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(54) Artificial limb joint control device containing an electrorheological fluid

(57) An artificial limb for an above knee amputee has a control device (18) in the form of a piston and cylinder assembly in which chambers (26, 28) on either side of the piston (24) contain an electrorheological fluid and are linked by a passageway (44A-44E) including an electroviscous valve. The valve has two electrodes, one being a metallic valve block (38) and the other being a metallic rod (46) housed coaxially in a portion (44C) of the above-mentioned passageway. Restriction of fluid flow is achieved by applying a voltage across the electrodes. Additional restriction is achieved by means of a electromechanical valve (48).

The piston and cylinder assembly (18) is connected between upper and lower components of the prosthesis to control flexion and extension at the knee.

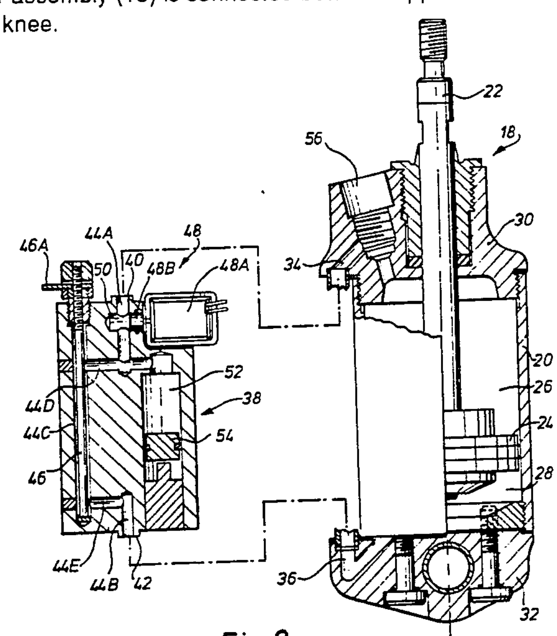

Fig.2.

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy

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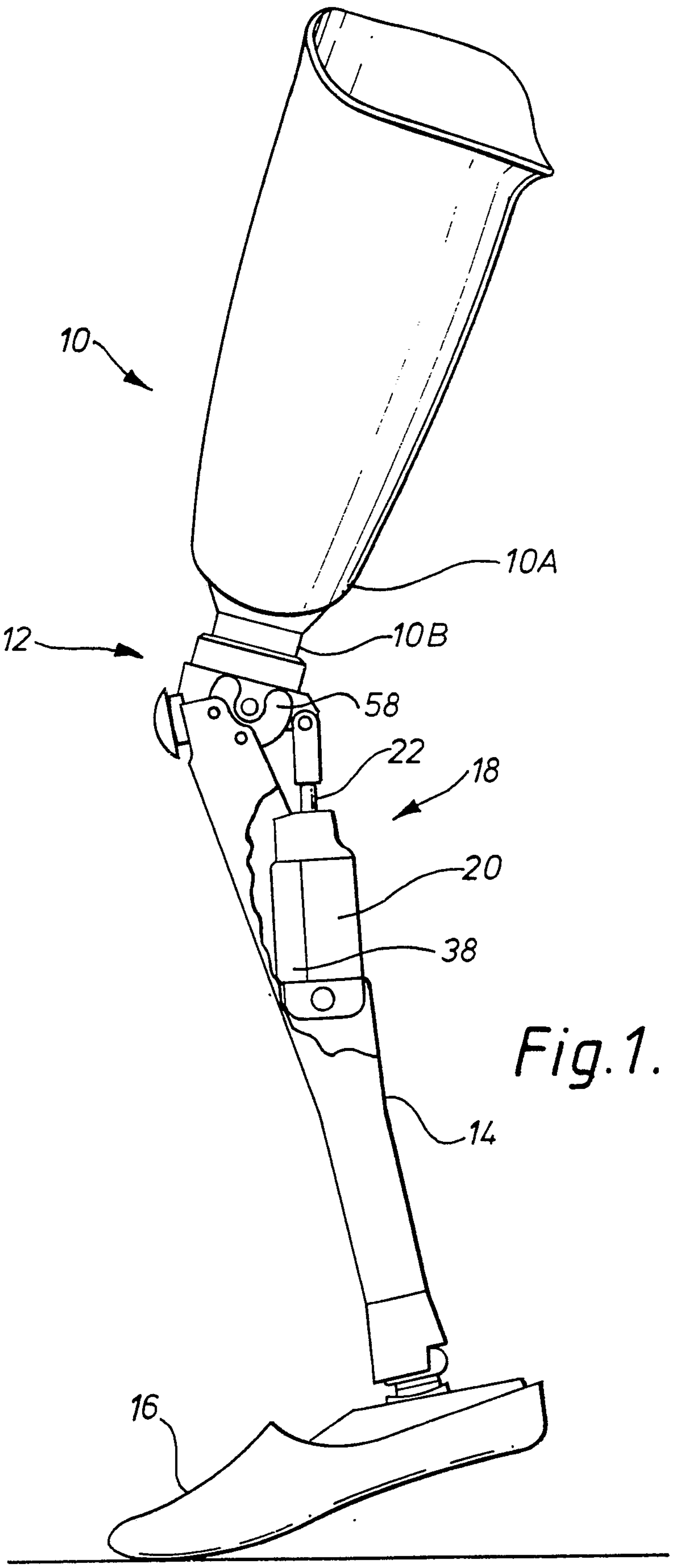

Fig.1.

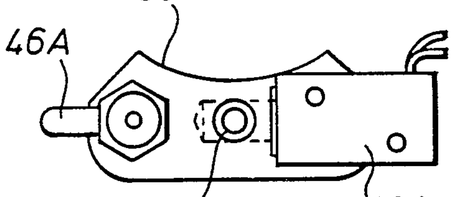
38A
46A
40
48A
38

Fig. 3.

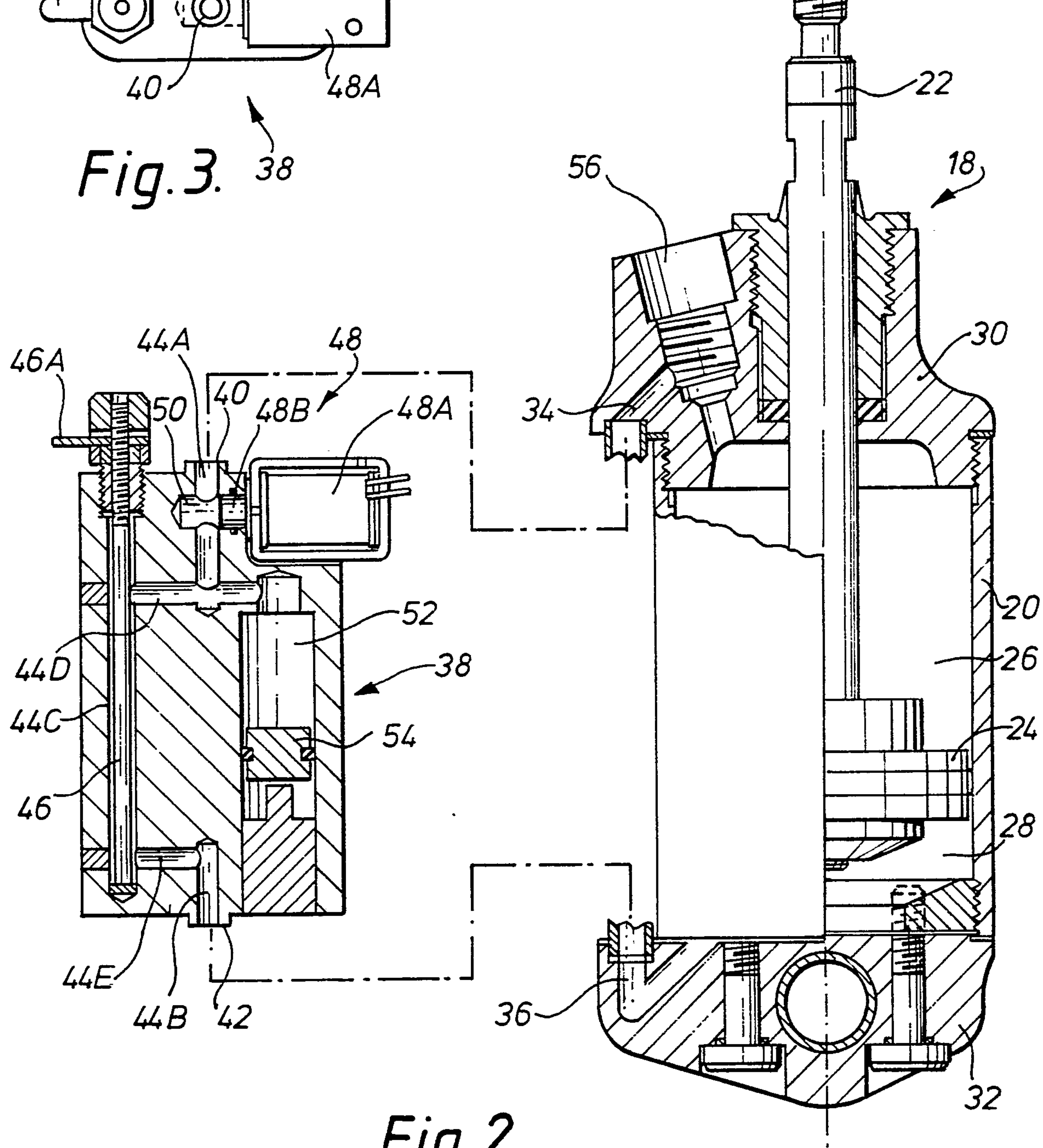
22
56
18
30
44A
48
46A
50
40
48B
48A
34
20
52
26
44D
38
44C
54
24
46
28
44E
44B
42
36
32

Fig. 2.

AN ARTIFICIAL LIMB

This invention relates to artificial limbs and in particular to a device for controlling the movement of an artificial limb joint.

Passive devices for controlling the movement of artificial limb joints are well-known. A knee joint, for example, may be controlled by a pneumatic piston and cylinder device coupled between the thigh and shin members to restrict movement of the shin and foot during the flexion and extension of the joint. Valves and orifices associated with the device are used to set the resistance to movement which is generally different during flexion from that during extension to achieve a required gait similar to that of the natural leg.

A knee joint may also include a knee stabiliser in the form of a friction brake which is automatically engaged when the patient's weight is placed on the leg. When engaged, the stabiliser exhibits greater resistance to joint flexion than to joint extension.

Such devices, being mechanically actuated by forces applied to them through the limb components as the patient walks, have limitations in the functions which they can carry out.

According to this invention an artificial limb has a joint and an improved control device containing an electrorheological fluid. Such a fluid has the property that its viscosity can be altered over a wide range by the application of a controllable electric field. If the field is sufficiently strong, the fluid behaves virtually as a solid, providing the shear force applied to the fluid is maintained below a predetermined maximum value. The fluid may be contained in a piston and cylinder device associated with a knee joint, mounted in a similar manner to a known pneumatic swing phase control device, the flow of fluid within the cylinder being controlled, for instance, by an electroviscous valve.

Being electrically activated, a control device incorporating an electrorheological fluid is particularly suitable for electronic control. Current consumption of an electrorheological device can be extremely low being typically less than 1 milliamp and often as little as tens of microamps, with the result that power consumption, generally a limitation with electrical artificial limb devices, can be comparatively low, even at the high voltages required to obtain the necessary field strength. The action of the control device can be virtually instantaneous, unlike existing electromechanical systems.

The invention also includes an electrically activated artificial limb control device responsive to the electrical potentials which accompany muscle contractions. In the case of a device such as a flexion damper or stabiliser relying on the changing viscosity of an electrorheological fluid, such myoelectric control is especially advantageous, further reducing or eliminating moving parts in the activating apparatus. In this way, myoelectric voltages associated with, for example, muscle remnants in the amputee's stump may be amplified to control directly the fluid viscosity, offering a very rapid response and improved control of the limb by the patient than is possible with a mechanically operated device.

As an alternative or as an adjunct to myoelectric activation, the control device may be activated by a load sensor associated with the limb. Thus, a strain gauge attached to a load-bearing member of the limb, a microswitch operated by a load-sensitive mechanism, or a pressure sensitive transducer (for instance a force-sensing variable film resistor incorporated in the foot) may be used to alter the electric field of the device and consequently the viscosity of the electrorheological fluid to obtain the required control of limb movement. Control of the electric field may be performed by means of a microprocessor in response to one or more of the stimuli mentioned above, or in response to other stimuli.

The characteristics of an electrorheological fluid can be designed by selection of its composition so that, for example, the absolute viscosity with no electric field applied can be prescribed, as well as the range of viscosity available over a given field strength range. In some circumstances, the available range of viscosity and/or a limit on the size of the control device may be such that virtual locking of the knee joint, or locking without the continuous application of excessive power, cannot be achieved while being able to achieve sufficiently low resistance to flexion when the field strength is zero. In a preferred embodiment of the invention, the control device includes both the electroviscous valve and a mechanically operating valve such as an electromechanical valve incorporating a solenoid. In this way, it is possible to achieve a total lock without the continuous application of power. The mechanically operating valve may be actuable by a solenoid arrangement requiring only momentary application of a voltage of a predetermined polarity to close the valve and a momentary application of a voltage of the opposite polarity to open it. Alternatively, the solenoid arrangement may have respective input terminals for closing and opening the valve, both actuable by a pulse of the same polarity. During the period in which the solenoid controlled valve is closed, the electric field applied to the fluid in the electroviscous value can be removed to reduce power consumption during the locked condition.

The invention will now be described by way of example with reference to the drawings in which:-

Figure 1 is a side elevation of a lower limb prosthesis including a swing phase control device;

Figure 2 is a composite diagram in exploded form, showing in section parts of a control device for use in an artificial limb in accordance with the invention; and

Figure 3 is a plan view of a valve block shown in Figure 2.

Referring to Figure 1, a lower limb prosthesis for an above-knee amputee has an upper limb component 10 in the form of a thermoplastic socket 10A coupled via an alignment device 10B to a knee joint mechanism 12. The mechanism 12 is mounted in a lower limb component comprising a hollow fibre-reinforced plastics shin 14 which, in turn, is connected to an artificial foot 16. Coupled between the upper limb component 10 and the lower limb component 14 is a piston and cylinder swing phase control device 18. This control device has a cylinder assembly 20 pivotally connected to the shin component 14 and a piston rod 22 pivotally connected to the upper limb component 10. As described so far, such an arrangement is conventional, the control device 18 serving to resist relative movement of the upper and lower limb components by restriction of the fluid flow from one side to the other of a piston (not shown in Figure 1) housed in the cylinder 20.

The control device 18 is shown in detail in Figures 2 and 3. Referring to these Figures, it will be seen that the piston rod 22 is connected to a piston 24 inside the cylinder 20, thereby dividing the interior of the cylinder into two chambers 26, 28, the volumes of which respectively increase or decrease in alternation as movement occurs at the knee joint 12. The cylinder body includes upper and lower caps 30, 32 which extend beyond the cylindrical outline of the central part of the cylinder 20 which houses the piston 24 to provide for connection outside the cylinder to chambers 26 and 28 via fluid passages 34 and 36. It should be understood in this connection that the caps 30 and 32 are sectioned in this drawing in different planes on the left and right hand sides of the centre line of the piston rod 22.

Fitted between the passageways 34 and 36 is a valve block 38 which is shown in section in Figure 2 and in plan view in Figure 3. The sectioning plane of the valve block 38 in Figure 2 is perpendicular to the sectioning planes used for the piston and cylinder assembly, a concave face 38A of the valve block 38, visible in Figure 3, abutting the wall of the cylinder 20.

The cylinder block 28 has upper and lower ports 40, 42 connected by a passageway 44 comprising upper and lower vertical portions 44A, 44B, an intermediate vertical portion 44C, and horizontal connecting portions 44D, 44E. By connecting the ports 40 and 42 to the passages 34 and 36 in the caps 30, 32 in the piston and cylinder assembly, a bypass passage is formed connecting the chambers 26, 28 on either side of the piston 24. The passageway portions 44A-44E are bored out of a conductive metallic valve block body which forms one electrode of an electroviscous valve associated with the passageway portion 44C. The other electrode comprises an electrically conductive rod 46 mounted axially in the passageway portion 44C so as to form a space of annular cross section through which electrorheological fluid may flow between one chamber 26 and the other chamber 28. Application of a high electrical potential between the two electrodes causes an increase in the viscosity of the fluid in the passageway portion 46, thereby resisting fluid flow. The potential is applied to two terminals, one of which 46A is electrically connected to the rod 46, and the other of which (not shown) is connected to the body of the valve block 38. It will be understood that these terminals are connected to electrical circuitry including a power supply, a microprocessor, and an amplifier for applying a variable voltage in response to any of a number of alternative stimuli, such as myoelectric signals picked up from the patient's stump, or signals from an electrical transducer operable to sense forces applied to the limb. Such a transducer may be a load sensitive transducer attached to the extremity of the limb to sense application of the patient's weight, or it may be a strain gauge attached to a load bearing member such as the shin 14. Signals may be obtained, in addition, from an accelerometer. The power supply and electrical circuitry are not shown in the drawings.

As has already been mentioned, in certain circumstances it is desirable to be able to block completely the passageway 44A-44E, for example, to lock the knee joint during long periods of standing, when a comparatively large load is applied to the limb, or as a means of reducing the time during which it is necessary to apply an intense electrical field to the fluid in passageway portion 44C. For this purpose, an electromechanical valve 48 is mounted adjacent passageway portion 44A. The valve 48 comprises a solenoid 48A connected to a plunger 48B housed in a transverse passage 50 intersecting passageway portion 44A. Operation of the solenoid 48A causes the plunger to move across or to be withdrawn from passageway portion 44A, according to the signals applied to the solenoid winding.

Since the control device 18 includes a single ended piston and cylinder assembly, an expansion chamber 52 with a sliding expansion piston 54 is provided in valve block 38.

The control device 18 may be charged with electrorheological fluid through a charging port 56 in the top cap 30 of the cylinder 20. It will be appreciated that this port is normally plugged.

The embodiment of the invention described above and shown in the drawings includes a control device for controlling the swing phase of knee joint movement and restriction of flexion, i.e. stabilisation, during the stance phase, the control device 18 using for example, a load sensor or an alternative stimulus. It will be appreciated, however, that the stabilising function could be carried out by a conventional mechanical knee stabiliser using a load-sensitive friction brake, leaving the swing-phase to be controlled by the control device described above.

A further refinement of the preferred device, not shown in the drawings, is the provision of a variable volume fluid chamber, associated with the valve block 38 or the cylinder assembly 20, which fluid may enter against the pressure of a spring or other resilient means. Preferably, the chamber is connected to passageway portion 44B in the valve block 38. This feature allows a limited degree of knee flexion during the stance phase, i.e. when the control device 18 is otherwise locked and providing stability.

CLAIMS

1. An artificial limb comprising limb components which are interconnected by a joint allowing rotational movement between the components, and a control device associated with the joint for resisting relative movement between the components, the control device containing an electrorheological fluid and electrical actuating means.

2. An artificial limb according to claim 1, wherein the actuating means includes an electrical transducer operable to sense forces applied to the limb.

3. An artificial limb according to claim 2, wherein the transducer is a load-sensitive transducer arranged to produce a changing electrical signal in response to application of a patient's weight to the limb.

4. An artificial limb according to claim 2 or claim 3, including a pressure sensitive transducer attached to an extremity of the limb.

5. An artificial limb according to any preceding claim, wherein the actuating means includes a microprocessor.

6. An artificial limb according to claim 2 or 3, including a strain gauge for attachment to a load-bearing member of the limb.

7. An artificial limb according to claim 2 or claim 3, including an accelerometer.

8. An artificial limb according to any preceding claim, wherein the actuating means includes a myoelectric sensor.

9. An artificial limb according to any preceding claim, wherein the control device comprises a cylinder containing the electrorheological fluid, and a piston housed in the cylinder.

10. An artificial limb according to claim 9, wherein the cylinder and the piston are coupled to respective ones of the limb components.

11. An artificial limb according to claim 9 or claim 10, wherein the control device further comprises an electroviscous valve associated with the assembly of the piston and the cylinder for restricting the movement of the piston in the cylinder.

12. An artificial limb according to any of claims 9 to 11, wherein the valve is associated with a passage connecting a cylinder space on one side of the piston with a cylinder space on the other side of the piston.

13. An artificial limb according to claim 12, wherein the electroviscous valve has an elongate passageway with a conductive wall, and an electrode located axially within the passageway, the electrode being electrically insulated from the conductive wall.

14. An artificial limb according to any of claims 1 to 8, wherein the control device is associated with a knee joint, and has first and second parts which are movable relative to each other and connected respectively to an upper limb component and a lower limb component, wherein the device has chambers containing the electrorheological fluid and is so arranged that flexion of the knee joint causes fluid to flow from one of the chambers to another through a passageway, and wherein the passageway includes an electroviscous valve and a mechanically operating valve in series with each other.

15. An artificial limb according to claim 14, wherein the mechanically operating valve is electrically actuated and is operable substantially to block the passageway.

16. An artificial limb according to any preceding claim, further comprising a mechanical friction brake associated with the joint.

17. An artificial limb according to claim 16, wherein the friction brake is load-sensitive.

18. A control device for use in an artificial limb as claimed in any preceding claim.

19. A control device for an artificial limb, the device being constructed and arranged substantially as herein described and shown in Figures 2 and 3 of the drawings.

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