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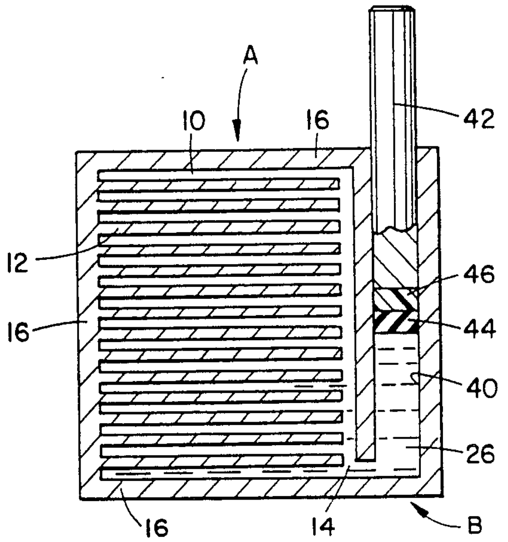


(57) Abstract

A pressure vessel (A) is defined by end walls (16) and side walls (18). In the interior, a plurality of fins (12) define an assembly of thin passages (10) that are filled with a material (26) that expands as it changes from a solid to a fluid state. The passages are thin, on the order of 0.01 inches such that heat is transferred relatively quickly into and out of the material. The passages communicate with a manifold area (14) to a piston bore (40) or other structure (B) for converting fluid pressure into mechanical movement. The piston bore holds a low durometer seal (44), a higher durometer seal (46), and a movable piston (42). To generate rotary motion, the piston and vessel assembly are mounted for rotation about an eccentrically placed member (88). As the pressure vessel goes through heating and cooling reservoirs, the pistons expand and contract causing rotation (Figs. 5-7). In another application, at least two of the assemblies are interconnected by a heat pump (94) such that heat can be moved back and forth between the two. Additional heat pumps are provided for moving heat from the ambient air or other sources of heat to the pressure vessels (fig. 8). The actuator is also used to control a two position valve (fig. 10) and a three position valve (Fig. 11). A pair of actuator vessels (170, 172) are connected by a common heat transfer device (174) for causing differential movement between pistons (176, 178, Fig. 13).

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# HIGH FORCE THERMOCHEMICAL ACTUATOR

## Technical Field

The present invention relates to mechanical power supplies. It finds particular application in conjunction with creating a high pressure fluid for extensible piston actuators and will be described with particular reference thereto. However, it is to be appreciated that the invention will also find application in conjunction with other high pressure fluid systems, as well as, other mechanical power supplies, such as solenoid type actuators, pumps, motors, valve controllers, and the like.

## Background Art

Heretofore, various sources of mechanical power have been provided. Solenoids are a common extensible actuator. Although solenoids are relatively simple to control and relatively inexpensive, they have several drawbacks. First, solenoids produce relatively little force for their physical size. Second, solenoids generate relatively small starting forces, i.e. they do not generate full force from a dead start. Even once extended, solenoids require full power to remain in their actuated state. Further, under low voltages or marginally higher loads, solenoids stall or fail to pull. Third, the inductive coil can generate RF interference that interferes with electronic control circuitry. Also, solenoids tend to be noisy. They "clack" when pressed open and tend to chatter or buzz under heavy loads.

Electric gear motors are less easy to control than solenoids but produce more force for their physical size. However, gear motors, particularly AC operated gear motors, tend to induce RF interference which interferes with control circuitry. Like a solenoid, gear motors do not start at full force. Gear motors can stall under high start up load conditions. Gear motors tend to be relatively slow. Like solenoids, when first actuated, gear motors draw a large initial surge current. Gear motors tend to be noisy, making a growling sound as they operate.

For higher power densities, hydraulic actuators are commonly utilized. However, the control lines, pumps, fluid reservoirs, pressure regulators, and other associated support devices render hydraulic and pneumatic cylinder assemblies complex to use and space inefficient. Moreover, hydraulic systems tend to be dangerous in a failure mode. When the high pressure fluids are unexpectedly released, the pressure is sufficiently great that they can penetrate or break surrounding structures, injure human attendants either directly and though high pressure oil induced blood poisoning, or the like. Moreover, hydraulic systems tend to be associated with an undesirable whine.

The present invention contemplates a new and improved actuator which overcomes the above-referenced problems and others.

## Disclosure of Invention

A pressure vessel defines in its interior an array of thin paths which merge into a manifold region. Within paths have a minimal dimension defined between thermally conductive surfaces. A phase change compound which expands as it changes between solid and liquid bases fills the thin paths. A heat means selectively adds heat to the phase change compound to cause the phase change compound to expand.

In accordance with a more limited aspect of the invention, a fluid pressure to mechanical motion converting means is operatively connected with the manifold region for converting pressure on the phase change compound to mechanical movement.

In accordance with yet more limited aspect of the present invention, the phase change compound changes phases substantially isothermally. A means is provided for adding and removing heat to hold the phase change compound substantially at a melting temperature, for adding heat to melt the compound and for removing heat to solidify the compound.

In accordance with another more limited aspect of the present invention, the fluid mechanical movement converting means includes a surface that extends as the compound melts and retracts as the compound solidifies.

In accordance with yet more limited aspects of the present invention, the actuator assemblies are used to make a rotary motor, a valve actuator, and the like.

One advantage of the present invention resides in its high power density.

Another advantage of the present invention is its flexibility and simplicity of operation.

Still further advantages of the present invention reside in its silent operation, its relative freedom from stallout, the elimination of RF interference by the use of DC control currents, reduced power consumption to maintain an extended state, adaptive peak force level that automatically adapts to the application, and reliability of service even over a large number of repetitions.

Still further advantages of the present invention will become apparent to those of ordinary skill in the art upon reading and understanding the following detailed description.

## **Brief Description of the Drawings**

The invention may take part in various components and arrangements of components, and in various steps and arrangements of steps. The drawings are only for purposes of illustrating the preferred embodiment and are not to be construed as limiting the invention.

FIGURE 1 is a perspective view in partial section of an actuator including a fluid pressure generating vessel and fluid pressure to mechanical motion converter in accordance with the present invention;

FIGURE 2 is a longitudinal sectional view of the system of FIGURE 1;

FIGURE 3 is an enlarged transverse sectional view of a portion of the pressure vessel portion of FIGURE 1;

FIGURE 4 is a diagramatic illustration of an actuator in accordance with the present invention;

FIGURE 5 is a sectional view of a motor employing a plurality of the actuators of FIGURE 1;

FIGURE 6 is a side sectional view of the motor of FIGURE 5;

FIGURE 7 is an enlarged transverse sectional view illustrating actuator mounting;

FIGURE 8 illustrates an alternate embodiment of a motor utilizing a vapor phase heat pump;

FIGURE 9 is an exploded view of another alternate embodiment of the present invention using thermoelectric heating and cooling means;

FIGURE 10 illustrates a valve assembly incorporating an actuator analogous to that of FIGURE 1 utilizing Peltier heating and cooling;

FIGURE 11 is a sectional view through the pressure vessel of the actuator of FIGURE 10;

FIGURE 12 illustrates a multi-position spool valve controlled by the actuator of FIGURE 1 utilizing Peltier heating and cooling;

FIGURE 13 illustrates a pair of actuators of FIGURE 1 mounted to provide differential movement utilizing Peltier heating and cooling;

FIGURE 14 illustrates a plurality of the actuator pairs of FIGURE 13 assembled into a robotic hand;

FIGURE 15 illustrates an alternate pressure vessel core construction technique; and,

FIGURE 16 illustrates a pressure vessel core assembled with the technique of FIGURE 15.

## Best Modes for Carrying Out the Invention

With reference to FIGURES 1, 2, and 3, a pressure vessel means **A** selectively generates a high pressure fluid which is converted into mechanical movement by a fluid pressure-mechanical motion converting means **B**. The pressure vessel means includes a multiplicity of thin paths **10** defined by a multiplicity of heat carrying and structural strength providing members or fins **12**. The thin paths merge at a manifold area **14** which is interconnected with the fluid pressure to mechanical movement generating means **B**. The pressure vessel is further defined by relatively strong end walls **16** and strong, readily heat conductive faces **18**. In the preferred embodiment, the thin paths **10** are cut in a single block **20** leaving three end walls **16**, one face **18**, and fins **12** all integrally connected. The second of faces **18** is defined by a plate **22** that is brazed by silver braze **24** to the end walls and the fins. The brazing not only provides effective heat transfers, but provides with the fins and opposite face an I-beam like structure for pressure stability.

More specifically, the pressure vessel is designed to optimize heat transfer into and out of a phase change material **26**, such as a wax or polymer, that fills the thin paths and manifold area of the pressure vessel. To this end, the pressure vessel is constructed of a high thermal conductivity metal, such as beryllium copper that is alloyed to have a conductivity of at least 1.1 Cal.gm./hr.cm.$^2$ °C. In each path, there is a point **30** which is most remote from a thermally conductive fin or metal portion. It is advantageous to make point **30** as close as possible to one of the fins or conductive surfaces. To this end, a minimum dimension **32** of the thin paths is less than 0.025 cm., at preferably less than 0.0125 cm. Because most phase change materials tend to have relatively poor thermal conductivity properties relative to the thermal conductivity properties of the fins and housing, it is desirable for the minimum dimension to be only the thickness of a few molecules of the phase change material. Alternately, additional heat conductive structures are provided for carrying heat into the thin paths more quickly, e.g., thin wires or rods, porous, highly thermally conductive foam, a sintered thermally conductive material, suspended thermally conductive particles.

The end walls **16** and faces **18** are at least as thick as the width of the thin paths and preferably at least twice as thick and of heat treated beryllium copper which has a tensile strength of 6,650 kg./cm.$^2$. Preferably, the overall vessel has the capacity to hold an internal pressure of 2000 kg./cm.$^2$. However, for some applications, only lower internal pressures are generated.

The use of fins or other heat conductive structures is provided to define a long, thin path or plurality of interconnected path segments. In an embodiment in which the pressure vessel is about 40 cm., about 40 cm. long path segments each having a width of 0.025 cm. are provided. This provides a path width to length ratio of about 11,000:1. Preferably, the path length to minimum width ratio is at least 10,000:1.

The fluid pressure to mechanical movement converting means **B** includes a bore **40** in which a piston **42** is slidably received. Preferably, the piston and piston bore are of high strength materials, such as metal. To prevent fluid from flowing between the piston and piston bore under the high pressures generated, a low durometer seal member, such as a soft rubber disk **44** is slidably mounted in the bore **40** between the piston **42** and the fluid **26**. Under the very high pressures generated, there is a tendency for the low durometer seal to flow partially in between the piston and the bore. Accordingly, a higher durometer seal member, such as a nylon or teflon disk **46**, is interposed between the low durometer member and the piston. The higher durometer seal deforms sufficiently under pressure that it is pressed into sufficient conformity with the bore that the low durometer seal cannot move flow therebetween. Optionally, additional intermediate durometer members may be interposed, as necessary, to assure that the fluid **26** is restrained by the lowest durometer seal and that the shape integrity of each seal is maintained.

Of course, other pressure to mechanical movement devices are also contemplated. In one alternate embodiment, a snap dome is utilized instead of the piston. A snap dome is advantageous in that a fluid tight seal can be made between the edges of the dome and the vessel. In another embodiment, bellows type expansible chambers are utilized. As another alternative, the low durometer seal may interface with the phase change compound **26** on one side and a second fluid to be pressurized or compressed at the other. In this manner, pumping or pressurizing of a fluid is achieved without intervening mechanical members.

Although the fluid pressure to mechanical movement means **B** is illustrated as being at one end of the pressure vessel **A**, other arrangements are contemplated. For example, a second pressure reservoir may be connected to an opposite side of the piston bore and fluidly interconnected with the manifold area. Additional pressure vessels can also be interconnected at various angles with the manifold area. As yet another alternative, the manifold area may be defined in the brazed-on end plate **22** in a generally central region thereof. Conversely, a second fluid pressure to mechanical motion converting means can be connected with the pressure vessel. If the fluid pressure to mechanical motion converting means each include a piston, the pistons extend with equal pressure, but not necessarily equal travel. Numerous other placements of the pressure to mechanical motion converting means **B** relative to the pressure vessel **A** are also contemplated as may be appropriate to the application.

The phase change compound can be any of a wide variety of compounds which change dimension as they undergo a generally isothermal phase change between liquid and solid phases. The compound preferably increases about 10%-15% in volume as it changes from its solid to its liquid state. It is to be appreciated that the invention functions analogously, but inversely, with a compound that expands as it solidifies. By using a generally isothermal phase change, the compound can be expanded and contracted, i.e. moved back and forth between its solid and liquid states, by using heating and cooling sources that are only a couple of degrees apart. A suitable compound is a wax that melts at 50° C. Other polymers and substances are also contemplated.

A temperature changing means **50**, preferably a Peltier effect thermoelectric heating/cooling chip, selectively adds and removes heat from the expandable medium in the chamber. When connected with a source of electricity of one polarity, the Peltier effect chip heats its surface **52** closest to the chamber to transmit heat energy into the wax. When connected with the opposity polarity, the Peltier chip draws heat from its face against the chamber and discharges the heat through cooling fins **54** on an opposite face. A temperature control means **56** controls the Peltier chip to hold the expandable medium substantially at its melting temperature.

When thermal energy is applied to room temperature wax, the wax retains its solid form but increases in temperature until it reaches its melting point. The additional energy necessary to change from the solid to liquid phase is supplied by the application of additional thermal energy. However, the absorbed thermal energy causes an isothermal phase change rather than increasing the temperature of the wax until the phase change is completed. If additional thermal energy is applied after the phase change, the liquid wax would increase in temperature. When thermal energy is removed, the liquid wax isothermally solidifies and contracts. In this manner, the wax expands and contracts about 12-15% as heat is added to or removed from the wax which is held at its melting point temperature.

In the embodiment of FIGURE 4, the temperature control means **56** includes no direct thermal element in the preferred embodiment. Rather, it controls the temperature of the expandable medium by monitoring the volume. The expandable medium **26** is heated to and held at the melting point temperature. A small additional amount of heat is added to a small fraction of the expansion, e.g. to change a small percentage of the expandable medium to its liquid state. This marks the equilibrium retracted position. A first cam operated switch **60** that is received in a first recess **62** in the piston closes each time the piston starts to retract and opens whenever the piston starts to extend. When the switch closes, indicating that the small percentage of the liquid phase is starting to solidify, the first switch **60** closes conducting electrical current to the heating means to add additional heat energy into the expandable medium. When the retracted equilibrium position is again attained, the cam operated switch **60** opens and the application of heat is terminated.

To expand or retract the piston, voltage of an appropriate polarity is applied to a control lead **64**. To expand the piston, a first polarity voltage is applied to the lead and conveyed through a second cam operated switch **64 - 66** to the Peltier chip. Voltage of the first polarity causes the Peltier chip to pump heat into the expandable medium **26** effecting the phase change (expansion of the medium), and extension of the piston **42**. When the piston has been extended its full range, the second cam operated switch engages the first recess **62** and opens to terminate the supply of power to the Peltier chip. In the extended position, the second cam switch **66** engages the first recess **62** and opens. The second switch **66** closes each time the piston starts to retract, supplying more heating polarity voltage and opens when it returns to the full extended position.

To retract the piston, the opposite polarity potential is applied to the control lead **64**. The opposite polarity control voltage is conveyed through the second switch **66** to the Peltier chip **50** to operate it in a heat removal mode. The heat is removed until the cam of the second switch **66** falls into a second recess **68** in the piston, opening the second switch and stopping the appliation of second polarity potential. The first switch **60** interacts with the first recess **62** in the piston to maintain the piston in the retracted position.

With reference to FIGURES 5, 6, and 7, a rotary motor is configured with a plurality of the actuators of FIGURE 1. Specifically, a plurality of actuators **70** with rollers or cam surfaces **72** on the ends of the pistons **42** are mounted to a movable member **74**, e.g. a ring. The fluid vessels extend radially outward from the ring **74**. The ring and actuators are mounted to an output shaft **76** which is mounted by bearings **78** in a stationary housing **80**.

The housing **80** defines an arcuate hot water bath or heating reservoir **82** and an arcuate cold water bath or cooling reservoir **84**. The reservoirs each extend generally along a half circle. Fluid seals **86** are provided between the hot and cold water baths to block intermixing of the hot and cold water while allowing the pressure vessels to move therethrough. The rollers on the ends of the pistons engage an eccentric member **88** which is mounted to the stationary body **80**. The eccentric member is mounted offset closest to one junction between the hot and cold water baths. When a pressure vessel first enters the hot water bath, the compound starts changing from its solid to its liquid state causing the piston to extend. Extension of the piston against the stationary eccentric member forces the actuator to move to a position where it is more remote from the eccentric member, i.e. rotate counterclockwise in the illustrated embodiment. As the fluid chamber becomes warmer, the piston extends still further until it reaches its point of maximum extension at the other interface between the hot and cold water baths. Once in the cold water bath, the composition starts to solidify, retracting the piston and allowing continued rotation about the eccentric member.

With reference to FIGURE 8, rotary motion can also be produced by a pair of oppositely mounted stationary actuators **90**. The piston **42** of each actuator is pivotally connected with a rotatably mounted crankshaft **92**. A heat transfer means **94**, preferably a vapor phase heat pump, transfers heat alternately between the two actuators causing them to cycle out of phase. Each actuator includes a coil **96** which is able to function as either an evaporator coil or a condenser coil. A reversible compressor or valve arrangement **98** for reversing flow pumps heat from one actuator to the other during about 180° rotation of the crankshaft. During the second 180° of rotation of the crankshaft, the compressor reverses and pumps the heat in the other direction. More specifically, freon gas is compressed by the compressor. The compressing elevates the temperature of the compressed gas or freon liquid, which hot freon liquid carries heat to one of the coils which is functioning as a condenser. The condenser coil heats the associated actuator. An expansion valve **100** allows the freon liquid to evaporate, it adsorbs heat, becoming cold. The cold freon gas flows through the other of coils **96** which is functioning as a condenser coil, removing heat from the other actuator. Once 180° of rotation is completed, the compressor reverses, reversing which of coils **96** functions as the condenser and which functions as the evaporator. In this manner, heat is moved in the other direction. Because a heat pump works most efficiently when moving heat between two reservoirs of substantially the same temperature, the heat pump system works near optimal efficiency.

A pair of additional heat transfer means **102**, preferably vapor phase heat pumps, are provided to replace heat losses at the two actuators. Specifically, each of the heat pumps **102** include a compressor **104** which selectively compresses freon removing heat from the ambient air or other heat source and discharging it into the associated actuator through a condenser coil **106**. An expansion valve **108** allows the freon liquid to expand to the gaseous state, absorbing heat from the ambient air. If the ambient air or other reservoir from which heat is removed is close to the working temperature of the actuators, the heat pump **102** again works at high efficiency.

With reference to FIGURE 9, thermoelectric chips **111**, such as Peltier chips, are placed against faces **18** of the pressure vessel. Heat sinks, such as an array of fins **112** are mounted to opposite sides of the thermoelectric chips. The thermoelectric chips efficiently move heat from the ambient air into the pressure vessel **A** and from the pressure vessel back out to the ambient air. High and low travel limit switches **114**, **116**, respectively, monitor for the piston to reach first and second degrees of extension. In the illustrated embodiment, the piston **42** engages a lever **118** which is cammed about a pivot point. The lever is interconnected at one end with associated equipment which is to be powered. The other end of the lever engages the limit switches **114, 116.**

With reference to FIGURES 10 and 11, a valve body housing **120** has a valve member **122** biased by a spring **124** across a valve seat **126.** In the preferred embodiment, fluid under pressure from an inlet end assists the spring in biasing the valve member **122** against the valve seat **126.** An actuator **128** selectively moves the valve member away from the valve seat to permit fluid flow through the valve.

The actuator includes a pressure vessel **130** of substantially the construction illustrated in FIGURES 1-3. That is, a multiplicity of small passages or thin passages **132** filled with the phase change composition funnel to a manifold area **134.** The manifold area connects with a bore **136** in which a piston **138** is mounted. A heat transfer means **140**, such as a Peltier chip, selectively adds or removes heat from the pressure vessel **130.** Depending on the temperature of the fluid flowing through the valve, the fluid in the valve can be used either add or remove heat from the pressure vessel.

With reference to FIGURE 12, a three-way spool valve is provided. A spool member **150** is slidably mounted in a housing **152**. An actuator **154**, generally of the construction illustrated in FIGURES 10 and 11, but with longer piston travel has a piston **156** for moving the spool member against a spring **157**. In the preferred embodiment, the piston has a tapered surface **156a** in a confined chamber, against which the phase change compound presses. A monitoring means **158** monitors the position of the spool member hence the extension of the piston. A control means **160** controls a heat transfer means **162** to transfer heat into and out of a phase change compound holding chamber arrangement **164** in an annular ring around the confined piston chamber of the actuator **154**.

With reference to FIGURES 13 and 14, a pair of pressure vessels **170**, **172** are mounted parallel to each other, with a common temperature transfer means **174** therebetween. Pistons **176**, **178** of fluid pressure to mechanical motion converting means **180**, **182** associated with each pressure vessel selectively extend and contract. Piston extension sensor means **184** provides an output signal indicative of the degree of relative piston extension. A pressure sensing means **186** senses the pressure within the pressure vessel, hence the pressure with which each piston is being extended. Based on this information, a computer control means selectively supplies electricity to the temperature controlling means **174** to adjust the relative extension and contraction of the pistons. As illustrated in FIGURE 13, a multiplicity of these dual piston, dual controlled actuators can be interconnected in various robotic configurations, such as a hand configuration.

With reference to FIGURES 15 and 16, the pressure vessel **A** can be fabricated with different techniques. For example, a thin sheet of thermally conductive material **190** such as beryllium copper alloy, is accordion pleated. The accordion pleated sheet is coated with the phase change material and compressed between end blocks **192**. Alternately, the phase change material may be drawn in its liquid state into the paths after assembly. Top and bottom plates **194** are brazed at least to the end blocks and preferably to the pleated sheet for thermal conductivity and strength. The open ends of the compressed accordion pleated sheet are connected with a structure (not shown) that defines a manifold area leading to a piston bore as in FIGURES 1 and 2.

Numerous applications of these actuators readily identify themselves. In the automotive area, actuators can readily be used to control windshield wipers, power seats, power windows, power mirrors, power trunk openers, choke actuators, and other mechanisms which require proportional travel or variable rates of movement. The actuators are also suitable for power trunk latches, gas cap latches, rotating headlamp or headlamp covers, starter solenoids, axle shift devices, inter-axle shift devices, and the like which require merely on/off states.

The actuators also find uses in appliances including a number of directly actuated valves, gravity drain valves, dishwasher drain valves, three-way hydraulic-type valves, metering valves, pressure control valves, washing machine valves, video tape cassette ejection mechanisms, power door openers, ventilation duct damper actuators, ice cube dump mechanisms, zone valves, office equipment, and the like. The actuators can also be adapted for use with a variety of powered hand held devices, such as riveters, embossers, shears, hose crimpers, and the like. The technology is also useful for replacing explosive bolts, expandable rivets, one shot safety brake systems, deployable booms, field swaging operations, fly-by-wire actuators, large hydraulic valve actuators, proportional controllers, robotics, and the like.

**Claims**

1. An apparatus comprising:

a fluid pressure vessel which defines in an interior thereof an array of thin paths which merge into a manifold region, the thin paths having a minimal dimension defined between thermally conductive surfaces;

a phase change compound which expands as it changes between solid and liquid states filling the thin paths;

a heat means for selectively adding heat to the phase change compound to cause the phase change compound to change states and expand.

2. The apparatus as set forth in claim 1 further including a pressure to mechanical movement converting means for converting fluid pressure into mechanical movement, the pressure to mechanical movement converting means being operatively connected with the manifold region.

3. The apparatus as set forth in claim 2 wherein the phase change compound undergoes the phase change substantially isothermally, wherein the heat means selectively adds and removes heat from the phase change compound, and further including a temperature control means for controlling heat means to (1) hold the phase change compound substantially at a temperature at which it undergoes the phase change, (2) add heat energy to cause mechanical motion in a first sense, and (3) remove heat to cause mechanical motion in a second sense.

4. The apparatus as set forth in claim 2 wherein the pressure to mechanical movement converting means includes an element that extends as the phase change compound changes to the liquid state and retracts as the phase change compound changes to the solid state.

5. The apparatus as set forth in claim 2 wherein the pressure to mechanical movement converting means includes a piston bore, a lower durometer member is slidably received in the bore in contact with the phase change compound, a higher durometer member is slidably received in the bore adjacent the lower durometer member, and a piston is slidably received in the bore abutting the higher durometer member.

6. The apparatus as set forth in claim 2 wherein the fluid pressure vessel has generally flat opposite wall surfaces; and wherein heat means includes at least one thermoelectric chip mounted against one of the vessel flat wall surfaces and a heat sink mounted in thermal communication with the thermoelectric chip, the thermoelectric chip being selectively operable for moving heat back and forth between the vessel and the heat sink.

7. The apparatus as set forth in claim 2 wherein:

the heat means includes a heating zone and a cooling zone; and

further including a movable member to which the vessel and the pressure to mechanical movement converting means are mounted for movement relative to the heating and cooling zones for selectively moving the vessel cyclically between the heating and cooling zones, the pressure to mechanical movement converting means providing motive force to move the movable member.

8. The apparatus as set forth in claim 2 further including:

a second pressure vessel and a second fluid pressure to mechanical movement converting means for selectively converting fluid pressure from a phase change compound in the second pressure vessel that changes phase from a solid to a liquid state to mechanical movement; and wherein the heat means includes a heat transfer means for selectively moving heat back and forth between from the first pressure vessel and the second pressure vessel.

9. The apparatus as set forth in claim 2 wherein the pressure vessel is mounted to a valve with the pressure to mechanical movement converting means being operatively interconnected with a valve member for selectively changing states of the valve.

10. A method of selectively extending and retracting an element and a pressure vessel combination in which the pressure vessel contains a medium that undergoes a substantially isothermal phase change between a first, contracted state and a second, expanded state at a phase change temperature, the method comprising;

maintaining the medium substantially at the phase change temperature;

adding heat energy to the medium such that the medium changes from the first state to the second state expanding and causing the element and pressure vessel combination to extend;

removing heat energy from the medium such that the medium changes phase from the second phase to the first phase contracting and causing the element and pressure combination to retract.

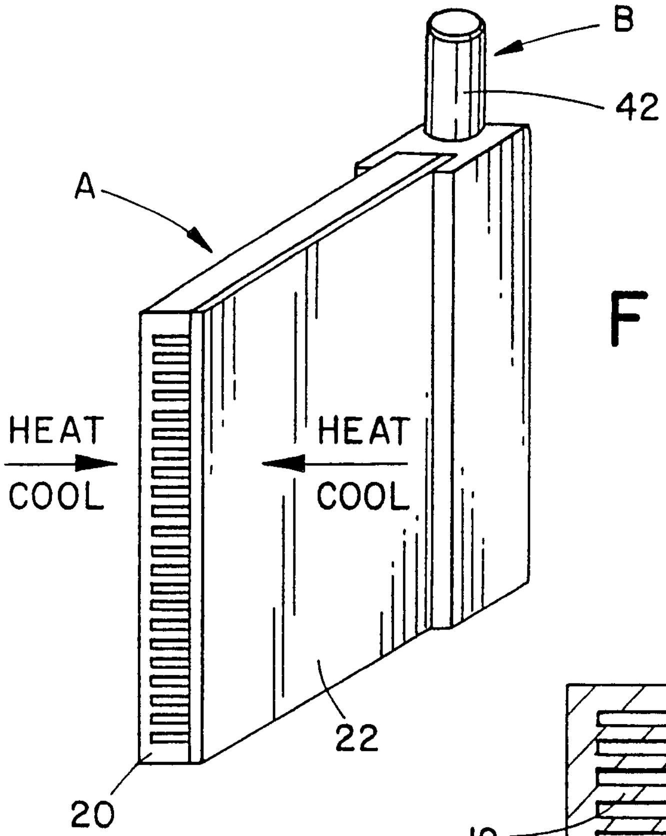


FIG. 1

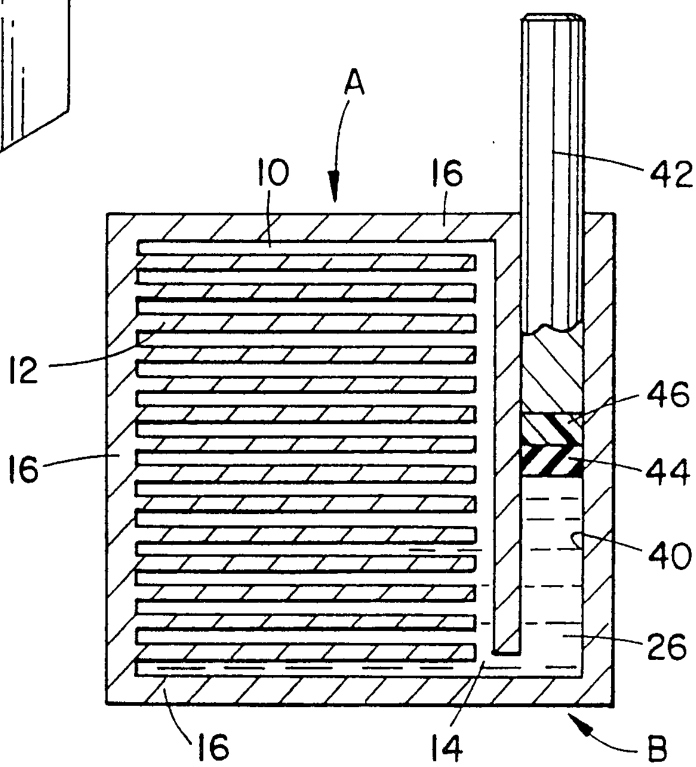


FIG. 2

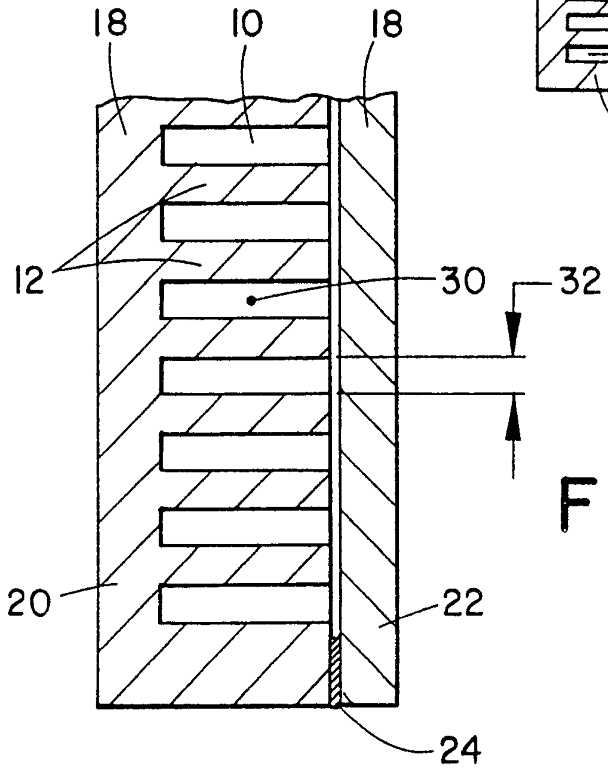


FIG. 3

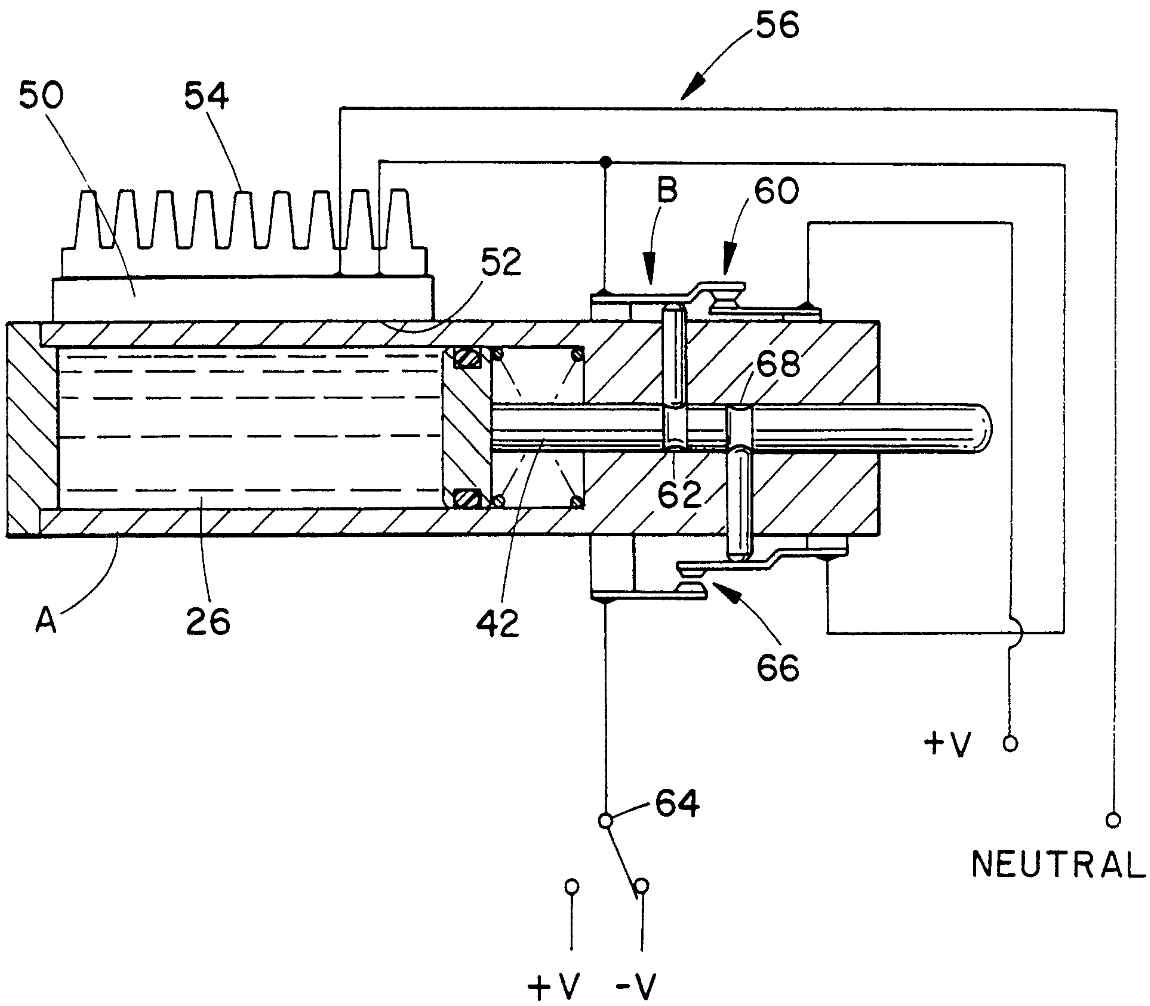


FIG. 4

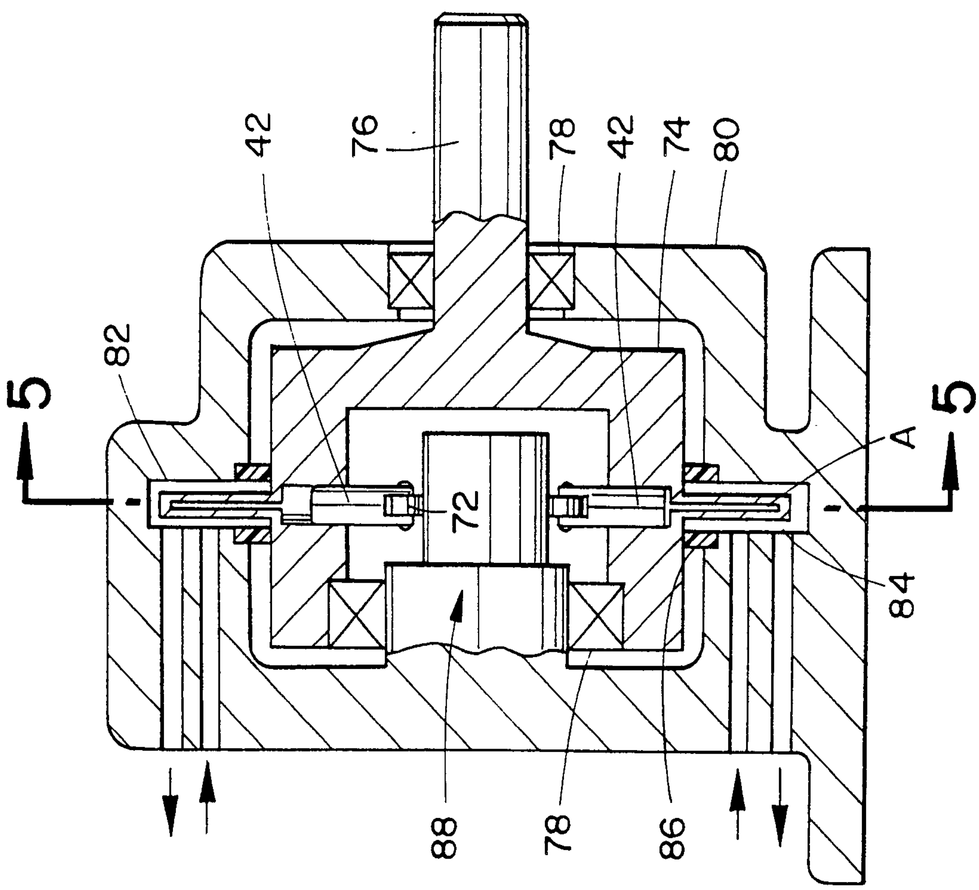


FIG. 6

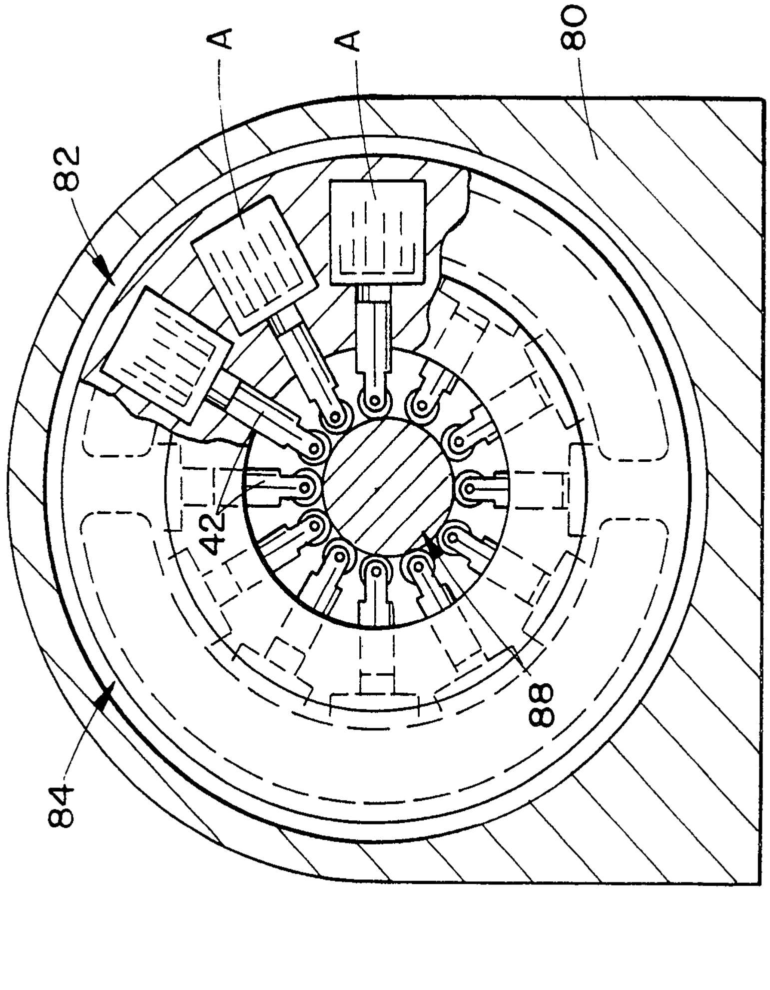


FIG. 5

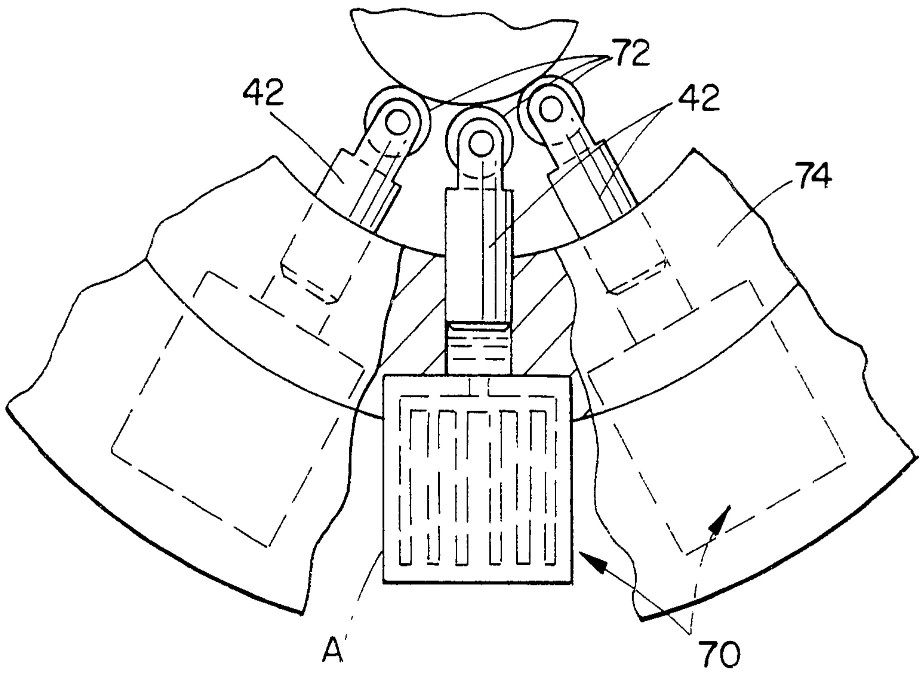
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FIG. 7

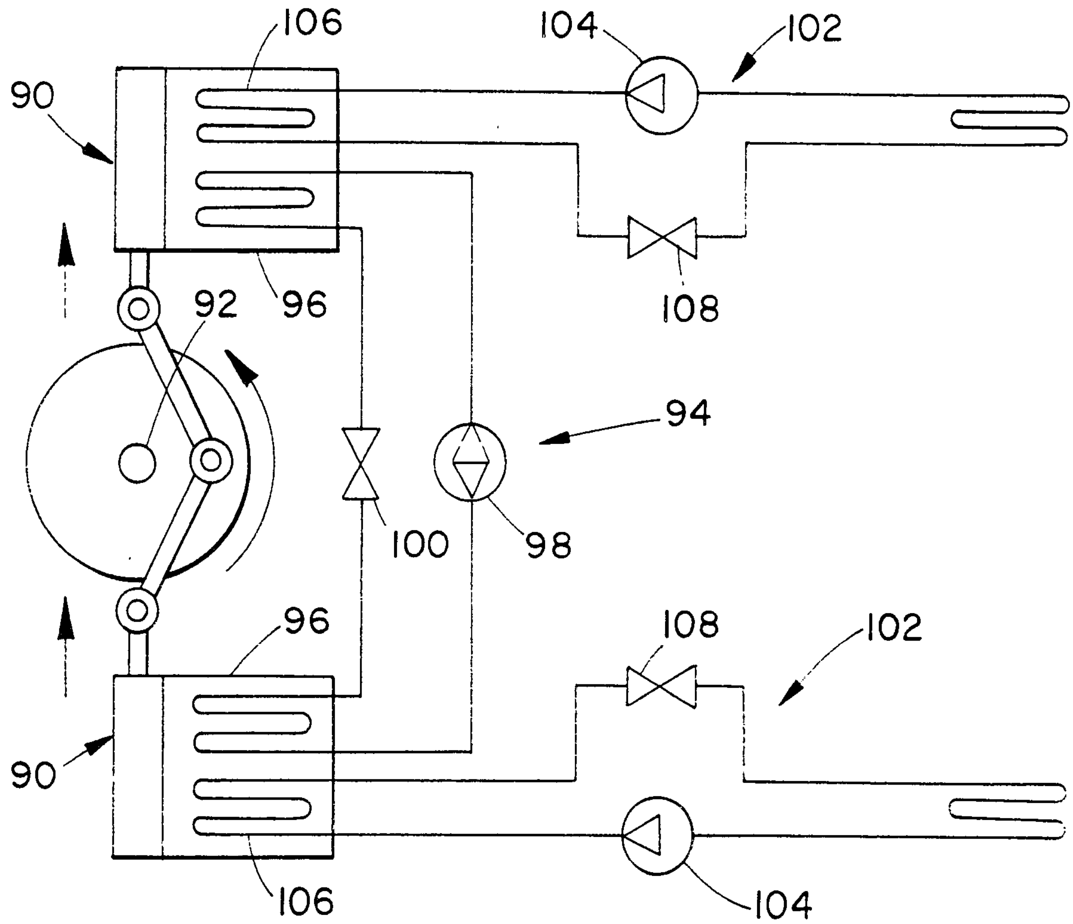
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FIG. 8

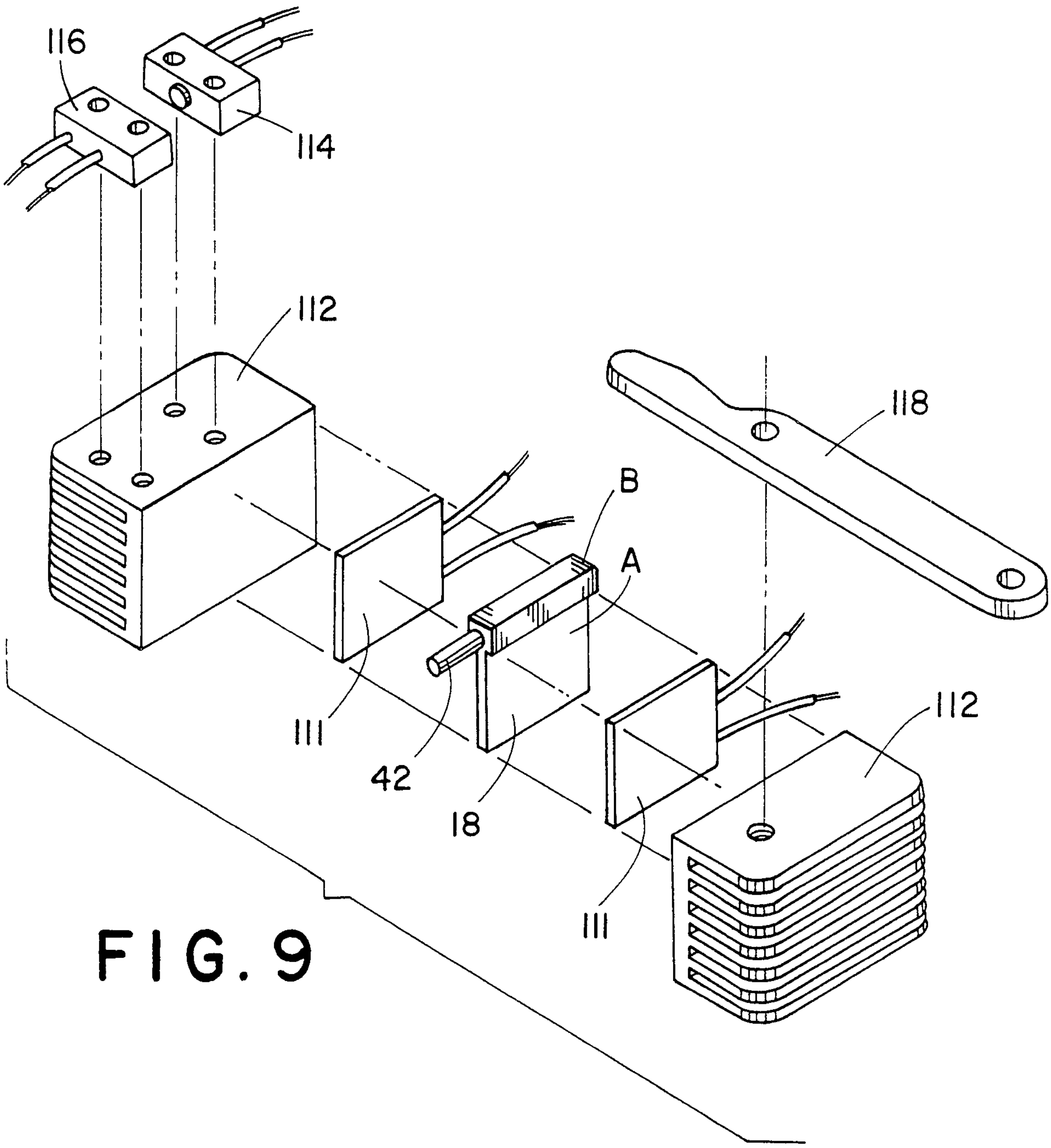



FIG. 9

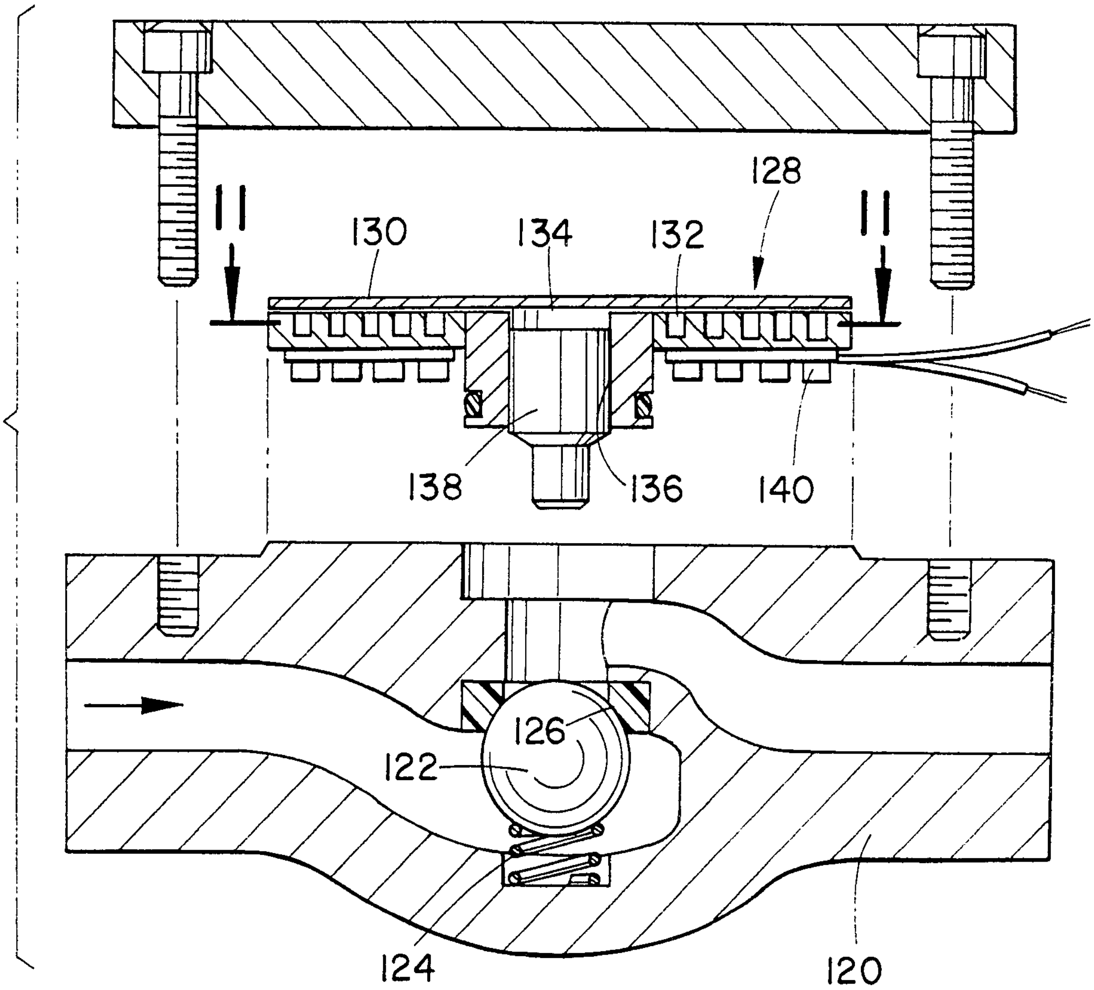



FIG. 10

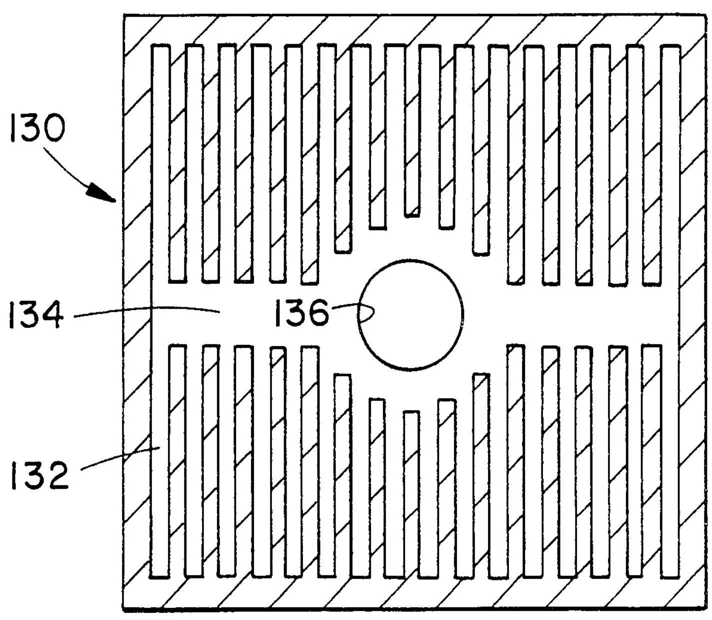



FIG. 11

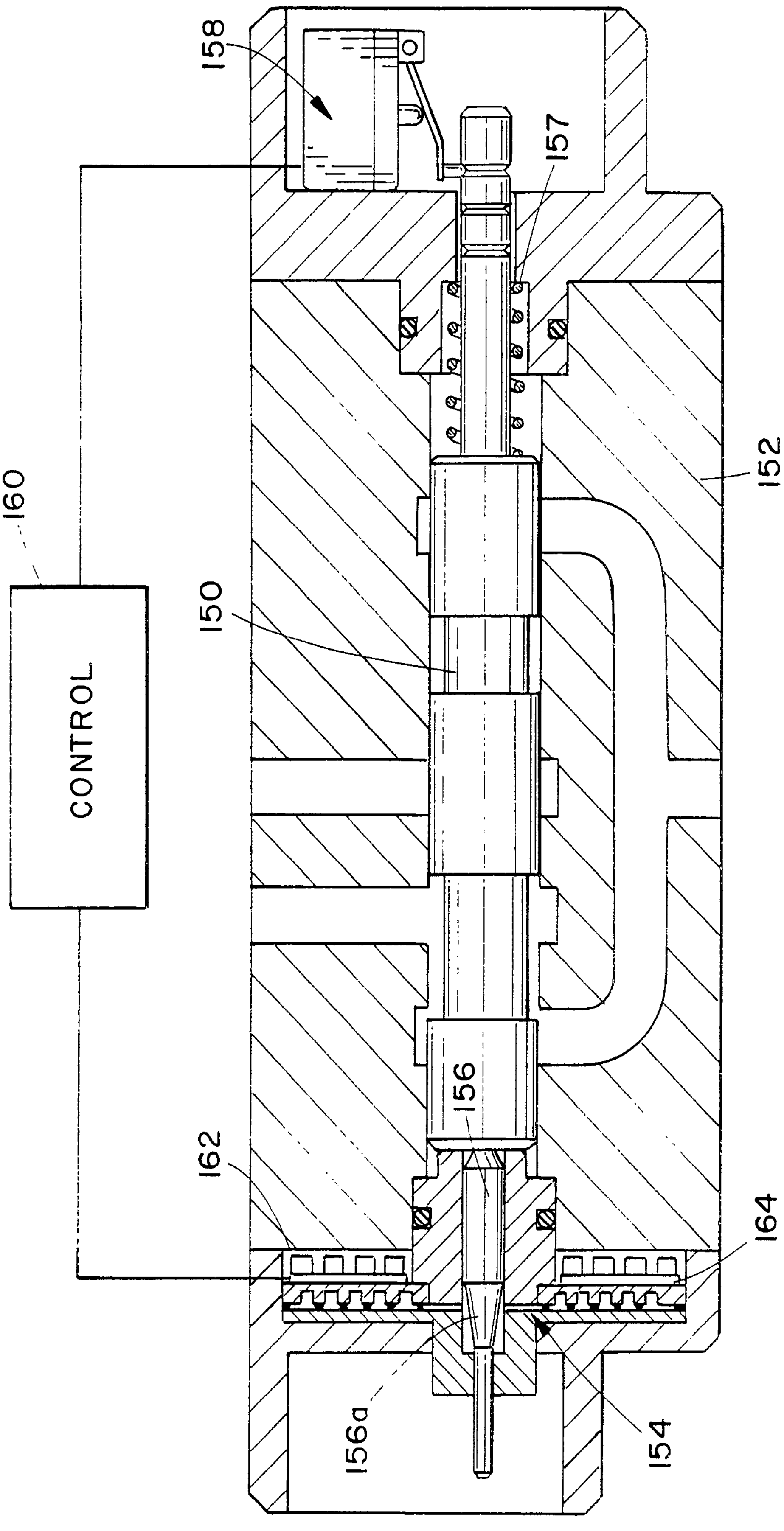



FIG. 12

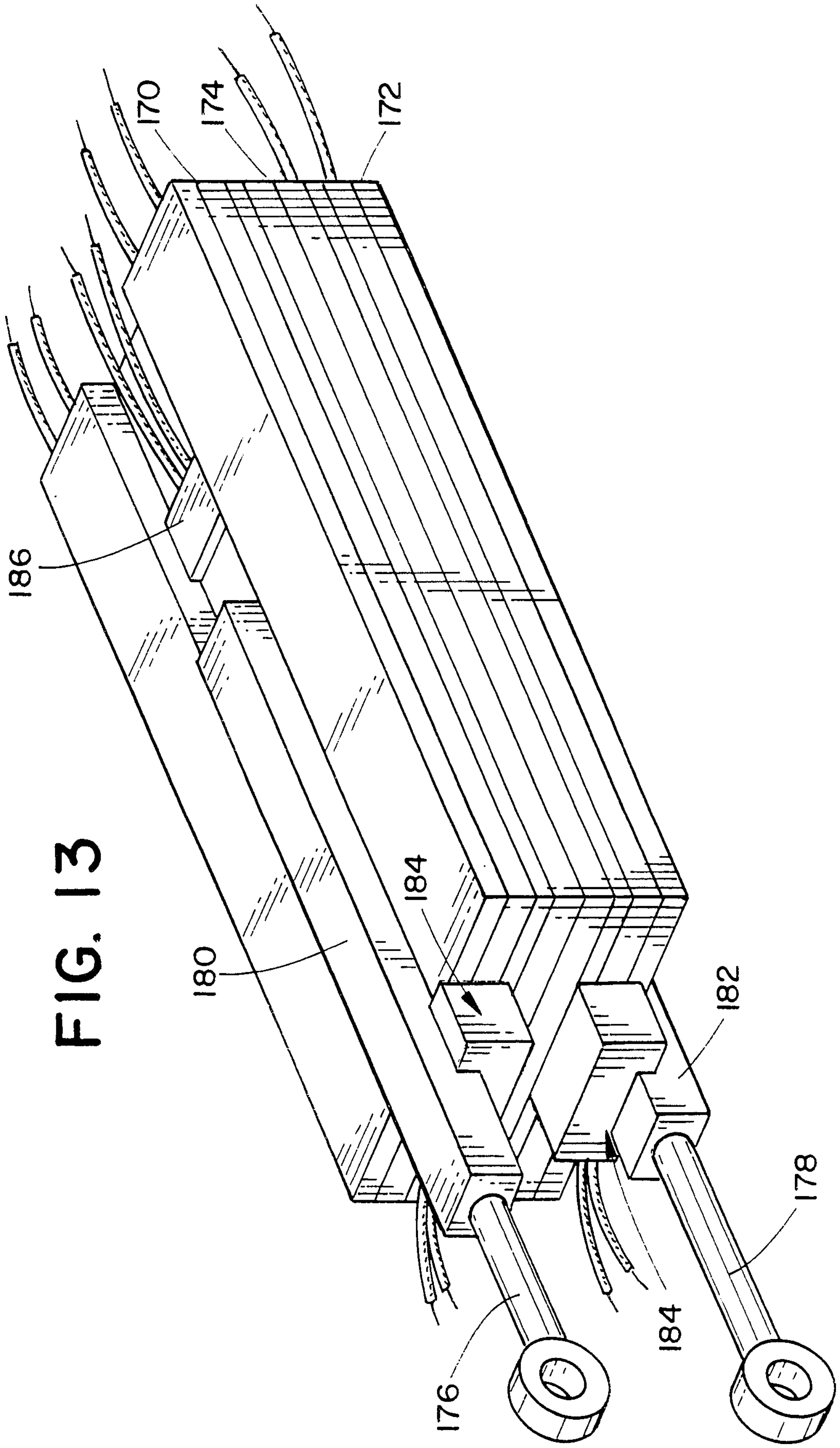
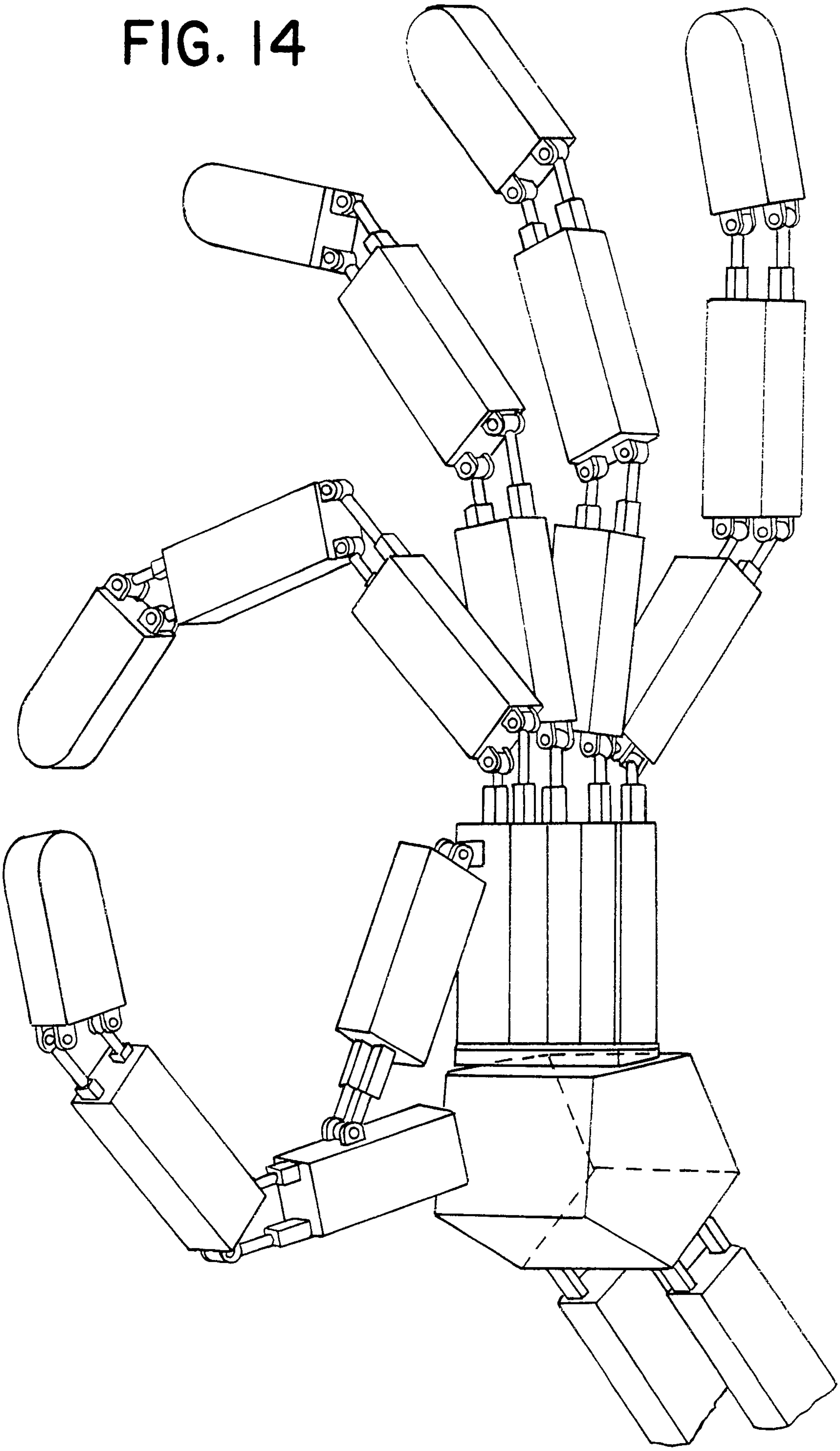



FIG. 13

FIG. 14



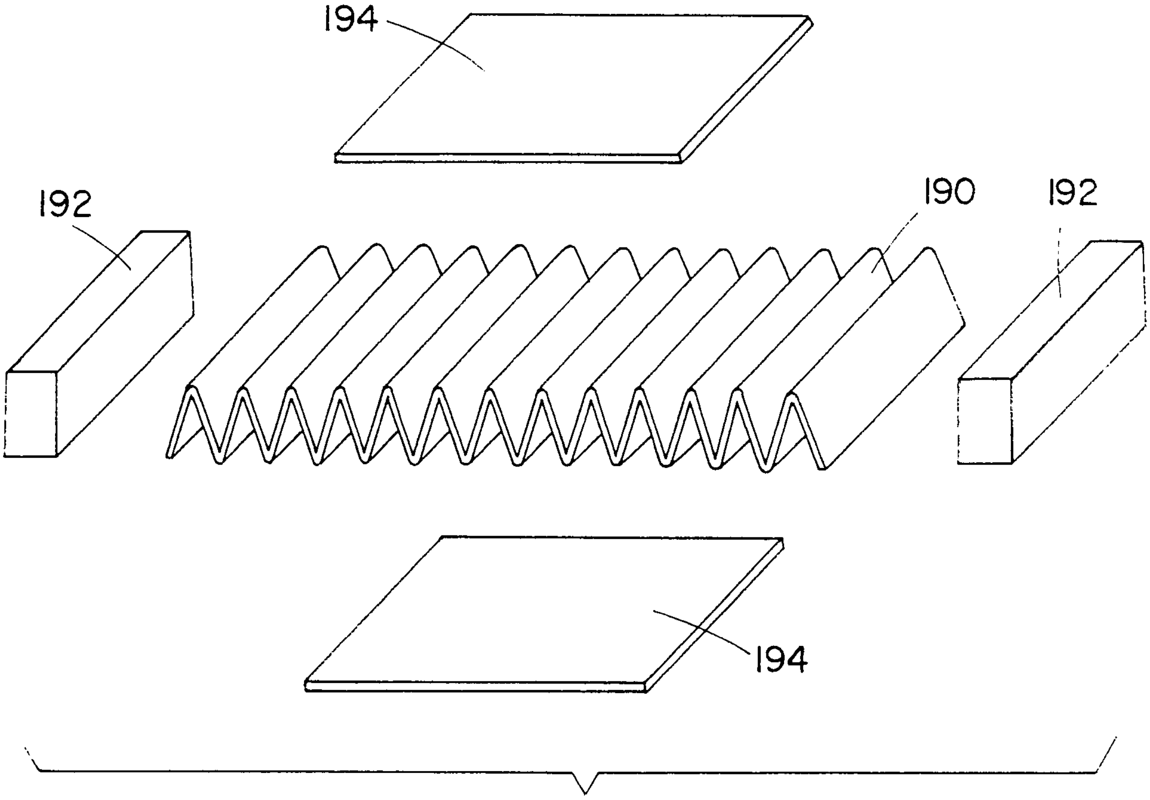



FIG. 15

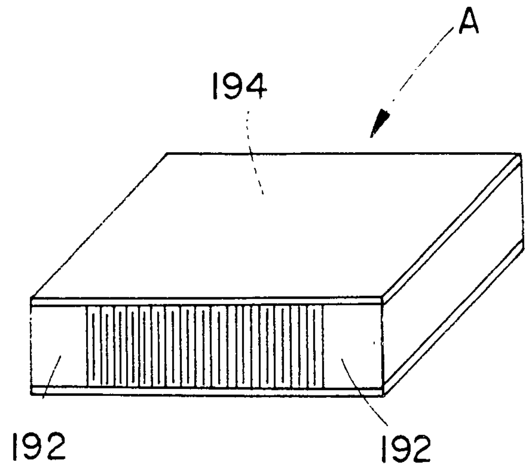



FIG. 16

# INTERNATIONAL SEARCH REPORT

International Application No PCT/US 91/04178

**I. CLASSIFICATION OF SUBJECT MATTER** (if several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl. 5 F03G7/06; F15B21/06

**II. FIELDS SEARCHED**

Minimum Documentation Searched[7]

| Classification System | Classification Symbols |
|---|---|
| Int.Cl. 5 | F03G ; F15B |

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched[8]

**III. DOCUMENTS CONSIDERED TO BE RELEVANT**[9]

| Category ° | Citation of Document, [11] with indication, where appropriate, of the relevant passages [12] | Relevant to Claim No.[13] |
|---|---|---|
| A | US,A,4 235 075 (ERB) 25 November 1980<br>see abstract<br>see column 2, line 33 - column 14, line 12; figures<br>--- | 1,4,7 |
| A | US,A,4 253 304 (LAMB) 3 March 1981<br>see column 2, line 36 - column 4, line 37; figure<br>--- | 1,2,5 |
| A | GB,A,2 114 741 (LOOMHURST LIMITED) 24 August 1983<br>see page 1, line 43 - page 2, line 40; figure<br>--- | 1,3,6 |
| A | US,A,3 475 904 (HAYES) 4 November 1969<br>see column 2, line 33 - column 4, line 31; figures<br>--- | 1,2,5 |
| A | FR,A,2 408 049 (DANFOSS A/S) 1 June 1979<br>see figure 3<br>---<br>-/-- | 9 |

° Special categories of cited documents : [10]

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

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

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

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

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

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

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

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

"&" document member of the same patent family

**IV. CERTIFICATION**

| Date of the Actual Completion of the International Search | Date of Mailing of this International Search Report |
|---|---|
| 1 26 NOVEMBER 1991 | 06 JAN 1992 |
| **International Searching Authority** | **Signature of Authorized Officer** |
| EUROPEAN PATENT OFFICE | MOUTON J.M.M.P. |

International Application No PCT/US 91/04178

| III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET) | | |
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| Category ° | Citation of Document, with indication, where appropriate, of the relevant passages | Relevant to Claim No. |
| A | GB,A,2 095 338 (LAUWRENCE) 29 September 1982<br>--- | |

# ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. US 9104178
SA 50513

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The members are as contained in the European Patent Office EDP file on
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| GB-A-2095338 | 29-09-82 | None | |



For more details about this annex : see Official Journal of the European Patent Office, No. 12/82