March 9, 1954 C. E. REGNELL 2,671,224

ARTIFICIAL LEG

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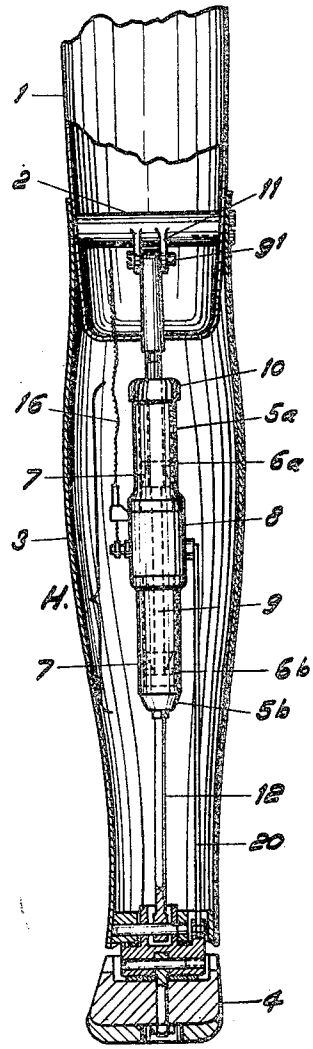


Fig. 2

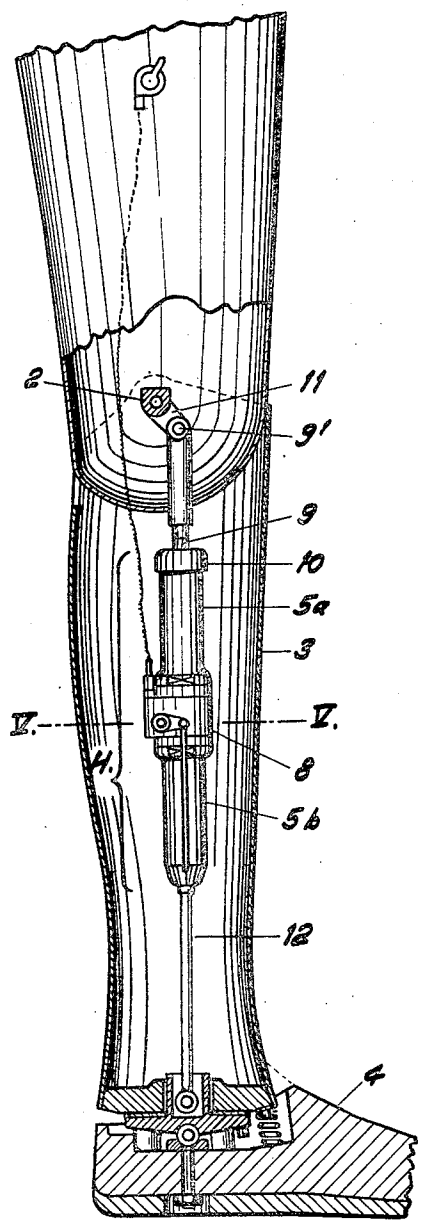


Fig. 1

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March 9, 1954 C. E. REGNELL 2,671,224

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Filed July 19, 1951 5 Sheets-Sheet 2

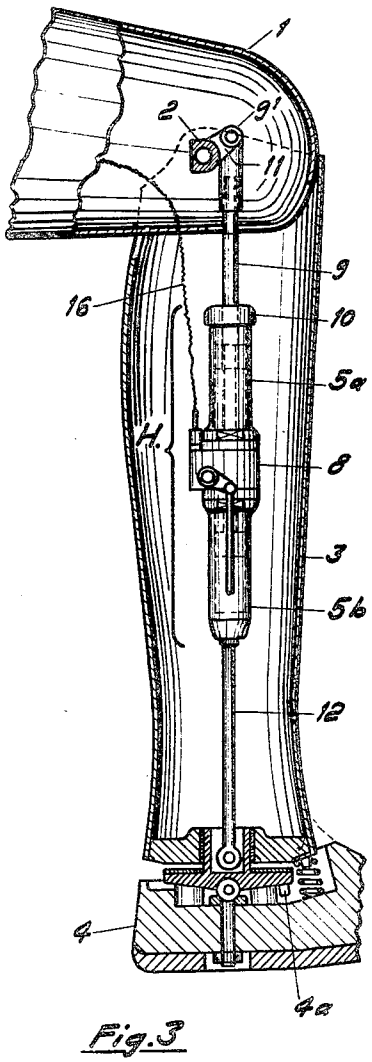


Fig. 3

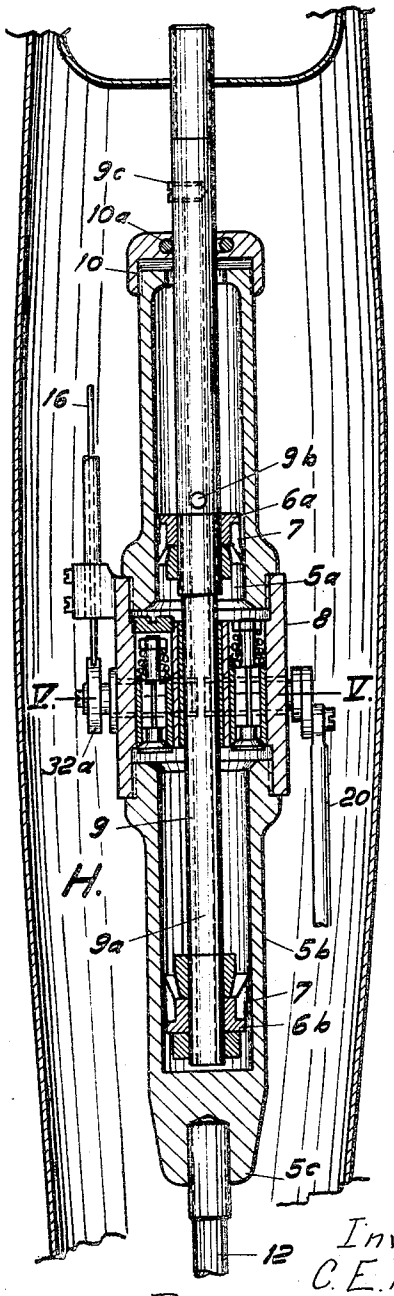


Fig. 4

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March 9, 1954 C. E. REGNELL 2,671,224

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Filed July 19, 1951 5 Sheets-Sheet 3

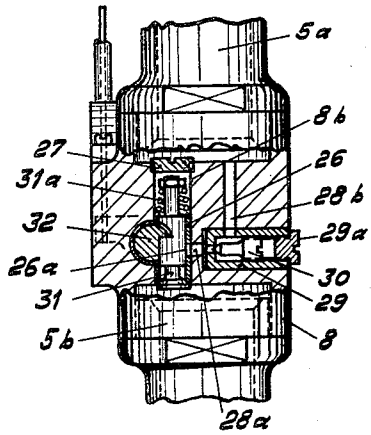


Fig. 6

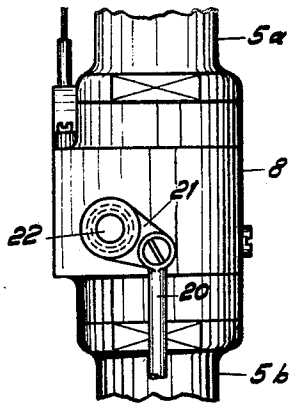


Fig. 7

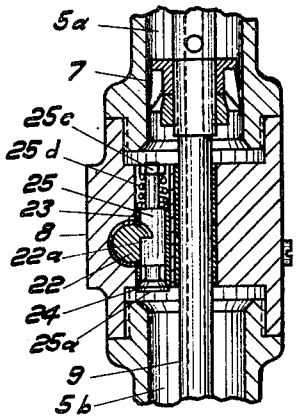


Fig. 8

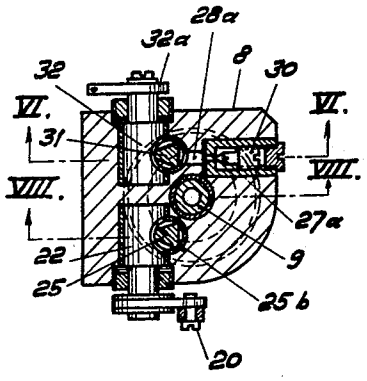


Fig. 5

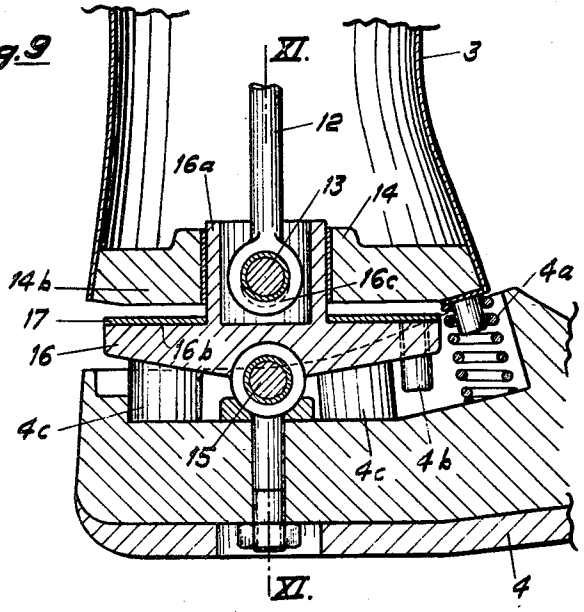
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March 9, 1954 C. E. REGNELL 2,671,224

ARTIFICIAL LEG

Filed July 19, 1951 5 Sheets-Sheet 4

Fig. 9



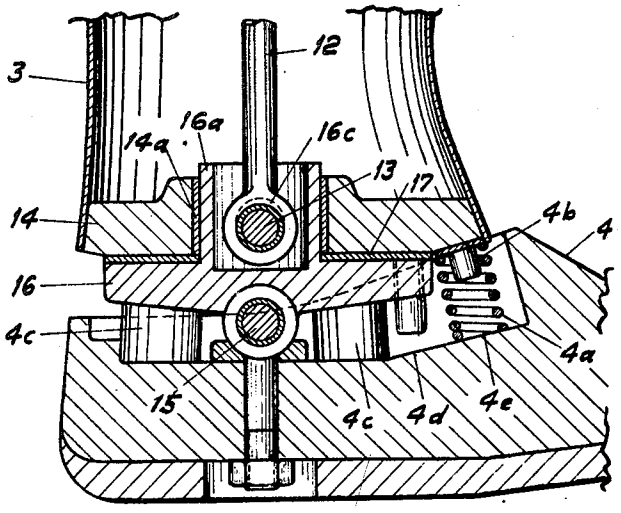


Fig. 10

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March 9, 1954 C. E. REGNELL 2,671,224

ARTIFICIAL LEG

Filed July 19, 1951 5 Sheets-Sheet 5

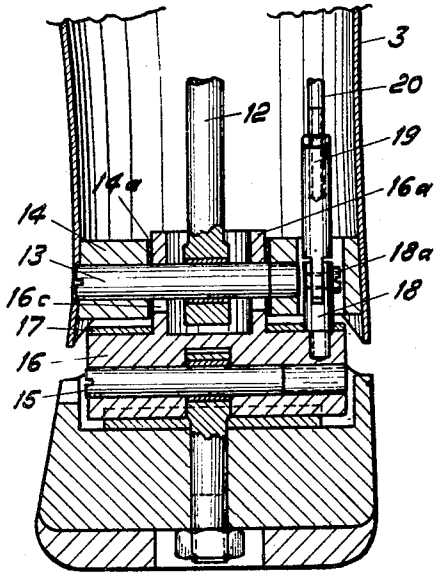


Fig. 11

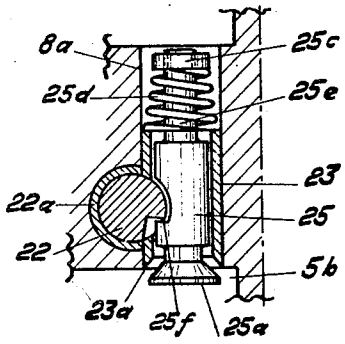


Fig. 12

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UNITED STATES PATENT OFFICE

2,671,224

ARTIFICIAL LEG

Carl E. Regnell, Vaxjo, Sweden

Application July 19, 1951, Serial No. 237,561

Claims priority, application Sweden July 2, 1951

9 Claims. (Cl. 3—1.2)

1

This invention relates to new and useful improvements in artificial leg designs and, more particularly, to an artificial leg of the type comprising an upper or thigh portion for a thigh or femoral stump, a lower limb portion pivotably connected to the thigh portion by means of a knee-joint and a foot portion having a restricted angular movement with respect to the lower limb, wherein the last-mentioned limb portion may be moved freely through an angular range between substantially 90 degrees or even a somewhat acute angle and full extension or alignment of approximately 180 degrees in an unloaded condition of the prosthesis, while a knee-joint locking device therein is rendered effective instantaneously in response to a thrust applied to the foot portion of the artificial leg in order immediately to inhibit any bending motion of the lower limb with respect to the thigh portion irrespective of the angular relationship between the two limb portions at the instant of time in which such locking action occurred.

Roughly, artificial legs may be divided into two main groups or classes dependent upon whether such a prosthesis has to substitute a natural leg which has been amputated above or below the knee. The problems involved when an artificial leg has to replace a natural leg which has been amputated at some point between the knee and the ankle, i. e. a prosthesis for a tibial stump, are rather simple as compared with those arising in connection with artificial legs for thigh or even femoral stumps, that is, for legs which have been amputated above the knee at some point between the latter and the hip. In the first mentioned case the natural knee almost generally will be able to control the angular movement of the artificial knee-joint of the prosthesis and, hence, contribute to the smoothening of the gait of its wearer. However, quite different aspects arise in connection with an artificial leg for a person who has lost one or even both natural legs above the knee at some point more or less remote from the haunch or hip, in which case there is no possibility whatsoever for the amputee to exert any active control as to the relative angular movement of the lower limb with respect to the thigh or upper portion of an artificial leg. Because of the fact, however, that the present invention is concerned solely with the design of an artificial leg of the last-mentioned group, i. e. the substitution for a natural leg which has been amputated above the knee, or in other words for a thigh or femoral stump, only the problems

2

encountered in this particular case will be discussed in the following.

A great variety of artificial leg designs have been proposed in the past and many thereof have been practically tested and actually used. Artificial-limb producers have endeavoured to create artificial legs which not only permit an amputee to similate his gait as closely as possible to that of individuals with two natural and sound legs but also may impose the wearer the courage fully to rely upon his artificial support. It has been found that most essential difference between normal and artificial gait and, accordingly, the most severe disadvantage of heretofore known artificial legs consist in the fact, that an artificial limb drops jerkily at the knee-joint once each step. Although scientific research and experimental tests in combination have resulted in a reduction of this drawback to some extent, there is still a pronounced tendency of such prostheses to buckle under the wearer's weight, since it has not been possible heretofore to create a reliable locking device for the knee-joint which in a fully satisfactory manner eliminates this buckling tendency.

Accordingly, the main object of this invention is to overcome the above-mentioned and other drawbacks and to provide an artificial leg which in an unloaded condition readily permits a pivotable movement of the lower limb with respect to the thigh portion about a knee-joint shaft common thereto, which securely becomes locked in the knee-joint not only in its full extension but also in any possible angular position of the lower limb relative to the upper limb when subjected even to the slightest load or thrust and which simultaneously reduces the aforementioned and highly undesirable jerkiness to a minimum.

These and further objects are realized according to my invention by the provision of an artificial leg comprising an upper thigh portion, a lower limb portion, a knee-joint pivotally and mutually connecting said two limb portions with one another and a foot portion attached to the lower limb with a restricted pivotal movement with respect thereto, wherein a hydraulic knee-joint locking device is mounted in the interior of said lower limb and adapted to be actuated both in response to a thrust affecting said foot portion and the release of such thrust in order to permit an angular movement of the lower limb with respect to the thigh portion in an unloaded condition of said foot portion and invariably and automatically to prevent any bending motion between said two limb portions or buckling of the

prosthesis in a loaded condition thereof and irrespective of the momentary angular position of the lower limb with respect to the thigh portion at the instant of time in which such blocking action is rendered effective.

According to another feature of this invention, means are provided in said hydraulic knee-joint locking device and adapted in the blocked state of the lower limb with respect to the thigh portion as a result of a thrust acting against the foot still to allow an extension of the lower limb relative to the thigh portion intentionally initiated by the amputee.

According to still another feature of my invention, further means are provided in said hydraulic knee-joint locking device in the object, in a loaded condition of the prosthesis and in response to the amputee's entire control to permit a slow and smooth bending of the lower limb with respect to the thigh portion from a substantially full extensional relationship toward the extreme angular state of the prosthesis as determined by the constructive properties of the latter in other respects.

The above exemplified as well as a variety of other features according to my invention are made possible by the provision of a hydraulic knee-joint locking device located in the lower limb of an artificial leg of the aforementioned type and substantially comprising two coaxially related cylinders, viz. an upper and a lower cylinder on either side of an intermediate valve housing, which jointly in combination with a number of valve controlled liquid ducts in said valve housing between said cylinders form a closed liquid container as confined by the lower surface of a piston in said upper cylinder and the top surface of a piston in said lower cylinder. These two pistons are invariably spaced apart on a piston rod common thereto and extended upwards for co-operation with and actuation by lever means on a shaft which constitutes the knee-joint of the artificial leg. The above mentioned closed liquid container intermediate the two pistons is arranged in such a manner that a fluid, e. g. oil, enclosed therein is allowed to flow from the one to the other of said cylinders through a primary valve controlled direct liquid duct between said cylinders in an open state of said valve, that is, in the unloaded condition of the prosthesis, and thereby to permit an axial movement of said pistons in their respective cylinders and, hence, also an angular movement of the lower limb relative to the thigh portion about the common knee-joint shaft and via said lever means, while the transfer of said primary valve to its closed position in response even to the slightest thrust against the foot portion of the prosthesis instantaneously, automatically and effectively inhibits not only any liquid flow through said direct liquid duct from the lower to the upper cylinder but also any upward displacement of the pistons and their common piston rod relative to said cylinders and, consequently any bending motion between the two limb portions of the artificial leg irrespective of the momentary angular relationship between said two limb portions at the instant in which the primary valve was closed. However, despite the fact, that the prosthesis effectively is blocked against bending, the specific design of the primary valve still permits an extension of the lower limb with respect to the thigh portion if so desired for the convenience of the amputee. Moreover, there is provided in said valve housing also an indirect liquid duct between the two cylinders under the control of a secondary valve which is adapted to be manually controlled by the amputee in order to allow a slow, smooth and gradual bending of the lower limb relative to the thigh portion in the loaded state of the prosthesis, i. e. while the primary valve occupies its closed position, so as to as closely as possible similate an amputee's gait to that of a person with two natural legs, as will be more precisely explained in a later part of this specification.

The above enumerated and further features of this invention will be readily understood from the following detailed description of one preferred embodiment thereof when taken in conjunction with the accompanying drawings, in which:

Fig. 1 represents a side elevation, partially in section, of an artificial leg according to the invention and with the lower limb in aligned or full extensional position with respect to the upper or thigh portion;

Fig. 2 shows a vertical cross sectional view as seen from the rear of the embodiment according to Fig. 1;

Fig. 3 illustrates the same embodiment as that shown in Fig. 1, but with an angle of substantially 90 degrees between the two limb portions;

Fig. 4 shows a vertical, sectional view of the hydraulic knee-joint locking device as mounted in the interior of the lower limb portion;

Fig. 5 represents a cross sectional view through the horizontal plane of the valve housing taken substantially along the line V—V of Fig. 4;

Fig. 6 shows a vertical section through the valve housing and the secondary valve facilities, taken substantially along the line VI—VI of Fig. 5;

Fig. 7 illustrates an elevational view of the valve housing as seen from the primary valve side of the latter;

Fig. 8 shows a vertical section through the valve housing and the primary valve in the direct liquid duct between the two cylinders, taken substantially along the line VIII—VIII of Fig. 5;

Fig. 9 represents a vertical sectional view of the foot portion of an artificial leg according to this invention as seen from the side in its state of unload;

Fig. 10 shows the same sectional view of the foot portion, but in a loaded condition due to a thrust acting thereon;

Fig. 11 illustrates a vertical sectional view of the foot portion as seen from its rear and taken substantially along the line XI—XI of Fig. 9, while

Fig. 12 is an explanatory representation of the primary valve and its mode of actuation and operation.

There is shown in Figs. 1 through 3 that the lower limb 3 of the artificial leg is pivotally attached to a thigh or upper limb portion 1 by means of a knee-joint shaft 2 so as to secure a pivotal movement between these two limb portions within an angular range of at least 90 degrees. The lower limb 3 carries at its lowermost end a foot portion 4 with a limited pivotal movability with respect to the lower limb and in a plane which corresponds to that of the lower limb's angular movement relative to the thigh portion, as will be more precisely explained in conjunction with the detailed description of foot assembly.

The aforementioned hydraulic knee-joint locking device, generally designated by the reference symbol H, is mounted and arranged to operate in the interior of the lower limb 3 and between

the thigh portion 1 and the foot portion 4. As clearly shown in Fig. 4 the said device H substantially consists of two coaxially related cylinders, viz. an upper cylinder 5a and a lower cylinder 5b, securely fixed to the oppositely related end surfaces of an intermediary valve housing 8. Each of said cylinders accommodates a piston, i. e. an upper piston 6a and a lower piston 6b, respectively, which pistons are invariably spaced apart on a piston rod 9 common thereto. Each piston is fitted with a packing 7, the purpose of which will be described later. A number of liquid ducts provided in the valve housing 8 and separately governed by an individual control valve constitute in combination with the entire space in the interior of the cylinders 5a and 5b as confined between the lowermost surface of the upper piston 6a and the top face of the lower piston 6b a closed and oil-filled accommodation which forms a first, active liquid communication system of the hydraulic knee-joint locking device and which is adapted on the one hand to be acted upon due to the reciprocal movement of the piston rod 9 and the two pistons 6a and 6b in the cylinders 5a and 5b, respectively, in response to an angular movement of the lower limb 3 relative to the thigh portion 1 in an open state of either of said liquid ducts and on the other hand to fulfil the active task of effectively preventing motion of the pistons and the piston rod in an upward direction and, hence, a bending or buckling tendency of the lower limb portion 3 with respect to the thigh portion 1 in a closed state of said liquid ducts in a manner to be disclosed in a later part of this specification.

It will readily be derived from Fig. 4 that the common piston rod 9 mentioned above carries the lower piston 6b at its lower end and projects upwards through a central bushing in the valve housing 8 and further through the upper piston 6a and an annular sealing packing 10a inserted in a closure lid 10 at the top of the upper cylinder 5a. As shown in Figs. 1, 2 and 3 has this common piston rod 9 its uppermost extremity pivotally attached to a journal 9' at the outer end of a lever 11 which is secured in the thigh portion 1 of the prosthesis and pivotable about the knee-joint shaft 2 of the latter.

The entire hydraulic knee-joint locking device H so far described rests by means of a stem 12 securely fixed at the bottom part 5c of the former pivotally on though invariably spaced apart from a bolt 13 forming part of an attachment 14 which constitutes the bottom termination of the lower limb 3, as will readily be seen in Fig. 11, and which is adapted to co-operate with the foot assembly of the prosthesis as follows. A bolt 15 is fixed in the foot portion 4 in any suitable manner and at right angles to the longitudinal plane thereof so as to enable a limited pivotal movement with respect to the lower limb 3, or more precisely, to an intermediate member 16 which is displaceable solely in the axial direction relative to said attachment, as will now be explained. The attachment 14 is provided with a substantially central, circular opening 14a and with a plane bottom surface 14b in order to serve as a guide for the intermediate member 16, the substantially plane top surface of which integrally or in any other suitable manner carries a cylindrical socket 16a which projects into the circular opening 14a of the attachment 14. The two diametrical holes 16c in the socket 16a, which are necessary for the passage of bolt 13 during the process of assembly and for retaining the socket 16a in the opening

14a, are slightly elongated or oval in the vertical plane as shown in Figs. 9, 10 and 11. Thus, the opening 14a in the attachment 14 not only constitutes a guide for the socket 16a and, hence, for the entire foot assembly in the vertical direction of the artificial leg but also permits a minute axial movement thereof. This axial movement is utilized according to this invention for effecting control of the hydraulic knee-joint locking device H, as will be described hereinafter. It is understood that such movement instantaneously occurs each time the foot portion is subjected to an upward thrust in an upward direction and in the opposite or downward direction in the same moment in which such thrust is released or ceases. In order to achieve a smooth and non-jerky approach of the plane and annular top surface 16b of the intermediate member 16 toward and into abutment with the corresponding plane bottom surface 14b of the attachment 14, either or both of these surfaces will be covered with a resilient and/or soft take-up pad 17 of suitable material. The magnitude of this relative displacement of the intermediate member 16 with respect to the attachment 14 is very small, as will be mentioned and stated later.

In addition to the aforementioned constituents of the foot assembly there are shown further operative members, viz. a compression spring 4a, a stop member 4b and pad means 4c in Figs. 9, 10 and 11. These members serve a special object in connection with the actual control of the operation of the hydraulic knee-joint locking device H, as will be explained in a later part of this description.

It will readily be seen from Fig. 11 that the intermediate member 16 carries a rigidly secured stud 18 which is pivotally connected to a sleeve 19 or the like by means of a journal 18a. A movement transfer rod 20 is with its lowermost end screwingly or in any other suitable manner adjustably in the longitudinal direction fixed in said sleeve, while its uppermost end is linked to a short lever 21 on an actuating member 22 for a primary control valve in the valve housing 8, as is shown in Fig. 7. This rod 20 has for its object to transfer the slight reciprocal movement of the intermediate member 16 relative to the attachment 14 in response to the unloaded or loaded condition of the foot portion 4 and, accordingly, to control the automatic operation of the hydraulic knee-joint locking device H in a manner now to be explained.

It has been mentioned in the ultimate paragraph that the movement transfer rod 20 is linked to a short lever 21 on an actuating member 22 for a primary valve. The combined primary valve assembly in the valve housing 8 is indicated in Fig. 8 and fully disclosed in exaggerated scale in Fig. 12.

A direct liquid duct 8a between the two cylinders 5a and 5b in a plane parallel with the centre line of said cylinders accommodates a valve lining 23, the lower end of which, i. e. the end adjacent the lower cylinder 5b, forms a valve seat 23a. The lining 23 serves as the guide for a primary valve 25 which is arranged to be axially movable in the former and which consists of a valve head 25a matching the valve seat 23a, a valve stem with three symmetrically flattened longitudinal faces which impart this stem a substantially triangular cross sectional area, and an upper extension 25c with a reduced diameter with respect to that of the lining 23. The length of the latter is shorter than that of the direct liq-

uid duct 8a in order to provide the necessary space for a weak compressional spring 25d which is inserted between the upper rim of the lining 23 and a detent 25c terminating the upper end of said extension. It will thus be seen that the compressional spring 25d normally tends to retain the primary valve 25 in its closed position with its head 25a tightly fitting the valve seat 23a.

The primary valve actuating member 22 is journalled in a horizontal bushing 22a in the valve housing 8 perpendicular to the lining 23. The periphery of bushing 22a overlaps to some degree that of the lining 23 in order to provide an open space therebetween and also a co-operative possibility between the actuating member and the primary valve. To this end the actuating member 22 has been provided with projection 22b which in response to a slight clockwise rotation of the former engages a corresponding notch 25f in that of the three longitudinal fins of the primary valve stem which opposes said projection. Suitable means (not shown) prevent a radial movement of the primary valve 25 in its lining 23. It should be particularly stressed in this connection that the actuating member 22 only compulsorily governs the primary valve 25 to its open position due to a clockwise rotation of the former and in response to an unloaded condition of the prosthesis, while said member 22 during and after its rotation to the extreme counterclockwise position in response to a thrust acting against the foot portion of the artificial leg exerts no influence whatsoever upon the primary valve, since its projection 22b under these circumstances has been fully withdrawn from the path of the notch 25f. Thus, immediately after the actuating member 22 has been set to its extreme counterclockwise position, the compressional spring 25d transfers the primary valve 25 to its closed position, and this means that no liquid can flow from the lower to the upper cylinder, that an upward movement of piston 6b in cylinder 5b is effectively prevented and that no bending or buckling of the lower limb 3 is possible with respect to the thigh portion 1. However, if the amputee so desires, an extensional movement between the two limb portions is permissible, since in this case the excessive pressure of the liquid in the cylinder space above the valve housing and the direct channel or liquid duct 8a due to the intentional downward movement of the piston rod and pistons will cause the primary valve to open against the compressional tension of the weak spring 25, so that liquid may flow along the space between the valve lining 23 and the flattened faces of the valve stem and through this open valve to the cylinder space below said valve housing. As soon as a pressure equilibrium has been re-established on both sides of said housing, the spring 25d immediately causes the primary valve to close. It will readily be understood that the primary valve by virtue of its special design is rendered capable of acting as a single motion poppet or back valve under the last-mentioned conditions. In summary, a state of unload or zero load of the prosthesis invariably results in a compulsory opening of the primary valve and that the control of the latter becomes automatically transferred to the weak spring 25d immediately after the compulsory actuating impulse or cause has been rendered ineffective. This means in general that the primary valve will be opened compulsorily exactly in the moment in which the foot portion is allowed to or else leaves the ground.

Under certain circumstances, however, and particularly during normal walk, it has been found very desirable for the convenience of the amputee to secure a slightly premature opening of the primary valve, i. e. a short moment before the foot portion of the artificial leg actually leaves the ground, and to cause this to occur within an interval of time between the instant in which the body's weight substantially has been taken up by the natural or the other artificial leg and the moment in which the foot portion actually is removed from or else leaves the ground, since such possibility considerably would contribute toward a more natural artificial gait. This facility is accomplished by the combined action of the compressional helical spring 4a and the stop member 4b mentioned in the foregoing and shown in Figs. 9, 10 and 11. In order to disclose the manner in which this rather essential feature of my invention is attained solely by the use of these very simple means, it will be necessary to make a rough analysis of one complete step made by the amputee, who for the sake of simplicity is assumed to wear only one artificial leg, although the same conditions likewise apply to two prostheses. It will further be assumed that this particular step commences and terminates with the two feet in a side by side position on the ground. Due to the fact, that artificial legs are like thumb prints, that is, that no two are exactly alike, the following analysis as well as the operation of the artificial foot in this particular respect will be referred to an average case. It is obvious that such a complete step is made up of two partial components, viz. a first "natural" stage followed by a second "artificial" stage, the latter in its turn being composed of a number of different phases.

Thus, in the course of the first natural stage the amputee lifts his sound leg and moves it forward in ordinary manner and with the whole of the body's weight resting on the prosthesis, in which stage the lower limb 3 thereof is caused to follow this movement and, hence, to be tilted forward from its substantially vertical position as represented in Fig. 1 to a somewhat inclined position in the direction of gait. During this initial phase there is a corresponding pivotal movement of the lower limb 3 with respect to the foot portion 4, as will be evident from Fig. 10, about the bolt 15 which results in a compression of the helical spring 4a positioned between the attachment 14 and a corresponding surface 4e on the foot portion 4 which during this initial stage or phase permanently rests with its entire lowermost supporting surface on the ground as explained above. This pivotal motion continues under the control of the spring 4a until the stop member 4b, which projects downward from the frontal part of the intermediate member 16, abuts against a corresponding bearing point 4d at the upper face of the foot portion 4. This happens in the same moment in which the natural foot touches the ground and initiates a second phase of the artificial leg's cycle of gait movements. Simultaneously with the resulting partial release of the thrust on the prosthesis, the foot portion 4 is caused to act as a two-armed lever with its one arm behind and the other arm in front of its fulcrum formed at the bearing point 4d and bearing against the stop member 4b, so that the hinder or heel part of the artificial foot is raised gradually from the ground in response to the pulling force created by the complex movement of the amputee's body through

the lower limb 3, while the toe piece articulately joined with the foot portion still rests on the ground. In other words, the point of angular motion between the foot portion and the lower limb has, in effect, temporarily been dislodged from the normal axis 15 to the bearing point or fulcrum 4d, in which moment the above mentioned cycle enters its third phase in that the intermediate member 16 forcibly is withdrawn from the attachment 14 on account of the aforementioned lever action and hence, the primary valve is opened a short interval of time prior to the moment in which the foot portion is removable from the ground, as stated above. In the course of the fourth and last cycle phase, the amputee lifts the entire prosthesis, throws the lower limb forward to full extension with respect to the thigh portion and places the foot portion on the ground juxtaposed the natural foot, in which moment the prosthesis immediately is blocked against bending or buckling and a new step may commence. The instant of time in which the third phase of the gait cycle takes place and, accordingly, the primary valve is caused to open, may be adjusted arbitrarily either by the proper choice of the compressional tension of the spring 4a or even by making this spring adjustable. Rubber pads 4c on either side of the bolt 15 in the longitudinal plane of the foot portion 4 contribute to a smooth movement between the foot portion 4 and the intermediate member 16 both about the normal axis 15 and the temporary fulcrum 4d.

The above described feature according to my invention may advantageously be utilized by the amputee in connection with a change from the upright to a sitting attitude. It should be borne in mind that the knee-joint of the prosthesis is locked in the amputee's first-mentioned attitude due to the weight resting thereon. In this upright attitude and with his back turned toward a chair, a bench or the like, he may urge the toe piece of the foot portion against some suitable stationary matter and thereby intentionally set the former toward its extreme angular relation with respect to the lower limb portion so as to give rise to the aforementioned displacement of the mutual pivot between these two portions from the normal axis 15 to the temporary fulcrum 4d, in which case the primary valve will be opened under the amputee's voluntary control, so that the lower limb portion is allowed to buckle toward the extreme position with respect to the thigh portion when his body approaches the chair by the aid of the natural leg.

The operative action of the hydraulic knee-joint locking device so far described is purely automatic in response to an unloaded or loaded condition of the artificial leg. It may, however, be rather desirable to provide means in said device so as to permit also a manual control thereof, particularly in the automatically locked state of the artificial leg's knee-joint due to a condition of load. This is achieved according to the present invention by incorporating in the valve housing 8 of the device H also a secondary valve which is adapted to be controlled manually by the amputee by means of some suitable actuating member at or near the upper, outer part of the thigh portion 1, as indicated by reference numeral 1a in Fig. 1 by way of an example. This member 1a readily accessible to the amputee's hand through his or her clothes is arranged to set the secondary valve to its open and closed position, respectively, via suitable mechanical means, such as a Bowden cable 1b or the like. The design of the entire secondary valve arrangement is, however, so similar to that of the primary valve facilities, that a detailed description thereof is deemed unnecessary. The main difference between these two valves resides in the fact, that secondary valve is compulsorily controlled both to its open and to its closed state in response to the amputee's manipulation of the aforementioned actuating member and that it is adapted to control an indirect liquid duct between the two cylinders provided in the valve housing and having a sectional area which is considerably smaller than that of the primary valve controlled direct liquid duct mentioned in the foregoing.

Now referring to Fig. 6, there is shown a second quasi-direct channel 8b between the two cylinders 5a and 5b, which, however, is sealingly closed at its upper end, as indicated at 27. This channel 8b is fitted with a valve lining 26 for the secondary valve 31, whereby the lower end of said lining forms a valve seat for the downwards turned head of the secondary valve in the same manner as has previously been described in connection with the primary valve. It will be observed that both the lining 26 and the secondary valve 31 are slightly shorter than the primary valve 25 and its lining 23 by obvious constructional reasons. The secondary valve 26 is adapted to be set to its open and closed position by its individual actuating member 32 having a lever 32a fixed at its outer end for co-operation with the actuating member 1a at the upper, outer part of the thigh portion 1, as stated above. The secondary valve 31, the design and operation of which are analogous to that of the primary valve, is arranged axially movable in its lining 26 under the control of a compressional spring 31a, as explained with reference to the primary valve.

The indirect liquid duct between the two cylinders 5a and 5b under the control of the secondary valve 31 is made up of two perpendicularly related branches 28a and 28b, the former, 28a, extending horizontally between an opening 26a in the lining 26 and the bottom part of a valve bushing 29 secured in a corresponding opening in the valve housing 8, while the last-mentioned branch 28b extends between the upper cylinder 5a and an opening at the periphery of said bushing. Apart from the fact, that the sectional area of the indirect liquid duct, and particularly that of its horizontal branch 28a, per se is considerably smaller than that of the primary valve, an adjustable needle valve 30 is arranged in the valve bushing 29 so as to provide an accurate adjustability of the operative cross sectional area of this liquid duct, as will be explained later. The outer end of the valve bushing 29 is closed by a removable protective lid 30.

It has been stated in the foregoing that the secondary valve 31 is adapted to be operated manually by the amputee and particularly in the automatically locked state of the artificial leg's knee-joint. This applies specifically to the case of the amputee's walk downstairs. After having placed the whole of the body's weight upon the artificial leg and in continuation of a step downstairs with the natural or even a second artificial leg removed from the initial step of a stair, the amputee may cause the opening of the secondary valve which now permits a restricted liquid flow from the lower to the upper cylinder under the action of the pistons and, hence, a slow and gradual bending of the

prosthesis toward its extreme position in this sense.

It will be readily appreciated that this bending of the prosthesis under load takes place under the amputee's full control and that he is in a position to stop and recommence this motion at any time by a corresponding manipulation of the actuating member which in its turn controls the secondary valve. It will also be obvious to those skilled in the art that the considerably restricted cross sectional area of the secondary valve controlled indirect liquid duct as compared with that controlled by the primary valve forms an essential feature of this invention with regard to two different considerations. In the first instance it secures a slow, gradual and more natural bending motion of the lower limb with respect to the thigh portion of the prosthesis, while there is a second reason for this facility, viz. a matter of safety. If the sectional area of the secondary valve controlled liquid duct were not considerably smaller than that of the direct and primary valve controlled duct and if the amputee, an obstacle or some other object inadvertently would set the actuating member at the upper part of the thigh portion to its operative position, there would be no slow bending, but a sudden collapse of the prosthesis toward its extreme position in the bending sense. This severe risk is fully obviated in an artificial leg according to this invention. The needle valve forming part of the indirect liquid duct and readily accessible to a screw-driver after removal of the protective lid forms a convenient means for adjusting the sectional area of this duct and, accordingly, the rate of the bending motion to the individual requirements of the amputee with special regard to his weight and other factors of importance.

It has been mentioned in the previous description of the hydraulic knee-joint locking device H with particular reference to Fig. 4 that the entire space inside the cylinders 5*a* and 5*b* and within the liquid ducts between the two pistons 6*a* and 6*b* forms a first, active liquid communication system, the object of which has been fully explained in the foregoing. In addition to this active system and in order to reduce the friction of the pistons and/or their packings in their respective cylinders, there has been provided also a second, inactive or passive liquid communication system which comprises the cylinder spaces above the upper piston 6*a* and below the lower piston 6*b* as well as a liquid channel 9*a* in the center of the piston rod 9. It will thus be seen with further reference to Fig. 4 that the liquid present in the cylinder 5*a* above piston 6*a* is caused to flow out through an opening 9*b* and further through the channel 9 and its lowermost open end into the cylinder space below the piston 6*b* in response to an upward movement of the piston rod 9 due to a bending of the prosthesis and to flow in the reversed direction on account of a downward movement of said piston rod as a result of a relative movement of the lower limb with respect to the thigh portion of the prosthesis toward its full extension. The fluid, preferably oil, enclosed in this second, passive communication system contributes materially to a substantially frictionless reciprocal movement of the pistons in their cylinders and to a perfect tightening of the piston packings 7 with respect to the liquid enclosed in the first, active system. Moreover, the passive system is capable of immediately compensating even the slightest leakage of fluid which may occur in the active system, since the piston packings 7 are arranged to pass fluid along the cylinder walls in the direction from the passive to the active system but to prevent any leakage in the opposite direction, that is, from the active to the passive liquid system. The liquid channel 9*a* in the piston rod 9 has accordingly been further extended upwards from the opening 9*b* to a point well above the closure lid 10 where there is provided a normally closed opening 9*c* to said channel 9*a* for liquid or oil replenishment in case of need.

Before the following brief summary of the mode of operation of the heretofore described artificial leg and its hydraulic knee-joint locking device, it should be pointed out with particular stress that the knee-joint shaft is located in the center line of gravity in the prosthesis according to this invention; an essential feature which has not yet been attainable in connection with heretofore known artificial legs of this special type due to the lack of a reliable knee-joint locking device up to the present. The provision of this knee-joint shaft in the center line of gravity eliminates the jerky gait so objectionable in conjunction with previous prosthesis designs which due to the aforementioned grounds inevitably have their knee-joint shaft located at some point behind the said center line of gravity.

In the condition of load of the artificial leg as illustrated in Figs. 1 and 2 with the foot portion resting on the ground, a minute movement of the intermediate member has established an abutting relation between this member 16 and the attachment 14 and likewise effected a displacement of the rod 20 to its uppermost position with the result that the actuating member 22 has been removed from the path of the primary valve 25, so that this valve is closed under the compressional control of its spring 25*b*, in which case no liquid can flow from the lower cylinder 5*b* to the upper cylinder 5*a* and, accordingly, a bending or buckling of the lower limb 3 with respect to the thigh portion 1 is fully impossible.

As soon as the amputee has transferred the whole of the body's weight from the artificial to the natural or even to a second artificial leg at the end of the "natural" stage of a step or stride, the intermediate member 16 immediately re-assumes its remote relation with respect to the attachment 14 with a resulting downward displacement of the rod 20 and, consequently, a compulsory opening of the primary valve, as has been stated in the foregoing. The amputee may now lift this artificial leg and throw its lower limb forward to full extension and so place the foot portion thereof on the ground, thereby completing the "artificial" stage of the step or stride, in which moment its knee-joint becomes locked and a new cycle of gait may commence.

At the moment of initiating a step downstairs, the knee-joint will be locked in the normal manner due to the loaded state of the prosthesis. The amputee may thus lift and stretch his natural leg for a step downstairs and simultaneously set the actuating member at the upper, outer part of the thigh portion to its operative position so as to open the secondary valve, which now slowly permits liquid to flow therethrough from the lower to the upper cylinder in response to the pulling force now acting on the piston rod 9 and, particularly, the lower piston 6*b*. This results in a slow and gradual bending of the artificial leg about its knee-joint shaft under the amputee's full control and very similar to a step

downstairs by an individual with two natural and sound legs. Although this bending motion may be stopped at any time by setting the last-mentioned actuating member to its stop or inoperative position, it normally continues until the natural foot comes to rest on the next step of the stair, in which moment the artificial leg is released, so that the amputee may withdraw its foot portion from the initial step of the stair, throw its lower limb substantially into alignment with the thigh portion and then place its foot portion on the next lower step of the stair on which the natural foot rests, whereupon the next step downstairs may begin.

It will readily be understood that the operation of the hydraulic knee-joint locking device above described with particular reference to a walk downstairs also applies to a walk up or down a steep hill or the like.

It has been pointed out in conjunction with the previous description of the artificial foot with reference to Figs. 9, 10 and 11 that the relative movement of the intermediate member **16** with respect to the attachment **14** and, hence, that of the movement transfer rod **20** with respect to the stem **12** and the locking device H is very minute. Careful experimental tests with various artificial leg embodiments according to this invention have proven that this movement in effect may be reduced to approximately .02 of an inch while maintaining an absolutely safe control of the primary valve's action in response to a condition of load and unload, respectively, of the artificial leg. This minimal movement along the vertical plane, which is imperceptible both to the amputee and to any observer, eliminates in conjunction with the feature that the knee-joint shaft is located in the artificial leg's center line of gravity the jerkiness of "artificial" gait under which the heretofore known prosthesis of the type under consideration invariably have suffered. The change from a locked to an unlocked state of the artificial leg's knee-joint in response to the action of the hydraulic device H occurs in the same smooth manner when the wearer removes the foot portion from the ground in order to initiate a new step.

Finally, it should be mentioned that the compressional helical spring exerting control of the primary valve in its closed condition and signified as the weak spring in the corresponding part of this specification is made up of a wire material of a comparatively small diameter of .02 of an inch, for example, which has been found the most suitable size for securing a fully satisfactory and reliable operation of this very important valve.

Although my invention has been described in the foregoing specification with reference only to a single embodiment thereof as exemplified in the accompanying drawings merely by means of some examples, it will be understood that the invention by no means is restricted to this preferred embodiment, since a multitude of various modifications may be made by those skilled in the art without departing from the scope of this invention as manifested and defined in the appended claims.

What is claimed is:

1. Leg prosthesis for a femoral stump, comprising an upper thigh part, a lower limb part, a knee joint axis pivotally connecting said limb parts, a prosthesis foot articulated to the lower limb part, knee joint axis hydraulic blocking means inside the lower limb part including a central valve casing, two cylinders attached on two sides of said central valve casing in coaxial relation to each other and in communication therewith, a piston in each said cylinder, a common piston rod interconnecting said pistons, a lever connected to the knee joint axis, said common piston rod being pivotally connected to said lever, a fluid channel between said two cylinders, a primary valve interposed in said channel for control of fluid flow therein, the space between the two pistons and the channel being filled completely with fluid, an activating organ for the primary valve, an axially slidable intermediate member between said foot and said lower limb part, a joint system interconnecting said activating organ and said intermediate member, a spring biassing said primary valve to closed position, the primary valve automatically closing under the influence of said spring upon a load effecting said prosthesis foot thereby moving said intermediate member and actuating said joint system to actuate said activating organ to prevent fluid passage from the lower cylinder to the upper cylinder through said channel and preventing bending of the lower limb part relative to the upper thigh part regardless of the angle assumed by said limb parts at the moment the load becomes effective, said joint system actuating said primary valve to open position on removal of the load to assure free passage for fluid from one to the other cylinder through said channel for unhindered swinging movement of the lower limb part with respect to the upper thigh part about the knee joint axis.

2. Leg prosthesis as claimed in claim 1, a head on said primary valve directed towards the lower cylinder, a spindle on said valve having triangular cross section and a reduced upward projecting cylindrical extension, a valve lining axially guiding said valve inserted in the channel between said two cylinders, a valve seat for said valve head at the lower end of said lining, said spring being a helical spring, a screw nut on said cylindrical extension, said spring being inserted between said screw nut and the upper rim of the valve lining, said valve in closed position preventing passage of fluid from the lower to the upper cylinder and a bending of the prosthesis, stretching movement of said lower limb part with respect to the upper causing an excess fluid pressure in the upper cylinder and a downward movement of said piston rod and said pistons and opening said primary valve against the pressure of said spring so that desired stretching movement can be executed without hindrance, the primary valve acting as a return valve during stretching.

3. Leg prosthesis as claimed in claim 1, a valve lifter mounted in said valve casing and cutting through the wall of said valve lining at a right angle thereto, a cam on said lifter, said valve spindle having a recess in the side thereof, said cam being engageable with said recess, movement of the intermediate member acting through said joint system on release of a load against the foot to rotate said lifter in clock-wise direction and forcing said cam against a face of said recess in said spindle to move the valve forcibly into open position, a load on said foot rotating the valve lifter in counterclock-wise direction to effect the immediate removal of the cam from the path of the face through the intermediate member and through the said joint system, whereby control over said primary valve is directly and automatically transferred to said spring, through which a

fluid flow in the direction from the lower to the upper cylinder and with it a bending of the prosthesis is effectively prevented, but permitting fluid flow in the opposite direction and a stretching movement of the lower limb part towards the upper thigh part.

4. Leg prosthesis as claimed in claim 3, including a second channel in said valve casing between said two cylinders formed of two branch channels, a valve case with a substantially smaller cross section than that of the first mentioned channel, a secondary valve for control of said second channel similar to said primary valve, a valve lining in said valve case, said secondary valve being axially movable in said valve lining, a bore between said two cylinders closed at the upper end and containing said valve lining, a valve lifter and a lever arm secured thereto for actuating said secondary valve, a regulating member attached at the upper, outer end of the upper thigh part actuatable manually and operably connected with the outer end of said lever arm, said secondary valve upon opening permitting a small flow of fluid in said valve casing for a slow swinging movement of the lower limb part from a stretched position in the direction of an acute angle in relation to the upper thigh part as the result of a load acting against the prosthesis foot even though said primary valve is in closed position.

5. Leg prosthesis as claimed in claim 4, an adjustable needle valve in the valve case forming a part of said second channel for fine adjustment of the cross-section area of said second channel and of a horizontal one of said branch channels to adjustably regulate the speed of the slow swinging movement, a sealing member on the outer end of said valve case, the second of said branch channels connecting the upper cylinder with said valve case at right angles to the horizontal one of said branch channels.

6. Leg prosthesis as claimed in claim 1, said common piston rod having a bore therethrough, a lid on the upper end of said upper cylinder forming a cylinder chamber between the upper piston and said lid, a second passive fluid communication system formed by said cylinder chamber and a lower chamber between the lower piston and the floor of the lower cylinder and said central bore in said piston rod opening into said lower chamber, said second passive fluid communication system being filled with fluid and assuring free fluid passage from one to the other of said cylinder chambers at the side of the pistons most distant from the valve casing through the bore under the influence of up and down movement of said piston rod as the result of a rotating movement between the lower limb and the upper thigh part about the knee point axis, whereby fluid enclosed in said second passive fluid system exerts an effective sealing function against the fluid enclosed in the active fluid communicating system, with simultaneous reduction of friction between the pistons and the cylinder walls.

7. Leg prosthesis as claimed in claim 6, single directional fluid flow packing seals on each said piston, effectively fluid sealing in the direction away from the valve casing but permitting fluid passage therebetween and the cylinder walls in a direction toward the valve casing to compensate a fluid deficiency arising in the active system by fluid from the second passive system.

8. Leg prosthesis as claimed in claim 7, wherein the bore in the common piston rod is prolonged beyond the point of connection with the cylinder space above the upper piston upwards to a point above said sealing lid closing off the upper cylinder, a filling opening entering into said prolonged bore, said prolonged bore constituting means to supply fluid supplementing the second passive fluid system upon demand through said filling opening.

9. Leg prosthesis as claimed in claim 1, a plate fastened on the lower end of said lower limb part, a stem, a bolt movably mounting said stem on said plate, said hydraulic blocking means being connected to and supported by said stem and preventing axial movement between the hydraulic blocking device and the plate part, a circular bore in said plate, a cylindrical socket formed in one piece with the upward turned plate surface of said intermediate member, said circular bore constituting guide means for said socket, two diametrically opposite openings in said socket slightly oval in the axial direction, said foot being connected to said intermediate part, a shaft inserted in said oval recesses securing said stem and said intermediate part and permitting a strongly limited axial back and forth movement of the intermediate member and of the prosthesis foot in dependence on a load becoming effective or ineffective against the same in relation to said plate and to the hydraulic blocking device and excluding all other movements, whereby a movement of said intermediate member in the direction towards said plate effects the closing of the primary valve with the exclusive control of said spring and a movement of the intermediate member in the direction away from the plate forcing open said valve through said valve lifter and through said joint system.

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