Aug. 9, 1949. J. H. F. STEWART 2,478,721

ARTIFICIAL LIMB

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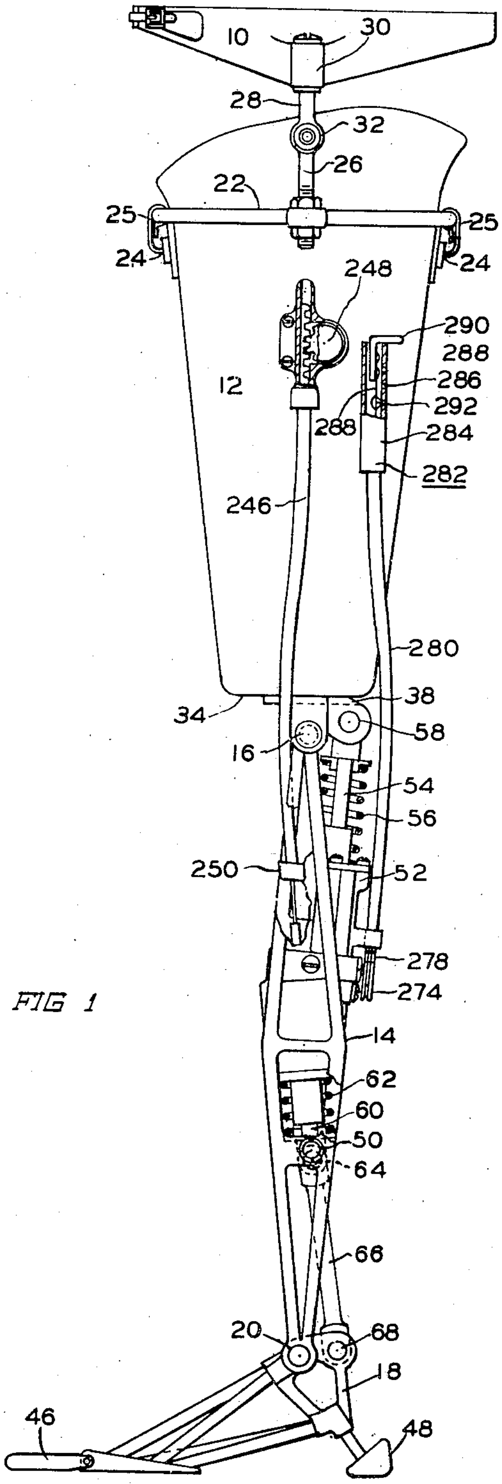
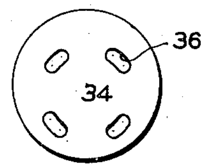


FIG 1

FIG 3



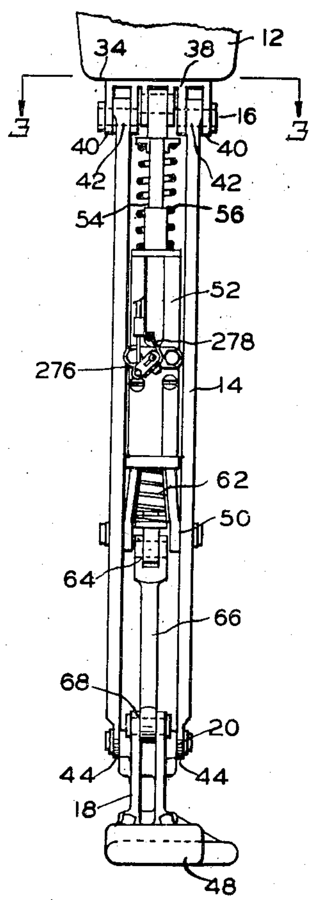


FIG 2

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ARTIFICIAL LIMB

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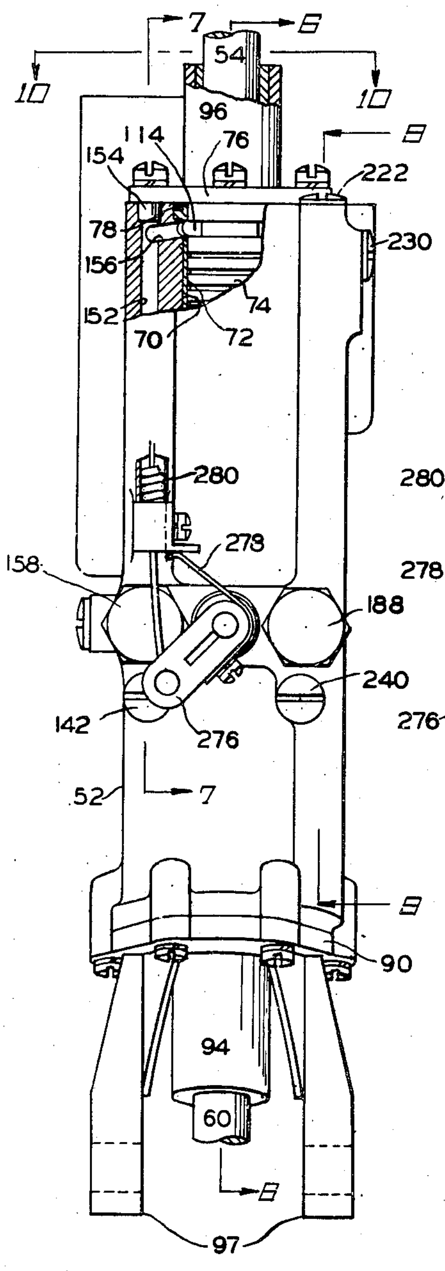

FIG 4

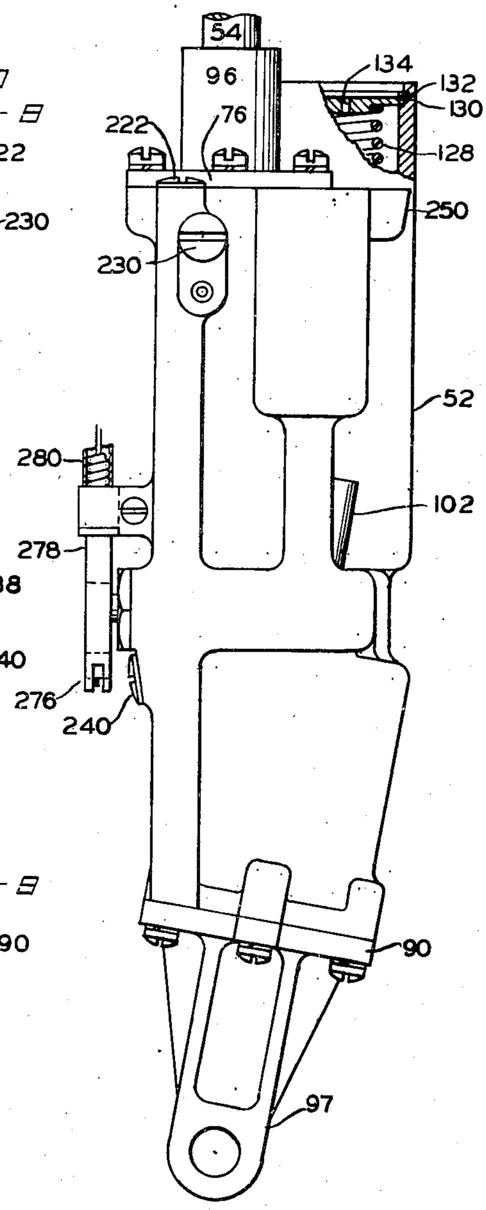

FIG 5

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ARTIFICIAL LIMB

Filed Aug. 10, 1946 6 Sheets-Sheet 3

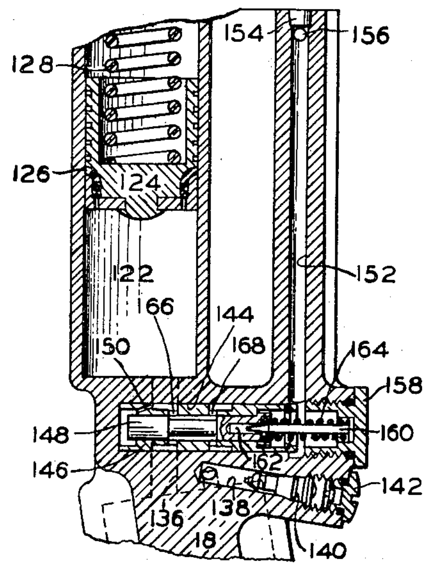

FIG 7

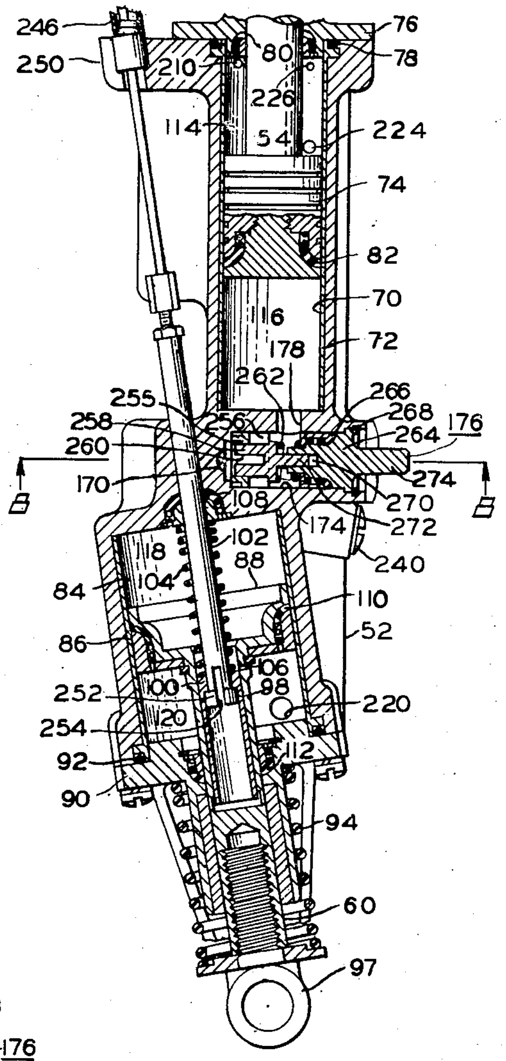

FIG 6

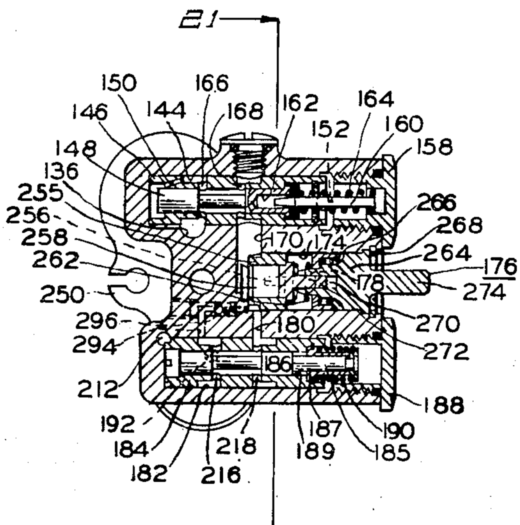

FIG 8

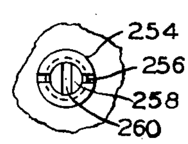

FIG 21

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Filed Aug. 10, 1946 6 Sheets-Sheet 4

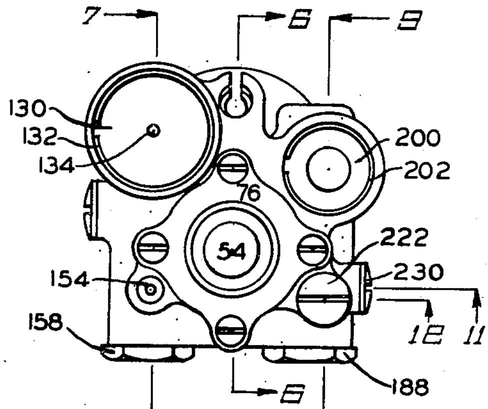


FIG 10

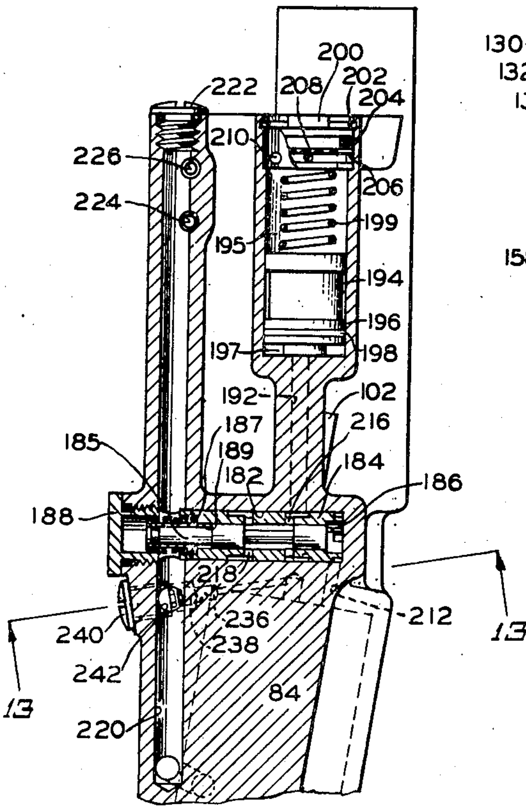


FIG 8

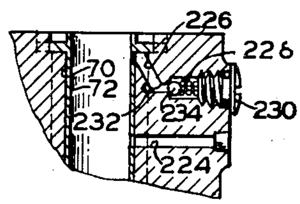
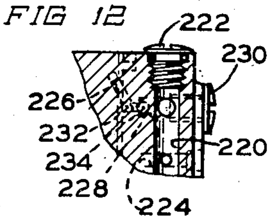


FIG 11

FIG 12



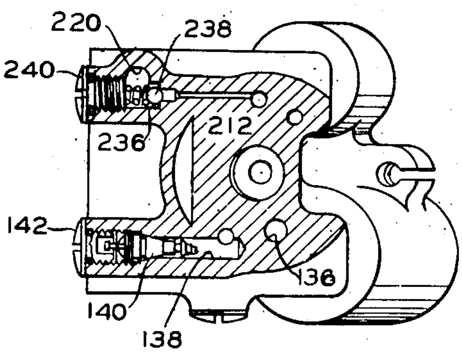


FIG 13

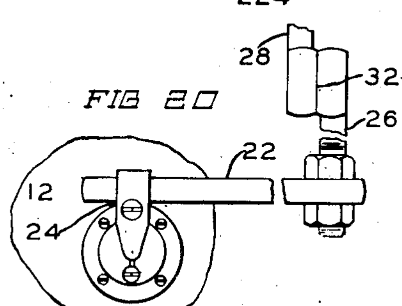


FIG 20

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ARTIFICIAL LIMB

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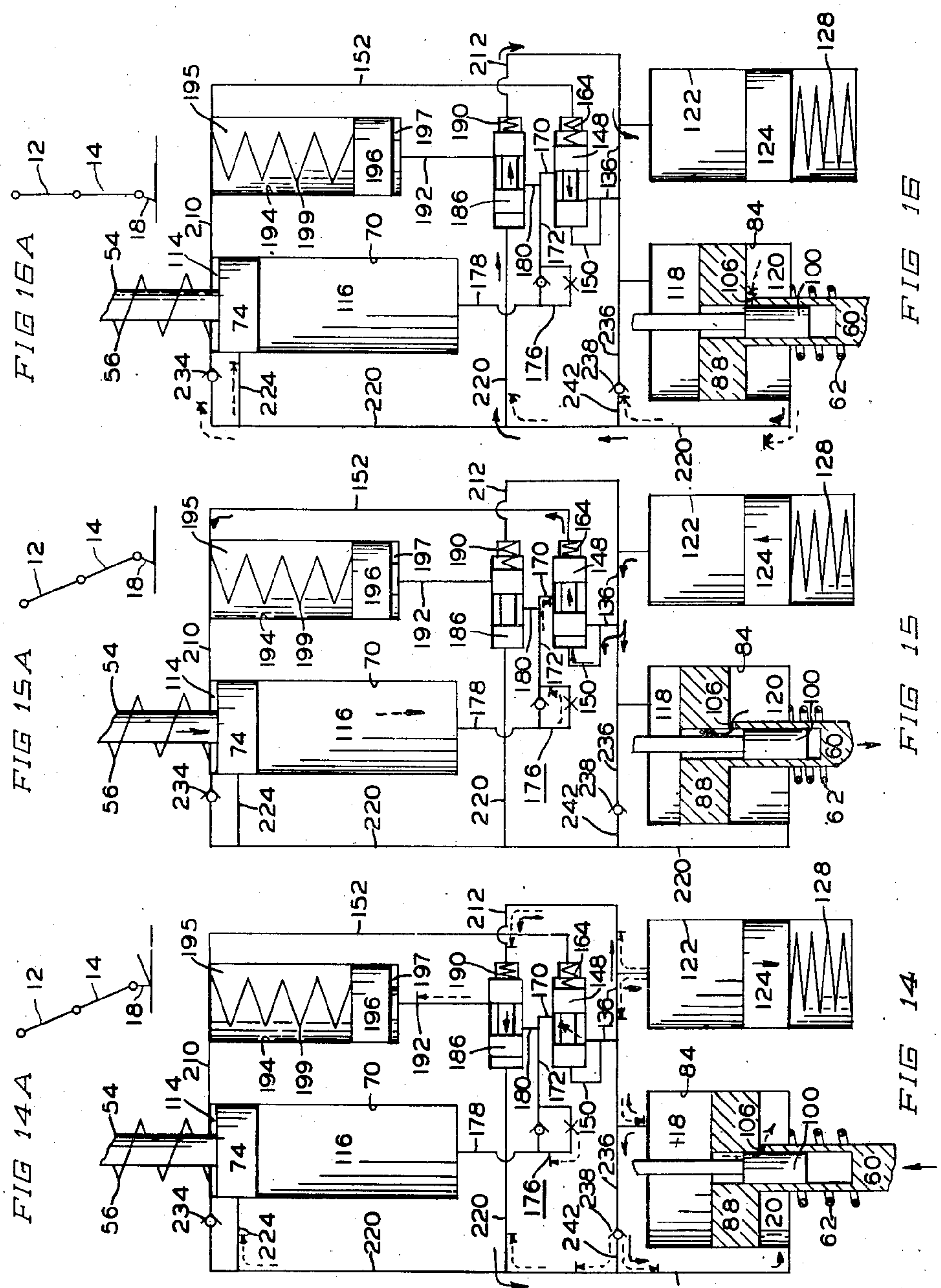

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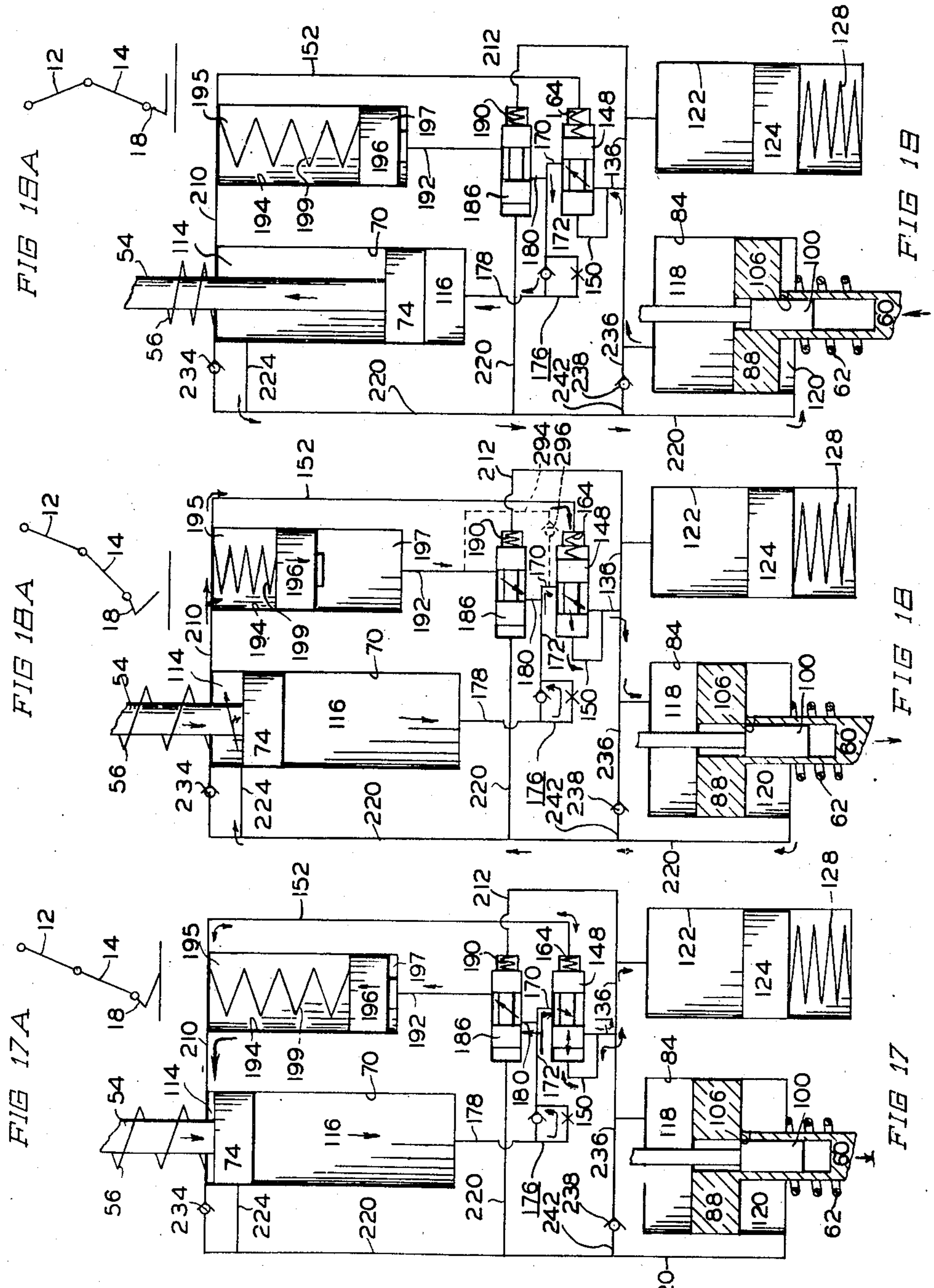
ARTIFICIAL LIMB

Filed Aug. 10, 1946 6 Sheets-Sheet 6



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Patented Aug. 9, 1949 2,478,721

UNITED STATES PATENT OFFICE

2,478,721

ARTIFICIAL LIMB

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Application August 10, 1946, Serial No. 689,724

39 Claims. (Cl. 3—2)

1

This invention relates to artificial body members and more particularly to an artificial leg.

It is an object of the present invention to provide a novel artificial leg construction with self-animation of both knee and ankle joints in a manner which closely simulates the animation of a natural leg.

In its preferred form, the present invention embodies hydraulic means associated with the knee and with the ankle joints and so interconnected and controlled as to coordinate the bending of the ankle with the bending of the knee at proper times during normal walking. At the same time, the same hydraulic elements are preferably utilized to supervise each other in such a way as to add greatly to the safety of the prosthesis under abnormal or difficult walking conditions.

It is an object of the present invention, therefore, to provide a device of this character with improved hydraulic actuation and control means for the joints which enables a user to walk naturally, with greater safety and which will, furthermore, be capable of use for running, dancing and other activities where prior prostheses cannot be readily used, including even the use by double amputees without canes or crutches.

Further objects and advantages of the present invention will be apparent from the following description, reference being had to the accompanying drawings wherein a preferred form of the present invention is clearly shown.

In the drawings:

Figure 1 is a side view of an artificial leg incorporating a preferred form of the present invention.

Figure 2 is a fragmentary rear view of the leg shown in Figure 1.

Figure 3 is a top view of the bottom portion of the thigh socket.

Figure 4 is a rear view of the hydraulic actuation and control unit.

Figure 5 is a side view of the unit of Figure 4.

Figure 6 is a vertical sectional view on line 6—6 of Figure 4.

Figure 7 is a vertical cross section on line 7—7 of Figures 4 and 10.

Figure 8 is a horizontal cross section on line 8—8 of Figure 6.

Figure 9 is a vertical cross section on line 9—9 of Figures 4 and 10.

Figure 10 is a top view of the unit shown in Figure 4.

Figure 11 is a fragmentary vertical cross section on line 11—11 of Figure 10.

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Figure 12 is a fragmentary vertical cross section on line 12—12 of Figure 10.

Figure 13 is a horizontal cross sectional view on line 13—13 of Figure 9.

Figures 14 and 14*a* through 19 and 19*a* are diagrammatic views showing conditions in the hydraulic circuit at various stages in a normal walking cycle.

Figure 20 is a fragmentary view of the upper portion of the leg.

Figure 21 is a vertical cross section on line 21—21 of Figure 8.

Referring now to Figures 1, 2 and 3, the embodiment there illustrated comprises a pelvic band 10 universally jointed to a thigh member 12. This in turn is pivoted to a shin member 14 at the knee joint 16, and a foot member 18 is pivoted to the shin by an ankle joint 20. Articulation of the pelvic band 10 to the thigh socket 12 is preferably obtained by a semicircular yoke 22 pivoted to the thigh on a fore and aft horizontal axis at 24 and carrying an eye bolt 26 adjustably but rigidly secured thereto. Another eyebolt 28 is pivotally secured in a boss 30 attached to the band 10 and is pivoted on a horizontal lateral axis at 32 to the eye bolt 26. The yoke 22 is adjustable laterally in and out by means of a frictional clamp 25 and may also be adjusted circumferentially to some extent so as to locate the pivotal axis 32 as closely as possible to the extension of the natural hip pivot.

The thigh member 12 may be formed of any suitable material so as to provide a socket for the amputated stump of the user and is provided with a flat bottom wall 34 having a plurality of elongated holes 36 by which a knee bracket 38 may be secured thereto in an adjustable manner. The knee bracket 38 has two pairs of ears 40 for the reception of the pins forming the pivot at 16 and receives suitable eyes 42 formed at the upper end of the shin member 14. The latter is preferably formed as a truss-like welded tubular structure comprising a pair of trusses, one at either side, as shown in Figure 2. Similar eyes 44 are formed at the lower end of the shin member to receive the pin at the ankle joint 20. The foot member comprises a welded tubular structure having a toe section 46 resiliently pivoted at its forward end and a rigid heel 48. The structure as a whole may be provided with any suitable rigid or semirigid external covering to simulate the shape of the natural leg. The particular configurations of the structural parts shown are intended as illustrative only and it will be understood that so far as the present invention is concerned, the "thigh member," "shin member," and "foot member" referred to hereinafter and in the claims may be of any suitable form to receive and be connected with additional structure to form a completely finished thigh, shin, and foot, respectively.

Pivotally mounted on the shin member 14 at 50 is a hydraulic unit 52. The unit 52 has an upwardly extending knee piston rod 54 which is pivotally connected to the bracket 38 and is preferably biased upwardly by a spring 56. The pivot point 58 is preferably located as shown in Figure 1 slightly to the rear of the knee pivot 16 and slightly above the same so that as the knee is bent, the entire hydraulic unit 52 is swung counterclockwise on the pivot 50 to permit the knee to be bent considerably beyond 90 degrees from the position shown in Figure 1 without interference between the thigh member 12 and the shin member 14. The hydraulic unit 52 also has a downwardly extending ankle piston rod 60 which is biased downwardly by a spring 62. The rod 60 is connected at 64 to a link 66 which is pivoted at 68 to the foot member 18 somewhat to the rear of the ankle pivot 20. The location of the piston rods 54 and 60 is preferably such that in all positions their center lines intersect the pivot point 50 for the hydraulic unit 52.

Referring now to Figures 4 through 13, the construction of the hydraulic unit 52 is there illustrated. It comprises essentially a double-acting knee cylinder and piston connected to the rod 54, a double-acting ankle cylinder and piston connected to the rod 60, a transfer cylinder, a pressure fluid reservoir and certain automatic and manual control valves. As shown more clearly in Figure 6, the knee cylinder 70 is provided with a liner 72 in which a piston 74 connected to rod 54 is slidable. The upper end of cylinder 70 is closed by a cap 76 and an O-ring seal 78. A shaft seal 80 of the type shown in my Patent No. 2,332,763 forms a sliding seal for the rod 54. The piston 74 is also provided with a similar sliding seal 82. Formed in the lower portion of the hydraulic unit is an ankle cylinder 84 provided with a liner 86 and having a sliding piston 88 connected to the rod 60. An end cap 90 closes the lower end of the cylinder and is provided with an O-ring seal 92. The end caps 90 and 76 are provided with sliding bearing extensions 94 and 96, respectively (see Figure 4). Cap 90 is also provided with trunnion arms 97 for pivotally supporting the unit 52.

The piston 88 and rod 60 are provided with a central bore 98 closed at its lower end in which is slidably mounted a control valve sleeve 100. The latter has a stem 102 projecting upwardly through the body of the unit and a spring 104 which biases the valve sleeve 100 downwardly. The valve sleeve 100 is normally stationary but may be adjusted upwardly and downwardly for a purpose later to be described. It coacts with a plurality of small ports 106 connecting between the bore 98 and the space beneath piston 88. Sliding seals 108, 110 and 112 are provided for the rod 102, piston 88 and the piston rod 60, respectively.

It will thus be seen that the structure thus far described provides a slidable knee piston 74 dividing the cylinder 70 into an upper chamber 114 and a lower chamber 116, while the ankle piston 88 divides the cylinder 84 into an upper chamber 118 and a lower chamber 120.

Also formed in the body of the unit 52 is a fluid reservoir 122 (see Figure 7). This is provided with a floating piston 124 having a sliding seal 126 and is biased downwardly by a spring 128. The upper end of the cylinder 122 (see Figure 5) is closed by a cap 130 retained by a snap ring 132 and having a vent hole 134. The reservoir cylinder 122 connects directly to the upper angle cylinder space 118 by a drilled passage 136. Another drilled passage 138 extends from the outside of the unit to connect with the space 118 and contains a charging valve 140 similar to an ordinary tire valve and is closed by a screw plug 142. The passage 136 intersects a horizontal bore 144 which contains an automatic valve comprising a sleeve body 146 stationarily mounted in the bore 144 and a sliding spool 148. The left-hand end of the spool is exposed to reservoir pressure by a plurality of small passages 150 while the right-hand end of the spool is in communication with a passage 152 closed at its upper end by a plug 154. A short transverse passage 156 (see Figure 4) connects to the upper knee cylinder chamber 114. The right-hand end of bore 144 is closed by a screw plug 158 which carries a pin 160 having a tapered end adapted to be received in a bore 162 in the spool 148 for the purpose of cushioning the movement thereof. A spring 164 normally biases the valve 148 to the left in Figure 7.

The sleeve 146 has ports 166 communicating with passage 136 and ports 168 communicating with a passage 170 (see Figure 8). In the normal position of the valve illustrated, these ports are connected but when the valve is shifted to the right, ports 166 are blocked. Passage 170 communicates with a valve bore 174 adapted to receive an adjustable restriction valve 176, later to be described. The valve 176 controls the flow between a passage 178 leading from the lower knee cylinder chamber 116 and passage 170. The passage 170 has an extension 180 connecting with a valve bore 182 which contains a stationary sleeve 184 and a sliding spool 186. The right-hand end of bore 182 is closed by a screw plug 188 and the spool 186 is biased to the right by a spring 190. The stem 185 of spool 186 slides in a sleeve 187 secured to sleeve 184 and forms a dash-pot chamber 189. This serves to retard shifting movements of the spool by the restriction of fluid passing into and out of chamber 189 through the clearance between stem 185 and sleeve 187.

Referring now to Figure 9, the valve bore 182 communicates by a passage 192 with a transfer cylinder 194. The latter has a floating piston 196 provided with a seal 198 and dividing the cylinder into an upper chamber 195 and a lower chamber 197. A spring 199 urges piston 196 downwardly at all times. The upper end of cylinder 194 is closed by a cap 200 retained by a snap ring 202 and having an O-ring seal 204. The cap 200 also has a communication groove 206 which connects with the inner face of the cap by a hole 208 in the cap and connects with the upper knee cylinder space 114 by a hole 210 in the body of unit 52. The right end of bore 182 in Figure 9 communicates with the upper ankle cylinder space 118 by a passage 212. The valve spool 186, when in the position illustrated, establishes communication between a set of ports 216 communicating with passage 192 and a second set of ports 218 communicating with passage 180 (see Figure 8). When the valve spool is shifted to the right in Figure 9, the passages 218 are blocked.

The bottom ankle cylinder space 120 is in communication with a vertical passage 220 which intersects the valve bore 182 at its left-hand end in Figure 9. The passage 220 is closed at its upper end by a screw plug 222 and communicates directly with the upper knee cylinder space 114 by a passage 224. Passage 224 enters the knee cylinder at a point below the top thereof so that it is closed off by the piston 74 (see Figure 6) before the piston reaches the upper limit of its stroke. The passage 220 also communicates with the space 114 by means of a passage 226 (see Figure 12) which intersects a check valve chamber 228 closed by a screw plug 230. A passage 232 connects from the chamber 228 to the upper end of space 114 and a ball check valve 234 prevents flow into the space 114 through this path.

Referring again to Figure 9, the body of the unit 52 is provided with a passage 236 having a check valve 238 therein and closed at its outer end by a screw plug 240. The discharge side of the check valve 238 communicates with passage 220 by a short horizontal passage 242.

Referring now to Figures 1 and 6, there is provided a manual control for the valve sleeve 100 comprising a Bowden wire cable 246 having an operating wheel 248 secured to the upper portion of the socket 12. The cable 246 extends downwardly through a bracket 250 formed on the hydraulic unit 52 and connects with the stem 102 for the purpose of raising and lowering the same. The lower end of the stem 102 is not rigidly secured to the valve sleeve 100 but has a head 252 provided with a slot 254 for fluid communication purposes. The head 252 normally rests on a shoulder in the interior of sleeve 100 and the latter is biased downwardly against the head 252 by the spring 104. When the rod 60 and piston 88 are moved upwardly slightly beyond the position shown, the sleeve 100 bottoms at the lower end of bore 98 and is carried upwardly along with the rod 60 compressing spring 104 without further upward movement of the stem 102.

The valve 176 contained in bore 174 comprises a stationary sleeve 255 pressed into the bottom end of the bore. The sleeve 255 is provided with two diametric slots 256 and has a central bore which receives a headed cylindrical piston valve member 258. The valve member is also provided with a diametric slot 260. A light spring 262 urges the valve 258 into the position shown. Rotatably mounted in the outer end of bore 174 is a plug 264 having a seal 266. The plug 264 is retained in the bore by a snap ring 268 and has a square socket 270 slidably but non-rotatably associated with a square stem 272 formed on the valve 258. The plug 264 also has an outwardly extending operating stem 274 by which the latter may be rotated.

The stem 274 has an operating lever 276 (see Figure 4) provided with a leaf spring 278 urging the latter counterclockwise. The end of the lever 276 is connected to a Bowden wire control cable 280 which extends upwardly to a manual control assembly 282. The latter comprises a tube 284 having a series of perforations 286 at suitable locations and a leaf spring 288 having a handle 290 is secured to the upper end of the Bowden wire 280. The spring carries a stud 292 which may be positioned in any of the various holes 286 to retain the lever 276 in any suitable adjusted position.

Before considering the action of the artificial leg in detail, certain considerations relating to the action of walking whether with natural or artificial legs should be considered. For purposes of clarity, a single complete step of one leg may be considered as six separate parts some of which may slightly overlap with each other. These

parts are (1) foot placement, (2) body ascension, (3) body propulsion, (4) foot disengagement, (5) leg recovery-acceleration, and (6) leg recovery-deceleration.

In the normal walk of an able bodied person, these parts of the step involve the following actions: During foot placement, the knee is straight, the thigh and shin project forward and downwardly and the heel contacts the ground first. Thereafter, the ankle bends to depress the toe and place the foot in full contact with the ground. This ankle movement sometimes overlaps with the following part and is also accompanied by a slight knee bend and subsequent straightening. The beginning of foot placement is diagrammed in Figure 14*a*. During body ascension, the body moves forwardly and upwardly pivoting about the ankle and the knee remains straight. The forward body movement is derived partly from momentum and partly from forward propulsion by the opposite foot. The beginning of body ascension is diagrammed in Figure 15*a*. When the leg is substantially vertical, body propulsion begins as shown in Figure 16*a*. This consists primarily of a falling forward with the knee straight but instead of pivoting about the ankle, the ankle is held rigid and the foot rocks up onto the toe portion. During body propulsion, the entire body weight is supported on the leg under consideration.

Foot disengagement, while considered separately for the present purposes, actually merges with leg recovery-acceleration. As the body weight is relieved from the leg, the thigh is swung forwardly about the hip. This together with the inertia of the shin and foot and also the frictional drag of the toe on the ground causes the knee to bend. Foot disengagement is shown about to start in Figure 17*a*. Leg recovery-acceleration consists in a forward swing of the thigh about the hip and a continued bending of the knee. This causes the shin to incline backwardly relative to the thigh and in turn lifts the ankle upwardly. At the same time the ankle starts to bend causing elevation of the toe so that on subsequent swinging of the foot forward, the toe will clear the ground. The beginning of leg recovery-acceleration is shown in Figure 18*a*. Leg recovery-deceleration, illustrated in Figure 19*a*, consists of a slight further movement of the thigh forward bringing it to a stop and a rapid inclination of the shin forward with a resulting straightening of the knee. At the same time the ankle bends to depress the toe somewhat so that the leg is again ready for foot placement. The present invention aims to duplicate to a large extent in the artificial leg these natural actions.

The operation of the device can best be understood from Figures 14 and 14*a* through 19 and 19*a* which show the positions of the parts and the fluid flow conditions during these six stages of a single step. With the device entirely filled with oil starting from the position shown in Figure 14, the leg is in the position indicated in Fgure 14*a* where the thigh has been swung forward to its maximum extent and the heel has just been placed on the ground. Under these conditions the fluid reservoir 122 and its spring pressed piston 124 maintain a light pressure, as for example, 50 pounds per square inch; as indicated by the dotted arrows with K shaped heads which indicate maintenance of pressure without any flow taking place. In this and in the following diagrams solid arrows are used to indicate the flow which takes place during movement from the position shown in one diagram to that shown in the next.

Valve 186, before the heel touches the ground, is in its open position as shown in Figure 14 due to the higher pressure maintained in chamber 120 as compared with that in reservoir 122. This higher pressure is due to the force of spring 62 plus the increment of pressure obtained by the differential area of chambers 118 and 120 and this pressure holds check valve 238 seated. The first action which takes place between Figures 14 and 15 is the upward movement of the ankle piston 88 caused by the swinging of the foot into position parallel with the ground. This action takes place freely and piston 88 moves upwardly opposed only by the spring 52 and the fluid pressure from reservoir 122 exterted over an area equivalent to the area of rod 60. Oil flows at first from chamber 118 through conduit 236, check valve 238, conduits 242 and 220, to the chamber 120. After a slight upward movement, flow can take place additionally through the apertures 106, as shown by the dotted arrow. This flow may be restricted somewhat by ports 106 to prevent "slapping" of the toe on the ground at this time. At the start of upward movement of piston 88, the valve 186 moves to the left due to equalization of pressures at its opposite ends permitting the spring to force the valve over. A small momentary flow occurs from line 136 through line 212 to valve 186 and from there through line 220 to chamber 120. At about this time, the body weight is transferred to the artificial leg and the body swings forwardly pivoting about the ankle joint.

Any tendency for the knee to bend forcing piston 74 downwardly as indicated in Figure 15 will immediately tend to draw a vacuum in chamber 114 since piston 74 is blocking port 224 and check valve 234 prevents flow into chamber 114. Accordingly, valve 148 will be pulled over against the spring by the reduction of pressure in passage 152 and by the maintenance of pressure from fluid reservoir 122 in conduits 136 and 150. This locks the knee effectively regardless of the contour of the ground upon which the foot is placed. In other words, the ankle is free to take up any position consistent with the ground contour although the knee cannot bend. It will be noted that at this time the ankle is bent with the toe downwardly thus raising the piston 88 considerably above its normal position.

As the body swings forwardly about the ankle as a pivot, piston 88 moves downwardly toward its normal position causing flow through ports 106. When this position is reached, as shown in Figure 16, ports 106 close. This point is determined by the adjustment of sleeve valve 100 and for normal walking conditions on level ground will be set to take place when the sole of the foot is perpendicular to the leg axis. When ports 106 close, the spring 62 plus the differential area of the ankle cylinder build up the pressure in chamber 120 so as to again open valve 186. A very small momentary flow takes place from chamber 120 through line 220 to valve 186, and also from valve 186 through line 212 to reservoir 122 thus opening valve 186 against the spring. When ports 106 close, the ankle is locked against further downward movement of piston 88 and the oil in chamber 120 is trapped. It cannot escape through the passage 220 as it is locked at all exits as shown by the dotted K headed arrows in Figure 16. This enables the user to exert forward propulsion by reason of the pivot point transferring from the ankle to the toe, thus giving a greater forward component to the body movement under the action of gravity.

During this time, of course, the opposite leg is being swung forward and at about the time that the heel touches the ground, the leg in consideration is in the position of Figure 17*a*.

This illustrates the condition at the instant when the weight of the user has been transferred to the opposite leg and is just being released from the leg in consideration. As the weight is relieved from the toe, pressure in chamber 120 and line 220 falls but does not equalize with reservoir pressure due to spring 62 and the differential area. This maintains valve 186 in open position. The thigh now starts to swing forwardly, pivoting about the hip at the beginning of the forward step and due to the frictional contact of the toe with the ground and also due to the inertia of the shin and foot member, this tends to bend the knee forcing rod 54 and piston 74 downwardly. Since there is no possible path for entrance of fluid to the chamber 114, pressure is reduced in this chamber and in the line 152 to a value below reservoir pressure which enables the reservoir pressure acting through conduits 136 and 150 to shift the valve 148 to closed position against spring 164. The fluid discharged from chamber 116 is delivered as shown by the arrows in Figure 17 through conduits 178, 172 and 180, through valve 186 and conduit 192 to the chamber 197 of transfer cylinder 194. Piston 196 is accordingly lifted against its spring and the upper chamber 195 of the transfer cylinder supplies fluid to the chamber 114 through conduit 210. This enables the knee to bend during that portion of the stroke of piston 74 before passage 224 is uncovered. Due to the differential area at piston 74 more oil is pushed out of chamber 116 than is required to fill chamber 114. The excess is permitted to pass to the reservoir 122 by the action of valve 148. This valve automatically regulates the opening at passage 136 to just the correct size to permit such flow. The action is such as to maintain in chambers 114 and 195 a pressure which is lower than reservoir pressure by an amount equivalent to the force of the spring 164 of valve 148 acting over the end area thereof; and the valve acts analogously to a relief valve to permit the excess fluid represented by the volume of rod 54 to pass into the reservoir 122. The ankle piston 88 remains locked during this movement since fluid cannot escape from chamber 120 either through ports 106 or line 220.

When the point is reached where piston 74 uncovers passage 224, conditions are as illustrated in Figure 18. As the thigh continues swinging forwardly and the shin begins to follow, the toe would normally drag on the ground unless the hip was bodily raised or the knee excessively bent. To prevent the necessity of this action which creates a limp, the toe is raised in the following manner: The opening of port 224 permits oil to flow from chamber 120 through line 220 into chamber 114 thus equalizing the pressure therein. Consequently, valve 148 is immediately opened by flow from chamber 114 through line 152 to valve 148 from which flow returns through lines 150 and 136 to chamber 118. As the knee continues bending with valve 148 thus opened, piston 74 forces oil out of chamber 116 through the valve 148 to the chamber 118. This forces piston 88 downwardly raising the toe and the oil discharged from chamber 120 is free to pass through the passage 220 and port 224 to the chamber 114. Thus at this time, the knee piston and ankle piston are in a closed circuit and one can transfer oil to the other. At the same time, the oil displaced previously into the transfer cylinder chamber 197 is enabled to escape through passages 192, valve 186, lines 180 and 170, valve 148 and line 136 to the chamber 118. From chamber 120 additional flow occurs through line 220, passages 224 and 210 to chamber 194. During all of this action from the moment port 224 was opened, the spring 62 and the reservoir pressure acting over the differential area of the piston also exert forces urging the piston 88 downwardly.

It will be noted that during this forward movement of the thigh and shin, the toe is raised considerably above normal position as shown in Figure 19*a*. At this point the knee begins to straighten and piston 74 accordingly starts moving upwardly. Since the knee and ankle pistons are still in their closed circuit communication and ports 106 in the ankle piston are still blocked, the ankle is accordingly bent oppositely to lower the toe relative to the shin as the knee straightens out and the shin swings forwardly at its lower end. This in effect maintains the sole of the foot substantially parallel to the ground during the first movement and during the latter movement the toe lowers relative to the shin until it comes to the position illustrated in Figure 14*a* where another cycle is resumed. The opening of ports 106 by the piston 88 as it reaches normal position prevents further lowering of the toe as the knee completes its straightening.

During the action thus described, the valve 176 was maintained in the position wherein the slots 260 line up with the slots 256 so that the valve is open to free flow in either direction. The valve may be adjusted as desired to impose progressively greater restriction to bending of the knee as oil is forced out of chamber 116. In this way the valve may serve as a means for regulating the speed of bending of the knee during normal walking and the operation of the leg may be tailored to suit any individual gait. Regardless of the degree of restriction imposed, the valve 258 always permits free flow into the chamber 116 and thus enables the knee to straighten freely under all circumstances.

The valve 176 may also be used for the purpose of descending stairs in a natural manner. For this purpose, the control lever 290 is adjusted with the stud 292 in the next to the top notch 286 which creates a fairly high degree of restriction at the valve 176.

To descend stairs, the leg in consideration is first placed on a step beneath the opposite leg and as the body weight is swung forward, the knee bends as soon as the weight of the body is transferred to the toe. This shifts valve 186 as shown in Figure 16 and permits the knee to bend and start causing flow as shown in Figure 17. The downward movement of piston 74 is retarded, however, by the restriction at valve 176. The ankle is maintained rigid until the piston 74 reaches the position where port 224 is opened as shown in Figure 18. Thereafter, the ankle bends causing flow to occur as shown in Figure 18. During this movement, of course, the opposite leg is swung outwardly to land on the step below the one where the leg in consideration is standing, after which the leg in consideration may be swung outwardly straightening the knee which always occurs freely due to the check valve action at 176. At the same time the ankle is also straightened due to flow as illustrated in Figure 19. In this way, a natural descent of stairs can be obtained wherein each leg lands on alternate steps.

It will be noted that a valuable feature of the present invention resides in the fact that the reservoir 122 maintains all of the chambers filled with oil and replenishes any leakage which may occur from one chamber to another automatically at each step just prior to the beginning to the sequence as previously described. This action is shown clearly in Figure 14 and the check valve 238 performs an important function in this respect. The chamber 120 which is subjected to the heaviest pressure of any chamber during walking, et cetera, is replenished automatically through check valve 238 from reservoir 122 at the instant the heel is placed on the ground. This permits free and rapid filling of chamber 120 as the heel is placed on the ground in the event that any fluid was lost therefrom during a previous step. It also maintains the charge in chambers 114 and 195 during the conditions indicated in Figure 18.

In order to obtain the best walking action with the device disclosed, certain relationships should exist between the various springs illustrated, having regard for the piston area over which such springs are effective. It is preferred to make the spring 199 substantially heavier than the spring 128 in the sense that piston 124 can never force oil into chamber 197 when the two are connected whereas piston 196 can always force oil in the opposite direction whenever it is above its bottom position.

Spring 190 for valve 186, in the form disclosed, is relatively light so that it may be overcome by the pressure created in chamber 120 when ports 106 are closed even though the weight of the user is not placed on the toe. This creates an action wherein the knee is normally unlocked during the stages shown in Figures 16 through 19, inclusive, as well as at all times when the leg is freely suspended off the ground. As an alternate construction, the spring 190 may be made heavier so that it can only be overcome by the additional pressure created in chamber 120 by the weight of the user being placed on the toes in the stages illustrated in Figures 16 and 17 only, and as soon as the foot is lifted from the ground, as shown in Figure 18, the valve 186 again closes. With this alternate construction an additional passage 294 having a check valve 296 as shown in Figure 18 is required to permit oil to discharge from chamber 197 to line 180. This passage and check valve may be located as indicated by dotted lines in Figure 8. This alternate construction is advantageous in the case of prostheses for double amputees since it maintains the knee locked at all times except when the weight of the user is on the toes. The normal construction, on the other hand, maintains the knee unlocked at all times except when the weight of the user is on the heel.

The spring 164 for valve 148 may be relatively light in all cases so that it may be overcome by the pressure from reservoir 122 whenever there is a slight reduction in pressure in chamber 114. The value of ankle spring 62 is not critical but it has been found that some spring force at this point is of material assistance. It should not, however, be so heavy as to prevent ready depression of the toe as shown in Figures 14 and 15. The spring 62 is of principal importance during the action illustrated in Figure 18. At this time it is important that a rapid downward movement of piston 88 be obtained so that the toe will lift quickly to avoid scraping on the ground or tripping on a curb stone. The spring 62 is of assistance and in addition the spring 199 further speeds this movement by rapidly driving the liquid out of chamber 197 and into chamber 118.

The knee spring 56 is likewise uncritical and, in fact, may be omitted entirely in many instances. Its chief value is in fitting various natural gaits of different users, some requiring assistance in straightening the knee during the latter part of the forward swing of the thigh.

Another important feature of the present invention resides in the fact that automatic knee locking can take place only during the initial bending of the knee, that is, during the travel of piston 74 from its upper limit down to the point shown in Figure 18 where port 224 is opened. At any degree of knee bend beyond this, the knee is free to flex and at the same time the knee and ankle are connected for coordination of motion. It is, of course, possible to lock the knee at any position by pulling out the control handle 290 to its extreme position. This, however, is merely for the purpose of creating a rigid leg whenever such is desired due to unusual circumstances. At all other times when the manual lock control 290 is not in locking position, the knee is free to bend to any degree after it has bent through the first limited movement. This is of great assistance in such cases as sitting down and getting up, as well as during the normal walking cycle.

The manual adjustment of valve sleeve 100 is particularly useful for such requirements as different heights of various shoe heels and for walking uphill or downhill. It serves to adjust the normal, at rest, position of the foot to make it perpendicular to the leg axis or to raise or lower the foot to any desired degree away from perpendicular.

The entire leg is preferably designed for minimum weight consistent with necessary strength and for this purpose the body of the hydraulic unit and other large parts are formed of light weight material such as magnesium. In addition the hydraulic cylinders are made with relatively small areas so that maximum pressures of the order of 3,000 pounds per square inch are developed. By careful design in this regard it has been possible to construct a satisfactory leg having a weight of only 5½ pounds suitable for a 180 pound user.

It will thus be seen that the present invention provides a greatly improved artificial leg which is entirely self-contained and self-activated to create a very close simulation of the natural walking step. At the same time, the leg is extremely safe and it is impossible to collapse the same due to walking on uneven ground due to the fact that the knee remains locked whenever any part of the weight of the user rests on the heel.

In distinction to previous artificial legs, the present leg provides a free swinging ankle at the time of foot placement and requires no limitation on the amount of toe depression which may occur at this time due to uneven ground contour. It is particularly important when the heel rests on a pebble or other obstruction higher than the front part of the foot to permit such additional toe depression at this time. The present invention thus assures that there is no tendency for

the knee to be bent when the body weight comes on to the leg. In other words, a pebble under the heel cannot because of limited ankle motion throw the upper part of the shin and the knee forward to thus bend the knee and cause it to collapse when weight is placed on it.

Another important feature regarding the present ankle action resides in its ability to lock against toe elevation during the body propulsion part of the step. This permits the leg to rock up on the fore part of the foot for propulsion purposes. At the same time, however, the ankle is not permanently blocked against toe elevation beyond this point. Thus during leg recovery, the ankle is positively operated by means of the knee cylinder and the transfer cylinder to lift the toe clear of the ground and to elevate the same above the lock position which occurs during body propulsion.

It will also be noted that at the end of leg recovery-deceleration, there is provided a cushioning action to prevent "slamming" of the shin into fully straight position. This comes about by reason of the closure of port 224 by piston 74 and the necessity of forcing further oil out of chamber 114 through the check valve 234 which imposes significant resistance as compared with the free passage 224.

This same portion of the mechanism performs a further function during leg recovery-acceleration. During this part of the step it is necessary with the artificial leg to cause knee bending without muscular assistance at the knee and relying solely on thigh movement from the hip. The present invention assures knee bending by delaying ankle movement until the knee piston 74 has moved downwardly past the port 224. This permits the toe to remain on the ground in frictional contact thus making it easier to bend the knee and not having to rely solely on the inertia of the shin and foot for this purpose.

Another advantage of the present invention resides in the action of the leg when idle, that is, when the user is standing still and merely casually takes a slight step forward with it. If the user's weight is not resting on the artificial leg but it is hanging idly or resting lightly on the ground, the ankle spring 62 maintains pressure in chamber 120 which holds the lock valve 186 open. Thus the transfer cylinder 197 is in direct communication with the knee cylinder 116. Any casual bending of the knee which occurs is resisted by the spring bias on transfer piston 198 and as soon as the foot is lifted clear of the ground, the knee has an automatic tendency to straighten. The bias produced in this way may be quite strong so that for any casual standing around and subsequent lifting of the artificial leg, it has a strong tendency to straighten quickly. A permanent bias on the knee of this nature, however, would be objectionable during normal walking because it would resist bending of the knee during leg recovery-acceleration and would hasten straightening of it during leg recovery-deceleration. By the present invention, the knee bias is removed at such times for the reason that the fluid in chamber 197 is discharged into the ankle cylinder 118 for the purpose of elevating the toe. The opening of valve 148 at this time permits such action to occur.

While the form of embodiment of the invention as herein disclosed constitutes a preferred form, it is to be understood that other forms might be adopted, all coming within the scope of the claims which follow.

What is claimed is as follows:

1. A prosthesis for amputation at the thigh comprising a thigh member, a shin member and a foot member pivoted together to simulate knee and ankle joints, a first hydraulic piston and cylinder connected between the thigh and shin members, a second hydraulic piston and cylinder connected between the shin and foot members, and fluid passage means connecting said cylinders for conjoint actuation and control of bending of the knee and ankle joints.

2. An artificial leg comprising a thigh member, a shin member connected to the thigh member by an artificial knee joint, a foot member connected to the shin member by an artificial ankle joint, and a hydraulic control unit cooperating with both joints and comprising an expansible chamber mechanically connected between the thigh and shin members to control flexing of the knee, a second expansible chamber mechanically connected between the shin and foot members to control flexing of the ankle joint, and hydraulic conduit means connecting said chambers for the transfer of fluid to and fro between them.

3. A prosthesis for amputation at the thigh comprising a thigh member, a shin member and a foot member pivoted together to simulate knee and ankle joints, means constituting a hydraulic chamber expansible and contractible with bending movements of the knee, valve means connected with the chamber for hydraulically locking the chamber to prevent bending of the knee, and means for actuating the valve means in response to force applied to the foot member through the heel, said valve means unlocking the chamber in response to release of said force.

4. An artificial leg comprising a thigh member, a shin member connected to the thigh member by an artificial knee joint, a foot member connected to the shin member by an artificial ankle joint, and a hydraulic control unit comprising an expansible chamber mechanically connected between the thigh and shin members to control flexing of the knee, a hydraulic control circuit connected to said chamber, valve means in said circuit to lock the chamber against bending of the knee upon application of a force to the foot member through the heel, said valve means being responsive to the release of said force for releasing the chamber.

5. A prosthesis for amputation at the thigh comprising a thigh member, a shin member and a foot member pivoted together to simulate knee and ankle joints, means constituting a first hydraulic chamber expansible and contractible with bending movements of the knee, valve means connected with the first chamber for locking the chamber against bending of the knee, means constituting a second hydraulic chamber expansible and contractible with bending movements of the ankle, and fluid conduit means connected with the valve means to actuate the valve means to knee locking position upon a reduction in pressure in the last mentioned chamber.

6. An artificial leg comprising a thigh member, a shin member connected to the thigh member by an artificial knee joint, a foot member connected to the shin member by an artificial ankle joint, and a hydraulic control unit comprising an expansible chamber mechanically connected between the thigh and shin members to control flexing of the knee, means normally biasing the knee into straight position when the leg is idle, and means for disabling the biasing means during at least the latter part of the leg-recovery part of a normal step.

7. A prosthesis for amputation at the thigh comprising a thigh member, a shin member and a foot member pivoted together to simulate knee and ankle joints, means constituting a hydraulic chamber expansible and contractible with bending movements of the knee, valve means connected with the chamber for hydraulically locking the chamber to prevent bending of the knee, means for actuating the valve means in response to force applied to the foot member through the heel, said valve means unlocking the chamber in response to release of said force, and a second valve means in series with the first valve means and manually shiftable to impose a predetermined degree of restriction to liquid passing through the first valve means to control the rate of knee bending.

8. An artificial leg comprising a thigh member, a shin member connected to the thigh member by an artificial knee joint, a foot member connected to the shin member by an artificial ankle joint, a hydraulic control unit comprising an expansible hydraulic chamber mechanically connected between the shin and foot members to control flexing of the ankle, and means for locking said chamber in response to a predetermined degree of construction thereof to prevent movement of the foot upward beyond a predetermined position.

9. An artificial leg having thigh, shin and foot members articulated by knee and ankle joints, the ankle joint having an angular range of movement approximately equal to that of an average human ankle, and a hydraulically operated expansible chamber device connected to operate and control the ankle, said chamber having means normally preventing elevation of the forepart of the foot beyond a predetermined position where the foot is substantially perpendicular to the shin whereby the ankle is effectively locked during the body propulsion part of a step, said chamber permitting free movement of the foot to any position below said predetermined position when the foot is placed on the ground at the end of the leg recovery part of a step.

10. A prosthesis for amputation at the thigh comprising a thigh member, a shin member and a foot member pivoted together to simulate knee and ankle joints, means constituting a double-acting hydraulic chamber expansible and contractible with bending movements of the knee, means constituting a second double-acting hydraulic chamber expansible and contractible with bending movements of the ankle, passage means connecting said chambers to pass fluid from the first chamber to the second to cause the forward end of the foot to lift clear of the ground during a forward swing of the thigh while bending the knee and effective upon straightening the knee during the latter part of the forward swing to lower the forward end of the foot to a predetermined position relative to the shin, and means for varying said predetermined position.

11. A prosthesis for amputation at the thigh comprising a thigh member, a shin member and a foot member pivoted together to simulate knee and ankle joints, means constituting a double-acting hydraulic chamber expansible and contractible with bending movements of the knee, means constituting a second double-acting hydraulic chamber expansible and contractible with bending movements of the ankle, passage means connecting said chambers to pass fluid from the

first chamber to the second to cause the forward end of the foot to lift clear of the ground during a forward swing of the thigh while bending the knee and effective upon straightening the knee during the latter part of the forward swing to lower the forward end of the foot to a predetermined position relative to the shin, and means including a manually adjustable valve associated with the second chamber for varying said predetermined position.

12. A prosthesis for amputation at the thigh comprising a thigh member, a shin member and a foot member pivoted together to simulate knee and ankle joints, means constituting a double-acting hydraulic chamber expansible and contractible with bending movements of the knee, means constituting a second double-acting hydraulic chamber expansible and contractible with bending movements of the ankle, passage means connecting said chambers to pass fluid from the first chamber to the second to cause the forward end of the foot to lift clear of the ground during a forward swing of the thigh while bending the knee and effective upon straightening the knee during the latter part of the forward swing to lower the forward end of the foot to a predetermined position relative to the shin, means including a manually adjustable valve associated with the second chamber for varying said predetermined position, and a remote control accessible from adjacent the upper part of the thigh for actuating said valve.

13. An artificial leg comprising a thigh member, a shin member connected to the thigh member by an artificial knee joint, a foot member connected to the shin member by an artificial ankle joint, a hydraulic control unit comprising an expansible hydraulic chamber mechanically connected between the shin and foot members to control flexing of the ankle, means for locking said chamber in response to a predetermined degree of contraction thereof to prevent movement of the foot upward beyond a predetermined position, and means including a manually adjustable valve associated with the chamber for varying said predetermined position.

14. An artificial leg comprising a shin member, a foot member connected to the shin member by an artificial ankle joint, a hydraulic control unit cooperating with said joint and comprising an expansible chamber mechanically connected between the shin and foot members to control flexing of the ankle, means forming a bypass for said chamber, and means for locking said chamber to prevent movement of the fore part of the foot upward beyond a predetermined point whereby the foot is free to move downwardly or upwardly to all positions below said predetermined point.

15. An artificial leg comprising a shin member, a foot member connected to the shin member by an artificial ankle joint, a hydraulic control unit cooperating with said joint and comprising an expansible chamber mechanically connected between the shin and foot members to control flexing of the ankle, means forming a bypass for said chamber, means for locking said chamber to prevent movement of the fore part of the foot upward beyond a predetermined point whereby the foot is free to move downwardly or upwardly to all positions below said predetermined point, and a check valve permitting free movement of the foot downwardly from any position throughout its range of travel.

16. An artificial leg comprising a shin member, a foot member connected to the shin member by an artificial ankle joint, a hydraulic control unit cooperating with said joint and comprising an expansible chamber mechanically connected between the shin and foot members to control flexing of the ankle, means forming a by-pass for said chamber, said by-pass imposing a predetermined degree of restriction, and means for locking said chamber to prevent movement of the fore part of the foot upward beyond a predetermined point whereby the foot is permitted to move downwardly or upwardly at a controlled rate to all positions below said predetermined point.

17. An artificial leg having thigh, shin and foot members articulated by knee and ankle joints, the ankle joint having an angular range of movement approximately equal to that of an average human ankle, and being free, when the foot is first placed on the ground at the beginning of a step, to position both heel and toe on ground of irregular contour without causing bending of the knee, hydraulic means between the shin and foot members preventing toe elevation during the body-propulsion part of a step, and valve means for releasing said hydraulic means to permit elevation of the fore part of the foot during the leg recovery part of a step.

18. A prosthesis for amputation at the thigh comprising a thigh member, a shin member and a foot member pivoted together to simulate knee and ankle joints, means constituting a hydraulic chamber expansible and contractible with bending movements of the knee, means constituting a second hydraulic chamber expansible and contractible with bending movements of the ankle, and passage means connecting said chambers to pass fluid from the first chamber to the second to cause the forward end of the foot to lift clear of the ground during a forward swing of the thigh.

19. An artificial leg comprising a thigh member, a shin member connected to the thigh member by an artificial knee joint, a foot member connected to the shin member by an artificial ankle joint, a hydraulic control unit cooperating with both joints and comprising an expansible hydraulic chamber mechanically connected between the shin and foot members to control flexing of the ankle, and means responsive to bending of the knee for hydraulically operating said chamber to raise the fore part of the foot.

20. An artificial leg comprising a thigh member, a shin member connected to the thigh member by an artificial knee joint, a foot member connected to the shin member by an artificial ankle joint, a hydraulic control unit cooperating with both joints and comprising an expansible hydraulic chamber mechanically connected between the shin and foot members to control flexing of the ankle, and means for delivering fluid to said chamber in response to bending of the knee for causing the fore part of the foot to raise.

21. An artificial leg having thigh, shin and foot members articulated by knee and ankle joints, the ankle joint having an angular range of movement approximately equal to that of an average human ankle, a hydraulically operated expansible chamber device connected to operate and control the ankle, and fluid control means operated by the normal movement of the leg in walking for operating said chamber to raise the fore part of the foot during the leg-recovery part of a normal step.

22. An artificial leg comprising a thigh mem-

ber, a shin member connected to the thigh member by an artificial knee joint, a foot member connected to the shin member by an artificial ankle joint, and a hydraulic control unit cooperating with both joints and comprising an expansible chamber mechanically connected between the shin and foot members to control flexing of the ankle, means responsive to bending of the knee for hydraulically operating said chamber to raise the fore part of the foot, said last means including an expansible chamber operated by the knee, a transfer chamber connected to receive fluid during the first part of a knee bend, and means controlled thereafter by the knee for delivering fluid both from the knee operated chamber and from the transfer chamber to the ankle control chamber to rapidly raise the foot.

23. An artificial leg comprising a thigh member, a shin member connected to the thigh member by an artificial knee joint, a foot member connected to the shin member by an artificial ankle joint, a hydraulic control unit cooperating with both joints and comprising an expansible chamber mechanically connected between the shin and foot members to control flexing of the ankle, and means operated by bending of the knee to deliver fluid to said expansible chamber to raise the foot and including means for storing and later redelivering a part of such fluid.

24. An artificial leg comprising a thigh member, a shin member connected to the thigh member by an artificial knee joint, a foot member connected to the shin member by an artificial ankle joint, and a hydraulic control unit cooperating with both joints and comprising an expansible chamber mechanically connected between the shin and foot members to control flexing of the ankle, means responsive to bending of the knee for hydraulically operating said chamber to raise the fore part of the foot, said last means including an expansible chamber operated by the knee, a transfer chamber connected to receive fluid during the first part of a knee bend, and a resiliently biased movable wall for said transfer chamber whereby the knee is normally biased toward straight position by said movable wall acting on the fluid in the knee-operated expansible chamber.

25. A prosthesis for amputation at the thigh comprising a thigh member, a shin member and a foot member pivoted together to simulate knee and ankle joints, means constituting a hydraulic chamber expansible and contractible with bending movements of the knee, means constituting a second hydraulic chamber expansible and contractible with bending movements of the ankle, passage means connecting said chambers to pass fluid from the first chamber to the second to cause the forward end of the foot to lift clear of the ground during a forward swing of the thigh, and means for delaying operation of the ankle chamber until the knee has bent to a predetermined angle.

26. An artificial leg having thigh, shin and foot members articulated by knee and ankle joints, the ankle joint having an angular range of movement approximately equal to that of an average human ankle, a hydraulically operated expansible chamber device connected to the shin and foot members to operate and control the ankle, a second hydraulically operated expansible chamber device interposed between the thigh and shin members to operate and control the knee joint, and means including a hydraulic circuit connecting said devices and effective to raise the toe in response to knee bending only beyond a predetermined angle during the leg-recovery part of a normal step.

27. An artificial leg having thigh, shin and foot members articulated by knee and ankle joints, the ankle joint having an angular range of movement approximately equal to that of an average human ankle and being free, when the foot is first placed on the ground at the beginning of a step, to position both heel and toe on ground of irregular contour without causing bending of the knee, means preventing foot elevation beyond a predetermined position during the body propulsion part of a step, and motor means for positively operating the ankle joint to lift the foot beyond that position during the leg-recovery part of a step.

28. An artificial leg comprising a thigh member, a shin member connected to the thigh member by an artificial knee joint, a foot member connected to the shin member by an artificial ankle joint, a hydraulic control unit cooperating with both joints and comprising an expansible chamber mechanically connected between the shin and foot members to control flexing of the ankle, means for at times locking the knee in response to conditions in said chamber, and means responsive to bending of the knee for hydraulically operating said chamber to raise the fore part of the foot.

29. An artificial leg having thigh, shin and foot members articulated by knee and ankle joints, the ankle joint having an angular range of movement approximately equal to that of an average human ankle and being free, when the foot is first placed on the ground at the beginning of a step, to position both heel and toe on ground of irregular contour without causing bending of the knee, hydraulic means between the shin and foot members preventing toe elevation during the body-propulsion part of a step, valve means for releasing said hydraulic means to permit elevation of the fore part of the foot during the leg recovery part of a step, and means operated by the normal leg movement for operating the ankle joint to cause further toe elevation during the leg recovery part of a step.

30. In an artificial leg having a thigh member, a shin member connected to the thigh member by an artificial knee joint, and a foot member connected to the shin member by an artificial ankle joint, a control unit comprising a hydraulic knee cylinder having a double acting piston effective to displace fluid in said cylinder, a hydraulic ankle cylinder having a double acting piston effective to displace fluid in the ankle cylinder, means forming a circuit connecting said cylinders, a knee-lock valve responsive to pressure conditions at the ankle cylinder for blocking flow to lock the knee against bending, an ankle control valve responsive to the position of the ankle for by-passing the ankle piston, and means controlled by the knee piston for rendering the circuit effective to deliver fluid between the knee and ankle cylinders to operate their pistons in unison during a forward swing of the foot.

31. A hydraulic control unit for use in artificial legs having thigh, shin and foot members connected by artificial knee and ankle joints comprising a hydraulic knee cylinder having a double acting piston effective to displace fluid in said cylinder, a hydraulic ankle cylinder having a double acting piston effective to displace fluid in the ankle cylinder, means forming a cir-

cuit connecting said cylinders, a knee-lock valve responsive to pressure conditions at the ankle cylinder for blocking flow to lock the knee against bending, an ankle control valve responsive to the position of the ankle for by-passing the ankle piston, means controlled by the knee piston for rendering the circuit effective to deliver fluid between the knee and ankle cylinders to operate their pistons in unison during a forward swing of the foot, and a transfer cylinder effective to delay operation of the ankle piston until the knee piston has moved a predetermined amount and for thereafter accelerating the ankle piston faster than it would be driven by the knee piston alone.

32. An artificial leg comprising a thigh member, a shin member connected to the thigh member by an artificial knee joint, a foot member connected to the shin member by an artificial ankle joint, and a hydraulic control unit comprising an expansible chamber mechanically connected between at least two of the members to control flexing of the joint between them, and a resiliently loaded fluid pressure reservoir forming a fluid charging source for the unit, said unit being removable as a self-contained unit without exposing the hydraulic fluid to atmosphere.

33. An artificial leg comprising a thigh member, a shin member connected to the thigh member by an artificial knee joint, a foot member connected to the shin member by an artificial ankle joint, and a hydraulic control unit comprising an expansible chamber mechanically connected between at least two of the members to control flexing of the joint between them, valve means for controlling the fluid propelled to and from the expansible chamber, and a resiliently loaded reservoir forming a fluid charging source for the chamber and for actuating the valve means in response to a reduction in pressure in the expansible chamber.

34. An artificial leg comprising a thigh member, a shin member connected to the thigh member by an artificial knee joint, a foot member connected to the shin member by an artificial ankle joint, a hydraulic control unit cooperating with both joints and comprising an expansible chamber mechanically connected between the thigh and shin members to control flexing of the knee, a second expansible chamber mechanically connected between the shin and foot members to control flexing of the ankle joint, hydraulic conduit means connecting the chambers in a circuit, and a resiliently loaded accumulator for maintaining a slight superatmospheric pressure in the circuit, said hydraulic unit being entirely sealed off from atmospheric communication at all points.

35. An artificial leg comprising a thigh member, a shin member connected to the thigh member by an artificial knee joint, a foot member connected to the shin member by an artificial ankle joint, a hydraulic control unit cooperating with both joints and comprising an expansible chamber mechanically connected between the thigh and shin members to control flexing of the knee, a second expansible chamber mechanically connected between the shin and foot members to control flexing of the ankle joint, hydraulic conduit means connecting the chambers in a circuit, a resiliently loaded accumulator for maintaining a slight superatmospheric pressure in the circuit, and a check valve opening into communication with at least one of said chambers for replenishing fluid lost therefrom.

36. An artificial leg comprising a thigh member, a shin member connected to the thigh member by an artificial knee joint, a hydraulic knee cylinder having a double acting piston effective to displace fluid in said cylinder, a foot member connected to the shin member by an artificial ankle joint, a hydraulic ankle cylinder having a double acting piston effective to displace fluid in the ankle cylinder, means forming a circuit connecting said cylinders, a knee-lock valve responsive to pressure conditions at the ankle cylinder for blocking flow to lock the knee against bending, an ankle control valve responsive to the position of the ankle for by-passing the ankle piston, means controlled by the knee piston for rendering the circuit effective to deliver fluid between the knee and ankle cylinders to operate their pistons in unison during a forward swing of the foot, and a fluid reservoir resiliently loaded to maintain the cylinders, valves and circuit filled with fluid and to compensate for variations in total displacement volume at different piston positions.

37. An artificial leg comprising a thigh member, a shin member connected to the thigh member by an artificial knee joint, a foot member connected to the shin member by an artificial ankle joint, and a hydraulic control unit cooperating with both joints and comprising an expansible chamber mechanically connected between the thigh and shin members to control flexing of the knee, a second expansible chamber mechanically connected between the shin and foot members to control flexing of the ankle joint, hydraulic conduit means connecting said chambers for the transfer of fluid to and fro between them, and automatic control valve means effective to lock the knee while the leg is placed with the foot forward and to lock the ankle while the foot is supporting the user and to the rear of vertical position.

38. An artificial leg comprising a thigh member, a shin member connected to the thigh member by an artificial knee joint, a foot member connected to the shin member by an artificial ankle joint, and a hydraulic control unit cooperating with both joints and comprising an expansible chamber mechanically connected between the thigh and shin members to control flexing of the knee, a second expansible chamber mechanically connected between the shin and foot members to control flexing of the ankle joint, hydraulic conduit means connecting said chambers for the transfer of fluid to and fro between them, and automatic control valve means effective to lock the knee while the leg is placed with the foot forward and to lock the ankle while the foot is supporting the user to the rear of vertical position, said valve means acting automatically to connect the first and second chambers for conjoint flexing of the knee and ankle when the leg is swung forwardly free of the ground.

39. An artificial leg comprising a thigh member, a shin member connected to the thigh member by an artificial knee joint, a hydraulic knee cylinder having a double acting piston effective to displace fluid in said cylinder, a foot member connected to the shin member by an artificial ankle joint, a hydraulic ankle cylinder having a double acting piston effective to displace fluid in the ankle cylinder, means forming a circuit connecting said cylinders, a knee-lock valve responsive to pressure conditions at the ankle cylinder for blocking flow to lock the knee against

bending, an ankle control valve responsive to the position of the ankle for by-passing the ankle piston, means controlled by the knee piston for rendering the circuit effective to deliver fluid between the knee and ankle cylinders to operate their pistons in unison during a forward swing of the foot, and a transfer cylinder effective to delay operation of the ankle piston until the knee piston has moved a predetermined amount and for thereafter accelerating the ankle piston faster than it would be driven by the knee piston alone.

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