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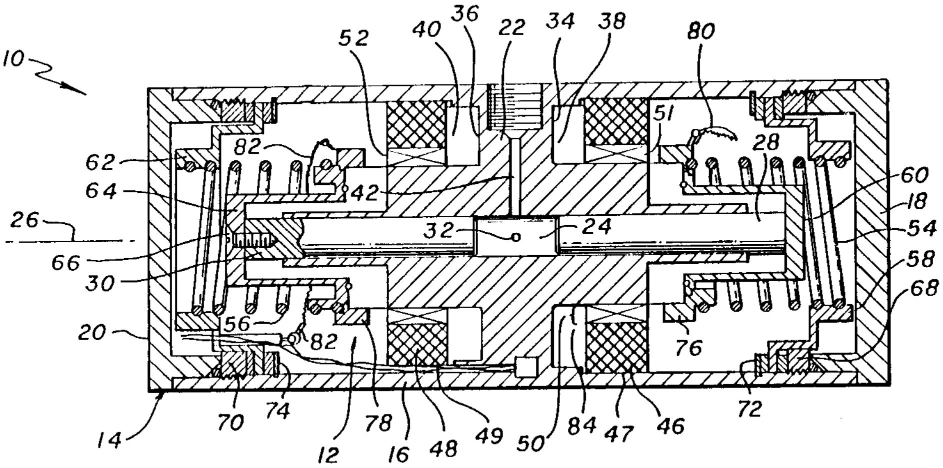
(54) Low cost linear actuator.

(57) An inexpensive linear actuator compressor motor for cryogenic coolers includes a linear actuator (10) having a unique core (22) with a cylindrical bore (24) disposed through the axial center of the core (22) along the longitudinal axis (26) thereof. The bore (24) includes first and second parallel annular peripheral recesses (34 and 36) circumferentially coaxially disposed about the longitudinal axis (26) thereof to provide first and second cavities (38, 40) therein. The actuator (10) includes first and second pistons (28, 30) located within said bore (24). First and second annular magnets (46, 48) as well as first and second coils (51, 52) are located within the first and second annular cavities (38, 40), respectively. A tap hole is provided for charging air space behind an air gap (50) with a working fluid, e.g. helium. When the coils (51, 52) are energized, magnetic fields are created which interact with the magnetic fields provided by magnets (46, 48) to cause linear motion of the first and second pistons (28, 30). The movement of the pistons (28, 30) is effective to compress the working fluid in the compression space (32).

FIG. 1



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The present invention relates to cooling systems. More specifically, the present invention relates to compressor motors utilized in low cost cooling systems.

While the present invention is described herein with reference to illustrative embodiments for particular applications, it should be understood that the invention is not limited thereto. Those having ordinary skill in the art and access to the teachings provided herein will recognize additional modifications, applications, and embodiments within the scope thereof and additional fields in which the present invention would be of significant utility.

Cryogenic coolers are used for numerous application including the cooling of infrared sensors. Cryogenic coolers generally include a compressor, driven by a motor, which compresses a working fluid causing it to release energy in the form of heat. When the working fluid is allowed to expand, it absorbs heat and thereby provides for refrigeration of the cooled device or volume. This application generally requires a compressor driven by a high force motor with low losses.

Conventional cryogenic coolers have used a rotary motor type compressor which was found to be complex and susceptible to wear.

Accordingly, linear actuators were developed for simplicity and good wear characteristics. Linear actuators are electromagnetic devices that provide linear mechanical motion in response to the interaction of magnetic and electrical circuits. U. S. Patent No. 4,808,955 discloses a Moving Coil Linear Actuator with Interleaved Magnetic Circuits. The interleaved magnetic design offers increased power in a given volume. However, this design is complex and somewhat expensive.

Accordingly, a need remains in the art for an inexpensive linear actuator compressor motor for cryogenic coolers.

The need in the art is addressed by the linear actuator of the present invention which includes a unique core having a cylindrical bore disposed through the axial center of the core along the longitudinal axis thereof. The bore includes first and second parallel annular peripheral recesses circumferentially coaxially disposed about the longitudinal axis of thereof to provide first and second cavities therein. The actuator includes first and second pistons located within the bore. First and second annular magnets located within the first and second annular recesses respectively. First and second coils are disposed within the first and second annular recesses respectively.

When the coils are energized, magnetic fields are created which interact with the magnetic fields provided by the magnets to cause linear motion of the first and second pistons.

When implemented in a compressor, the invention includes a cylindrical housing and a core disposed within the housing. The core includes a cylindrical bore disposed through the axial center of the core along the longitudinal axis thereof to provide a compression space. A fluid flow passage is provided between the compression space and a valve. Again, first and second parallel annular peripheral recesses are circumferentially coaxially disposed about the longitudinal axis of the core to provide first and second cavities therein. The first and second pistons are located within the bore on opposing sides of the compression space. First and second annular magnets and first and second coils are located within the first and second annular recesses respectively. First and second end caps mounted at open ends of the housing to enclose the compressor. First and second springs are located between the first and second end caps and the first and second pistons, respectively. And a working fluid is disposed within the housing into the compression space.

Again, when the coils are energized, magnetic fields are created which interact with the magnetic fields provided by the magnets to cause linear motion of the first and second pistons. The movement of the pistons is effective to compress the working fluid in the compression space.

Hence, the present invention provides an inexpensive linear actuator compressor motor for cryogenic coolers.

Illustrative embodiments and exemplary applications will now be described with reference to the accompanying drawings to disclose the advantageous teachings of the present invention.

Fig. 1 is a simplified sectional side view of a preferred embodiment of the linear actuator of the present invention in an illustrative compressor implementation.

Fig. 2 is a detailed sectional side view of the preferred embodiment of the linear actuator of the present invention in an illustrative compressor implementation.

Fig. 3 is a detailed sectional end view of the preferred embodiment of the linear actuator of the present invention in an illustrative compressor implementation.

As shown in Fig. 1, the compressor 10 includes the linear actuator 12 of the present invention mounted within a housing 14. The housing 14 is provided by a cylindrical shell 16 which is closed at each end by first and second end caps 18 and 20 respectively. The shell 16 and the first and second end caps 18 and 20 are made of steel or other suitable material. The end caps may be screwed or welded into the shell 16.

The linear actuator 12 includes a unique solid wall core 22 made of cold rolled magnetic steel or other magnetic material, twin opposed pistons, two aligned annular magnets and dual opposed coils. The core 22, which is used to carry magnetic flux to the air gap where coils are located, is integral with the shell 16. This is advantageous because, in a fixed volume design, the radial space previously taken by the case is available to the motor, which leads to a stronger and more powerful compressor. In addition, the design integrates components that would otherwise have to be fabricated and would have to be controlled for an optimal fit. Specifically, the problematic interfacing of parts (fasteners, gaskets, and etc.) is mitigated if not obviated altogether. In addition, all functions, such as charge valve seat, transfer line seat, and hermetic closure, and welding details, are not separate parts, but machined features on a single bar of magnetic material as discussed more fully below.

A cylindrical bore 24 is drilled through the axial center of the core 22 along the longitudinal axis 26 thereof to provide a channel for the reciprocation of first and second pistons 28 and 30. The first and second pistons 28 and 30 are located within the bore 24 in opposed relation such that a gas compression space 32 is provided therebetween. First and second parallel annular peripheral recesses 34 and 36 are circumferentially coaxially milled about the longitudinal axis 26 of the core 22 to provide first and second cavities 38 and 40 therein. In addition, a fluid flow passage 42 is provided between the compression space 32 and a gas port 45.

The first and second annular magnets 46 and 48 are located within the first and second annular cavities 38 and 40 respectively. The magnets may be made of Neodymium-Iron-Boron or other suitable material. The magnets are aligned in the same direction. That is, the first permanent magnet 46 is polarized in the same radial direction as the second permanent magnet 48 on the other side of the wall between the recesses 36 and 38 of the core 22. The magnets 46 and 48 are preassembled on a rings 47 and 49 (shown more clearly in detailed view of Fig. 2). The rings 47 and 49 are then assembled into each end of the core 22 on the outside of an air gap 50. This is advantageous in that the magnets are located at the air gap which is known to minimize magnetic field leakage. Also, the location of the magnets on the outside of the air gap requires a longer magnet circumference and tends to include more magnetic material. This is believed to lead to a more powerful and efficient motor. The air gap 50 is a dimensionally tolerant location in the motor because it involves the running clearance of the coil. By locating the magnet ring in this area, the tolerance of this part is less stringent. Also, the magnet ring is a simple, open geometry. This facilitates the location and assembly of the magnets and the shaping of the final part. The concentricity of the ring to the piston bore can be fixtured during final assembly.

First and second coils 51 and 52 are disposed within the first and second annular cavities 38 and 40 respectively inside the first and second annular magnets 46 and 48 respectively. The coils 51 and 52 are aligned in opposition. In the preferred embodiment, the coils are of the shape of a short solenoid for simple construction. The critical alignment of the compressor is the concentricity of each coil and the corresponding piston. The coil and piston should be aligned coaxially by bonding while the coil and piston are in an alignment fixture during assembly. This relaxes the requirements for precision dimension specifications on individual parts.

First and second springs 54 and 56 are located between the first and second end caps 18 and 20 and the first and second pistons 28 and 30 respectively. The first spring 54 is seated between a hat shaped metal washer 58 and a hat shaped armature plate 60. The armature plate may be made of tungsten or other suitable material. Likewise, the second spring 56 is seated between a second hat shaped washer 62 and a second hat shaped armature 64. Rubber washers 68, 70 and hence the coil piston assemblies, are secured in place in each end of the compressor by endcaps 18 and 20 pushing the washers against stops 72 and 74 respectively. Each piston is secured to an associated armature plate by a head screw 66 (one shown in phantom, the other not shown) aligned with the longitudinal axis 26 of the compressor 10.

Each coil is energized by wires connected to aluminum terminal blocks 76 and 78 fixed on the first and second armature plates 60 and 64, respectively, and connected to an external power supply (not shown) by wires 80 and 82 extending from the terminal blocks 76 and 78 respectively. Apertures are provided for the threading of the wires from one side of the compressor through the other to the external power supply.

A tap hole 84 is provided for charging the airspace behind the air gap 50 with a working fluid, e.g., helium. The tap hole communicates with a fill valve 86 and an inlet port 88 (see Fig. 3). The working fluid flows along the pistons into the compression space 32 until a point of equilibrium is reached. When the coils are energized, magnetic fields are created which interact with the magnetic fields provided by the magnets to cause linear motion of the first and second pistons. The movement of the pistons is effective to compress the working fluid in the compression space. Vibration is canceled by running the identical coil piston assemblies at equal amplitudes. Stray magnetic radiation is suppressed by the orientation of the coils in opposition.

Hence, the present invention provides an inexpensive linear actuator compressor motor for cryogenic coolers.

Thus, the present invention has been described herein with reference to a particular embodiment for a particular application. Those having ordinary skill in the art and access to the present teachings will recognize additional modifications, applications and embodiments within the scope thereof.

It is therefore intended by the appended claims to cover any and all such applications, modifications and embodiments within the scope of the present invention.

Claims

1. A linear actuator, characterized by a core (22) having:
   - a cylindrical bore (24) disposed through the axial center of said core (22) along the longitudinal axis (26) thereof and first and second parallel annular peripheral recesses (34, 36) circumferentially coaxially disposed about the longitudinal axis (26) of said core (22) to provide first and second cavities (38, 40) therein;
   - first and second pistons (28, 30) located within said bore (24);
   - a first and second annular magnets (46, 48) located within said first and second annular recesses (34, 36) respectively; and
   - first and second coils (51, 52) disposed within said first and second annular recesses (34, 36), respectively.

2. The actuator of claim 1, characterized by a housing (14) within which said core (22) is disposed.

3. The actuator of claim 2, characterized in that said housing (14) is provided by a shell (16) integral with said core (22).

4. A compressor, characterizied by:
   - a cylindrical housing (14);
   - a core (22) disposed within said housing (14) and having: a cylindrical bore (24) disposed through the axial center of said core (22) along the longitudinal axis (26) thereof to provide a compression space (32);
   - a fluid flow passage between said compression space (32) and a valve (86); and
   - first and second parallel annular peripheral recesses (34, 36) circumferentially coaxially disposed about the longitudinal axis (26) of said core (22) to provide first and second cavities (38, 40) therein;
   - first and second pistons (28, 30) located within said bore (24) on opposing sides of said compression space (32);
   - a first and second annular magnets (46, 48) located within said first and second annular recesses (34, 36), respectively;
   - first and second coils (51, 52) disposed within said first and second annular recesses (34, 36), respectively; and
   - first and second end caps (18, 20) mounted at open ends of said housing (14).

5. The actuator of claim 4, characterized by first and second springs (54, 56) located between said first and second end caps (18, 20) and said first and second pistons (28, 30), respectively.

6. The actuator of claim 4 or 5, characterized by a working fluid disposed within said housing (14).

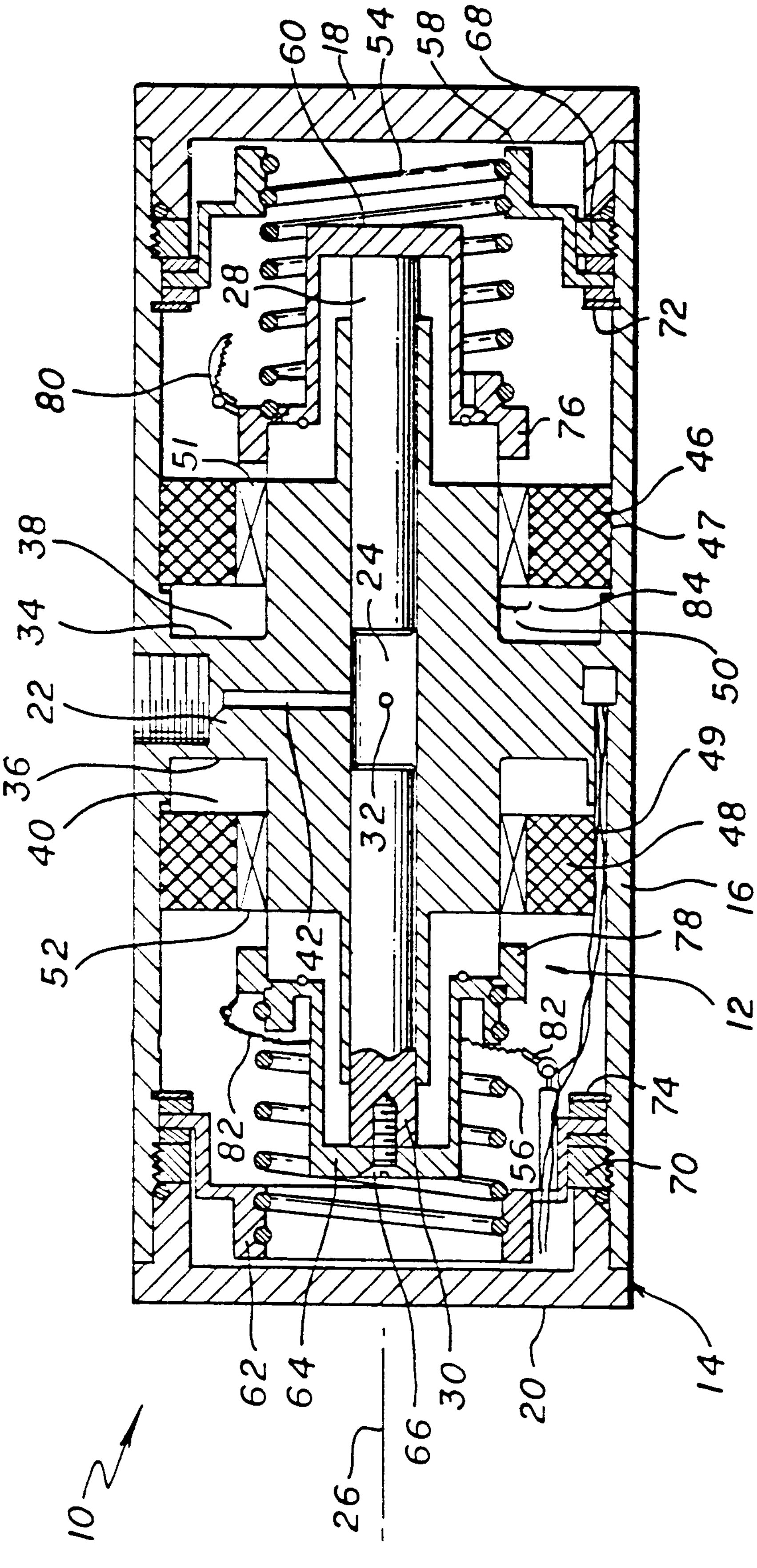
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FIG. 1

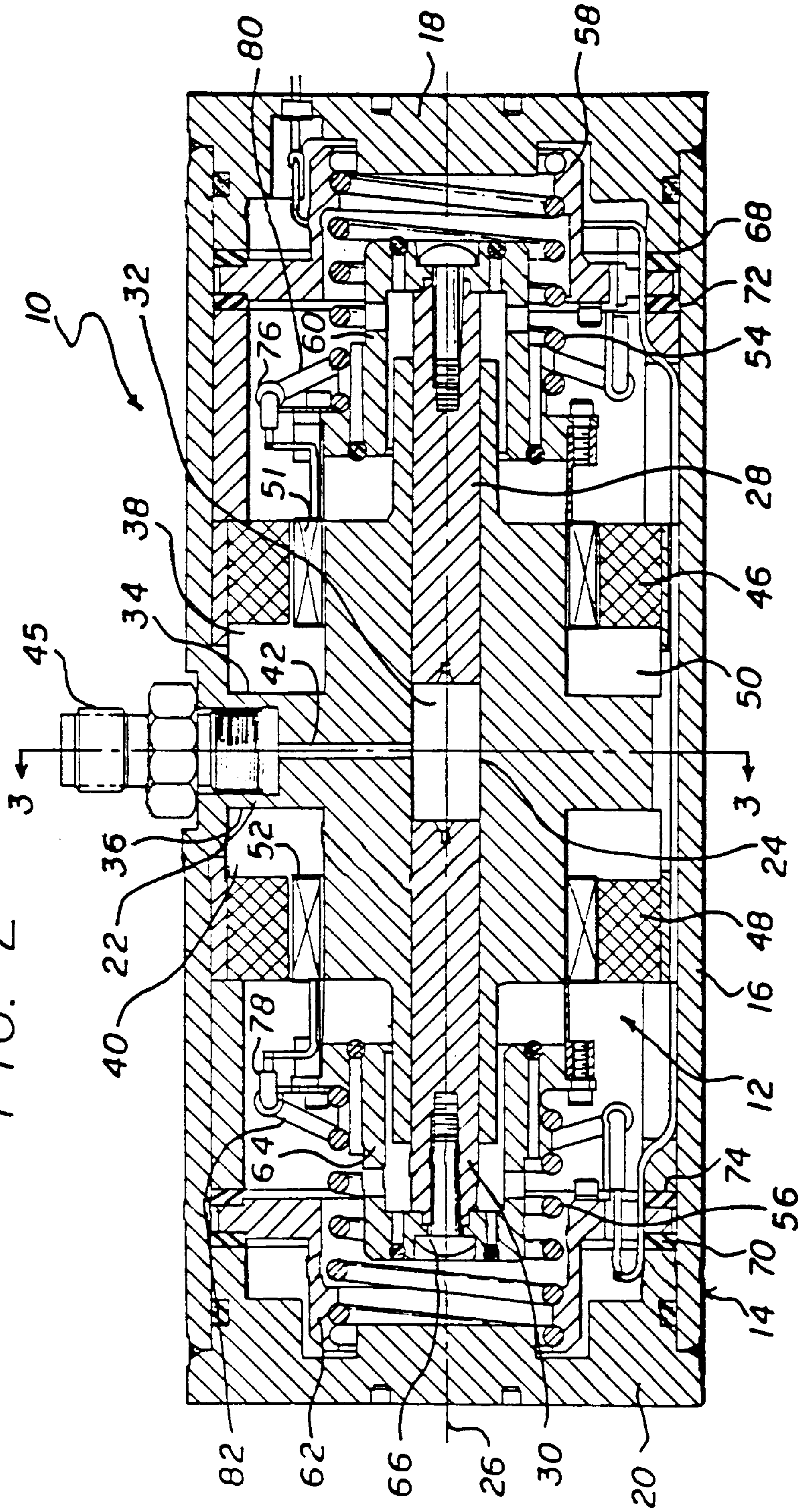
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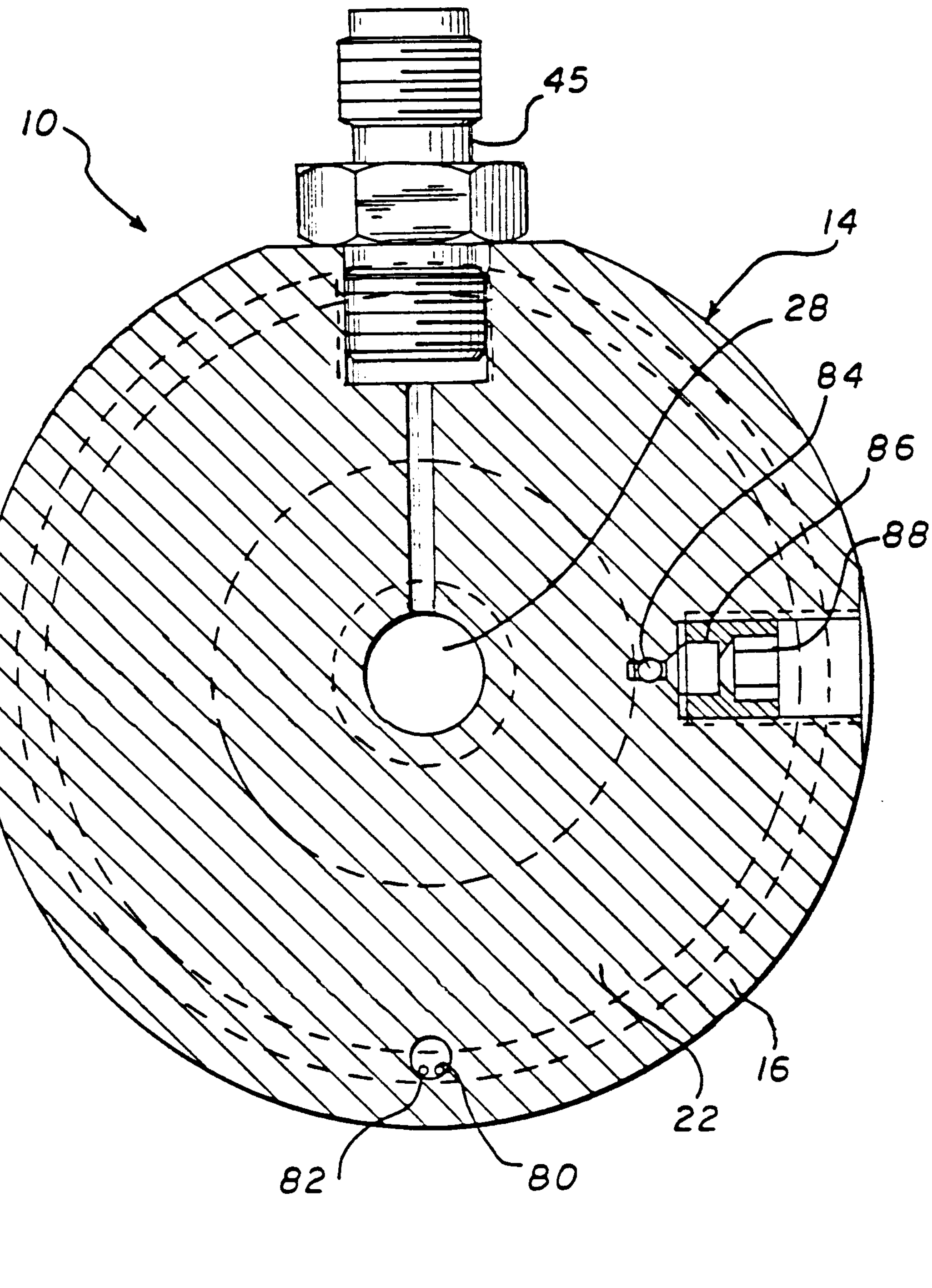
FIG. 2

FIG. 3



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EUROPEAN SEARCH REPORT

Application Number

EP 92 10 0178

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
Y	FR-A-1 258 407 (SOCIETE ANONYME DES USINES CHAUSSON) * the whole document * ---	1-6	H01F7/16 F04B35/04 F04B3/00
Y	US-A-2 054 097 (REPLOGLE) * page 1, line 34 - page 2, line 64; figure 1 * -----	1-6	

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

H01F
F04B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	23 APRIL 1992	MARTI ALMEDA R.

CATEGORY OF CITED DOCUMENTS

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