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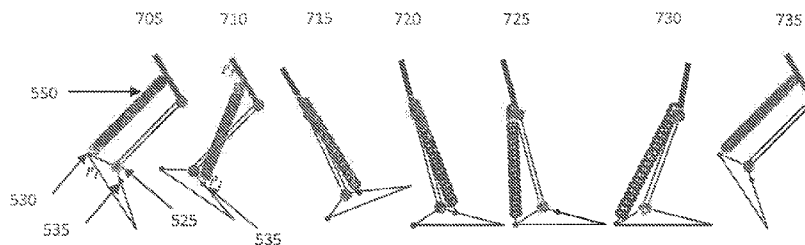


Fig. 7

(57) Abstract: A prosthetic or orthotic device comprises an upper leg portion (505), a lower leg portion (510), a foot portion (520), a knee joint (515) and an ankle joint (525). The device further comprises an elastic element (550), which elastically interconnects the upper leg portion and the foot portion. The elastic element is movably (1105, 1105a, 1105b) connected to the foot portion and/or movably connected to the upper leg portion. During performing a gait cycle with the device, the elastic element actually moves according to said movability or movabilities. At least during a swing phase of said gait cycle, the elastic element absorbs energy.

A PROSTHETIC OR ORTHOTIC DEVICE

FIELD OF ART

The invention relates to a prosthetic or orthotic device and to a method for using such a device. The invention aims at improving the energy efficiency needed for the mobility of such a device by maximizing the absorption, storage, and release of energy generated during movement of such a device.

BACKGROUND

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The design of lower limb prosthetic devices is of great interest due to the crucial impact of usability to amputees. One of the challenges is providing enough mobility in an energy efficient manner in terms of metabolic energy consumption and external actuation. Energy must be generated to move portions of a lower leg prosthetic device to mimic the natural gait cycle of a person in an energy efficient manner to conserve metabolic energy.

The natural gait cycle includes the movement of the lower leg, e.g., the thigh, calf, ankle, and foot, to allow a person to walk. By understanding the movement of the lower leg during the natural gait cycle, a prosthetist can design a lower leg transfemoral prosthetic device based on kinematic relationships of these body parts.

Currently, the majority of lower limb prosthetic devices can be classified as having a passive, controlled, or powered movement. Passive prosthetic devices typically are aesthetically pleasing but have little functionality. Some of these passive prosthetic devices are functional in that the prosthetic devices has been designed to exploit some of the dynamics involved in walking by using special kinematic configurations to move different parts of the lower limb prosthetic device.

Amputees, however, consume a large amount of metabolic energy (approximately 60%) to move the prosthetic device by using muscles that are not normally used for walking to compensate for energy normally provided and transferred from the lower leg muscles during the gait cycle. This type of artificial movement uses large amounts of metabolic energy by forcing the movement of the prosthetic device which not only wastes energy but also does not allow the movement of the prosthetic device to follow the natural gait cycle.

To provide a prosthetic device that mimics the natural gait cycle, controlled and powered prosthetic devices are used. Controlled prosthetic devices use internal actuators and a microprocessor to control the dynamics, i.e., movement, of the prosthetic device. Since the controlled prosthetic device uses a microprocessor to sense and control the actuators to replicate the human gait, the mobility of the controlled prosthetic device is improved over passive prostheses.

Powered prosthetic devices inject power to various portions of the prosthetic device during the gait cycle in order to support push-off generation and to reduce extra metabolic energy consumption. The powered prosthetic device can reduce the extra metabolic energy consumption by replacing true muscle activity to bend and straighten the knee by controlling the powered portions to mimic the natural gait cycle.

The controlled prosthetic devices and the powered prosthetic devices, however, require complex control schemes involving sensors, processors, and actuators, which add weight to the transfemoral prosthetic device.

Recently, designs of transfemoral prosthetic devices having these movements have been improved by using energy storage components to reduce power consumption of the transfemoral prosthetic device during a gait cycle. These improvements, however, have failed to maximize the overall energy

produced from the natural gait cycle using a simple and lightweight configuration.

SUMMARY

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In view of these known designs, there is still a need for an improved prosthetic or orthotic device that has the simplicity of the passive transfemoral prosthetic device and functionality of a powered or controlled prosthetic device that replicates the energetic behavior that occurs during a natural human gait
10 cycle in order to maximize energy efficiency.

For that purpose the present invention provides a prosthetic or orthotic device according to appended independent claim 1. Furthermore the present invention provides a method according to appended independent claim 11, said method being for using a prosthetic or orthotic device. Specific
15 embodiments of the invention are set forth in the appended dependent claims 2-10 and 12-14.

Hence, the device according to the invention comprises an upper leg portion, a lower leg portion, a foot portion, a knee joint and an ankle joint, wherein the upper leg portion is pivotally connected to the lower leg portion by
20 means of the knee joint and wherein the lower leg portion is pivotally connected to the foot portion by means of the ankle joint. The device according to the invention further comprises a first elastic element, which elastically interconnects the upper leg portion and the foot portion by means of a first connection between the first elastic element and the foot portion and by means
25 of a second connection between the first elastic element and the upper leg portion. The first connection may provide first movability, e.g. first slidability, of the first elastic element relative to the foot portion. Additionally or alternatively, the second connection may provide second movability, e.g. second slidability, of the first elastic element relative to the upper leg portion.

During performing a gait cycle with the device, the first movable elastic element actually moves according to said first movability and/or said second movability. The first movable elastic element absorbs energy by loading the first movable elastic element during a swing phase and a stance phase of said gait cycle. Said energy absorbed by the first movable elastic element is subsequently released by unloading the thus loaded first movable elastic element during a push-off phase of said gait cycle for generating push-off energy for the foot portion to push-off. Said loading and said unloading are taking place at mutually different movement positions of the first movable elastic element relative to the foot portion and/or relative to the upper leg portion.

By providing a device that absorbs and releases energy at different phases of the natural gait cycle without the need of an electronic controller, a device is provided that mimics the movement and energetic behaviors of the natural knee and ankle joints of a person in a simplified and non-bulky prosthetic device.

The numerous advantages, features and functions of the various embodiments herein will become readily apparent and better understood in view of the following description and accompanying drawings. The following description is not intended to limit the scope of the transfemoral prosthetic device, but instead merely provides exemplary embodiments for ease of understanding.

Hereinafter, the present invention is mostly described with reference to a prosthetic device. However, it has to be understood that the invention similarly applies, with similar effects, to an orthotic device. An example of a device according to the present invention is a transfemoral prosthetic device that replicates the absorption and release of energy by a natural knee joint and ankle joint during the gait cycle in an energy efficient manner.

BRIEF DESCRIPTION OF THE DRAWINGS

Examples of a device according to different embodiments of the present disclosure will now be explained in more detail with reference to the following drawings.

Figs. 1A and 1B are illustrative graphs showing the power flow of a knee joint and an ankle joint, respectively, during one stride of a natural human gait.

Fig. 2 is an illustrative graph showing an angular positioning of an ankle joint and a knee joint during a single stride of a natural human gait.

Fig. 3 is an illustrative graph showing the angular positioning of an ankle joint in relation to the angular positioning of a knee joint during the push-off phase of a natural human gait.

Fig. 4 is an illustrative graph showing the torque at the knee and ankle during a stride of a natural human gait.

Fig. 5 is a highly schematical side view showing a first exemplary embodiment of a transfemoral prosthetic device that can be used to maximize the power flow illustrated in Figs. 1A and 1B.

Figs. 6A and 6B are highly schematical side views showing different embodiments of a linkage mechanism of the transfemoral prosthetic device of Fig. 5.

Fig. 7 is a highly schematical side view showing a movement of a first movable elastic element of the transfemoral prosthetic device of Fig. 5 during a gait cycle.

Figs. 8A and 8B are highly schematical side views showing the first movable elastic element and a second elastic element of the transfemoral prosthetic device of Fig. 5 during different roll-over intervals of a stance phase.

Fig. 9 is a highly schematical side view showing the movement of the first movable elastic element and second elastic element of the transfemoral prosthetic device during different phases of a gait cycle

Fig. 10 schematically shows, in a perspective and partly cut-away view, a more detailed embodiment of the transfemoral prosthetic device of Fig. 5.

Fig. 11 schematically shows, in a perspective view, another embodiment of the transfemoral prosthetic device of Fig. 5.

Fig. 12 is a highly schematical side view showing the first movable elastic element and a third elastic element of the transfemoral prosthetic device of Fig. 5 at the beginning of the toe off stage of the foot portion of the device.

In the various figures, similar elements are provided with similar reference numbers. It should be noted that the drawing figures are not necessarily drawn to scale, or proportion, but instead are drawn to provide a better understanding of the components thereof, and are not intended to be limiting in scope, but rather provide exemplary illustrations.

DETAILED DESCRIPTION OF VARIOUS EMBODIMENTS

A. Overview

In designing an orthopedic or prosthetic device, a prosthetist or orthotist can analyze the natural power flow and movement of different body parts. By understanding the energetic and kinematic relationships that occur during different movements, the prosthetist or orthotist can develop an orthopedic or prosthetic device that mimics the natural movement and energetic behaviors of different body parts.

For example, the design of an energy efficient prosthetic device can relate to integrating the power flow of the natural human gait as described by D.A. Winter in "The Biomechanics and Motor Control of Human Gait: Normal, Elderly, and Pathological," University of Waterloo Press (1991) into a transfemoral prosthetic device.

As illustrated in the graph of Fig. 1, an ankle and knee have different energy absorption intervals, i.e., power levels below zero, and power generation intervals, i.e., power levels above zero, during a natural human gait cycle, i.e., namely stance, pre-swing, and swing phases. While there are many different energy absorption and generation intervals that occur during the gait cycle, the design of this embodiment of the disclosure relates to utilizing and mimicking the energy intervals from the knee absorption intervals, i.e., a pre-swing absorption interval 101 and a swing absorption interval 102, and the ankle absorption interval, i.e., a roll-over absorption interval 103, to generate power for push-off generation interval 104 at an ankle. By using these absorption intervals around the knee and ankle to generate push-off energy, the power required for the mobility of the transfemoral prosthetic device can be maximized in an energy efficient manner and replicate the natural gait cycle of a person.

Generally, Fig. 1 shows that during a human gait cycle of a knee joint, the knee joint is mainly an energy absorber, whereas the ankle joint is mainly an energy generator. Fig. 1 further illustrates that there is almost a complete balance between the generated and absorbed energy at the ankle and knee joints, as evidenced by the fact that the total energy generated for the push-off generation interval 104 is substantially equal to the total energy absorbed during the pre-swing absorption interval 101, the swing absorption interval 102, and the roll-over absorption interval 103. The energy absorption and generation of the ankle and knee joints at each phase of the gait cycle is discussed below in detail.

As seen in Fig. 1, during the stance phase, i.e., between about 0% and about 45% of the stride, the knee absorbs energy during knee flexion and generates about an equal amount of energy for knee extension. Meanwhile, the ankle joint absorbs energy during the roll-over absorption interval 103 due to transference of position of a weight bearing load on the lower leg, i.e., during

dorsi-flexion of the ankle, which occurs during the stance phase between about 10% and 45% of the stride.

During the pre-swing phase, the knee absorbs energy during a pre-swing absorption interval 101, which occurs between about 50% to about 70% of stride. On the other hand, the ankle generates the majority of the energy needed for a push-off generation interval 104 at about 45% to about 60% of stride. Fig. 1 also shows that the energy generated for the push-off interval 104 by the ankle is about 80% of the overall power generation that occurs during the entire stride.

Finally during the swing phase, the knee absorbs energy during the swing absorption interval 102, which occurs during the late swing phase of about 80% and 95% of stride, while the ankle joint provides negligible energy.

These absorption intervals can be used in the design of a transfemoral prosthetic device based on the kinematic relationship that naturally occurs between a knee and ankle of a person which can be observed when comparing the respective angular positions of the knee and ankle. For example, as illustrated in Fig. 2, the angular positions of the knee and ankle are similar, as seen in angular positions 201 and 202, respectively, but move in opposite directions, when the stride is between about 45% and about 65%. At this moment of the stride, a push off of a foot occurs, i.e., the ankle starts plantar flexing, while the knee starts flexing, i.e., the angular position of the knee decreases. Moreover, Fig. 3 shows that the angular positions 301 and 302 of the knee and ankle, respectively, are almost linear with respect to one another when the stride is between about 45% and about 65%.

Additionally, as seen in Fig. 4, the torque 401 around a natural knee is in a flexion direction between about 45% and 55% of the stride. Therefore, if this kinematic constraint is used in the design of the transfemoral prosthetic device, it will further provide to the natural walking kinematics while additionally providing an energy contribution to the ankle push-off generation from the knee joint as a consequence of closed-loop kinematic chain to imitate

the natural absorption and generation of energy that occurs around a knee and ankle joint of a person.

B. Discussion of Various Embodiments

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As generally discussed above, the joints of a person act as energy absorbers and generators by storing and releasing energy based on the movement of the person. By understanding these energetic and kinematic relationships between different body parts, a prosthetic device can be developed that replicates the energetic behavior of these natural joints to maximize energy efficiency and provide natural movement of the device. For example, a prosthetic device that mimics the absorption and movement of a natural knee and ankle joint is provided in a transfemoral prosthetic device 500, as discussed below.

15 Fig. 5 generally shows an embodiment of the transfemoral prosthetic device 500 that utilizes and replicates the energy absorption and energy generation intervals, as seen in Fig. 1, that naturally occurs during the human gait cycle by using the known kinematic constraints between the natural knee and ankle joints. By using these kinematic relationships, the transfemoral prosthetic device 500 uses three mechanisms, i.e., a linkage mechanism 545, a first movable elastic element 550, and a second elastic element 555, to absorb energy around knee and ankle portions of the transfemoral prosthetic device 500 and then transfer the absorbed energy to generate energy for a foot push-off interval, i.e., toe off of a foot portion. This absorption and release of energy
20 by these mechanisms imitates the different energy absorption and generation intervals that occur around the natural knee and ankle joints during a natural gait cycle.

One having ordinary skill in the art would appreciate by maximizing the absorption of these intervals, a transfemoral prosthetic device having these
30 features overcomes the deficiencies of the prior art by providing a transfemoral

prosthetic device that imitates the natural gait cycle in an energy efficient manner by providing a simple and non-bulky transfemoral prosthetic device.

The linkage mechanism 545 replicates the energetic behavior of the natural knee joint by connecting a knee portion 515 to an ankle portion 525 in a kinematic relationship and is responsible for the transference of the energy from the pre-swing absorption interval 101 to the ankle push-off generation interval 104.

The first movable elastic element 550 mimics the energy absorption of the knee joint by energetically linking the knee portion 515 to the ankle portion 525 and is responsible for the absorption of the energy from the swing absorption interval 102 and the transference of the energy from the swing absorption interval 102 to the ankle portion 525 to generate energy needed during the push-off generation interval 104. The first movable elastic element 550 is also capable of a partial absorption of energy from a roll-over absorption interval 103 that occurs during a stance phase of the gait cycle and transference of that energy to the ankle portion 525 for the ankle push-off generation interval 104.

The second elastic element 555 replicates energy absorption by the ankle joint by providing a braking torque and energy absorption of the roll-over absorption interval 103 during the stance phase of the gait cycle by connecting a heel portion 530 to a lower leg portion 510. Although the first movable elastic element 550 contributes to partial absorption of the roll-over absorption interval 103 during the stance phase, the second elastic element 555 serves as a complementary component to the first movable elastic element 550 by providing enough braking torque to stop the movement of the transfemoral prosthetic device depending on the stiffness of the first movable elastic element 550.

As discussed above, the linkage mechanism 545 is responsible for the transfer of the energy from the pre-swing absorption interval 101 to the ankle for the push-off generation interval 104. The transfer of energy is

accomplished by using the kinematic relationship between the natural knee and ankle joints in the design of the prosthetic device.

The linear relationship between the natural knee and ankle joints, as discussed above, is replicated by connecting the knee portion 515 to the ankle portion 525 by using the linkage mechanism 545, examples of which are an elastic spring, wire, belt, link, steel cable, or similar elastic or non-elastic connection, in a way such that a knee flexion of the transfemoral prosthetic device is linked to an ankle plantar-flexion and vice versa. By having this connection, the linkage mechanism 545 can be mechanically activated at push-off and deactivated at toe-off, which allows the simultaneous generation and absorption of energy during the pre-swing and push-off stride intervals.

In the embodiment shown in Fig. 6A, the linkage mechanism 545 comprises a first pulley 605 connected to the knee portion 515 and a second pulley 610 connected to the ankle portion 525 of the transfemoral prosthetic device 500 which are then connected by a connection element 615, which can be a steel cable, chain, belt, polymer fiber, rope, elastic or inelastic band, or other linkage element. By connecting the connection element 615 to the pulleys 605, 610, the linear relationship between the angular positions of the knee portion 515 to the ankle portion 525 is realized.

In a variation shown in Fig. 6B, the linkage mechanism 545 instead comprises a first lever 620 linked to the knee portion 515 and a second lever 625 linked to the ankle portion 525 which are connected by a connection element 630. In this variation, the connection element 630 is elastic. It will be appreciated, however, that connection element 630 can also be a non-elastic element; for example, a steel cable having an elastic coupling used to couple the first and second levers 620, 625.

As seen in these variations, the connection element 615 is capable of transferring a push-off torque from the knee portion 515 to the ankle portion 525 by maintaining a torque relationship between the knee and ankle portions that occurs around the natural knee and ankle joints during the same interval

of the natural gait cycle, i.e., when the stride is between about 45% and about 65%.

Turning to the first movable elastic element 550, the first movable elastic element 550 stores the kinetic energy of the lower leg during the swing
5 absorption interval 102, i.e., between about 70% to about 98% of the stride, and/or a part of the roll-over absorption interval 103 during the stance phase. The first movable elastic element can comprise a spring, a belt, a chain, a hydraulic cylinder, or other mechanical device or configuration that is capable of absorbing and releasing energy. One having ordinary skill in the art would
10 appreciate that the term elastic, as used throughout this application, refers to a device that is capable of absorbing energy and releasing the stored energy.

The energy is absorbed during the swing phase and stance phase by having the first movable elastic element 550 move, e.g., by sliding, rolling, or other mechanism that allows the repositioning of one end point of the first
15 movable elastic element, between a position near the heel portion 530 and a mid-position 535 in front of the ankle portion 525 which causes the first movable elastic element 550 to load to thereby store energy. This stored energy is then released during the movement of the first movable elastic element 550 when it returns back to its initial position and is used for the
20 lifting of the transfemoral prosthetic device 500.

The first movable elastic element 550 absorbs energy by having one end attached to the upper leg portion 505 by fastening mechanisms well known in the art, such as hook, welds, pins, screws, bolts, or other mechanical means that fixes the positioning of one end of the first movable elastic element
25 550. The other end of the first movable elastic element 550 is then movable between at least two positions on the foot portion 520 by attaching the end to a movable device, such as, a slider, bolt, pin, carriage, roller, or other slidable device, that moves along a pre-determined guided trajectory part, for example, along a groove, track, or other guided path.

The foot portion 520 comprises the pre-determined guided trajectory part, which is located between the mid-position 535 and the heel portion 530, so that the first movable elastic element 550 can move or slide during different phases of the gait cycle. Alternatively, one having ordinary skill in the art
5 would appreciate that the pre-determined guided trajectory part can be located in different positions depending on the type and amount of energy that is to be absorbed during the natural gait cycle.

Fig. 7 shows the working principles of the first movable elastic element 550, which is capable of transferring absorbed energy to the ankle
10 portion for the push-off generation interval 104. As seen in frames 705 and 710, the first movable elastic element 550 is configured in a way such that after the pre-swing phase, i.e., at full flexion of the knee portion, the one end of the first movable elastic element 550 attached to a movable device, e.g., a slidable device, moves from a position near the heel portion 530 to a mid-
15 position 535 in front of the ankle portion 525.

Frame 715 shows the position of the mechanism just before the foot will touch the ground at the end of the swing phase. In this position, the first movable elastic element is under tension, having absorbed the energy from the swing absorption interval 102 as shown in Fig. 1.

20 Frames 720 and 725 show that after the end of the swing phase, i.e., during the loading response phase, the first movable elastic element 550 is loaded further and moves, i.e., slide, from the mid-position 535 back to the position at the heel portion 530. As seen in frame 730, as roll-over of the foot portion 520 occurs during the stance phase, the first movable elastic element
25 550 is configured to further partially absorb energy from the roll-over absorption interval 103.

Finally, frames 730 and 735 show that when the first movable elastic element 550 is loaded, the first movable elastic element 550 releases the absorbed energy to generate a portion of the energy required for the push-

off generation interval 104 around the ankle portion 525 for toe lift off of the foot portion 520.

Although in this embodiment the first movable elastic element 550 is attached to a fixed position on the upper leg portion 505 and moves, e.g.,
5 slides, along the foot portion 520, one having ordinary skill in the art would appreciate that the attachment points can be reversed or re-positioned to maximize energy absorption during different phases of the natural gait cycle. For example, the one end of the first movable elastic element 550 connected to the upper leg portion 505 can also be movable, so that both ends of the first
10 movable elastic element 550 are movable. Alternatively, while the one end of the first movable elastic element 550 attached to the upper leg portion 505 is movable, the other end connected to the foot portion can be fixed.

The second elastic element 555 replicates the energetic behavior of the ankle joint and is placed near the ankle portion 525 to connect the heel
15 portion 530 and the lower leg portion 510. One end of the second elastic element 555 is attached to the lower leg portion 510, for example, by a hook, bolt, screw, pin, or other attachment device.

As seen in Fig. 8A, the other end of the second elastic element 555 is attached near the heel portion 530 at a heel position 805 on the foot portion
20 520 by a hook, bolt, screw, pin, or other attachment device. Preferably, the second elastic element 555 is fixed to the heel position 805 and lower leg portion 510, but can be movable to maximize the absorption and release of energy during the gait cycle.

The second elastic element 555 absorbs and releases this energy by
25 comprising a linear or non-linear spring, a belt, a chain, a hydraulic or pneumatic cylinder, or other mechanical device or configuration that is capable of absorbing and releasing energy.

As discussed above, the second elastic element 555 provides a braking torque around the ankle portion as a complementary component to the
30 first movable elastic element 550 to primarily absorb the energy from the roll-

over absorption interval 103 during the stance phase of the gait cycle, i.e., between about 6% and about 45% of the stride.

Figs. 8A and 8B show that during the roll-over interval of the stance phase, i.e., while the ankle portion 525 moves in a dorsiflexion motion from Fig. 8A to Fig. 8B, the second elastic element 555 stores the energy generated by the roll-over of the body weight across the ankle portion 525, i.e., the shifting of the weight of the body of a user. The first movable elastic element 550 and second elastic element 555 then release the energy absorbed during the roll-over absorption interval 103 near the ankle portion 525 to generate the energy required for the push-off generation interval 104.

Referring to Fig. 9, the relationship of the energetic behavior of the first movable elastic element 550 and the second elastic element 555 during a full gait cycle of the transfemoral prosthetic device is shown. As seen in frame 900, during the initial heel strike of the stance phase, only the first movable elastic element 550 is active to absorb energy, as seen in the directional arrow 901. Frame 905 illustrates, by the lengthening of the directional arrow 901, that the first movable elastic element 550 continues to absorb energy after heel strike and during the stance phase. As shown in frame 910, after weight acceptance by the foot portion, the position of the first movable elastic element 550 changes while essentially remaining at the same length by moving from a front position to a back position along the foot portion, to preserve the energy which was stored during the swing phase. Then during the roll-over phase seen in frame 915, the energy generated during the roll-over phase, for example, the energy required for the braking torque, is absorbed by the first movable elastic element 550 and the second elastic element 555 as illustrated by the directional arrows 901 and 902.

The energy absorbed by the first movable elastic element and the second elastic element during frames 900-915 of the gait cycle is then released as illustrated in frames 920 and 925 to enable toe-off of the foot portion of the transfemoral prosthetic device. After toe-off starting in frame 930, the swing

phase begins with the dorsiflexion of the ankle for sufficient ground clearance. At this time, as seen in frame 935, the first movable elastic element 550 moves, e.g., slides, from the position near the heel portion to the mid-position in front of the ankle portion to absorb the energy created during the swing
5 phase. During the swing phase as shown in frames 935-955, the first movable elastic element absorbs the swing absorption interval 102 of Fig. 1. The stride of the gait cycle is then completed with the subsequent heel strike as seen in frame 900 at the end of the swing phase.

Fig. 12 shows a third elastic element 777, that may optionally be
10 applied in the device according to the present invention as an alternative to, or in addition to, the described linkage mechanism. The third elastic element 777 elastically interconnects the upper leg portion 505 and the lower leg portion 510. In Fig. 12 the third elastic element is, merely by way of example, shown as a spring element 777. Fig. 12 shows the beginning of the toe off stage of the
15 foot portion 520 of the device, which stage is comparable to the stage shown in frame 735 of Fig. 7. At this toe off stage the gait cycle is, or nearly is, at the end of the pre-swing phase. During the pre-swing phase the third elastic element 777 has been loaded, i.e. the third elastic element 777 has absorbed energy. This absorbed energy is subsequently released by the third elastic
20 element by unloading the thus loaded third elastic element 777 during the subsequent swing phase of the gait cycle. Thus, swing energy is generated for the lower leg portion 510 to swing.

Fig. 10 shows another embodiment of a transfemoral prosthetic device that absorbs energy from the natural gait cycle and releases the
25 absorbed energy to maximize energy efficiency by mimicking the absorption and generation of a natural knee and ankle joint of a person. In this embodiment the knee portion 515 can comprise a single axis connection having two ball bearings.

The upper leg portion 505 and lower leg portion 510 can be made
30 from an aluminum alloy, e.g., 6061 aluminum alloy, steel, carbon fiber, plastic,

or similar material having the proper strength and physical characteristics. Additionally, a small damper can be fitted inside the knee to dampen the knee extension at the end of the swing phase. The damper is configured to compensate for a large swing momentum, due to excessive hip flexion, by preventing a full knee extension. The damper is also used to set the degrees of hyperextension during the stance phase.

The pulley linkage system 545 includes a first gear 1005, a second gear 1010, and a first pulley 1015, which are used to form the knee portion 515. From the knee portion 515, a cable 1020 can run through the lower leg portion 510 to a second pulley 1025 in the ankle joint 525. The cable 1020 flexibly runs over small diameter guidance wheels 1030 that feed the cable into the lower leg portion 510. The cable can be made from steel, plastic, carbon fiber, aluminum, or other similarly strength material.

The cable 1020 is tensioned by a threaded socket that extends the lower leg portion 510 by a rotation of a nut 1035. The connection between the second gear 1010 to the first pulley 1015 can be made elastic by a flange coupling which allows the adjustment of the stiffness of the linkage mechanism 545 according to a user preference for normal walking.

The lower leg portion 510 is connected to a foot portion 520 having a heel portion 530 by a rotational joint that forms an ankle portion 525. The second elastic element 555 comprises linear or non-linear ankle springs or other deformable element that are fitted into two cylinders extending and contracting from an ankle dorsiflexion angle between about 0° to about 10°. Additionally, connection ends between the lower leg portion 510 and foot portion 520 can comprise a length adjustable ball socket rod end and a shaft with sliding bushings to allow the adjustment of the size of the transfemoral prosthetic device.

The foot portion 520 can be made from carbon-fiber sheets, steel, aluminum alloy, or other similar material that provides strength and flexion. Finite-Element-Method (FEM) calculations have been done with a

flexural module of 125000 MPA related to 45° layered uni-directional (UD) carbon-fiber material. The heel portion 530 is designed to flex between 7.8 mm and 15.4 mm according to a leg angle at heel-strike. The toe portion 540 bends to a maximum of 30°, which is derived from a ground pressure plot. A peak
5 ground reaction force occurs during push-off corresponding to a toe angle of 30°.

As discussed above, the second elastic element 555 can include at least two springs, which are designed to absorb the available energy created during the stance phase roll-over absorption interval 103, i.e., about 0.13 J/Kg.
10 This energy is sufficient to compress the two springs over a length of 10 mm. An additional push-off torque can be generated by including a moment arm having a length of 55 mm towards the ankle joint, which enable the springs to deliver an extra 98 Nm of push-off torque.

The first movable elastic element 550 can be connected to the lower
15 leg portion 510 by a fastening device, such as a hook, pin, button, weld, or other fastening system, and to the foot portion by a hook, pin, button, or welded to a movable device. As discussed above, the first movable elastic element 550 can move, e.g., by sliding, between a first position at the heel portion 530 to a second position at a mid-position 535 in front of the ankle
20 portion 525. A release angle to allow the movable device to allow the movement of the first movable elastic element 550 can be determined by maximizing the total available energy of the natural gait cycle.

For example in this embodiment, the movable device can be releasable at 6° roll-over of the ankle portion 525 by using a small pin that
25 pushes down a slider hook when the foot portion 520 dorsiflexes. The sliding device trajectory can be designed as adjustable by using a left/right hand threaded stud to maximize the energy absorption and release. Therefore, the release angle can be set such that the sliding device reaches the end of the guided trajectory part at zero velocity.

In a case where the angle velocity is set incorrectly, a rubber stopper can be fitted to prevent the hitting of the sliding device at the ends of the trajectory path. Additionally, a groove can be provided to hold the sliding device in position during push-off generation, until all of the energy is released.

Additionally, the first movable elastic element 550 provides a natural swing braking torque around the knee portion 515 by capturing substantially all the energy from swing absorption interval 102. The absorption of the swing absorption interval 102 avoids any velocity remaining at final extension of the lower leg, which could cause an uncomfortable movement of the transfemoral prosthetic device past an expected extension angle or an incomplete extension of the knee, which could lead to the knee buckling at heel strike. In this way, the natural knee moment profile of Fig. 4 can be more closely followed by using the transfemoral prosthetic device to obtain a low knee torque at the end of the swing phase and reduce the risk of incomplete extension.

The first movable elastic element 550 captures the energy using a spring or other deformable element that becomes progressively loaded, i.e., the force increase, while the knee torque profile shows a decreasing torque. By using a special (non-linear) force-length relation of the spring and by proper configuration of the rotation point, the moment arm can effectively become zero so that the loaded spring does not cause a knee flexion moment.

The braking torque can be captured by the first movable elastic element 550 by using a combination of design parameters, e.g., spring dimensions and required stiffness values. In one example, a progressive spring fitted inside a 30 mm diameter tube is used to provide the proper force needed to apply the braking torque to stop the movement of the body and transfemoral prosthetic device.

Additionally, the first movable elastic element 550 can comprise at least a second spring which is configured as a knee full-flexion stop. In this

case, if the user delivers a redundant hip flexion motion during pre-swing, instead of flexing the knee over 65°, which is set as a limit for normal walking, the knee brakes the lower leg portion 510 from extending by compressing the at least second spring. Following the full-flexion of the knee, this energy will
 5 be released to the lower leg portion 510 during the swing phase.

Fig. 11 shows yet another embodiment of the transfemoral prosthetic device that absorbs energy from the gait cycle and releases the absorbed energy for ankle push-off. Similar to the prosthetic device shown in Fig. 10, this embodiment can have the same structural elements, with at least
 10 the exception that the first movable elastic element 550 can be a pneumatic or hydraulic cylinder having at least one end connected to the upper leg portion 505 by bolt, screw, pin or other fastening element. The other end of the first movable elastic element 550 is connected to the guided trajectory path 1105 by pin, bolt, screw, or other element that can move in the guided trajectory path.

As seen in Fig. 11, the end of the first movable elastic element 550 connected to the guided trajectory path 1105 is movable, e.g., slidable, between at least two positions, i.e., 1105a and 1105b. It will be appreciated that the first movable elastic element 550 may have a linkage structure to allow the movement between at least two positions to allow the absorption and release of
 15 energy during the gait cycle.

To support a user having a weight of 80 kilograms (kg) and length of 1.80 meters (m), this embodiment can have a transfemoral prosthetic device having a total weight of 2.49 kg and the following design parameters:

	Length (m)	Height (m)	Range (deg)	Mass (kg)	Torque (Nm)
Knee			-5°/100°		-16
Ankle			15°/-25°		123
Lower Leg	0.47			1.44	
Foot	0.26	0.07		1.05	

As seen from the table of the design specifications of the transfemoral prosthetic device, the foot portion is relatively heavy compared to the lower leg portion. This relative weight is used in order to have the center of mass (CoM) at a distal side from the knee portion, so many parts are placed in the foot portion. This weight distribution is necessary to obtain similar swing dynamics as of a natural human leg, which weighs around 4.9 kg for an 80 kg person. With this weight distribution, the moment of inertia around the knee portion 515 of the lower leg portion 510 and the foot portion 520 is about 0.3 kgm².

If the prosthetic device has a moment of inertia that is lower than the moment of inertia for a natural human leg, less energy would be stored during the swing phase, which would necessarily result in a lower amount of energy for push-off generation. Since most of the push-off energy is used to propel the body forward, but not the lower leg, a light weight prosthetic device will not significantly reduce the amount of energy required for push-off. However, since a lightweight prosthetic device is desired for a user's comfort, this embodiment of the transfemoral prosthetic device is designed to provide the proper moment of inertia for a natural swing dynamic while having a light weight.

C. Detailed Description of the Energy Absorption during the Different Phases of the Gait Cycle

25

1. Pre-swing Phase

When viewing the power flow of the knee and ankle joints of a person during the pre-swing phase, the challenges in maximizing and mimicking the energy absorption are due in part to the generation and

absorption of energy taking place simultaneously. During this phase, the knee joint absorbs the kinetic energy of the lower leg due to ankle push-off.

The embodiments of this disclosure capture the simultaneous absorption and release of energy during this phase by using a linkage mechanism 545. Linkage mechanism 545 not only absorbs the energy during the pre-swing phase of a gait cycle but also contributes to the energy required for the generation of the push-off generation interval 104.

The energy absorption and generation characteristics of the knee joint are replicated by connecting the ankle portion 525 to the knee portion 515 by the linkage mechanism 545. The linkage mechanism 545 then transfers the energy from the push-off generation interval 104 from the ankle portion 525 to the knee portion 515 with a transmission ratio that is similar to the natural kinematic relationship between the knee and ankle joints of a person.

The capturing of the kinematic relationship between the knee and ankle portions allows the transfemoral prosthetic device to replicate the natural walking kinematics of a person while providing an energy contribution to the generation of the ankle push-off generation interval 104 from the knee portion 515 as a consequence of the closed-loop kinematic chain.

2. Energy Storage During Swing Phase

During the swing phase, the first movable elastic element 550 is used to store the kinetic energy of the lower leg during the swing motion of the transfemoral prosthetic device to imitate the energetic behavior of the knee joint of a person. The first movable elastic element 550 then transfers the stored kinetic energy to the ankle portion 525 by moving an end attached to a movable device on the foot portion 520 along a guided trajectory part that keeps the length of the first movable elastic element 550 the same. It follows that during the swing phase, the first movable elastic element 550 moves, for example, by sliding, from a position near the heel portion 530 to a mid-position 535 in front of the ankle portion 525 of the foot portion 520.

3. Energy Storage During Stance Phase

During the stance phase, i.e., while the ankle is in dorsiflexion motion, a braking torque is required to be applied to the ankle portion in order to bear the weight of the body when the body moves forward. While many transfemoral prosthetic devices in the prior art use a braking system which merely dissipates the braking torque energy, the present disclosure uses a second elastic element 555 in conjunction with the first movable elastic element 550 to store the energy from the braking torque and then transfer the stored energy to the ankle portion 525 for generation of the energy needed for the push-off generation interval 104.

The first movable elastic element 550 partially absorbs the braking torque energy by storing energy during the movement from the mid-position 535 back to the position near the heel portion 530 during the stance phase of the natural gait cycle. Therefore, by having the first movable elastic element 550 near the heel portion 530 and the second elastic element 555, the braking torque energy can effectively be stored.

At the end of the stance phase, the second elastic element 555 and the first movable elastic element 550 are both near the heel portion 530 and ready to release the total energy absorbed from the swing absorption interval 102 and the roll-over absorption interval 103 around the ankle portion 525 to generate the majority of the energy required for the push-off generation interval 104.

When the weight of the body shifts around about 40% to about 50% of the stride to start the push-off of the foot portion 520, the second elastic element 555 and the first movable elastic element 550 start releasing their respective absorbed energy around the ankle portion 525 and at the same time, the linkage mechanism 545 is engaged to contribute to the overall energy generation for the push off generation interval 104.

In this embodiment, the linkage mechanism 545 is only active between push-off and toe-off, i.e., in the pre-swing phase of the gait cycle, while the second elastic element 555 is only active during the stance phase of the gait cycle. By having the elements only active during specific phases of the gait cycle, any undesirable interference between the energy storage elements during the gait cycle can be avoided.

Moreover, since the activation and deactivation of the storage elements can be engaged when the velocities of the related joints, i.e., during walking, are zero, ideally no dissipation of the energy is present; substantially all of the energy that is absorbed can be realized for generating the energy required for the push-off generation interval.

While the foregoing embodiments have been described and shown, it is understood that alternatives and modifications of these embodiments, such as those suggested by others, may be made to fall within the scope of the disclosure. Moreover, any of the principles described herein may be extended to any other orthopedic devices, prosthetic devices or other types of articles requiring similar functions of those structural elements described herein.

For example, the use of these foregoing elements are not limited to the use in a transfemoral prosthetic device, but can also be used in a transtibial prosthetic device or similar lower leg prosthetic device. As discussed above, the disclosure is generally directed to analyzing the power flow that naturally occurs around the joints of a person during different movements. Different elements are then used to design the prosthetic device that imitates these known natural energetic behaviors.

While this energetic behavior has been discussed relating to a prosthetic device to imitate the natural gait cycle, this analysis and design of the working relationships and energetic behavior of natural joints can also be applied for transradial and transhumeral prosthetic devices based on the movement of the arm. A prosthetist would understand that once the energetic

and kinematic relationship of the arm is analyzed, different mechanisms can be used to replicate these natural relationships in an energy efficient manner.

Moreover, an orthotist can appreciate that the above mentioned elements can be used to supplement the energetic behavior of the natural joints of a wearer of an orthopedic device, such as, a lower exoskeleton or brace, to assist the wearer during a gait cycle. In this embodiment, the orthopedic device may have a first movable elastic element that connects the thigh and foot of the wearer. During the swing phase of the gait cycle, the first movable element would partially absorb energy generated by the swinging of the lower leg at a first position, and subsequently release the stored energy at a second position to assist the pushing off of the foot.

This embodiment could also include a linkage mechanism that connects the knee portion and foot portion of the orthopedic brace and a second elastic element near the Achilles' tendon of the wearer. Similar to the energetic behavior of these elements with respect to the prosthetic device, the linkage mechanism absorbs energy during a pre-swing absorption of the leg, and releases the stored energy to assist the wearer for push-off generation of the foot. The second elastic element would assist the Achilles' tendon of the wearer by partially absorbing energy from the roll-over interval of the stance phase and releasing the energy to assist the pushing-off of the foot.

Claims

1. A prosthetic or orthotic device comprising:
an upper leg portion, a lower leg portion, a foot portion, a knee joint
and an ankle joint;
wherein the upper leg portion is pivotally connected to the lower leg
5 portion by means of the knee joint; and
wherein the lower leg portion is pivotally connected to the foot
portion by means of the ankle joint;
characterized by
a first elastic element, which elastically interconnects the upper leg
10 portion and the foot portion by means of a first connection between the first
elastic element and the foot portion and by means of a second connection
between the first elastic element and the upper leg portion;
wherein the first connection provides first movability, e.g. first
slidability, of the first elastic element relative to the foot portion and/or
15 wherein the second connection provides second movability, e.g. second
slidability, of the first elastic element relative to the upper leg portion;
wherein, during performing a gait cycle with the prosthetic or
orthotic device, the first elastic element actually moves according to said first
movability and/or said second movability; and
20 wherein the first elastic element absorbs energy at least during a
swing phase of said gait cycle.
2. A prosthetic or orthotic device according to claim 1, at least wherein
the first connection provides said first movability, and wherein said first
25 movability provides that a first attachment area between the first elastic
element and the foot portion, by which first attachment area the first elastic
element and the foot portion are attached to one another, moves, e.g. slides,

relative to the first elastic element and/or relative to the foot portion during a pre-swing phase, a stance phase, and the swing phase of said gait cycle.

3. A prosthetic or orthotic device according to claim 2, wherein said
5 moving of the first attachment area is along a first predetermined trajectory between a heel position at a heel portion of the foot portion and a forefoot position at a forefoot portion of the foot portion.
4. A prosthetic or orthotic device according to any one of the preceding
10 claims, at least wherein the second connection provides said second movability, and wherein said second movability provides that a second attachment area between the first elastic element and the upper leg portion, by which second attachment area the first elastic element and the upper leg portion are
15 attached to one another, moves, e.g. slides, relative to the first elastic element and/or relative to the upper leg portion during a pre-swing phase, a stance phase, and the swing phase of said gait cycle.
5. A prosthetic or orthotic device according to any one of the preceding
20 claims, further comprising a second elastic element, which elastically interconnects the lower leg portion and a heel portion of the foot portion, wherein the second elastic element absorbs energy as a result of pivotal motion at the ankle joint of the lower leg portion relative to the foot portion during a stance phase of said gait cycle.
- 25 6. A prosthetic or orthotic device according to any one of the preceding claims, further comprising a third elastic element, which elastically interconnects the upper leg portion and the lower leg portion, wherein the third elastic element absorbs energy as a result of pivotal motion at the knee joint of the upper leg portion relative to the lower leg portion during a pre-
30 swing phase of said gait cycle.

7. A prosthetic or orthotic device according to any one of the preceding claims, further comprising a linkage mechanism, which couples:

- angular positions at the knee joint of the upper leg portion relative to the lower leg portion, and
 - angular positions at the ankle joint of the lower leg portion relative to the foot portion,
- during said gait cycle in a constraint kinematic relationship with one another.

10

8. A prosthetic or orthotic device according to claim 7, wherein said coupling between said angular positions is realized in that the linkage mechanism comprises a first pulley connected to the knee joint, a second pulley connected to the ankle joint, and a linking element interconnecting the first pulley and the second pulley.

15

9. A prosthetic or orthotic device according to claim 7 or 8, wherein said coupling between said angular positions is an elastic coupling for absorbing and releasing energy during said gait cycle.

20

10. A transfemoral prosthetic or orthotic apparatus, comprising a prosthetic or orthotic device according to any one of the preceding claims, wherein the prosthetic or orthotic device is fully-passive.

25

11. A method for using a prosthetic or orthotic device according to any one of the preceding claims on a residual or complete limb by performing a gait cycle with the prosthetic or orthotic device, the method comprising the steps of:

- absorbing energy by the first elastic element by loading the first elastic element during a swing phase and a stance phase of said gait cycle; and

- releasing said energy absorbed by the first elastic element by unloading the thus loaded first elastic element during a push-off phase of said gait cycle for generating push-off energy for the foot portion to push-off;

5 said loading and said unloading taking place at mutually different movement positions of the first elastic element relative to the foot portion and/or relative to the upper leg portion.

12. A method according to claim 11, wherein the prosthetic or orthotic device comprises a second elastic element, which elastically interconnects the
10 lower leg portion and a heel portion of the foot portion, wherein the second elastic element absorbs energy as a result of pivotal motion at the ankle joint of the lower leg portion relative to the foot portion during a stance phase of said gait cycle, the method further comprising the steps of:

15 - absorbing energy by the second elastic element by loading the second elastic element during a stance phase of said gait cycle; and

- releasing said energy absorbed by the second elastic element by unloading the thus loaded second elastic element during a push-off phase of said gait cycle for generating push-off energy for the foot portion to push-off.

20 13. A method according to claim 11 or 12, wherein the prosthetic or orthotic device comprises a third elastic element, which elastically interconnects the upper leg portion and the lower leg portion, wherein the third elastic element absorbs energy as a result of pivotal motion at the knee joint of the upper leg portion relative to the lower leg portion during a pre-
25 swing phase of said gait cycle, the method further comprising the steps of:

- absorbing energy by the third elastic element by loading the third elastic element during a pre-swing phase of said gait cycle; and

30 - releasing said energy absorbed by the third elastic element by unloading the thus loaded third elastic element during a swing phase of said gait cycle for generating swing energy for the lower leg portion to swing.

14. A method according to any one of claim 11-13, wherein a linkage mechanism of the prosthetic or orthotic device couples:

- angular positions at the knee joint of the upper leg portion relative
5 to the lower leg portion, and
 - angular positions at the ankle joint of the lower leg portion relative
to the foot portion,
- during said gait cycle in a constraint kinematic relationship with
one another.

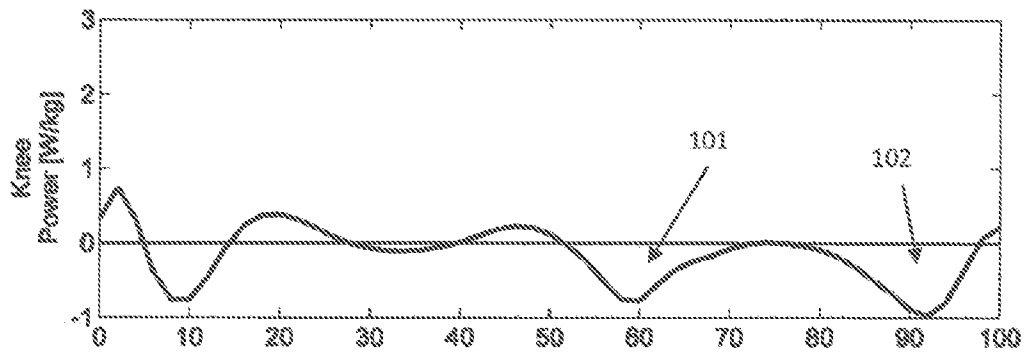


Fig. 1A

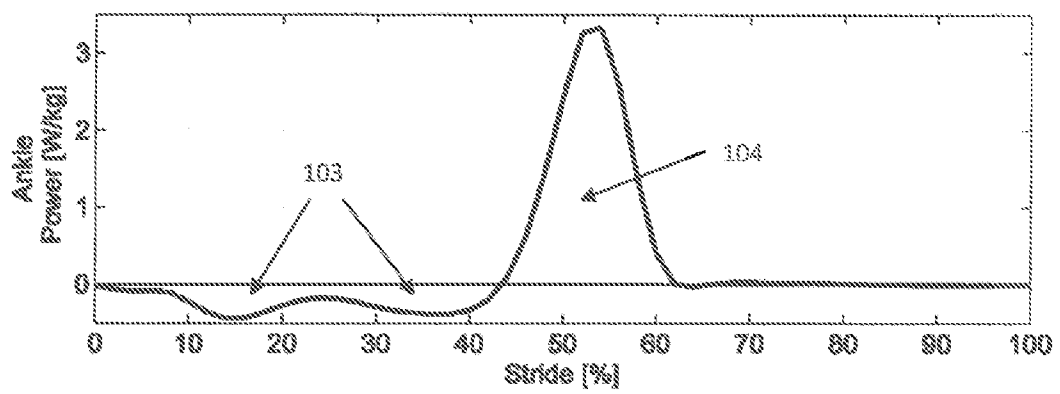


Fig. 1B

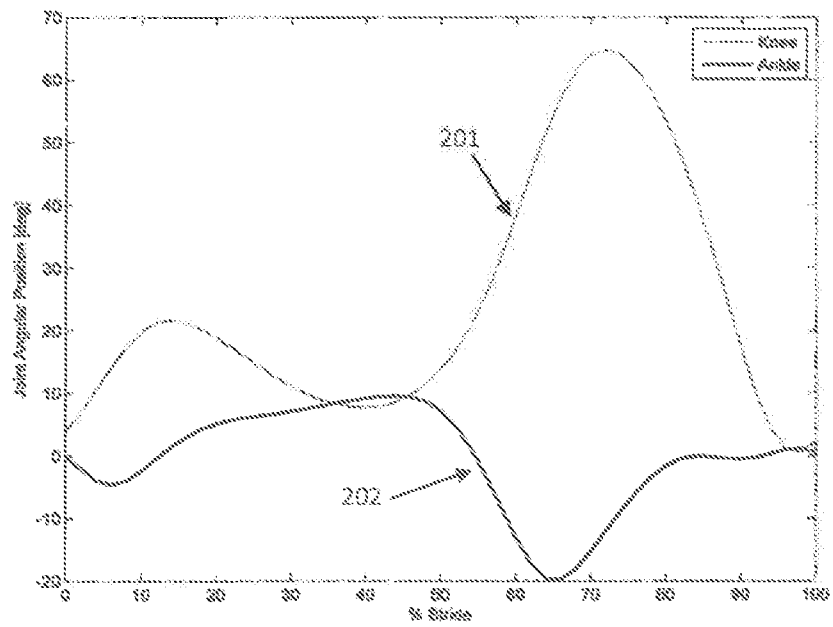


Fig. 2

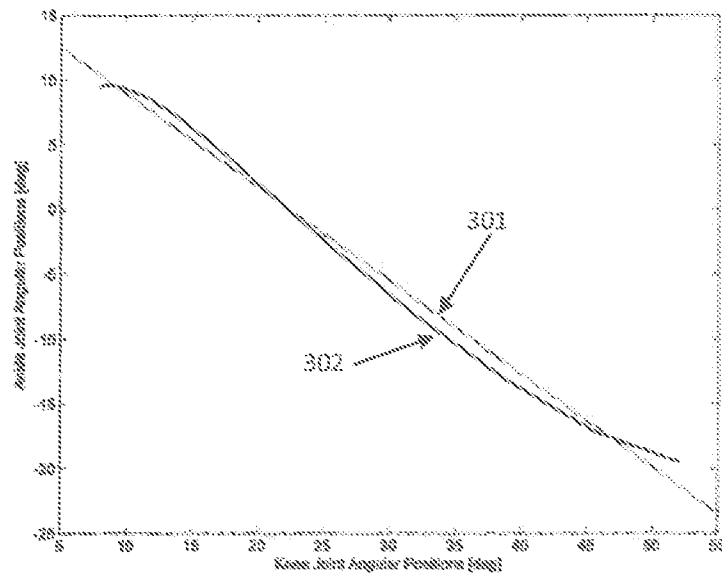


Fig. 3

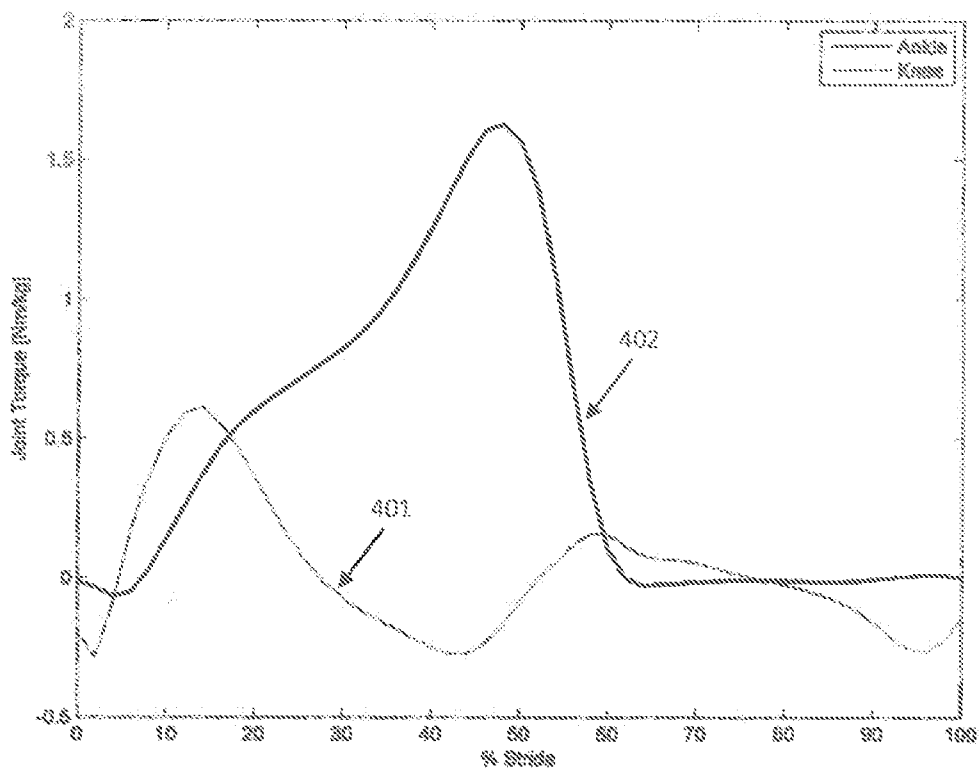


Fig. 4

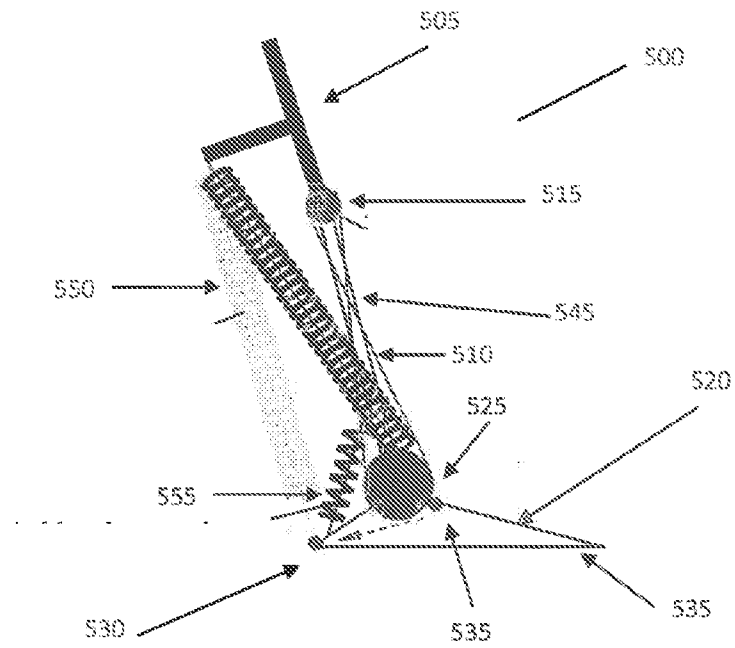


Fig. 5

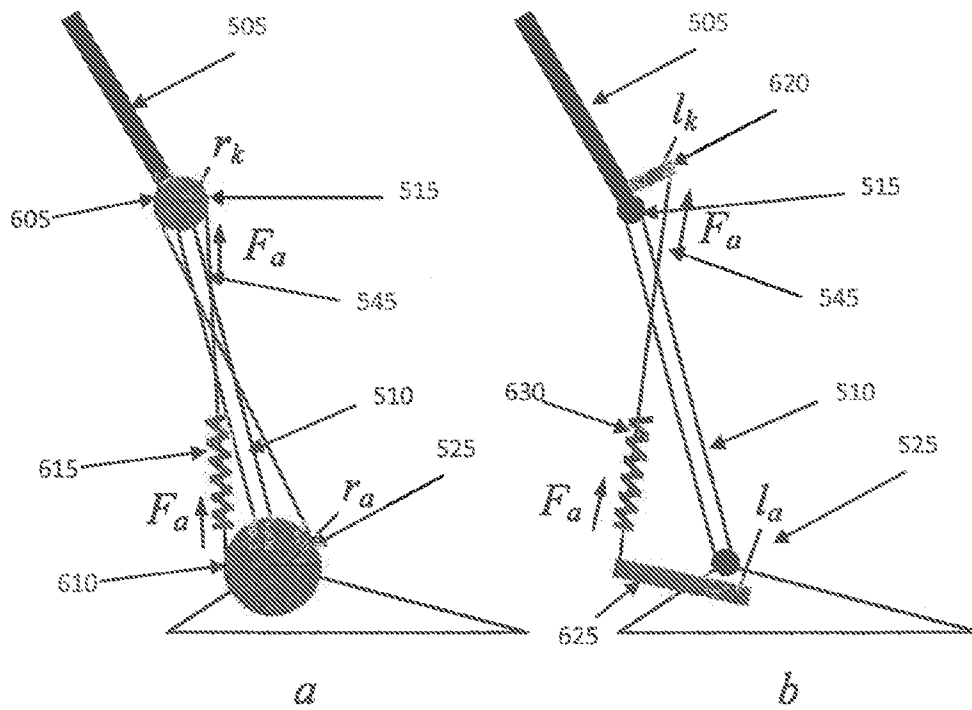


Fig. 6A

Fig. 6B

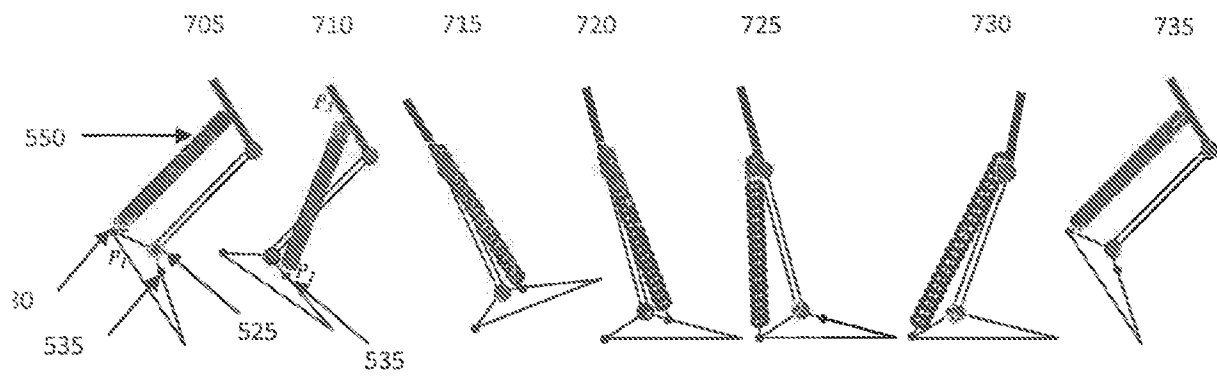


Fig. 7

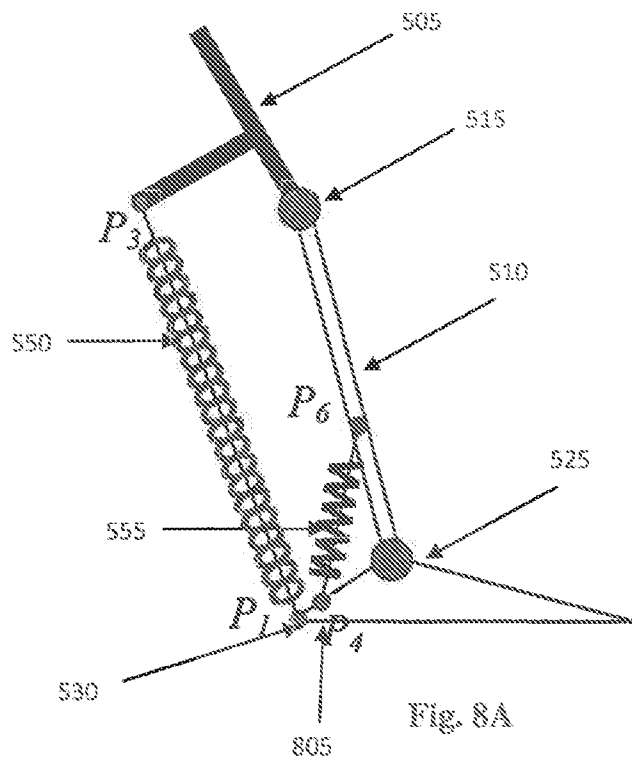


Fig. 8A

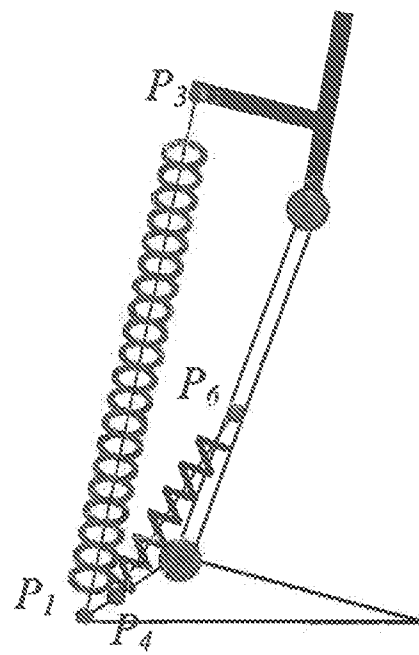


Fig. 8B

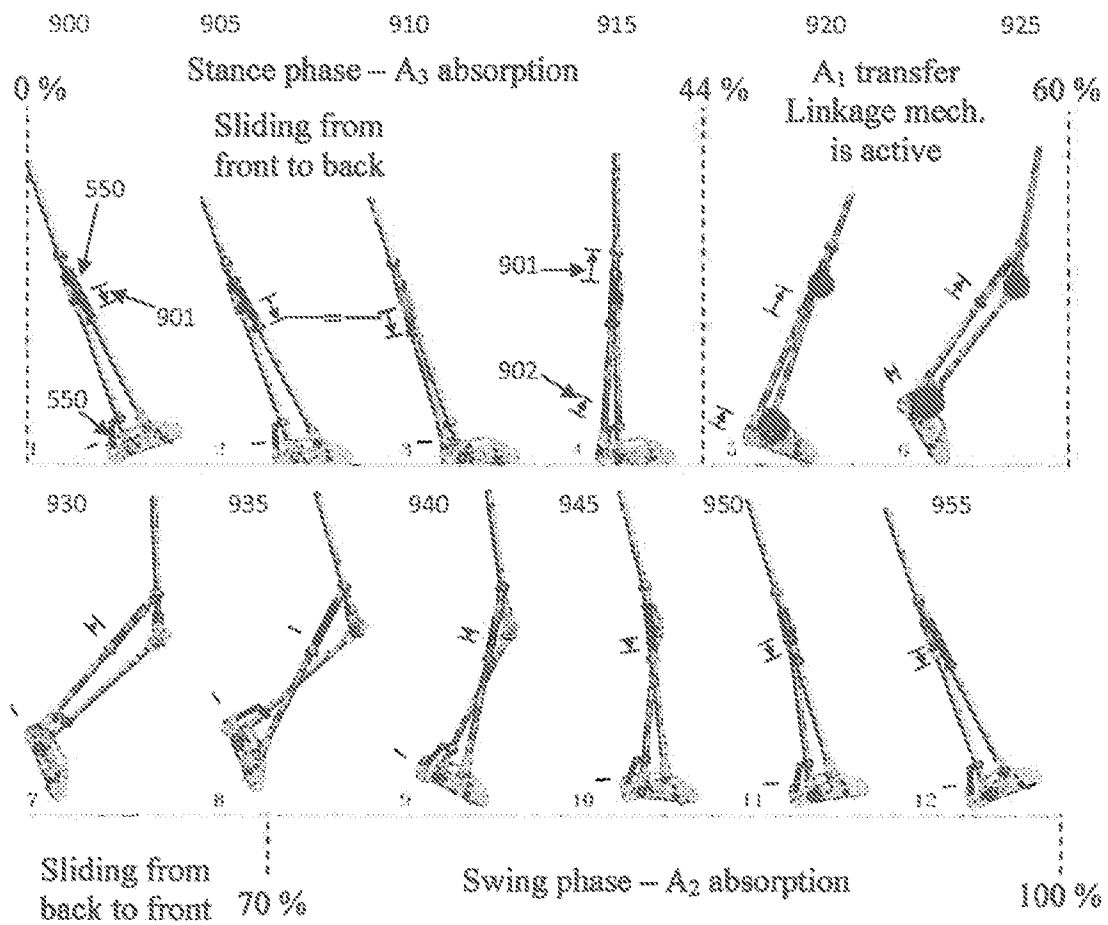


Fig. 9

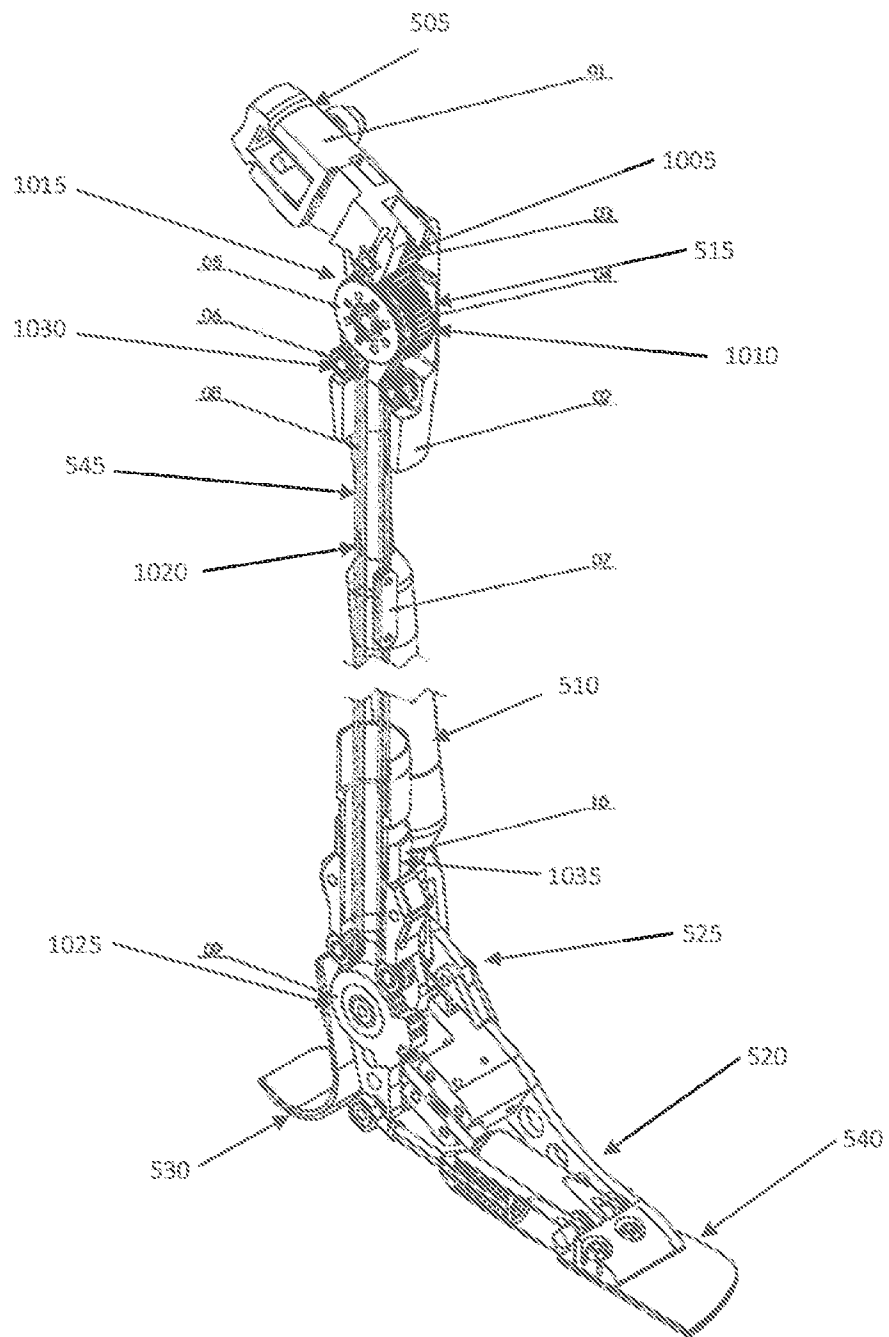


Fig. 10

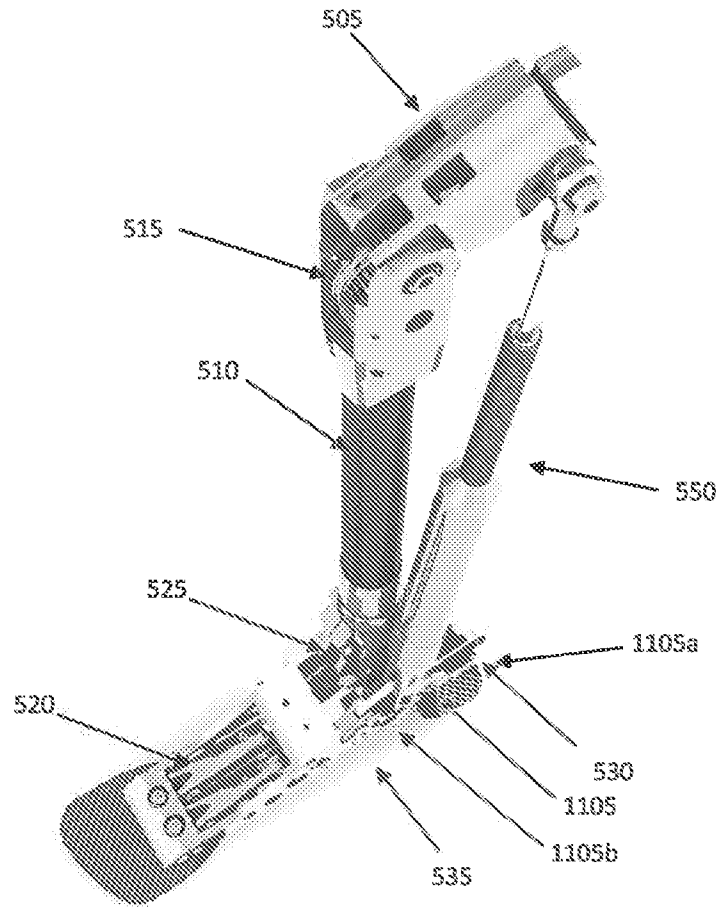
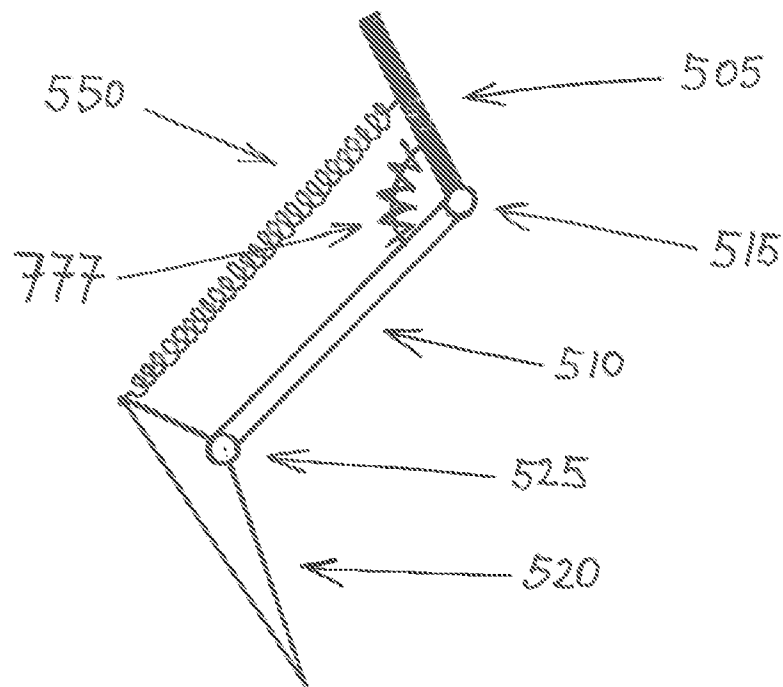


Fig. 11

Fig. 12

INTERNATIONAL SEARCH REPORT

International application No
PCT/NL2012/050421

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61F5/01 A61F2/60
ADD. A61F2/50

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2006/249315 A1 (HERR HUGH M [US] ET AL) 9 November 2006 (2006-11-09)	1-4,10
A	abstract; figures 43-49 paragraphs [0002], [0184] - [0191]	5-9
A	DE 475 303 C (WILHELM LANG) 23 April 1929 (1929-04-23) the whole document	1-10
A	US 167 779 A (JOSEF O'BRIEN) 14 September 1875 (1875-09-14) the whole document	1-10
	----- -/-	



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

20 September 2012

Date of mailing of the international search report

01/10/2012

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
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Authorized officer

Lager, Johan

INTERNATIONAL SEARCH REPORT

International application No.
PCT/NL2012/050421

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☒ Claims Nos.: 11-14
because they relate to subject matter not required to be searched by this Authority, namely:
Claims 11-14 do not fulfil the requirements of Rule 39.1(iv) PCT since they define a method for treatment of the human or animal body by therapy.
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No

PCT/NL2012/050421

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 03/013401 A1 (STICHTING TECH WETENSCHAPP [NL]; COOL JAN CONSTANT [NL]; TE RIELE FRED) 20 February 2003 (2003-02-20) abstract; figures page 2, line 7 - page 3, line 12 page 4, line 3 - page 6, line 9 -----	1-10
A	DE 10 2009 004950 A1 (KRIEG BERND [DE]) 8 July 2010 (2010-07-08) paragraph [0020]; figures 3a,3b -----	1-10
A	US 360 446 A (H.M. KREEMER) 5 April 1887 (1887-04-05) page 1, lines 15-39; figures -----	1-10

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/NL2012/050421

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2006249315 A1	09-11-2006	US 2006249315 A1	09-11-2006
		US 2011264230 A1	27-10-2011
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US 167779 A	14-09-1875	NONE	
WO 03013401 A1	20-02-2003	EP 1411873 A1	28-04-2004
		NL 1018616 C2	27-01-2003
		US 2004243253 A1	02-12-2004
		WO 03013401 A1	20-02-2003
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