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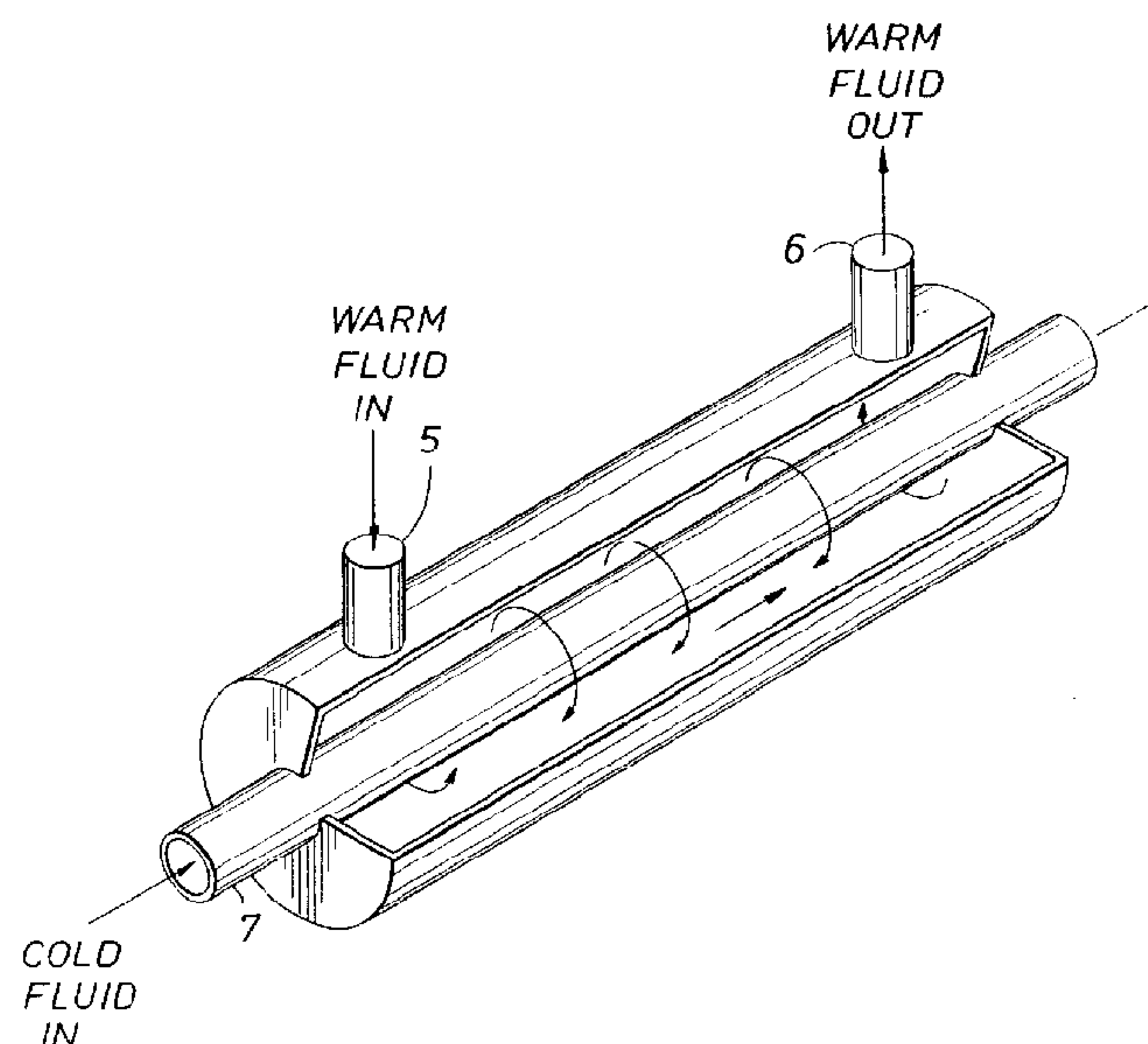
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(54) Titre : APPAREIL ET METHODE POUR REFROIDIR ACTIVEMENT DES INSTRUMENTS DANS UN ENVIRONNEMENT A TEMPERATURE ELEVEE

(54) Title: APPARATUS AND METHOD FOR ACTIVELY COOLING INSTRUMENTATION IN A HIGH TEMPERATURE ENVIRONMENT



(57) Abrégé/Abstract:

An apparatus and method are disclosed for actively cooling instrumentation, in particular electronic circuits, in especially, high temperature environment. This apparatus has a tank containing a cooling agent, a heat exchanger to transfer heat from the instrumentation to the cooling agent, a compressor and a tank to hold cooling agent removed from the first tank. In this operation, the cooling agent tank is located in close proximity to the instrumentation. As the instruments generate heat, the heat is transferred through the heat exchanger to the cooling agent. The cooling agent boils and vaporizes from the heat and is pumped out of the tank by a compressor. As the cooling agent vaporizes and is pumped out of the tank, heat contained in the cooling agent is transferred out of the tank as well. The rate at which the vapor is pumped out of the tank controls the temperature of the cooling agent in the tank. The vapor is compressed under pressure and pumped to a storage tank where the vapor condenses back to a liquid.



Abstract of the Disclosure

An apparatus and method are disclosed for actively cooling instrumentation, in particular electronic circuits, in especially, high temperature environment. This apparatus has a tank containing a cooling agent, a heat exchanger to transfer heat from the instrumentation to the cooling agent, a compressor and a tank to hold cooling agent removed from the first tank. In this operation, the cooling agent tank is located in close proximity to the instrumentation. As the instruments generate heat, the heat is transferred through the heat exchanger to the cooling agent. The cooling agent boils and vaporizes from the heat and is pumped out of the tank by a compressor. As the cooling agent vaporizes and is pumped out of the tank, heat contained in the cooling agent is transferred out of the tank as well. The rate at which the vapor is pumped out of the tank controls the temperature of the cooling agent in the tank. The vapor is compressed under pressure and pumped to a storage tank where the vapor condenses back to a liquid.

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Apparatus and Method for Actively Cooling Instrumentation in a High Temperature Environment

Field of the Invention

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This invention relates to an apparatus and method for cooling instruments in an apparatus while operating that apparatus in high temperature environments. In particularly it relates to the use of a cooling agent to cool the electronics in a logging tool when the tool is exposed to earth formation temperatures and thereby preventing tool failure.

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Background of the Invention

The environment encountered by downhole oil exploration tools can be very severe. Temperatures up to and in excess of 200°C and pressures up to 1.38x10⁸Pa are not uncommon. Consequently, producers of oil exploration tools must design robust tools that can operationally sustain these harsh conditions for extended lengths of time. Perhaps the most challenging of all conditions to design electronics that can reliably operate in high temperature environments. Standard electronic components are usually rated to operate only up to approximately 125°C. Thus, it becomes necessary to create or experimentally find electric components that can survive the high temperatures existing downhole. Since the components are constantly changing via new manufacturing techniques, updates, etc., this process of creating electronic components is expensive, time consuming, and never ending. In an effort to combat the high temperature requirement of electronics, the chassis or electronics compartments in downhole tools could be kept at or below 125°C.

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Today, tools rated to 175°C are sometimes inserted into Dewar Flasks when exploring boreholes in excess of 175°C. Dewar Flasks act to insulate the tool electronics and to slow the heating of the electronic chassis similar to a large “thermal bottle”. The flask is a passive system that extends the downhole residence time of the tools by approximately four to six hours. Often the downhole residence times required for exploration are much greater than those offered by the expensive Dewar Flask system.

The problem at hand points toward the need for an active cooling system that can maintain the electronic chassis below 125°C for extended lengths of time. Standard electronics could then be used without the need for the expensive high temperature components.

Active cooling systems already exist for a variety of applications such cooling food products, motor vehicles and buildings. These active cooling systems, better known as air conditioners and refrigerators, can effectively operate for extended periods of time with little to no maintenance. A cooling system makes heat move. It takes heat from one location and moves it to another location. The location from which heat was removed obviously becomes colder. For example, a refrigerator takes heat out of the inside and moves it to the outside. The heat flows into the air and the inside, having lost heat, becomes colder.

Vapor compression active cooling systems work by evaporation. When a liquid turns into a vapor, it loses heat and becomes cooler. This change is because the molecules of vapor need energy to move and leave the liquid. This energy comes from the liquid; the molecules left behind have less energy and so as a result, the liquid is cooler.

For an active cooling system to work continuously, the same cooling agent (etc., Freon) must be repeatedly used for an indefinite period. These cooling systems have

three basic patterns: the vapor-compression system, the gas-expansion system and the absorption system. The vapor-compression system is the most effective and is used more extensively than the other arrangements. The vapor-compression system consists of four main elements: an evaporator, a compressor, a condenser and an expansion device.

Referring to Figure 1, in the evaporator 1, the cooling agent boils (evaporates) at a temperature sufficiently low to absorb heat from a space or medium that is being cooled. The boiling temperature is controlled by the pressure maintained in the evaporator, since the higher the pressure, the higher the boiling point. The compressor 2 removes the vapor as it is formed, at a rate sufficiently rapid to maintain the desired pressure. This vapor is then compressed and delivered to a condenser 3. The condenser dissipates heat to circulating water or air. The condensed liquid cooling agent, which is now ready for use in the evaporator 1, is then sharply reduced in pressure by passing it through an expansion valve 4. Here, the pressure and temperature of the cooling agent drop until they reach the evaporator pressure and temperature, thus allowing the cooling cycle to repeat.

During expansion some of the liquid of the cooling agent flashes into vapor so that a mixture of liquid and flash vapor enters the evaporator. In a cooling system, the low pressure in the evaporator is set by the cooling temperature which is to be maintained. The high pressure maintained in the condenser is determined ultimately by the available cooling medium (etc., the temperature of circulating water or the atmosphere air temperature. The process is one in which the cooling agent absorbs heat at a low temperature and then under the action of mechanical work, the cooling agent is compressed and raised to a sufficiently high temperature to permit the rejection of this heat. Mechanical work or energy supplied to the compressor as power is always required to raise the temperature of the system.

To further explain the cooling process, the four major components are examined in greater detail. The evaporator 1 is the part of the cooling system in which the cooling is actually produced. The liquid cooling agent and vapor from the expansion valve 4 are introduced into the evaporator. As the liquid vaporizes, it absorbs heat at low temperature and cools its surroundings or the medium in contact with it. Evaporators may be direct expansion (acting directly to cool a space or product) or they may operate as indirect-expansion units to cool a secondary medium, such as water or a brine which in turn is pumped to a more distant point of utilization. A domestic refrigerator, for example, is a direct-expansion unit in that its evaporator directly cools the air in the food compartment and also directly contacts the water trays used for making ice.

Evaporators vary greatly in design, with those used for cooling air often made as continuous pipe coils, with fins mounted outside the pipes to give greater surface contact to the air being chilled. For cooling liquid, such as a brine water, the shell and tube arrangement is common. In this case, the brine passes through tubes surrounded by the boiling (evaporating) cooling agent, which is contained in a larger cylindrical shell. The brine tubes, in turn, are welded or rolled into tube sheets at the end of the shell to prevent leakage of the cooling agent from the shell or into the brine circuit.

The expansion valve 4 that feeds the evaporator must control the flow so that sufficient cooling agent flows into the evaporator for the cooling load but not in such excess that liquid passes over to the compressor, with the possibility of causing damage to it.

The compressor 2, the key element of the system, can be powered by means such as electric motor, steam or internal combustion engine, or steam or gas turbine. Most compressors are of the reciprocating (piston) type and range from the fractional-horsepower size, such as those found in domestic refrigerators or in small air-conditioning units, to the large multi-cylinder units that serve large industrial systems. In these large multi-cylinder units, capacity can be controlled with automatic devices that prevent the in certain cylinders from closing. For example, in a six-cylinder unit, if

the valves are held open on two of the cylinders to keep them inoperative, the capacity of the machine is reduced by one-third when operating at normal speed.

Centrifugal compressors are used for large refrigeration units. These compressors employ centrifugal impellers that rotate at high speed. Centrifugal
5 compressors depend for their compression largely on the dynamic action of the gases themselves as they flow in the diffusion passages of the compressor. These compressors can be large centrifugal compressors made with a single impeller or with two to four or more impellers in series, to compress the gas through the range required. These compressors are used extensively for large air-conditioning installations and also
10 for usage in the industrial field when gases are compressed for liquefaction or for transportation, such as in the natural-gas industry, and when air is compressed to produce liquid oxygen or nitrogen.

The condenser 3 of a vapor system must dissipate heat from the hot vapor it
15 receives from the compressor and condense this vapor to liquid for reuse by the evaporator. Condensers either dissipate heat to the ambient atmosphere through externally finned surfaces or by a shell and tube arrangement in which the vapor delivers heat to a circulating fluid (etc., water) that passes through tubes contacting the cooling agent vapor. The temperature of the vapor is kept above that of the circulating
20 water or air by compression to insure that heat is transferred to the coolant; thus, when the vapor is allowed to expand, its temperature drops well below that of the cooling agent.

Double-pipe condensers are also used. In such units, the cooling agent vapor
25 and condensate pass in one direction through the annular space between the two tubes, while the water, flowing in the opposite direction through the central tube, performs the cooling function.

The air conditioning concept works on the principle of exchanging heat from a
30 heated substance to a cold substance. In this principle, the temperature from a hot

substance (such as a fluid) is transferred to a cold fluid. As the temperature of the hot fluid decreases, the temperature of the cold fluid increases. Heat exchangers are manufactured in many different designs and are used extensively in various industries. Heat exchangers are given different names when they serve a special purpose. Thus
 5 boilers, evaporators, superheaters, condensers and coolers may all be considered heat exchangers.

An example of a heat exchanger is illustrated in Figure 2a and explains the basic operation of a hat exchanger. This exchanger is constructed from two pipes 5 and 6 in
 10 a concentric arrangement. Inlet and exit ducts are provided for the two fluids. In the sketch, the cold fluid flows through the inner tube 7 and the warm fluid via inlet pipe 5 in the same direction through the annular space between the outer and the inner tube. This flow arrangement is called parallel flow. In it heat is transferred from the warm fluid through the wall of the inner tube (the so-called heating surface) to the cold fluid.
 15 The temperature in both fluids varies as shown in Figure 2b. In plot 9, the temperature of the warm fluid decreases from t_{w1} to t_{w2} . In plot 10, the temperature of the cold fluid increases from t_{c1} to t_{c2} . The amount of heat Q that is transferred from one fluid to the other per unit of time, called heat flow, can be calculated from the following equation:

$$Q = mc (t_2 - t_1) \quad (1)$$

This equation states that the heat flow $Q(\text{kW})$ can be obtained by multiplying the mass per unit of time of fluid $m(\text{kg/sec})$ by the specific heat $c(\text{KJ/kg-}^\circ\text{C})$ of the fluid and by the temperature increase $t_2 - t_1$ ($^\circ\text{C}$) of the fluid entrance to the exit of the heat exchanger.

25 The specific heat is a property of the fluid involved and its current state. The amount of heat leaving the warm fluid must be the same as the amount of heat received by the cold fluid. The mass flow and the temperature increase for the cold or the decrease for the warm fluid can therefore be entered into equation (1). The heat exchanger may have to be designed, for example, to increase the temperature of a prescribed mass
 30 per unit time m_c of cold fluid from t_{c1} to t_{c2} . Entering these value into equation (1) then

determines the heat flux Q which has to be transferred in the heat exchanger. This value will be needed in the following discussion to calculate the heating surface of the exchanger.

5 The temperature difference Δt_1 between the fluids at the entrance of the heat exchanger decreases to the value Δt_2 at the exit, as illustrated in Figure 2a. A heat exchanger is operated in counterflow when the direction of one of the fluids is reversed. The counterflow arrangement has the advantage that the exit temperature t_{c1} of the colder fluid can be increased beyond the exit temperature t_{w2} of the warm fluid. In
10 addition, a smaller surface area is required in counterflow than in parallel flow to transfer the same amount of heat. This is so because the mean temperature difference Δt_m in the counterflow heat exchanger, for a given heat flux and prescribed inlet temperatures, is higher than in the parallel-flow exchanger.

15 The heating surface of the heat exchanger can be obtained from the equation:

$$A = \frac{Q}{U\Delta t_m} \quad (2)$$

The equation indicates that the required surface area A (m^2) is obtained by dividing the heat flux Q obtained with equation (1) by the overall heat transfer coefficient U and the mean temperature difference Δt_m ($^{\circ}\text{C}$). Larger heat exchangers utilize a bundle of tubes
20 through which one of the fluids flows. The tubes are enclosed in a shell with provisions for the other fluid to flow through the spaces between the tubes. Fluid flowing outside the tubes can be directed either in the same direction as or counter to the effective flow in the tube bundles. In the latter arrangement, parallel or counter flow can be approximated in the way shown in Figure 2a. In another arrangement, the cold fluid is
25 distributed in such a manner that it flows in parallel through the tubes forming the heating surface and is then collected by a header. This arrangement creates a cross flow, as shown schematically in Figure 2a. In nuclear reactors, fuel rods may replace the tubes, and the cooling fluid flowing around the rods removes the heat generated by

the fission process. In a similar way, rods containing electric resistance heaters may supply heat to the fluid passing through the exchanger between the rods.

As previously mentioned, there is a need for a downhole cooling system that can keep logging tool electronics cool in order to avoid tool failure from the extreme downhole temperatures. There have been attempts to apply the refrigeration concept to downhole tools. In 1977, Mechanics Research attempted to develop a system that incorporated a refrigeration technique for use in a geothermal well. The system design was to be a closed system that would operate continuously, similar to the refrigerator cooling concept of Figure 1. However, the specific objective of the project was to develop a compressor for such a system. The project did not achieve its chief objectives. Therefore, a need still remains for a system that can actively cool instrumentation in a high temperature environment.

Summary of the Invention

In the present invention, an active cooling system allows constant low pressure vaporization of a tank of water while in thermal communication with the electronic chassis of downhole logging tool. The tool electronics and a lower tank of water are in thermal communication with one another via a cold heat exchanger. The heat from the electronics, as well as that from the hot borehole (up to approximately 200°C) causes the water in the lower tank to boil or vaporize into steam. As the water vaporizes, the steam is removed from the tank and compressed via a compressor to an upper tank. By removing the steam from the lower tank as it is generated, its pressure and resulting temperature can be regulated and thereby regulating the temperature of the electronics. For instance, the temperature of lower tank can be maintained at approximately 100°C if its internal pressure is kept at approximately $1.01 \times 10^5 \text{ Pa}$ (14.7 psi). The vapor in the upper tank must be compressed to a pressure greater than the saturation pressure of the steam at the temperature of the borehole in order to empty the lower tank. A 200°C borehole would require a pressure of $1.55 \times 10^6 \text{ Pa}$ (225 psi). Once the steam enters the

70261-72

upper tank, it is allowed to cool to the borehole temperature. Thus, the upper tank serves as the hot heat exchanger in the system. A control system between a lower tank pressure sensor and the compressor maintains a constant pressure vaporization in the lower tank. Once the lower tank is emptied of water, the system is spent and the tool must return to the surface and the tank refilled. Likewise, the upper tank must be emptied before the tool re-enters the borehole.

10 One broad aspect of the invention provides an apparatus for actively cooling instrumentation contained in a logging tool comprising: a) a first container having a cooling agent therein, said container being located adjacent said instrumentation; b) a heat exchanger in thermal
15 communication with said first container and said instrumentation for transferring heat from said instrumentation to said cooling agent in said container; c) a second container for receiving said heated cooling agent; and d) a compressor in fluid communication with said first
20 and second containers for extracting and compressing a vapor portion of said heated cooling agent from said first container to said second container.

 Another broad aspect of the invention provides an apparatus for actively cooling instrumentation contained in
25 a logging tool comprising: a) a first means for containing a cooling agent, said first means being located adjacent said instrumentation; b) a means for transferring heat from said instrumentation to said cooling agent in said first container means; c) a second means for containing said
30 cooling agent after said cooling agent has been heated and transferred from said first container means; and d) a cooling agent transfer means in fluid communication with

70261-72

said first and second container means for extracting and compressing a vapor portion of said heated cooling agent from said first container means to said second container means.

5 Another broad aspect of the invention provides a method of actively cooling instrumentation contained in a logging tool comprising the steps of: a) transferring heat from said instrumentation to a cooling agent stored in a tank adjacent said instrumentation; b) allowing sufficient
10 heat to transfer such that said cooling agent begins to boil, thereby creating a vapor portion of said cooling agent; c) removing said vapor portion of said cooling agent from said tank; d) compressing said vapor portion; and e) transferring said compressed vapor portion into a second
15 tank.

Three major subsystems are combined in the present invention as shown in Figure 3. The subsystems are the compressor 11, the cold heat exchanger (evaporator) 10 and the hot heat exchanger (condenser) 12. In addition, a
20 sample wireline electronics chassis including heat-dissipating electronics is implemented. A schematic of the present invention in its simplest form is shown in Figure 4. The evaporator 17 encompasses a lower tank of stored water 16 in thermal contact with a cold heat exchanger 18 from the
25 electronics and is all within a Dewar flask 15. This system allows the heat from conduction into the flask and electronic component dissipation, to be transferred to the tank of water. Consequently, the water begins to vaporize. The second major component is the compressor 23. The
30 compressor maintains the lower tank 17 at the specified atmospheric pressure value. It accomplishes this task by pulling the vaporized water or stream out of the lower tank and transporting it into the upper tank or hot heat

70261-72

exchanger 24, outside the Dewar flask. Thus, the compressor must attain pressures greater or equal to the saturation pressure of water at a given borehole temperature, along with the flowrates of stream produced by the total cooling
5 load. For instance, the worst-case-scenario of a 200°C borehole requires compressor outlet pressures equal to or greater than $15.5 \times 10^5 \text{ Pa}$ and a flowrate equal to $3.5 \times 10^{-5} \text{ kg/s}$ at the 80-W cooling load. The upper tank/hot heat exchanger 24 is simply a tank to which the compressed stream is
10 transported and allowed to condense at borehole temperatures. The volume of the upper tank should be sized at least 1.16 times larger than the lower tank due to the increased specific volume of saturated water at 200°C over that at 100°C. Additionally, with knowledge of worst-case
15 heat transfer coefficients in the downhole system, the upper tank must be

made thermally conductive towards the borehole. Heat transfer of the cooling load and compressor work must be accomplished with as small a temperature as possible over that of the borehole.

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Brief Description of the Drawings

Figure 1 is a schematic of the components of a refrigeration cooling concept.

Figure 2a is an isometric cross-sectional view of a parallel-flow heat exchanger.

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Figure 2b is a graph of the changes in fluid temperatures that take place in the parallel heat exchanger.

Figure 3 is a diagram of the hybrid vapor compression once-through system of the present invention.

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Figure 4 is a diagram of the active cooling system of the present invention.

Figures 5a- 5d represent a diagram of a sample electronics chassis.

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Figures 6a-6d represent a diagram of a cold heat exchanger.

Figures 7a-7c represent a diagram of the cold heat exchanger and lower tank assembly of the present invention.

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Figure 8 is a diagram of a compressor assembly.

Figures 9a-9b represent a diagram of the lubrication assembly of the present invention.

Figure 10 is a diagram of the hot heat exchanger upper tank assembly of the present invention.

Figures 11a-11c represent a diagram of the compressor/motor assembly.

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Detailed Description of the Invention

The overall assembly of the invention is shown in Figure 4 and includes the
 10 sample electronics **16**, lower tank/cold exchanger **19** (evaporator), compressor **23**,
 lubrication system, and upper tank/hot heat exchanger **24** (condenser) assemblies.
 The invention is described in the context of a designed and manufactured prototype of
 the invention. Although not downhole compatible, aluminum pieces were used in the
 prototype. Aluminum was used in the tubes of the lower and upper tanks, and the
 15 compressor valve head piece. In practice, the tubes of the upper tank and compressor
 valve head piece should not be made of aluminum in a downhole design.

Figures 5a-5d show the electronic chassis assembly containing the logging tool
 electronics. The detailed assembly drawings are given in Applicant's publication
 20 entitled "Active Cooling for Electronics in a Wireline Oil-Exploration Tool" ,
 Massachusetts Institute of Technology, June 1996. The chassis has a base **30** made
 of aluminum. The diameter and lengths of the chassis are 0.0699m and 0.43m,
 respectively. End pieces **31** and **32** are connected to the chassis base **30** by screws
35. End piece **31** is connected to a lower tank and is therefore smaller in length than
 25 end piece **32**. A breadboard **34** containing electronic components is attached to the
 chassis as shown. It is attached to the base via screws **36**. The breadboard contains
 the electronic components **37**. In the test structure, Kapton Strip heaters serve as the
 electronics. These heaters have a resistance of 15.68 ohms and when connected in
 parallel have a total resistance, R_t of 6.4 ohms at a temperature of 100°C. The sample

electronics are powered by a Hewlett Packard #6443B DC power supply. The voltage, V_{heat} , required to produce an electronic heat dissipation, P_{heat} , is equal to:

$$V_{heat} = \sqrt{P_{heat} R_t} \quad (3)$$

5

Electronics heat dissipation values between 0W and 50W are available with the given power supply.

Figures 6a-6d show the cold heat exchanger assembly. As shown, the
 10 electronic chassis **40** has a chassis base piece **30**, end pieces **31** and **32**, sample
 electronics **37** attached to a breadboard **34**. Also shown is a portion of a cold heat
 exchanger **41** adjacent the electronics **37**. Heat pipe holder **42** contains heat pipes **43**.
 The heat pipes **43** are mounted in the channels of the holder. A heat pipe brace **44**
 secures the pipes in the holder **42**. Screws **36** and **46** secure the heat exchanger and
 15 heat pipe brace.

In Figures 7a-7c, the heat exchanger prototype **39** has two 0.457m by 0.0165m
 by 0.00660m, Noren Products flat TPhcBS heat pipes **43** mounted on an aluminum
 holder **42** that is placed on a thin, high thermal conductive pad (Berquist Co. Sil Pad
 20 400) insulator **47** on top of the Kapton strip heaters **37**. The heat pipes transfer the
 heat from the electronics **37** to the water contained in the lower tank **50** through an
 aluminum mating piece **54**. The mating piece **54** is in contact with the heat pipes **43**
 through the heat exchanger portion **41**. A screw **56** attaches the heat exchanger to the
 lower tank. The air gaps between the heat pipes, aluminum holder and aluminum
 25 mating piece are eliminated by filling these gaps with a high thermally conductive Dow
 Corning 340 heat sink compound. An O-ring **55** provides a seal between the lower tank
 and the heat exchangers to prevent water flow to the electronics. Two other O-rings **53**
 and **53b** are located at the uphole end **51** and the downhole end **52** of the lower tank.
 The lower tank **50** is sized to fit into the flask and carry 1kg of water. The volume of the
 30 lower tank is approximately 0.001m³. However, when the system is laid in the

horizontal position with the exit of the tank in the center of the cross-section, the effective volume of the tank is halved. Thus, only 0.5kg of water can be carried in the lower tank in horizontal tests.

5 The flask used in the present invention is a UDFH-KA Dewar flask manufactured by National K-Works. The flask properties and diameter dimension schemes are detailed in Chapter 3 of the inventor's dissertation entitled "Active Cooling for Electronics in a Wireline Oil-Exploration Tool" Massachusetts Institute of Technology, June 1996. The flask has a total length of 2.36m and a payload or insulated length of
10 1.71m. The ends of the flask are insulated with Teflon shavings.

Figure 8 displays the compressor assembly used in the active cooler. The compressor is composed of several mechanical parts. The outer housing 60 of the compressor contains two volumes: the compression chamber 61 and the crankshaft
15 chamber 62. In the compressor chamber is a piston 63, piston rod 64, piston cylinder 65 and valve head piece 66. The piston cylinder guides the stroke of the piston. The piston/cylinder seal is a dynamic lapped design with the piston made of mehanite and the cylinder made of 12L14 steel. These parts were manufactured to last for approximately 126 million strokes at a temperature of 232°C. These specifications
20 equal a downhole time of approximately 1000 hours at compressor shaft speeds of 2000 rpm.

The intake port 67 is located at the bottom of the piston stroke and the exit port 68 is located at the top of the piston stroke. In operation, as the piston travels
25 downward, a small vacuum is created in the compression chamber. The port 67 is exposed as the piston crosses its surface and steam is sucked into the compression chamber volume. On the upward stroke of the piston, the port 67 is sealed by the circumferential area of the piston and lubricant. The steam is compressed by the upward motion of the piston. This high pressure vapor exits via the compression valve
30 head piece 66 and port 68. A miniature Lee check valve 69 is placed in the valve head

piece and serves as the exhaust valve in the compressor. The valve is hard-mounted in the compressor head piece. A miniature spacer **70** and Lee mechanical plug **71** keep the check valve **69** in a pressure-sealed position. To filter large particles from the vapor flow, a small 40 μm Mectron Industries, Inc. filter **73** is placed in front of the miniature check valve in the valve head piece on the chamber inlet side. The filter keeps contaminants from entering and plugging the valve, especially during the break-in period of the seal. In this design, an intake valve is eliminated, along with its design complexities and inefficiencies.

The valve head piece **66** utilizes a 95 durameter viton o-ring **72** to isolate the compression chamber volume from the environment. The piston stroke is controlled by the spinning of the crankshaft assembly. The crankshaft assembly is made from a crankshaft **75**, bearings **76** and **76b**, a rotary seal **77** and a pin welded **78** into the shaft. In operation, the crankshaft pin **78** is inserted in the piston rod **64**. When the crankshaft is rotated the piston **63** moves up and down. Two different, but standard-sized ball bearings **76** and **76b** guide the rotation of the crankshaft. A Greene-Tweed steam-service rotary seal **77**, spacer **79** and bearings **76** are contained in the compressor assembly by an end piece **82** held in place by six socket head screws. The crankshaft is held inside the compressor by an end piece **80** which is held in place by three socket head screws. This end piece also utilizes a 95 durameter viton o-ring **84** for pressure isolation between the compressor internals and the environment. For compatibility with the rotary seal, a hardness of 45-55Rc is specified for the crankcase. As mentioned earlier, the piston connecting rod is taken directly from the Fox 40-size engine.

Figures 9a-9b show the lubricant system for the compressor. This system has a lubricator tube **85**, with a lubricator piece **86**. Lubricant in the tube is maintained under pressure and is compensated by two springs **87** in series. These springs **87** are separated by a spacer **88**. The springs are contained on one end by the end piece **89**. The end piece and lubricator piece utilize a 95 durameter viton o-ring **90** and **90b** for pressure isolation from the environment. The other end of the springs is contained by a

piston **91**. The springs apply force to the piston which then applied pressure to a lubricant stored on the other side of the piston. The piston maintains the lubricant seal with a 95 durameter viton o-ring **90c**. A three-way normally-closed, high-temperature Lee Co. solenoid valve **93** is periodically opened and closed as a function of time,
5 allowing lubricant to travel into the compressor intake line through a Lee Co. Visco-Jet restrictor **94**. The restrictor piece restricts the flow of lubricant to lower flowrates than that of the solenoid valve alone. Both the restrictor and valve pieces are located in the lubricator piece. From the intake line, the lubricant travels into the compression chamber of the compressor and maintains the dynamic lapped pressure seal. Some
10 lubricant also "blows-by" the seal and serves to lubricate the crankcase internals. A hydraulic line is connected to the lower line on the lubricator piece that contains the solenoid valve and is used to fill the lubricant reservoir before operation. The lubricant inlet line is then plugged during operation.

15 Lubricant is periodically pumped into the reservoir under pressure. The reservoir pressure is measured by a pressure gage. In practice, a screw-drive system could maintain the reservoir pressure autonomously. The lubricant used in the final tests was Dow Corning-200, 500cSt Silicone oil, however, the choice of lubricant should be based on trying to maintain the best seal. A model of the piston/cylinder seal displayed the
20 need for a viscosity of approximately 50cSt at the operating temperature and shaft speeds of the compressor.

The motor assembly is used to spin the crankshaft of the compressor. The motor shaft is coupled to the crankshaft of the compressor by a telescoping universal
25 joint. The motor assembly housing and compressor housing are connected by a spacer piece and held in place by eight socket head screws.

The hot heat exchanger/upper tank assembly is shown in Figure 10. The assembly comprises an upper tank **100**, uphole **101** and downhole ends **102** and O-rings **103** and **103b**, and serves to both store the high pressure steam and conduct
30

heat from the steam to the borehole through its walls. As mentioned above, the tank is made of aluminum which is not compatible with the downhole environment. However, the aluminum housing makes no difference from a heat transfer standpoint in the design. In other words, the limiting resistance to thermal conduction is the borehole film coefficient, not the material of the upper tank. The temperature difference required for the aluminum housing is only 0.3°C less than that required for the downhole-compatible stainless steel housing.

The original downhole motor/compressor assembly is shown in Figures 11a-11c. The motor assembly is a standard motor containing major parts such as a motor mount 110, a motor end 111, motor add-on shaft 112, the pump out motor 113, a motor housing 114, a spacer 115, which perform standard operations. A universal end 116 and female end 117 to connect the motor the compressor. A universal joint 118 connects the motor and compressor and provides the means by which the motor drives the compressor. The universal joint is connected to the compressor by a male end 119. The assembly has an outer diameter of approximately 0.102m. The 2/3HP high-temperature downhole motor displayed in the assembly is a commonly used motor in wireline tools. The development of a new motor to fit the geometry constraints does not represent a serious design challenge. However, due to time and costs, a new downhole was not purchased for the uphole prototype.

The method and apparatus of the present invention provides a significant advantage over the prior art. The invention has been described in connection with the preferred embodiments at the time of filing. However, the invention is not limited thereto. Selection of particular materials should be based on the environment in which the apparatus will operate. Changes, variations and modifications to the basic design may be made without departing from the inventive concept in this invention. In addition, these changes, variations modifications would be obvious to those skilled in the art having the benefit of the foregoing teachings contained in this application. All such

changes, variations and modifications are intended to be within the scope of the invention which is limited by the following claims.

70261-72

CLAIMS:

1. An apparatus for actively cooling instrumentation contained in a logging tool comprising:

5 a) a first container having a cooling agent therein, said container being located adjacent said instrumentation;

b) a heat exchanger in thermal communication with said first container and said instrumentation for transferring
10 heat from said instrumentation to said cooling agent in said container;

c) a second container for receiving said heated cooling agent; and

15 d) a compressor in fluid communication with said first and second containers for extracting and compressing a vapor portion of said heated cooling agent from said first container to said second container.

20 2. The apparatus of claim 1 wherein said first and second containers are near and far tanks respectively in relation to said instrumentation.

25 3. The apparatus of claim 2 wherein said near tank is connected to said instrumentation via said heat exchanger.

4. The apparatus of claim 2 further comprising an insulated flask for containing said near tank, said heat
30 exchanger and said instrumentation.

5. The apparatus of claim 4 wherein said instrumentation is electronic circuits.

70261-72

6. The apparatus of claim 1 wherein said cooling agent is water.

7. The apparatus of claim 6 further comprising a vapor control system to maintain a constant pressure vaporization of said cooling agent in said first container.

8. The apparatus of claim 7 further comprising a pressure controller to maintain pressure in said second container of steam which results from heating said cooling agent.

9. The apparatus of claim 8 wherein the pressure of said steam is measured by a pressure gage inside said first container.

10. An apparatus for actively cooling instrumentation contained in a logging tool comprising:

a) a first means for containing a cooling agent, said first means being located adjacent said instrumentation;

b) a means for transferring heat from said instrumentation to said cooling agent in said first container means;

c) a second means for containing said cooling agent after said cooling agent has been heated and transferred from said first container means; and

d) a cooling agent transfer means in fluid communication with said first and second container means for extracting and compressing a vapor portion of said heated

70261-72

cooling agent from said first container means to said second container means.

11. The apparatus of claim 10 further comprising an
5 insulated means for containing said means for containing said cooling agent, said means for transferring heat, and said instrumentation.

12. The apparatus of claim 10 wherein said cooling agent
10 transfer means comprises a compressor means and a vapor control means.

13. The apparatus of claim 12 wherein said control means
is located such that said control means controls vapor entering
15 said compressor means and vapor exiting said compressor means.

14. The apparatus of claim 10 further comprising a
pressure sensing means for detecting pressure of cooling agent
when said cooling is transformed from a liquid state to a vapor
20 state.

15. A method of actively cooling instrumentation
contained in a logging tool comprising the steps of:

25 a) transferring heat from said instrumentation to a cooling agent stored in a tank adjacent said instrumentation;

b) allowing sufficient heat to transfer such that
said cooling agent begins to boil, thereby creating a vapor
30 portion of said cooling agent;

c) removing said vapor portion of said cooling agent
from said tank;

70261-72

d) compressing said vapor portion; and

e) transferring said compressed vapor portion into a
5 second tank.

16. The method of claim 15 wherein the vaporized portion
of said cooling agent is transferred from said tank by:

10 pumping said vaporized cooling agent from said tank;
and

regulating the flow rate of said vaporized agent from
said cooling agent tank to maintain a desired vapor pressure.
15

17. The method of claim 16 wherein said vaporized cooling
agent is maintained at a pressure of approximately $1.01 \times 10^3 \text{Pa}$.

18. The method of claim 15 further comprising the step of
20 condensing said vapor into liquid cooling agent.

19. The apparatus of claim 1 wherein said compressor is a
positive displacement steam compressor.

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PATENT AGENTS

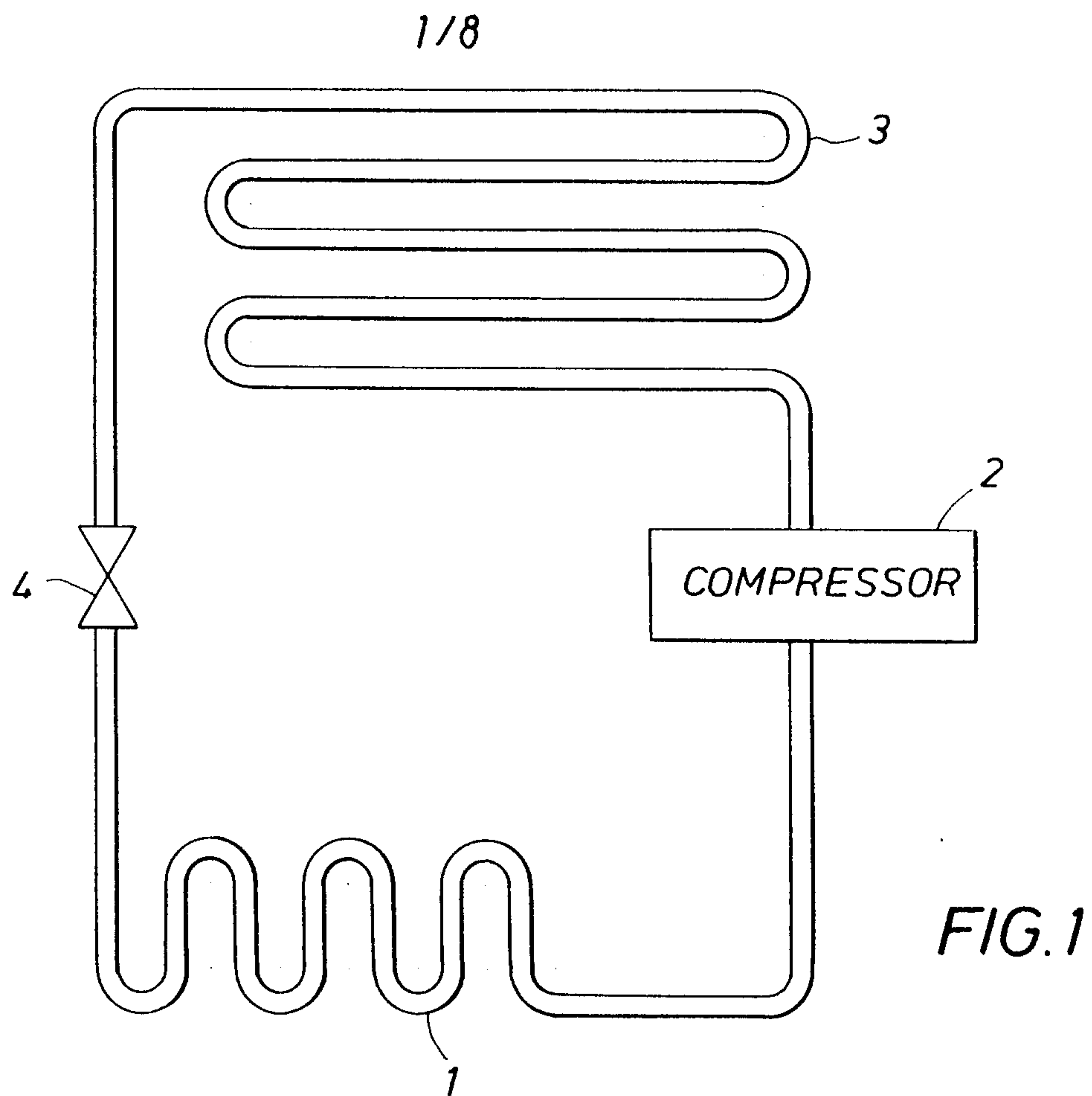


FIG. 1

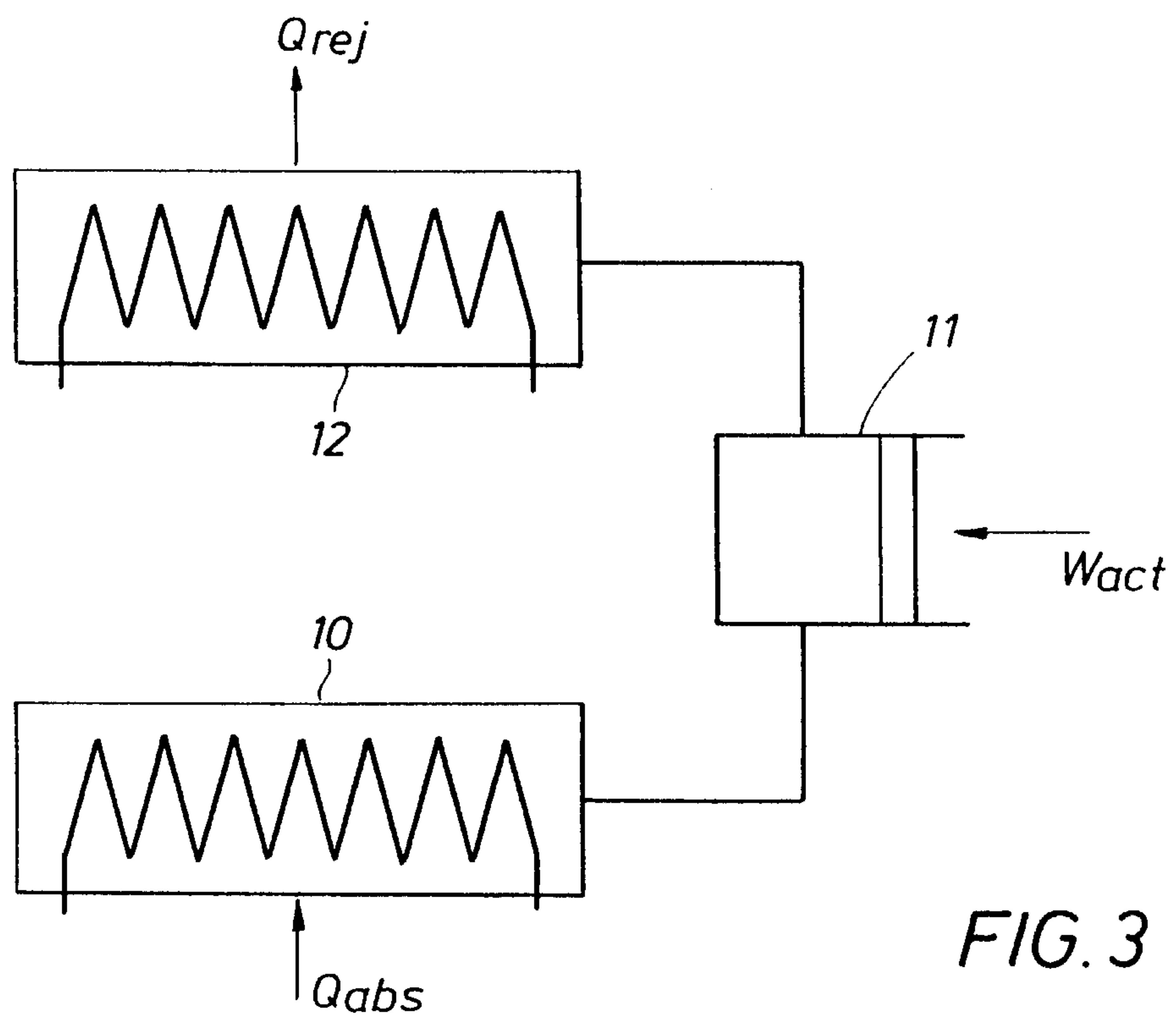


FIG. 3

2/8

FIG. 2a

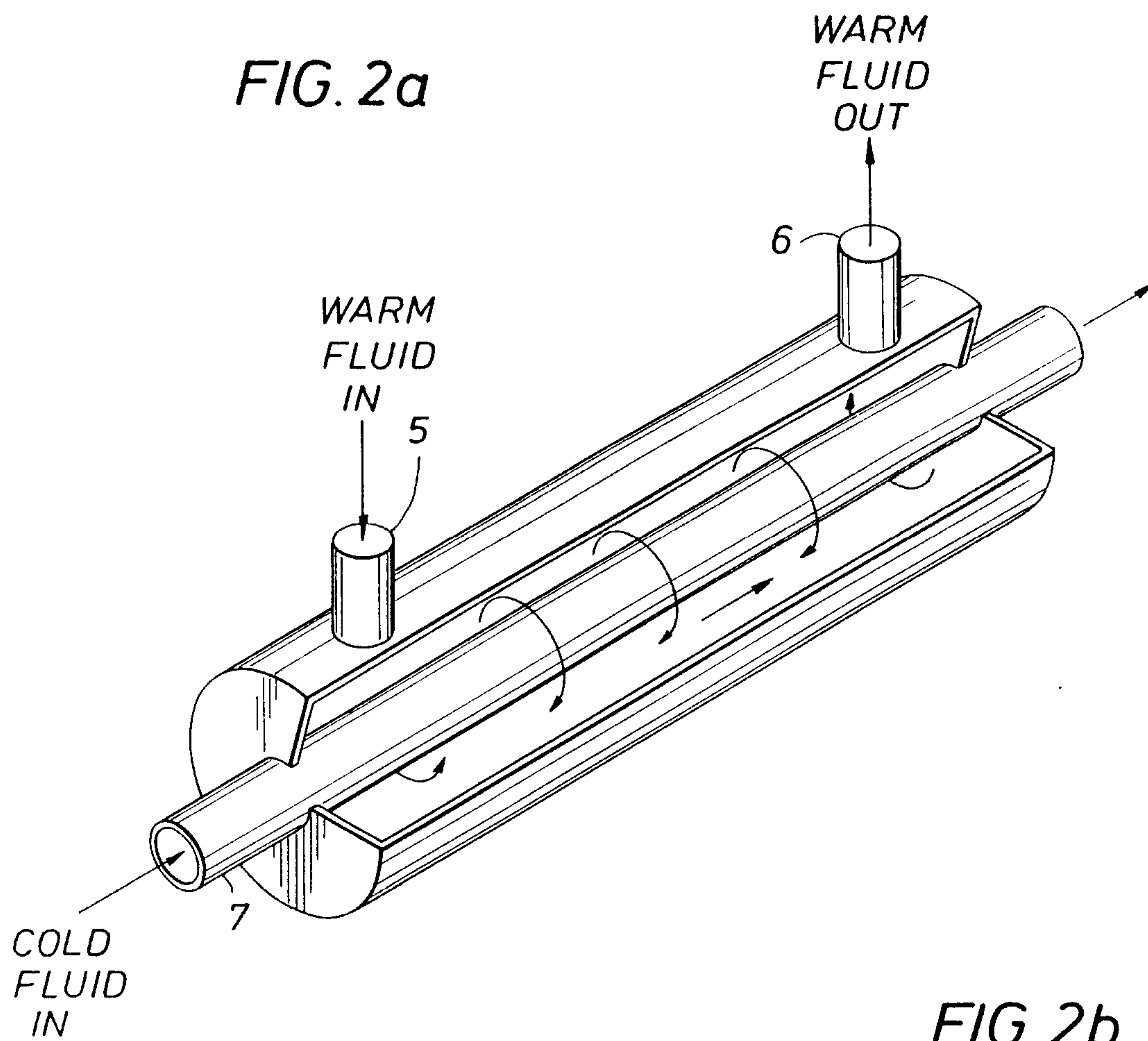
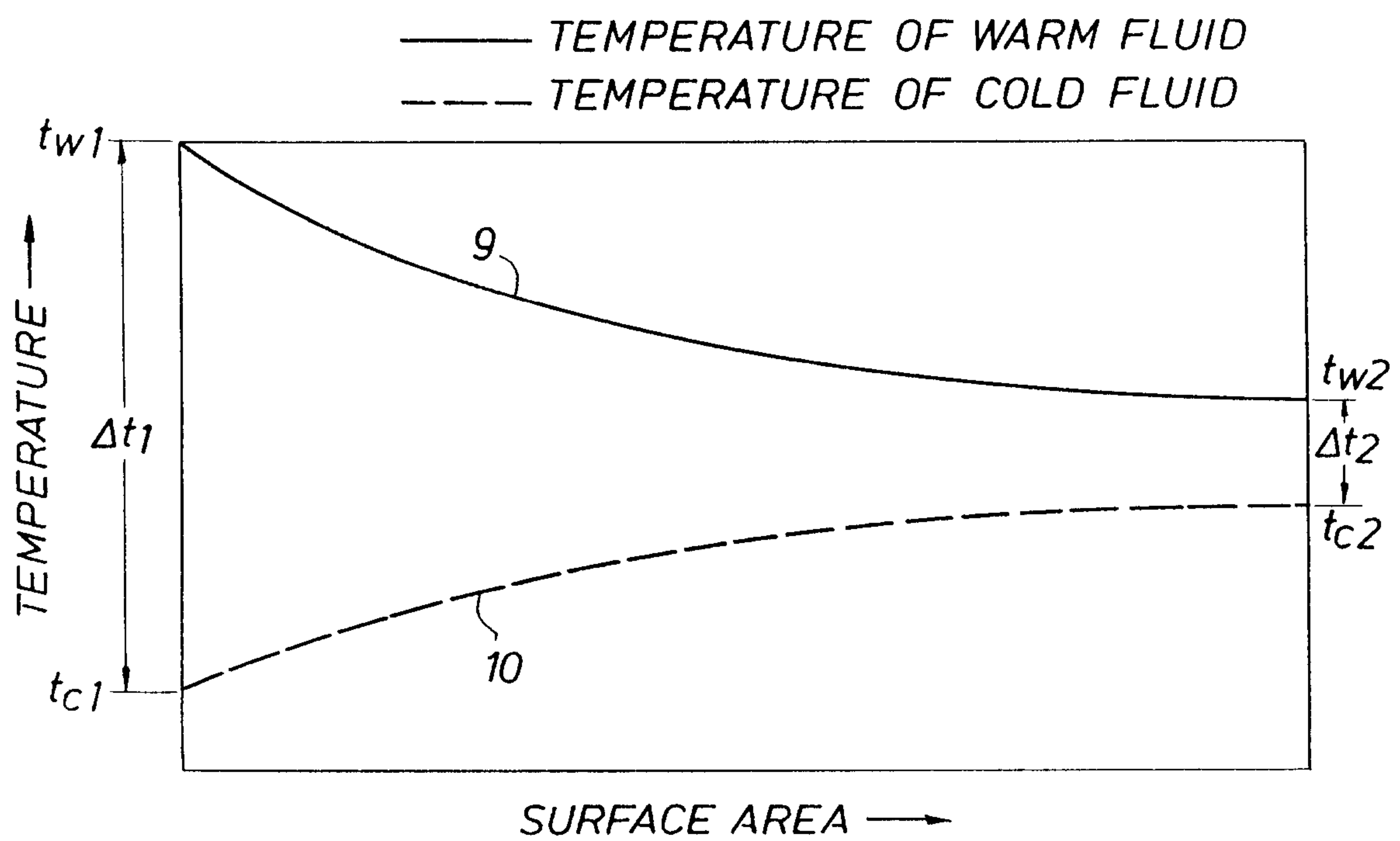


FIG. 2b



3/8

FIG. 4

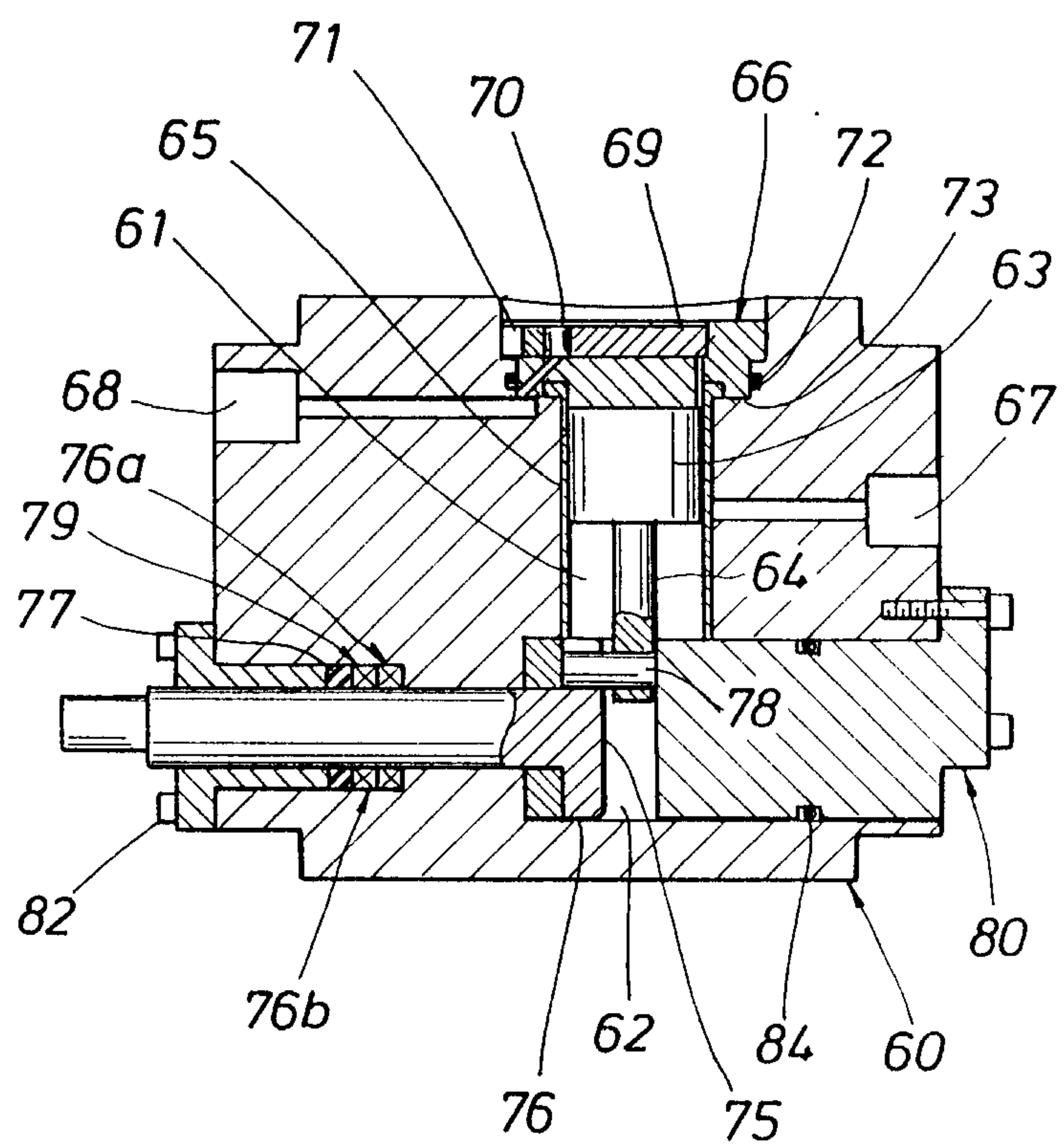
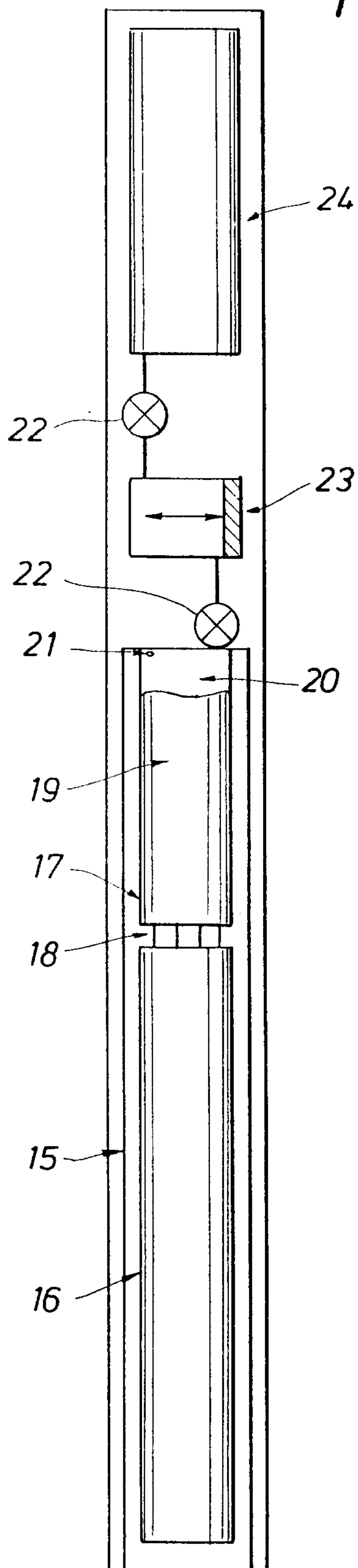


FIG. 8

FIG. 5B

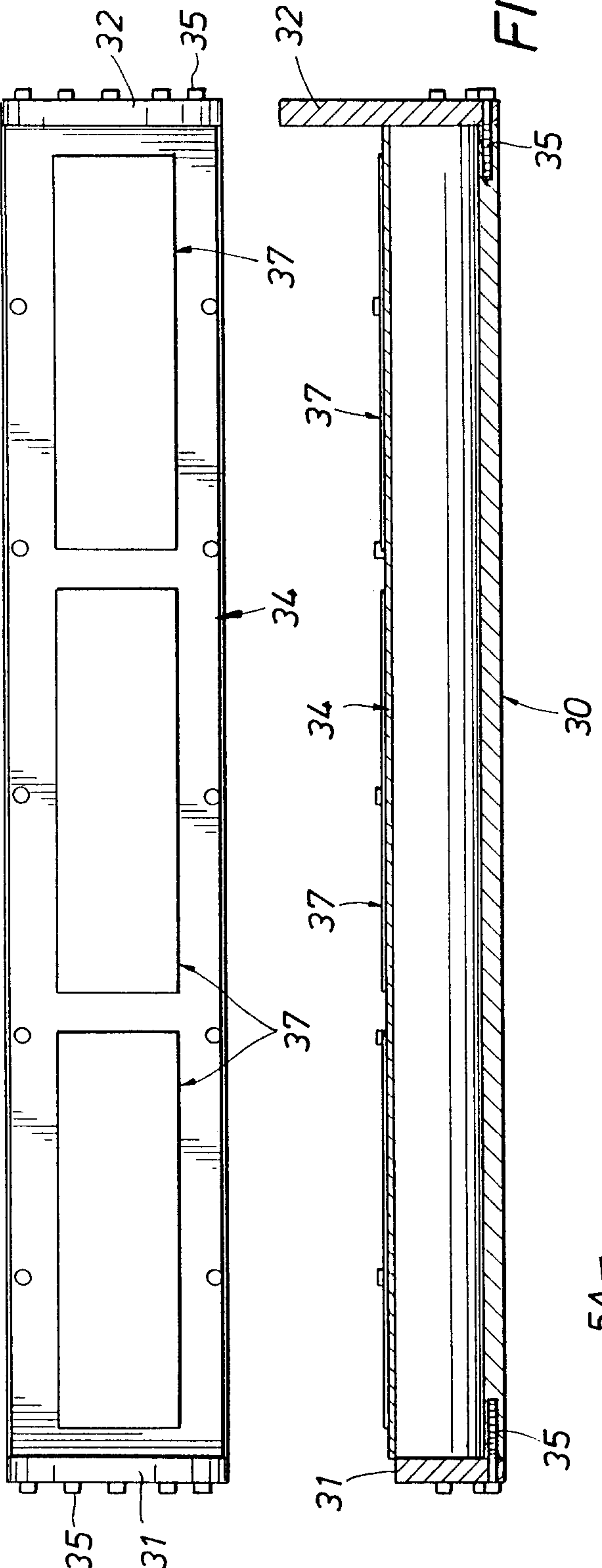


FIG. 5A

5A

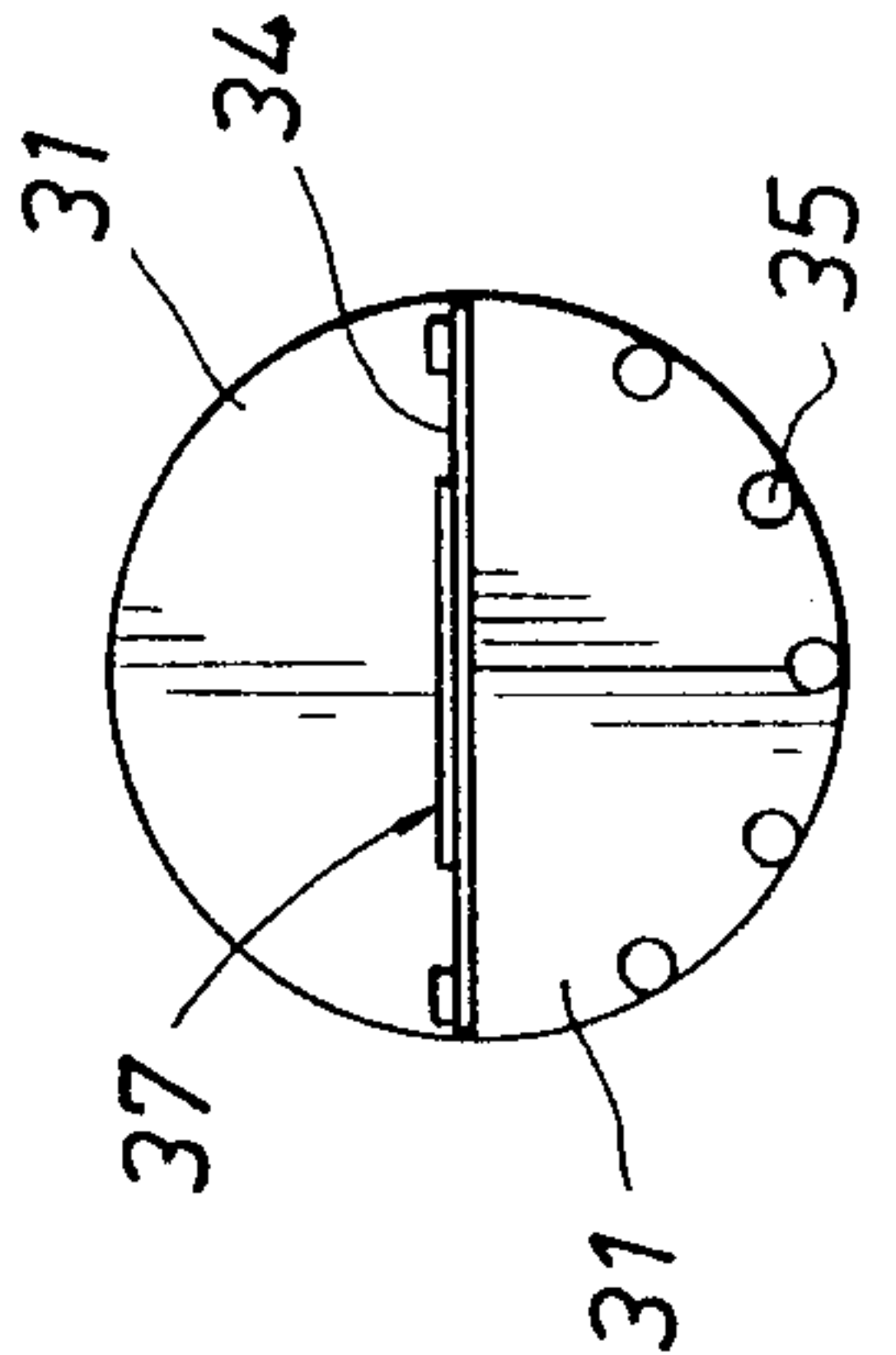


FIG. 5C

5A

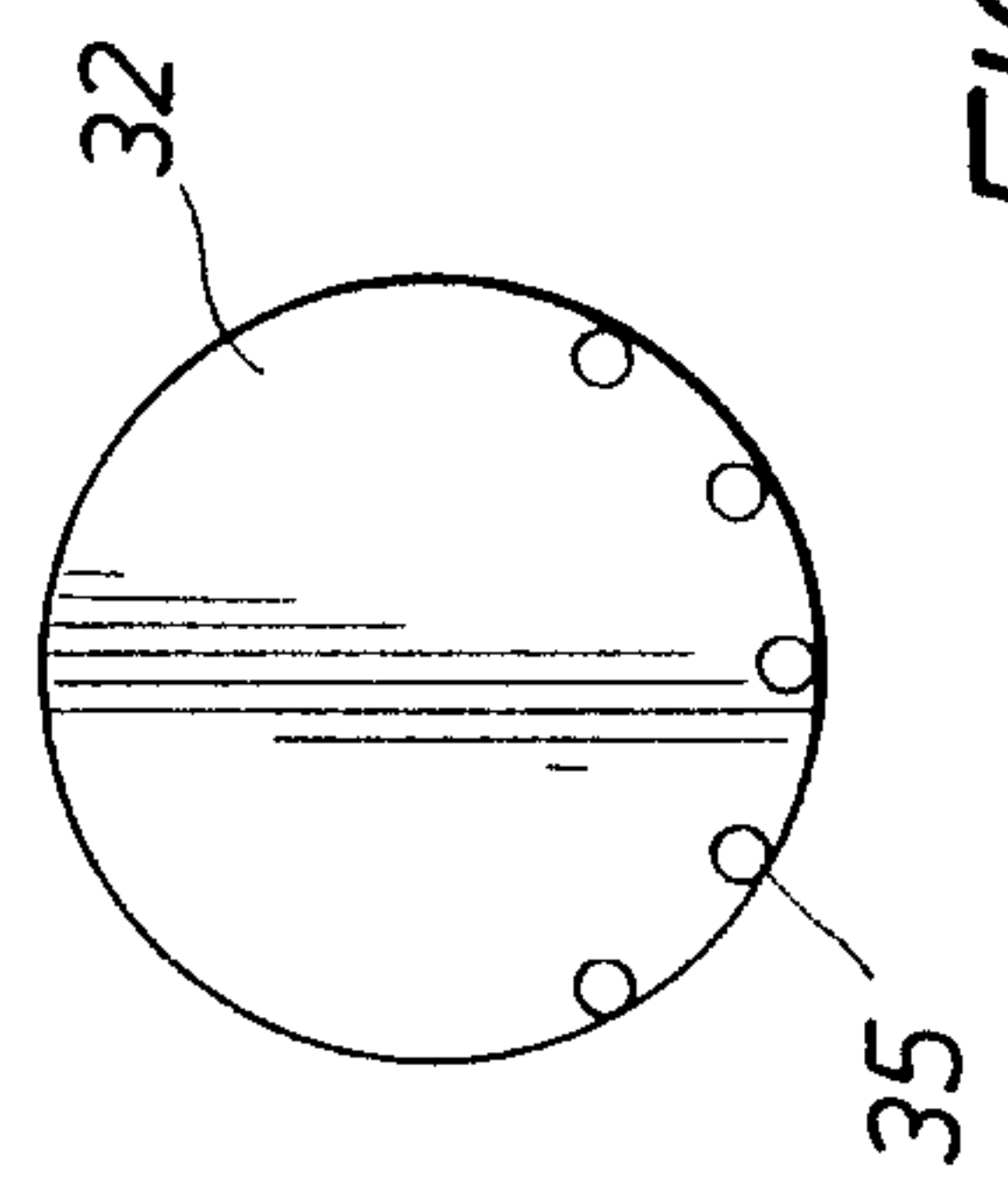
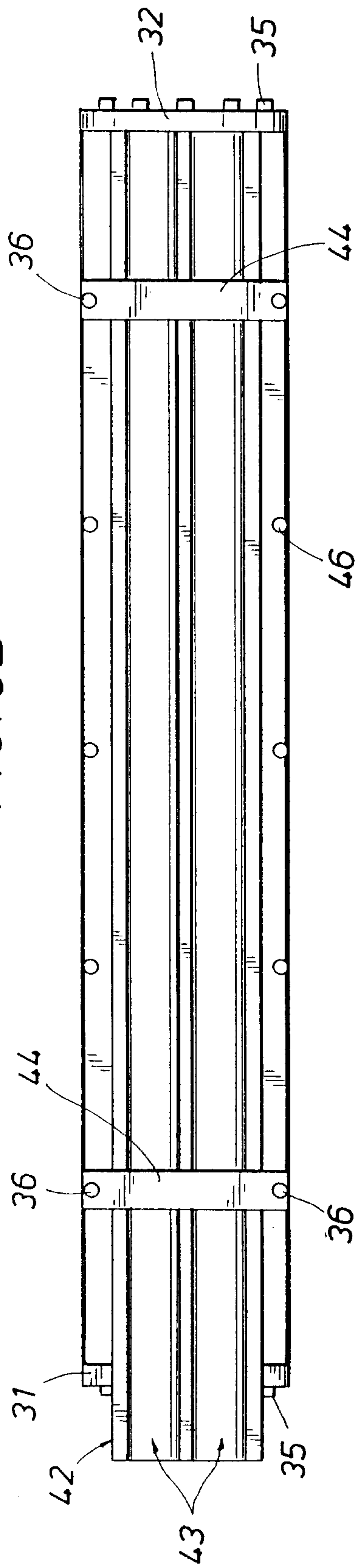


FIG. 5D

FIG. 6B



5/8

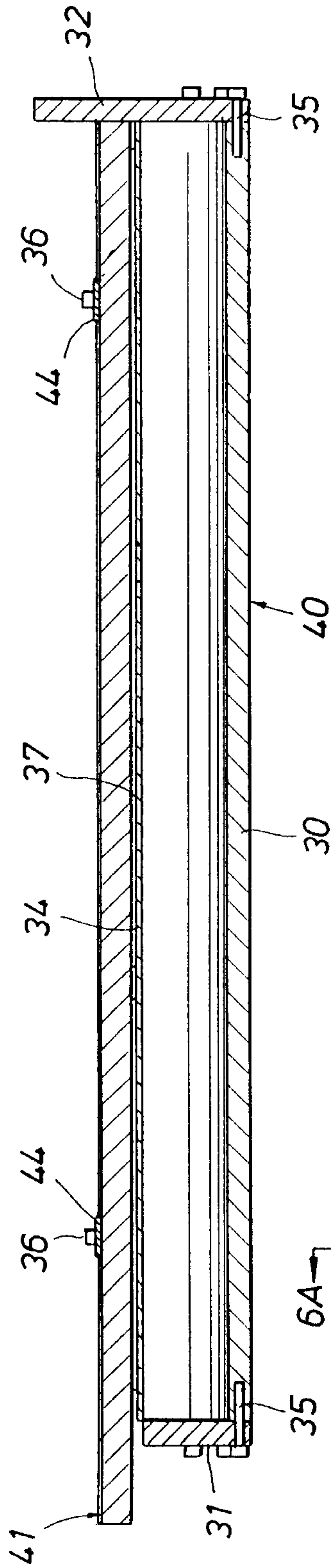


FIG. 6A

FIG. 6D

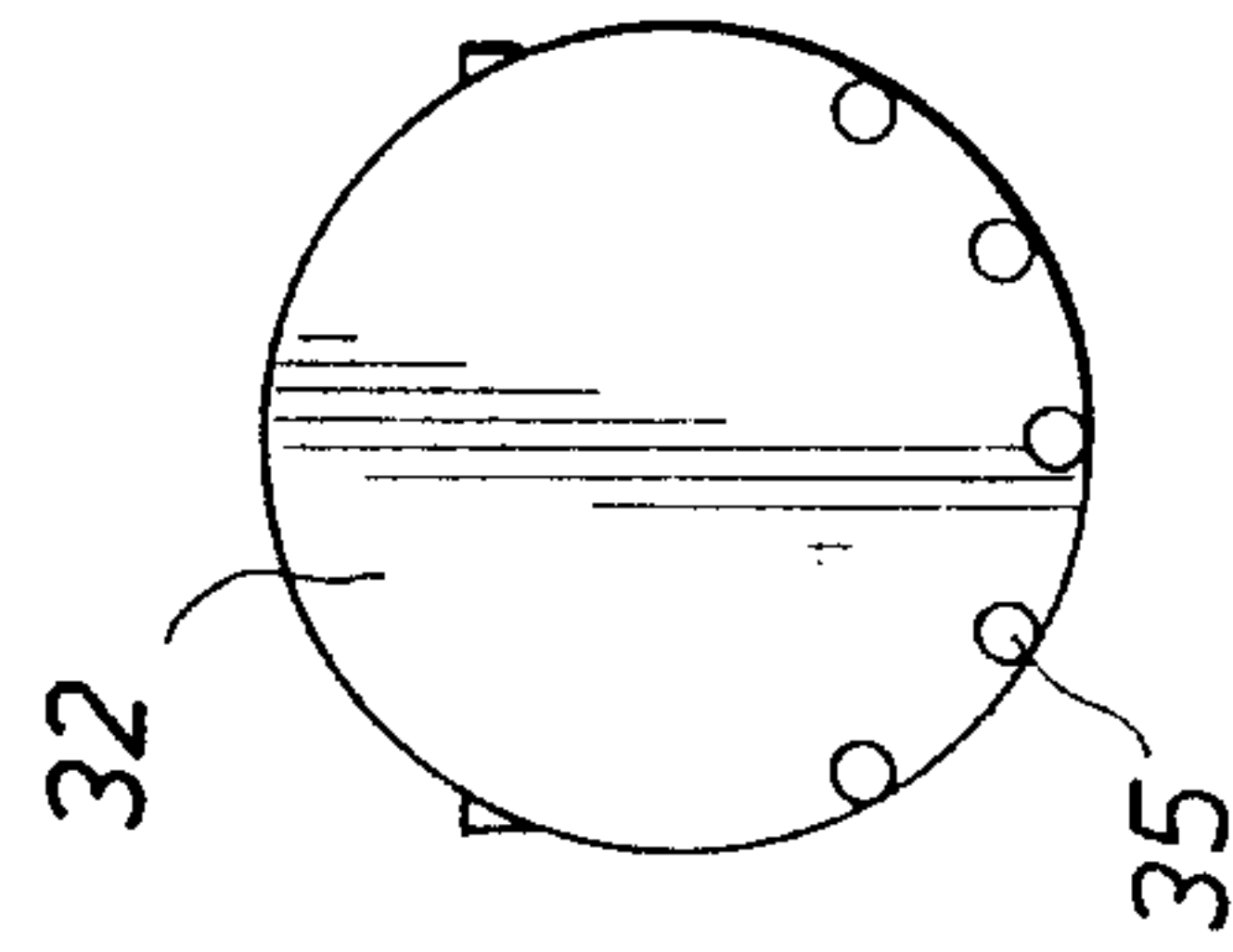


FIG. 6C

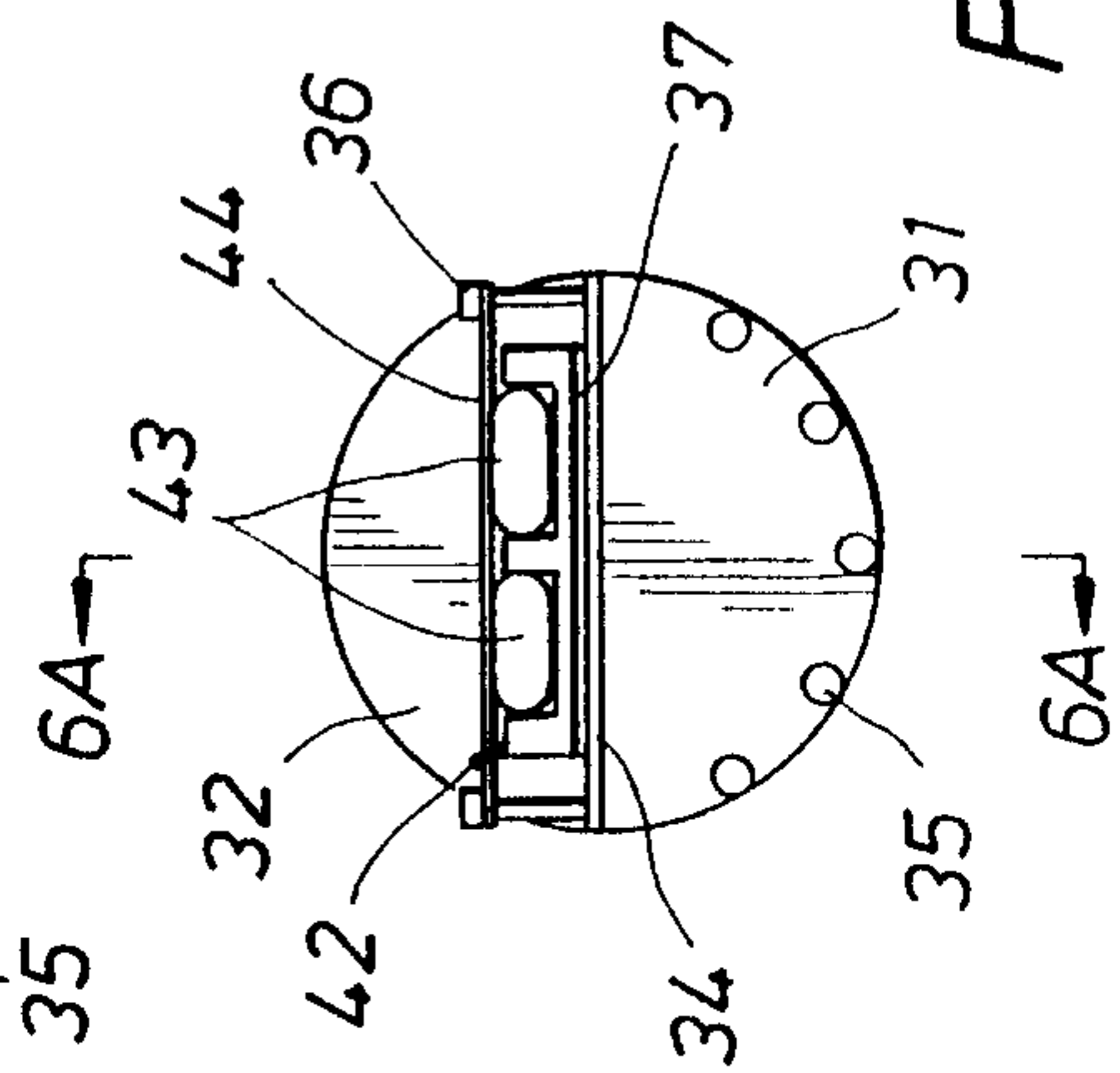


FIG. 7B

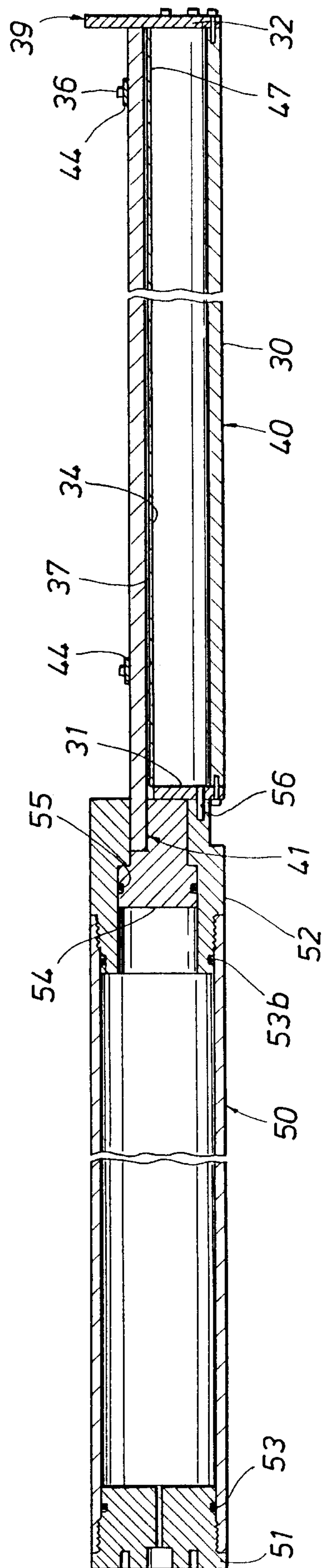
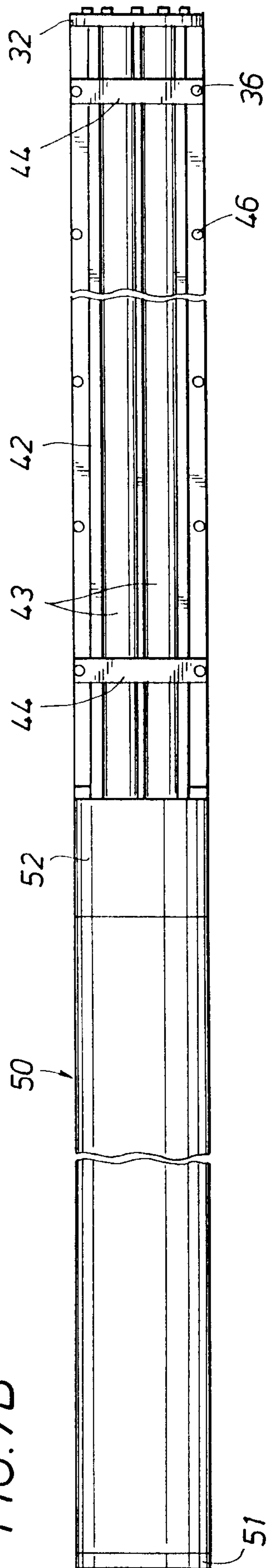


FIG. 7A

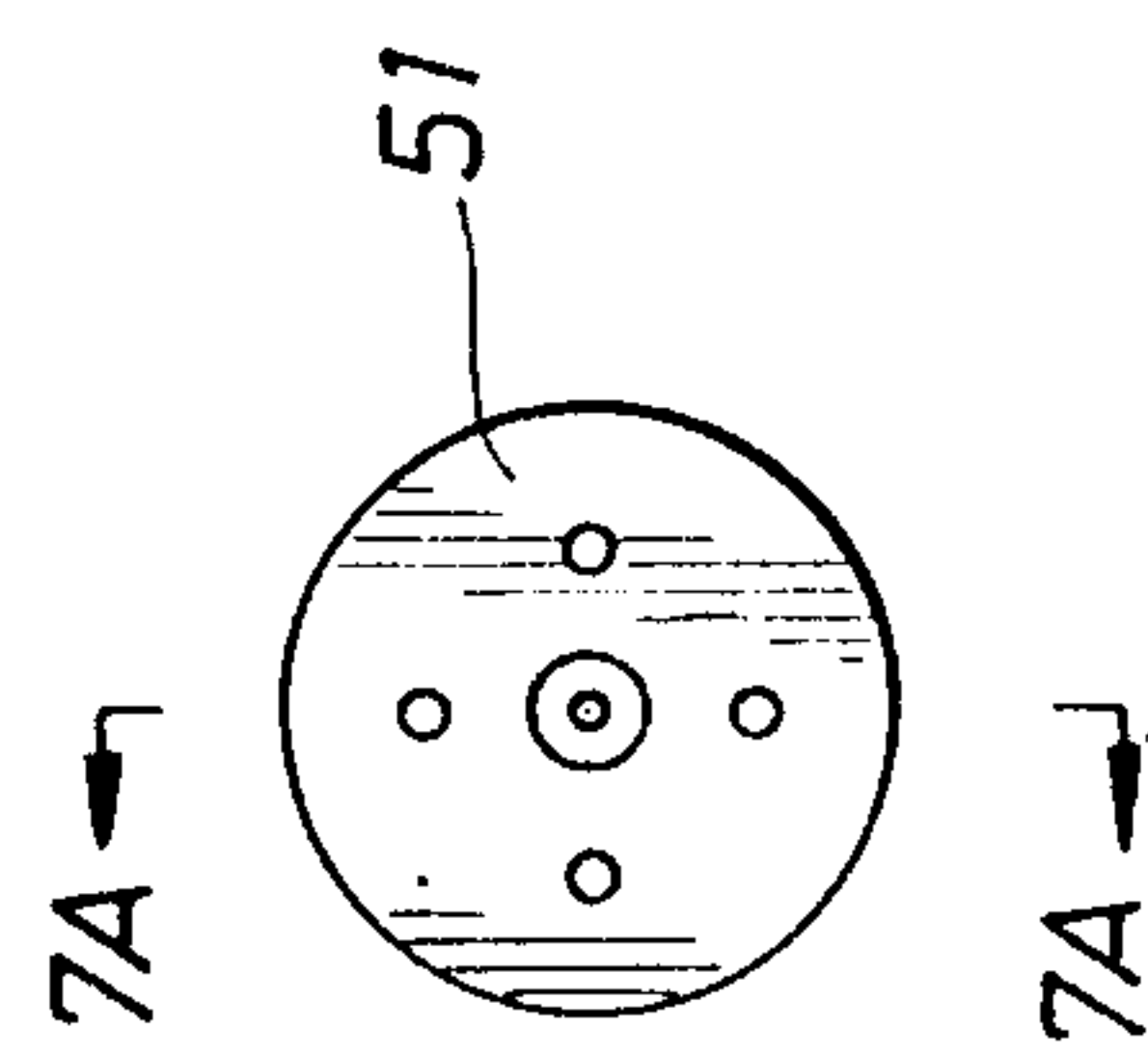


FIG. 7C

7/8

FIG. 9A

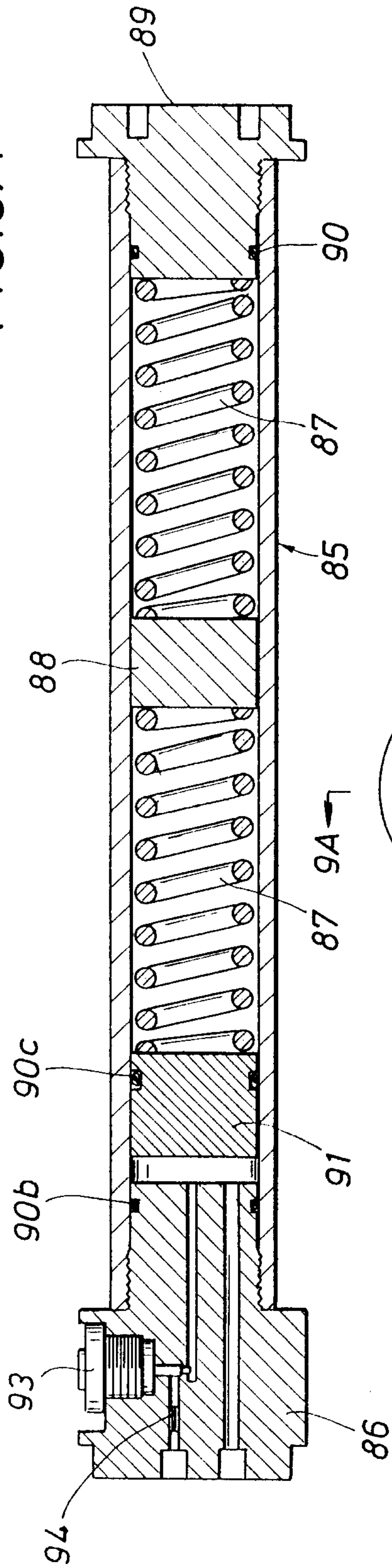


FIG. 9B

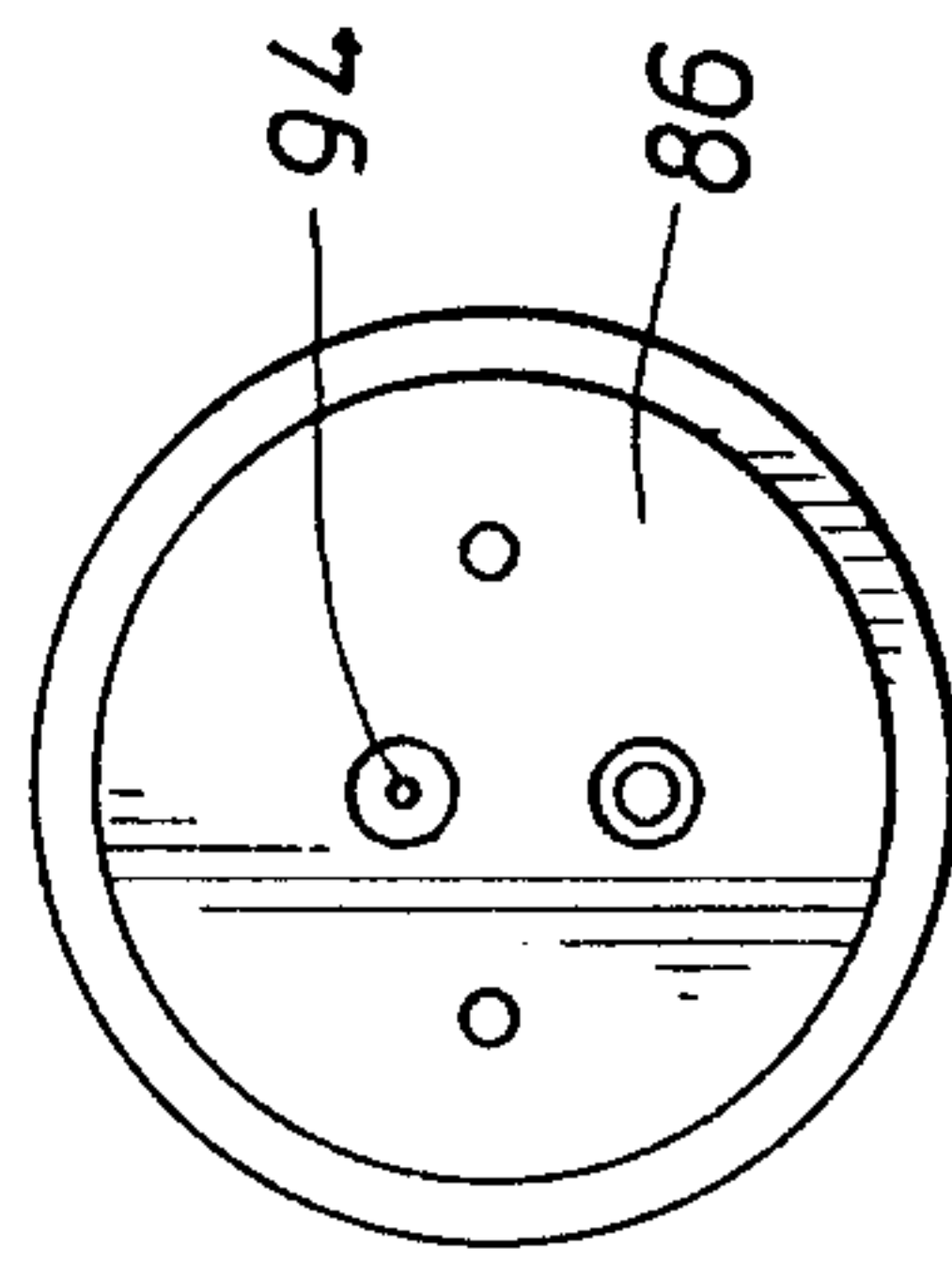


FIG. 10

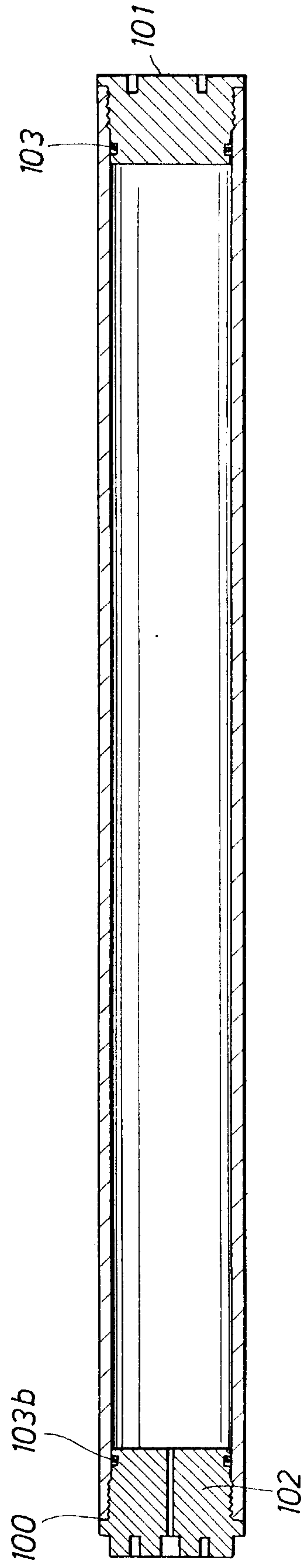


FIG. 11A

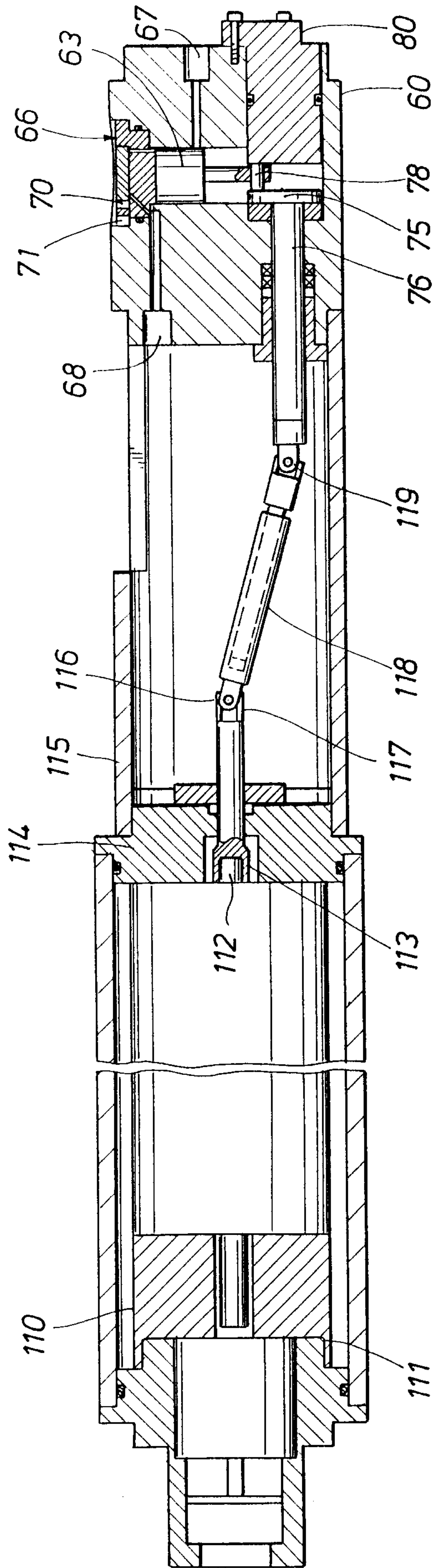
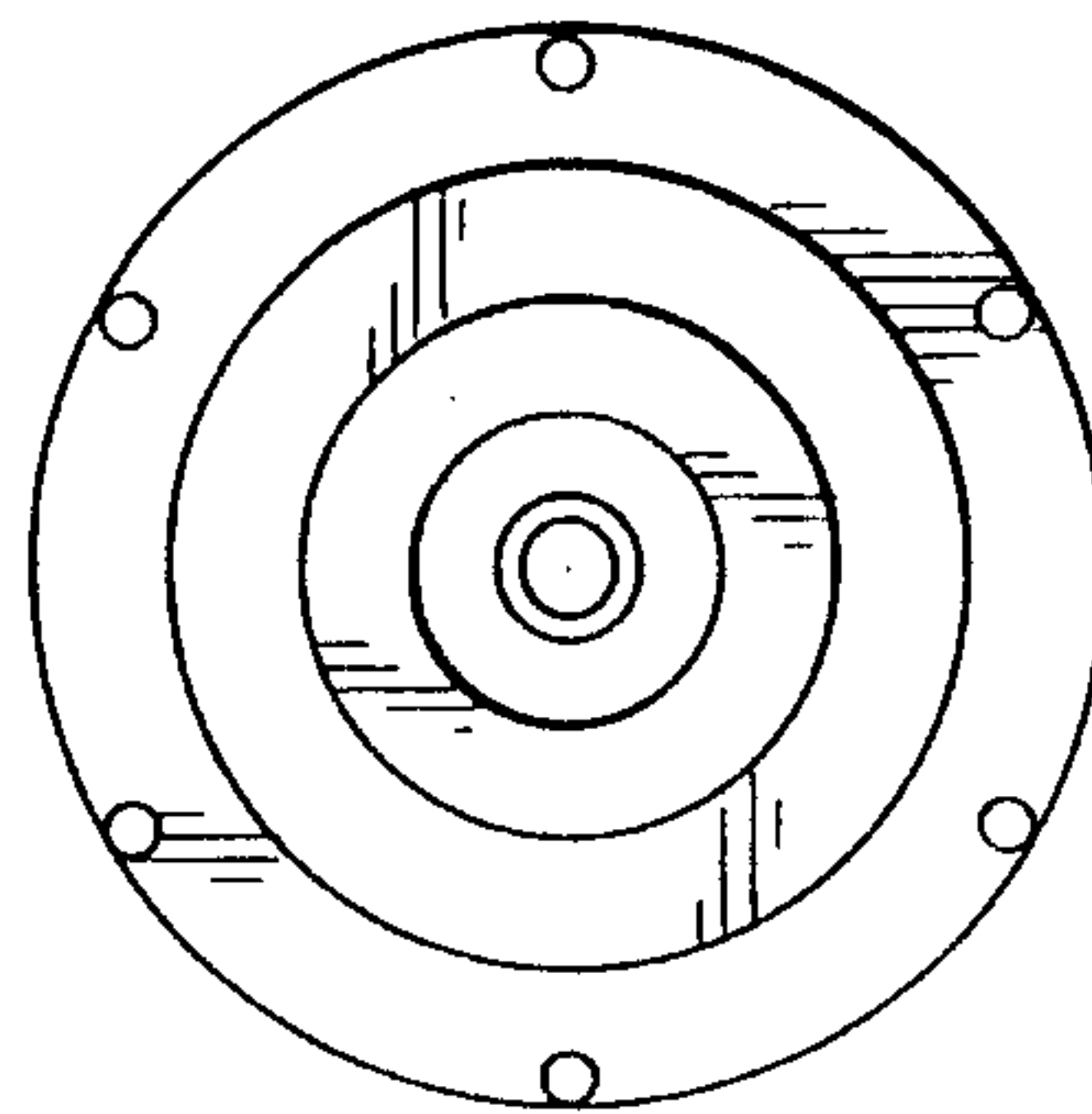


FIG. 11B

11A →



11A →

FIG. 11C

