

Dec. 7, 1971

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3,625,015

ROTARY-VALVED CRYOGENIC APPARATUS

Filed April 2, 1970

4 Sheets-Sheet 1

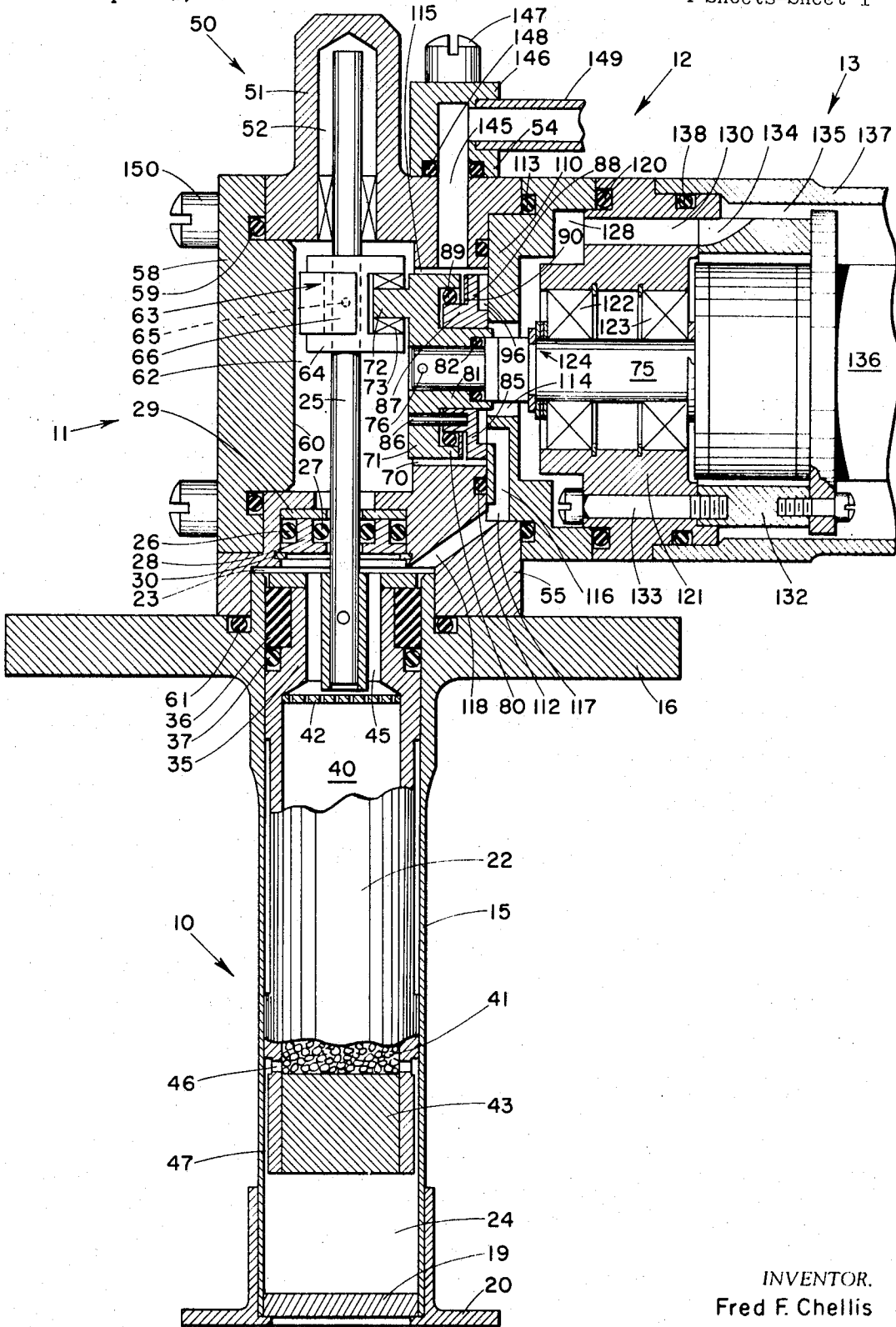


Fig. 1

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4 Sheets-Sheet 2

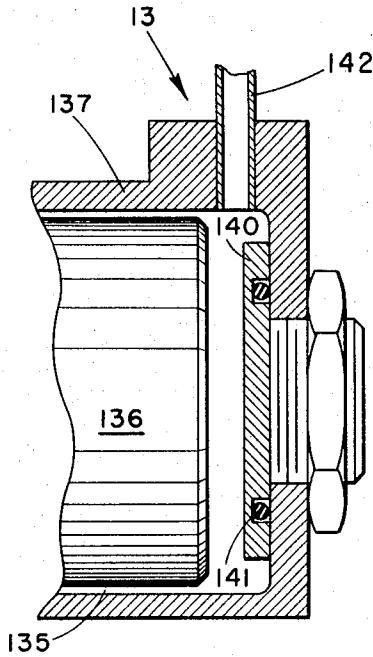


Fig. 2

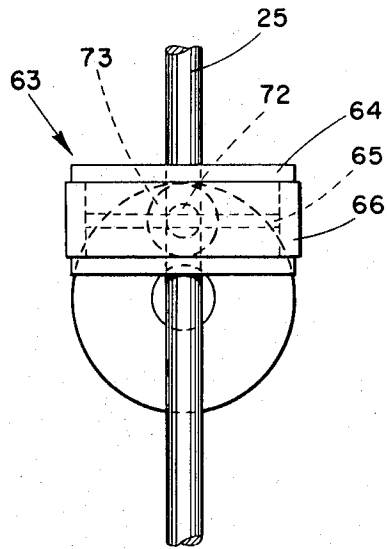


Fig. 3

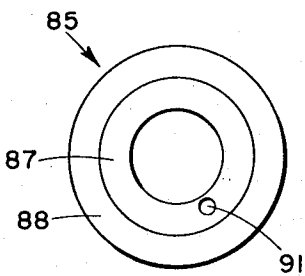


Fig. 5

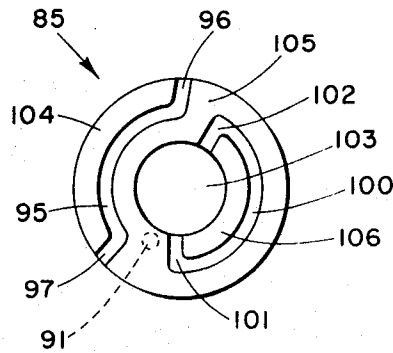


Fig. 6

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4 Sheets-Sheet 3

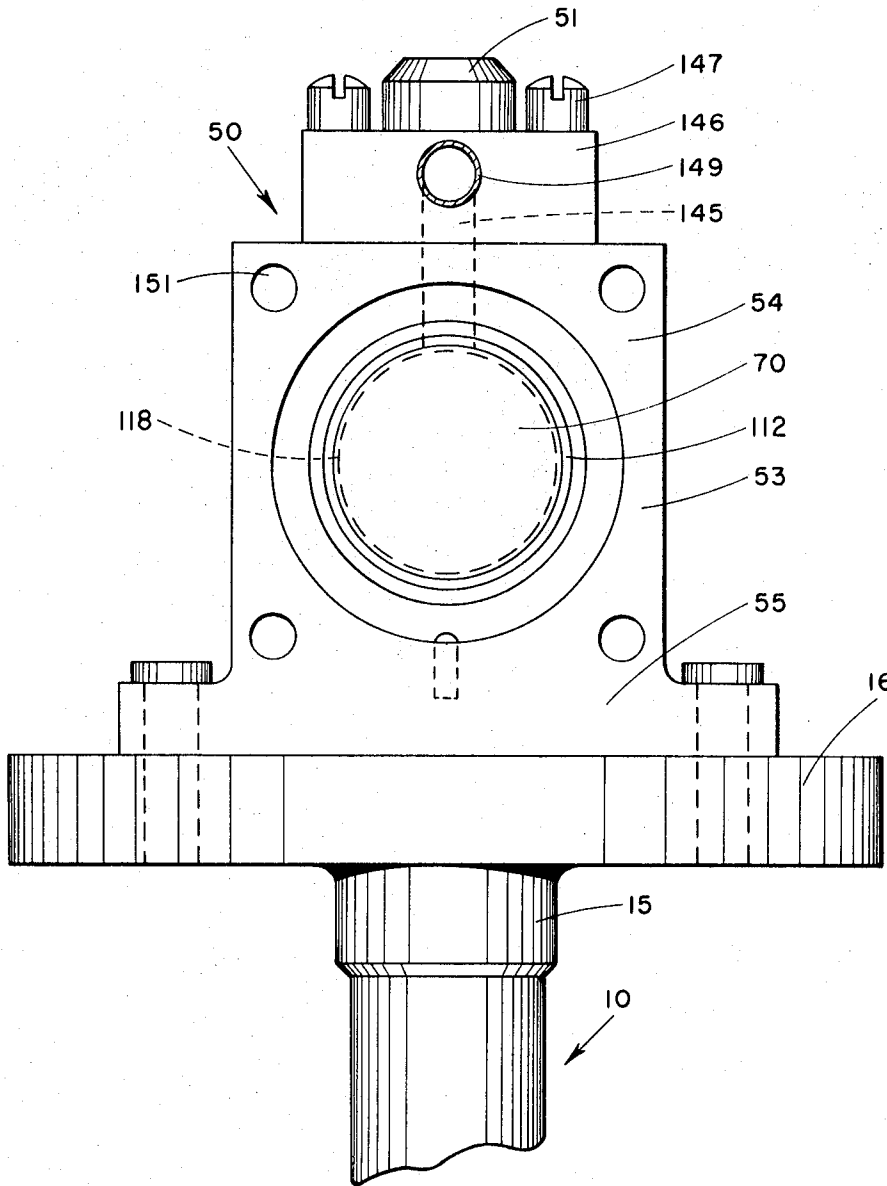


Fig. 4

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4 Sheets-Sheet 4

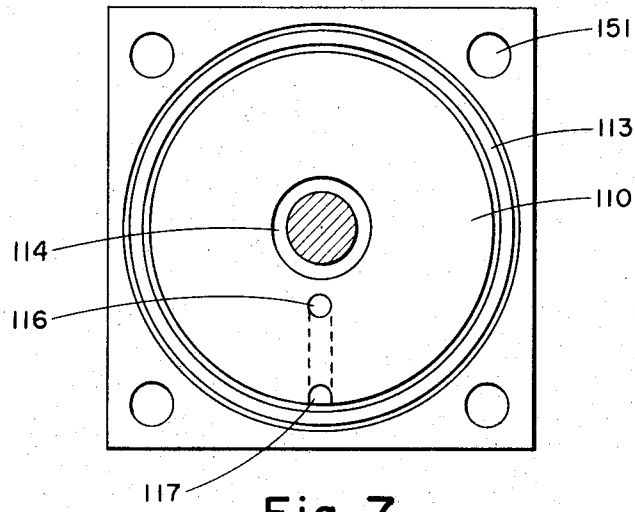


Fig. 7

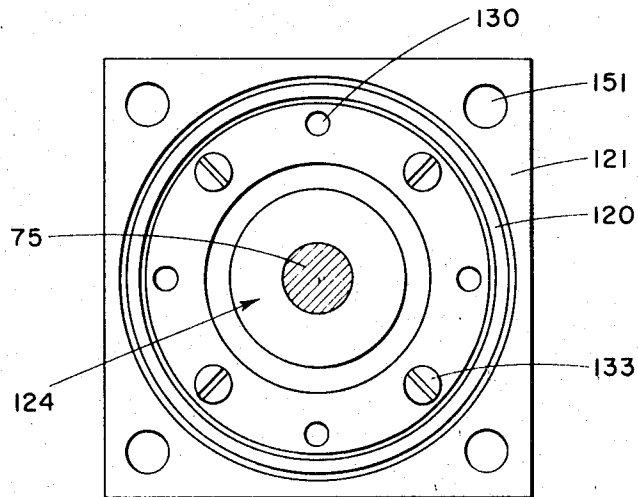


Fig. 8

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3,625,015

**ROTARY-VALVED CRYOGENIC APPARATUS**  
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U.S. Cl. 62-6

9 Claims

## ABSTRACT OF THE DISCLOSURE

Cryogenic refrigerator of liquefier operating on the cycle of U.S. Pat. 2,966,035. Flow of high-pressure fluid into and withdrawal of low-pressure fluid from the apparatus is controlled by a rotary valve which is readily installed and interchanged, if desired, to alter the timing of the cycle. No valve adjustments are required after assembly of the apparatus.

This invention relates to cryogenic apparatus and more particularly to apparatus suitable for performing the refrigeration cycle described in United States Pat. 2,966,035.

The refrigeration cycle of United States Pat. 2,966,035 requires that a high-pressure fluid be introduced into a "warm" chamber of variable volume to flow along a heat storage path into at least one "cold" expansion chamber of variable volume, that the volumes of these chambers be varied by the movement of a displacer and that the fluid be discharged as low-pressure fluid into a low-pressure fluid reservoir, e.g., the inlet of a compressor. The control of fluid flow and movement of the displacer must be continuously and accurately timed, and the action of the valves controlling the fluid flow must be perfectly coordinated with the mechanical driving means associated with the displacer.

A number of different types of valves have been used in connection with various displacer driving means for apparatus designed to operate on the so-called "no-work" cycle of United States Pat. 2,966,035. These valves include those of the poppet types as well as those designed for pneumatically driven apparatus (see for example U.S. Pat. 3,119,237, 3,188,821). Those valves designed for operation of a mechanically-driven apparatus require expensive machining operations to make them, as well as long and tedious timing adjustments once they are installed. Moreover, once installed and adjusted it is impractical to change their timing sequence and the apparatus in which they are installed must normally continue to operate on a fixed timing. Although a fixed timing sequence is acceptable in many apparatus uses, it is desirable sometimes to be able, for example, to alter the time over which high-pressure fluid is introduced, or the time period over which any initial expansion cooling is achieved entirely within the refrigerator before final expansion cooling is accomplished by discharging the fluid in the refrigerator into the low-pressure reservoir.

Likewise, the valving of pneumatically-driven apparatus is complicated, expensive to construct, adjust and time, and it is generally impractical to change the valving system to accommodate a desired change in timing sequence. The apparatus of this invention is, however, not concerned with a pneumatically-driven device; but is concerned with a mechanically-driven "no-work" refrigeration apparatus which overcomes some of the difficulties associated with valve design, construction and adjustment associated with previous "no-work" apparatus no matter how driven, and provides more flexible equipment with respect to the timing of the cycle operation.

It is, therefore, a primary object of this invention to provide a rotary-valved, mechanically-driven cryogenic apparatus which uses a relatively simple valve mechanism, inexpensive to manufacture and requiring no adjustments

after assembly. It is another object to provide cryogenic apparatus of the character described in which the valving mechanism is readily interchangeable, the interchangeable parts being of a character which permits the ready altering of the timing sequence of the cycle. It is therefore another primary object of this invention to provide a more flexible cryogenic apparatus than has heretofore been available. Other objects of the invention will in part be obvious and will in part be apparent hereinafter.

The invention accordingly comprises the features of construction, combinations of elements, and arrangements of parts which will be exemplified in the constructions hereinafter set forth, and the scope of the invention will be indicated in the claims.

For a fuller understanding of the nature and objects of the invention reference should be had to the following detailed description taken in connection with the accompanying drawings in which

FIG. 1 is a detailed longitudinal cross section through the refrigerator, the driving mechanism and the valving mechanism;

FIG. 2 is a cross section of the end of the motor housing which is an extension of FIG. 1 and which shows the completion of the low-pressure fluid flow path;

FIG. 3 is a side view of the mechanical driving means associated with the displacer shaft;

FIG. 4 is a plan view of the reverse surface of the crank shaft housing which mates with the rotary valve means;

FIG. 5 is a plan view of the obverse surface of the rotary valve member which is positioned within the crank case;

FIG. 6 is a plan view of the reverse surface of the rotary valve member which defines the fluid passages and seals with the valve plate;

FIG. 7 is the plan view of the obverse surface of the valve plate member which forms the fluid passages and seals with the reverse valve surface of FIG. 6; and

FIG. 8 is a plan view of the obverse surface of the main shaft support ring which forms fluid passages with the valve plate member.

The apparatus of this invention is illustrated in detailed cross sections in FIGS. 1 and 2, FIG. 2 being a continuation of FIG. 1. In describing this apparatus it will be convenient to consider it as comprising the refrigerator assembly 10, the mechanical driving means 11, the rotary valve assembly 12 and the motor and associated housing means 13. The term "refrigerator" is used hereinafter in a generic sense and is meant to also include a liquefier.

The refrigerator assembly 10 comprises an enclosure housing 15 which is integral with an upper flanged member 16 which in turn provides the means by which the refrigerator assembly 10 is joined to the mechanical driving means as described later. The refrigerator housing is closed on the lower colder end by a relatively thick end plate 19. A heat station in the form of a flanged tubular member 20 is bonded to the housing wall and is in heat exchange relationship with the cold fluid within the refrigerator. The end plate 19 and heat station 20 are formed of a metal, e.g., copper, which exhibits good thermal conductivity at the cryogenic temperatures encountered.

A displacer 22 moves within the housing to define an upper warm chamber 23 of variable volume and a lower cold expansion chamber 24 of variable volume. The displacer is affixed to a displacer shaft 25 and a fluid sealing means is provided to form a fluid-tight seal around shaft 25 to isolate chamber 23 from the fluid volumes within the crankcase housing. This sealing means, located within the lower portion of the crankcase, comprises concentric elastomeric O-rings 26 and 27, ring retaining members 28 and 29 and a snap ring 30.

It is, of course, within the scope of this invention to use a multistaged refrigerator such as that disclosed in U.S.P. 3,218,815 as well as that disclosed in copending applications Ser. No. 867,661 filed in the name of James A. O'Neil and Ser. No. 10,228 filed in the name of Walter H. Bamberg, all assigned to the same assignee as this application.

It will be appreciated that in this description of the refrigerator assembly the descriptive words "upper," "lower," "warm," "cold," and the like, are employed for convenience and are relative only. It is to be understood that the apparatus may be employed in any orientation and that the position shown in the drawings is only for convenience in presenting this description.

A fluid seal is formed between the upper section 35 of the displacer and the inner surface of the refrigerator housing 15 by an O-ring 37, and a split annular ring 36 is used as a guiding means.

Within the displacer is a regenerator 40 which contains a suitable heat storage means, such for example as lead balls 41. The upper end of the regenerator 40 is defined by a foraminous plate 42 and the lower end by a displacer end plug 43. Communication between the warm chamber 23 and cold chamber 24 is through fluid passages 45 in the upper section of the displacer, the regenerator 40, a series of radial passages 46 and an annular passage 47 defined between the lower displacer wall and the inner housing wall.

The mechanical driving means to impart reciprocal motion to the displacer is a scotch yoke (FIGS. 1 and 3) and it is housed within a fluid-tight crankcase generally indicated by the reference numeral 50. This main crankcase housing has an upper extended section 51, which defines volume 52 therein, and a face member 53 which for convenience of referencing may be divided into an upper portion 54 and a lower portion 55. These portions are, of course, one integral member as shown in FIG. 4. A crankcase cover 58 is sealed to the main crankcase housing by an elastomeric O-ring seal 59, and internal wall 60 of the crankcase cover is a hardcoated surface. The crankcase is sealed to the upper flanged member 16 of the refrigerator by O-ring seal 61 and it defines an internal volume 62 in which the scotch yoke mechanism 63 for driving displacer 22 is located. This scotch yoke mechanism 63 comprises a scotch yoke 64 affixed to shaft 25 through yoke pin 65 and a yoke guide 66 which slips onto yoke 64 to retain yoke pin 65 in place and to act as an antirotation element by rubbing against the hard-coated internal surface 60 of the crankcase cover. Extending through the central opening 70 of the crankcase (FIG. 4) is the scotch yoke driving means which comprises a scotch yoke overhand crank 71, crank pin 72 and bearing 73. This scotch yoke driving means is mechanically linked to main drive shaft 75 through pin 76.

The scotch yoke overhand crank 71 is configured to define on its reverse surface an outer annular ring extension 80 and an inner ring extension 81. (In describing the various components which are assembled to form the driving and valving means, that surface of the component which faces toward the crankcase will, for convenience, be designated the "obverse" surface while that which faces away from the crankcase will be designated the "reverse" surface.) Inner annular ring extension 81 has an internal recess adapted to contain an O-ring 82 to provide a fluid seal with the surface of main drive shaft 75.

The rotary valve 85, in the form of a ring molded from a synthetic resin such as a filled polytetrafluorethylene, is linked to the scotch yoke crank 71 through a pin 86 and thus it is connected for rotation by main drive shaft 75. The obverse surface of the rotary valve is shown in plan view in FIG. 5. It will be seen to be molded to have an inner raised annular ring section 87 and an outer, lower

annular ring section 88, the former forming with outer annular extension 80 of the overhang crank a recess in which is positioned an O-ring seal 89 and the latter being spaced from the overhang crank member by a wavy spring 90. A pin hole 91 extends into ring 85 and is adapted to receive pin 86.

The reverse side of the rotary valve is shown in plan view in FIG. 6. It will be seen that this reverse surface is molded to define a high-pressure fluid passage 95, having fluid connections 96 and 97 with the periphery of the valve which is continuously exposed to high-pressure fluid as explained below; low-pressure passage 100, having fluid connections 101 and 102 with the central ring opening 103; lands 104 and 106; and a sealing surface 105 which forms a fluid-tight seal with the obverse surface of valve plate 110 to isolate the high-pressure and low-pressure passages.

The obverse side of valve plate 110, which makes sealing contact with the sealing surface of the reverse surface of the rotary valve, is shown in plan view in FIG. 7. It will be seen from FIGS. 1 and 7 that the valve plate is configured in a manner to complement and fit the reverse surface of crankcase face 53 and that the fluid sealing of these parts is accomplished by O-rings 112 and 113. The central opening in the valve plate is of sufficient diameter to define an annular passage 114 around the periphery of the main drive shaft 75; and the peripheries of the overhang crank 71 and rotary valve 85 form an annular fluid channel 115 with the internal wall of central opening 70 of the crankcase face. A right-angled fluid passage 116 is drilled in the valve plate to terminate in an opening 117 which is aligned and in fluid communication with an angled passage 118 drilled through the bottom portion 55 of the crankcase face. Passage 118 opens into the warm chamber 23 of the refrigerator. The combination of right angled passage 116, opening 117 and angled passage 118 provide fluid communication alternatively with high-pressure and low-pressure passages of the rotary valve as it is rotated.

The reverse side of the valve plate is seen in FIG. 1 to take the form of a series of integral stepped annular rings. The valve plate is sealed, through O-ring 120 to a main shaft support member 121 which contains shaft bearings 122 and 123 and which is held to the shaft by a snap ring and washer system generally indicated at 124. The main shaft support member has an obverse face which generally conforms to the reverse face of the valve plate and which is spaced apart from it to define a low-pressure fluid passage 128 which communicates with a plurality of passages 130 drilled through the main shaft support which in turn is affixed to a motor extension ring 132 through a plurality of screws 133. The motor extension ring 132 has a plurality of fluid passages 134 which are aligned with passages 130 and flared outwardly to open into a fluid passage 135 defined between the outer casing wall 136 of the motor and the internal wall of motor housing 137. This flow path for the cold exhaust fluid is designed to conduct the discharged low-pressure fluid around the motor as a coolant. The motor housing 137 is sealed to the shaft support member 121 through O-ring 138 and is closed at the end with a sealing plate 140 and O-ring seal 141 (FIG. 2). The low-pressure fluid is withdrawn from motor housing through a conduit 142 which is connected to a low-pressure reservoir, e.g., the inlet of a compressor (not shown).

High-pressure fluid from a suitable source, e.g., a compressor is brought into the apparatus through the high-pressure fluid inlet passage 145 which is located partly in the upper section 54 of the crankcase face section and partly in a fluid conduit block 146 fastened to the crankcase through screws 147 and sealed by an O-ring 148. An external fluid conduit 149 connects pas-

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sage 145 with the high-pressure fluid source, e.g., a compressor (not shown).

It will be obvious that the entire apparatus is readily assembled by fitting the component pieces together and fastening them in fluid-tight relationship by a series of screws 150 which extend from the outer side of the crankcase cover, through the aligned openings 151 such as those shown in the plan views of FIGS. 4, 7 and 8 to threaded holes provided in motor housing 137. Each component part is so configured that it can only be mated with adjacent parts in the correct alignment.

It is now possible to trace the fluid flow within the refrigerator as it is controlled by the coordinated rotation of the rotary valve and movement of the displacer. It may be assumed to begin a cycle that the displacer is in its lowermost position. At this point, the rotary valve is positioned to provide fluid communication between the high-pressure fluid passage of the rotary valve and the warm chamber 23 by way of passage 116, opening 117 and passage 118. Since there is a continuous supply of high-pressure fluid being delivered by way of external fluid conduit 149 through high-pressure inlet passage 145 to the annular passage 115 defined between the wall of the crankcase central opening 70 (FIG. 4) and the peripheries of overhang crank 71 and rotary valve 85, a supply of high-pressure fluid will be continuously present around rotary valve 85 for passage through the high-pressure flow line formed of passages 95, 96 and 97 (FIG. 6). Thus high-pressure fluid is made available to warm chamber 23 as the displacer is moved upwardly. This high-pressure fluid is in turn transferred from chamber 23 through the internal flow path of the refrigerator (passages 45, regenerator 40, and passages 46 and 47) into expansion chamber 24 and is initially cooled by refrigeration stored in regenerator 40 derived from the preceding cycle.

In this apparatus the high-pressure volumes are isolated from the low-pressure volumes primarily by O-ring seal 89. It will be seen that volumes 52 and 62 are open to the high-pressure side and thus they contain high-pressure fluid throughout the operation of the apparatus.

It is generally desirable to time the flow of high-pressure fluid into the refrigerator so that it is cut off prior to that point in the cycle when the displacer reaches its uppermost position. This cutoff time is controlled by the design of the reverse side configuration (FIG. 6) of the rotary valve. With the completion of any fluid expansion which is to be accomplished in chamber 24, the internal volume of the refrigerator is opened to the low-pressure reservoir (inlet of a compressor) for final expansion and cooling of the fluid. During that portion of the cycle when fluid is discharged the displacer is driven downwardly and the valve is rotated to connect the low-pressure line in the valve (passages 100, 101 and 102, FIG. 6) with passages 116 and 117. The low-pressure fluid leaving the rotary valve passes through annular passage 114, passage 128, passages 130 and 134, annular motor cooling passage 135 and finally conduit 142 (FIG. 6) which returns it to a low-pressure reservoir. With the discharge of the low-pressure fluid from the refrigerator through this flow path, the cycle is ready to begin again.

It will be obvious to those skilled in the art that the fluid flow passages of rotary valve 85 may be varied to attain the desired timing for high-pressure fluid introduction and low-pressure fluid withdrawal. Thus to alter this timing for the refrigerator it is only necessary to change rotary valves. Moreover, once a rotary valve has been placed into position and locked to the overhang crank 71 by pin 86, no valve adjustments are required. Once a suitable mold is designed, the valves may be made at a relatively low cost since they do not require any machining.

It will thus be seen that the objects set forth above,

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among those made apparent from the preceding description, are efficiently attained and, since certain changes may be made in the above constructions without departing from the scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

I claim:

1. A rotary-valved, mechanically driven cryogenic apparatus, comprising in combination:

- (a) a fluid-tight enclosure defining a refrigerator;
- (b) displacer means movable within said refrigerator thereby to define a warm chamber of variable volume and at least one cold expansion chamber of variable volume;

(c) fluid control means adapted to control the sequential delivery of high-pressure fluid into and the exhausting of fluid from said refrigerator, said fluid control means comprising

- (1) a stationary valve plate having a fluid passage therein, said fluid passage being in fluid communication with the warm chamber of said refrigerator;

- (2) a rotary valve rotatable in surface contact with said valve plate thereby to define with said valve plate a high-pressure fluid passage and a low-pressure fluid passage, said passages being alternately in fluid communication with said fluid passage in said valve plate as said rotary valve is rotated;

(d) first fluid passage means adapted to deliver high-pressure fluid to said high-pressure fluid passage in said fluid control means;

(e) second fluid passage means adapted to receive expanded fluid from said low-pressure fluid passage in said fluid control means; and

(f) mechanical driving means arranged to rotate said rotary valve and to impart reciprocal motion to said displacer, the rotation of said rotary valve and the reciprocal motion of said displacer being so coordinated that high-pressure fluid is delivered to said refrigerator while said displacer is moved upwardly to a predetermined level and fluid is discharged from said refrigerator when said displacer reaches its uppermost position and while it travels downwardly to a predetermined level.

2. A cryogenic apparatus in accordance with claim 1 wherein said rotary valve is molded from a filled polytetrafluorethylene.

3. A cryogenic apparatus in accordance with claim 1 wherein said first fluid passage means comprises a high-pressure fluid inlet conduit and an annular fluid passage defined around the periphery of said rotary valve.

4. A cryogenic apparatus in accordance with claim 1 wherein said mechanical driving means comprises:

- (1) a motor,
- (2) a main drive shaft driven by said motor,
- (3) a displacer shaft,
- (4) means to convert rotary motion to reciprocal motion mechanically linking said main drive shaft and said displacer shaft, and
- (5) means to mechanically link said rotary valve to said main drive shaft.

5. A cryogenic apparatus in accordance with claim 4 including fluid-tight enclosure means in which said mechanical driving means are located.

6. A cryogenic apparatus in accordance with claim 5 wherein said second fluid passage means includes an annular fluid passage surrounding said motor, whereby said fluid exhausted from said refrigerator serves as a coolant for said motor.

7. A cryogenic apparatus in accordance with claim 4 wherein said means to convert rotary motion to reciprocal motion comprises an overhang crank linked to said main

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drive shaft and scotch yoke means rotatably affixed to said crank and linked to said displacer shaft.

8. A rotary-valved, mechanically driven cryogenic apparatus, comprising in combination:

- (a) a fluid-tight enclosure defining a refrigerator; 5
- (b) displacer means movable within said refrigerator thereby to define a warm chamber of variable volume and at least one cold expansion chamber of variable volume;
- (c) fluid control means adapted to control the sequential delivery of high-pressure fluid into and the exhausting of fluid from said refrigerator, said fluid control means comprising 10
  - (1) a stationary valve plate having a fluid passage therein, said fluid passage being in fluid communication with the warm chamber of said refrigerator, 15
  - (2) a rotary valve rotatable in surface contact with said valve plate thereby to define with said valve plate a high-pressure fluid passage and a low-pressure fluid passage, said passages being alternately in fluid communication with said fluid passage in said valve plate as said rotary valve is rotated; 20
- (d) first fluid passage means adapted to deliver high-pressure fluid to said high-pressure fluid passage in said fluid control means comprising a high-pressure fluid inlet conduit and an annular fluid passage defined around the periphery of said rotary valve; 25
- (e) mechanical driving means arranged to rotate said rotary valve and to impart reciprocal motion to said displacer comprising 30
  - (1) a motor,
  - (2) a main drive shaft driven by said motor,
  - (3) a displacer shaft,

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(4) means to convert rotary motion to reciprocal motion mechanically linking said main drive shaft and said displacer shaft, and

(5) means to mechanically link said rotary valve to said main drive shaft,

(6) fluid-tight enclosure means, the rotation of said rotary valve and the reciprocal motion of said displacer being so coordinated that high-pressure fluid is delivered to said refrigerator while said displacer is moved upwardly to a predetermined level and fluid is discharged from said refrigerator when said displacer reaches its uppermost position and while it travels downwardly to a predetermined level, and

(f) second fluid passage means adapted to receive expanded fluid from said low-pressure fluid passage in said fluid control means and conduct said expanded fluid to a low-pressure reservoir, said second fluid passage means including an annular fluid passage surrounding said motor, whereby said fluid exhausted from said refrigerator serves as a coolant for said motor.

9. A cryogenic apparatus in accordance with claim 8 wherein said means to convert rotary motion to reciprocal motion comprises an overhang crank linked to said main drive shaft and scotch yoke means rotatably affixed to said crank and linked to said displacer shaft.

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35 WILLIAM J. WYE, Primary Examiner