measurement based on deflection of the compliant member; and a controller configured to use the torque measurement to control the actuator, wherein during a stance phase of a gait cycle the prosthetic knee device is configured so that: said compliant member first absorbs energy from ground contact and deflects relative to the rotatable shin structure, and then releases energy and moves back toward an undeflected position, and said motor of said actuator is immobilized, and wherein during a swing phase of the gait cycle the prosthetic knee device is configured so that the controller causes the actuator to adopt a force following behavior, based on the torque measurement, in cooperation with energy released or absorbed by the compliant member.

[0036] Other objects, advantages and features of the present invention will become more apparent upon reading of the following non-restrictive description of illustrative embodiments thereof, given by way of example only with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE FIGURES

[0037] In the appended drawings, where like reference numerals indicate like elements throughout and where:

[0038] Figure 1 is a perspective view of prosthetic device including the joint actuation mechanism of the present invention in accordance with an embodiment thereof;

[0039] Figure 2 is a front view of the prosthetic device of Figure 1;

[0040] Figure 3 is a sectional view of the actuation assembly of Figure 2 along line 3 - 3 thereof excluding the sensor assembly of the invention;

[0041] Figure 4 is a simplified view of a portion of Figure 3;

[0042] Figure 5 is another simplified view of a portion of Figure 3 including the sensor assembly of the invention in accordance with an embodiment thereof;

[0043] Figure 5a is a perspective view of the stator assembly of the joint actuation mechanism of Figure 1 in accordance with an embodiment of the invention;

[0044] Figure 5b is a perspective view of the motor rotor assembly of the joint actuation mechanism of Figure 1 in accordance with an embodiment of the invention;

[0045] Figure 5c is a perspective view of the transmission output assembly of the joint actuation mechanism of Figure 1 in accordance with an embodiment of the invention;

[0046] Figure 5d is a perspective view of the shank assembly of the joint actuation mechanism of Figure 1 in accordance with an embodiment of the invention;

[0047] Figure 6 is a front view of the compliant transmission assembly of the invention in accordance with an embodiment thereof;

[0048] Figure 7 is a front view of the compliant transmission assembly of Figure 6 when the knee section of the prosthetic device is in a flexion movement;

[0049] Figure 8 is partial front view of the compliant transmission assembly of Figure 6;

[0050] Figure 9 is a partial front view of the compliant transmission assembly of Figure 7;

[0051] Figure 10 is a partial front view of a compliant element of the compliant transmission assembly of Figure 6;

[0052] Figure 11 is a partial front view of a compliant element of the compliant transmission assembly of Figure 7;

[0053] Figure 12 is another perspective view of the prosthetic device of Figure 1;

[0054] Figure 13 is a perspective view of the locking device of the joint actuation mechanism of Figure 1 in an unlocked position;

[0055] Figure 14 is a perspective view of the locking device of the joint actuation mechanism of Figure 1 in a locked position;

[0056] Figure 15 is a graph showing the desired compliant element behavior of the joint actuation mechanism of Figure 1 on the stiffness of the normal human knee joint at different walking speeds;

[0057] Figure 16 is a schematic example representing the compliant transmission geometry of the invention in accordance with one non-limiting embodiment thereof;

[0058] Figure 17 is a perspective view of an orthotic device including a joint actuation mechanism of the invention in accordance with an embodiment thereof;

[0059] Figure 18 is a lateral schematic view of the orthotic device of Figure 17;

[0060] Figure 19 is a schematic representation of an mechanical actuator assembly for the joint actuation mechanism of Figure 17;

[0061] Figure 20 is a schematic representation a Magnetorheological (MR) rotational damper for the joint actuation mechanism of Figure 17; and

[0062] Figures 21A, 21B, 21C, 21D and 21E, are schematic representation of a variety compliant transmission assemblies in accordance with non-limiting embodiments of the present invention.

DETAILED DESCRIPTION OF THE ILLUSTRATIVE EMBODIMENTS

[0063] Generally stated, the present invention relates to a prosthetic/orthotic device having at least one device portion (prosthetic or orthotic portion) and joint portion. The joint portion provides for the at least one device portion to pivot between flexion and extension movements relative to another adjacent device portion or an adjacent limb segment (such as a stump) of the user. The device includes a compliant transmission assembly in operational communication with the joint portion. The compliant transmission assembly comprises a compliant member and a pivot interposed between this compliant member and the joint portion. Thecompliant member absorbs energy during flexion and releases this energy during extension. When absorbing energy, the compliant member dampens flexion and when releasing energy, compliant member assists extension.

[0064] With reference to the appended drawings illustrative embodiments of the present invention will now be described so as to exemplify the invention only and by no means limit the scope thereof.

Prosthetic device

[0065] Figures 1 and 2 show a joint mechanism 10 in accordance with an embodiment of the present invention. In this example the powered joint mechanism 10 is a knee joint mechanism

[0066] The knee joint mechanism 10 is mounted to and forms part of a prosthetic device 12. The prosthetic device 12 is a lower leg structure or shank structure 12 having a top end and bottom end, 14 and 16, respectively, front and rear faces 18 and 20 respectively and lateral sides 22 and 24. More specifically, the prosthetic lower leg structure 12 defines a knee joint portion 11, a prosthetic shin portion 23 and a prosthetic ankle portion 25 (only a reference to an area not an ankle per se, which is not shown). The knee actuation mechanism 10 includes a prosthetic connector 26 at the top end 14 which sits on an actuator assembly 28 that in turn is mounted to a rotatable knee shank structure 30. It should be noted here that the rotatable knee shank structure 30 includes the knee portion 11 of the shank structure 12 as well as the actuator assembly 28, thus the knee shank structure 30 (excluding the actuator assembly 28) is integral with the shank structure 12. The prosthetic connector 26 is configured to be connected to a common socket (not shown) that is mountable to the leg stump of a user. The shank structure 12 includes a distal connector 32 at the bottom end 16 (or ankle portion 25) for connecting a common prosthetic ankle and foot product thereto (not illustrated).

[0067] As will be discussed herein the knee actuation mechanism 10 includes a compliant transmission assembly 34 mounted to the knee portion 11 and the shin portion 23 of prosthetic lower leg shank structure 12.

[0068] The prosthetic lower leg shank structure 12 also includes an electronic assembly comprising a power board 40, an I/O board 38 and a battery 36 all of which are respectively held by covers 42, 44 to the shin portion 23 of prosthetic shank structure 12. Inertial sensor boards (not shown) are located respectively on the shin portion 23 of the prosthetic shank structure 12 and load cells or floor contact switches 48 are located at bottom end 16 (ankle portion 25).

Actuator assembly

[0069] With particular reference to Figure 3, the actuator assembly 28 will now be described.

[0070] The actuator assembly 28 includes an actuator housing 50 for housing an actuator 52, which can be a motor rotor for example, such as a Brushless DC motor in a particular non-limiting example, rotatably mounted within a stator 53.

[0071] Actuator 52 is in operational communication with a first hollow shaft 54 defining the knee rotation axis X between flexion and extension. Shaft 54 is directly connected to a harmonic transmission assembly 56 (in the form of a harmonic drive gearing) at one end 58 thereof, while the floating end 60 is guided by ball bearings 62 mounted to the housing 50.

[0072] The shaft 54 is hollow, as such second shaft 64 (see Figure 5) is inserted therein but it should be noted that shaft 54 does not act on shaft 64 but merely rotates thereabout.

[0073] In this non-limiting example, the harmonic transmission assembly 56 includes a wave generator 68 whose locational and rotational guidance is ensured by a circular spline 70 which is mounted to the actuator housing 50 via fasteners, glue, press fitting and the like. More specifically, the wave generator 68 is an assembly of bearings in a steel disk plug having a generally elliptical outer shape and including a central aperture 74 for operatively receiving the shaft 54 therethrough.

[0074] With reference to Figures 3 and 4, the harmonic transmission assembly 56 also includes a flexspline 76 having one end 78 mounted between the wave generator 68 and the circular spline 70 and defining a brim composed of gear teeth. A flexible cup portion 80 extends from the brim end 78 to define an opposite end 82 having an aperture 84 (see Figure 4).

[0075] In general, the flexspline 76 comprises a thin-walled steel cup 80 with gear teeth machined on the outer surface of the brim end 78. When the harmonic transmission assembly 56 is assembled, the wave generator 68 is inserted inside the flexspline 76 such that the bearings are at the same axial location as the flexspline 76 gear teeth. The flexspline 76 wall near the brim end 78 conforms to the same elliptical shape of the wave generator 68 outer surface providing the flexspline 76 to have an elliptical gear pitch on its outer surface. The flexspline 76 and more specifically, the flexible cup 80 is the output member of the harmonic transmission assembly 56 and is mounted to the compliant transmission assembly 34 as will be explained herein. In general, the circular spline 70 is a rigid circular steel ring with teeth on the inside diameter. The circular spline 70 is located such that its teeth mesh with those of the flexspline 76.

[0076] Of course, other types of harmonic transmission assemblies can be used within the context of the present invention.

[0077] Turning now to Figure 4 in order to simplify and recapitulate the foregoing, the motor rotor 52 and the harmonic transmission assembly 56 define a reducer assembly 86. The stator 53 and the circular spline 70 are connected together via the actuator housing 50 which is connected to the prosthetic connector 26 as shown in Figures 1, 2 and 3. The motor rotor 52 is directly inserted onto first shaft 54 which connects to the wave generator 68 via shaft-receiving aperture 74 and bolts (not shown). The output stage of the transmission is the flexible cup portion 80 of the flexspline 76, which as mentioned above, connects to the compliant transmission assembly 34.

[0078] In one non-limiting example, the reducer assembly 86 provides a reducing ratio of 51:1 between the input stage and the output stage of the actuator assembly 28. Of course, as the skilled artisan will readily contemplate, different transmission ratios are available for this type of transmission, but a relatively low ratio leads to lower motor 52 rotational speed, therefore helping to maintain low mechanically generated noise and reducing the inertia of motor rotor 54 in respect to the output stage. In one embodiment, a low inertia is desirable to reduce the kinetic energy of the knee actuation mechanism 10 and to provide a faster response time.

[0079] With reference again to Figure 3, the output end or output stage of the actuator assembly 28 will now be described in greater detail.

[0080] The flexspline 76 is secured in place between a backing plate 88 and a retaining cover 90 both of which are fastened together via

fasteners 91 such as dowell pins for example. The rotational motion of the flexspline 76 is transmitted to the compliant transmission assembly 34 via the retaining cover 90 which is connected to the lever 92 (which can be any type of cam or like member) of the compliant transmission assembly 34 as will be discussed herein. The flexspline retaining cover 90 is guided during rotation thereof about axis X by cross-roller bearings 94, which are mounted to the knee shank structure 30. Therefore as the retaining cover 90 turns, it turns the lever 92 in unison therewith.

[0081] Referring to Figure 5, the second shaft 64 runs through the wave generator 68 into the flexible cup 80 and is in communication with a sensor assembly 112 within the flexible cup 80 as will be discussed herein.

[0082] Referring to Figures 3, 4 and 5, the sensor assembly 112 is also in communication with a third shaft 66 within the flexible cup 80, this third reference shaft 66 exits the flexible cup 80 via aperture 84 and into a tubular member 98. The third reference shaft 66 is guided by double-row ball bearings 99.

[0083] With reference to Figures 1 and 3, an elongate connector 100 is securely mounted to the free end 102 of the third shaft 66 at one end 104 thereof and to the knee shank 30 (knee joint portion 11) at an opposite end 106 thereof. In this way, as the knee shank 30 (and effectively the entire shank 12) rotates about axis X, the elongate connector 100 turns this third shaft 66 in unison. The connector 100 is fixedly mounted to the shaft 66 via a nut and washer assembly 108. It should be noted that the elongate connector 100 is so configured as to provide a clearance for the compliant transmission lever 92.

Torque sensor and rotational axis sensor

[0084] With reference to Figure 5, the knee rotational axis sensor assembly 112, mentioned above and in accordance with an embodiment of the invention will be herein described.

[0085] The sensor assembly 112 comprises two rotational sensors 114 and 116. In one non-limiting embodiment, the sensors 114 and 116 are one-turn absolute optical type and comprise of a respective partial disk 118 and 120, a respective light emitter 122 and 124 as well as a respective sensor element 126 and 128. The sensor element 128 measures the relative displacement between the knee shank structure 30 and the output stage (the flexible cup 80) of the harmonic transmission assembly 56. This displacement corresponds to the angular deflection of the compliant transmission assembly 34 (which will be discussed below).

[0086] The partial disk 120 is attached to the third shaft 66 which is connected to the shank structure 30 via connector 100, the light emitter 124 and the sensor element 128 are attached to the flexible harmonic transmission output (the flexible cup 80).

[0087] The partial disk 118 is attached to the second shaft 64, while the light emitter 122 and the sensor element 126 are attached to the harmonic transmission output (flexible cup 80).

[0088] When rotating, the motor rotor 52 and shaft 54 assembly produce a relative rotational motion between the stator 53 and the transmission output assembly (see Figure 5c). This relative motion is measured with the sensor partial disk 118 and its sensor detector element

126.

[0089] The motion of the transmission output assembly (see Figure 5c) tends to transmit the movement to the shank 30 through the compliant transmission 34. If the shank 30 resists to the movement (acceleration or external force on the shank structure 12), the compliant transmission 34 will be deflected. The deflection of the compliant transmission 34 creates relative rotational movement between the transmission output assembly (see Figure 5c) and the shank structure 12. This relative motion is measured with the sensor partial disk 120 and its sensor detector 128 thereby providing a torque sensor.

[0090] Of course, the skilled artisan will readily appreciate that other types of sensors (such as magnetic sensors, optical sensors, potentiometers) could be used within the context of the present invention. Sensors with relative displacement measurement instead of absolute displacement could also be used. Furthermore, the skilled artisan can position the sensor that measures the deflection of the compliant transmission assembly 34 (i.e. the torque sensor) in a different location, for example in a linear position on the spring assembly (which will be described herein).

[0091] With reference to Figures 5a, 5b, 5c and 5d the foregoing will be summarized for clarity purposes only.

[0092] Figure 5a shows the stator assembly which includes the motor stator 53, the second shaft 64 and the circular spline 70. Stator 53 which as aforementioned is fixed to the housing 50. Second shaft 64

carries the sensor partial disk 118 of sensor 114 at one end thereof and is linked to the housing 50 at another opposite end 64e thereof. The circular spline 70 is also mounted to the housing 50.

[0093] Figure 5b shows the motor rotor assembly which includes the motor 52, the motor shaft 54 and the wave generator 68.

[0094] Figure 5c shows the transmission output assembly which includes the flexible cup 80, both sensors 114 and 116 of the sensor assembly 112 which are mounted within the flexible cup 80 and the lever 92 of the compliant transmission assembly 34 (that will be discussed in greater detail below) which is mounted to the flexible cup 80 via retaining cover 90. The sensors 114 includes the light emitter 122 and the sensor element 126 and the sensor 116 includes the light emitter 124 and the sensor element 128.

[0095] Figure 5d shows the shank assembly including the shank structure 12 (in this case only the knee portion 11 – which is included in the knee shank structure 30 as explained above – is shown), a connector 100 fixedly mounted to the third shaft 66 at one end thereof, with the other end of the shaft 66 carrying the sensor partial disk 120 of sensor 116. Referring back to Figure 5, when Figures 5a to 5b are assembled the partial disks 118 and 120 are respectively positioned between sensor element 126 and light emitter 122 and between sensor element 128 and light emitter 124.

Compliant transmission assembly

[0096] Turning now to Figures 1, 6 and 7, the compliant transmission assembly 34 will be described herein.

[0097] The compliant transmission assembly 34 comprises a connector in the form of a generally circular lever 92 that is connected to the retaining cover 90 so as to move in unison with the knee shank structure 30 (which as discussed is integral to the shank structure 12). The lever 92 has a bottom extension 129 defining a lower end 130 movably, and in this case pivotally, mounted to a compliant member in the form of a spring assembly 132 via pivot 133. The spring assembly 132 is mounted to the shin portion 23 of the shank structure 12 through a quick connecting mechanism 134 mounted to shank structure 12 via an attachment pin or pivot 136. The spring stack assembly 132 comprises a spring-carrying body 137.

[0098] With reference to Figures 8 and 9, the spring-carrying body 137 comprises an outer body portion 138 (see Figures 6 and 7) and an inner body portion 140 both of which have respective top extensions defining a top end 142 for pivotally mating with the bottom end 130 of the lever 92 via pivot 133. The quick connecting mechanism 134 comprises an outer body portion 144 (see Figures 6 and 7) and an inner body portion 146. A stress member in the form of a pair of stress tubes 148 and 150 are mounted to the body portion 140 and respectively sandwich, between their mutual lower platform 152 and their respective top t-formations or shoulders 153 and 154, a respective compliant element, in this example, being a spring stack 156 and 158 (see Figures 8 and 9). The respective bottom portion 160 and 161 of each stress tube 148 and 150 is configured to receive a respective stress actuator in the form of screws 162 and 164 and includes a respective retaining ring 166 and 168 mounted thereto.

Therefore, the stress tubes 148 and 150 and retaining rings 166 and 168 provide a predetermined high pre-stress to the spring stack assembly 132. This pre-stress is accentuated by the screws 162 and 164 during assembly. It is also possible to adjust the spring stiffness by tightening or loosening the screws 162 and 164, this could help accommodate users of different weights, as the ideal stiffness would be higher for heavier users and lower for lighter users.

[0099] In one embodiment, the spring stacks 156 and 158 can be made from a limited displacement dual stack of Belleville washers. Of course, the skilled artisan will readily comprehend that other configurations could include a different or equivalent number of stacks, comprised of either Belleville washers, helicoidal springs, machined springs, rubber stacks or any other component composed of any other material that could provide the desired behavior within the context of the present invention.

[00100] With respect to Figures 10 and 11, in the present non-limiting example, each spring stack 156 and 158 is comprised of seventeen Belleville washers 170 (only six shown here) placed back to back. Other implementations could include a different number as well as different types of washers 170 to accommodate different ranges of user weights. Between each pair of Belleville washers 170 is placed a spacer 172 that is used to limit the deflection of the washers 170 so as to control the maximum deflection angle of the compliant transmission and to extend the fatigue life of the springs 156 and 158.

[00101] Turning now to Figure 12, the compliant transmission assembly 34 provides for disengaging the spring assembly 132 from compliant transmission lever 92. The foregoing provides for the free swing

mode which be useful when the prosthesis runs out of power, as the knee actuation mechanism 10 would demonstrate an important resistance to movement, making walking quite strenuous. With the spring assembly 132 disengaged, the compliant transmission lever 92 is freed and the knee actuation mechanism 10 becomes unrestrained for rotation. A passive mechanism applying resistance to the rotation motion could be added to obtain a more appropriate behavior. To detach the spring stack assembly 132 and enter the free swing mode from the lever 92, tension in the screws 162 and 164 is released and the pivot 133 removed.

Actuator locking device

[00102] With reference to Figures 13 and 14, the knee actuation mechanism 10 also includes a locking device 174 which allows for manually locking the knee joint actuation mechanism 10 at a desired knee angle. As shown in Figure 2, the locking device 174 is positioned on lateral side 24 of the knee portion 11 of the shank structure 12. Figures 13 and 14 respectively show a simplified view of the motor assembly 176 and of the locking device 174 in unlocked operation and in locked operation. The motor assembly 176 comprises the motor rotor 52, the shaft 54 and of the wave generator 68 of the harmonic transmission assembly 56. The locking device 174 comprises a locking slider 178 and a locking slider guide 180. When the locking device is engaged, the locking slider 178 engages between teeth 182 located at the extremity end 184 of the shaft 54.

[00103] The foregoing provides locking the input stage (i.e. motor 52, shaft 54, and wave generator 68 of the harmonic transmission assembly

56) at predetermined angles determined by the configuration of the teeth 182. In this non-limiting example, the predetermined angles are at every 90 degrees of rotation about the axis X. In the case where the harmonic transmission ratio is 51:1, a 90 degree locking angle provides for the output stage of the harmonic transmission assembly 56 to be blocked at every 1.76 degrees of rotation about the axis X.

[00104] The ability to lock the knee joint mechanism 10 at multiple angles provides for the user to increase comfort for activities such as standing for extended periods or other activities requiring locking of the knee joint mechanism 10. In one non-limiting embodiment, the locking device 174 includes locking of the input stage of the harmonic transmission 56 at higher or smaller portions of a rotation about the X axis, as such the number of teeth 182 of the shaft 54 and the size of the slider 178 are designed accordingly. In another non-limiting embodiment, the locking device 174 includes a frictional braking system (not illustrated), allowing locking at any desirable angle.

[00105] Therefore, the knee actuation mechanism 10 comprises an actuator assembly 28, a harmonic transmission assembly 56 and a compliant transmission assembly 34.

Operation

[00106] In operation, the motor 52 actuates the shaft 54, which rotates about axis X, causing the wave generator 68 to rotate therewith, thereby actuating the flexspline 76 (and hence the flexible cup 80) and consequently reducing the rotation movement, movement that is

transmitted from the flexspline 76 to the circular spline 70. The circular spline 70 being connected to the housing 50 causes the rotation of the knee shank structure 30 (and consequently of the shank structure 12) about axis X and in accordance with this reduced transmitted rotational movement, between flexion and extension of the knee joint actuation mechanism 10 (depending on the rotational direction of the shaft 54 as the skilled artisan will readily understand).

[00107] As the housing 50 rotates, the second shaft 64 being linked thereto will rotate along therewith, thus rotating the sensor partial disk 118, providing the sensor assembly 112 to detect the position or angle of the stator assembly relative to the transmission output assembly (as described above).

[00108] As the flexspline 76 rotates about axis X, the reduced movement thereof is transferred to the lever 92, since it is connected to the simultaneously rotating flexspline cover 90, causing lever 92 to rotate therewith.

[00109] The rotation of the lever 92 causes a deflection between the lever 92 and the spring assembly 132 about pivot 133. This aforementioned deflection will depend on whether the movement of the shank structure 12 originates from the motor 52 or from the user (not shown).

[00110] When the movement of shank structure 12 originates from the motor 52 as described above and the shank structure 12 rotates about X in the direction shown by R1 in Figure 7, during flexion, the lever 92 is

rotating along with the flexspline 76 (in direction R1) and as such pulls on the spring assembly 132 causing the springs 156 and 158 to contract (as shown by arrow T in Figure 11), thereby causing pivot 133 to deflect in the direction shown by arrow D1 (towards the left). In this way, the compliant transmission 34 pulls the shank structure 12 towards direction R1. When the shank structure 12 rotates about X in the direction shown by R2 in Figure 7, during extension, the lever 92 is rotating along with the flexspline 76 (in the direction shown by R2) and pulls on the spring assembly 132 causing the springs 156 and 158 to contract (as shown by arrow T in Figure 11), thereby causing pivot 133 to deflect in the direction shown by arrow D2 (towards the right). In this way, the compliant transmission 34 holds back the shank structure 12 as it moves in direction R1.

[00111] When the movement of the shank structure 12 originates from the user (i.e. when motor 52 is not in function and as such the flesxpsline 76 and by extension the lever 92 are idle), the operation of the compliant transmission assembly is as follows. If the user wants to cause a flexion movement (R1), they apply a force to the shank structure 12 via their limb stump, this force (torque) causes the shank structure to move in the direction shown by arrow R1 (flexion), the shin portion 23 of the shank structure 12 moves before the knee portion 11, hence, the lever 92 resists the movement of the shin portion 23, causing the springs 156 and 158 to compress (T) and causing a deflection of pivot 133 in the D2 direction (towards the right). If the user wants to cause an extension movement (R2), they apply a force to the shank structure 12 via their limb stump, this force (torque) causes the shank structure 12 to move in the direction shown by arrow R2 (extension), the shin portion 23 of the shank structure 12 moves before the knee portion 11, hence, the lever 92 resists the

movement of the shin portion 23, causing the springs 156 and 158 to compress (T) and causing a deflection of pivot 133 in the direction shown by D1 (towards the left). Hence, in these cases, the lever 92 impedes the movement of the shank structure 12. The same occurs during normal walking or any type of heel strike or standing. As soon as there is a force (torque) applied to the shank structure 12, the compliant transmission assembly 34 will resist this movement. Thereby adding rigidity to the shank structure 12 during standing or a more fluid and less abrupt movement.

[00112] Therefore, the presence of the compliant element (the action of springs 156 and 158) between the actuator output and the prosthetic shank structure 12 allows for relative motion of the knee section 11 about the knee axis X, without necessarily requiring motor motion. In one embodiment, deflection of the compliant element is limited to a range of about ±15 degrees with respect to the compliant transmission lever 92 position. The non-linearity of springs 156 and 158 is either defined through appropriate spring behavior or spring assembly length, or compliant transmission lever 92 length, or by design.

[00113] In general, the design of both the behavior and deflection limit of the compliant transmission assembly 34 with respect to a prosthetic knee actuation mechanism 10 is substantially based on human leg dynamics. The stiffness of the normal healthy human leg during the whole stance phase including heel strike changes with ambulation speed. The faster the walking speed, the stiffer the knee joint is. The maximum spring 156 and 158 deflection (15 degrees) corresponds approximately to the maximum deflection angle of the human knee during walking. The

stiffness of the human leg also increases with body mass. In one embodiment, the stiffness of the springs 156 and 158 should substantially match the user's weight.

[00114] The graph in Figure 15 shows the desired compliant element (spring 156 and 158) behavior based on the stiffness of the normal human knee joint at different walking speeds.

[00115] Presence of the springs 156 and 158 at this level of the compliant assembly 34 allows to quantify net torque (R1 or R2) through measurement of the relative angle between the shank structure 12 and harmonic transmission output (the flexspline 76/flexible cup 80). The sensor assembly 122 in the knee actuation mechanism 10 provides for torque measurement. Torque measurement is advantageously used for the implementation of an actuator digital control scheme generally known as impedance control. Other means to measure torque could include: measuring the torsion efforts on the flexspline 76 by means of strain gages; measuring the strain of some other transmission or structural elements by means of strain gages or other force or torque sensing devices.

[00116] Another benefit of the compliant transmission 34 is that the vibrations induced by the motor 52 and harmonic transmission assembly 56 are somewhat absorbed by the springs 156 and 158 instead of transmitted to the lower leg shank structure 12 and the components thereof. This helps to reduce the noise level generated by the prosthetic device 12.

[00117] Typical knee joint actuation mechanism 10 operation includes locomotion tasks commonly encountered in daily living. More specifically, level, upwards, and downwards surface walking, as well as stairs ascent, descent, standing-up, sitting-down, standing and sitting are the major locomotion tasks supported by the motorized prosthetic knee joint actuation mechanism 10. The knee joint actuation mechanism 10 design can be optimized for level walking task; accordingly, spring 156 and 158 stiffness is selected as the average knee joint stiffness during stance phase of the gait cycle, as found from non-amputee subject torque-position characteristics.

[00118] During level walking, presence of the mechanical springs 156 and 158 allows to passively (i.e., no motor movement is required, nor desirable) sustain stance phase knee flexion and optimize the energy exchange that takes place between the user and the motorized prosthetic knee actuation mechanism 10. Hence, following the occurrence of heel strike, a constant position command is sent to the motor 52, blocking the latter, and allowing the spring stack assembly 132 to extend as knee flexion occurs. Stored energy then brings back the shank structure 12 in extension as the torque imposed on the shank structure reduces. Subsequent transition from late stance to early swing is also facilitated by the presence of the passive springs 156 and 158, which allows to gracefully transition the motor 52 behavior from constant position regulation to swing initiation trajectory.

[00119] In swing phase, the mechanism 10 adopts a force-following behavior where the motor 52 is used to compensate inertial and friction efforts and restore natural dynamics, by using the spring-generated torque

measurement as actuation command, following the completion of the initial push-off phase.

[00120] In ascent and descent locomotion portions, presence of the passive springs 156 and 158 both allow to ease foot placement and loading phases, as well as support the implementation of the force following swing phase, hence generating a system behavior very similar to what can be observed on a normal joint. For power generation tasks, such as stairs ascent, inclined ascent or rising from a seated position, spring 156 and 158 non-linearity and deflection limitations are used in order to control the impacts of the compliant transmission elements on the torque and angular velocity capabilities of mechanism 10.

[00121] The deflection of the compliant transmission 34 causes a relative rotational movement to the third shaft 66 which is measured by the sensor assembly 112 (specifically the sensor partial disk 120 and its sensor detector 128).

[00122] Generally. the stiffness of the compliant transmission mechanism is determined by the stiffness of the normal human knee joint during the stance phase. As the human leg stiffness increases with walking speed, it was desired that the compliant transmission has a non-linear stiffness behavior. At faster walking speed (thus larger torque value), the compliant transmission mechanism generally demonstrates stiffer behavior than at slower walking speeds (thus lower torque).

Compliant transmission geometry

[00123] In accordance with another embodiment of the invention and for more clarity, Figure 16 shows a schematic representation of a compliant transmission geometry, with (a) representing the length of the knee lever such as 92; (b) representing the length of the transmission assembly such as 34; (Θ) representing the angle of deflection measured on the knee rotating axis X; and F representing the force on the compliant member (depending on the stiffness of the springs 156 and 158 or on the load cell for example – as will be described for the orthotic mechanism 200).

[00124] Therefore, the geometry of an embodiment of the compliant transmission assembly of the present invention provides the required characteristics with a simple design. As explained, many considerations lead to the foregoing: the knee joint stiffness of the human leg while walking varies with cadence; the knee flexion amplitude varies with cadence; at higher torque levels, such as when going up the stairs, it is important to limit the magnitude of the deflection, in order to limit the energy stored in the system and increase equivalent stiffness at high torque levels; keeping a smooth transition between the "compliant" behavior and the flexion-limiting bumper.

Orthotic device

[00125] With reference to Figures 17 to 20, a joint mechanism 200 is shown in accordance with another embodiment of the present invention. In this example the joint mechanism 200 is a knee joint mechanism.

[00126] With particular reference to Figures 17 and 19, the knee joint

mechanism 200 is mounted to and forms part of an orthotic leg support device 201 comprising a proximal orthotic portion or shell 202 for supporting a user's thigh segment 203, a distal orthotic portion or shell 204 for supporting a user's shank segment 205, with a knee support 206 therebetween for supporting the knee 207.

[00127] The knee support 206 comprises a lateral actuator mechanism 208 and medial hinge 210.

[00128] Battery packs 212 are integrated within the top element 214 of the proximal orthotic shell 202; whereas a processing platform 216 and power board 218 are integrated within a lower element 220 of the proximal orthotic shell 202.

[00129] In the present non-limiting example, the processing platform 216 comprises a CPU and I/O subsystem, hosting a knee actuator controller SW and the power board 218 comprises an actuator drive as well as a processing platform and battery power management circuitry.

[00130] The proximal orthotic shell 202 also comprises proximolateral structural support 222 connected to a torque-measurement load cell 224 which is connected to the lateral actuator mechanism 208. The distal orthotic shell 204 also comprises a distolateral structural support 226 having a compliant transmission non-linear spring 228 mounted thereon and connected to a compliant transmission lever 230 on the lateral actuator mechanism 208. The distal orthotic shell 204 also includes a laterodistal sensor module 229 mounted on the lower element 231 of the shell 204.

[00131] Referring to Figure 19, the lateral actuator mechanism 208 comprises a housing 232 for housing an actuator 234, such as a brushless motor for example, that is in operational communication with a shaft 236 that is in communication with a harmonic transmission assembly 238 at one end thereof and an actuator angular sensor 240 at another end thereof. The harmonic transmission cover 242 is connected to both a proximolateral anchor 244, which is mounted to the proximolateral structural support 222, and a distolateral anchor 246 (via the non-linear spring 228), which is mounted to the distolateral structural support 226. The brushless motor 234 is positioned within a stator 247 that is fixed to the distolateral anchor 246.

[00132] The shaft 236 defines the axis of rotation X' of the orthotic knee mechanism 200. The shaft 236 is guided by bearings 248 during rotation thereof, while the housing 232 is guided by bearings 250 during rotation about the X' axis.

[00133] In another embodiment shown in Figure 20, instead of a mechanical actuator 228 a Magnetorheological (MR) rotational damper 252 is used. In the MR actuator 252, the dissipative braking torque is obtained by applying a magnetic field 254 through the magnetorheological fluid 256 occupying interstices between the stator blade array 258 and rotor blade array 260. Side plates 261 close the magnetic field 254 propagation path. Furthermore, the magnetic field 254 can be dynamically controlled by regulating the current circulating in the inductive coil 262 folded about the electromagnetic core 264. In the absence of a magnetic field 254, the magnetorheological fluid 256 viscosity is very low and the rotor body 266 is free to rotate inside the stator body 268. When the

magnetic field 254 increases, the fluid's ferromagnetic particles align with the magnetic field 254 and created shear resistance between stator blades 258 and rotor blades 260, offering a breaking torque against applied moment through the knee joint.

[00134] Therefore, the orthotic knee actuation mechanism 200 comprises an actuator mechanism 208, a compliant transmission mechanism 300 (including lever 230 and spring 228) and a torque sensor 229.

[00135] In this way, the orthotic knee actuation mechanism 200 dynamically regulates the support provided to the user's knee 207. This dynamic regulation and compliant transmission avoids abrupt transitions between the locked and unlocked states of the knee hinge 210 during typical walking and descending locomotion tasks for example. In typical walking, the knee actuation mechanism 200 provides the ability to support the stance phase while allowing knee flexion for a more natural weight acceptance, from heel strike to mid-stance. Moreover, the knee actuation mechanism 200 significantly improves transitions between stance and swing phases, where the knee actuator 208 can provide appropriate support without abrupt locking and unlocking events. For descending portions, the ability of both actuator 208 implementations to absorb potential energy through passive damping during knee flexion provides step over step ambulation.

[00136] In essence, the compliant element of the invention absorbs energy during flexion of a joint for the dampening thereof and releases this energy during extension of the joint for assistance thereof. In an

embodiment, the compliant element of the invention stores energy during flexion of a joint for the retardation thereof and releases this energy during extension of the joint for the acceleration thereof.

Compliant transmission assembly

[00137] With respect to Figures 21A, 21B, 21C, 21D and 21E, show a variety of general schematic alternative embodiments of the compliant transmission of the present invention.

[00138] Figure 21A represents a compliant transmission assembly 300A having a lever or cam 302 and a compliant element 304 which can be a cross-shaped or cylindrical shaft in torsion, a beam in flexion, that can be guided by mechanical stops 306. Many mechanical stops can be used to provide non-linear stiffness as is required. Figure 21B shows a compliant transmission assembly 300B having a lever or cam 308 and a linear compliant element 310 which can be made of a variety of flexible structural components. In one embodiment, the linear compliant element 310 comprises linear springs such as Belville washers, helical springs, elastomer springs, gas springs and the like. Figure 21C shows a compliant transmission assembly 300C having a lever or cam 312 and a compliant element 314 in the form of a constant force spring. Figure 21D shows a compliant transmission 300D having a lever or cam 316, a cam follower 318 loaded with a compliant element 320 such as springs. Figure 21E shows a compliant transmission 300E having a lever or cam 322, a belt 324 mounted to compliant elements 326 such as springs.

[00139] Torque can be evaluated by measuring the deflection of the

compliant transmission. Other means for measuring the torque could include the following non-limiting implementations:

[00140] - strain gages on the flexible cup of the compliant transmission;

[00141] - load cell or strain gages on structural components to measure torque;

[00142] - load cell in series with the elastic element to directly measure the force applied on the elastic element;

[00143] - Strain gages placed directly on the elastic element; and

[00144] - the load cells could utilize strain gages, piezo-ceramic force transducer or any other appropriate technology.

[00145] In the non-limiting examples discussed herein, the joint actuation mechanism is a knee actuation mechanism, of course a similar mechanism can also be used for an elbow joint or other joints of the human body for either prosthetic or orthotic devices. These mechanisms can be powered or not.

[00146] The skilled artisan can contemplate a variety of compliant

transmission structures for joint actuation mechanism for orthotic or prosthetic devices within the context of the present invention. As such a variety of compliant elements, such as springs and the like can be used with various compliant element carrying bodies. These compliant elements can operationally communicate with the prosthetic or orthotic joint mechanism via various structural connections as a skilled artisan can contemplate and design within the scope of the present invention.

[00147] The skilled artisan will readily understand that the various features of the various embodiments discussed herein can be combined in a variety of ways so as to produce other non-illustrated examples within the context of the present invention.

[00148] The scope of the claims should not be limited by the embodiments set forth above, but should be given the broadest interpretation consistent with the description as a whole.

What is claimed is:

1. A prosthetic device for replacing the limb of a user comprising:

at least one prosthetic portion;

a joint portion interposed between said prosthetic portion and another adjacent prosthetic portion or an adjacent limb segment of the user, said joint portion comprising a joint actuator assembly configured to pivot said at least one prosthetic portion between flexion and extension movements relative to said another adjacent prosthetic portion or the adjacent limb segment of the user when mounted thereto;

a compliant transmission assembly in operational communication with said joint portion and comprising a compliant member; and

a torque sensor in communication with a controller of the prosthetic device,

wherein said compliant member absorbs energy when a torque is applied between said at least one prosthetic portion and said another adjacent prosthetic portion or the adjacent limb segment of the user.

2. A prosthetic device according to claim 1, wherein said compliant member absorbs energy during flexion and releases this energy during extension.

3. A prosthetic device according to claim 1 or 2, wherein when absorbing energy said compliant member dampens flexion of said prosthetic device, and when releasing energy said compliant member assists extension of said prosthetic device.

4. A prosthetic device according to any one of claims 1 to 3, wherein said compliant member comprises at least one compliant element, said compliant element being a deformable and resilient element.

5. A prosthetic device according to claim 4, wherein said compliant element comprises a spring member.

6. A prosthetic device according to claim 4, wherein said compliant member comprises a pair of side by side compliant elements.

7. A prosthetic device according to claim 6, wherein said compliant elements are springs.

8. A prosthetic device according to claim 6, wherein said compliant elements are placed under stress by a stress member.

9. A prosthetic device according to claim 8, wherein said stress member comprises a pair of stress tubes having a bottom platform and a top shoulder for sandwiching therebetween said compliant elements.

10. A prosthetic device according to claim 9, wherein each said stress tube includes a respective stress actuator configured to provide a predetermined pre-stress to each compliant element.

11. A prosthetic device according to any one of claims 1 to 10, wherein said compliant transmission assembly is in operational communication with said joint portion via a connector mounted to said compliant member and said joint portion.

12. A prosthetic device according to claim 11, wherein said connector comprises a lever.

13. A prosthetic device according to claim 12, wherein said lever comprises a generally circular lever.

14. A prosthetic device according to claim 11, wherein said connector is integrally mounted to said joint portion.

15. A prosthetic device according to claim 11, wherein said connector is mounted to said compliant member via a pivot.

16. A prosthetic device according to claim 15, wherein the flexion and extension movements cause a respective deflection between said connector and said compliant member about said pivot.

17. A prosthetic device according to claim 11, wherein said connector is disengageable from said compliant member.

18. A prosthetic device according to claim 1, wherein said compliant transmission assembly further comprises a pivot interposed between said compliant member and said joint portion.

19. A prosthetic device according to claim 18, wherein the flexion and extension movements cause a respective deflection between said joint portion and said compliant member about said pivot.

20. A prosthetic device according to claim 19, further comprising a sensor for sensing said deflection.

21. A prosthetic device according to claim 20, wherein said torque sensor is mounted to said joint actuator assembly.

22. A prosthetic device according to claim 21 wherein said torque sensor is mounted to said compliant transmission assembly.

23. A prosthetic device according to any one of claims 1 to 22, wherein said joint portion comprises a prosthetic knee joint.

24. A prosthetic device according to claim 23, wherein said at least one prosthetic portion comprises a proximal end and an opposite distal end, wherein said opposite distal end provides for receiving a prosthetic foot member.

25. A prosthetic device according to any one of claims 1 to 22, wherein said joint portion comprises a prosthetic ankle joint.

26. A prosthetic device according to any one of claims 1 to 22, wherein said joint portion comprises a prosthetic hip joint.

27. A prosthetic device according to any one of claims 1 to 22, further comprising at least one additional joint portion.

28. A prosthetic device according to any one of claims 1 to 22, wherein said at least one prosthetic portion comprises a proximal end and an opposite distal end, said proximal end comprising a socket configured to couple to the limb segment of the user.

29. A prosthetic device according to any one of claims 1 to 28, wherein said compliant member is a non-linear compliant member configured to provide the limb with a normal torque stiffness.

30. A prosthetic deice according to any one of claims 1 to 29, wherein said joint actuator assembly is selected from the group consisting of a mechanical actuator, a hydraulic actuator, an electric actuator, a pneumatic actuator, a magnetorheological (MR) damper and a combination thereof.

31. An orthotic device for a limb of a user, said orthotic device comprising:

a proximal orthotic portion to be mounted to a proximal limb segment of the user;

a distal orthotic portion to be mounted to a distal limb segment of the user;

an orthotic joint portion interposed between said proximal and distal orthotic portions to be mounted to the joint of the user's limb for supporting the user's joint during flexion and extension thereof, said orthotic joint portion comprising a joint actuator assembly;

a compliant transmission assembly in operational communication with said orthotic joint portion and comprising a compliant member; and

a torque sensor in communication with a controller of the orthotic device,

wherein said compliant member absorbs energy when a torque is applied between said proximal and distal portions.

32. An orthotic device according to claim 31, wherein said compliant member absorbs energy during flexion of the user's joint and releases this energy during extension of the user's joint.

33. An orthotic device according to claim 31 or 32, wherein when absorbing energy said compliant member dampens flexion and when releasing energy said compliant member assists extension.

34. An orthotic device according to any one of claims 31 to 33, wherein a pivot is interposed between said compliant member and said orthotic joint portion.

35. An orthotic device according to claim 34, wherein the flexion and extension movements cause a respective deflection between said orthotic joint portion and said compliant member about said pivot.

36. An orthotic device according to claim 35, wherein said torque sensor is for sensing said deflection.

37. An orthotic device according to claim 36, wherein said torque sensor is mounted to said joint actuator assembly.

38. An orthotic device according to claim 36, wherein said torque sensor is mounted to said compliant transmission assembly.

39. An orthotic device according to claim 33, wherein said compliant transmission assembly further comprises a connector mounted to said compliant member and said orthotic joint portion.

40. An orthotic device according to claim 39, wherein said connector is movably mounted to said orthotic joint portion so as to be moved during flexion and extension movements.

41. An orthotic device according to claim 40, wherein the flexion and extension movements cause a respective deflection between said orthotic joint portion and said compliant member.

42. An orthotic device according to claim 40, wherein said connector is pivotally mounted to said orthotic joint portion.

43. An orthotic device according to claim 39, wherein said connector comprises a lever.

44. An orthotic device according to claim 39, wherein said connector comprises a cam.

45. An orthotic device according to any one of claims 31 to 38, wherein said compliant member comprises at least one compliant element.

46. An orthotic device according to claim 45, wherein said compliant element comprises a spring.

47. An orthotic device according to claim 46, wherein said compliant element is mounted at one end thereof to a support member and to a connector at another end thereof.

48. An orthotic device according to claim 47, wherein said support member is mounted to said distal orthotic portion.

49. An orthotic device according to any one of claims 31 to 48, wherein said joint actuator assembly is selected from the group consisting of a mechanical actuator, a hydraulic actuator, an electric actuator, a pneumatic actuator, an MR damper and a combination thereof.

50. An orthotic device according to any one of claims 31 to 49, wherein said proximal orthotic portion comprises an orthotic shell for the thigh of the user, and said distal orthotic portion comprises an orthotic shell for the shank of the user, and wherein said orthotic joint portion comprises a knee joint support for the knee of the user.

51. An orthotic device according to any one of claims 31 to 49, wherein said orthotic joint portion comprises an orthotic ankle.

52. An orthotic device according to any one of claims 31 to 49, further comprising an additional orthotic joint portion.

53. A prosthetic/orthotic device comprising:

at least one device portion;

a joint portion configured to pivot said at least one device portion between flexion and extension movements relative to another adjacent device portion or an adjacent limb segment of the user;

a compliant transmission assembly in operational communication with said joint portion, said compliant transmission assembly comprising a compliant member and a pivot interposed between said compliant member and said joint portion; and

a torque sensor in communication with a controller of the prosthetic/orthotic device,

wherein said compliant member absorbs energy when a torque is applied between said at least one device portion and said another adjacent prosthetic portion or the adjacent limb segment of the user.

54. A prosthetic/orthotic device according to claim 53, wherein said compliant member absorbs energy during flexion and releases this energy during extension.

55. A prosthetic/orthotic device according to claim 53 or 54, wherein when absorbing energy said compliant member dampens flexion of said device

portion and when releasing energy said compliant member assists extension of said device portion.

56. A prosthetic/orthotic device according to any one of claims 53 to 55, wherein said compliant member comprises at least one compliant element.

57. A prosthetic/orthotic device according to claim 56, wherein said compliant element comprises a deformable and resilient element.

58. A prosthetic/orthotic device according to claim 56, wherein said compliant element comprises a spring member.

59. A prosthetic/orthotic device according to any one of claims 53 to 58, wherein the flexion and extension movements cause a respective deflection between said joint portion and said compliant member about said pivot.

60. A prosthetic/orthotic device according to claim 59, further comprising a sensor for sensing said deflection.

61. A prosthetic/orthotic device according to any one of claims 53 to 60, wherein said joint portion comprises a joint actuator assembly.

62. A compliant transmission assembly for a prosthetic/orthotic device comprising at least one device portion and a joint portion configured to pivot the at least one device portion between flexion and extension movements relative to another adjacent device portion or an adjacent limb segment of the user, said compliant transmission assembly comprising:

a connector coupleable to the joint portion;

a compliant member mountable to the device;

a pivot interposed between said connector and said compliant member; and

a torque sensor in communication with a controller of the prosthetic/orthotic device,

wherein said compliant member absorbs energy when a torque is applied between said at least one device portion and said another adjacent prosthetic portion or the adjacent limb segment of the user.

63. A compliant transmission assembly according to claim 62, wherein said compliant member absorbs energy during flexion of the device portion and releases this energy during extension of the device portion.

64. A compliant transmission assembly according to claim 62 or 63, wherein the flexion and extension movements cause a respective deflection between said connector and said compliant member about said pivot.

65. A compliant transmission assembly according to any one of claims 62 to 64, wherein said compliant member is mountable to the at least one device portion.

66. A compliant transmission assembly according to any one of clams 62 to 65, wherein said compliant member comprises at least one compliant element.

67. A compliant transmission assembly according to claim 66, wherein said compliant element comprises a deformable and resilient member.

68. A compliant transmission assembly according to claim 66, wherein said compliant element comprises a spring.

69. A compliant transmission assembly according to claim 66, wherein said compliant member comprises a pair of side by side compliant elements.

70. A compliant transmission assembly according to any one of claims 62 to 69, wherein said compliant element is placed under stress by a stress member.

71. A compliant transmission assembly according to any one of claims 62 to 69, further comprising a stress actuator configured to provide a predetermined stress to said compliant member.

72. A compliant transmission assembly according to any one of claims 62 to 71, wherein said connector and said compliant member are disengageable.

73. A method for determining deflection of a prosthetic/orthotic device having a joint portion thereof configured to enable flexion and extension movements of the device, said method comprising:

providing a compliant member to be in operational communication with the joint portion;

providing for a deflection between the compliant member and the joint portion during the flexion and extension movements;

determining characteristics of the complaint member in operation; and

determining the deflection.

74. The method according to claim 73, wherein the method further comprises determining the torque based on the characteristics of the compliant member.

75. A prosthetic knee device comprising:

a knee joint interposed between a prosthetic shin and another adjacent prosthetic portion or an adjacent limb segment of a user, said knee joint comprising a joint actuator assembly configured to pivot said prosthetic shin between flexion and extension movements relative to said another adjacent prosthetic portion or the adjacent limb segment of the user when mounted thereto;

a compliant transmission assembly in operational communication with said knee joint via a rotatable connector mounted to a compliant member and said knee joint, the rotatable connector located between the joint actuator assembly and the compliant transmission assembly, wherein said compliant member absorbs energy and rotates relative to the prosthetic shin when a

torque is applied between said prosthetic shin and said another adjacent prosthetic portion or the adjacent limb segment of the user;

a sensor that provides for torque measurement; and

a controller configured to use said torque measurement to control said joint actuator assembly,

wherein during a stance phase of the gait cycle the prosthetic knee device is configured so that the actuator assembly does not provide said pivot between flexion and extension and the compliant transmission assembly absorbs and returns energy, and

wherein during a swing phase of the gait cycle the prosthetic knee device is configured so that the controller causes the actuator assembly to adopt a force following behavior based on the torque measurement.

76. A prosthetic knee device according to claim 75, further comprising a rotational axis sensor.

77. A prosthetic knee device according to claim 76, wherein the rotational axis sensor is an optical sensor.

78. A prosthetic knee device according to claim 77, wherein the optical sensor comprises a partial disk, light emitter, and sensor element.

79. A prosthetic knee device according to any one of claims 75 to 78, further comprising an actuator locking device for manually locking the knee joint at a desired knee angle.

80. A prosthetic knee device according to claim 79, wherein the desired angle is at a 90 degree rotation.

81. A prosthetic knee device according to claim 79, wherein the actuator locking device comprises a locking slider and a locking slider guide.

82. A prosthetic knee device according to claim 81, wherein the actuator locking device further comprises a frictional brake.

83. A prosthetic knee device according to claim 79, wherein the actuator locking device is configured to lock the knee joint at multiple angles.

84. A prosthetic knee device according to any one of claims 75 to 83, wherein said connector is disengageable from said compliant member.

85. A prosthetic knee device according to claim 75, wherein the sensor provides for torque measurement based on a deflection of the compliant member.

86. A prosthetic knee device according to claim 75, wherein the sensor provides for torque measurement based on a rotation of the compliant transmission assembly relative to the prosthetic shin.

87. A prosthetic knee device according to claim 75, wherein the sensor provides for torque measurement by means of a strain gage.

88. A prosthetic knee device comprising:

a prosthetic connector configured to be connected to a leg socket;

a knee joint actuator assembly comprising an actuator housing connected to the prosthetic connector and housing an actuator comprising a motor;

a rotatable shin structure configured to rotate about a pivot axis relative to the actuator housing, said rotation configured to be powered by the actuator to cause flexion and extension movements, wherein the actuator is mounted about the pivot axis;

a compliant transmission assembly connected between the rotatable shin structure and the knee joint actuator assembly, said compliant transmission assembly comprising a connector mounted to a compliant member and the knee joint actuator assembly, the compliant member being also mounted to the rotatable shin structure;

a sensor that provides for torque measurement based on deflection of the compliant member; and

a controller configured to use the torque measurement to control the actuator,

wherein during a stance phase of a gait cycle the prosthetic knee device is configured so that said compliant member first absorbs energy from ground contact and deflects relative to the rotatable shin structure, and then releases energy and moves back toward an undeflected position, and said motor of said actuator is immobilized, and

wherein during a swing phase of the gait cycle the prosthetic knee device is configured so that the controller causes the actuator to adopt a force following behavior, based on the torque measurement, in cooperation with energy released or absorbed by the compliant member.

89. A prosthetic knee device according to claim 88, wherein the knee joint actuator assembly further comprises a harmonic drive assembly.

90. A prosthetic knee device according to claim 88 or 89, wherein the connector is rotatably mounted to the compliant member.

91. A prosthetic knee device according to claim 88 or 89, wherein the compliant member is rotatably mounted to the rotatable shin structure.

92. A prosthetic knee device according to any one of claims 88 to 91, wherein the compliant member deflects forward during the stance phase of the gait cycle as the compliant member absorbs energy.

93. A prosthetic knee device according to any one of claims 88 to 91, wherein the compliant member deflects backward during the stance phase of the gait cycle as the compliant member releases energy.

94. A prosthetic knee device according to any one of claims 88 to 91, wherein the rotatable shin structure has a flexion movement during the stance phase of the gait cycle as the compliant member absorbs energy.

95. A prosthetic knee device according to any one of claims 88 to 91, wherein the rotatable shin structure has an extension movement during the stance phase of the gait cycle as the compliant member releases energy.

96. A prosthetic knee device according to any one of claims 88 to 95, wherein said connector is disengageable from said compliant member.

97. A prosthetic device comprising:

at least one device portion;

a joint portion for providing for said at least one device portion to pivot about an axis between flexion and extension movements relative to another adjacent device portion or an adjacent limb segment of a user, the joint portion comprising two connectors on opposite sides of the joint portion for connection to the at least one device portion and the another adjacent device portion or the adjacent limb segment of the user, the joint portion further comprising a powered actuator configured to power pivoting between the at least one device portion and said another adjacent device portion or said adjacent limb segment of the user; and

a compliant transmission assembly in operational communication with said joint portion, said compliant transmission assembly comprising at least one compliant member and a pivot such that the compliant member is configured to pivot relative to said powered actuator about a pivot axis, the pivot axis between the compliant member and the powered actuator being located at a distance from a lower connector of the two connectors that is less than a distance of the axis of the joint portion from the lower connector, the compliant member comprising a deformable and resilient element,

wherein said compliant member absorbs energy when a torque is applied between said at least one device portion and said another adjacent prosthetic portion or the adjacent limb segment of the user.

98. A prosthetic device according to claim 97, wherein said compliant member is configured such that it can absorb energy during flexion and can release the energy during extension.

99. A prosthetic device according to claim 97, wherein when absorbing energy said compliant member resists flexion of said joint portion and when releasing energy said compliant member assists extension of said joint portion.

100. A prosthetic device according to claim 97, wherein said compliant member comprises a spring member.

101. A prosthetic device according to claim 97, wherein the flexion and extension movements cause a respective deflection between said joint portion and said compliant member about said pivot of the compliant transmission assembly.

102. A prosthetic device according to claim 101, further comprising a deflection sensor configured to measure torque.

103. A prosthetic device according to claim 97, wherein said powered actuator comprises a motor.

104. A prosthetic/orthotic device comprising:

at least one lower device portion and a knee joint portion for providing for the at least one lower device portion to pivot between flexion and extension movements relative to another adjacent device portion or an adjacent limb segment of a user about an axis corresponding to a natural knee joint of the user, the knee joint portion comprising a powered actuator configured to power pivoting between the at least one lower device portion and said another adjacent device portion or said adjacent limb segment of the user; and

a compliant transmission assembly positioned to transmit the pivoting of the powered actuator from the knee joint portion between the at least one lower device portion and said another adjacent device portion or said adjacent limb segment of the user; the compliant transmission assembly comprising

a lever for being mounted to the knee joint portion and

a compliant member mountable to the at least one lower device portion, wherein said compliant member has a non-linear stiffness such that the compliant member is configured to be stiffer at a first torque value than at a second torque value, wherein said first torque value is larger than said second torque value, and wherein said compliant member is configured to pivot relative to said powered actuator about a pivot axis, the pivot axis being located at a distance from the lower device portion that is less than a distance of the axis of the joint portion from the lower device portion, and the compliant member comprises a deformable and resilient element.

105. A prosthetic/orthotic device according to claim 104, wherein said compliant member absorbs energy when a torque is applied between said at least one lower device portion and said another adjacent prosthetic portion or the adjacent limb segment of the user.

106. A prosthetic/orthotic device according to claim 105, wherein said compliant member is configured such that it can absorb energy during flexion of the joint portion and can release the energy during extension of the joint portion.

107. A prosthetic/orthotic device according to claim 104, wherein the lever is configured to pivot relative to said compliant member.

108. A prosthetic/orthotic device according to claim 107, wherein the flexion and extension movements cause a respective deflection between said lever and said compliant member about said pivot axis between the compliant member and the powered actuator.

109. A prosthetic/orthotic device according to claim 104, wherein said compliant member comprises at least one compliant element.

110. A prosthetic/orthotic device according to claim 109, wherein said compliant element comprises a spring.

111. A prosthetic/orthotic device according to claim 109, wherein the device is a prosthetic device and said compliant member comprises a pair of side by side compliant elements.

112. A prosthetic/orthotic device according to claim 109, wherein the device is a prosthetic device and said compliant member comprises a stack of compliant elements.

113. A prosthetic/orthotic device according to claim 104, wherein the device is a prosthetic device and said compliant member is placed under stress by a stress member.

114. A prosthetic/orthotic device according to claim 104, wherein the device is a prosthetic device, the device further comprising a stress actuator for providing a predetermined stress to said compliant member.

115. A prosthetic/orthotic device according to claim 104, wherein said lever and said compliant member are disengageable.

116. An orthotic device comprising:

a joint portion for mounting directly to two adjacent limb segments of a user and providing for said two adjacent limb segments to pivot between flexion and extension movements relative to each other, the joint portion comprising two mounts on opposite sides of the joint portion for direct connection to the adjacent limb segments of the user, the joint portion further comprising a powered actuator configured to power pivoting between the adjacent limb segments of the user; and

a compliant transmission assembly in operational communication with said joint portion, said compliant transmission assembly comprising a compliant member and a pivot such that the compliant member is configured to pivot relative to said powered actuator, the compliant member comprising a deformable and resilient element,

wherein said compliant member absorbs energy when a torque is applied between the adjacent limb segments of the user.

117. An orthotic device according to claim 116, wherein said compliant member is configured such that it can absorb energy during flexion and can release the energy during extension.

118. An orthotic device according to claim 116, wherein when absorbing energy said compliant member resists flexion of said joint portion and when releasing energy said compliant member assists extension of said joint portion.

119. An orthotic device according to claim 116, wherein said compliant member comprises a spring member.

120. An orthotic device according to claim 116, wherein the flexion and extension movements cause a respective deflection between said joint portion and said compliant member about said pivot.

121. An orthotic device according to claim 120, further comprising a deflection sensor configured to measure torque.

122. An orthotic device according to claim 116, wherein said powered actuator comprises a motor.

123. An orthotic device comprising:

a joint portion for mounting directly to two adjacent body portions of a user separated by a natural joint of a user and providing for said two adjacent body portions to pivot between flexion and extension movements relative to each other about the natural joint, the joint portion comprising two mounts on opposite sides of the joint portion for direct connection to the adjacent body portions of the user, the joint portion further comprising a powered actuator disposed between the two mounts and configured to power pivoting between the adjacent body portions of the user; and

a compliant transmission assembly disposed between the two mounts and in operational communication with said joint portion, said compliant

transmission assembly comprising a compliant member and a pivot such that the compliant member is configured to pivot relative to said powered actuator, the compliant member comprising a deformable and resilient element,
wherein said compliant member absorbs energy when a torque is applied between the adjacent body portions of the user.

124. An orthotic device according to claim 123, wherein said compliant member is configured such that it can absorb energy during flexion and can release the energy during extension.

125. An orthotic device according to claim 123, wherein when absorbing energy said compliant member resists flexion of said joint portion and when releasing energy said compliant member assists extension of said joint portion.

126. An orthotic device according to claim 123, wherein said compliant member comprises a spring member.

127. An orthotic device according to claim 126, wherein the spring member comprises a non-linear spring member.

128. An orthotic device according to claim 123, wherein the flexion and extension movements cause a respective deflection between said joint portion and said compliant member about said pivot.

129. An orthotic device according to claim 128, further comprising a deflection sensor configured to measure torque.

130. An orthotic device according to claim 123, wherein said powered actuator comprises a motor.

131. An orthotic device according to claim 123, wherein said powered actuator comprises a harmonic transmission assembly.

132. An orthotic device according to claim 123, further comprising a battery disposed between the two mounts.

133. An orthotic device according to claim 123, further comprising a processor disposed between the two mounts.

134. An orthotic device comprising:

a joint portion for mounting directly to two adjacent body portions of a user separated by a natural joint of a user and providing for said two adjacent body portions to pivot between flexion and extension movements relative to each other about the natural joint, the joint portion comprising two mounts defining opposite sides of the orthotic device and providing for direct connection to the adjacent body portions of the user, the joint portion further comprising a powered actuator configured to power pivoting between the adjacent body portions of the user; and

a compliant transmission assembly in operational communication with said joint portion, said compliant transmission assembly comprising a compliant member and a pivot such that the compliant member is configured to pivot relative to said powered actuator, the compliant member comprising a deformable and resilient element,

wherein said compliant member absorbs energy when a torque is applied between the adjacent body portions of the user.

135. An orthotic device according to claim 134, wherein said compliant member is configured such that it can absorb energy during flexion and can release the energy during extension.

136. An orthotic device according to claim 134, wherein when absorbing energy said compliant member resists flexion of said joint portion and when releasing energy said compliant member assists extension of said joint portion.

137. An orthotic device according to claim 134, wherein said compliant member comprises a spring member.

138. An orthotic device according to claim 137, wherein the spring member comprises a non-linear spring member.

139. An orthotic device according to claim 134, wherein the flexion and extension movements cause a respective deflection between said joint portion and said compliant member about said pivot.

140. An orthotic device according to claim 139, further comprising a deflection sensor configured to measure torque.

141. An orthotic device according to claim 134, wherein said powered actuator comprises a motor.

142. An orthotic device according to claim 134, wherein said powered actuator comprises a harmonic transmission assembly.

143. An orthotic device according to claim 134, further comprising a battery disposed between the two mounts.

144. An orthotic device according to claim 134, further comprising a processor disposed between the two mounts.

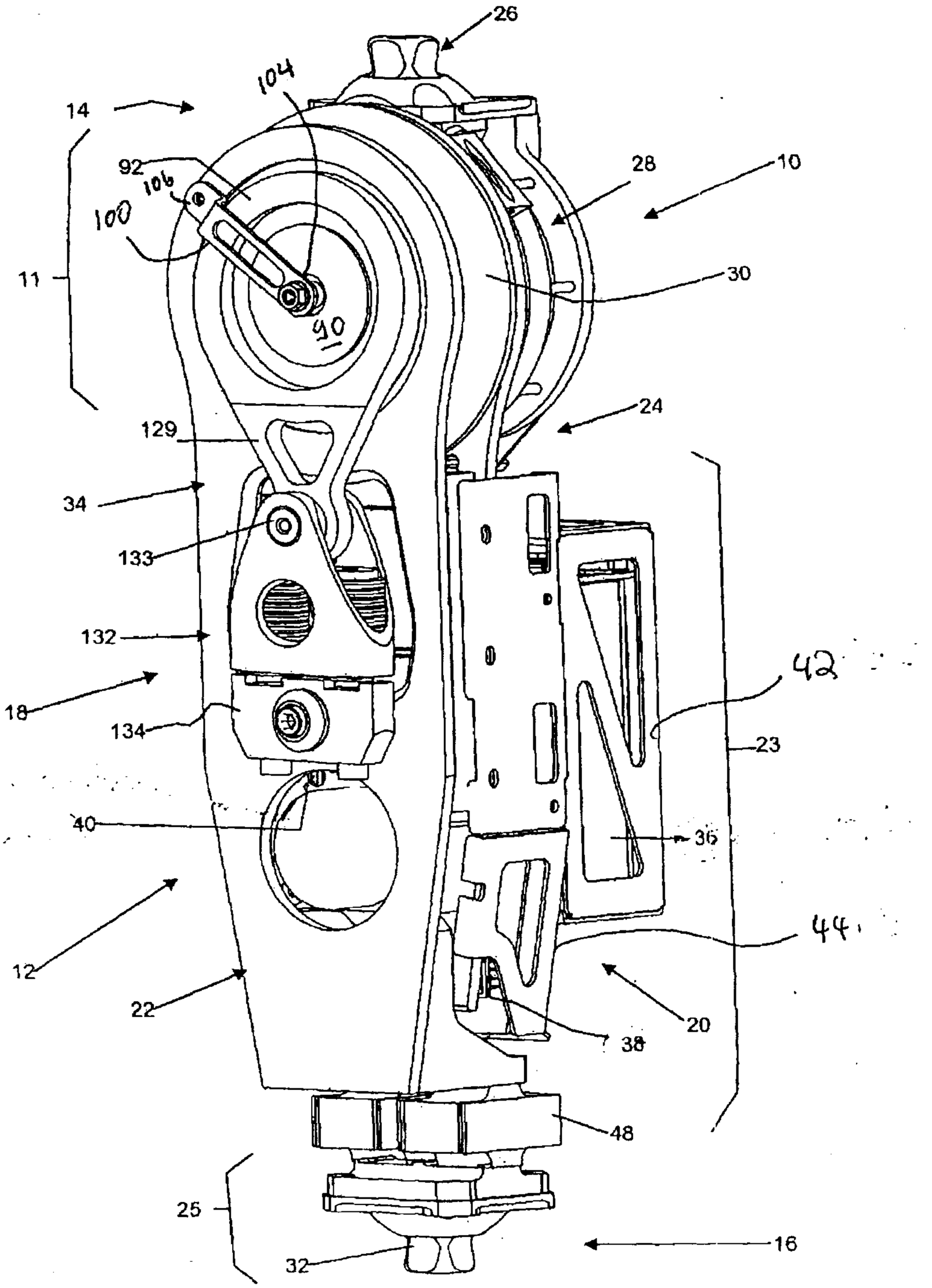
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FIGURE 1

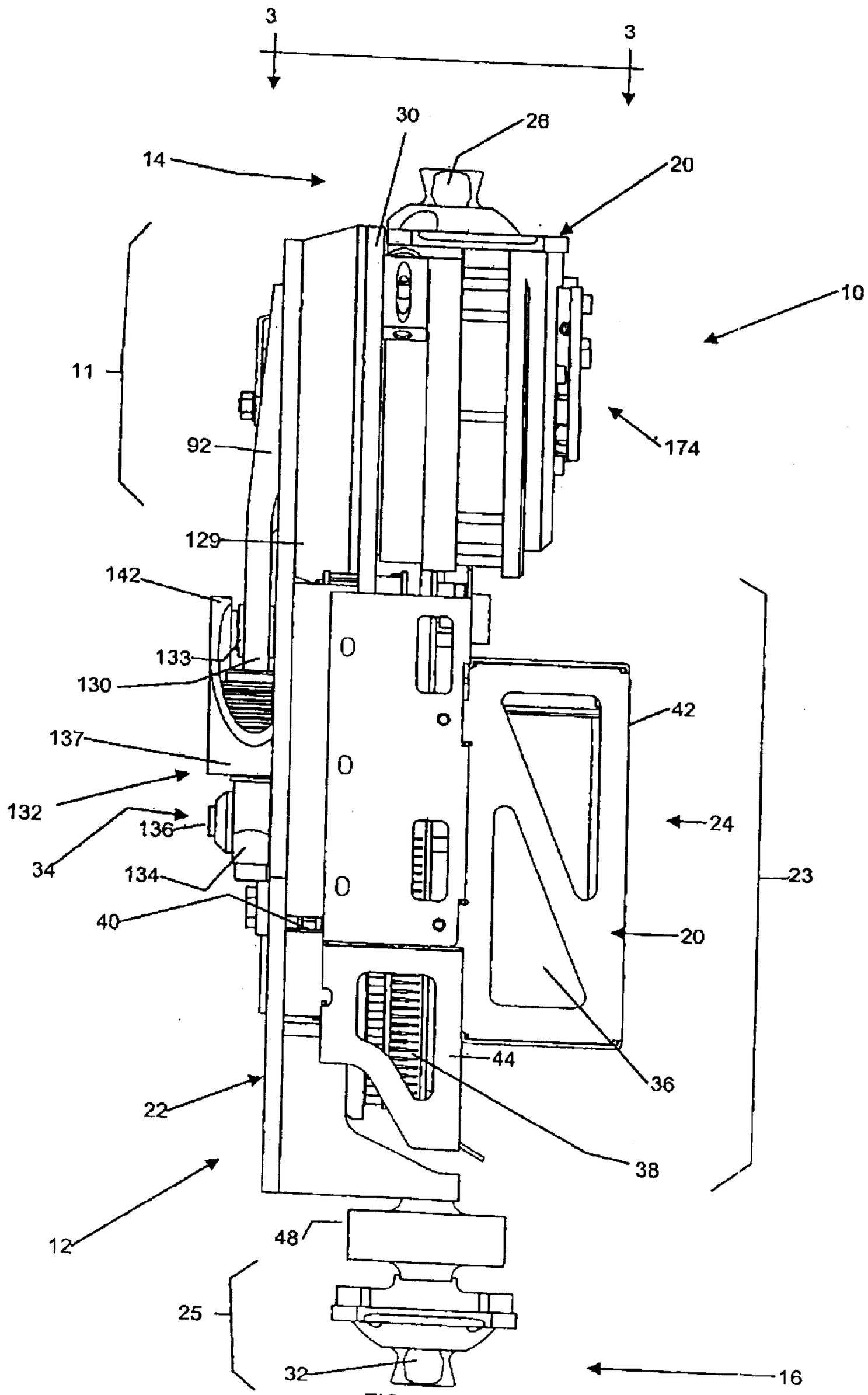
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FIGURE 2

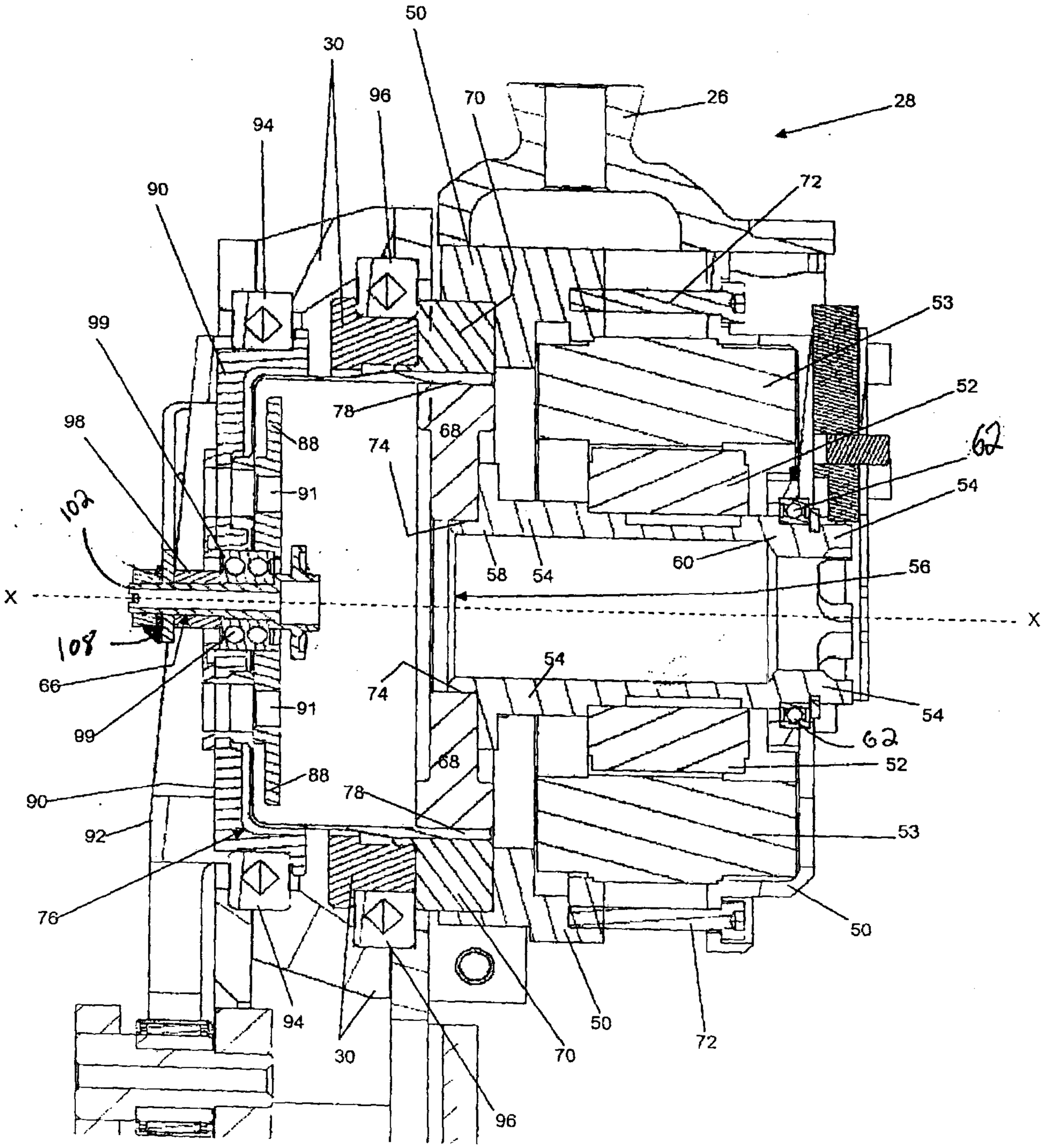
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FIGURE 3

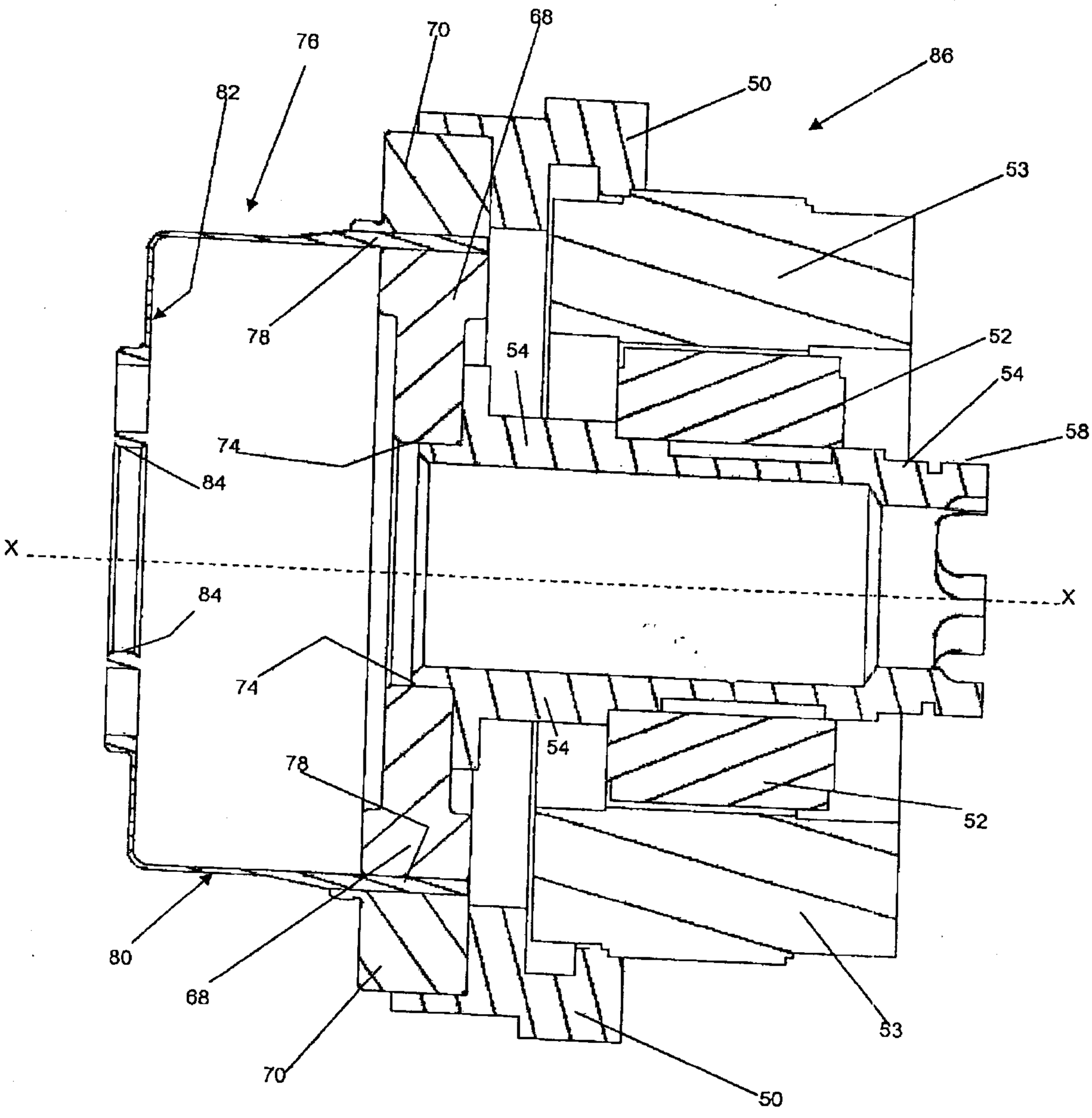
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FIGURE
4

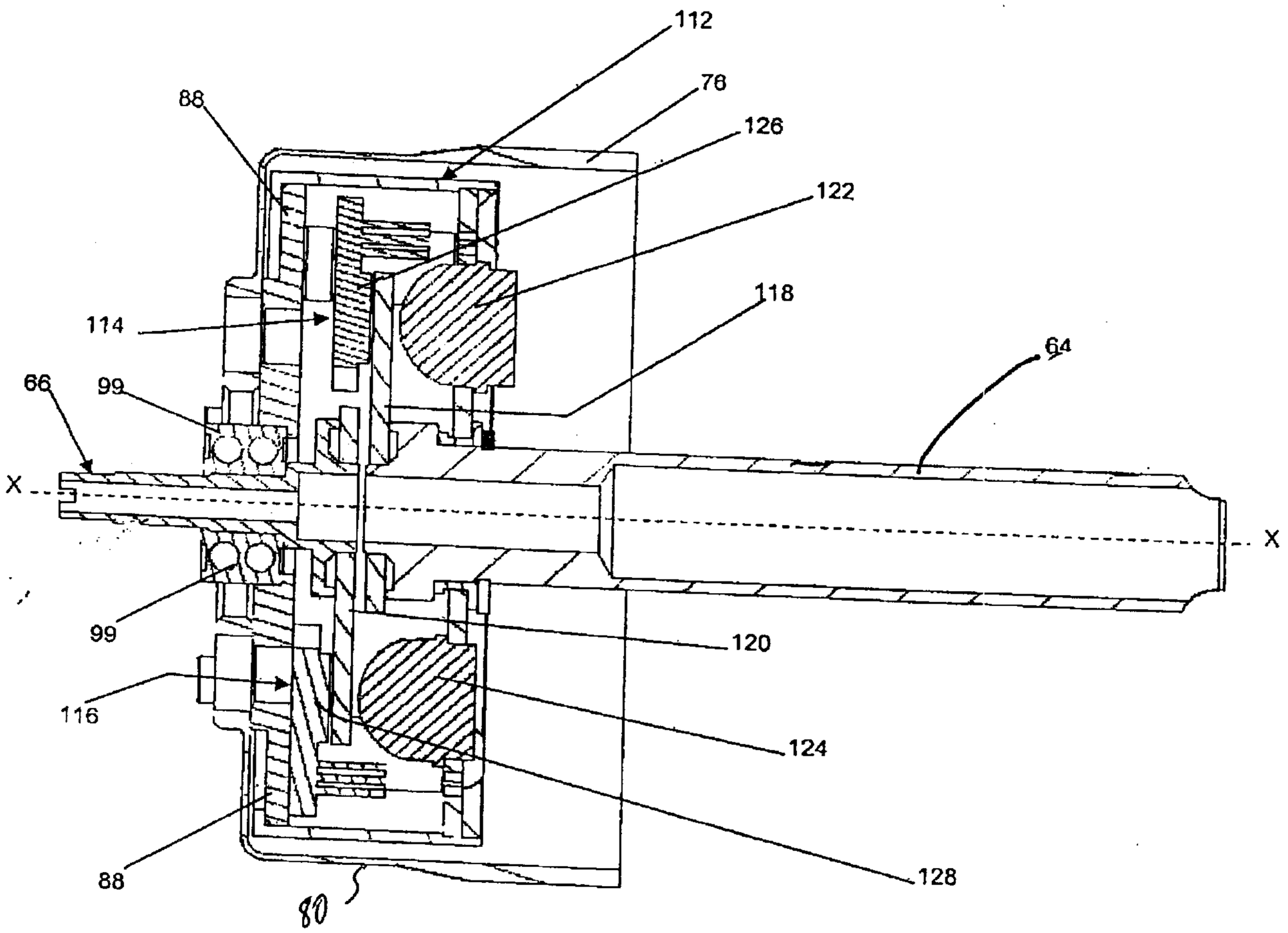

FIGURE 5

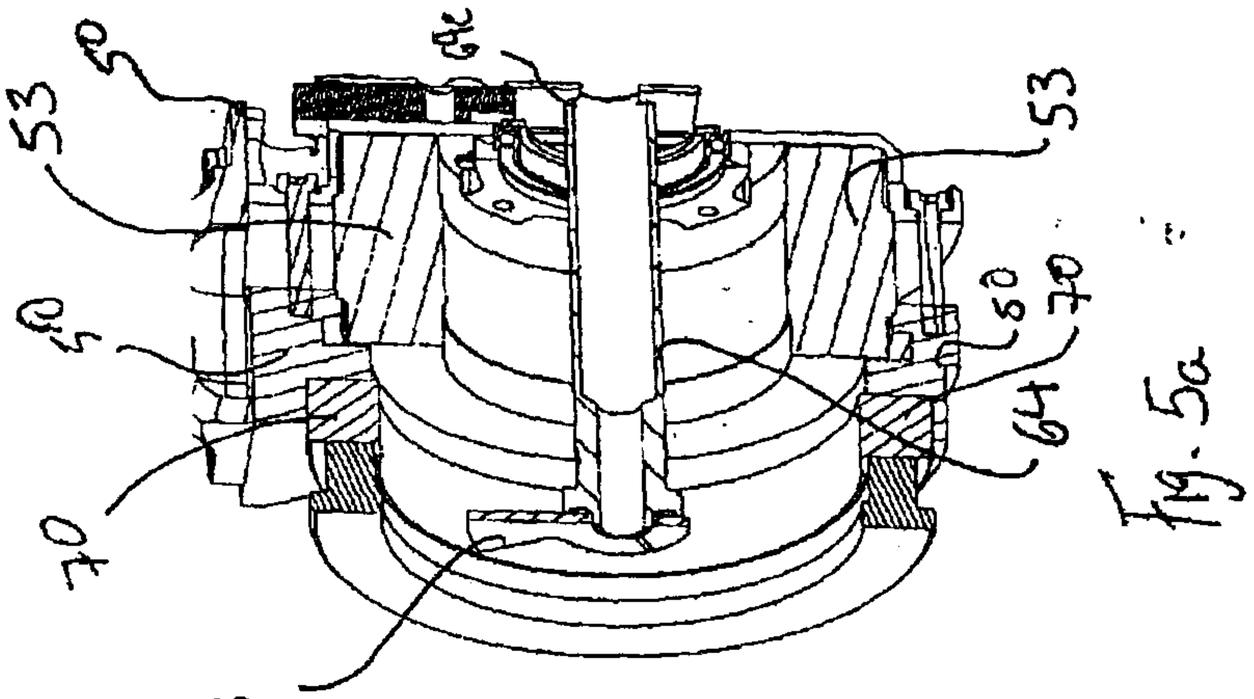

Fig. 5a

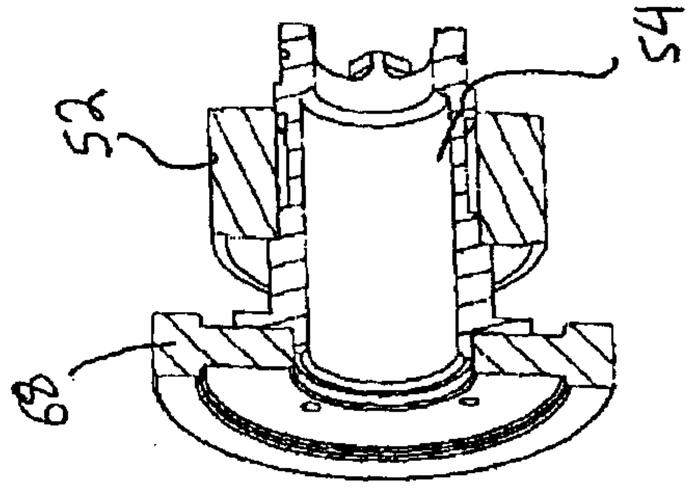

Fig. 5b

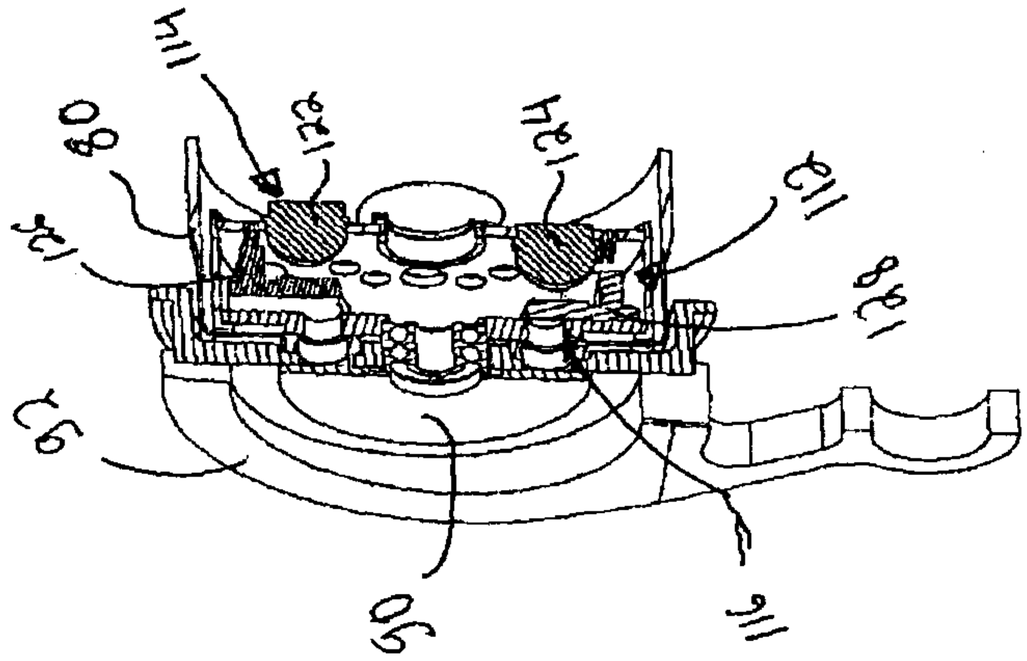

Fig. 5c

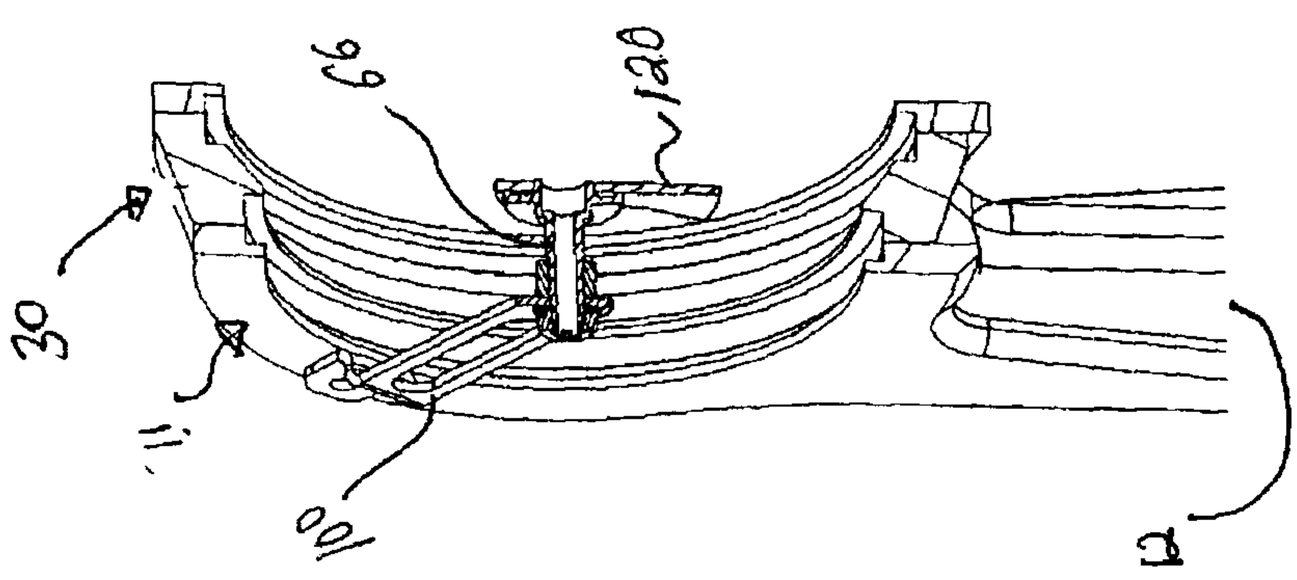

Fig. 5d

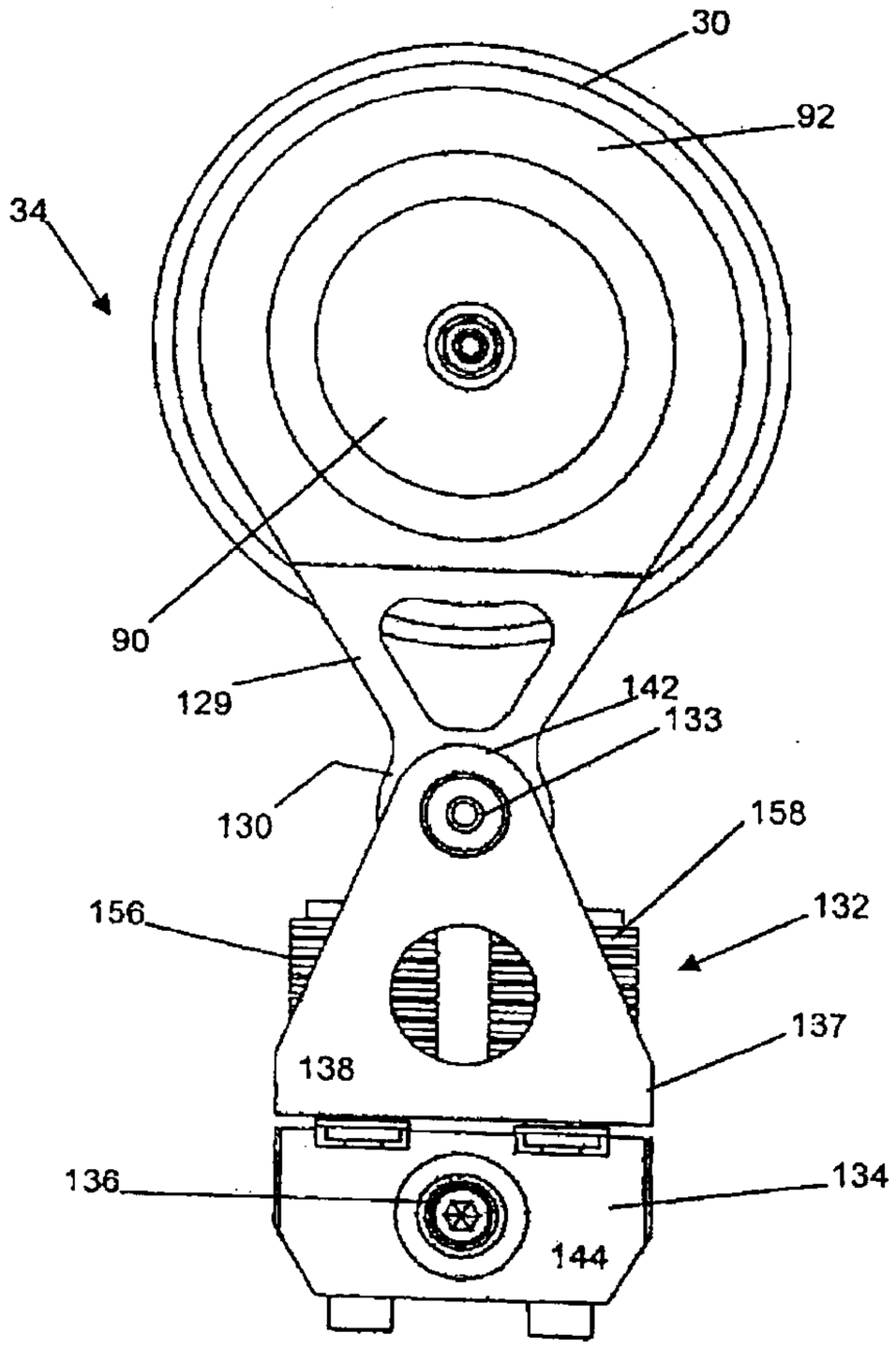

FIGURE 6

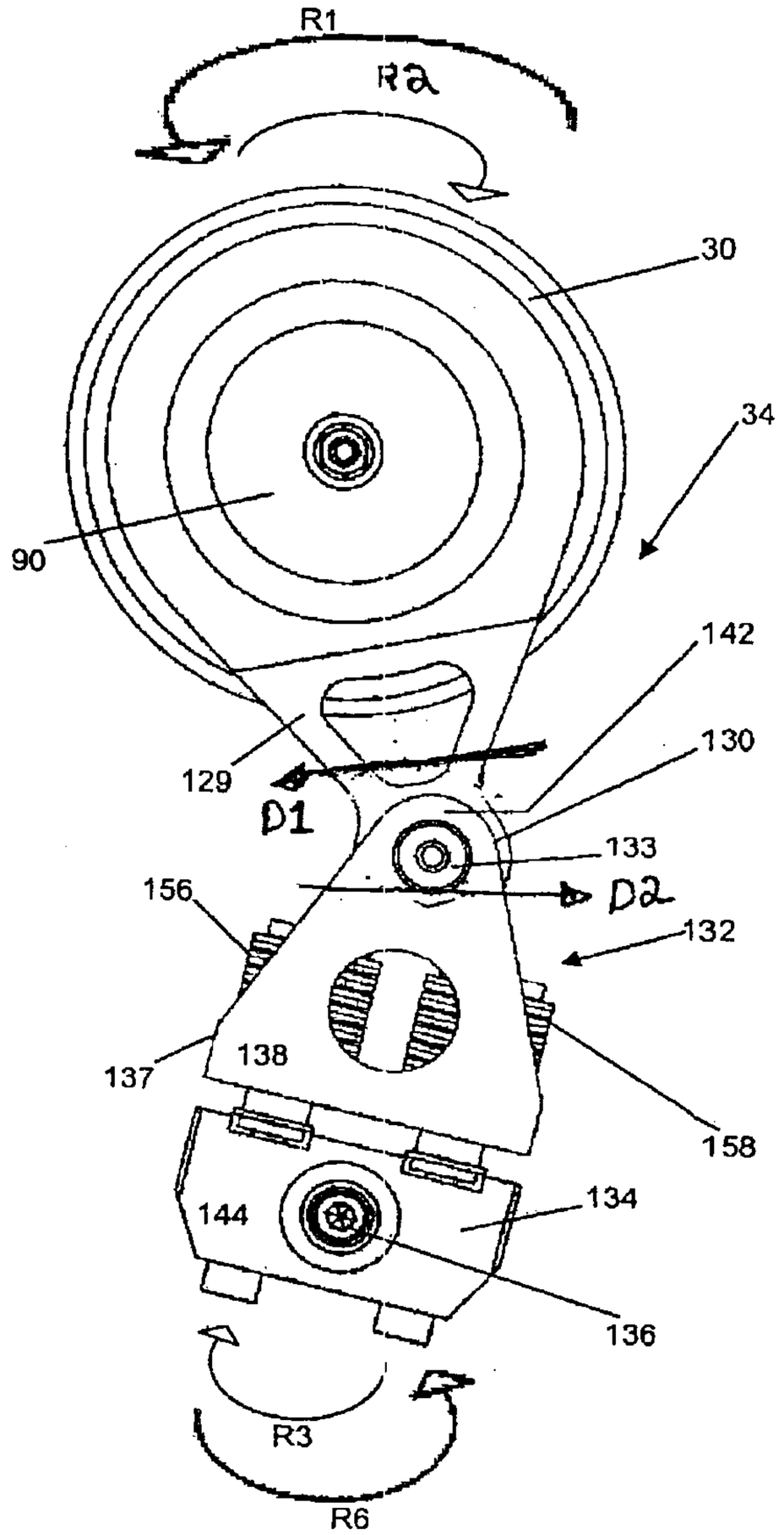

FIGURE 7

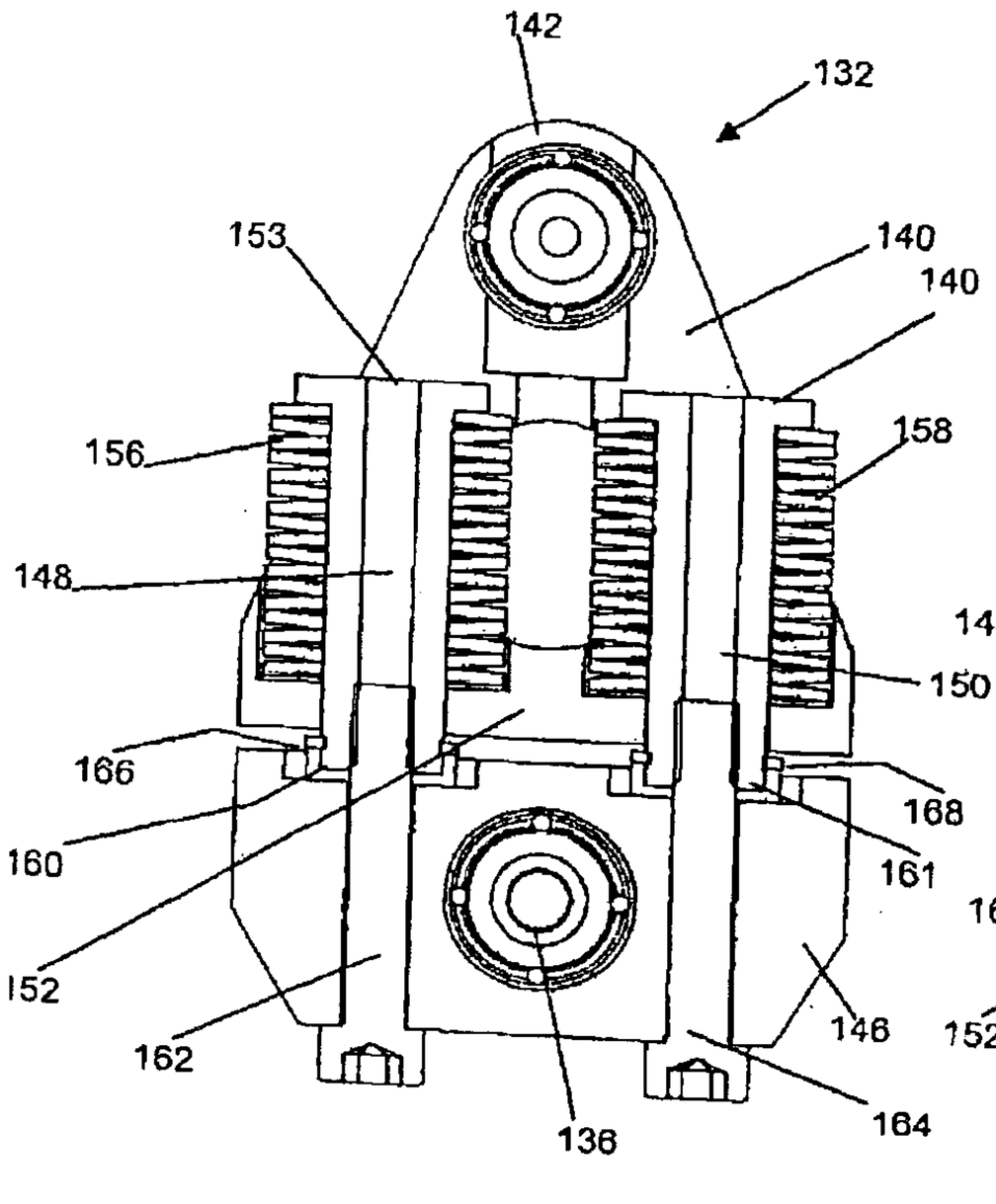

FIGURE 8

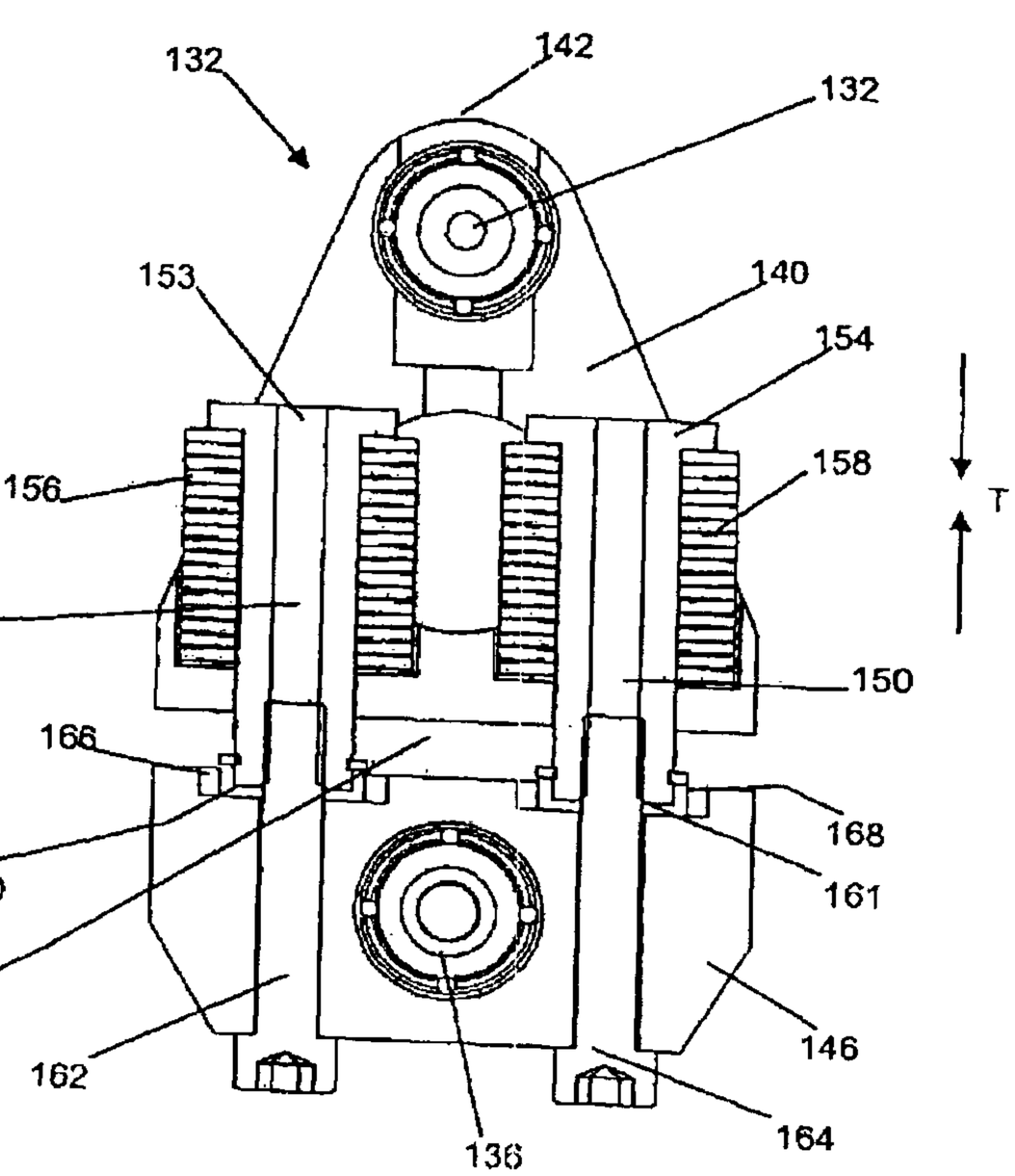

FIGURE 9

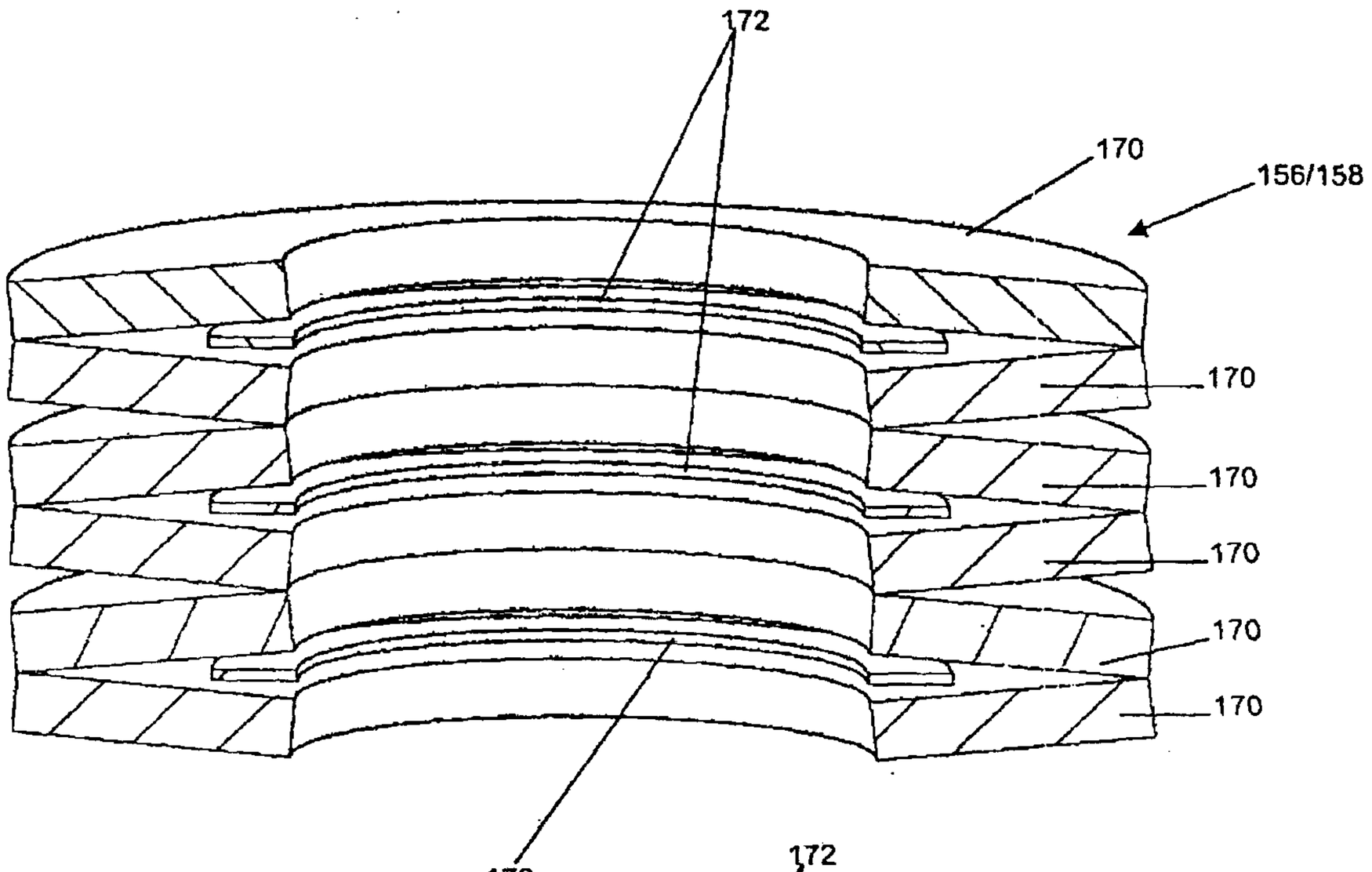

FIGURE 10

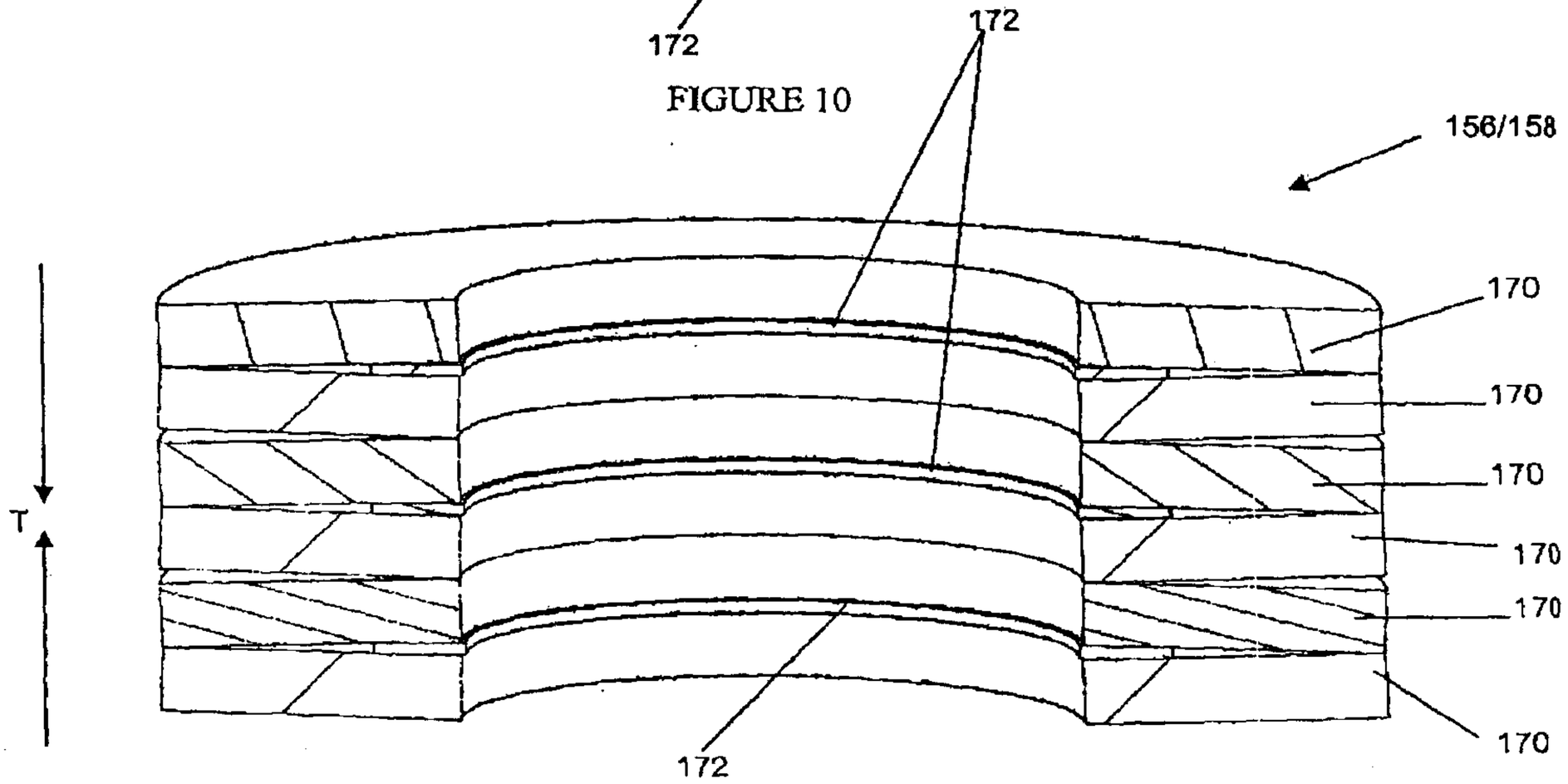

FIGURE 11

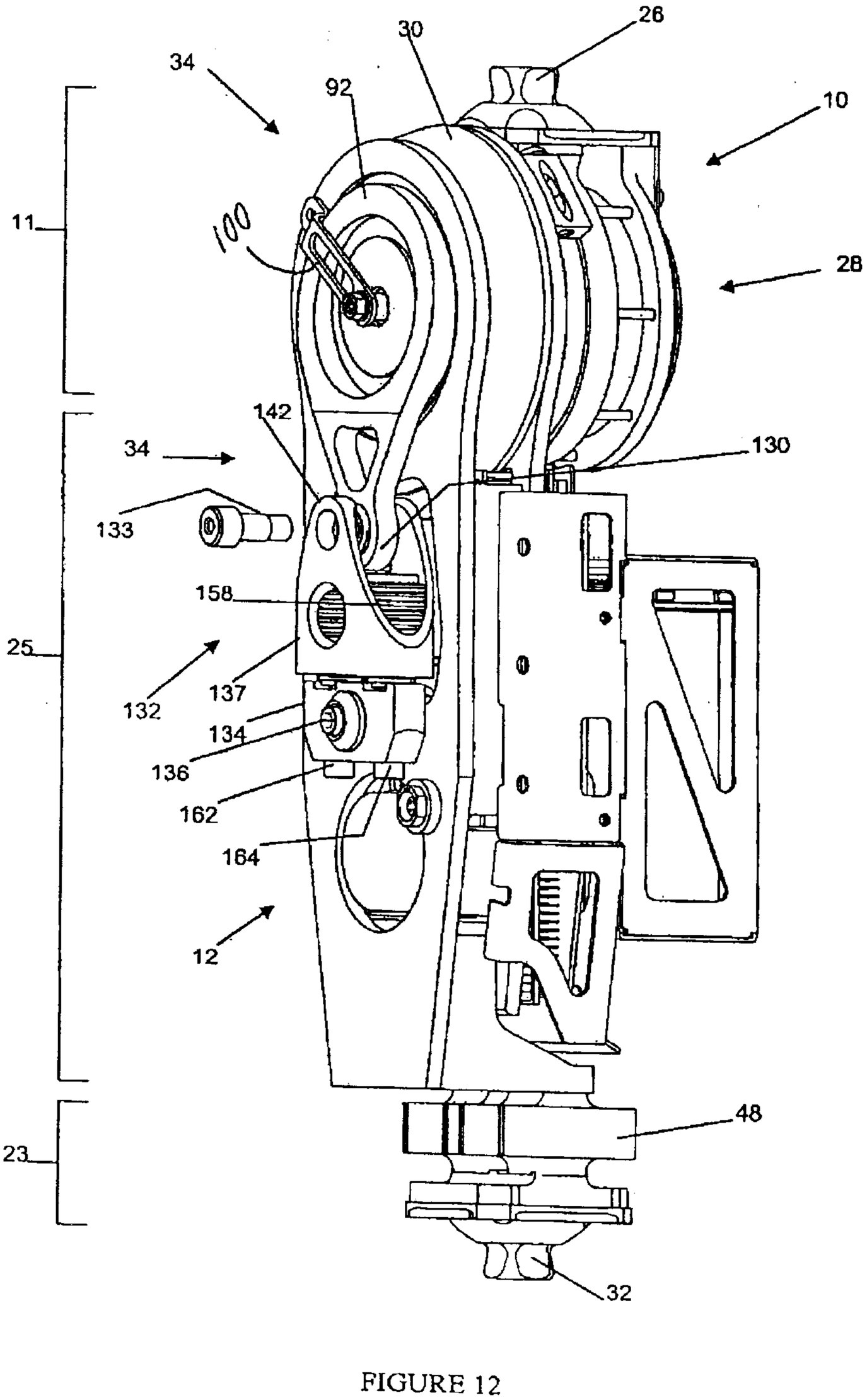
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FIGURE 12

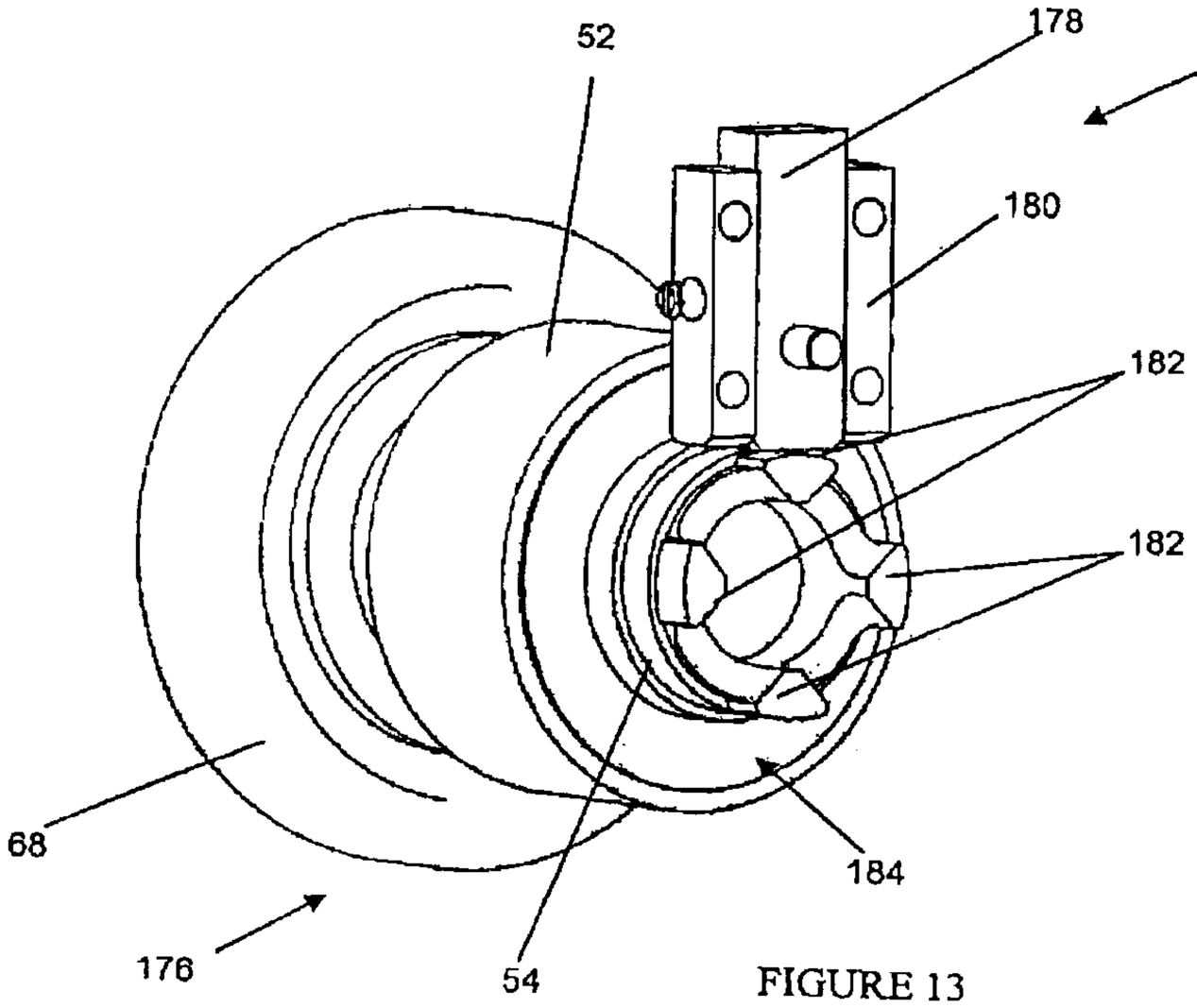

FIGURE 13

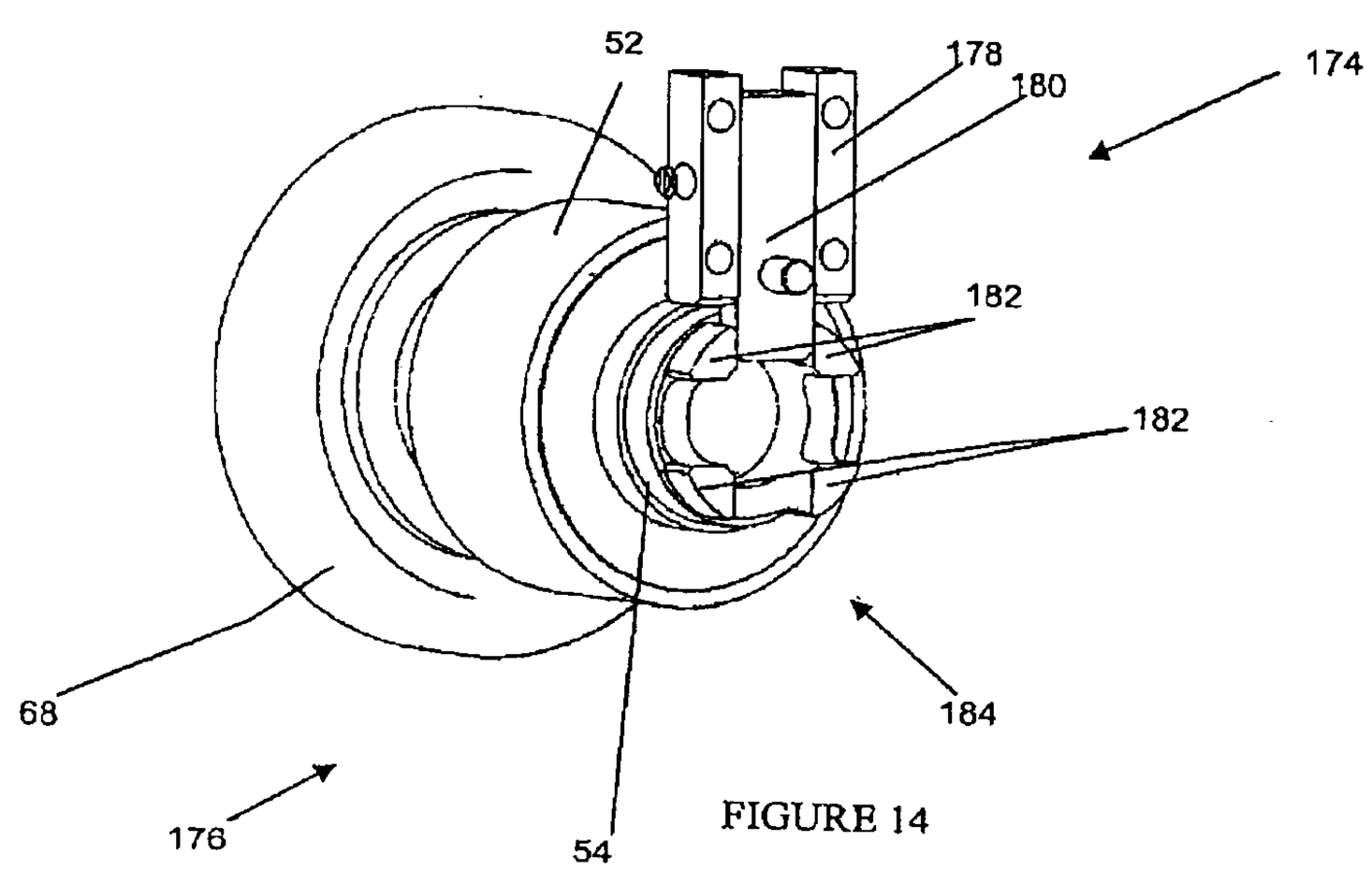

FIGURE 14

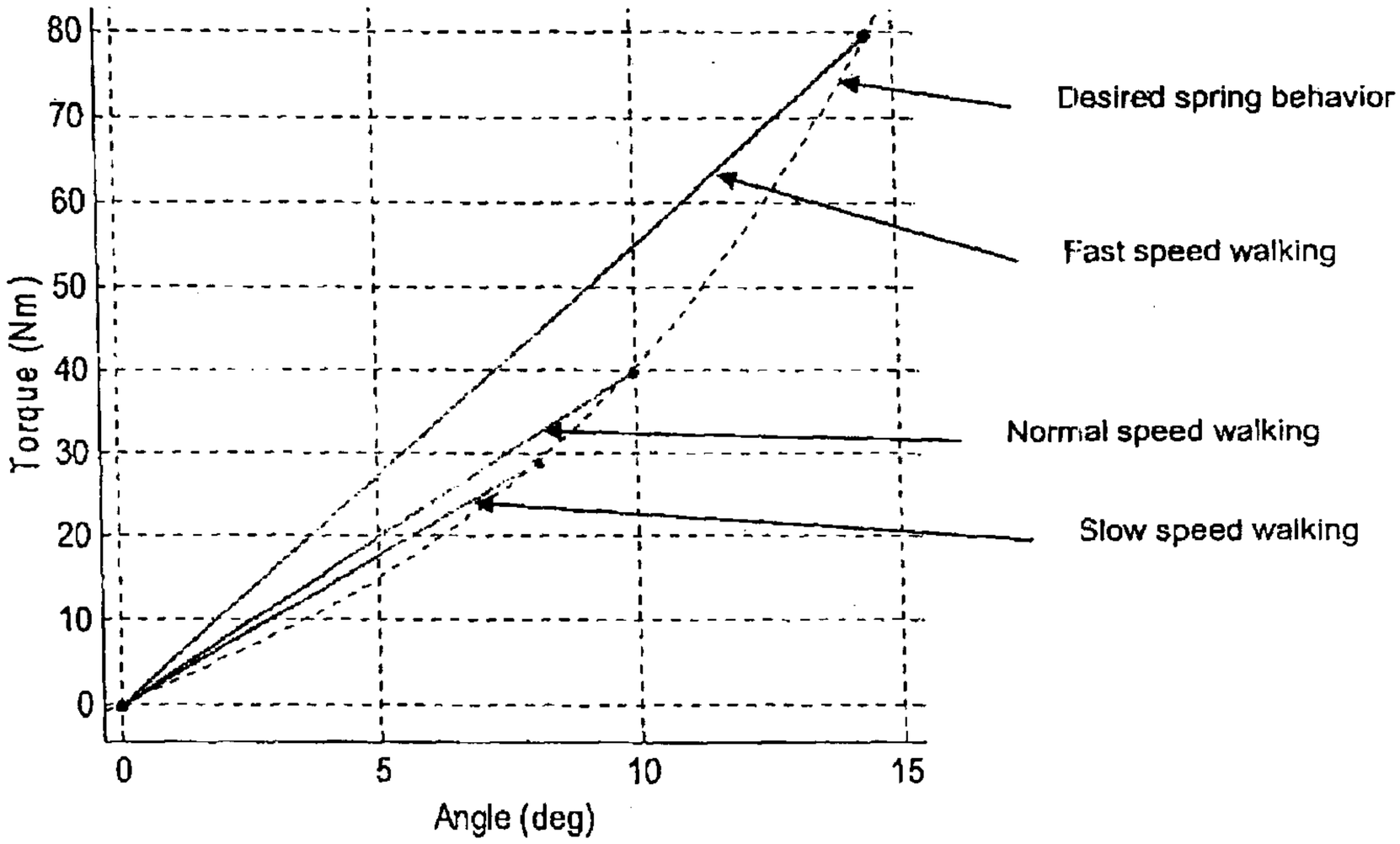

FIGURE 15

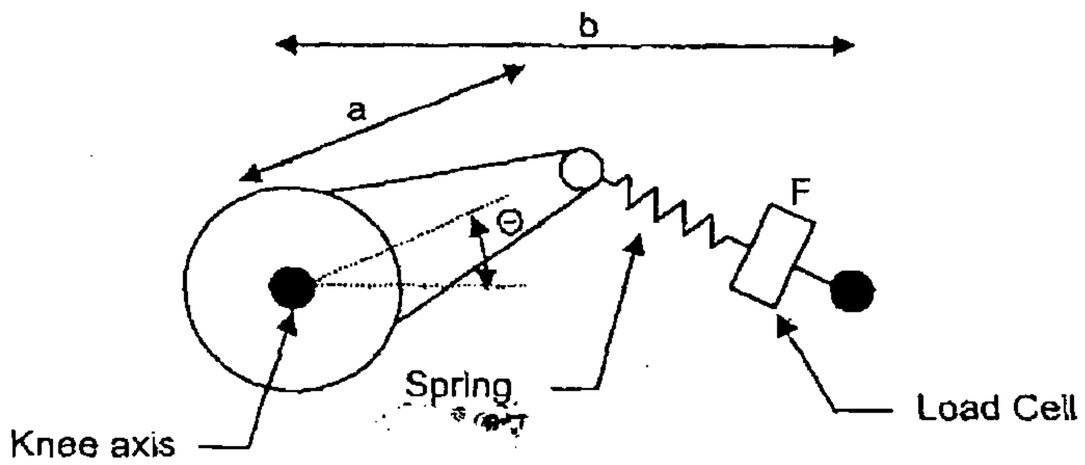

FIGURE 16

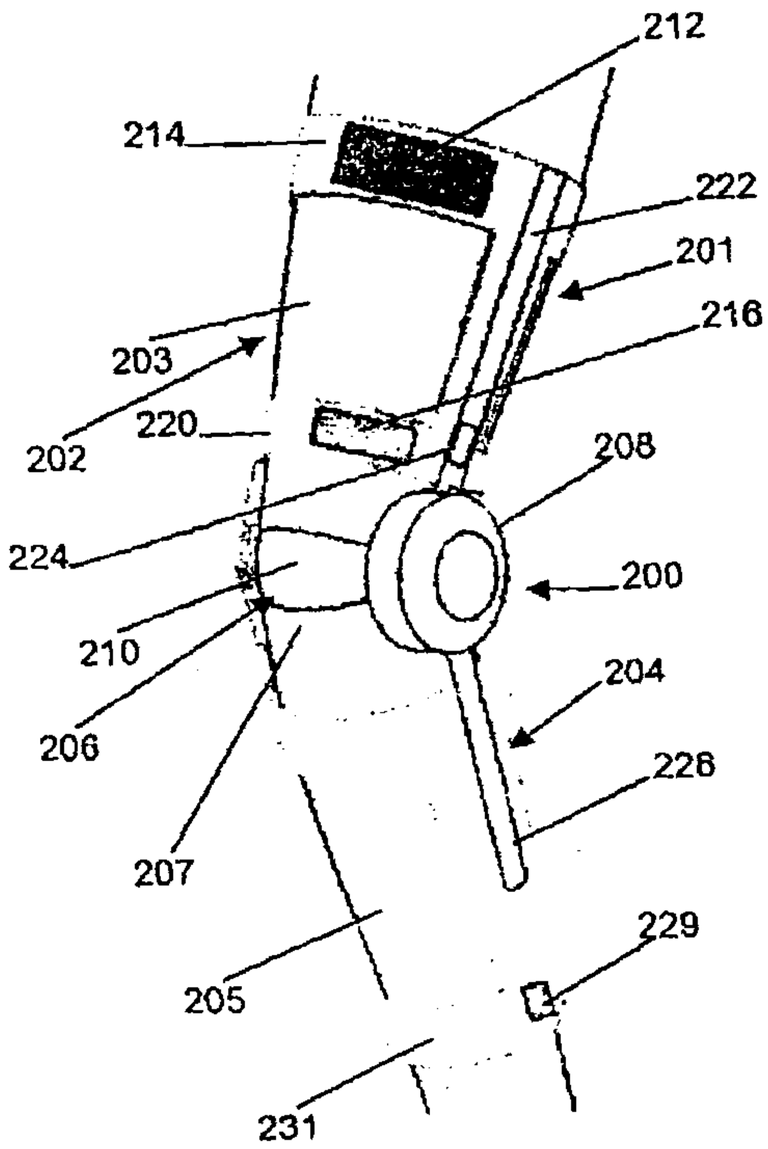

FIGURE 17

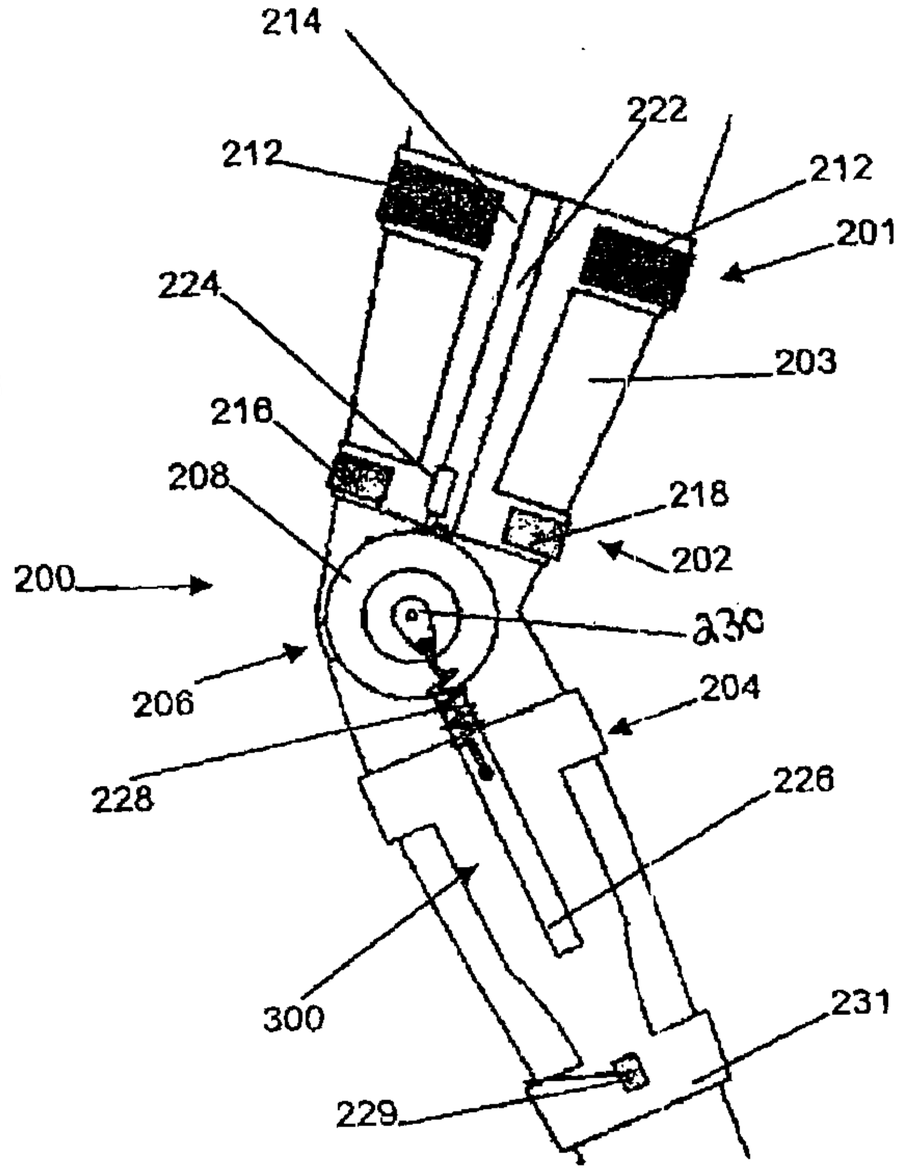

FIGURE 18

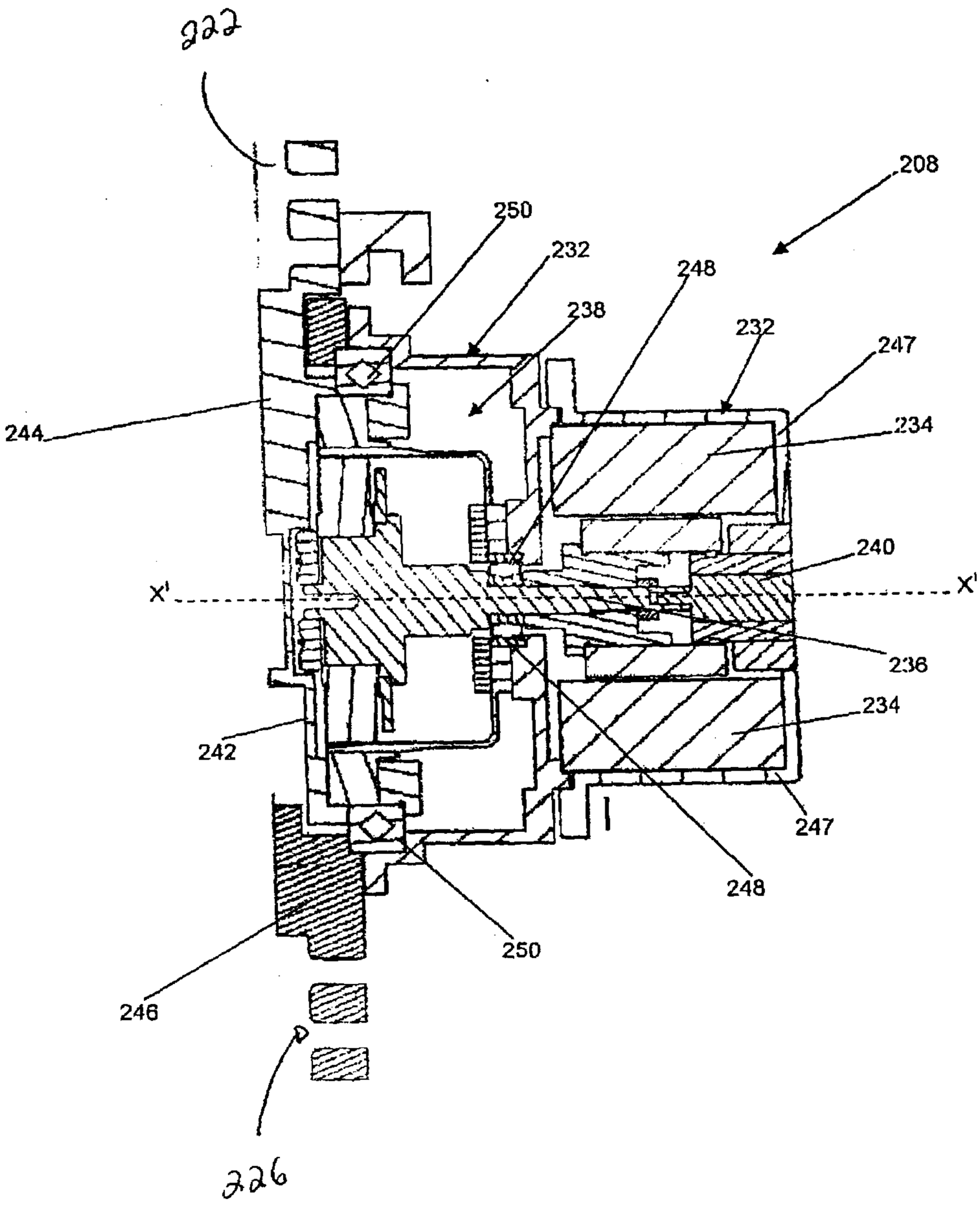
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FIGURE 19

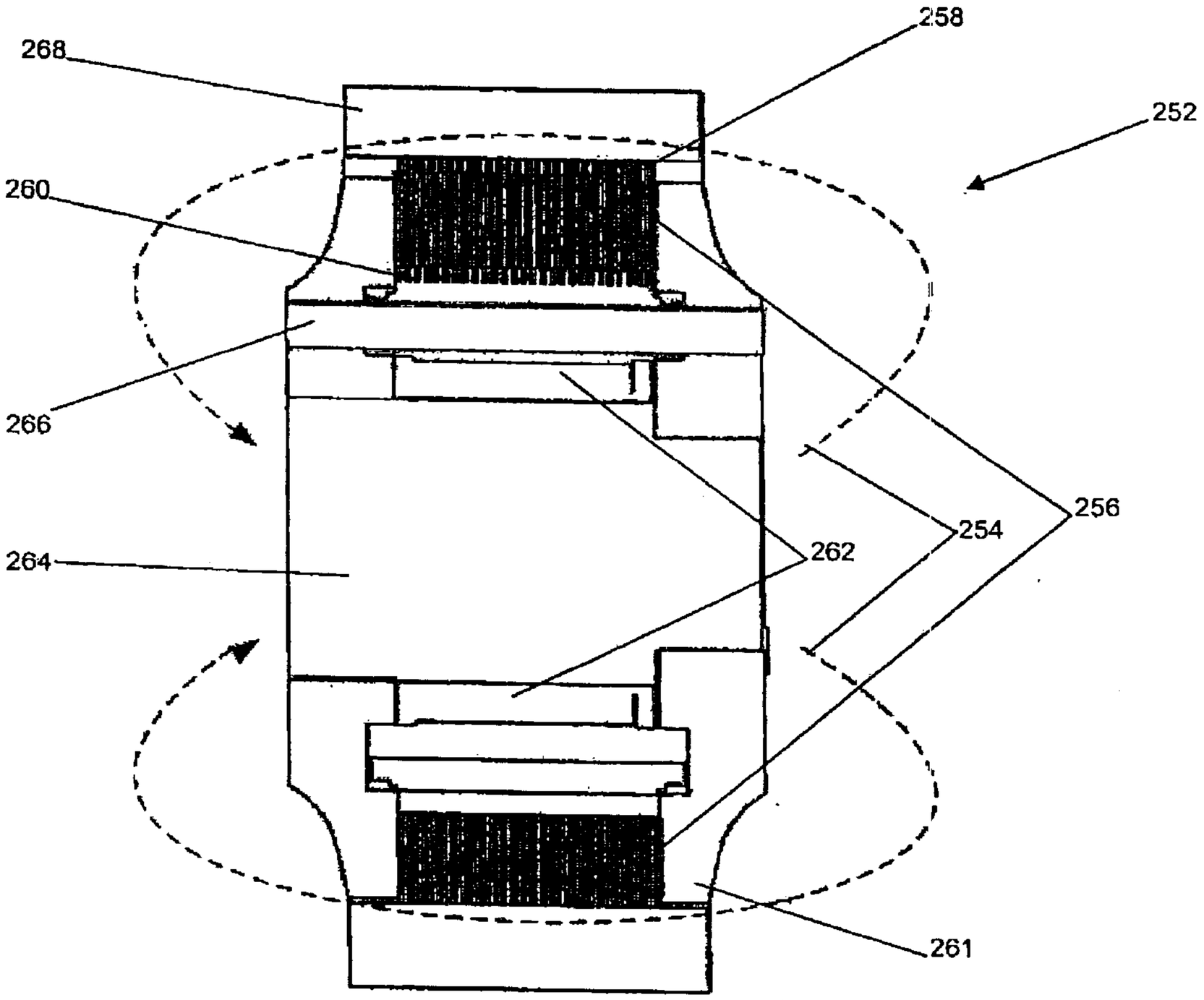


FIGURE 20

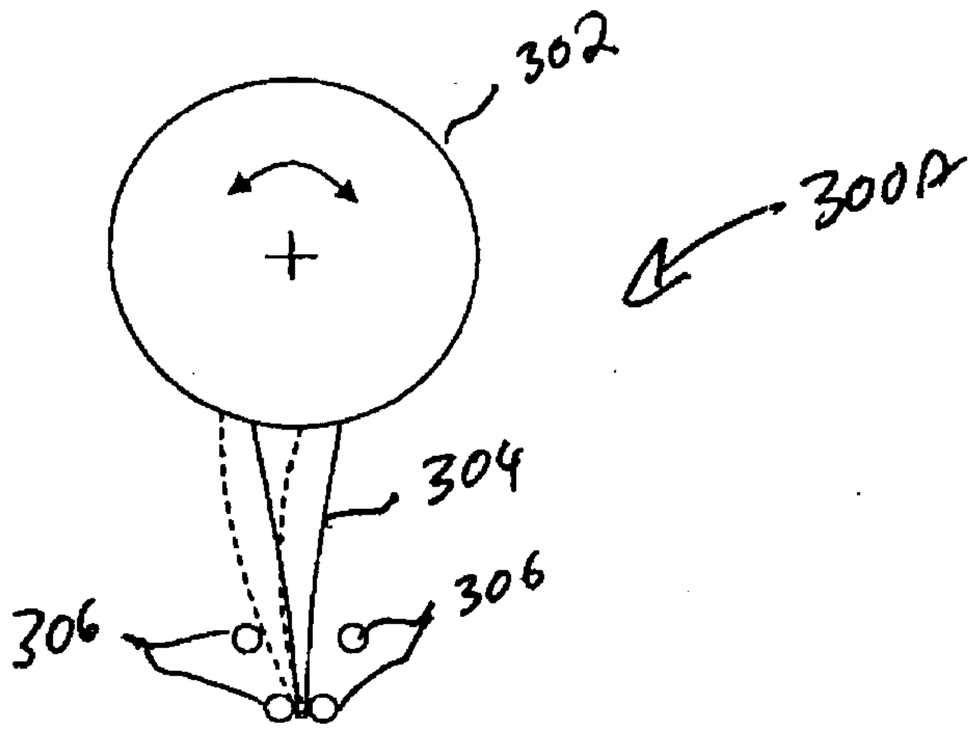


FIG. 21A

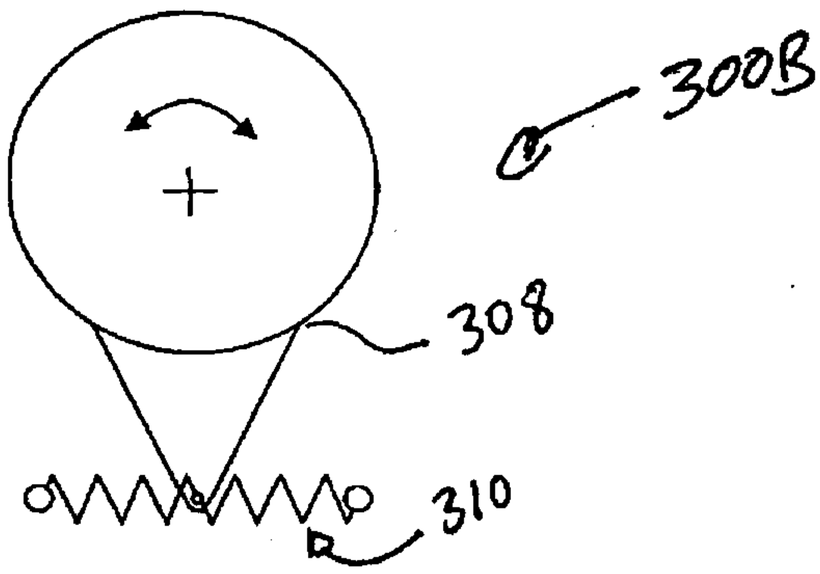


FIG. 21B

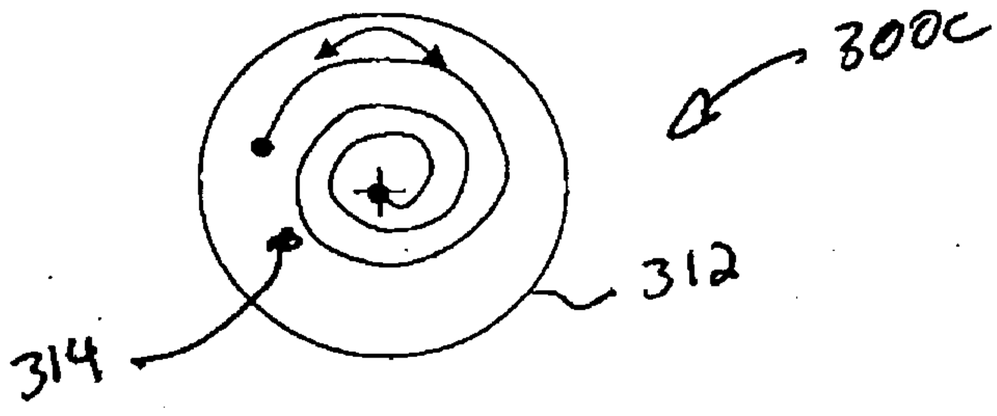


FIG. 21C

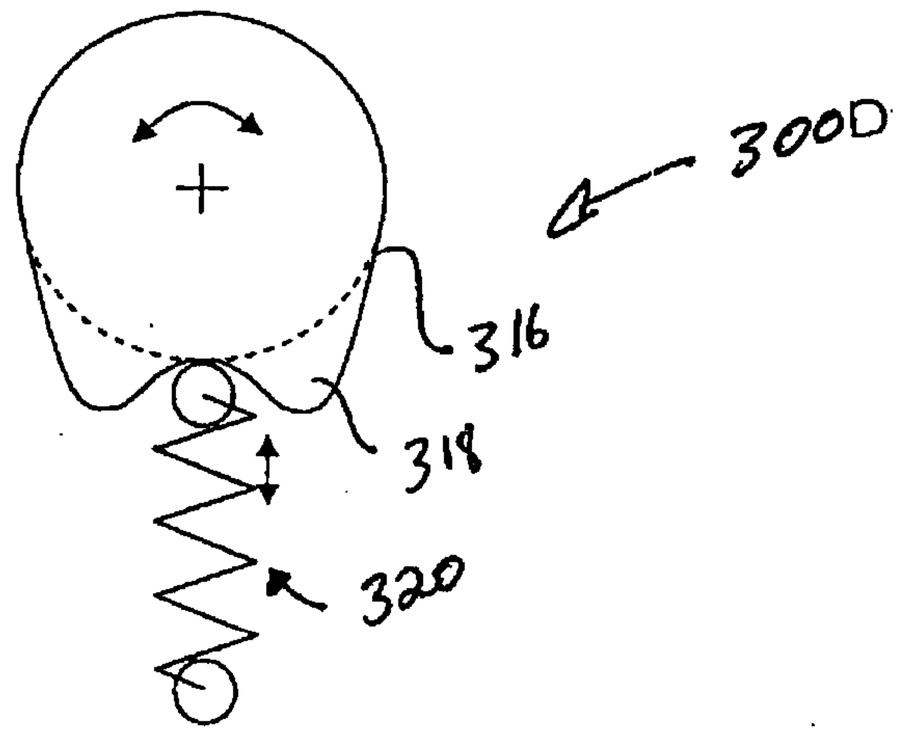


FIG. 21D

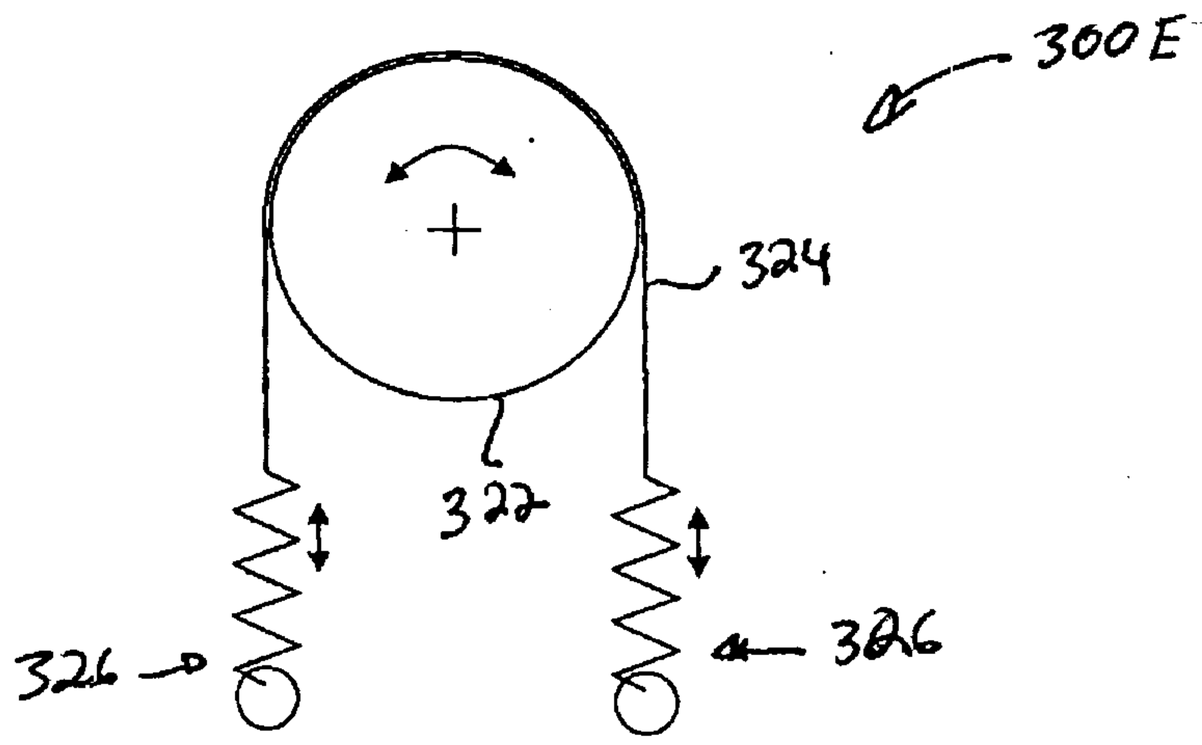
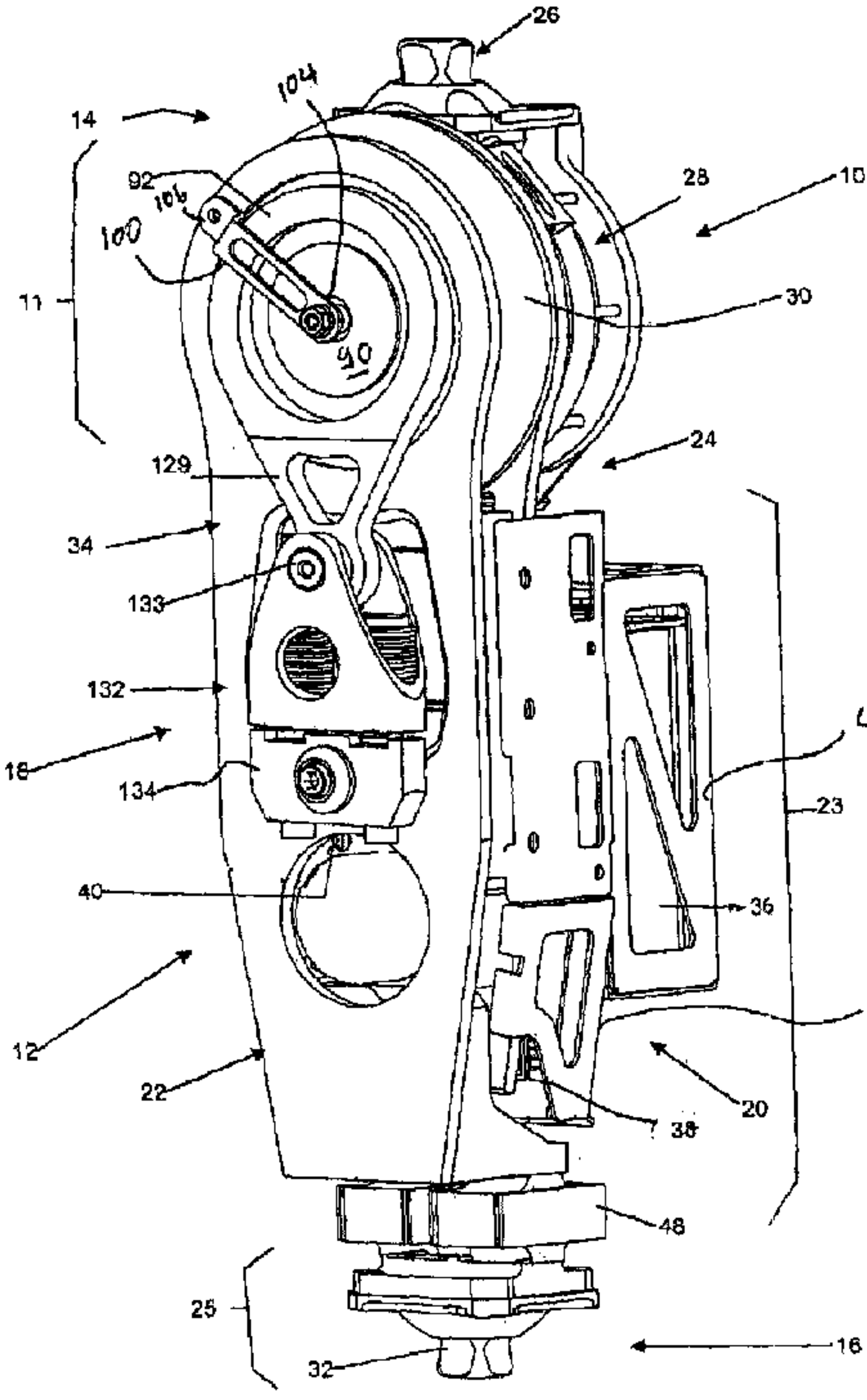


FIG. 21E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