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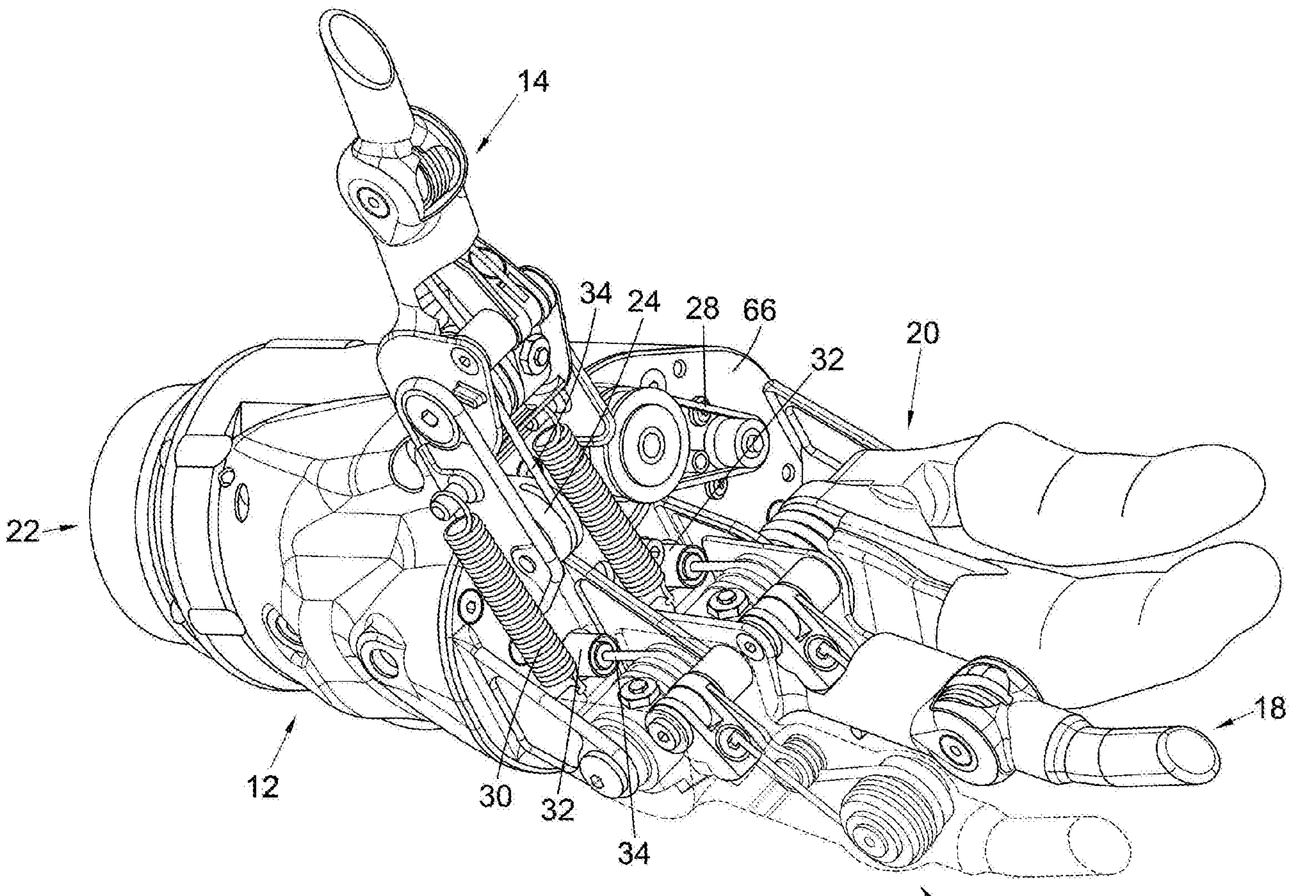

Fig.1A
(Prior art)

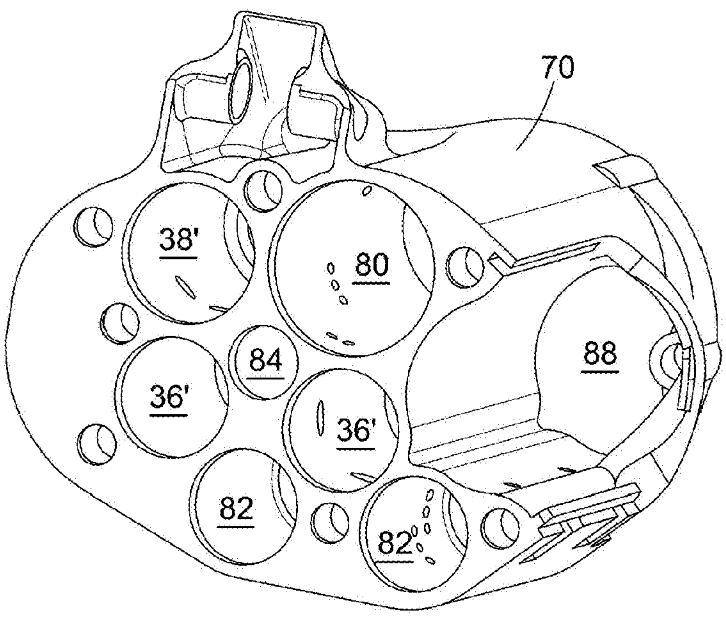

Fig.1B
(Prior art)

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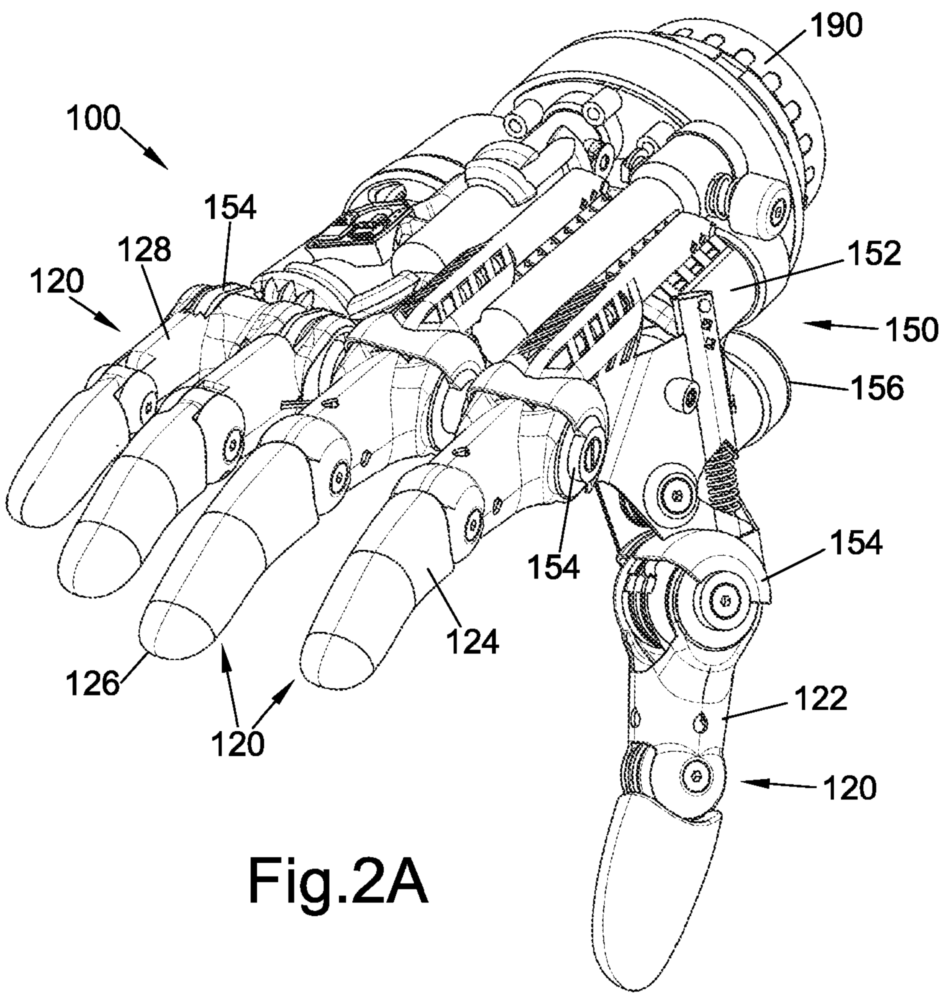

Fig.2A

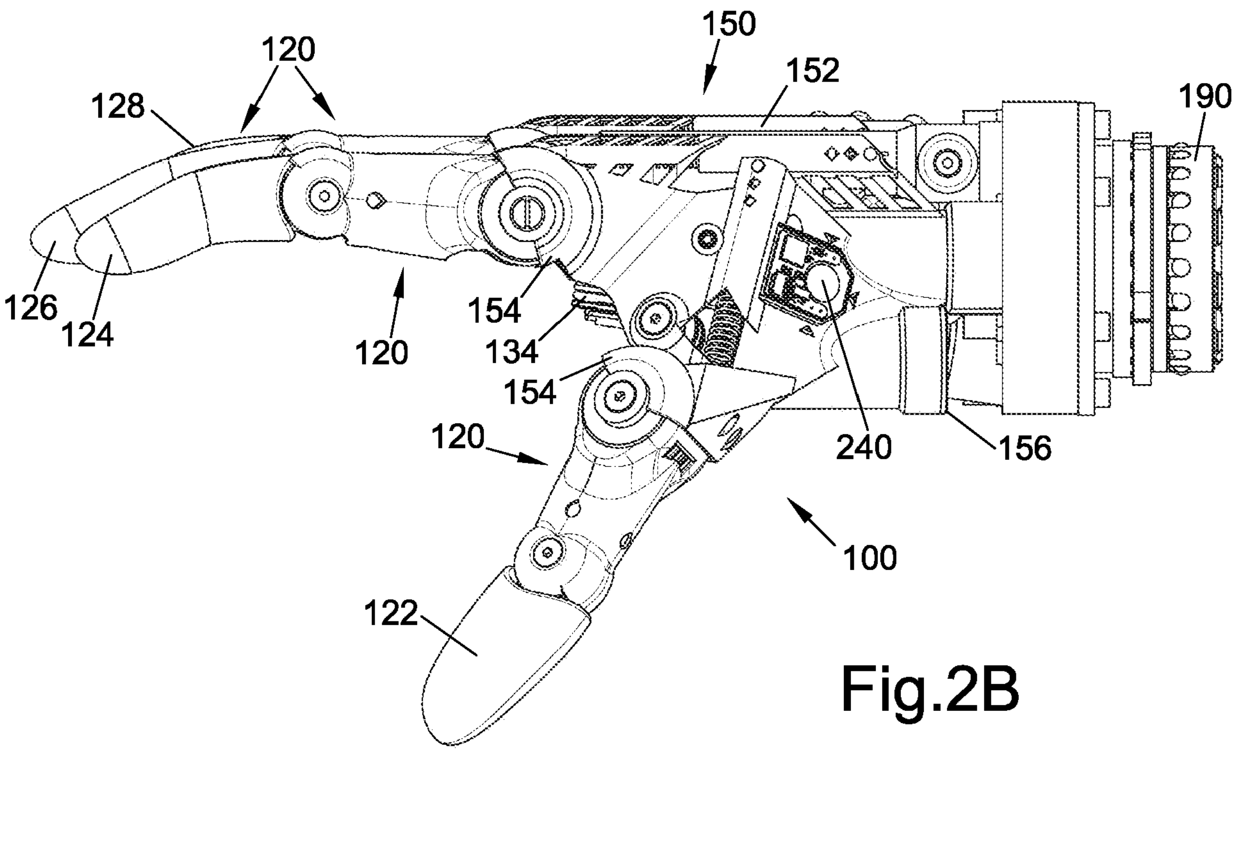

Fig.2B

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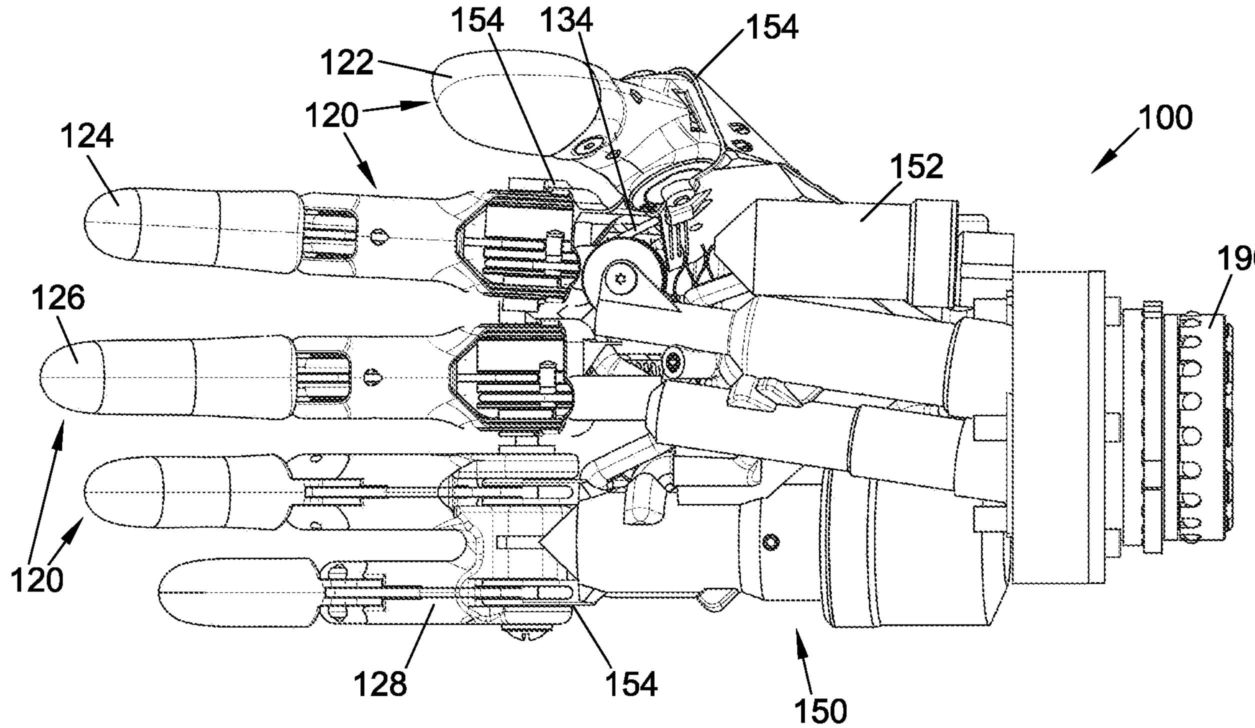

Fig.2C

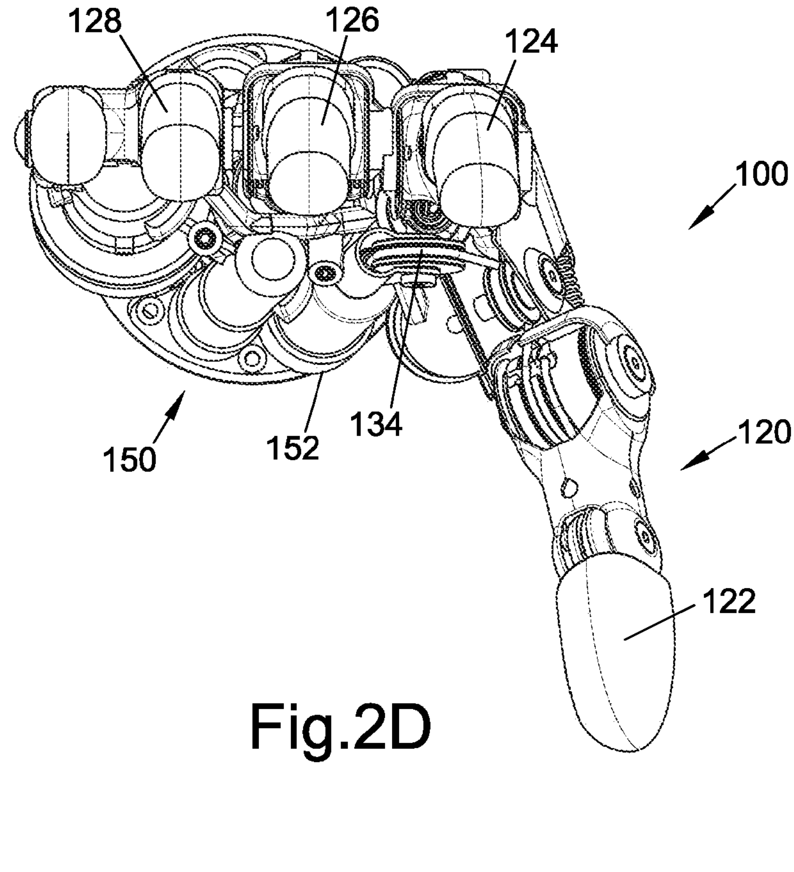

Fig.2D

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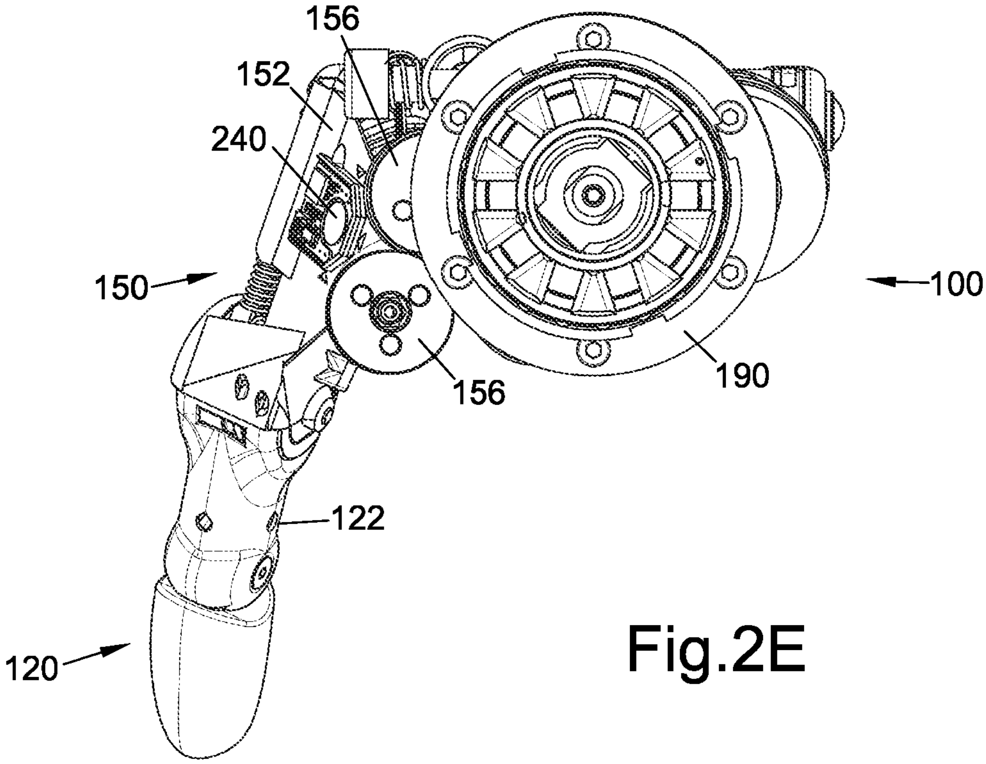

Fig.2E

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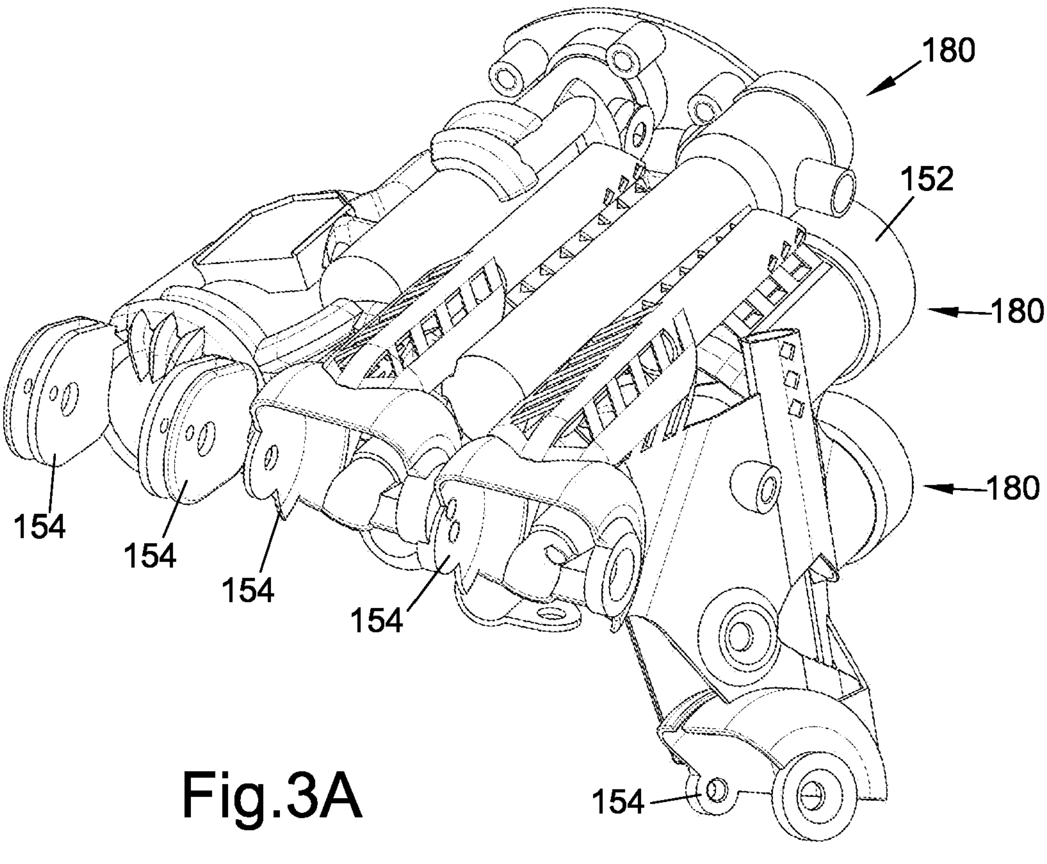

Fig.3A

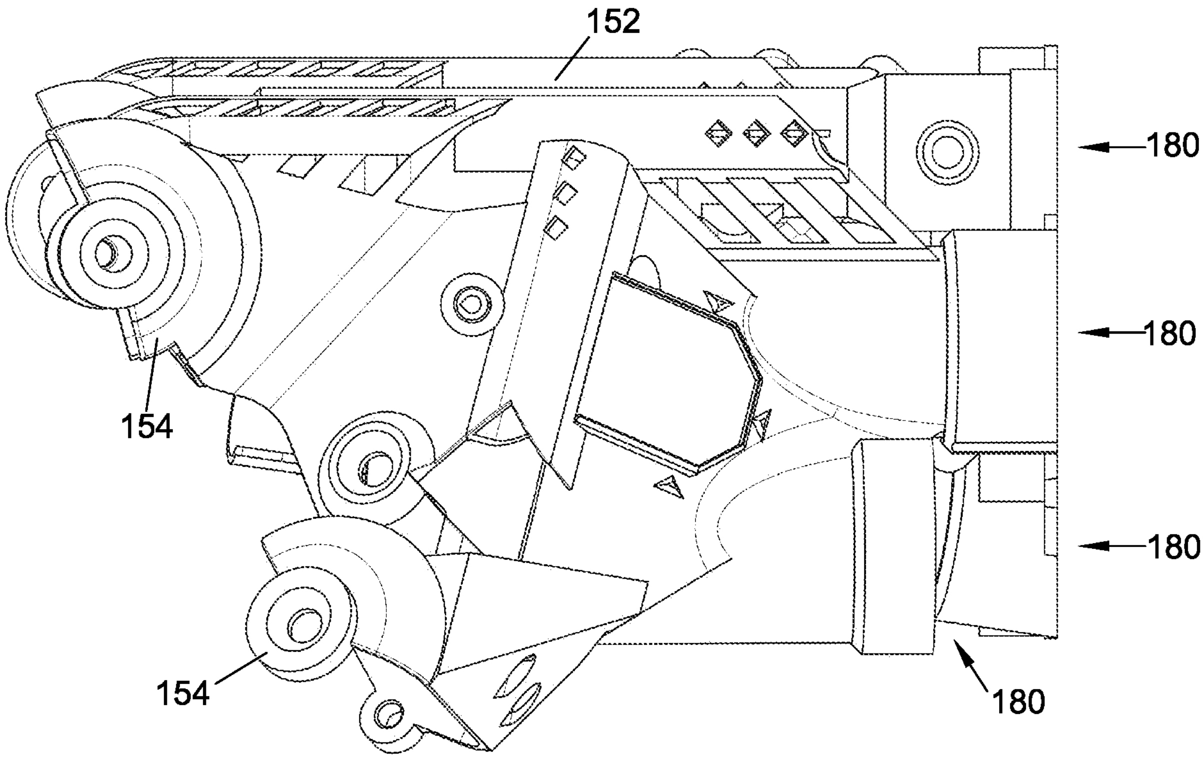

Fig.3B

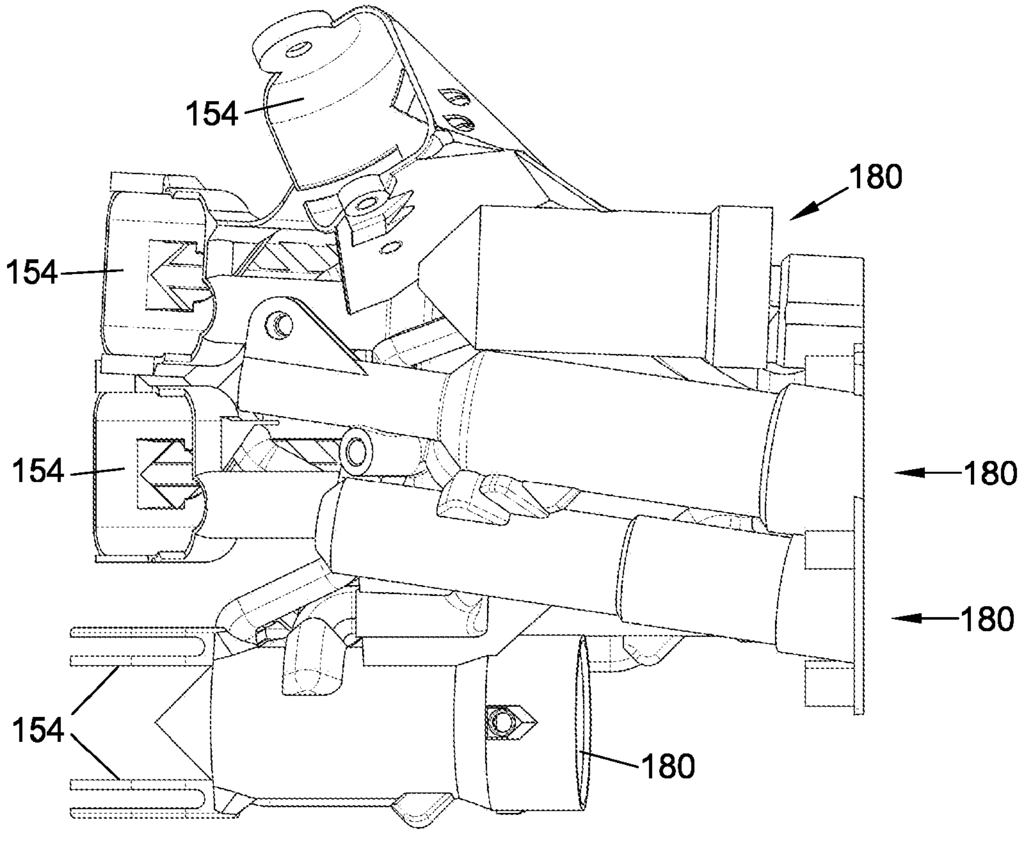

Fig.3C

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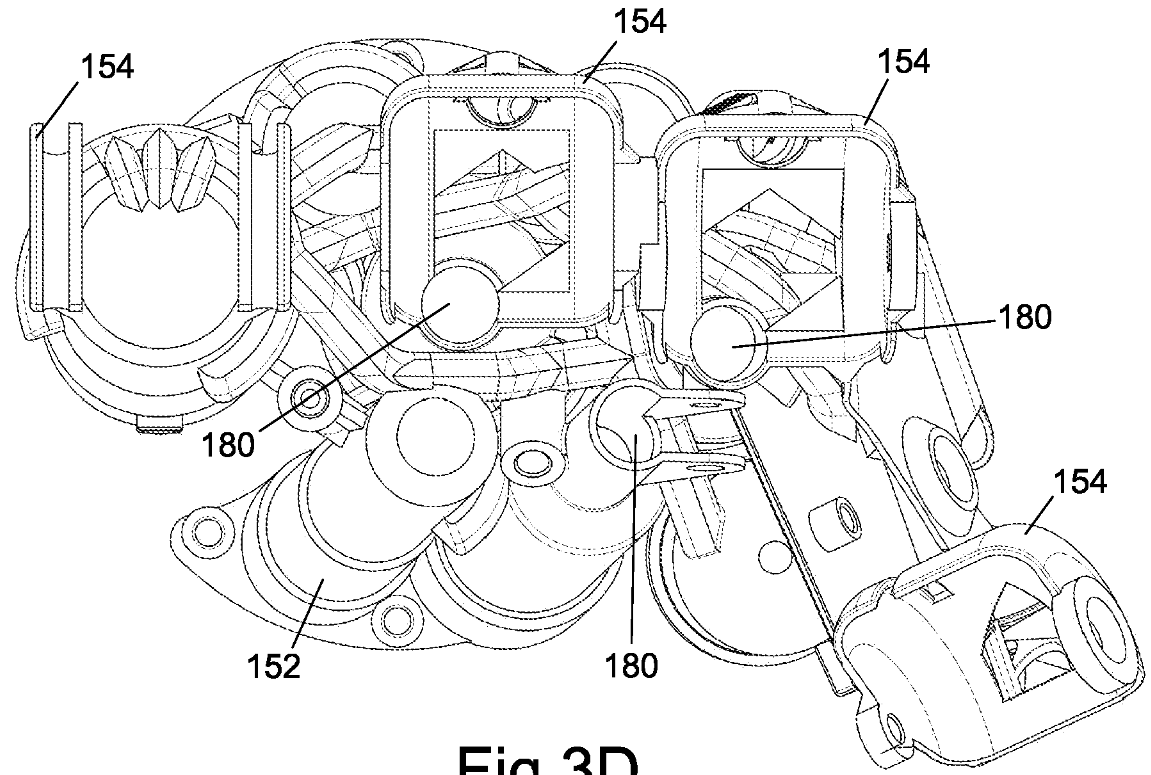

Fig.3D

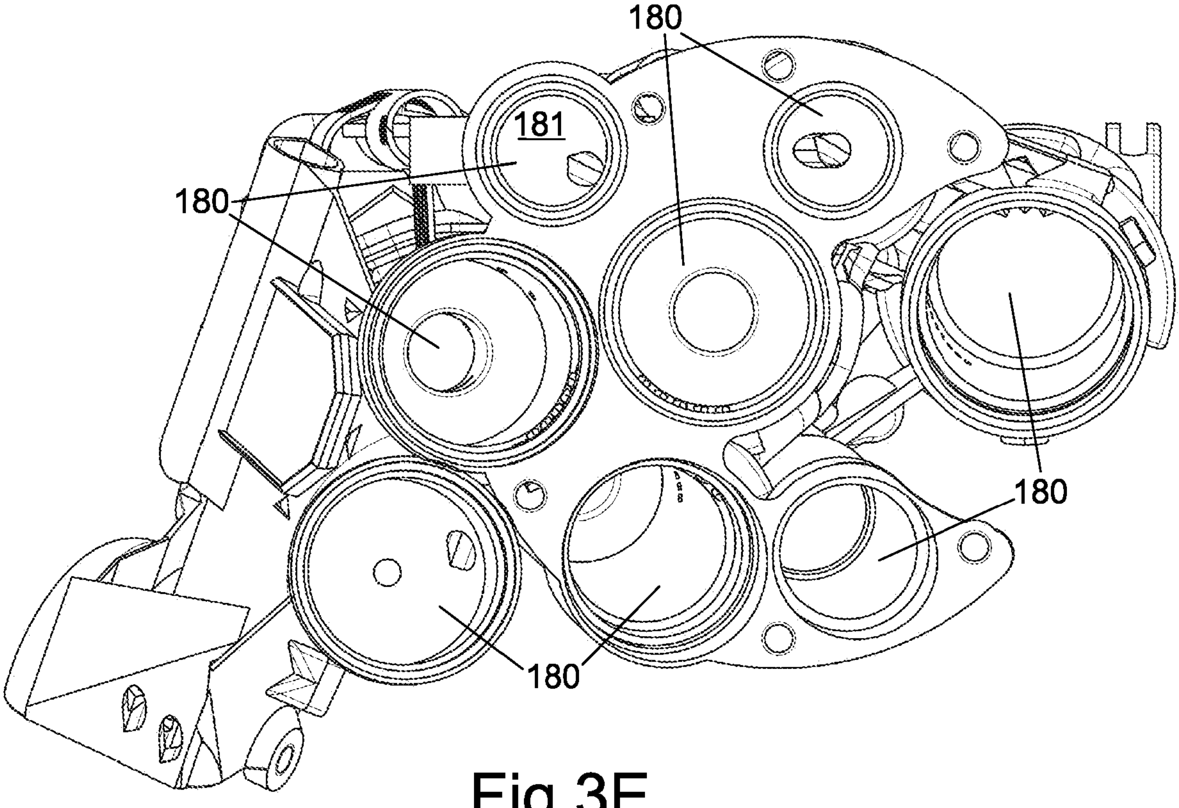

Fig.3E

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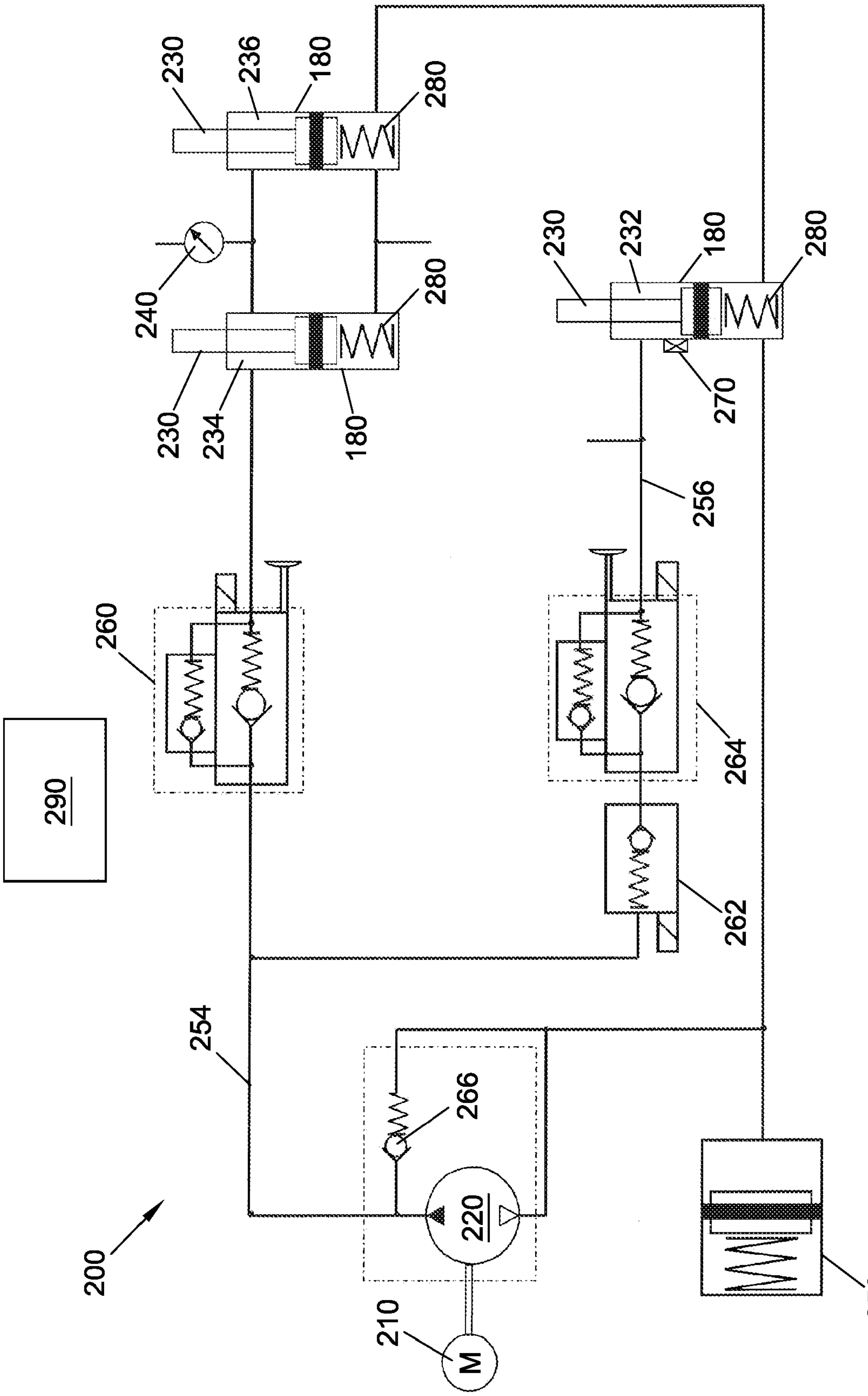
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Fig.4

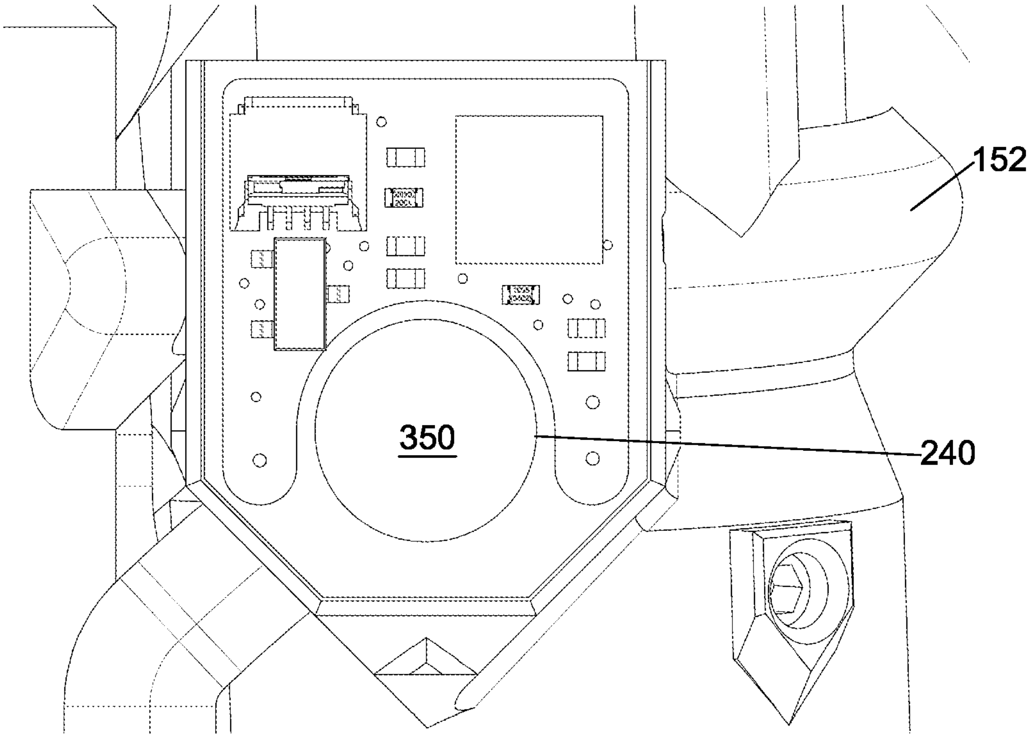

Fig.5A

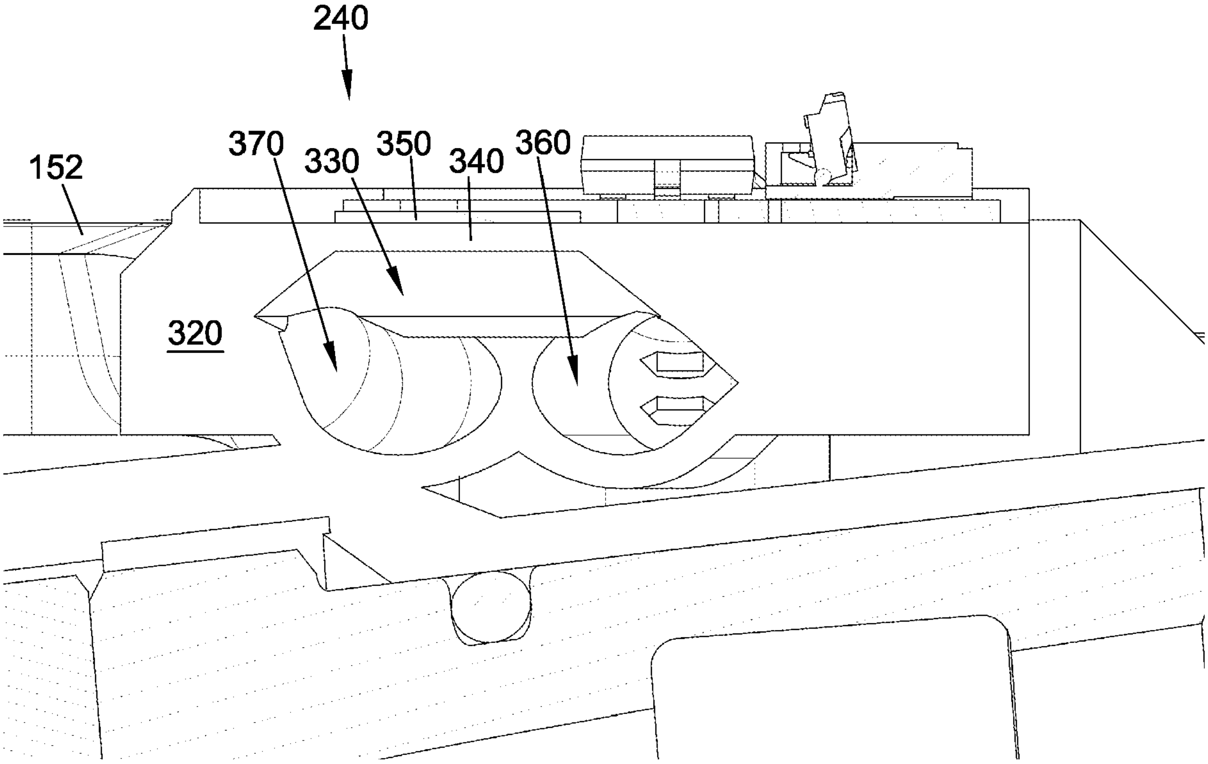

Fig.5B

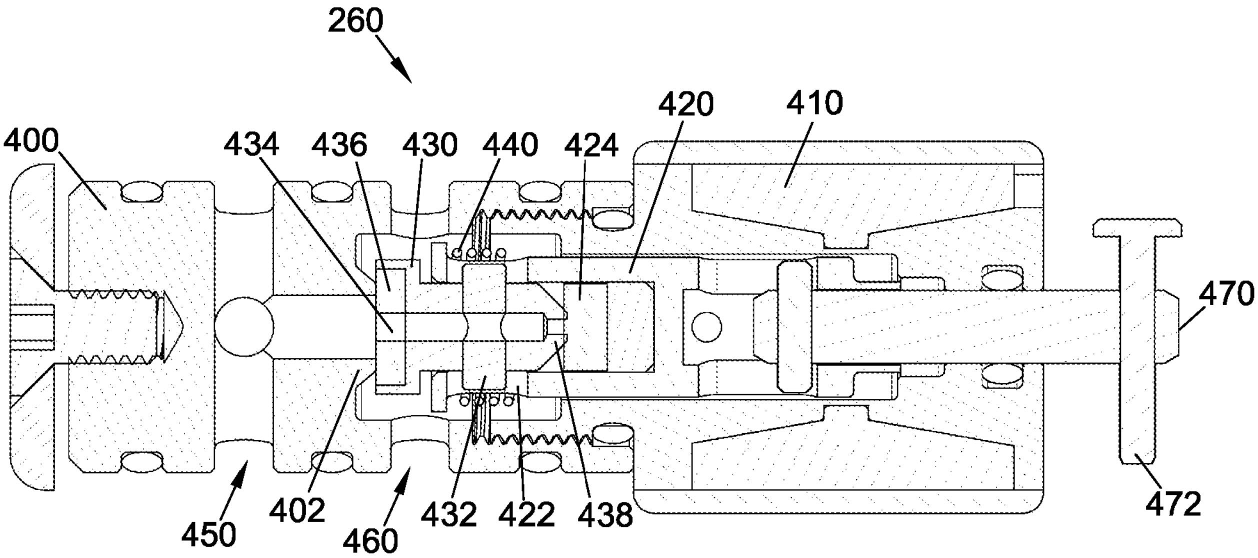

Fig.6A

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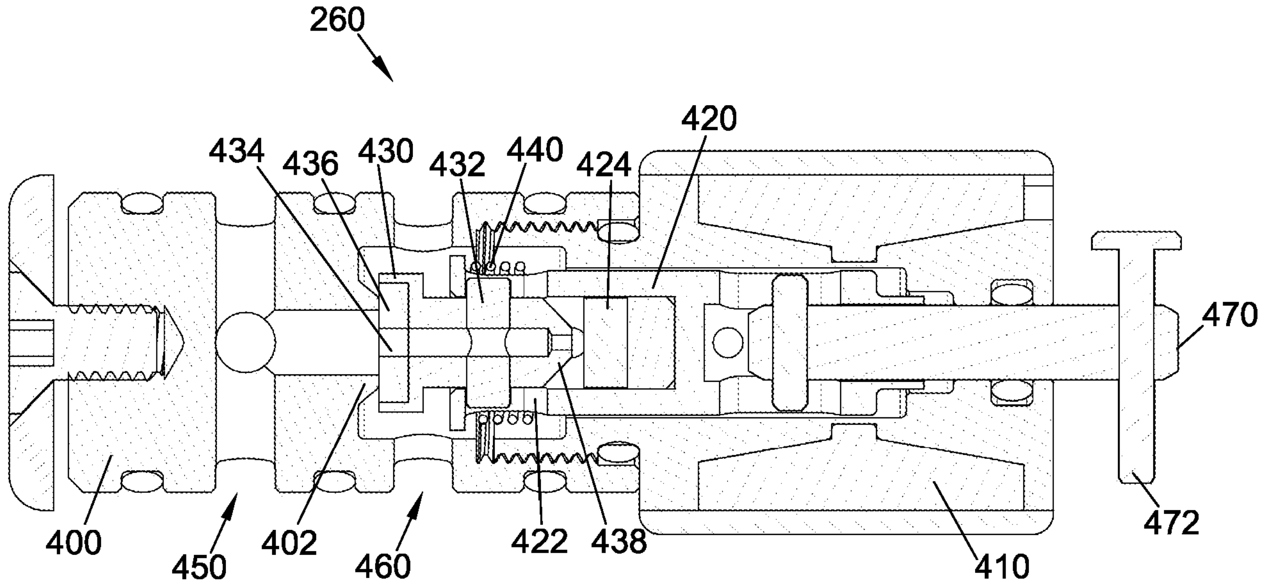

Fig.6B

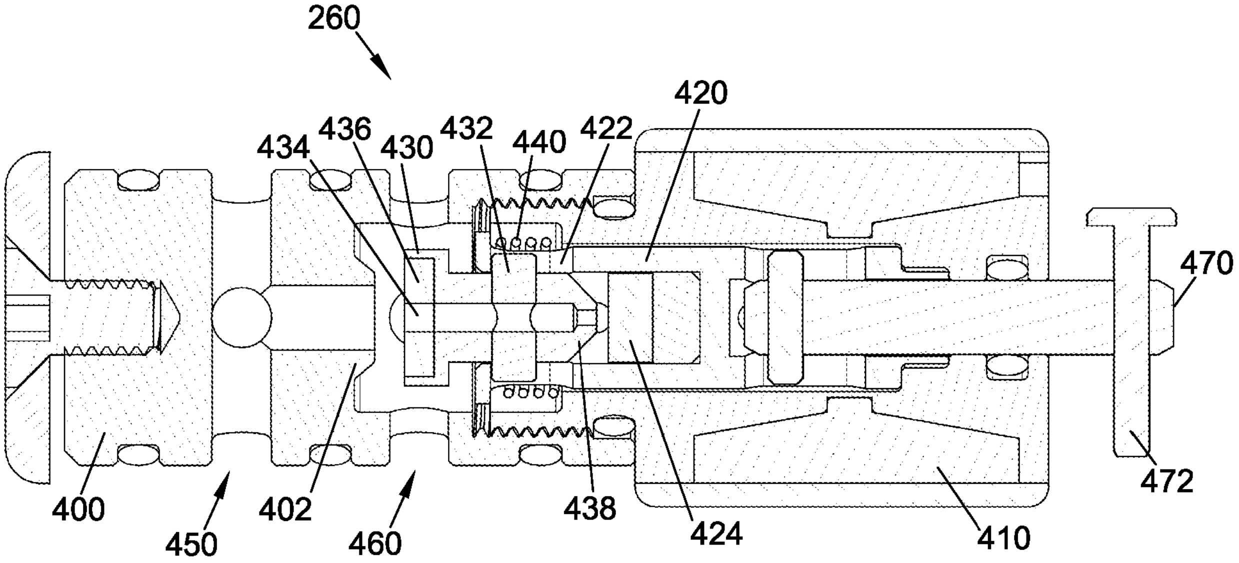

Fig.6C

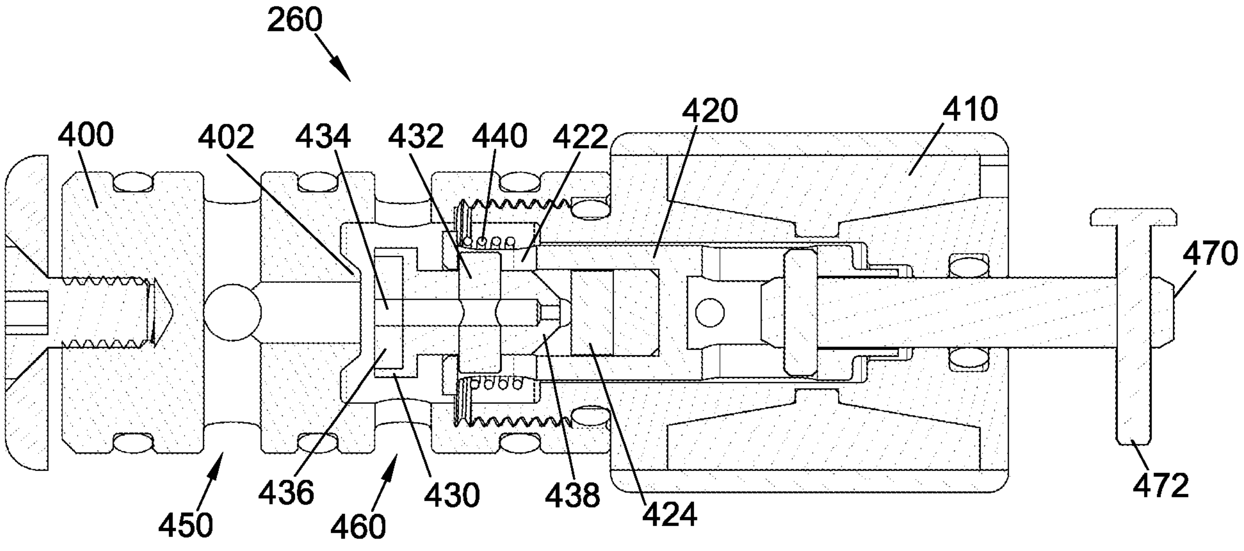

Fig.6D

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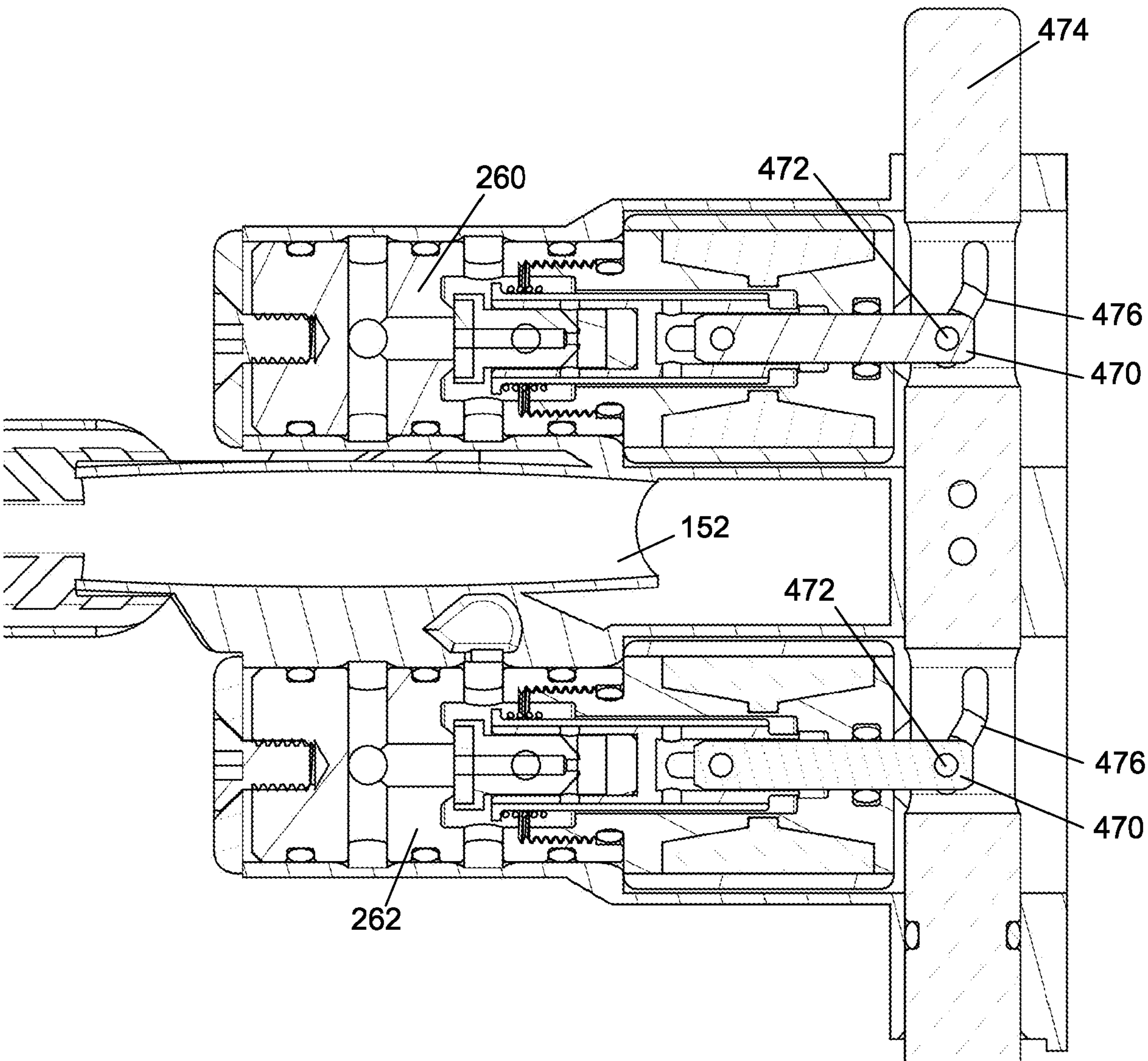

Fig.6E

METHOD OF CONTROLLING AN ARTIFICIAL HAND

Field

The present invention relates to a method of controlling an artificial hand, in particular a method of controlling an artificial hand used to replace a person’s missing hand.

Background

There is an on-going demand for improvements in artificial hands not only for use as prosthetics but also in relation to robotics and automated handling devices that can mimic the dexterity of the human hand. The last few decades have seen great advances in relation to myoelectric artificial hands, which use electromyography signals or potentials from voluntarily contracted muscles within a person's residual limb to control the movements of the hand. A sensor or multiple sensors are placed on the surface of the skin to receive the signals. Some time ago Otto Bock (Otto Bock HealthCare Deutschland GmbH of Duderstadt, Germany, www.ottobock-group.com) designed a wrist connector unit that has become a standard in the field of myoelectric artificial hands. Devices also exist that use electromechanical switches actuated by body movements in order to control the artificial hand.

A review of anthropomorphic prosthetic hands can be found in “Mechanical design and performance specifications of anthropomorphic prosthetic hands: A review” by Joseph T. Belter et al, JRRD, volume 50, number 5, 2013, pages 599-618. As discussed in that review, a number of companies are active in the field and have commercial products on the market. The commercial products make use of various combinations of electrical motors and mechanical couplings to actuate the fingers and thumb of the hand with varying degrees of freedom. Whilst these commercially available hands can in some cases provide a suitable level of dexterity for an artificial hand for use as a prosthetic hand they generally suffer from excessive weight, causing discomfort for the user, and they are complex and expensive.

Hydraulically actuated hands have also been proposed, but typically are operated at a rather low pressure (9 to 10 bar) which means that the gripping force is relatively low. Another disadvantage is the use of externally mounted hoses and couplings, which are vulnerable to damage and mean that the hand is not sufficiently robust for everyday use as a prosthetic. There is also a significant risk of leakage of the hydraulic fluid.

Significant advances in hydraulically actuated artificial hands were made by the present inventors and disclosed in a series of patents, GB2537898, GB2537899, and GB2537900. An example of an artificial hand according to the disclosure of those patents is shown in Fig. 1, and while that hand represents substantial improvements compared to previously known hydraulically powered artificial hands, further improvements may still be made, for example by reducing the weight, bulk, and/or complexity of the artificial hand, as well as improving its reliability, dexterity and ease of use, and simplifying its manufacture.

Summary

According to a first aspect of the invention there is provided a method of controlling digit mechanisms of an artificial hand, comprising fixing the position of an actuable digit mechanism at a predetermined position using a two-stage valve.

The digit mechanism of the artificial hand (e.g. a thumb digit mechanism) may be actuable to close in a gripping motion (e.g. for use in gripping an object) and may be actuable to open in a releasing motion (e.g. for releasing a gripped object). The method may therefore comprise locking the digit mechanism at the predetermined position so that it is not moveable e.g. by an externally applied force. The position of the digit mechanism may be fixed by preventing actuation of a hydraulic actuator arranged to actuate the digit mechanism. Preventing actuation of the hydraulic actuator may comprise preventing flow of hydraulic fluid to and/or from the hydraulic actuator. The method may therefore comprise using the two-stage valve to prevent fluid flow to and/or from the hydraulic actuator e.g. by ensuring that the two-stage valve is closed to prevent any fluid flowing through it. The method may comprise closing the two-stage valve, or maintaining the two-stage valve in a closed state.

The digit mechanism is preferably a thumb digit mechanism, because the process of fixing the position of a thumb digit mechanism mimics the operation of a human hand, and contrasts with processes wherein a thumb is simply actuated to close until further movement is prevented e.g. by contact with a gripped object. Typically during a gripping motion, and particularly during a strong gripping motion, a human thumb will be stationary and the opposing fingers will close against the stationary thumb. The strength of the grip then comes from the force of the fingers closing against the immovable thumb. Therefore, the method of the present invention behaves in a manner that a wearer of the artificial hand will likely instinctively understand, and therefore an artificial or prosthetic hand operating according the invention of the first aspect will feel more natural for a wearer and will be easier for the wearer to use.

Although the method of this aspect is applicable to a generic digit mechanism, the digit mechanism is preferably a thumb digit mechanism (e.g. for the reasons given herein) and the discussion herein therefore typically references a thumb digit mechanism. However, it will be appreciated that discussion of a thumb digit mechanism may also apply to any digit mechanism.

The use of a two-stage valve not only permits the position of the thumb digit mechanism to be fixed at any location, but also allows the use of relatively high pressures in the artificial hand. Thus, the artificial hand can exert a stronger grip than known artificial hands, whilst also improving functionality and ease of use. Other hydraulic hands may operate in the region of about 10 bar (1 MPa), whereas the artificial hand described herein may operate at pressures of greater than 25 bar (2.5 MPa), greater than 50 bar (5 MPa), and greater than 60 bar (6 MPa). The method may comprise providing a two-stage valve as described herein.

The method may comprise actuating the thumb digit mechanism to close in a gripping motion; and fixing the position of the thumb digit mechanism when it reaches the predetermined position. The method may therefore comprise moving the thumb digit mechanism, and then stopping it in a partially closed position. The method may comprise fixing the position of the thumb digit mechanism if and only if the thumb digit mechanism reaches the predetermined position. The method may comprise locking the position of the thumb digit mechanism in a partially closed position. The method may comprise using a position sensor to monitor the position of the thumb digit mechanism and may comprise fixing the position of the thumb digit mechanism when the position sensor indicates that the thumb digit mechanism has reached the predetermined position.

The method may comprise releasing (i.e. un-fixing) the thumb digit mechanism using the two stage valve, actuating the thumb digit mechanism to a second predetermined position, and fixing the thumb digit mechanism in the second predetermined position using the two-stage valve. The second predetermined position may be different to the first predetermined position. The second predetermined position may be a partially closed position. The thumb digit mechanism may therefore be moved after it has been fixed a first time, and then fixed in another position.

The method may comprise fixing the position of the thumb digit mechanism at its initial position before it has started closing i.e. fixing the thumb digit mechanism in its open position. The thumb digit mechanism may subsequently be released (i.e. un-fixed), moved, and fixed in another position.

The method may comprise fixing the position of the thumb digit mechanism when the thumb digit mechanism encounters a predetermined resistance. The predetermined resistance may be indicated by a predetermined pressure within the hydraulic actuator for the thumb digit mechanism, and the method may therefore comprise fixing the position of the thumb digit mechanism when pressure within the hydraulic actuator for the thumb digit mechanism reaches a predetermined level. The method may comprise fixing the thumb digit mechanism if and only if the pressure within hydraulic actuator reaches a predetermined level. When the thumb digit mechanism is contacting e.g. an object or an opposing finger digit mechanism, the pressure within the hydraulic actuator will increase as a pump is run to pump hydraulic fluid to the hydraulic actuator. The method may therefore include monitoring the pressure within the hydraulic actuator for the thumb digit mechanism, and may comprise monitoring the pressure using a pressure sensor. The pressure sensor may comprise any of the features of the pressure sensor described herein.

Fixing the position of the thumb digit mechanism may comprise using a solenoid valve in series with the two-stage valve. The solenoid valve may be arranged to control fluid flow to the hydraulic actuator for the thumb digit mechanism, and may be in series with the two-stage valve but oriented in an opposite direction thereto in order to check (i.e. stop) fluid flow in the opposite direction to the two-stage valve. The method may therefore comprise closing the solenoid valve to prevent fluid flow to and/or from the hydraulic actuator for the thumb digit mechanism. The method may include opening the solenoid valve e.g. by energising its solenoid, in order to provide hydraulic fluid to the hydraulic actuator and actuate the thumb digit mechanism. The method may comprise checking (i.e. stopping) fluid flow to the hydraulic actuator by closing the solenoid valve e.g. by de-energising its solenoid, to prevent fluid flow the hydraulic actuator thereby stopping movement of the thumb digit mechanism e.g. in one direction.

The two-stage valve may be arranged to prevent movement of the hydraulic actuator in the opposite direction to the solenoid valve. The two-stage valve may be arranged to stop flow of hydraulic fluid away from the hydraulic actuator when it is closed (e.g. de-energised), and permit flow of fluid away from the hydraulic actuator when it is open (e.g. energised).

The method may therefore comprising providing a dual valve arrangement for controlling flow of hydraulic fluid to and from a hydraulic actuator arranged to actuate the thumb digit mechanism. The valves may control fluid flow to a high pressure side of the hydraulic actuator. The dual valve arrangement may comprise the two-stage valve and the solenoid valve. Both of the valves may be one-way valves, arranged to permit fluid flow in one direction whether or not they are open, and arranged to prevent (i.e. check or stop) fluid flow in the other direction unless open. The solenoid valve and the two-stage valve may therefore be arranged to allow one-way fluid flow in opposite directions, and the method may comprise providing such an arrangement. Therefore, when both valves are closed, hydraulic fluid will be prevented from flowing to and from the hydraulic actuator and the position of the hydraulic actuator, and hence the position of the thumb digit mechanism actuated thereby, will be fixed. Because hydraulic fluid is substantially incompressible, the thumb digit mechanism will not move under external forces. Movement of the thumb digit mechanism in either direction may then be controlled by opening the appropriate one of the solenoid valve or the two-stage valve (since the other will permit fluid flow whether open or closed).

The digit mechanism may be a first digit mechanism, and the method may comprise actuating a second digit mechanism to close in a gripping motion and react against the fixed first digit mechanism. The method may comprise actuating a finger digit mechanism to close in a gripping motion and react against the fixed thumb digit mechanism. The method may therefore enable the first and second digit mechanisms (e.g. thumb and digit mechanisms) to grip. The finger digit mechanism may be opposed to the thumb digit mechanism. The finger digit mechanism may be an index finger digit mechanism. The method may comprise fixing the position of the finger digit mechanism at a predetermined position using a second two-stage valve, and hence the method may comprise providing a second two-stage valve operable to prevent fluid flow to and/or from a hydraulic actuator for actuating the finger digit mechanism. The method may comprise providing a dual valve arrangement for the finger digit mechanism as described above with reference to the thumb digit mechanism. The arrangement for the finger digit mechanism may be same as that for the thumb digit mechanism, or may be different. For example, there may be no solenoid valve for controlling fluid flow to the hydraulic actuator for the finger digit mechanism.

The method may comprise actuating the thumb digit mechanism and the finger digit mechanism to close in a gripping motion simultaneously, prior to fixing the position of the thumb digit mechanism. The method may comprise gripping an object between the thumb digit mechanism and the finger digit mechanism. The method may comprise contacting the finger digit mechanism directly with the thumb digit mechanism, and may comprise the tips of the respective mechanisms touching e.g. in a pincer grip.

The method may comprise increasing the force of the grip by increasing the pressure actuating the finger digit mechanism. The process of closing fingers against a fixed, immovable thumb mimics the functionality and operation of a human hand, and contrasts with a process in which both the thumb and fingers close simultaneously until they both stop e.g. by contact with each other or an object. Therefore, an artificial hand operating according the method of the first aspect may be easier for a wearer to use. The method may comprise actuating a plurality of finger digit mechanism.

The method may comprise using a single pump to actuate a first (e.g. thumb) hydraulic actuator arranged to actuate the first (e.g. thumb) digit mechanism and actuating a second (e.g. finger) hydraulic actuator arranged to actuate the second (e.g. finger) digit mechanism. The method may comprise using a single pump to actuate all of the hydraulic actuators for the digit mechanism. The digit mechanisms may therefore all be part of the same hydraulic circuit.

The method may comprise after fixing the position of the thumb digit mechanism, actuating a finger digit mechanism to close a finger digit in a gripping motion, and actuating the thumb digit mechanism to close over the finger digit mechanism. The method may therefore comprise controlling the digit mechanism to make a fist.

The method may comprise releasing the thumb so that it is actuable by external forces. The method may comprise simultaneously opening the two-stage valve and the solenoid valve so that the hydraulic actuator for the thumb digit mechanism is moveable in both directions by external forces. The method may therefore comprise releasing the thumb digit mechanism for actuation in both a gripping motion and an opening motion, and applying an external force to the thumb digit mechanism to close it or open it. The method may comprise actuating the thumb digit mechanism without using the hydraulic actuator arranged to actuate the thumb digit mechanism. A wearer of the artificial hand may therefore actuate the thumb digit mechanism manually e.g. using their other hand.

The method may comprise monitoring pressure within a chamber containing a hydraulic actuator arranged to actuate the thumb digit, and determining that the thumb digit has encountered the predetermined resistance when the pressure reaches a predetermined threshold. The predetermined threshold may be any suitable value and may be between 10 bar (1 MPa) and 20 bar (2 MPa), and may be about 15 bar (1.5 MPa). The pressure may be monitored directly e.g. by a pressure sensor in fluid communication with the hydraulic actuator, or may be monitored indirectly by a pressure sensor in fluid communication with e.g. a hydraulic actuator actuating a finger digit mechanism which is reacting against the thumb digit mechanism. In this case, the pressure in the thumb actuator will necessarily match the pressure in the finger actuator.

The method may comprise fixing the position of the thumb digit mechanism in response to a predetermined signal. The signal may be from a force sensitive resistor, a switch, a myoelectric sensor or any suitable device. Thus, a wearer of the artificial hand may control its operation. Actuating the thumb digit mechanism may be in response to a predetermined signal. Actuating the finger digit mechanism may be in response to a predetermined signal.

The method may comprise controlling the artificial hand using inputs from only two sensors. For example, a first signal from a first sensor may control the thumb and finger digit mechanisms to begin closing by opening the solenoid valve so that the thumb digit mechanism starts closing. The finger digit mechanism may also begin closing simultaneously. The position of the thumb digit mechanism will then be fixed e.g. when it reaches the predetermined position, and the finger digit mechanism will continue to close until resisted by the stationary thumb, at which point the force of the grip will increase as the digit mechanisms continue to be actuated for closing e.g. by continued running of a pump.

A second signal may command the artificial hand to open, whereupon the two-stage valve for the thumb digit mechanism and the two-stage valve for the finger digit mechanism may both be opened to permit hydraulic fluid to leave the hydraulic actuators for the respective digit mechanisms, which may then permit the digit mechanism to open e.g. under the urging of a spring or the like.

The method may comprise controlling a plurality of digit mechanisms. The method may comprise closing a plurality of digit mechanisms, and may comprise closing a middle finger digit mechanism, and a ring and little finger digit mechanism. The method may comprise closing the finger digit mechanisms into a grip without reacting against the thumb digit.

The method may comprise providing an artificial hand comprising any and all of the features of the artificial hand described herein. The method may comprise fixing the positions of a plurality of digit mechanisms in different predetermined positions using respective two-stage valves.

There is also described herein a two-stage valve for an artificial hand, comprising: a main fluid flow path between a first opening and a second opening; a pilot valve moveable between a first pilot position in which the main fluid flow path is closed, and a second pilot position in which the main fluid flow path is open; and a fluid bypass arranged to bypass the pilot valve; wherein the valve is arranged to open by first opening the fluid bypass, and subsequently opening the main fluid flow path by moving the pilot valve to the second pilot position.

The two-stage valve may be used in the method described herein with reference to the first aspect of the invention. During use, a pressure differential will exist either side of the two-stage valve, and therefore across the pilot valve closing the main fluid flow path. That pressure differential must be overcome to move the pilot valve from the first pilot position to the second pilot position in order to open the two-stage valve for fluid flow in both directions. The fluid bypass may be easier to open against a given pressure differential than is the main fluid flow path. For example, the fluid bypass may have a smaller cross-section than does the main fluid flow path. Therefore, by opening the fluid bypass the pressure differential across the pilot valve may be reduced to a level where the pilot valve may be actuated more easily.

The two-stage valve may comprise: a piston actuable between a first piston position and a second piston position; a solenoid arranged to actuate the piston between the first piston position and the second piston position; wherein the fluid bypass is closed by the piston when the piston is in the first piston position; and wherein movement of the piston from the first piston position opens the fluid bypass, and movement of the piston to the second piston position moves the pilot valve to the second pilot position, thereby opening the main fluid flow path.

The piston may therefore be moveable relative to the pilot valve, so that the piston may move from the first piston position (e.g. to an intermediate piston position between the first piston position and the second piston position) when actuated by the solenoid to open the fluid bypass while the pilot valve remains in the first pilot position. Since the fluid bypass may be opened against a given pressure differential more easily than would be the pilot valve, the solenoid of the two-stage valve may be relatively small and hence the two-stage valve may be smaller and lighter than a single-stage valve that would otherwise be needed to open the pilot valve directly.

The pilot valve may be carried by the piston, and may be coupled thereto to allow relative movement between the pilot valve and the piston. The pilot valve may be carried by the piston and held by a pin in a slot. The slot may be defined in the piston. The pin may be moveable in the slot and hence permit movement of the pilot valve relative to the piston.

The two-stage valve may comprise a biasing element arranged to bias the pilot valve to the first pilot position, wherein the solenoid is arranged to actuate the pilot valve against the force of the biasing element. The biasing element may be arranged to bias the piston to the first piston position. The pilot valve may be biased to the first pilot position by contact with the piston. The solenoid may therefore be activated to move the piston to the second piston position (and consequently also the pilot valve to the second pilot position), and deactivated to allow the biasing element to move the piston to the first piston position (and consequently also the pilot valve to the first pilot position). Alternatively, the biasing element may be arranged to bias the piston to the second piston position, and the solenoid may be arranged to move the piston to the first piston position.

The piston may comprise a seal arranged to seal the fluid bypass when the piston is in the first piston position. The seal may be rubber seal and may be arranged to bear against an opening of the fluid bypass e.g. under action of the biasing element, thereby preventing flow of hydraulic fluid through the fluid bypass. The seal of the piston may therefore close the fluid bypass when the piston is in the first position, thereby preventing flow of hydraulic fluid through the two-stage valve.

The pilot valve may comprise the fluid bypass. The fluid bypass may be a fluid channel defined in the pilot valve. The pilot valve may comprise a shoulder against which the piston is arranged to bear to seal the fluid bypass when the piston is in the first piston position. Thus, when the pilot valve is moved to the second pilot position so that the main fluid flow path is opened, the fluid bypass may be closed. That is, the piston may close the fluid bypass when the pilot valve is in the second pilot position.

The pilot valve may comprise a seal arranged to close the main fluid flow path when the pilot valve is in the first pilot position. The seal may bear against an internal shoulder of the valve (e.g. by urging from the biasing element) to close the main fluid path, thereby sealing the main fluid flow path closed and preventing flow of fluid through the two-stage valve. The pilot valve may comprise a rubber seal arranged to seat against the shoulder in the first position.

The simple arrangement of seals means that the operation of the two-stage valve is reliable and hard-wearing, particularly in view of the simple operation of the valve. The simple arrangement also ensuring that manufacturing tolerances are sufficiently low to prevent manufacturing costs being too high.

The two-stage valve may comprise a manual release actuable to move the pilot valve to the second pilot position. The manual release may act in place of the solenoid, and may first cause the fluid bypass to open (e.g. by initial movement of the piston) before opening the main fluid flow path (e.g. by moving the pilot valve to the second pilot position). The manual release therefore benefits from the two-stage operation of the valve, and needs less force to open the valve when a pressure differential exists across the pilot valve in the first pilot position. The manual release may therefore be used by a wearer of the artificial hand. In contrast, a typical user may not be able to apply sufficient force to directly move the pilot valve against the pressure differentials expected within the two-stage valve.

There is also described herein a palm unit for an artificial hand, comprising a two-stage valve as described herein. Two-stage valves are typically larger, heavier, more expensive and less reliable than single-stage valves. Further, there is typically no need to include a two-stage valve in a palm unit for an artificial hand because typical artificial hands do not operate at high enough pressures to require their use. Therefore, the inclusion of a two-stage valve in a palm unit for an artificial hand is considered novel and inventive in its own right.

The palm unit may comprise a hydraulic circuit comprising a hydraulic actuator for actuating a digit mechanism of the artificial hand, and a dual-valve arrangement for controlling hydraulic fluid flow to the hydraulic actuator, the dual-valve arrangement comprising the two-stage valve and a solenoid valve, wherein the solenoid valve is in series with the two-stage valve, and is arranged to check (i.e. prevent) fluid flow in an opposite direction to the two-stage valve. Thus, both the solenoid valve and the two-stage valve are arranged to freely permit fluid flow in opposite directions when not open. When neither the solenoid valve nor the two-stage valve is open, the hydraulic actuator will be locked in position. Hydraulic fluid may be permitted to flow in either direction by opening the appropriate valve, the other valve being oppositely oriented so that fluid may flow therethrough whether or not the valve is open.

The term ‘check’ as used herein with respect to a valve, may be understood in the sense of e.g. a check valve, a one-way vale, a non-return valve or the like, wherein the valve is arranged to permit fluid flow in one direction, but prevent (i.e. check) fluid flow in the other direction unless it is opened (e.g. by a solenoid).

The dual valve arrangement makes it possible to fix the position of a digit mechanism of the artificial hand at any predetermined position by closing (e.g. de-energising) both the solenoid valve and the two-stage valve. Actuation of the digit mechanism in a direction can then be accomplished by opening one of the valves, the other valve being arrange to permit fluid flow in that direction whether open or not. This arrangement is considered novel and inventive in its own right. Therefore there is described herein a palm unit for an artificial hand comprising a hydraulic actuator, wherein hydraulic fluid flow to the hydraulic actuator is controlled by a dual-valve arrangement comprising a solenoid valve in series with a two-stage valve and oriented to check fluid flow in an opposite direction to the two-stage valve.

The dual valve arrangement also makes it possible to freely permit movement of the thumb digit e.g. by external forces. The solenoid valve and the two-stage valve may both be opened at the same time so that the hydraulic actuator may move freely. The thumb digit mechanism may therefore be close and/or opened by external forces e.g. by a wearers other hand.

The two-stage valve may be a first two-stage valve, and the palm unit may comprise a second two-stage valve comprising a manual release, the second two-stage valve being arranged to control fluid flow to a second hydraulic actuator, wherein the manual releases of the first two-stage valve and the second two-stage valve are mechanically connected to a release button so that both manual releases are actuated simultaneously upon actuation of the release button. The manual releases may be coupled to the release button by respective pins. The respective pins may be disposed in respective slots in the release button and the slots may be angled with respect to the direction of movement of the release button so that movement of the release button causes movement of the manual release in the direction of the angle of the slots. Therefore, in the event of a malfunction or an emergency that requires both twos-stage valves to be opened (e.g. to release gripping digit mechanisms), that opening is accomplished simultaneously. If only one valve was opened, the digit mechanism controlled by the other valve would be driven against the released digit by the pressure in the un-released hydraulic actuator. For example, if a thumb digit mechanism was released while an opposing finger digit mechanism was still exerting force, the finger digit mechanism would force back the released thumb digit mechanism and might cause an accident or injury. The simultaneous manual release of the two-stage valves prevents such a problem.

The palm unit may comprise a plurality of hydraulic actuators for actuating digit mechanisms of an artificial hand, and a plurality of dual-valve arrangements as described herein for controlling individual actuation of the hydraulic actuators separately from the others. By actuation of the appropriate valves, each digit mechanism may be actuated and fixed in position independently of the others.

The palm unit may comprise a controller arranged to open and close the two-stage valve. The controller may be arranged to actuate all valves in the palm unit, and may be arranged to actuate the valves based on inputs from only two sensors. The controller may control both the first and (where present) the second two-stage valves. The controller may be arranged to actuate the solenoid valve. The controller may be configured to actuate the valves in response to predetermined signals and/or in response to signals for the pressure sensor and/or position sensor.

The palm unit may comprise a pressure sensor arranged to measure pressure within a high pressure side of a chamber of the palm unit containing the hydraulic actuator. The pressure sensor may comprise the any and all of the features of the pressure sensor described herewith. The pressure sensor may be configured to communicate pressure measurements to the controller.

There is also described herein an artificial hand comprising a palm unit described herein, and a thumb digit mechanism arranged to be actuated by the hydraulic actuator. The thumb digit mechanism may be fixable using the dual-valve arrangement. The artificial hand may comprise a plurality of digit mechanisms arranged to be actuated by respective hydraulic actuators of the palm unit. The artificial hand may comprise digit mechanisms to correspond to a human hand.

The artificial hand may comprise a position sensor arranged to measure the position of the thumb digit mechanism. The position sensor may be integrally formed with the palm unit of the artificial hand, and may be formed therewith by additive manufacturing.

The artificial hand may comprise a controller having embodied thereon instructions that when executed cause the artificial hand to perform the method described herein with reference to the first aspect of the invention.

The method as described herein with reference to the first aspect of the invention may comprises using a two-stage valve as described herein, or using a palm unit as described herein, or using an artificial hand as described herein.

There is also described herein a method of manufacturing a palm unit for an artificial hand, the palm unit comprising: a palm unit body defining chambers for respective hydraulic components of a hydraulic circuit, and a topology for the hydraulic circuit; and a hydraulic component of the hydraulic circuit disposed within one of the chambers to provide at least part of the hydraulic circuit; wherein the topology of the hydraulic circuit is such that in use the chamber has a low pressure side and a high pressure side; wherein the method comprises inserting the hydraulic component into the chamber from the low pressure side of the chamber.

The palm unit may be combined with other components to provide an artificial or prosthetic hand, for example a wrist connector and/or digit mechanisms.

The hydraulic component inserted into the chamber may be a hydraulic actuator, arranged to actuate by a pressure differential within the chamber. The hydraulic actuator may be arranged for connection to a digit mechanism to actuate that mechanism. The hydraulic circuit may comprise any suitable hydraulic components. The pressure differential within the chamber may define a high pressure side of the chamber and low pressure side of the chamber e.g. a high pressure relative to a low pressure. The pressure differential may necessarily be oriented during use in a predetermined direction for operation of the hydraulic component e.g. the hydraulic actuator necessarily requires higher pressure on one side of the chamber than on the other side in order to actuate, and the hydraulic actuator may be arranged to actuate in a predetermined direction. Thus, one side of the chamber may be understood to be the high pressure side, while the other side of the chamber may be understood to be the low pressure side. The high pressure side of the chamber and the low pressure side of the chamber may be defined relatively to each other during use of the palm unit.

The hydraulic actuator may therefore be inserted into the chamber with a high pressure side first.

The hydraulic circuit topology may be any suitable topology and may comprise any suitable arrangement of fluid channels and chambers for operations of a prosthetic hand. The chambers may be for components of the hydraulic circuit such as hydraulic actuators, pumps, motors, and so on, and the hydraulic circuit may comprise such components. The hydraulic circuit may be arranged so that in use the hydraulic circuit has a high pressure zone in the region of the high pressure side of the chamber and a low pressure zone in the region of the low pressure side of the chamber. The arrangement of the hydraulic circuit therefore determines the high pressure and low pressure sides of the chamber in which the hydraulic component is inserted. The high pressure side of the chamber may be arranged to have in use a higher pressure than that of the low pressure side of the chamber. The low pressure side of the chamber may be arranged to have in use a lower pressure than that of the high pressure side of the chamber. The high pressure may be higher than the low pressure and the low pressure may be lower than the high pressure.

The method may comprise providing a mount on the palm unit body proximate the high pressure side of the chamber for mounting a digit mechanism of an artificial hand thereto. Thus, the palm unit body may be arranged to have digit mechanisms mounted adjacent the high pressure side of the chamber and arranged for actuation by the hydraulic component in the chamber. The low pressure side of the chamber may be arranged away from the mount and may be at the wrist end of the palm unit, i.e. the other side of the palm unit to the mounts. The mount may be a socket e.g. for receiving a portion of a digit mechanism, or may be a plug e.g. for mounting of a digit mechanism thereabout, or may be of any suitable type to allow attachment of a digit mechanism thereto. The mount may be integrally formed with the rest of the palm unit body. The method may therefore comprise inserting the hydraulic component from the wrist end of the palm unit body.

The chamber may be oriented for actuation of digit mechanisms, and as such the palm unit and/or hydraulic circuit may have high pressure sides and low pressure sides corresponding to the high pressure side and low pressure side of the chamber. The palm unit and/or hydraulic circuit may have low a pressure zone and a high pressure zone proximate the low pressure side and high pressure side of the chamber respectively.

The method may comprise putting hydraulic fluid into the chamber after inserting the hydraulic component into the chamber. The method may comprise at least partially filling the high pressure side of the chamber with hydraulic fluid after inserting the hydraulic component into the chamber. The method may comprise not putting hydraulic fluid into the hydraulic circuit prior to insertion of the hydraulic component into the chamber. The method may comprise charging or filling the hydraulic circuit of the palm unit with hydraulic fluid after inserting the hydraulic component into the chamber. The method may comprise filling more than 60% of the volume of the hydraulic circuit with hydraulic fluid after insertion of the hydraulic component into the chamber, and may comprise filling more than 70%, more than 80%, and/or more than 90% of the volume of the hydraulic circuit after insertion of the hydraulic component into the chamber and before the chamber is closed or sealed.

In prior versions of hydraulic prosthetic hands, such as the version shown in Fig. 1, the chambers housing hydraulic components were open towards their high pressure sides and during manufacture hydraulic components were inserted from the high pressure sides of the chambers. It was therefore necessary to firstly charge the hydraulic circuit with hydraulic fluid, and then insert the hydraulic components into their respective chambers. As such, spillage of hydraulic fluid was common during assembly. In contrast, the risk of spillage is reduced by the method described herein, which therefore improves ease and efficiency of manufacture and reduces wastage.

The method may comprise forming at least a portion of the low pressure side of the chamber of the palm unit body first, then forming the high pressure side of the chamber. The method may comprise forming the chamber and/or the palm unit body using additive manufacturing. The method may comprise forming the palm unit from the wrist side up e.g. forming the palm unit from a low pressure side first. By forming the low pressure side of the chamber first, the high pressure portion may be supported during formation by the low pressure side. As such, the high pressure side may be manufactured as needed (e.g. having a closed end and/or integral fluid channels) thereby reducing the need to attach and/or seal parts of the high pressure zone of the hydraulic circuit connected to the high pressure side of the chamber. Thus, forming the palm unit body from the low pressure side may reduce the amount of further work needed after formation for sealing of the high pressure side of the chamber and/or for sealing high pressure regions of the palm unit.

The method may comprise forming a preform of the palm unit body by additive manufacturing. The preform may be largely similar to the palm unit body and may have e.g. the same topology, but may comprise e.g. thicker walls than are needed for the final palm unit body. The preform may comprise all the necessary channels and chambers for defining the hydraulic circuit, albeit in an unfinished state. The preform of the palm unit body may then be finished e.g. by a machining process or the like to predetermined dimensions.

The method may comprise machining a chamber of the preform of the palm unit body to the desired size prior to inserting the hydraulic component into the chamber. Thus, the chamber of the preform may be finished by machining to provide the correct dimensions for insertion of the hydraulic component. This method may allow fine control over the final size of the chamber and hence allow high manufacturing tolerances.

The hydraulic circuit may be arranged such that in use a plurality of chambers of the palm unit body each have a low pressure side and a high pressure side, and the method may further comprise inserting hydraulic components into respective ones of the plurality of chambers of the palm unit body from the low pressure sides of the chambers. The method may comprise inserting a plurality of hydraulic actuators into chambers of the palm unit body. The method may comprise inserting separate hydraulic actuators for different digit mechanisms, and/or may comprise inserting one or more hydraulic actuators for actuation of multiple digit mechanisms. The method may comprise inserting a plurality of hydraulic components from the wrist end of the palm unit body.

The method may comprise forming the palm unit body so that the chambers of the palm unit body are oriented toward the same end of the palm unit body for insertion of the respective hydraulic components. The method may comprise simultaneously forming portions of the low pressure sides of each of the plurality of chambers first, and then simultaneously forming portions of the high pressure sides of each of the plurality of chambers. The orientation of the chambers may therefore be open towards the wrist end of the palm unit body, and the hydraulic components may all be inserted from the same direction so that assembly of the palm unit may be simplified.

The method may comprise securing the palm unit body or the preform of the palm unit body in a fixed position for machining. The method may comprise clamping the palm unit body or the preform in a clamp for machining. The method may comprise machining all of the chambers of the palm unit body that need machining without releasing the palm unit body or preform from the fixed position e.g. without releasing it from the clamp. Then, because the chambers may have openings in the same direction, machining and finishing of the chambers may be carried out from the same direction and simply achieved in a single step e.g. without having to release the palm unit body e.g. from the clamp. The chambers of the palm unit body may be oriented at small angles with respect to one another.

The method may comprise inserting all components of the hydraulic circuit into the palm unit body. The palm unit body may then contain all hydraulic components necessary for the circuit. The palm unit body may define the entire topology of the hydraulic circuit, including fluid channels and chambers for components, and may include all fluid channels and chambers. The palm unit may therefore be a single self-contained piece.

The method may comprise sealing the hydraulic component within the chamber to prevent leakage of fluid from the hydraulic circuit. The method may comprise screwing a cap into place to hold the hydraulic component in the chamber and/or seal the hydraulic circuit. The method may comprise sealing the plurality of components within respective chambers of the palm unit body. The method may comprise sealing the hydraulic component(s) within the palm unit body. The method may comprise sealing each chamber separately from the others e.g. with respective caps.

The method may comprise forming a pressure sensor body integrally with the palm unit body. The pressure sensor may be part of the hydraulic circuit. The palm unit body may be fluidly connected to the chamber. The pressure sensor may be arranged in use to detect pressure within the chamber of the palm unit body. The pressure sensor may be any pressure sensor as described herewith. The integral formation of a pressure sensor body with the palm unit body is considered novel and inventive in its own right.

The method may comprise inserting a valve into the palm unit body. The valve may be any valve as described herewith e.g. the valve may be a two-stage valve as described herein, and/or may be a solenoid valve as described herein.

There is also described herein a method of manufacturing an artificial hand comprising forming a palm unit of the artificial hand using the method described herein.

The method may comprise attaching a digit mechanism to the palm unit body and arranging the digit mechanism to be actuated by the hydraulic component e.g. a hydraulic actuator. The method may comprise attaching a plurality of digit mechanisms to the palm unit body and arranging each to be actuated by a hydraulic component e.g. a hydraulic actuator. The method may comprise attaching the digit mechanism(s) to the palm unit body proximate the high pressure side(s) of the chamber(s) and/or away from the low pressure side(s) of the chamber(s). The method may comprise sealing the high pressure side(s) of the chamber(s) with the digit mechanism(s) attached.

There is provided a palm unit for an artificial hand, the palm unit comprising: a palm unit body defining chambers for respective hydraulic components of a hydraulic circuit, and a topology for the hydraulic circuit; and a hydraulic component of the hydraulic circuit disposed within one of the chambers to provide at least part of the hydraulic circuit; wherein the topology of the hydraulic circuit is such that in use the chamber has a low pressure side and a high pressure side; and wherein the palm unit body is arranged so that the hydraulic component is inserted into the chamber from the low pressure side of the chamber.

The palm unit body may comprise a mount proximate the high pressure side of the chamber for mounting a digit mechanism of an artificial hand thereto. The mount may be adjacent the high pressure side of the chamber and/or may be on the other side of the palm unit body to the low pressure side of the chamber. The palm unit body may comprise a plurality of mounts for a plurality of digit mechanisms.

The low pressure side of the chamber and the high pressure side of the chamber may correspond to respective sides of the palm unit. The high pressure side may be arranged proximate the location for the digit mechanisms of the artificial hand and the low pressure side may be arranged proximate a location for a wrist connector. Thus, the chamber may open towards the wrist end of the palm unit, in the direction of the low-pressure side of the hydraulic actuators.

The palm unit may comprise a cap sealing the hydraulic component in the chamber. The cap may be a screw cap or any suitable sealing mechanism for containing the hydraulic component within the palm unit. The screw cap may screw into the chamber in order to seal it.

The palm unit body may have been formed by additive manufacturing. The portion of the palm unit body providing the high pressure chamber and associated high pressure regions of the hydraulic circuit may therefore be formed integrally, avoiding the need to connect or seal parts of the palm unit and thereby reducing the risk of leakage.

The palm unit body may comprise titanium or a titanium alloy. The palm unit body may comprise any suitable material, and is preferably robust and light.

The palm unit may comprise all components of the hydraulic circuit and/or may define the entire hydraulic circuit. The palm unit may therefore be a self-contained component for an artificial hand and include everything needed to operate, the palm unit body housing or carrying all components of the hydraulic circuit, and defining all fluid channels of the hydraulic circuit.

The palm unit body may comprise a plurality of chambers, and all of the chambers may open towards the wrist end of the palm unit, and/or may all be sealed in use e.g. with respective caps.

The palm unit may comprise a pressure sensor and the pressure sensor may comprise a pressure sensor body integral to the palm unit body. That is, a portion of the palm unit body may define a pressure sensor body. The pressure sensor may be any pressure sensor as described herein.

There is also described herein an artificial hand comprising the palm unit as described herein, and a digit mechanism mounted to the palm unit adjacent the high pressure side of the chamber and arranged to be actuated by the hydraulic component.

The artificial hand may comprise a plurality of digit mechanisms, each arranged to be actuated by a hydraulic component in the palm unit. The artificial hand may comprise a wrist connector, for example an Otto Bock wrist connector, which may be adjacent the low pressure side of the chamber, on the opposite side of the palm unit to the digit mechanisms. The digit mechanism(s) may be arranged to close into a grip upon actuation of the hydraulic actuator(s), and may be arranged to close when a cable of the digit mechanism is pulled.

There is also described herein a pressure sensor comprising: a sensor body comprising a fluid chamber within the sensor body, and a deformable membrane portion arranged to deform when subject to a pressure differential from fluid in the fluid chamber; and a sensor unit arranged to detect deformation of the membrane portion; wherein the sensor body including the membrane portion is integrally formed by additive manufacturing.

The pressure sensor may therefore detect when there is a pressure differential across the membrane portion e.g. when pressure within the fluid chamber is greater than the pressure outside it. The membrane portion may be configured to deform if and only if it is subject to a pressure differential from fluid in the fluid chamber. Since the pressure external to the fluid chamber may be approximately constant, the deformation of the membrane portion will typically be responsive only to pressure changes within the fluid chamber. As such, deformation of the membrane portion will be indicative of the pressure within the fluid chamber, and detection and/or monitoring (e.g. the amount) of that deformation by the sensor unit can be used to measure the pressure within the fluid chamber.

The sensor unit may be configured to detect deformation greater than a predetermined threshold and/or may be configured to detect a degree of deformation of the membrane portion. The pressure sensor may therefore be configured to detect pressure within the fluid chamber when it exceeds a threshold and/or may be configured to continuously monitor a range of pressures within the fluid chamber.

The sensor unit may comprise a strain gauge, or may comprise any component suitable to measure the deformation of the membrane portion. The strain gauge may be adjacent and in contact with the membrane portion of the sensor body, and may therefore be arranged to deform in concert with the membrane portion.

The sensor unit may be external to the sensor body. The deformable membrane portion may have an external face and the sensor unit may be arranged on the external face of the membrane portion. The external face of the deformable membrane portion may be arranged to be exposed to ambient atmospheric pressure. The sensor unit may be adhered or otherwise fixed to the external face of the membrane portion. Since the sensor unit may be external to the sensor body, the pressure sensor may be simply manufactured by arranging (e.g. adhering or otherwise affixing) the sensor unit to the deformable membrane portion after the sensor body has been formed by additive manufacturing. The simplicity of the pressure sensor may also improve reliability and/or may allow for easy repair of the pressure sensor.

The sensor body may comprise a single fluid inlet/outlet in fluid communication with the fluid chamber for providing fluid thereto. That is, the sensor may comprise a single channel for providing fluid to and from the fluid chamber. The single channel may be arranged in fluid communication with e.g. a hydraulic circuit so that the pressure sensor is arranged to monitor pressure in the hydraulic circuit.

The sensor body may comprise a fluid inlet and the fluid outlet, and the fluid chamber may be disposed between the fluid inlet and the fluid outlet so as to provide a portion of a fluid flow path. The fluid chamber may be between the fluid inlet and the fluid outlet in the sense that fluid flowing from the inlet to the outlet passes through the chamber, and/or the fluid chamber may be positioned on a the shortest path between the inlet and outlet. The fluid inlet and the fluid outlet may alternate roles depending on the direction of fluid flow through the pressure sensor.

The sensor body may be formed of titanium or a titanium alloy. The sensor body may be formed of any suitable material capable of withstanding suitable pressure differentials and deforming as needed to permit measurement of pressures within the fluid chamber.

The fluid chamber may be between 5 millimetres and 15 millimetres in diameter, and may be between 8 millimetres and 12 millimetres in diameter, and may preferably be about 10 millimetres in diameter. The fluid chamber may be between 1 millimetres and 5 millimetres deep, and may be between 2 millimetres and 3 millimetres deep, and may be between 2.5 millimetres and 2.9 millimetres deep, and may preferably be about 2.7 millimetres deep. The deformable membrane may be between 2 millimetres and 10 millimetres in diameter, and may be between 5 millimetres and 7 millimetres in diameter, and may preferably be about 6 millimetres in diameter. The deformable membrane may be between 0.1 millimetres and 1 millimetres in thickness, and may be between 0.3 millimetres and 0.7 millimetres in thickness, and may preferably be about 0.5 millimetres in thickness.

There is also described herein a palm unit for an artificial hand, comprising a palm unit body and a pressure sensor as described herein, wherein the palm unit body is integrally formed with the sensor body by additive manufacturing.

Thus the sensor body may be considered to be a portion of the palm unit body. The palm unit body may provide a hydraulic circuit and the pressure sensor may form part of the hydraulic circuit. The pressure sensor may be provided at an outer surface of the palm unit body, and the sensor unit may be provided on an external surface of the palm unit body. That is the membrane portion may form part of the external surface of the palm unit body. The pressure sensor may be arranged to monitor pressure within a chamber containing a hydraulic component of the hydraulic circuit.

The palm unit may comprise a controller arranged to receive a signal from the pressure sensor and configured to control functionality of the palm unit in response to the signal. For example the controller may be configured to start and/or stop a motor of the palm unit in response to measurement of the pressure within the fluid chamber by the pressure sensor. The controller may be configured to start the motor of the palm unit if the pressure measured by the pressure sensor falls below a predetermined lower threshold and/or the controller may be configured to stop the motor if the pressure measured by the pressure sensor exceeds a predetermined upper threshold.

The palm unit may comprise any and all of the features of any of the palm units described herein.

There is also described herein an artificial hand comprising the palm unit.

There is also described herein a method of manufacturing a pressure sensor comprising integrally forming by additive manufacturing a sensor body including a deformable membrane portion, wherein the sensor body comprises a fluid chamber within the sensor body, and wherein the deformable membrane portion is arranged to deform when subject to a pressure differential from fluid in the fluid chamber.

The method may comprise arranging a sensor unit to detect deformation of the membrane portion of the sensor body. The sensor unit may be a strain gauge and may be adhered or otherwise fixed to the membrane portion. The sensor unit may be any component suitable for detecting deformation of the membrane portion.

The method may comprise arranging the sensor unit external to the sensor body to detect deformation of the membrane portion of the sensor body. The membrane portion may comprise an external face and the method may comprise arranging the sensor unit on the external face of the membrane portion to detect deformation thereof. The pressure sensor may therefore be manufactured simply by affixing the sensor unit to the sensor body after the sensor body has been formed by additive manufacturing.

The method may comprise adhering the sensor unit to the membrane portion e.g. by glue, or affixing the sensor unit to the membrane portion by any suitable means.

There is also described herein a method of manufacturing a palm unit for an artificial hand comprising integrally forming a palm unit body of the palm unit with the sensor body of the pressure sensor.

The palm unit body may comprise any and all of the features of any of the palm units described herein.

There is also described herein a method of manufacturing a palm unit for an artificial hand, the palm unit comprising a pressure sensor integrally formed with the palm unit, the method comprising using additive manufacturing to integrally form at least a portion of the pressure sensor with at least a portion of the palm unit. There is also described herein a palm unit for an artificial hand comprising a pressure sensor integrally formed with the palm unit.

There is also described herein a method of controlling digit mechanisms of an artificial hand comprising a palm unit, the method comprising measuring pressure within the palm unit using a pressure sensor that has been integrally formed with the palm unit by additive manufacturing.

There is described herein a palm unit for an artificial hand comprising a palm unit body with an integrally formed pressure sensor arranged to measure pressure within a chamber of the palm unit body, the palm unit comprising a two-stage valve for controlling fluid flow to and/or from the chamber.

There is also described herein a method of manufacturing an artificial hand comprising providing a two-stage valve for controlling digit mechanisms of the artificial hand. The method may comprise providing a dual-valve arrangement as described herein.

There is also described herein a method of controlling an artificial hand comprising stopping movement of a digit mechanism at a predetermined position.

Figures

The invention is described in detail below by way of example only and with reference to the accompanying drawings, in which:

Figure 1A shows an artificial hand according to the prior art;

Figure 1B show a palm unit for the artificial hand of Fig. 1A;

Figure 2A shows a perspective view of an artificial hand comprising a palm unit;

Figure 2B shows a side view of the artificial hand of Fig. 2A;

Figure 2C show a bottom view of the artificial hand of Figs. 2A and 2B;

Figure 2D shows a front end view of the artificial hand of Figs. 2A to 2C;

Figure 2E show a rear end view of the artificial hand of Figs. 2A to 2D;

Figure 3A shows a perspective view of the palm unit body of the artificial hand of Figs. 2A to 2E;

Figure 3B shows a side view of the palm unit body of Fig. 3A;

Figure 3C shows a bottom view of the palm unit body of Figs. 3A and 3B;

Figure 3D shows a front end view of the palm unit body of Figs. 3A to 3C;

Figure 4 shows a schematic view of a hydraulic circuit for the artificial hand of Figs. 2A to 2E;

Figure 5A shows a perspective view of a pressure sensor for the hydraulic circuit of Fig. 4;

Figure 5B shows a cross section of the pressure sensor of Fig. 5A;

Figure 6A shows a two-stage valve in a closed state;

Figure 6B shows the two-stage valve of Fig. 6A in an intermediate state during opening;

Figure 6C shows the two stage valve of Figs. 6A and 6B in an open state;

Figure 6D shows the two stage valve of Figs. 6A to 6C opened by a manual release; and

Figure 6E shows a manual release button for two valves of the sort shown in Figs. 6A to 6D.

Description

Figure 1A shows a perspective view of a prosthetic hand according to the prior art. The prosthetic hand includes a palm unit 12, a plurality of digit mechanisms 20, including a thumb mechanism 14, an index finger mechanism 16, a middle finger mechanism 18, and a combined ring finger and little finger mechanism. Figure 1B shows a perspective view of a palm unit body 70 of the palm unit 12 of Fig. 1A. The palm unit body 70 is formed by additive manufacturing and comprises a plurality of chambers 36', 38', 80, 82, 84 and 88 for housing components of a hydraulic circuit in the palm unit body 70 for actuating the digit mechanisms 20. The palm unit body 70 also defines fluid channels between the chambers as necessary to provide the connections of the hydraulic circuit for operating the prosthetic hand. That is, the palm unit body 70 defines a topology of the hydraulic circuit.

During manufacture, the hydraulic components – including hydraulic actuators for actuating the digit mechanisms 20 – are inserted into the chambers of the palm unit body 70 and a structural end plate 66 is fixed to the palm unit body 70 to enclose the hydraulic components in the palm unit body 70 and help seal the hydraulic circuit. The digit mechanisms 20 are then mounted to the structural end plate 66 and cables 34 of the digit mechanisms 20 are connected to the hydraulic actuators via piston couplings 32. During use, the digit mechanisms 20 are closed (e.g. in a grip) by actuation of the hydraulic actuators, which actuation pulls on the cables 34 and causes the digit mechanisms 20 to operate. An example of a suitable digit mechanism is described in detail in GB2537899.

The hydraulic actuators each operate because of a pressure differential within the respective chamber of the palm unit body 70 that contains them, driving movement of part of the hydraulic actuator e.g. a piston. Relative high pressures are thus needed at one end of the chambers containing the hydraulic actuators, and relative low pressures at the other end of the chambers i.e. a pressure differential across the chamber. In order to provide the necessary grip strength by pulling of the cable 34, the high pressure portion of the chamber is proximate the digit mechanisms 20 and the low pressure portion of the chamber is oriented away from the digit mechanism 20, to drive actuation of the hydraulic actuator to pull the cable 34 and consequently close the finger of the artificial hand in a grip of suitable force.

Thus, the hydraulic circuit of the artificial hand of Fig. 1A is necessarily arranged so that the high pressure sides of the chambers containing the hydraulic actuators are proximate their respective digit mechanisms and in the region of the palm unit sealed by the structural end plate 66. It is therefore necessary for seals (e.g. about the structural end plate 66) of the hydraulic circuit in that region to seal against high pressure differentials, which can result in the artificial hand being susceptible to leakage and/or failure at those seals.

Fig. 2A shows a perspective view of a prosthetic hand 100. The hand 100 comprises a palm unit 150 comprising a hydraulic circuit 200 and hydraulic components of that hydraulic circuit 200. The palm until 150 also comprises a palm unit body 152 which defines the topology of the hydraulic circuit 200, including all the fluid channels and chambers for housing the hydraulic

01 06 21

components. The whole of the hydraulic circuit 200, including all of the hydraulic components, is contained and sealed within the palm unit body 152. The palm unit body 152 is formed from titanium (or an alloy thereof) by additive manufacturing and as such, chambers and channels of the hydraulic circuit 200 are formed simultaneously with the palm unit body 152.

A plurality of finger digit mechanisms 120 are mounted to the palm unit 150 and are actuable by operation of the hydraulic circuit to close in a grip (e.g. a pincer movement). Commonly, particularly for a prosthetic hand, finger mechanisms 120 (including a mechanism for a thumb) are provided to correspond to a human hand. The prosthetic hand of Fig. 2 comprises a thumb digit mechanism 122, an index finger digit mechanism 124 opposing the thumb digit 122, a middle finger digit mechanism 126 with a combined ring and little finger digit mechanism 128 coupled thereto so that movement of the ring and little finger digit 128 is responsive to the movement of the middle digit mechanism 126. Other arrangements of the digit mechanisms 120 may be used for alternative purposes. As with a human hand, the thumb digit mechanism 122 is arranged to oppose the other digit mechanisms 124, 126, 128 to provide grip e.g. about an object.

The prosthetic hand 100 also comprises a connector 190 on the wrist end of the palm unit 150 (i.e. the other end of the palm unit 150 from the digit mechanisms 120) for connecting the prosthetic hand 100 to a mount e.g. on a user's residual limb. The connector 190 may be any suitable type, and may be e.g. an Otto Bock connector.

The palm unit body 152 may be machined after the additive manufacturing process, for example by machining the interior of an undersized chamber to make it larger so that a hydraulic component may be inserted therein. As such, the initial product of the additive manufacturing process may be considered to be a palm unit body preform, which preform is finished by machining or the like to provide the final palm unit body 152. This approach of finishing the palm unit body 152 by machining allows for suitable tolerances, ensuring that chambers are sized appropriately for the components they house to prevent leakage from the hydraulic circuit 200.

Figures 2B to 2E show alternative views of the prosthetic hand 100 of Fig. 2A. In Figs. 2B and 2E a pressure sensor 240 (see below) for sensing pressure in the hydraulic circuit 200 is also visible.

Figure 3A to 3E show various views of the palm unit body 152 of the artificial hand 100 of Fig. 2A in isolation. The palm unit body 152 provides a frame for the prosthetic hand 100 and housing for its various components e.g. hydraulic components of the hydraulic circuit 200. It includes mounts 154 at one end to which the digit mechanisms 120 may be coupled. The mounts 154 may be sockets (e.g. as for the index and middle finger mechanisms 120), or may plugs (e.g. as for the ring and little finger mechanism 120), or may be any suitable type.

The palm unit body 152 also defines chambers 180 for housing the hydraulic components of the hydraulic circuit 200, such as hydraulic actuators for actuating the digit mechanisms 120. The chambers 180 of the palm unit body 152 are open at the wrist end of the prosthetic hand 100 for receiving inserted hydraulic components. As such, machining of the palm unit body 152 after additive manufacturing can be achieved easily and by using a single clamping step to fix the palm unit body 152 in place while the chambers 180 are machined from the same direction. All of the chambers 180 may be finished by machining without re-aligning the palm unit body 152, thereby simplifying the manufacturing process.

The chambers 180 of the palm unit body 152 are provided for the hydraulic components of the hydraulic circuit 200, and those chambers 180 are fluidly connected by channels of the hydraulic circuit 200 within the palm unit body 152 as required. The channels are integrally formed with the palm unit body 152 by the additive manufacturing process.

From Fig. 3E it can be seen that the chambers 180 open towards the wrist end of the palm unit body 152 (i.e. the end opposite to where the mounts 154 for the digit mechanisms 120 are provided), so that during manufacture the hydraulic components are inserted into the chambers in a direction towards the mounts (i.e. towards the fingers). This may be particularly advantageous for chambers 180 housing hydraulic actuators, since the end of the chamber through which the hydraulic actuators are inserted is (during use) the low pressure side. The hydraulic components are then sealed within their respective chambers 180 by caps 156 inserted and screwed into the openings of the chambers 180.

As described above in reference to the prosthetic hand of Fig. 1A, for chambers 180 containing hydraulic actuators, the high pressure ends of the chambers 180 are necessarily adjacent the digit mechanisms 120 in order to actuate them by pulling cables of the digit mechanisms. Thus, in the hand of Fig. 2A, the hydraulic actuators are inserted into the palm unit body 152 from the low pressure sides of the chambers 180 and the seals at those ends (e.g. the caps 156) need only seal against low pressures. Although the hydraulic actuators are connected to the digit mechanisms 120 at the high pressure sides of the chambers 180 by cables 134 so that seals are needed about the cables 134, there is no end plate 66 or the like (see Fig. 1) so that overall sealing of the hydraulic circuit is simplified. Moreover, the sealing of chambers 180 for containing components other than hydraulic actuators is also simplified, since those chambers 180 do not need to be open at their high pressure sides e.g. to connect to digit mechanisms and may instead be sealed at their low pressure sides.

Further, since the portions of the hydraulic circuit which contain high pressure can be formed using additive manufacturing, there are no connections or joints to seal and instead the high pressure regions may be contained within integrally formed material of a single piece. For example, as can be seen in Fig. 3E, a chamber 181 which is not for housing a hydraulic actuator is closed at its far end except for a fluid channel. It is therefore not necessary to provide additional seals at the high pressure side of the chamber 181, and fluid connections thereto are integral to the palm unit body 152. As a result, the hand of Fig. 2A may be less prone to leakage than the hand of Fig. 1A.

Figure 4 shows a schematic of the hydraulic circuit 200 of the prosthetic hand 100 of Fig. 2A. The circuit 200 is operated to control actuation of hydraulic actuators 230, which actuators 230 operate to control closing and/or opening of the digit mechanisms 120 of the hand 100 e.g. in a gripping action. Each of the thumb digit 122, index digit 124, and middle digit 126 have respective hydraulic actuators 230 for actuation thereof. The combined ring and little finger digit mechanism 128 is connected to the middle digit mechanism 126 so as to move in concert therewith e.g. to close when the middle digit mechanism 126 closes, and/or open when the middle digit mechanism 126 opens.

The circuit 200 comprises a motor 210 arranged to drive a pump 220 for delivering hydraulic fluid to the hydraulic actuators 230 for actuating the digit mechanisms 120. The motor 210 may be any suitable type of motor and may be directly connected to the pump 220 to drive it in at least one direction. The pump 220 may be any suitable type for delivering high pressure hydraulic fluid in at least one direction. The pump 220 is driven by the motor 210 to deliver high pressure fluid in a first direction to the line 254 e.g. for closing the digit mechanisms 120 in a gripping motion. The pump 220 may also operate in a second opposite direction to permit hydraulic fluid to flow in the second direction e.g. for opening the digit mechanisms 120.

The plurality of hydraulic actuators 230 of the hydraulic circuit 200 are operable to control the motion of the digit mechanisms 120. In the prosthetic hand of Fig. 2A and the hydraulic circuit 200 of Fig. 4, three hydraulic actuators 230 are provided, one for each of the thumb digit mechanism 122, the index finger digit mechanism 124, and the middle finger digit mechanism 126. The hydraulic actuator 232 is arranged to actuate the thumb digit mechanism 122, the hydraulic actuator 234 is arranged to actuate the index finger digit mechanism 124, and the hydraulic actuator 236 is arranged to actuate the middle finger digit mechanism 126. The ring and little finger digit mechanism 128 is slaved to the middle finger digit mechanism 126. However, one hydraulic actuator 230 could be provided for each digit mechanism, or any number of digit mechanisms could be responsive to movement of a single actuator, as needed.

In operation, the pump 220 delivers hydraulic fluid (e.g. oil) in the first direction to a high-pressure side of a first, two-stage solenoid valve 260 via line 254. The two-stage valve 260 is a one-way valve and a permits one-way fluid flow into high pressure sides of the chambers 180 housing the index finger actuator 234 and middle finger actuator 236, whether or not the two-stage valve 260 is open e.g. whether or not the solenoid of the two-stage valve is active. Fluid flow out of the high pressure sides of the chambers 180 of the index finger actuator 234 and middle finger actuator 236 is prevented by the valve 260 when it is closed e.g. unless the solenoid is activated. Hydraulic fluid is therefore delivered by the pump 220 to each of the hydraulic actuators 234 and 236, causing actuation of respective pistons. The movement of those pistons pulls on cables of the index and middle finger digit mechanisms 124 and 126, causing them to close in a grip. Continued operation of the pump 220 increases pressure within the high-pressure sides of the hydraulic actuators 230, thereby increasing the force with which the digit mechanisms 120 are closed, and hence increasing the strength of the grip.

The pump 220 also delivers fluid via hydraulic line 254 at the same time to a second solenoid valve 262, which second valve 262 is in series with a third, solenoid valve 264. The third valve 264 is a two-stage solenoid valve and is the same as the two-stage valve 260. The third valve 264 is a one-way valve and will permit fluid flow to the thumb actuator 232 whether or not it is open e.g. whether or not its solenoid is active. The second valve 262 will not permit fluid flow to the high pressure side of the chamber 180 containing the thumb actuator 232 unless it is open e.g. unless its solenoid is active. When the solenoid of the second valve 262 is open, hydraulic fluid is able to flow to the thumb actuator 232 and cause movement of the piston and hence actuation of the thumb digit mechanism 122.

Fluid flow away from the high pressure side of the thumb actuator 232 is prevented by the third valve 264, unless the third valve 264 is open e.g. unless its solenoid is activated. When the solenoid of the third valve 264 is active, fluid may flow away from the thumb actuator 232 via the second valve 262, regardless of whether or not the solenoid of the second valve 262 is active.

The second valve 262 and the third valve 264 therefore provide a dual valve arrangement for controlling actuation of the thumb digit mechanism 122 by controlling flow of hydraulic fluid through line 256. When both valves 262 and 264 are closed, hydraulic fluid cannot flow through the dual valve arrangement and therefore the thumb actuator 232 is fixed, thereby fixing the thumb digit mechanism 122. The thumb digit mechanism 122 will therefore be immovable by external forces when the dual valve arrangement is closed. One of the valves 262, 264 of the dual valve arrangement may be opened to allow actuation of the thumb digit actuator 232 in a desired direction. The second valve 262 may be opened to allow hydraulic fluid to flow through line 256 to the thumb actuator 232 for closing the thumb digit mechanism 122, since fluid may flow through the two-stage valve 264 whether or not it is in its open configuration. The two-stage valve 264 may be opened to allow hydraulic fluid to flow through line 256 away from the thumb actuator 232 for opening the thumb digit mechanism, since fluid may flow through the second solenoid valve 262 whether or not it is in its open configuration. Both the second valve 262 and the third valve 264 may be opened so that hydraulic fluid can flow freely two and from the thumb actuator 232, so that the thumb digit mechanism 122 may be manually actuated by external forces e.g. by a wearers other hand.

A controller 290 is provided to control operation of the motor 210, pump 220, and solenoid valves 260, 262 and 264. The controller 290 comprises software configured to carry out such control e.g. based on input signals and sensed pressures. In order to close the prosthetic hand 100 into a grip, the controller 290 opens the second valve 262 by activation of its solenoid, and then activates the motor 210 to drive the pump 220 to deliver high pressure fluid to line 254. Fluid flows to the actuators 230, and the pressure in the high pressure sides of the chambers 180 increases and the digit mechanism 120 are thereby actuated to close in a grip.

In order to allow the digit mechanisms 120 to open, the two-stage valves 260 and 264 are opened e.g. the solenoids of the first valve 260 and third valve 264 are activated (e.g. by the controller 290), and fluid is permitted to flow back to the pump via line 254. The pump 220 is driven in a second direction and the hydraulic fluid returns to the low pressure side of the hydraulic circuit 200 i.e. the side connected to the low pressure sides of the chambers 180 containing the actuators 230. Springs 280 are provided in the chambers 180 to drive the actuators 230 into open positions. Thus, when the first valve 260 and third valve 264 are opened, the respective pistons of the actuators 230 may return to their original positions and stop pulling on the respective cables of the digit mechanisms 120. Each of the digit mechanisms 120 may also be provided with a spring configured to urge the digit into an open position, so that upon the cessation of force from the hydraulic actuators 230, the digit mechanisms 120 will return to an open position.

An equaliser 250 is provided on the low pressure side of the hydraulic circuit 200 to accommodate volume changes in the circuit 200 caused by movement of the pistons of the actuators 230 into respective ones of the chambers 180. The equaliser 250 also provides positive pressure to the suction side of the pump 220 during closing of the digit mechanisms 120, thereby preventing cavitation. A high pressure safety valve 266 is also connected to the hydraulic line 254 so that if pressure gets too high, the valve 266 can bypass the pump 220, bleeding pressure into the low pressure side of the circuit 200.

The hydraulic circuit 200 also comprises a high-pressure pressure sensor 240 arranged to sense the pressure within the high pressure side of the chambers 180 of the index finger actuator 234 and middle finger actuator 236, and to provide that pressure reading to the controller 290. The pressure sensor 240 serves several functions, and can be used as part of a control arrangement of the controller 290 to provide different control processes for the prosthetic hand 100.

The control arrangement also includes a position sensor 270 provided on the thumb actuator 232 which measures the position of the thumb and provides those measurements the controller 290. The controller 290 can therefore monitor the position of the thumb digit mechanism 122 and determine when the thumb digit mechanism 122 reaches a preferred position e.g. the appropriate position for a pincer grip. The controller 290 can also monitor pressure within the high pressure sides of the chambers 180 driving the hydraulic actuators. Based on the information from the pressure sensor 240 and position sensor 270, and because of the arrangement of the valves 260, 262, and 264, the controller can provide several control options for the prosthetic hand 100.

For example, the controller can fix (e.g. lock) the position of the thumb digit mechanism 122 by closing (e.g. de-energising) the second and third solenoid valves 262 and 264. The second valve 262 prevents fluid flowing via line 256 into the high pressure side of the chamber 180 of the thumb actuator 232, while the third valve 264 prevents fluid leaving the high pressure side of the chamber 180 of the thumb actuator 232 via line 256. The position of the thumb digit mechanism 122 can therefore be locked at a chosen position. Further, the controller 290 might open (e.g. energise) both of the second valve 262 and the third valve 264, thereby allowing the thumb digit 122 to be moved in either direction.

During operation, the controller 290 may begin closing the digit mechanisms 120 simultaneously by opening the second valve 262 and running the motor 220 to deliver high pressure hydraulic fluid to the line 254. The first valve 260 and the third valve 264 may be de-energised during this process. Fluid pressure within the high-pressure sides of the chambers 180 will increase and the actuators 230 will start to close the digit mechanisms 120. The controller 290 can detect when the thumb digit mechanism 122 reaches a predetermined position using the position sensor 270 and can fix the position of the thumb digit 122 by closing the second valve 262. The index finger actuator 234 and the middle finger actuator 236 will continue to close as pressure in the respective high-pressure sides of the chambers increases.

The process of closing fingers against a fixed thumb is similar to how a human hand functions to apply a firm grip to an object. The strength of the grip typically derives from the force the fingers against the immovable thumb. The prosthetic hand 100 therefore operates in a manner that may be familiar to a wearer, and it may therefore be easier to operate. It may also be more efficient.

If the digit mechanisms 120 of the prosthetic hand 100 are closing about object, or if the closing finger mechanisms 124, 126 contact the fixed thumb 122, pressure will increase within the high-pressure sides of the chambers 180 of the index finger actuator 234 and the middle finger actuator 236. The finger mechanisms 124, 126 will then react against the thumb digit mechanism 122 and any pressure increase within the chambers 180 of the finger digit mechanisms 124, 126 will be mirrored by a corresponding pressure increase within the high-pressure side of the chamber 180 of the thumb actuator 232. That is, as the fingers 124 and 126 react against the thumb 122, the pressure in the high-pressure side of the thumb actuator 232 is necessarily equal to the pressure in the high-pressure sides of the index finger actuator 234 and middle finger actuator 236. Therefore the pressure sensor 240 also monitors pressure within the high-pressure side of the chamber 180 of the thumb actuator 232.

The hydraulic circuit 200 shown in figure 4 can therefore be used to provide increased options for control of prosthetic hand 100. For example, the controller 290 can control the thumb digit 122 to enable the prosthetic hand to make a fist, to regulate the maximum allowed system pressure by stopping the motor 210 when the maximum pressure is reached, and to keep the system pressure between a minimum and maximum desired value to mitigate against internal leakage over the pump 220. Other control processes are described below.

Figure 5A shows a perspective view of a pressure senor 240 of the artificial hand 100, and Fig. 5B shows a cross section of the pressure sensor 240 within the palm unit body 152. The pressure sensor 240 comprises a sensor body 320 defining therein a fluid chamber 330 and comprising a deformable membrane portion 340 which is arranged to deform (e.g. bulge) when pressure inside the fluid chamber 330 is different (e.g. greater) than pressure outside the sensor body 320. The sensor body 320, including the deformable membrane portion 340, in formed integrally as a single unit by an additive manufacturing process (e.g. 3D printing, laser sintering, material extrusion, powder bed processes, sheet lamination, and so on) from titanium, or an alloy of titanium. As can be seen from Fig. 5A, the pressure sensor body 320 is also integrally formed with the palm unit body 152. The fluid chamber 330 of the pressure sensor 240 is therefore part of the hydraulic circuit 200 defined by the palm unit body 152.

The pressure sensor 240 further comprises a strain gauge 350 disposed on the membrane 340 so as to measure the amount of deformation thereof. In use, the membrane 340 will deform by an amount depending upon the pressure differential across it. The artificial hand 100 will typically be used in atmospheric conditions and hence pressure outside of the sensor body 320 will be approximately constant, or at least will not vary significantly from about 1 bar (100 kPa). Therefore, the deformable membrane 340 will change shape in response to changes in fluid pressures in the fluid chamber 330, and hence in the region of the hydraulic circuit 200 in which it is located. As shown in figure 4, the pressure sensor 240 is in fluid communication with the chambers 180 containing the hydraulic actuators 230 of the index finger mechanism 124 and the middle finger mechanism 126. Fluid in the fluid chamber 330 will therefore be at the same pressure as fluid in the high-pressure sides of the chambers 180 of those mechanisms 124, 126. Different fluid pressures in the fluid chamber 330 will give rise to different degrees of deformation of the membrane 340. Therefore, the strain gauge 350 will provide different signals depending on the amount of deformation of the membrane 340, and hence can be used to measure the pressure within the fluid chamber 330, and therefore within the high-pressure sides of the chambers 180 of the finger digit mechanisms 120.

The strain gauge 350 is adhered to the outside of the sensor body 320, and as such can be simply added to the sensor body 320 after its formation by additive manufacturing e.g. after formation of the palm unit body 152. Since the membrane 340 is formed as part of the additive manufacturing process of the sensor body 320, the construction of the sensor 240 is relatively simply, and reliable.

As can be seen from Fig. 5B, the pressure sensor 240 comprises a fluid inlet 360 for providing fluid to the fluid chamber 330, and a fluid outlet 370 for exhausting fluid from the fluid chamber 330. In use, the fluid may be any suitable hydraulic fluid or oil. The inlet 360 and the outlet 370 may switch roles depending on the direction of fluid flow through the pressure sensor 240. The inlet 360 and outlet 370 are part of the hydraulic circuit 200.

Although the depicted pressure sensor 240 is shown having an inlet 360 and a separate outlet 370, the sensor 240 may instead have only a single fluid channel in communication with the fluid chamber 330.

The sensor body 320 of the pressure sensor 240 may be integrally formed with the palm unit body 152 as shown in Fig. 5B, and may be formed simultaneously therewith e.g. by 3D printing or the like. Thus, the sensor body 320 may be a part of the palm unit body 152, and may be formed as needed in (or adjacent) hydraulic channels of the palm unit body 152. The simultaneous integration of a pressure sensor 240 within a titanium additively manufactured artificial hand 100 is considered inventive in and of itself.

Figure 6A shows a cross-section of a two-stage solenoid valve, such as the first solenoid valve 260 and/or the third solenoid valve 262. The valve 260 comprises a valve body 400, a solenoid 410, and a piston 420 which is moveable between a first piston position in which the valve 260 is closed (leftmost in Fig. 6A), and a second piston position in which the valve 260 is fully open (rightmost in Fig. 6C). Activation of the solenoid 410 urges the piston 420 towards the second piston position, to the right in the orientation shown in Fig. 6A, and operates to open the valve 260 for fluid flow in two directions.

The two-stage valve 260 also comprises a pilot valve 430 which is movable relative to the piston 420. The pilot valve 430 has a first pilot position in which the two-stage valve 260 is closed and a second pilot position in which the two-stage valve 260 is open. The pilot valve 430 is movable with respect to the piston 420 because it is held in the piston 420 by a pin 432 which is moveable within a slot 422 of the piston 420. A spring 440 is provided to urge the piston 420, and therefore the pilot valve 430, to their closed positions i.e. their first positions. When the piston 420 moves to its second, open position, it also moves the pilot valve 430 to the second pilot position i.e. its open position.

The two-stage valve 260 has a low pressure side with a first opening 450 and a high pressure side with a second opening 460. The low pressure side and high pressure side are separated by the pilot valve 430. The first and second openings 450, 460 may be inlets or outlets depending on the direction of fluid flow through the valve 260. During use, when the motor 210 and the pump 220 are running to close the prosthetic hand 100 in a grip, fluid flows from the low pressure side to the high pressure side e.g. into the valve body 400 via the first opening 450, past the pilot valve 430, and out of the valve body 400 via the second opening 460. The valve may comprise any number of openings in the low pressure side and high pressure side as needed. The pilot valve 430 is moveable by higher pressure on the low pressure side of the valve 260.

Figure 6A shows the two-stage valve 260 in its closed configuration. When the pump 220 runs to close the digit mechanisms, fluid pressure on the low pressure side of the valve will increase, and fluid will flow from the low pressure side (e.g. from the first opening 450) to the high-pressure side (e.g. to the second opening 460) past the pilot valve 430, whether or not the solenoid 410 is energised. Hence, the two-stage valve 260 is arranged to freely permit fluid flow in that direction. Higher pressure on the low pressure side of the valve 260 will equalise with lower pressure on the high-pressure side.

However, when the pilot valve 430 is in its first position, fluid cannot flow freely from the high pressure side of the valve 260 to the low pressure side, because the high pressure urges the pilot valve 430 against an internal shoulder

402 of the valve body 400, thereby closing the valve 260 and preventing fluid flow in in that direction. Higher pressure on the high pressure side (e.g. at the second opening 460) is therefore prevented from normalising with lower pressure on the low pressure side (e.g. at the first opening 450) when the pilot valve 430 is in the first pilot position. The pilot valve 430 comprises a rubber seal 436 arranged to seal against the shoulder 402. The pilot valve 430 therefore simply closes the two-stage valve 260, and the provision of a rubber seal 436 means that the valve does not need to be manufactured to high tolerances to operate reliably.

The pilot valve 430 also comprises a fluid bypass 434 arranged to bypass the pilot valve 430 and provide fluid communication between the low pressure side of the valve 260 and the high-pressure side of the valve 260. However, when the piston 420 is in the first piston position, fluid communication through the fluid bypass 434 of the pilot valve 430 is prevented by engagement of a shoulder 438 of the pilot valve 430 with a rubber seal 424 of the piston 420. High pressures on the high pressure side of the valve 260 urge the piston 420 against the shoulder 438 of the pilot valve 430, thereby closing the fluid bypass 434. However, because the size of the fluid bypass 434 is smaller than the size of the main fluid flow path through the valve body 400, the piston 420 is held by the high pressure against the shoulder 438 of the pilot valve 430 with less force than the pilot valve 430 is held against the shoulder 402 of the valve body 400.

To open the prosthetic hand 100, the valve 260 transitions to its fully open arrangement in order to permit fluid to flow from the high pressure side (e.g. from the second opening 460) to the low pressure side (e.g. to the first opening 450). However, the prosthetic hand 100 is designed to operate at higher pressures than typical prosthetic hands. The use of higher pressures is desirable because it allows a wearer of the prosthetic hand 100 to grip objects more tightly, and thereby provides increased utility. For example, the hydraulic circuit 200 of the prosthetic hand 100 is arranged to operate with pressures greater than about 25 bar (2.5 MPa), preferably greater than about 50 bar (5 MPa), and more preferably around 60 bar (6 MPa).

However, the higher the pressure on the high-pressure side of the valve 260, the greater the force that is needed from the solenoid 410 to open the pilot valve 430 against that pressure i.e. the greater the force needed to pull the pilot valve 430 away from the shoulder 402. While a larger solenoid could be used to achieve such a force, the increase in size would increase the overall size and weight of the prosthetic hand 100, which is particularly undesirable given that it is to be worn by a user.

The two-stage valve 260 solves this problem by using a two-stage opening process in which the bypass 434 is opened first, and the pilot valve 430 is opened second. The solenoid 410 then only needs to provide enough force to open the bypass 434 against the high pressure. The solenoid 410 therefore only needs to pull the piston 420 away from the shoulder 438 of the pilot valve 430. The cross-section of the bypass 434 at the piston seal 422 is much smaller than the cross-section of the main fluid flow path at the seal 436 of the pilot valve 430, and as such less force is needed to open the bypass 434.Figure 6B shows the initial arrangement of the two-stage valve 260 during opening. The solenoid 410 is energised in order to starting moving the piston 420 towards the second piston position (towards the right in the orientation of Fig. 6B). Movement of the piston 420 is possible only because of the smaller surface area of the fluid bypass 434 of the pilot valve 430. The solenoid 410 therefore only needs to overcome a lesser force than if it were to directly pull the pilot valve 430 away from the shoulder 402. The solenoid 410 is not capable of providing sufficient force to open the pilot valve 430 directly.

Figure 6B therefore shows the piston 420 in an intermediate position between the first piston position and the second piston position, so that the bypass 434 of the pilot valve 430 is open and fluid communication between the high pressure side and the low pressure side the two-stage valve 260 is permitted and the pressures either side of the pilot valve 430 can start to equalise. The piston 420 moves relative to the pilot valve 430 because the pilot valve 430 is partially held within the piston 420 by the pin 432 disposed within the slot 422 of the piston 420.

When the pressures either side of the pilot valve 430 begin to equalise, the solenoid 410 is able to pull the piston 420, which in turn opens the pilot valve 430 from the shoulder 402 thereby fully opening the valve 260. Figure 6C shows the valve 260 in its fully open configuration, with the piston 420 and the pilot valve 430 in their respective second positions. The two-stage operation of the valve 260 is a smooth process, and once the bypass 434 is open the solenoid 410 can quickly open the pilot valve 430 as well.

The two-stage valve 260 also comprises a manual release 470. By pulling the manual release 470 (to the right in the orientation shown in Figs. 6A to 6E), a user is able to act in place of the solenoid 410 and manually open the valve 260.

For example, a user may release pressure in the hydraulic actuators 230 manually in the event of an emergency to allow the digit mechanisms 120 of the prosthetic hand 100 to open. The manual release 470 is sealed to prevent hydraulic fluid leaking from the valve 260. Figure 6D shows the manual release 470 in an activated state (e.g. pulled to the right), so that the valve 260 is manually opened. Actuation of the manual release 470 causes the bypass 434 to open, and subsequently causes the pilot valve 430 to open, as described above with reference to the operation of the solenoid valve. It would be difficult for a user to open the pilot valve 430 directly because of the large force needed to directly move the pilot valve 430 against the high pressures of the hydraulic circuit 200. The manual release 470 therefore uses the same two-stage opening process as the solenoid 410, and allows a user to manually open the two-stage valve by using less force.

When the prosthetic hand 100 is closed e.g. gripping an object, pressures in the hydraulic actuators 230 of each digit mechanism 120 are equal. It might therefore be dangerous to e.g. release pressure from only the thumb digit actuator 232 because the index finger actuator 234 and middle finger actuator 236 would still be pressurised. It is therefore preferable for the manual releases 470 of both the first valve 260 and the third valve 264 to be operated simultaneously. This is achieved by the arrangement shown in Fig. 6E, comprising a release button 474 which mechanically couples the manual releases 470 of the first valve 260 and the third valve 264 via respective pins 472. A pair of angled slots 476 is provided in the release button 474 so that when a user pushes the button 474, the pins 472 are urged along the slots 476 so that the manual releases 470 are subsequently actuated. In this way, both valves 260 and 264 are simultaneously manually opened.

The two-stage valve 260 therefore provides a mechanism for solenoid control of a valve in a hydraulic circuit 200 with relatively high pressures, without unduly increasing the weight and size of the prosthetic hand 100. The valve 260 is also relatively simply to manufacture and does not need high tolerances to operate reliably. For example, the rubber seal 436 of the pilot valve and the rubber seal 424 of the piston 420 are sufficiently reliable, and do not need high tolerance (and therefore costly) manufacturing.

As a result of the simple hydraulic arrangement and relatively small two-stage valves, the prosthetic hand may be made to be smaller than typical prosthetic hands. It is therefore possible to make a prosthetic hand for a child which is of a child-like size.

Various modes of operation of the prosthetic hand 100 will now be described by way of example. The prosthetic hand 100 may be operated using any suitable combination of myoelectric sensors, force sensitive resistors (FSR), and/or switches. However, the present hand 100 may perform a wide range of functions under operation of only two myoelectric sensors, thereby increasing the functionality for a user whilst being simple to operate.

In a first operational mode, the hand 100 may be closed into a pinch grip, with the thumb digit 122 and index digit 124 touching. In response to a user's signal, the controller 290 opens the second valve 262, and actuates all of the hydraulic cylinders 230 simultaneously, thereby closing all of the fingers 124, 126, 128 and the thumb 122 at the same time. When the position sensor 270 indicates that the thumb digit 122 is in a predetermined position, the controller 290 closes the second valve 262 thereby stopping motion of the thumb digit 122. Furthermore, since hydraulic fluid within the chamber 180 actuating the thumb 122 is held therein by the closed third valve 264, the thumb 122 will be fixed in its stopped position. Actuation of the index finger 124 and middle finger 126 continues while the thumb 122 is stopped. If there is nothing between the thumb 122 and index finger 124 preventing their touching, the tip of the index finger 124 will touch the tip of the thumb 122 and press against it. Since the position of the thumb 122 is fixed by the third valve 264 being closed, the index finger 124 will push against the thumb 122 in a pinch grip. Continued operation the pump 220 to close the hand 100 will cause the middle finger digit 126 – and the ring and little finger digit 128 attached thereto – to curl into a grip. Increased operation of the pump will cause pressure within the hydraulic actuators 230 to increase, thereby increasing the force of the grip. The pressure is monitored by the pressure sensor 240 and the controller 290 may stop the motor 210 and hence pump 220 at a maximum pressure threshold. The grip will then be held until the first valve 260 and third valve 264 are opened.

When the prosthetic hand 100 is used to grip an object, the operation starts in the same way. The controller 290 opens the second valve 262 in response to a control signal (e.g. from a wearer) and all of the digits 120 begin closing simultaneously. As the fingers 124, 126, 128 and thumb 122 close about an object, the continued operation of the pump 220 causes pressure to increase in the hydraulic actuators 230 and hence causes the strength of the grip to increase.

When the system pressure is at a predetermined level (e.g. about 15 bars), the controller 290 will close the second valve 262, thereby fixing the position of the thumb 122. Pressure will continue to increase in the hydraulic actuators 230 moving the index 124 and middle fingers 126, and as such those digits will increase their force against the fixed thumb 122. Any object disposed between the thumb 122 and the fingers 124, 126 will be gripped with increasing force.

The prosthetic hand 100 may also be operated so as to close into a fist. In response to a signal from a user, for example a simultaneous signal from two myoelectric sensors such as from co-contraction of two muscles, the controller 290 will close (or keep closed) the second valve 262, thereby fixing the position of the thumb 122. Operation of the pump 220 in a direction to close the prosthetic hand 100 will then cause the index 124 and middle fingers 126 to close while the thumb 122 remains fixed. Once the fingers encounter resistance (e.g. because they are fully closed) pressure within the high pressure side of the chambers 180 containing the index finger actuator 234 and middle finger actuator 236 will start to increase. Upon the pressure reaching a predetermined level (e.g. about 15 bars), the controller 290 will open the second valve 262, thereby allowing the thumb 122 to move and close over the index 124 and middle fingers 126, making a fist. The signal for this function may be e.g. co-contraction for a predetermined amount of time, e.g. a couple of tenths of a second.

The prosthetic hand 100 may also be closed into a fist without using a dedicated signal process. In this case, upon a signal to close the hand, the controller 290 opens the second valve 262 and starts the pump 220 in the first direction to close all of the fingers 120. However, the thumb 122 may be prevented from closing (e.g. by being held with a user's other hand, or by pressing it against a surface etc.) so that the fingers 124, 126, 128 curl into a grip. When the fingers 124, 126, 128 are closed, the thumb 122 is released so that it closes over the fingers, thereby making a fist.

A similar approach can be taken to cause the index finger 124 to point. Upon closing of the digits 120, the index finger 124 may be prevented from moving (e.g. by being held with a user's other hand, or by pressing it against a surface etc.). When the thumb 122 and other fingers 126, 128 are closed, the controller 290 stops actuating the digits 120 so that the index finger 124 remains pointing.

To open the hand 100, the controller opens the first valve 260 and the third valve 264, and allows the pump 220 to operate in the second (opposite) direction.

Springs 280 drive the hydraulic actuators 230 to their open positions, and hydraulic fluid flows back through the pump 220 to the low pressure side of the circuit 200. Springs in the digit mechanisms 120 will return the digits 120 to their open positions.

The above modes of operation may be achieved using only two sensors. Input from a single sensor may cause the hand 100 to close, while input from the other may cause it to open. Simultaneous input from both sensors may fix the position of the thumb 122 to allow the hand to make a fist etc. The fixture of the thumb 122 by operation of the second and third valves 262 and 246 is considered inventive in its own right.

Other functions may be achieved, and other valves included to fix the positions of any and all of the hydraulic actuators 230 in response to various controls as needed. For example, each digit mechanism 120 could be provided with a dual valve arrangement analogous to that of the second and third valves 262 and 264 provided for the thumb 122. The movement of each digit mechanism 120 could then be controlled independently of the others. Each digit mechanism could be provided with a position sensor 270 arranged to providing position measurements to the controller. Each hydraulic actuator 230 could be provided with a pressure sensor 240 and controlled by the controller 290 based on pressure increases indicative of resistance to the digit movement.

The prosthetic hand 100 described herein provides improved usability for a wearer, while keeping control options simple, improving reliability, and without unduly increasing weight and/or cost of the unit. It may also be used to provide prosthetic hands for children.

Claims:

1. A method of controlling digit mechanisms of an artificial hand, comprising fixing the position of an actuable digit mechanism at a predetermined position using a two-stage valve.

2. A method as claimed in claim 1, comprising
actuating the digit mechanism to close in a gripping motion; and
fixing the position of the digit mechanism when it reaches the predetermined position.

3. A method as claimed in claim 1 or 2, comprising fixing the position of digit mechanism when the digit mechanism encounters a predetermined resistance.

4. A method as claimed in claim 3, comprising monitoring pressure within a chamber containing a hydraulic actuator arranged to actuate the digit, and determining that the digit has encountered the predetermined resistance when pressure in the chamber reaches a predetermined threshold.

5. A method as claimed in any preceding claim, comprising releasing the digit mechanism using the two-stage valve, actuating the digit mechanism to a second predetermined position, and fixing the digit mechanism in the second predetermined position using the two-stage valve.

6. A method as claimed in any preceding claim, wherein fixing the position of the digit mechanism comprises closing a solenoid valve in series with the two-stage valve.

7. A method as claimed in claim 6, comprising opening the solenoid valve to actuate the digit mechanism.

8. A method as claimed in any preceding claim, wherein the digit mechanism is a first digit mechanism, the method comprising actuating a second digit mechanism to close in a gripping motion and react against the fixed first digit mechanism.

9. A method as claimed in any preceding claim, wherein fixing the position of the digit mechanism is in response to a predetermined signal.

10. A method as claimed in any preceding claim, comprising controlling the artificial hand using inputs from only two sensors.

11. A method as claimed in any preceding claim, comprising controlling a plurality of digits mechanisms.

12. A method as claimed in any preceding claim, wherein fixing the position of the digit mechanism comprises preventing flow of hydraulic fluid to and from a hydraulic actuator for actuating the digit mechanism.

13. A method as claimed in claim 8, comprising using a single pump to actuate a first hydraulic actuator arranged to actuate the first digit mechanism and actuating a second hydraulic actuator arranged to actuate the second digit mechanism.

14. A method as claimed in any of claims 1 to 13, comprising using a two-stage valve for an artificial hand, comprising:

a main fluid flow path between a first opening and a second opening;

a pilot valve moveable between a first pilot position in which the main fluid flow path is closed, and a second pilot position in which the main fluid flow path is open; and

a fluid bypass arranged to bypass the pilot valve;

wherein the valve is arranged to open by first opening the fluid bypass, and subsequently opening the main fluid flow path by moving the pilot valve to the second pilot position.