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HYDRAULICALLY DRIVEN CRYOGENIC REFRIGERATOR

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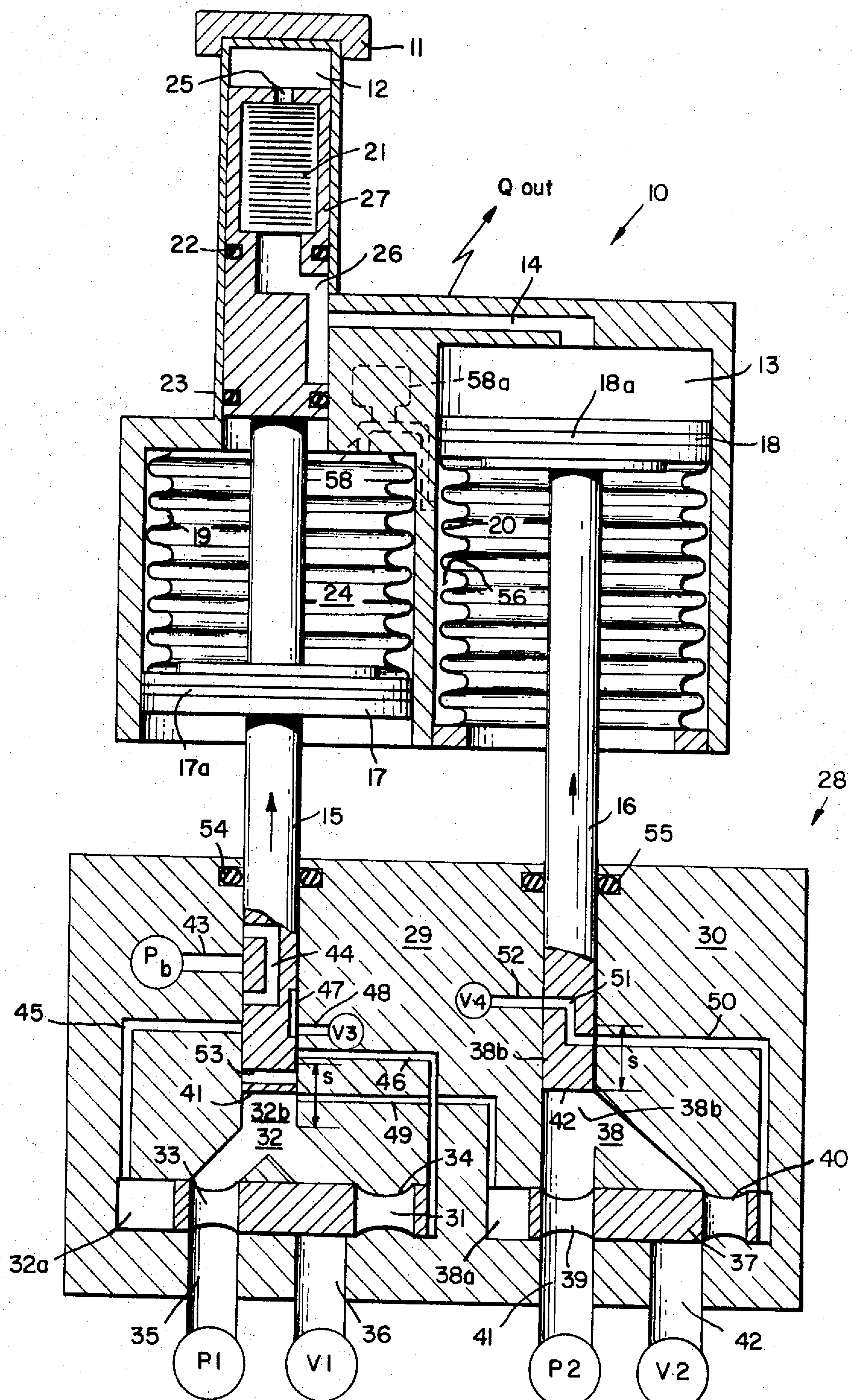

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HYDRAULICALLY DRIVEN CRYOGENIC REFRIGERATOR

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ABSTRACT OF THE DISCLOSURE

This disclosure specifically relates to an arrangement wherein cryogenic refrigerator expander and compressor pistons are actuated back and forth under the influence of refrigerant pressure and hydraulic pressure. Continuation of the refrigerant is avoided by providing bellows to hermetically seal the pistons within respective interconnected refrigerator subchambers. Each piston is controlled by a valve assembly having a two-position valve to allow refrigerant gas pressure to move the respective piston in a first direction when the valve is in a first position and to allow hydraulic pressure to move the respective piston in a second direction when the valve is in a second position. These valves are shifted between positions at appropriate times in the refrigeration cycle by hydraulic signals traveling through hydraulic passages including portions positioned within the pistons so that the pistons may reciprocate 90° out of phase.

This invention relates to a fluid drive unit for operating cryogenic refrigerators or other devices. The invention further relates to a hydraulic drive unit for reciprocating a plurality of pistons in phased synchonous relationship. More particularly, the invention relates to an arrangement wherein a hydraulic drive unit is utilized for reciprocating the pistons of a cryogenic refrigerator.

As is well known, cryogenic refrigerators utilizing the Stirling and other cycles, employ, in the transfer of a gas between a compression cylinder and an expansion cylinder, a regenerating device through which a compressible refrigerant gas is passed and which characteristically absorbs heat from the refrigerant as it moves to the expansion chamber, delivering gas thereto at a relatively low temperature. On the return phase of the cycle, the relatively cold refrigerant again passes through the regenerator, absorbing heat stored therein so that the refrigerant is delivered to the compression chamber at a realtively high temperature.

Cryogenic refrigerators of the prior art operating in this manner have conventionally employed electric motors producing a rotary motion and crank and rod mechanisms for converting the rotary motion into synchronously phased reciprocation of the compressor and expander pistons. Such an arrangement gives rise to problems. For example, this type of arrangement requires bearings and lubricants, and the lubricants tend to contaminate the refrigerant. More importantly, such arrangements are relatively noisy due to piston slapping, and side loads on the seals of the cryogenic refrigerator limit the useful life of the refrigerator. Further, and most significantly, the utility of such arrangements is somewhat restricted due to vibration thereof during operation. Operational vibrations are generally undesirable in mechanical devices and, with reference to cryogenic refrigerators which may be used in conjunction with vibration sensitive equipment or optical devices, such vibrations should be minimized as much as possible. Generally, when rotating mechanisms are used to drive a crank and rod arrangement, counter weights are rigidly placed on the crank in

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such a position as to reduce vibration. Also, it is common to dynamically balance the moving pistons of such prior art devices against vibration by operating two such devices, suitably arranged within a common housing, in opposed directions. In the first instance detrimental vibrations can not be completely avoided, while, in the second instance, detrimental vibrations can be completely avoided but at the expense of a duplicate mechanism.

It is, therefore, a primary object of the invention to provide a hydraulic drive unit for a plurality of pistons.

It is another object of the invention to provide a hydraulic drive unit for a cryogenic refrigerator wherein hydraulic fluid pressure is operable to reciprocate an expander and compressor piston in phased synchronous relationship whereby relatively noise-free long-life operation is obtainable.

It is another object of the invention to provide a cryogenic refrigerator which, in operation, is capable of approximating a Stirling cycle.

It is another object of the invention to provide an arrangement wherein the refrigerant of a cryogenic refrigerator is permanently sealed to avoid contamination by lubricants.

It is another object of the invention to provide an arrangement for reciprocating the pistons of a cryogenic refrigerator which can be readily dynamically balanced, due to the elimination of the conventional crank and rod, by the provision of opposite stroking weights to essentially eliminate vibrations during operation thereof.

These and other objects are accomplished in accordance with the invention by operating an expander piston and a compressor piston in out-of-phase synchronous relationship. The pistons respectively reciprocate in an expander cylinder and a compressor cylinder which are interconnected and which contain a compressible refrigerant gas such as helium or the like under pressure. These pistons are moved back and forth in the respective chambers by refrigerant pressure and hydraulic pressure by controlled application of fliud pressure to the pistons by means of suitable hydraulic valving. The valving includes a two-position valve for each piston to allow refrigerant pressure to move the respective piston in a first direction when the valve is in a first position and to allow hydraulic pressure to move the respective piston in a second direction when the valve is in a second position. These valves are shifted between positions at appropriate times in the refrigeration cycle by hydraulic signals traveling through hydraulic passages including portions positioned within the pistons so that the pistons are caused to reciprocate 90° out of phase.

These and other features and advantages of the invention can be more clearly understood by reference to the following specification and the related drawing wherein a preferred embodiment incorporating the invention is shown. In the drawing certain parts are shown in cross section to facilitate an understanding of the invention.

Describing the arrangement in detail and directing attention to the figure, it will be seen that the cryogenic refrigerator **10** for cooling load **11** comprises a hermetically sealed chamber in a housing. Cooling load **11** may be any device such as an infrared detector or parametric amplifier which must be maintained at cryogenic temperatures. The housing chamber is comprised of an expander subchamber **12** and a compressor subchamber **13** interconnected by a passage **14**. The wall of refrigerator **10** in the vicinity of expander subchamber **12** is extremely thin to limit flow of heat by conduction to subchamber **12** thus increasing the efficiency of refrigerator **10**. Expander piston **15** and compressor piston **16** have respective piston heads or displacers **17** and **18**. Disposed within a peripheral groove within each piston head is an Oring and continuous annular Teflon rider, **17***a* and **18***a* respectively, which effectively serve as seals and which may not be necessary in a given embodiment. Obviously, a skilled workman can design the pistons, and so forth, so as to obtain various piston compression ratios as deemed expedient. Respective resilient members such as bellows **19** and **20** are welded or otherwise suitably attached to peripheral portions of piston heads **17** and **18**, and to the walls of the housing so as to hermetically seal cryogenic refrigerator **10**. The chamber of cryogenic refrigerator **10** is filled with a compressible refrigerant gas such as helium or the like under a relatively high pressure.

Expander piston **15** has conventional regenerator means **21**, such as a one stage regenerator, through which refrigerant gas may pass back and forth. Exemplarily, regenerator means **21** may comprise stacked stainless steel screens, glass beads, lead balls, or the like, which characteristically have a suitable thermal capacity characteristic and a relatively high surface area to volume ratio.

The expander piston **15** is provided with peripheral grooves in which O-rings **22** and **23** are disposed. These O-rings are operative to expand respective seals (not shown), such as Teflon riders, of generally annular configuration having an L-shaped cross section, against the wall of the piston cylinder to prevent or minimize leakage of refrigerant gas back and forth between expander subchamber **12** and expander bellow chamber **24**. Expander passages **25** and **26** provide communication between expander subchamber **12** and compressor subchamber **13** via regenerator **21** which is mounted within an enlarged chamber in the expander piston portion or displacer **27**. Passage **26** is so arranged as to provide the aforementioned communication regardless of the position of expander piston **15**.

In order to provide for synchronous reciprocation of pistons **15** and **16** a hydraulic drive unit **28** is provided. Unit **28** comprises hydraulic drive valve assemblies **29** and **30**. In valve assembly **29**, a movable valve spool **31** is disposed within portion **32***a* of hydraulic reservoir **32**. Spool **31** and portion **32***a* are complementarily shaped so that spool **31** is snugly fitted within portion **32***a*, and portion **32***a* is of sufficient length to allow spool **31** to slide back and forth therein. Portion **32***b* of reservoir **32** is dimensioned for a snug slide fit with the corresponding portion of piston **15**.

In the embodiment shown, spool **31** is cylindrical, but it may be of any suitable shape. Spool **31** has transverse spaced holes or openings **33** and **34** drilled therethrough and so located that when valve spool **31** is in a first position opening **33** is aligned with valve port **35** and when valve spool **31** is in a second position, opening **34** is aligned with valve port **36**. In lieu of openings **33** and **34** peripheral grooves may be cut into spool **31** to serve the same purpose.

In hydraulic valve assembly **30**, it can be seen that movable valve spool **37**, hydraulic reservoir **38**, reservoir portions **38***a* and **38***b*, spool openings **39** and **40**, and valve ports **41** and **42** are arranged in a fashion similar to the arrangement of the comparable elements of hydraulic valve assembly **29**. Hydraulic pump P_1 is connected to port **35** and hydraulic pump P_2 is connected to port **41**. Port **36** is connected to vent line V_1 and port **42** is connected to vent line V_2.

Hydraulic conduit means operably connect hydraulic pump P_b to valve spools **31** and **37** whereby these spools may be moved back and forth to control the application of hydraulic fluid pressure to the faces **41** and **42** of the respective expander piston **15** and compressor piston **16**. Hydraulic fluid passages **43**, **44**, **45**, **46**, **47** and **48** are arranged so that, when expander piston **15** is at the bottom of its stroke, fluid pressure from hydraulic pump P_b will actuate valve spool **31** to bring valve spool opening **33** into alignment with valve port **35**. Hydraulic fluid passages **49**, **50**, **51** and **52** are arranged so that, shortly after expander piston **15** has completed one half of its upward stroke, hydraulic pump P_1 will actuate valve spool **37** to align valve spool opening **39** with valve port **41**. Hydraulic fluid passages **46** and **53** are arranged so that, when expander piston **15** has completed its upward stroke, a hydraulic path is completed between hydraulic pump P_1 and vent line V_3 whereby valve spool **31** is actuated so as to bring valve spool opening **34** into alignment with valve port **36**. Hydraulic fluid passages **50** and **49** are arranged so that, when compressor piston **16** has reached the top of its upward stroke, a hydraulic fluid path is completed between hydraulic pump P_2 and vent line V_1 whereby valve spool **37** is actuated to bring valve spool opening **40** into alignment with valve port **42**. Finally, O-rings **54** and **55**, together with respective seals (not shown) of the same type as those used in conjunction with previously mentioned O-rings **22** and **23**, are respectively disposed in peripheral grooves adjacent respective pistons **15** and **16** and seal the housing of hydraulic unit **28** to prevent or minimize leakage of hydraulic fluid therefrom.

In operation, assuming pistons **15** and **16** are in the position shown, piston **15** has completed slightly more than half of its upward stroke, piston **15** being driven upward by the force of hydraulic pressure upon piston face **41** exerted by hydraulic pump P_1. At this time, piston face **41** has cleared passage **49** while passage **51** of piston **16** interconnects passages **50** and **52** whereby a hydraulic fluid path is completed between pump P_1 and vent line V_4 and valve spool **37** is moved to align opening **39** with valve port **41**. Hydraulic pressure for pump P_2 now exerts a hydraulic force upon piston face **42** to drive compressor piston **16** upwardly. Both pistons **15** and **16** now travel concurrently upward, with expander piston **15** leading compressor piston **16** by approximately 90°, thereby compressing the refrigerant gas in the cryogenic refrigerator **10** to decrease the volume and increase the pressure thereof. During this initial phase of the cycle the heat of compression which is generated is rejected to the ambient through the walls of the housing, as indicated by Q_{out}, so that this phase is relatively isothermal.

Expander piston **15** now reaches its top position whereupon hydraulic fluid passages **46**, **45**, **53** and **48** complete a hydraulic fluid path between pump P_1 and vent line V_3 thus shifting valve spool **31** to bring valve spool opening **34** into alignment with valve port **36**. The refrigerant gas pressure of the refrigerant gas in the interconnected subchambers **12** and **13** and in the bellow chambers **24** is now operative to push expander piston **15** downward expelling hydraulic fluid from hydraulic reservoir **32** through port **36** to vent line V_1. The extent to which the refrigerant gas in the bellow chamber **24** pushes the expander piston **15** downward in relation to the extent to which the refrigerant gas in the interconnected subchambers **12** and **13** pushes the expander piston **15** downward depends upon the design of the pistons **15** and **16**, and so forth, as indicated earlier herein.

During the initial portion of this downward stroke of expander piston **15**, compressor piston **16** continues upward and the arrangement preferably is such that the total volume of the refrigerator chamber remains substantially constant. During this second phase of the refrigeration cycle, wherein expander piston **15** is moving downward and compressor piston **16** is moving upward, refrigerant gas is transferred from compressor subchamber **13** to expander subchamber **12** through regenerator **21**. Regenerator **21** absorbs and temporarily stores heat from the refrigerant. In this way the temperature and pressure of the refrigerant is reduced.

When compessor piston **16** reaches the top of its stroke the third phase of the refrigeration cycle begins wherein hydraulic pump P_2 is operably connected to vent line V_1 via hydraulic passages **50** and **49** to move valve spool **37** to the position wherein valve spool opening **40** is aligned with valve port **42**. The refrigerant gas pressure of the refrigerant gas in the interconnected subchambers **12** and **13** then moves compressor piston **16** downward to expell hydraulic fluid from reservoir **38** into vent line V_2. During this third phase of the refrigeration cycle both pistons are moving downward so that the total volume of the refrigerator chamber is increasing. During this phase of the cycle the increasing volume within the chamber tends to decrease the refrigerant temperature. However, the refrigerant, at this time, absorbs heat from the walls of the housing thereby maintaining the refrigerant at a constant temperature which is lower than the refrigerant temperature during the initial or first-mentioned phase of the cycle. Thus, the thid phase is relatively isothermal.

Expander piston **15** now completes its downward stroke and a fluid path is completed, via passages **43–48**, between hydraulic pump P_b and vent line V_3 so that valve spool **31** is moved to bring valve spool opening **33** and valve port **35** into alignment. Hydraulic pressure from hydraulic pump P_1 now exerts a hydraulic force upon piston face **41** and expander piston **15** begins its upward stroke. Thus the final or fourth phase of the refrigeration cycle is initiated. During this final phase pistons **15** and **16** are again moving in opposite directions and preferably in such a fashion as to maintain the volume of the refrigerator chamber constant. The upward traveling expander piston **15** now transfers refrigerant gas from expander subchamber **12** to compressor subchamber **13** through regenerator **21**. During this final phase the refrigerant gas obtains heat from regenerator **21** which was previously stored therein. Thus a complete refrigeration cycle has been generated. If the total volume of the refrigerator chamber has been maintained substantially constant during the second and final phases then a Stirling cycle will have been approximated.

Exemplarily, the refrigerant gas may be under a pressure in the range of, for example, from 100 p.s.i.g. to about 300 p.s.i.g. during the refrigeration cycle. The forces exerted upon displacers **27**, **17**, and **18** and the force exerted on faces **41** and **42** respectively depends on pressure of the refrigerant gas or hydraulic fluid multiplied by the area of the parts **27**, **17**, **18**, **41** and **42**. Pistons **15** and **16** may be reciprocated at any rate, as for example 2000 cycles per minute, depending on the cooling capacity desired. The motion of pistons **15** and **16** may be sinusoidal or linear with time or otherwise. If it is desired to approximate a Stirling cycle, the motion and size of the pistons, and other parameters should be selected to obtain substantially constant volume conditions during the second and fourth phases of the refrigeration cycle.

The timing of the initiation of the compression strokes of pistons **15** and **16** clearly depend on the manner in which the fluid passages are arranged. It should be equally clear that, by the provision of suitable means, such as apertured sleeves, circumscribing the portions of pistons containing passages **44**, **47**, **53** and **51**, and rotatably positioned thereabout, either on the associated piston portion or on the associated bore, the choice of a multiplicity of timing relationships is possible.

The cooling load may be maintained at cryogenic temperatures in a range of 20° Kelvin and higher. The cooling capacity of cryogenic refrigerator **10** can be adjusted simply by throttling or changing the fluid pressure of hydraulic pump P_1 and P_2. Rejection of heat through the walls of the housing may be expedited by the provision of external means such as the forced conduction of air or liquid coolants and by the provision of heat radiating fins. The various hydraulic fluid passages may be arranged to obtain any desired synchronous phasing of the pistons **15** and **16**. Thus, it will be appreciated that, while the described operation of the cryogenic refrigerator generates the well-known Stirling cycle, it should be readily apparent that other cycles may be generated with equal facility.

Various other modifications and improvements to the above-described preferred embodiment of the invention may be made within the skill of the art. Thus, if desired, the volume displaced by the moving pistons **15** and **16** can be varied by changing the size of the displacers **27** and **18** and corresponding subchambers **12** and **13**. Regenerator means **21** need not be carried by expander piston **15** and may be stationarily disposed adjacent piston portion **27**. Also the embodiment may be modified by use of multiple stage regenerator means in lieu of the shown regenerator means. Where bellow fatigue is found to be a problem one may extend the walls of the housing and provide additional piston heads to reduce mechanical load thereon. An additional passage may be employed, as indicated by the dotted lines **58**, interconnecting the bellow chamber **24** to bellow chamber **56** to shunt a part of the refrigerant therethrough to reduce the mechanical load on bellows **19**. Additionally, a plenum volume, as indicated by dotted lines **58***a*, in communication with such passage **58**, may be provided to dampen pressure fluctuations in chambers **24** and **56**. Such damping naturally lessens the force contribution of refrigerant gas in bellows chamber **24** to the downward pushing of the piston **15** during the previously described second phase of the refrigeration cycle.

Additionally, drive unit **28** can be readily modified so that hydraulic fluid may be utilized to drive pistons **15** and **16** in both directions if better control of piston motion is deemed desirable. Thus, should spring loads, insufficient refrigerant gas pressure, or other factors, impose strict design limitations to achieve the desired performance, additional piston faces, fluid passages, valve ports, and valve spool openings may be provided to facilitate control of downward motion of pistons **15** and **16**. Exemplarily, the fluid required to drive the aforementioned additional piston faces can be controlled by valve spools **31** and **37**.

Accordingly, it should be understood that the invention as described is by way of illustration and not limitation and may be modified all within the scope of the appended claims.

What is claimed is:

1. In combination:

a plurality of fluid chargeable reservoirs each having fluid inlet and fluid outlet means;

a plurality of reciprocable elements each having a face positioned within a respective reservoir so that application of pressurized fluid thereto upon fluid charging of the respective reservoir is operative to move the associated element;

valve means for allowing alternate fluid charging and discharging of each of said reservoirs via said fluid inlet and fluid outlet means by a source of pressurized fluid;

biasing means for urging and moving each of said elements upon termination of the application of pressurized fluid to the associated face, said biasing means comprising an envelope defining an enclosed space containing a pressurized medium arranged so that a movable part of said envelope can exert a force upon each of said elements; and

element position sensing means associated with said elements for controlling the operation of said valve means to produce movement of each of said elements in timed relationship.

2. The combination set forth in claim **1** wherein said envelope is partially defined by resilient means connected to each of said elements.

3. The combination of claim **2** wherein each of said resilient means comprises bellows.

4. The combination of claim **1** further comprising structure defining an enclosed space containing compressible refrigerant and also containing heat regenerator means and where said elements are arranged so that movement of said elements is operable to produce refrigeration.

5. The combination of claim 4 further including a cooling load associated with said structure.

6. The combination of claim 1 wherein said valve means comprises movable valve spool means associated with each of said fluid inlet and fluid outlet means.

7. The combination of claim 6 wherein each of said valve spool means comprises a member having fluid conducting means positionable by movement of said valve spool means to allow the aforementioned alternate fluid charging and discharging of each of said reservoirs.

8. The combination of claim 6 wherein said sensing means includes fluid control lines including fluid passages formed in said elements and arranged to operatively provide various fluid flow paths between said valve spool means and an external source of pressurized fluid so that fluid flow through such paths is operative to move and position each respective valve spool means in a predetermined fashion.

9. The combination of claim 8 further including a refrigerating device and a cooling load associated therewith and wherein said fluid control line means are interconnected so as to produce synchronous reciprocation of said elements and wherein said elements comprise part of said device so that reciprocation of said elements is operable to transfer heat away from said cooling load.

10. In combination:

a plurality of fluid chargeable reservoirs each having fluid inlet and fluid outlet means;

a plurality of reciprocable elements each having a respective face positioned within a respective reservoir;

means coupled to said reservoirs for supplying pressurized fluid thereto in order to charge said reservoirs;

valve means for allowing alternate fluid charging and discharging of each reservoir;

said faces each being arranged so that application of pressurized fluid thereto upon fluid charging of the associated reservoir is operative to move the associated element in a first direction;

means for urging and moving each of said elements in a second direction opposite to said first direction upon the termination of the application of pressurized fluid to the face of each element comprising an enclosed space partially defined by respective parts of each element which space contains a pressurized medium which can exert a force upon each of said parts to move the associated element in the second direction; and

element position sensing means associated with said elements for controlling the operation of said valve means to produce reciprocal movement of each of said elements in timed relationship.

11. In a refrigerating system comprising a refrigerating device and a fluid actuator therefor, the combination of:

first and second chambers, a passage connecting said chambers, a regenerator associated with said first chamber, and refrigerant gas in said chambers;

third and fourth reservoir chambers each having an inlet and an outlet;

a first piston element arranged for reciprocation in said first and third chambers;

a second piston element arranged for reciprocation in said second and fourth chambers;

said first piston including a first displacer arranged in said first chamber and said second piston including a second displacer arranged in said second chamber for displacing, compressing, and expanding said refrigerant gas, said pistons each being arranged for separate reciprocation in respective forward and reverse directions of reciprocation;

first and second valve means respectively associated with said third and fourth chambers respectively for valve controlling the opening and closing of said inlets and outlets whereby fluid under pressure may

be allowed alternately to enter and exit the respective reservoir chambers to alternately move each element in said forward direction of reciprocation and enable each element to be moved in said reverse direction of reciprocation;

fluid actuator means operatively connected to both said valve means and controlled by said piston elements for effecting sequential opening and closing of said inlets and outlets by said respective valve means in such a way as to time the reciprocation of the respective elements; and

said refrigerant gas in said chambers being means for moving each said element in said opposite direction of reciprocation.

12. In a refrigeration system comprising a refrigerating device and fluid actuator therefor, the combination of:

first and second refrigerator chambers, a passage connecting said chambers, refrigerant gas under compression in said chambers, and a regenerator arranged for storing heat absorbed from said refrigerant gas and for releasing the stored heat to the refrigerant gas;

a third reservoir chamber having an inlet and an outlet and a fourth reservoir chamber having an inlet and an outlet;

a first reciprocable piston element disposed for reciprocation in both said first and third chambers and a second reciprocable piston element disposed for reciprocation in both said second and fourth chambers;

said piston elements each being further arranged to be separately reciprocable in respective forward and reverse directions so that reciprocation of said elements in synchronous, out-of-phase relation is effective to sequentially expand and compress said refrigerant gas while said regenerator by absorbing and releasing heat as aforesaid effects cooling in the vicinity of said first chamber;

supply means connected to each inlet for supplying fluid under pressure to each of said third and fourth chambers;

said piston elements being arranged so that fluid under pressure when supplied to said third and fourth chambers respectively acts to drive each piston element respectively in its forward direction by the exertion of fluid force against each piston element;

vent means connected to each outlet for venting the fluid from each of said third and fourth chambers;

first and second valves each positionable in first and second positions, said first valve in its first position being operative to open said inlet and in its second position being operative to open said outlet of said third chamber, said second valve in its first position being operative to open said inlet and in its second position being operative to open said outlet of said fourth chamber, the positioning of said valves effecting the supply and venting of the fluid to and from each of said reservoir chambers by the opening and closing of said inlets and outlets in a predetermined sequence;

valve actuator means for fluidically positioning each of said valves by sequentially supplying fluid under pressure to each one or the other of respective valve actuator ports arranged on opposite sides of each of the respective valves;

fluid paths means communicating with said valve actuator ports for defining a multiplicity of sequentially selectable fluid paths by which fluid under pressure is conveyable via certain selected fluid paths to the one or the other of said valve actuator ports on the opposite sides of the respective valves to fluidically move either of said valves from either one to the other one of its aforementioned first and second positions;

fluid path defining passages provided in said piston elements each being alignable with said reservoir ports of the aforementioned fluid path means upon reciprocation of said piston elements and being thus alignable during the reciprocation of said piston elements to effect the aforementioned sequential selection of certain ones of the aforesaid multiplicity of fluid paths at certain times during such reciprocation in order to move each of said valves respectively at certain times during such reciprocation from either one to the other one of its aforementioned first and second positions;

each piston element being arranged to further compress said refrigerant gas during movement in its forward direction which refrigerant gas drives each piston element in its reverse direction by the exerof refrigerant gas compression force against each piston element;

whereby reciprocation of said piston elements are driven as aforesaid by said fluid and pressure forces during the operation of the refrigerating system.

13. In a refrigerating system including a refrigerating device and fluid actuator therfor, the combination comprising:

first and second interconected refrigerator chambers containing compressible refrigerant under pressure therein;

third and fourth reservoir chambers for fluid each having an inlet and an outlet;

a first piston element extending between said first and third chambers including a first displacer disposed in said first chamber and a first face disposed in said said third chamber;

a second piston element extending between said second and fourth chambers and including a second displacer disposed in said second chamber and a second face disposed in said fourth chamber;

fluid supply means arranged for supplying fluid under pressure to each of said third and fourth chambers via the inlets thereof, the fluid under pressure being supplied to said third and fourth chambers in order to push the faces of said pistons in order to move the associated piston element in a first direction of reciprocation;

first and second valves respectively pistionable in either of two positions and each being independent of said piston elements, each valve being positionable to either permit entry of fluid into different ones of said reservoir chambers via the inlets thereof or to permit the exhaust of such fluid from such chamber via the outlets thereof;

fluid control means for sequentially positioning said valves and controlled by the said piston elements in order to time the reciprocation of said piston elements, and

said valves and piston elements being arranged so that said refrigerant is operative to produce movement of each piston in a second direction of reciprocation.

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WILLIAM J. WYE, Primary Examiner

U.S. Cl. X.R.

91—191, 193; 60—24

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,530,681 Dated September 29, 1970

Inventor(s) AXEL G. DEHNE

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 16, delete the word "Continuation" and insert instead --Contamination--.

Column 9, line 16, delete "exer-" and insert instead the word --exertion--.

SIGNED AND
SEALED
JAN 19 1971

(SEAL)
Attest:

Edward M. Fletcher, Jr.
Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents