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(54) Laboratory freezer applicance.

(57) A laboratory freezer appliance providing a usable storage space on the order of 5 to 20 cubic feet (0.14 to 0.57 cubic metres) capable of storage temperatures of -160°C and lower including an insulated freezer chamber, heat transfer tubes in proximity to the freezer chamber carrying liquid argon at ultra-low temperatures which absorbs heat from the freezer chamber thereby vaporising the argon in the heat transfer tubes ; a closed cycle, hermetically-sealed free piston Stirling cycle heat pump providing a cold end above a vertical displacer driven by a linearly reciprocating piston at a temperature differential to the freezer chamber of about -13°C ; a condensing chamber surrounding the cold end of the heat pump for condensing argon vapour to the argon liquid ; and a distributor for distributing liquid argon from the condensing chamber to the heat transfer tubes and returning argon vapour to the condensing chamber, all without mechanical pumping of the argon, in a continuous, closed cycle refrigeration system.

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This invention relates to a cryogenic temperature storage chamber and, more particularly, to a laboratory freezer appliance that provides a freezer storage space, e.g., in the order of 5 to 20 cubic feet (0.14 to 0.57 cubic metres) capable of storage temperatures of -160°C and lower.

In both research and diagnostic laboratory applications, low temperature refrigeration of living biological systems and bio-materials is required to produce satisfactory preservations. That is, the biochemical and physical processes by which bio-materials sustain life are affected to varying degrees by temperature. Thus, in applications where ultra-low temperatures are successful in arresting these processes, lower storage temperatures are desired to achieve more satisfactory results, particularly for long term storage of biological specimens. The need therefore exists for a reliable laboratory freezer appliance which provides a usable freezer storage space at a consistent and uniform ultra-low temperature, e.g., -160°C and lower, for essentially unattended, extended storage periods.

A laboratory freezer appliance in accordance with one embodiment of the invention comprises an insulated freezer chamber, heat transfer tubes in heat transfer communication with the freezer chamber, the tubes sloping from one end to the other permitting downward flow by gravity of a heat transfer fluid as a liquid along the freezer chamber and the counterflow of the fluid as a vapour, a Stirling cycle heat pump, having a warm zone and a cold zone, a condensing chamber in heat transfer communication with the cold zone for condensing the heat transfer fluid from a vapour to a liquid, and heat transfer fluid distribution means which receives condensed heat transfer fluid from the condensing chamber and distributes it to the heat transfer tubes, and receives vapour from the heat transfer tubes and distributes it to the condensing chamber in a closed cycle of alternate condensation and vaporisation of the heat transfer fluid and consequently cools the freezer chamber.

Preferably a laboratory freezer appliance in accordance with an embodiment of the invention is characterised in that the heat transfer fluid distribution means does not incorporate physical pumping means.

In laboratory freezer appliances in accordance with embodiments of the invention, a heat transfer fluid such as argon enters a condensing chamber surrounding the cold end of a Stirling cycle heat pump in the form of argon gas. The argon gas is condensed therein to a liquid at an ultra-low temperature and flows by gravity to an argon distributor having a centrally located liquid argon reservoir and a number of tubes extending around the periphery of the reservoir which substantially evenly deliver the liquid argon refrigerant to heat transfer tubes which extend along either side of the freezer storage chamber in heat transfer communication therewith. The heat transfer tubes slope downwardly from the argon distributor such that the liquid argon flows along the tubes by gravity. The heat transfer tubes are externally finned to provide a large heat transfer surface. The liquid argon in the heat transfer tubes absorbs heat from the interior of the freezer storage chamber causing convective flow of ultra-low temperature air through the storage chamber in turn lowering of the chamber temperature to the desired operating temperature which may be in the order of -160°C or below. The liquid argon is vaporised by the absorbed heat, and the vapour returns to a head space above the reservoir of the argon distributor in the same heat transfer tubes that carry the liquid argon from the distributor. The argon gas then flows from the argon distributor to the condensing chamber surrounding the cold end of the Stirling cycle heat pump where the argon is again condensed to a liquid and returned to the argon distributor in a continuously operating closed cycle refrigeration process. The operating pressure of the system is on the order of 5 bar (500 Kpa). No external pumping means is provided to move the refrigerant through the system thereby eliminating any moving parts and the need for any lubricants which would freeze up at the ultra-low temperatures involved in the cryogenic freezer.

The argon gas refrigerant to be cooled circulates in the condensing chamber which is in the form of a pressure vessel external of but surrounding a cold end cup of the Stirling cycle heat pump. The cold end cup is formed of a highly heat conductive material that does not become brittle at temperatures of -160°C or lower, such as a stainless steel, and the outer surface of the cold end cup is provided with a heat conductive sleeve having a series of fins having an Adamak fin profile to increase heat transfer to the argon gas in the condensing chamber.

A temperature differential of about 13°C is maintained between the desired storage chamber temperature and the helium in the cold end of the heat pump and about 10°C between the storage chamber temperature and the temperature of the liquid argon. Thus, for a-160°C storage chamber temperature, the liquid argon is at -170°C and the helium is at -173°C. The 200 watts of heat input into the helium in condensing the argon gas in the pressure vessel surrounding the cold end cup plus the input work to drive the heat pump compression and expansion cycles are rejected to the environment external of the heat pump by a heat rejector/condenser assembly.

Embodiments of this invention provide a laboratory freezer appliance capable of providing consistent and repeatable storage conditions at temperatures of -160°C and lower for extended and unattended storage periods. The freezer has a usable storage space of, e.g., 5 to 20 cubic feet (0.14 to 0.57 cubic metres). The freezer operates on normally available

220 volt AC 50/60 Hz single phase electricity; the installation and start up consists of little more than unpacking and levelling the unit, plugging it into the power source, turning the unit on and waiting for it to cool down from room temperature to operating temperature, e.g., -160°C, which takes only about one-half day; the unit will operate continuously with only occasional unskilled maintenance for the first five years of continuous operation; the unit is configured to use space efficiently; and the aesthetic appearance of the freezer is pleasing and the noise and vibration levels are relatively low. Thus, the unit looks and sounds substantially like a typical household freezer.

As stated, the cryogenic freezer provides a suitable storage space, e.g., from 5 to 20 cubic feet (0.14 to 0.57 cubic metres), capable of providing a consistent and uniform freezer temperature of -160°C or lower. There are no external pumping means to pump the refrigerant through the distribution chamber and heat transfer tubes. Further, there is no traditional petroleum-based lubrication in the system which otherwise would be subject to freezing by virtue of the ultra-low temperatures of the system and to contamination of the refrigerant and the working gas in the heat pump. Rather, the moving parts of the heat pump are spun during operation to provide hydrodynamic non-contact gas bearings which, since no contact between rotating and stationary parts is allowed, eliminates the need for traditional lubricants.

Fig. 1 is an isometric view of an embodiment of a cryogenic freezer according to the present invention.

Fig. 2 is a front view of the embodiment of Fig. 1 with walls broken away to show internal components.

Fig. 3 is a view along line 3-3 of Fig. 2.

Fig. 4 is a view along line 4-4 of Fig. 2.

Fig. 5 is a view along line 5-5 of Fig. 4.

Fig. 6 is a view along line 6-6- of Fig. 5.

Fig. 7 is a cross-sectional view of the cold end heat exchanger, displacer, and rejector assembly of the Stirling cycle heat pump.

Referring now to Fig. 1, the cryogenic freezer 10 includes a cabinet 11 which houses a freezer storage chamber 12 interiorly of the cabinet 11, a lid 14 to seal closed the freezer storage chamber 12 and to provide access thereto, and a side car cabinet 16. An access panel 18 provides access to the Stirling cycle heat pump 20 (Fig. 2), which will be described in detail below. A condenser 22 and blower 24 are housed in the side car cabinet 16. The blower 24 draws air through a grill 26 (Fig. 1) in an end wall 27 of the cabinet 16 and over the condenser 22 to condense a refrigerant for removing heat from the heat pump 20, as also will be described in detail below.

The freezer 10 is generally rectangular in shape making it suitable for efficient use in a laboratory. The cabinet 11, lid 14, and side car 16 are formed of cold-rolled steel which is painted for protection and aesthetics. Typical physical dimensions of the freezer 10 are an overall external dimension of 91" (231cm) long by 46.5" (118cm) high by 28.5" (72cm) front to back. Typical interior chamber dimensions are 43.5" (110cm) long by 32" (81cm) high by 16 1/4" (41cm) deep, which provides two 42.5" (108cm) long by 27" (69cm) high by 6 1/4" (16cm) deep usable storage volumes, or about 8 cubic feet (0.22 cubic metres) of usable storage volume. Caster wheels 28 are provided to permit convenient movement of the freezer 10 in the laboratory or other facility.

Referring now to Figs. 2 and 3, the freezer storage chamber 12 is formed of stainless steel for good thermal conductivity and corrosion protection. The storage chamber 12 is surrounded by an insulative material 30 such as a foamed-in-place urethane. As shown in Fig. 2, the insulation 30 surrounds the bottom, side, and end walls of storage chamber 12 and extends around the Stirling cycle heat pump 20 to isolate the freezer storage chamber 12 and the cold end (shown generally at 32) of the heat pump 20 from the warm heat rejector 34 and compressor assembly 36 of the heat pump 20.

A hard, low thermal conductivity plastic panel 38 extends around the top between the freezer chamber 12 and the outer wall of the cabinet 11 and is adhesively joined to the steel cabinet and freezer chamber walls. The freezer lid 14 likewise has a foamed-in-place urethane insulative core 40, and a plastic mat lid liner 42 joined to the lid 14. A snap-in plastic extrusion (not shown) joins the lid 14 and lid liner 42 for foaming of the insulative core 40 in place. This extrusion also retains a bulb gasket 43 in the lid 14 surrounding chamber 12. These fibreglass mat reinforced panels 38, 42 have decreased thermal expansion while maintaining flexibility. A plastic foam sublid 44 rests above the top of the freezer chamber 12. The lid liner 42 is formed to receive a second gasket 46, which may conveniently be a combination of several feather gaskets, adhered in a groove in the plastic lid liner 42.

A stainless steel rack 48 is supported interiorly of the freezer storage chamber 12 which in turn supports standard storage boxes or items 50 contained in the freezer chamber 12. The rack 48 is spaced inwardly from the side and bottom walls of the chamber 12 and below the sublid 44, and the storage boxes 50 are in rows spaced from each other down the centre of the chamber 12 (figs. 3 and 4). This results in an open space 52 at the bottom of the chamber 12, spaces 54, 56 along the sides, a space 57 between the rows of storage boxes 50, and a space 58 above the storage boxes 50 and below the sublid 44. These spaces are important to permit circulation by convection of ultra-low temperature air in the freezer storage chamber 12, as described below.

A series of heat transfer tubes 60 extend along the length of the storage chamber 12 in the spaces 54, 56 between the inner wall of the chamber 12 and the support racks 48. The tubes 60 are formed of copper for its heat transfer properties and its corrosion resistance. Six vertically spaced tubes 60 are provided along the front of the chamber 12 and six along the rear of the chamber 12 for a total of twelve heat transfer tubes. The tubes 60 include external flat copper fins 62,0.008" (0.2mm) thick to increase the heat transfer to the surrounding air.

The copper heat transfer tubes 60 circulate a heat transfer fluid along the length of the storage chamber. The preferred heat transfer fluid is argon as a saturated liquid at -170°C when a storage chamber temperature of -160°C is desired. Other heat transfer fluids such as oxygen, nitrogen, and natural gas could be used. Oxygen and natural gas, however, have the disadvantage of being flammable, and nitrogen has a higher saturation pressure. Argon, on the other hand, is non-flammable and non-explosive at room temperature and atmospheric pressure, and argon has a saturation pressure of less than 50 psig (4.5 Pa) at -170°C. The liquid argon at ultra-low temperatures flows down the heat transfer tubes 60 along the length of the storage chamber 12 by force of gravity due to the tubes 60 being sloped downwardly from their inlet end 64 to their opposite end 66. Gravity flow of the argon refrigerant eliminates the need for a pump which would have moving parts which would require lubrication.

The liquid argon in the heat transfer tubes 60 absorbs heat from the storage chamber 12 cooling the surrounding air and causing the argon to vaporise in the tubes 60. The argon gas in the tubes 60 forms a gas head above the liquid in the heat transfer tubes 60 and is transported back to the inlet end 64 of the tubes 60 in a counter-flowing direction to the flow of the liquid argon.

Placement of the heat transfer tubes 60 at the top of the storage chamber 12, as shown in Figs. 2 and 3, causes a natural convective flow of ultra-low temperature air in the chamber 12 (in the direction shown by the arrows in Fig. 3) surrounding the storage boxes 50. That is, the ultra-low temperature air circulates downwardly along the side walls in spaces 54,56, across the bottom space 52, and upwardly in the space 57 between the storage boxes 50, and across the space 58 at the top of chamber 12 below the sublid 44 and back to the heat transfer tubes 60.

An argon distributor 70, whose location is shown generally in Figs. 2 and 4 and whose details are shown in Figs. 5 and 6, is located at the top of the freezer 10 outside of the storage chamber 12 between the cold end 32 of the heat pump 20 and the inlet end 64 of the heat transfer tubes 60. The argon distributor 70 consists of a domed chamber 72 formed of stainless steel, which is welded at its base to a reservoir 74, also formed of stainless steel, having a circular basin 76 therein which is fed with liquid argon through a tube 78 communicating at its other end with the cold end 32 of the Stirling cycle heat pump 20. Twelve liquid argon distribution tubes 80 communicate with the liquid argon reservoir 74 about its circumference. That is, the liquid argon distribution tubes 80 open into the bottom of the basin 76 and are spaced about its circumference to achieve a substantially uniform distribution of the liquid argon which flows into and fills the basin 76 to each of the tubes 80. The distribution tubes 80 are joined at their opposite ends to the inlets ends 64 of the twelve heat transfer tubes 60.

Argon gas is returned to the argon distributor 70 by flowing through the heat transfer tubes 60, the argon distribution tubes 80, and into a gas head space 84 above the liquid reservoir 74. A second tube 86, e.g., 1" (2.54cm) in diameter, connects the head space 84 to a condensing chamber 90 (Fig. 7) at the cold end 32 of the Stirling cycle heat pump 20 where the argon gas is condensed to a liquid, and flows back through feed tube 78 to the reservoir 74 of the argon distributor 70, whereby a continuous cycle of argon condensation, distribution, vaporisation, and condensation occurs. That is, the argon gas from the head space 84 in the argon distributor 70 flows through tube 86 to the condensing chamber 90 at the cold end 32 of the heat pump 20 where it is condensed to a liquid at -170°C or lower. The liquid argon flows back through tube 78, which is slanted downwardly from the condenser 90 toward the distributor 70, into the reservoir 74 of the distributor 70, into the argon basin 76, and then out through the distribution tubes 80 by the force of gravity and into and along the heat transfer tubes 60 along the length of the freezer storage chamber 12. The liquid argon in the tubes 60 absorbs heat in the storage chamber 12 causing the liquid argon to vaporise with the argon gas then returning to the head space 84 in the argon distributor 70 above the liquid reservoir 74 in a counter-flowing relation to the liquid argon and in a continuous sequence of argon gas condensation and vaporisation.

The source of refrigeration is the closed cycle, hermertically sealed, free-piston Stirling cycle heat pump 20, which is shown in detail in Fig. 7. The heat pump 20 is vertically disposed and includes the cold end 32 and associated condensing chamber 90 at the top, a heat rejector subassembly 34 therebelow, and the compressor assembly 36 below it.

The cold end 32 of the heat pump 20 includes a cold end cup 96 made of stainless steel. The cold end cup 96 is surrounded by a similar stainless steel cap 98 to form the argon condensing chamber 90 therebetween. The cold end cup 96 and condenser chamber cap 98 are joined to an annular stainless steel flange 100 with the cold end cup 96 being welded to the cold end flange 100 at 101 and the chamber cap 98 being welded at annular groove 102 to the flange 100. (The flange is shown diagrammatically in Fig. 7).

The liquid argon feed tube 78 and argon vapour tube 86 are welded to the wall of the chamber cap 98 and communicate with openings 103 and 104, respectively, in the wall of the cap 98 permitting flow of argon vapour through opening 104 into the space 105 between the cup 96 and cap 98 where the vapour is condensed to a liquid which then flows out by gravity through opening 103 and into the liquid argon supply tube 78 for return to the distributor 70.

The heat rejector assembly 34 includes an outer cylinder 108 mounted at its base 110 in the main support plate 94 and at its top in a groove 112 in the cold end flange 100, and an inner cylinder 114 mounted at its base 116 to the support plate 94. (Again flange 100 is shown diagrammatically). The outer 108 and inner 114 cylinders are formed of seamless stainless steel pipe. The heat rejector assembly 34 further includes a stainless steel upper flange 118 which is joined to the insulation support plate or pan 119 (Fig. 2). The tubes 120 are mounted at their bases in openings 124 in the support plate 94 and at their tops in openings 126 in an upper rejector tube support sheet 128 also formed of stainless steel. The tubes 120 are brazed in place as is tube support sheet 128. The tubes 120 are circumferentially spaced about the unit in three concentric rings.

Upper and lower rejector assembly stubs 130 and 132, respectively, extend through and are welded in the wall of the outer cylinder 108 of the rejector assembly 34 and communicate with the space 122 surrounding the rejector tubes 120. As will be described below, a refrigerant is circulated in the space 122 to remove heat from the gas passing through the tubes 120.

The tubes 120 open at their top ends into a regenerator 134 located between the rejector assembly 34 and the cold end cap flange 100. The regenerator 134 is of standard construction and is a matrix formed of 22 micron diameter stainless steel wire having 80% porosity. Filters 136 are located at the top and bottom of the regenerator 134 to prevent particles of the stainless steel wire from becoming dislodged and being caught in the gas flowing through the regenerator.

A displacer support plate 138 which includes a central hub 140 having an internally threaded recess 142 is bolted to the assembly by means of bolts 144 passing upwardly therethrough. A gasket 146 seals the periphery between the displacer support plate 138 and main support plate 94. Set screws 148 are provided in the displacer support plate 138.

A displacer support rod 152 is screwed into the recess 142 and then welded to the central hub 140.

A displacer assembly 154 includes a cylindrical displacer tube 156, a cylindrical displacer sleeve 157, a shell cap 158, a displacer rod guide 160, which surrounds the displacer rod 152 and to which the displacer sleeve 157 is threaded at its base, a support ring 162, and an insulator 164.

The displacer assembly 154 is surrounded by a cold end heat exchanger 168 formed of a phenolic which is threaded to an aluminum cylindrical stuffer 169. The cold end heat exchanger 168 at its end surrounded by the cold end cup 96 contains 30 passages 198 on its outer surface through which the helium gas passes into a gas expansion space 170. Since the gas in space 170 is at a temperature on the order of -173°C, the displacer assembly 154 is made of low thermal conductivity material, such as phenolic, to minimise thermal conduction losses.

The end of the stuffer 169 opposite the cold end heat exchanger 168 receives the three bolts 144 securing the displacer support plate 138 in place.

A gas spring cap 176 formed of aluminum is threaded to the top of the displacer rod guide 160 forming a generally closed space 178 therein extending down through the centre of the displacer support rod 152, which is filled with helium at an average pressure between the maximum and minimum pressure of the working gas in the heat pump to form a gas spring for the displacer assembly 154.

The displacer assembly 154 is spun about its longitudinal axis to provide non-contact hydrodynamic gas bearings between support rod 152 and rod guide 160.

Referring again to Figs. 2 and 7, heat is rejected from the rejector assembly 34 by the circulation of a refrigerant such as chlorodifluoromethane in the space 122 surrounding the rejector tubes 120. That is, the liquid refrigerant enters the space 122 through the pair of opposed lower stubs 132 (only one shown in Figs. 2 and 7) and absorbs heat from the helium gas passing through the rejector tubes 120 by heat conduction through the tube walls. The absorption of heat from the gas causes the refrigerant to vaporise, and the vapour leaves the rejector through the four circumferentially spaced upper stubs 120 (only one shown in Figs. 2 and 7). Stubs 130 connect with tubing 204 through which the vapour flows to the reflux condenser 22 mounted at the end wall 27 of the side car cabinet 16. The blower 24 is located in the bottom of the side car cabinet 16 and draws air through the grill 26 though a standard air filter 207 and over the condenser tubes 206 to condense the refrigerant therein. The liquid refrigerant then flows by gravity from the condenser 22 through tubing 208 connected to stubs 132 into the bottom of the heat rejector space 122.

Claims

1. A laboratory freezer appliance comprising an insulated freezer chamber; heat transfer tubes in heat transfer communication with the freezer chamber, the tubes sloping from one end to the other permitting downward flow by gravity of a heat transfer fluid as a liquid along the freezer chamber and the counterflow of the fluid as a

vapour a Stirling cycle heat pump having a warm zone and a cold zone, a condensing chamber in heat transfer communication with the cold zone for condensing the heat transfer fluid from a vapour to a liquid; and heat transfer fluid distribution means, which receives condensed heat transfer fluid from the condensing chamber and distributes it to the heat transfer tubes, and receives vapour from the heat transfer tubes and distributes it to the condensing chamber in a closed cycle of alternate condensation and vaporisation of the heat transfer fluid and consequently cools the freezer chamber.

2. A laboratory freezer appliance according to Claim 1, characterised in that the heat transfer fluid distribution means does not incorporate physical pumping means.

3. A laboratory freezer appliance according to claim 1 or 2, characterised in that the heat transfer fluid distribution means comprises a closed chamber including a liquid reservoir and a gas head space thereabove for receiving the liquid from the condensing chamber and distributing it to a plurality of tubes communicating at one end with the reservoir and at the other with inlet ends to the heat transfer tubes and for receiving the vapour back from the heat transfer tubes 3and distributing it from the gas head space to the condensing chamber.

4. A laboratory freezer appliance according to any preceding claim, characterised in that the freezer chamber comprises two smaller volumes spaced from one another along a generally central plane and in that the flow of air at low temperature moves from the bottom wall of the freezer chamber upwardly between the smaller volumes along the central plane.

5. A laboratory freezer appliance according to any preceding claim, characterised in comprising means for extracting heat from the working gas, the means comprising a chamber through which a refrigerant fluid circulates, a plurality of tubes located in the chamber, the interior of the tubes being in heat transfer communication with the refrigerant circulating in the chamber through the walls thereof, the working gas flowing through the tubes, and a condenser external of the heat pump for removing heat from the refrigerant.

6. A laboratory freezer appliance according to any preceding claim, characterised in that the heat transfer fluid is argon at a pressure in the order of 5 bar (500 kPa).

7. A laboratory freezer appliance according to any preceding claim, characterised in that Stirling cycle heat pump contains helium as a working gas and the helium cycles between a minimum pressure of about 285 psig (2.07 MPa) and a maximum pressure of about 375 psig (2.69 MPa).

8. A laboratory freezer appliance according to any preceding claim, characterised in that the freezer chamber is at a temperature of -160°C or lower.

9. A laboratory freezer appliance according to any preceding claim, characterised in that the heat transfer fluid is argon, the working gas is helium, the temperature differential between the freezer chamber and the argon liquid is about 10°C, the temperature differential between the argon in the condensing chamber and the helium in the expansion space is about 3°C, and the helium in the expansion space removes about 200 watts of heat from the argon vapour in the condensing chamber.

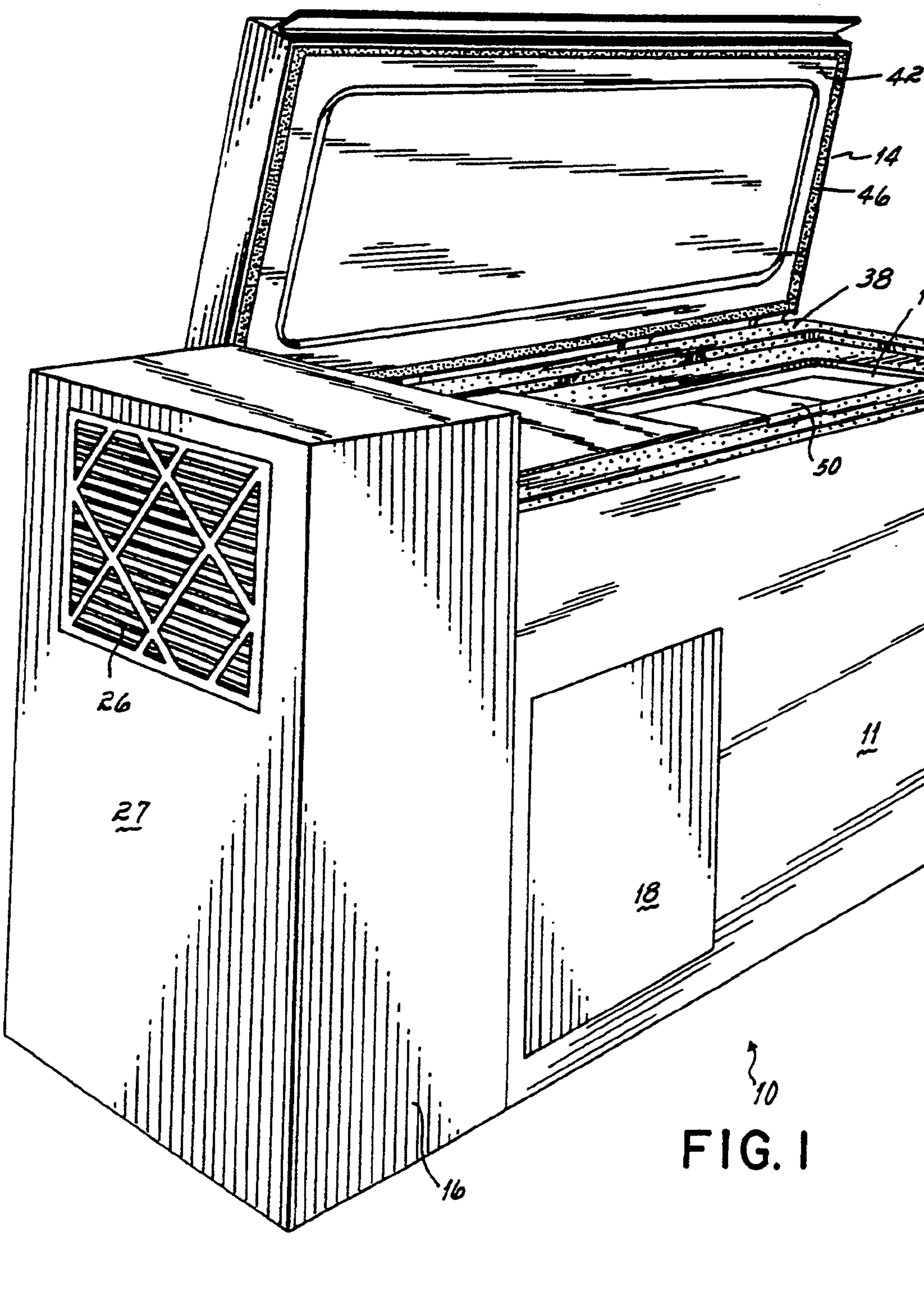

FIG. I

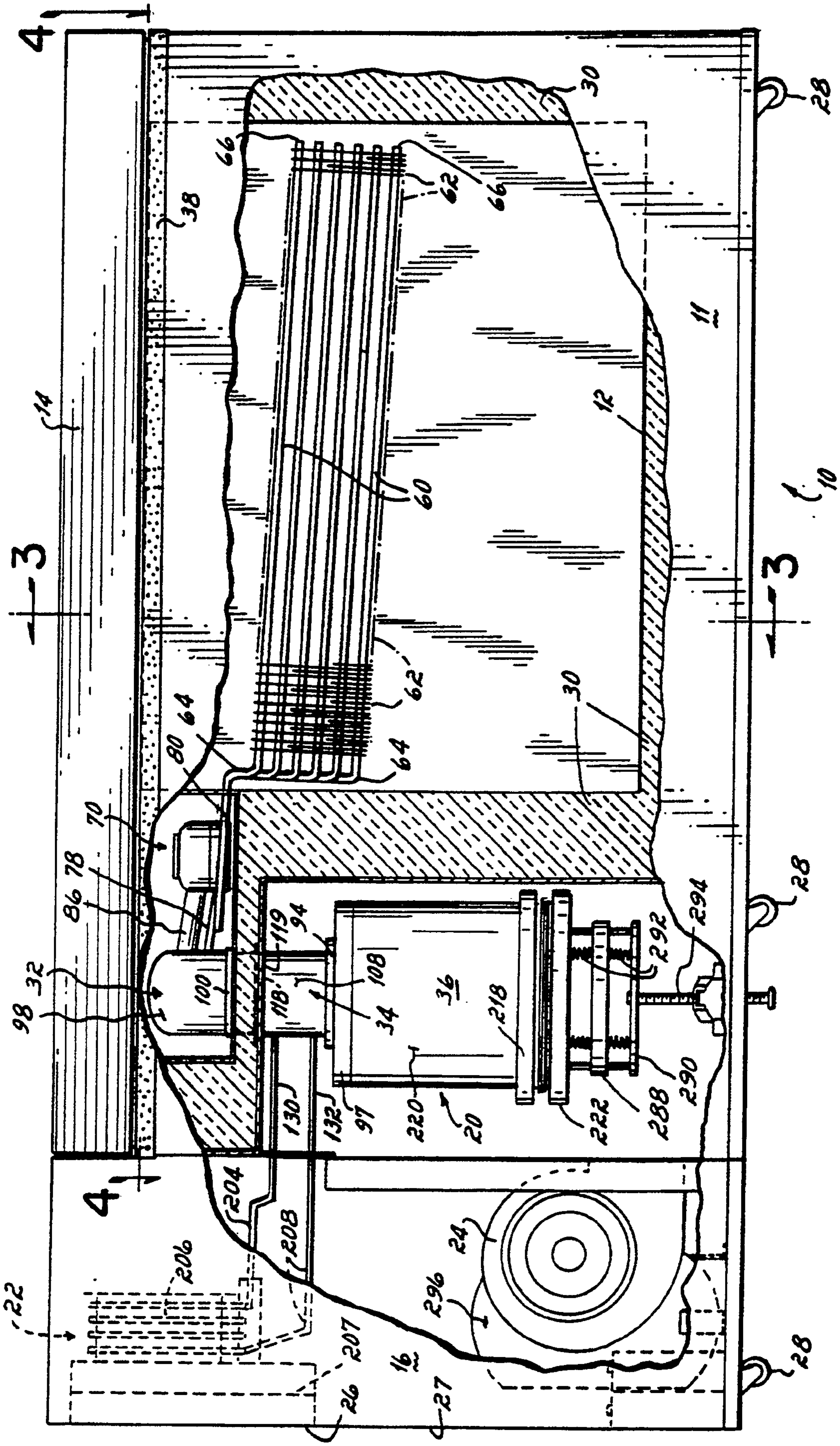
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FIG.2

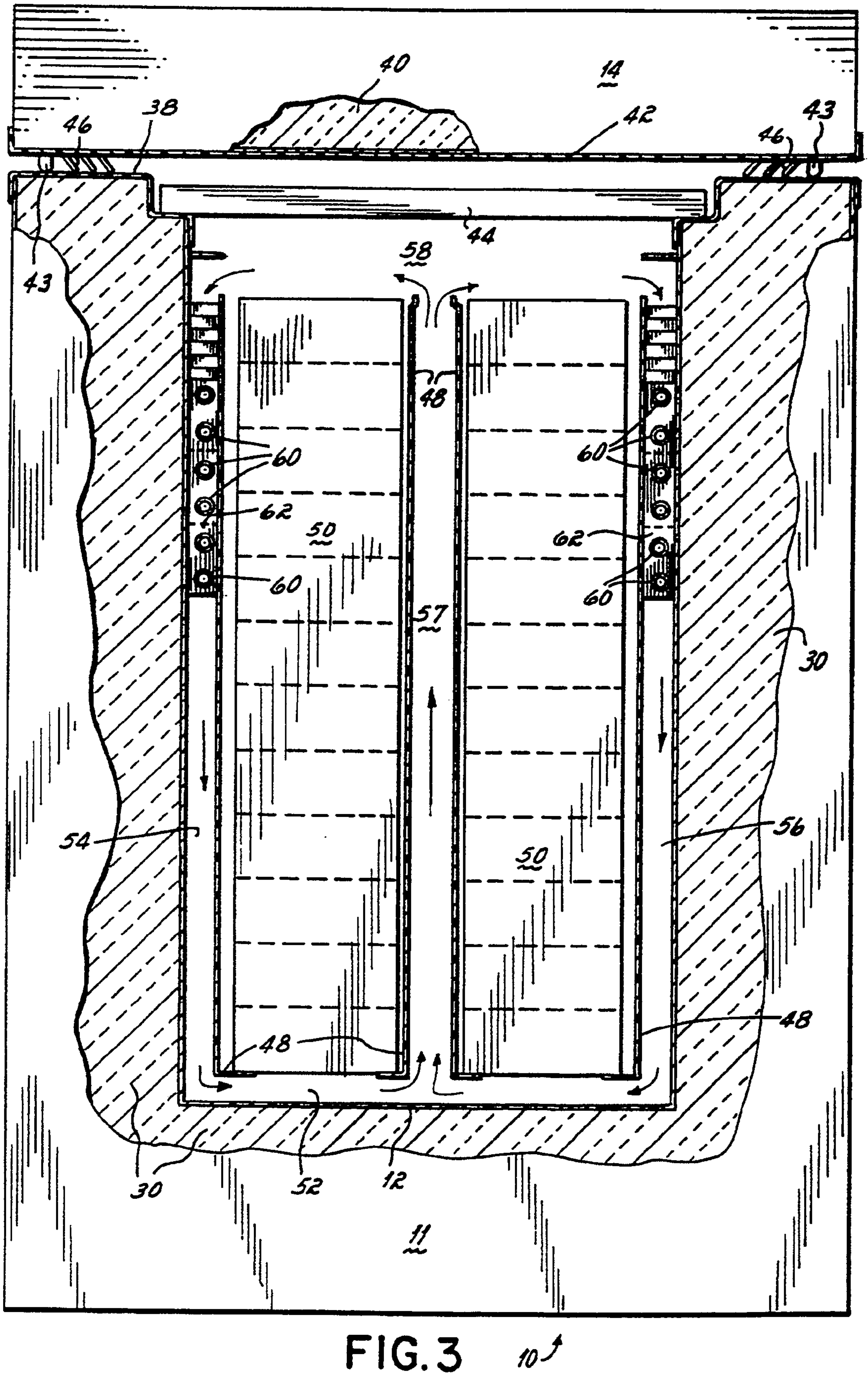
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FIG.3

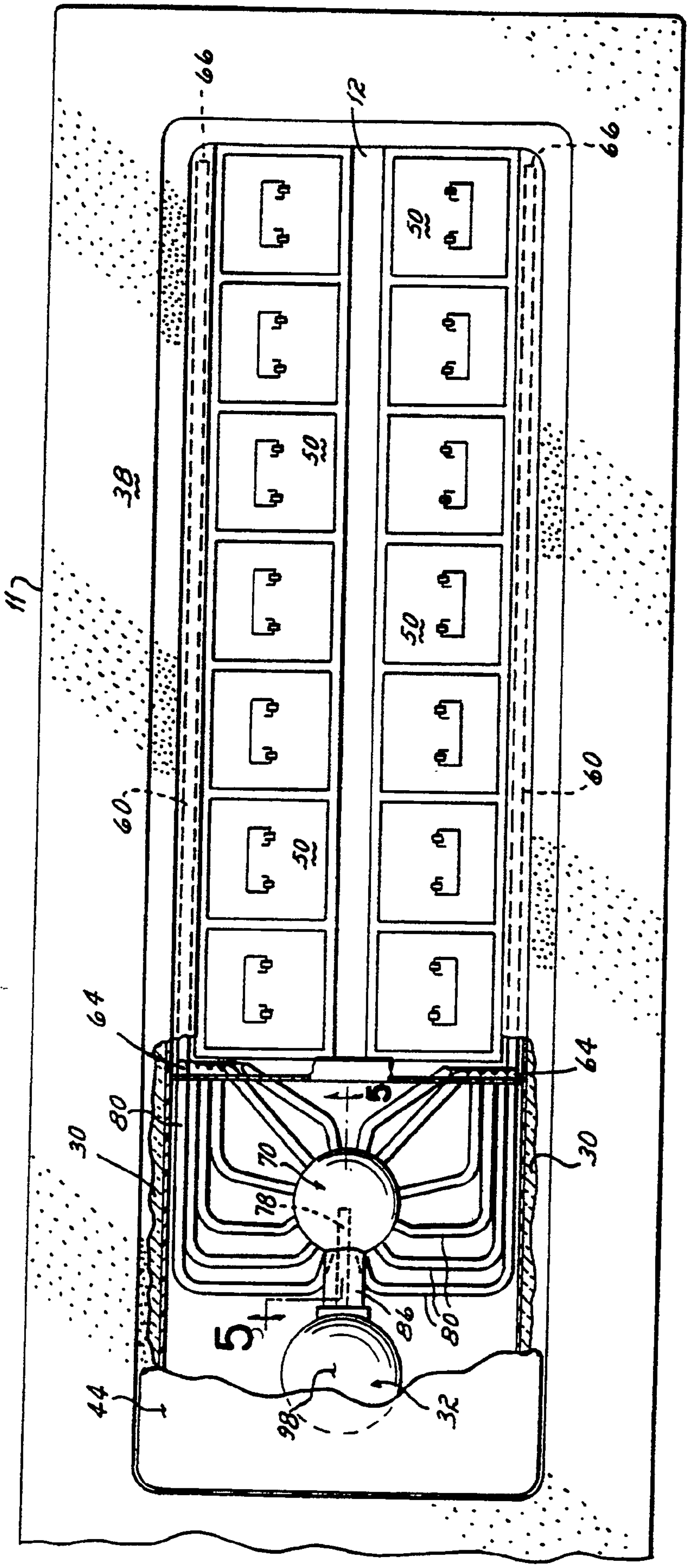
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FIG.4

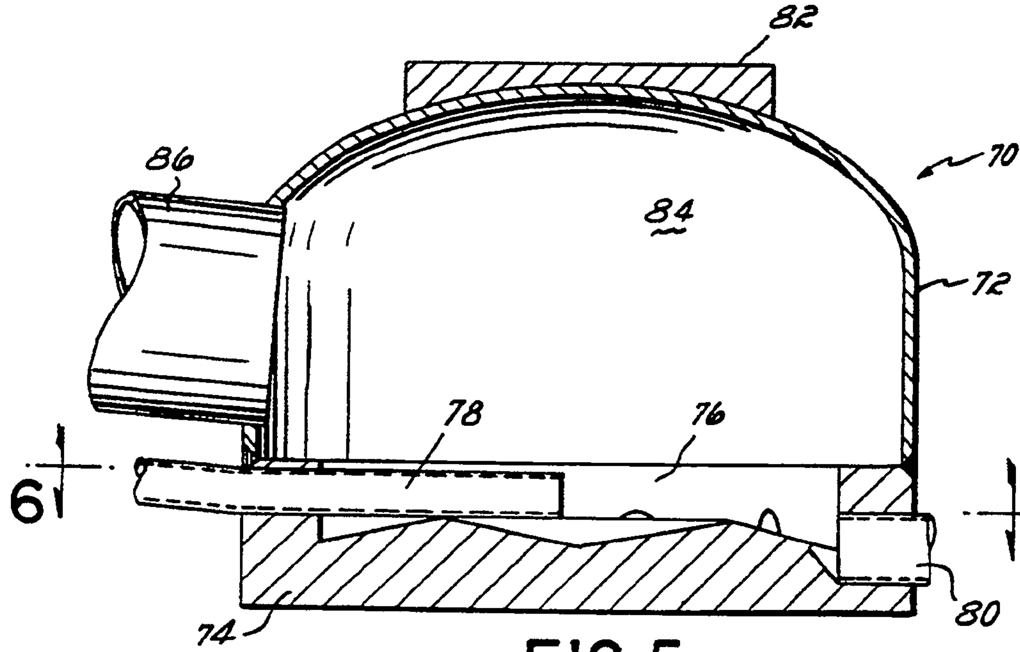
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FIG. 5

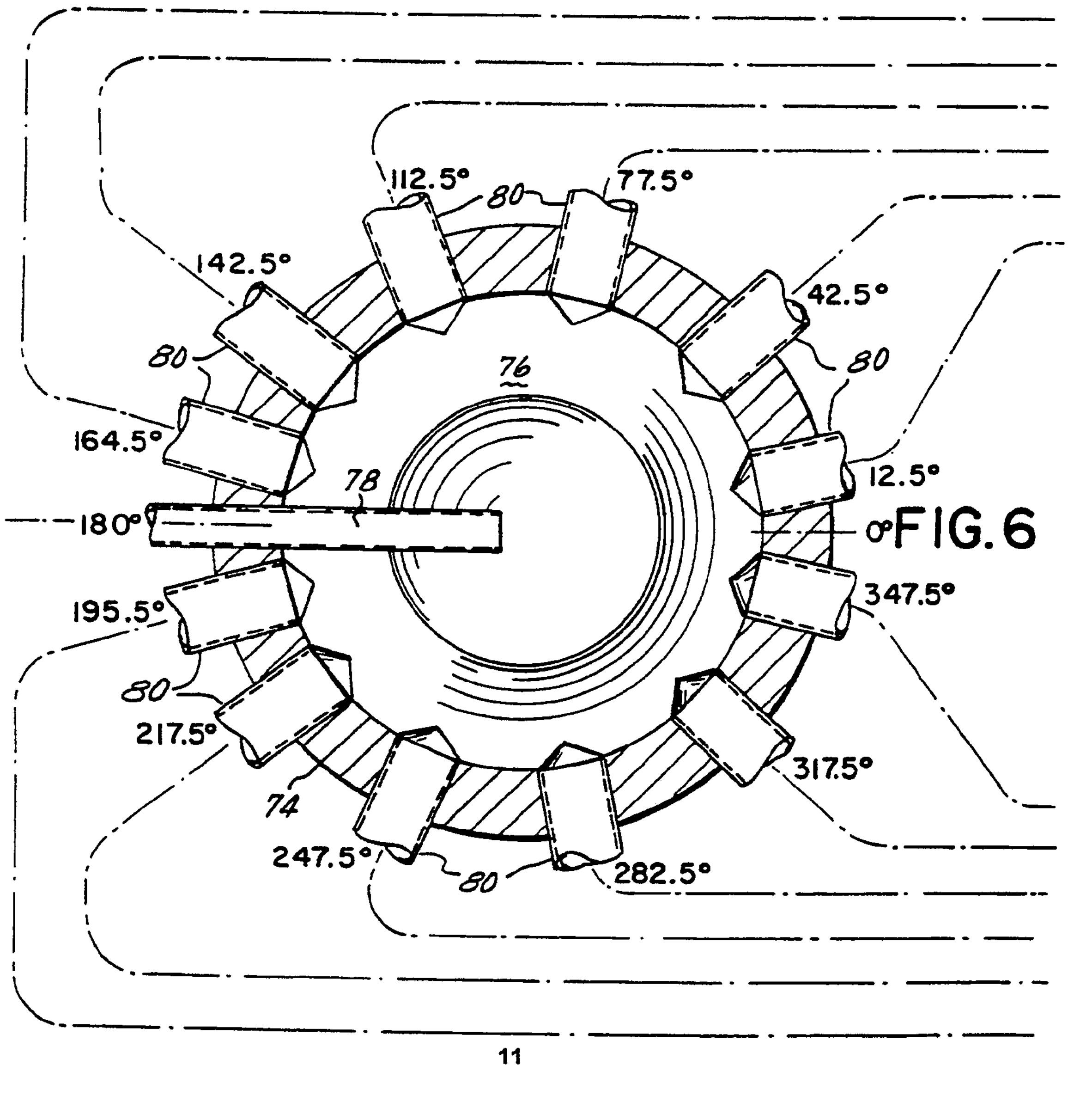
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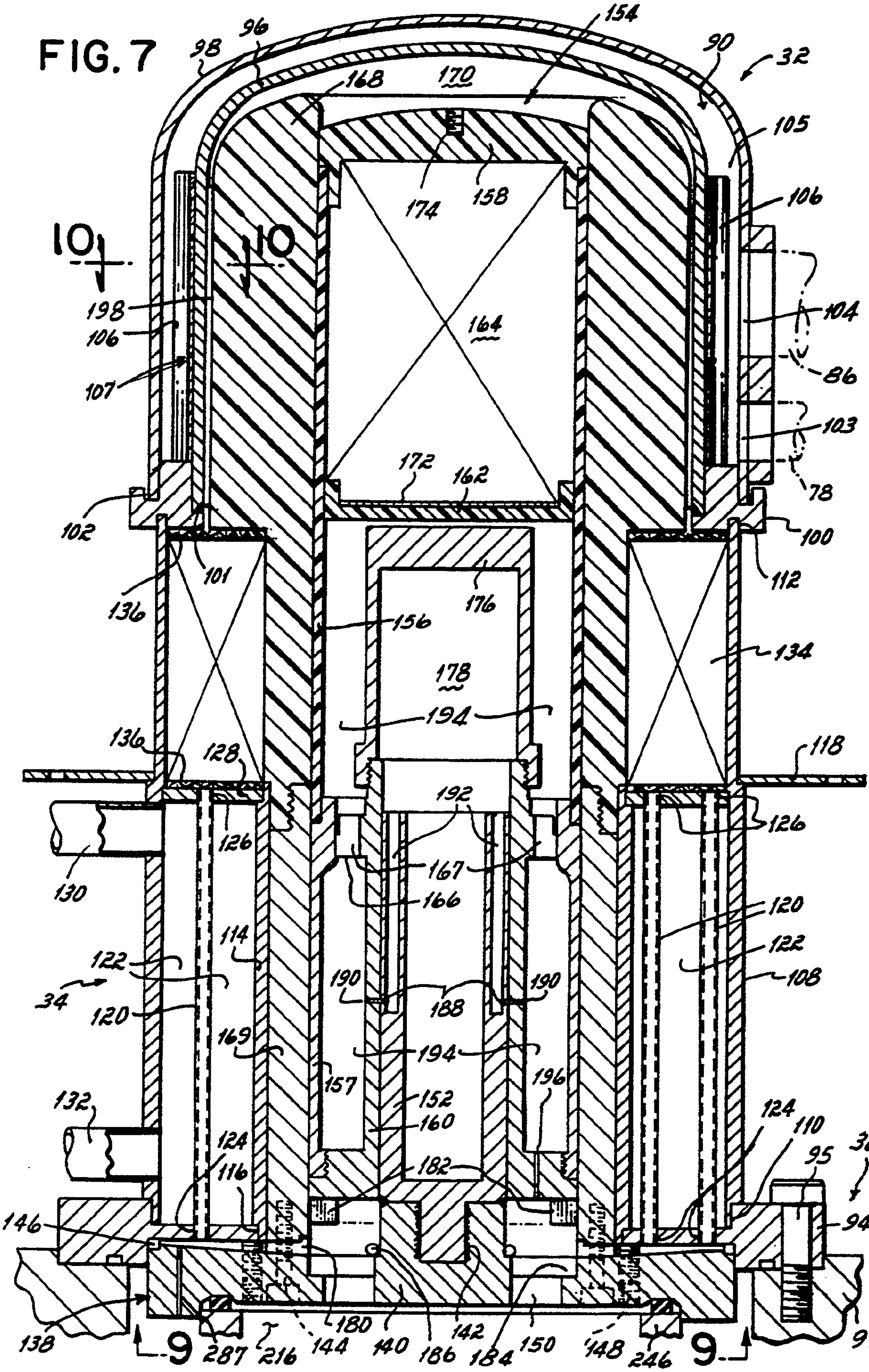
FIG. 6

FIG. 7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