

Jan. 28, 1964

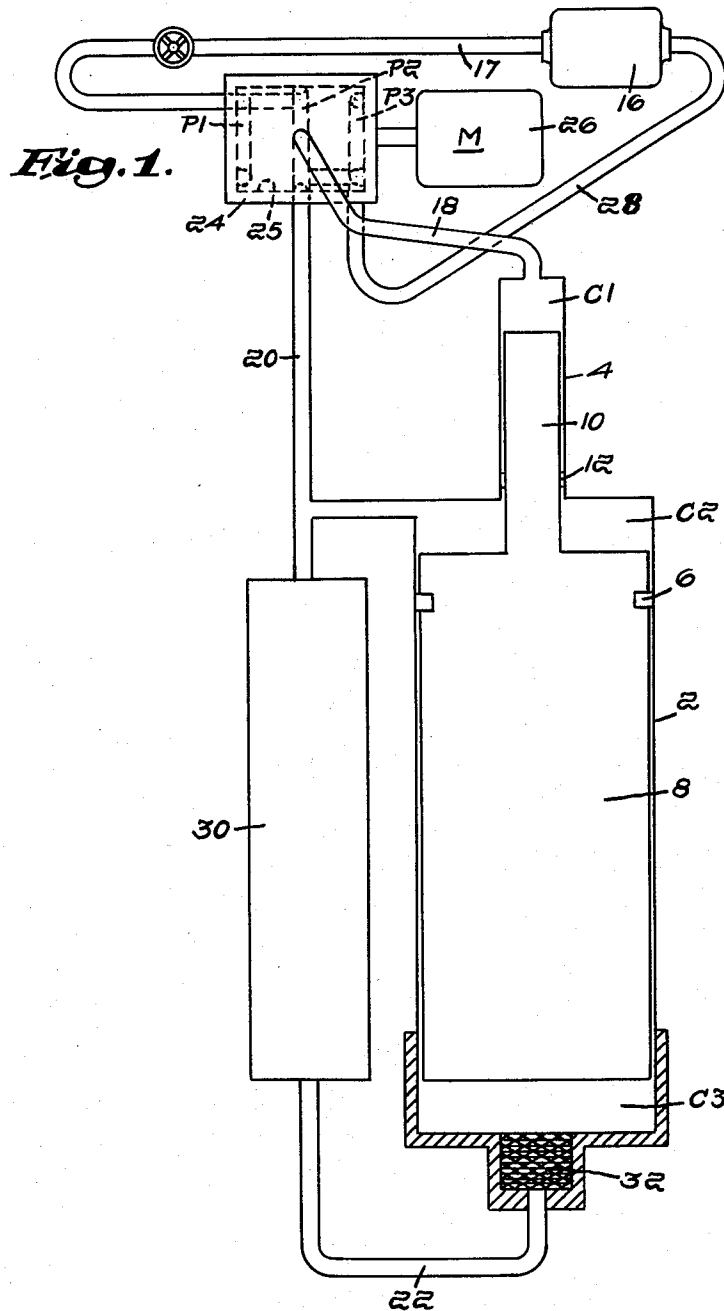
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3,119,237

GAS BALANCING REFRIGERATION METHOD

Filed March 30, 1962

5 Sheets-Sheet 1



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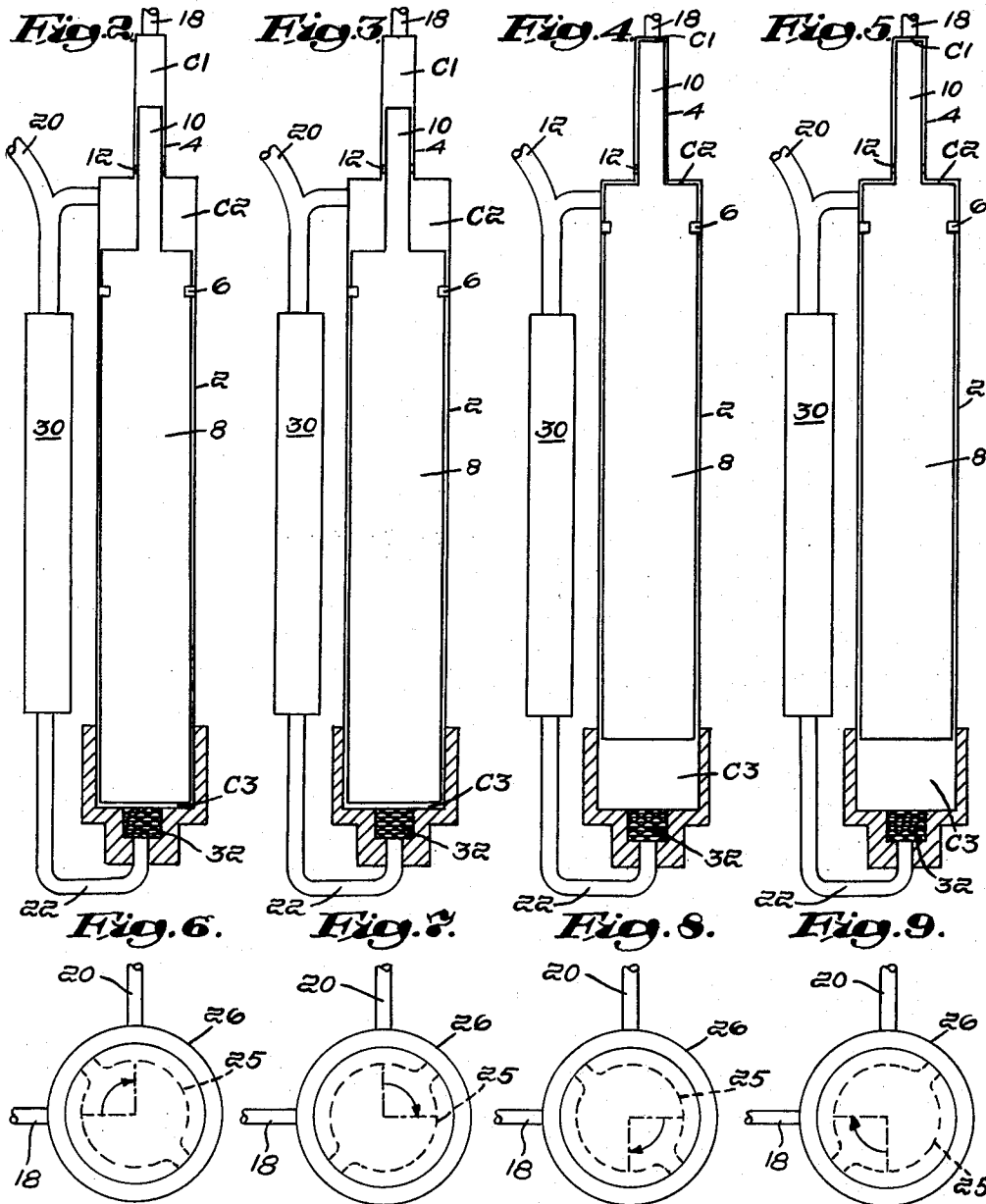
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GAS BALANCING REFRIGERATION METHOD

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5 Sheets-Sheet 2



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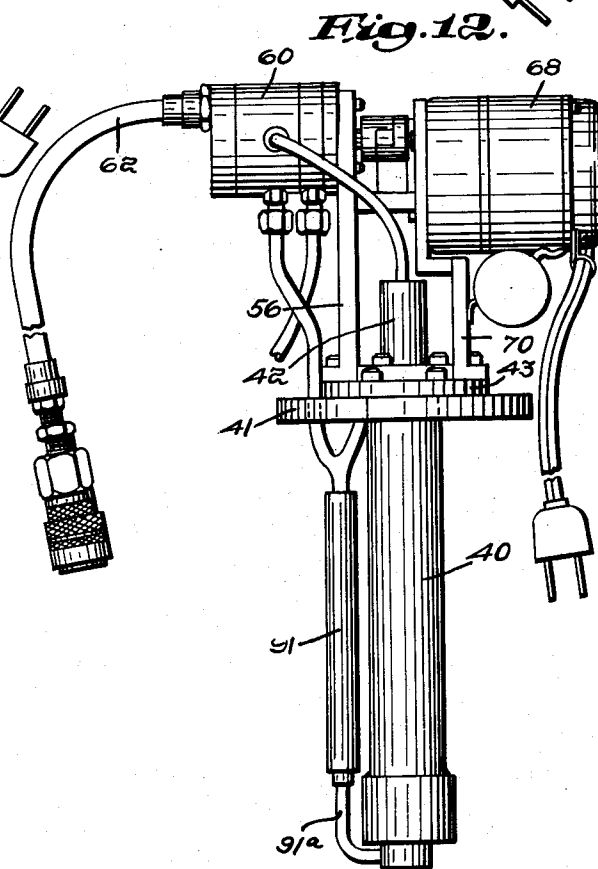
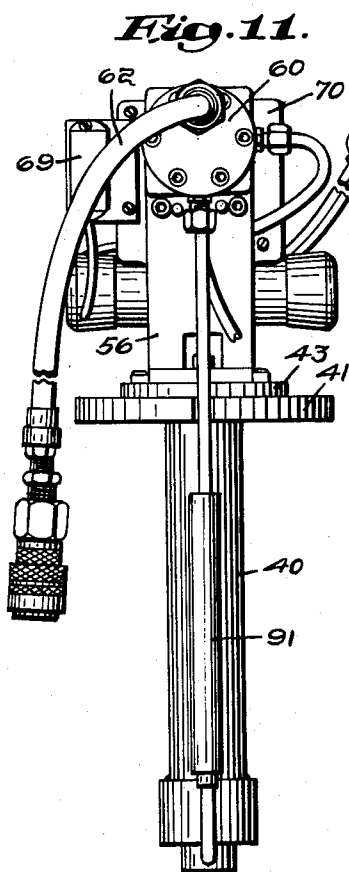
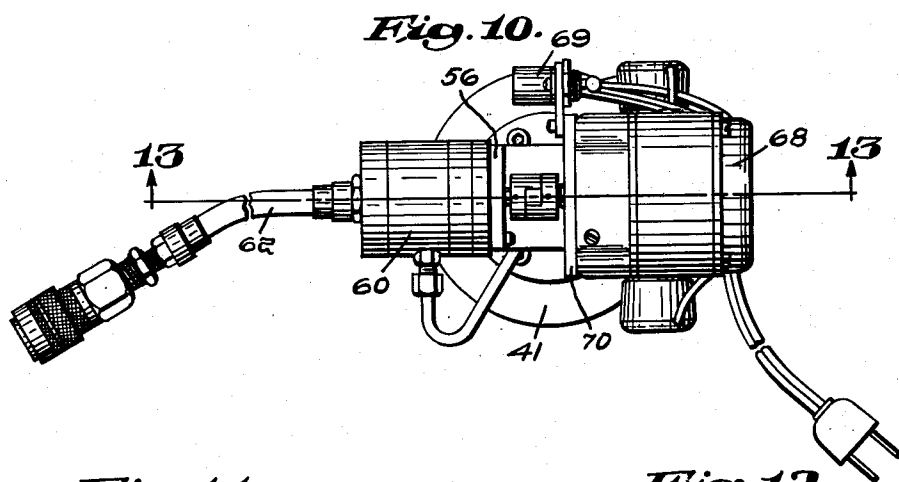
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GAS BALANCING REFRIGERATION METHOD

Filed March 30, 1962

5 Sheets-Sheet 3



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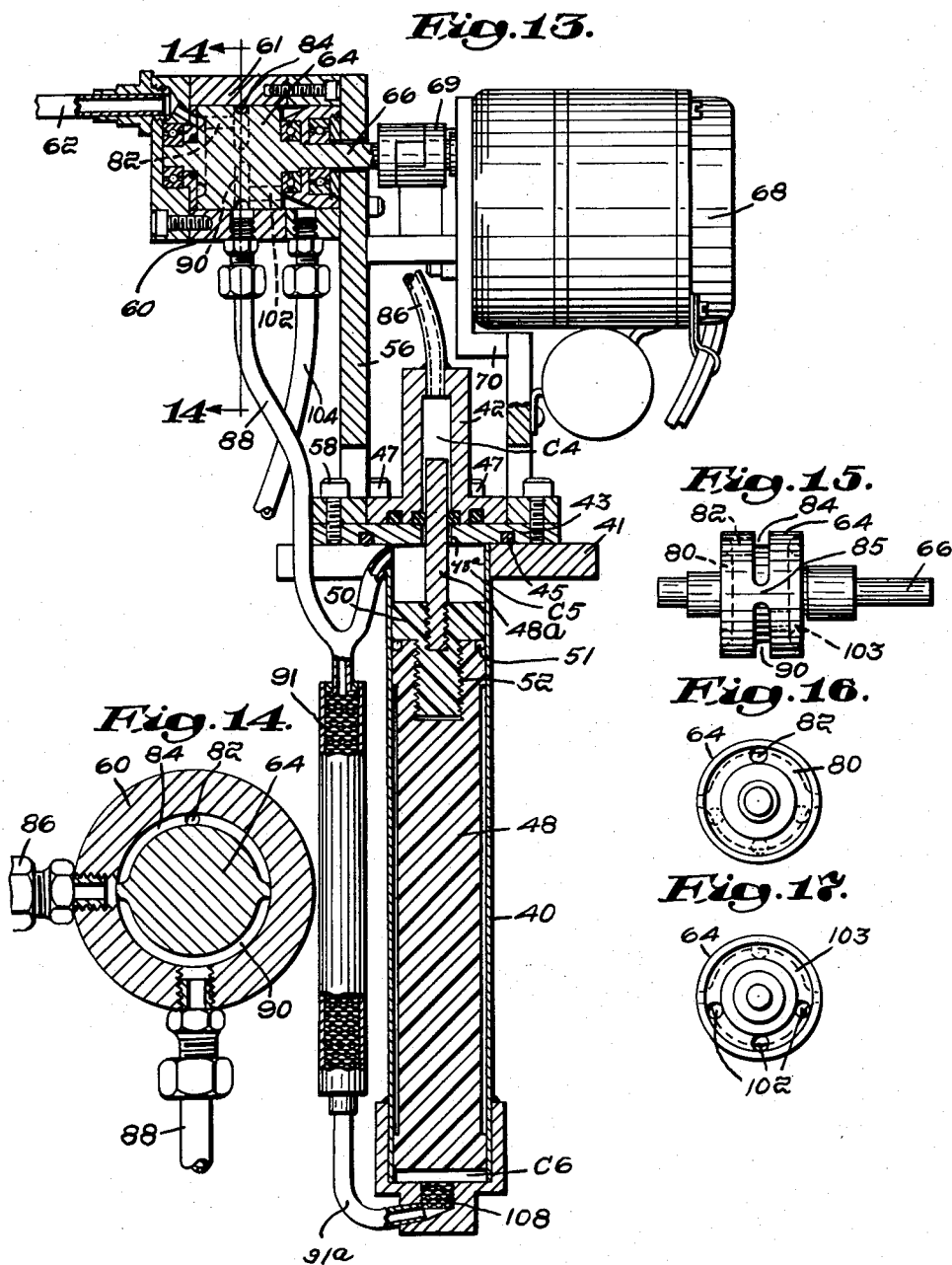
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GAS BALANCING REFRIGERATION METHOD

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5 Sheets-Sheet 4



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GAS BALANCING REFRIGERATION METHOD

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5 Sheets-Sheet 5

Fig. 18.

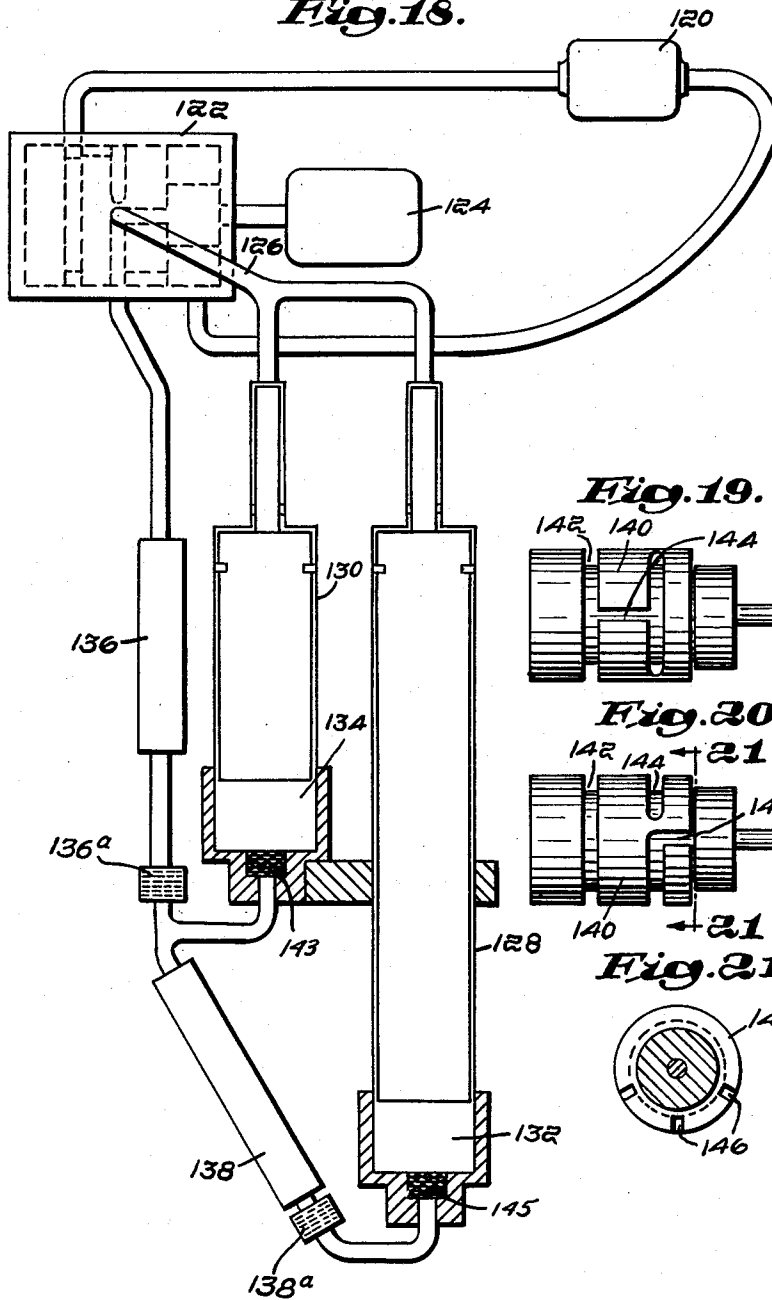


Fig. 19.

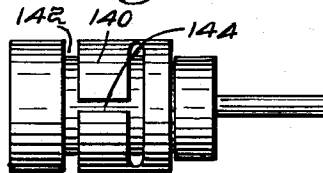


Fig. 20.

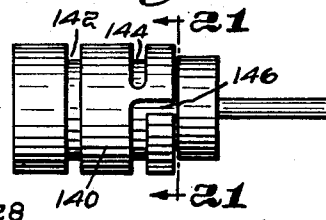
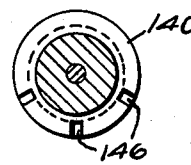


Fig. 21



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GAS BALANCING REFRIGERATION METHOD
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14 Claims. (Cl. 62—6)

This invention relates in general to cryogenic techniques and refrigeration systems. More specifically, the invention deals with an improved method for producing refrigeration at relatively low temperatures (100° K.—14° K.) by utilizing a gas system wherein related quantities of high pressure gas, confined as separated volumes, are caused to vary in magnitude in accordance with a novel pressure balancing cycle of operation. Refrigeration by means of this pressure balancing cycle is hereinafter referred to in the specification in a more abbreviated form as "Cryomatic Gas Balancing."

In conventional cryogenic devices, there are present various undesirable features which may tend to restrict use of these devices in many cases. Reference is had to problems in building suitable gas compression systems, in maintaining seals between moving parts of high compression devices, in dealing with the complexity of cryogenic components, in providing for satisfactory operating life and in lowering the cost of such devices.

It is a chief object of the present invention to improve cryogenic techniques and refrigeration apparatus and to devise a method and means for more efficiently producing required cooling. Another object of the invention is to provide a relatively small size refrigeration system which can be conveniently and cheaply assembled and operated for a wide range of refrigerating purposes. Still another object of the invention is to devise a combination gas cylinder, displacer and control valve mechanism for use with a wide range of refrigeration processes.

The cryomatic gas balancing method of the invention makes possible a realization of these objectives to an extent not heretofore realized and is based on the novel concept of balancing several confined gas volumes so that they may act in conjunction with one another in a unique cyclic manner whereby gas compression and gas expansion is selectively controlled and a net refrigeration is produced at one or more points in a refrigerating system.

I have discovered that this concept of balancing gas volumes may be practically carried out in one preferred embodiment by supporting in a refrigerating system several confined volumes of compressed gas in such separated relationship to one another that each of the volumes may be caused to vary in magnitude with a change in one or more of the remaining confined volumes.

I have further devised a special gas balancing apparatus which includes an enclosure body having a confined space and a gas displacer component which is constructed and arranged to partially fill the confined space. The gas displacer member is arranged to move in the enclosure body so as to divide the confined space into separated chamber sections whose respective volumes vary with position change of the gas displacer component.

I have further combined with the enclosure body a motor driven valve of novel form which is connected to a high pressure gas source for sequentially admitting high pressure gas to each of the chamber sections above-noted, and an important feature of the invention is the construction of this valve with interconnecting passageways which are designed to control flow of high pressure gas in timed relation to rotative travel of the valve body.

Still another important feature of the invention consists in the construction and arrangement of regenerator means so located as to serve not only as a heat storing agency, but also as an energy absorbing means to cushion abrupt change in direction of travel of a free displacer compo-

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nent during its reciprocable movement in the enclosure body.

The nature of the invention and its other objects and novel features are disclosed more fully in the following description of the invention.

In the accompanying drawings:

FIGURE 1 is a diagrammatic view illustrating a simplified form of cryomatic gas balancing apparatus;

FIGURES 2 to 5 inclusive illustrate steps in a typical cycle of operation of the gas balancing apparatus shown in FIGURE 1;

FIGURES 6 to 9 inclusive illustrate successive positions of the valve shown in FIGURE 1;

FIGURE 10 is a plan view of another desirable form of refrigeration apparatus;

FIGURE 11 is an end elevational view of the structure shown in FIGURE 10;

FIGURE 12 is a side elevational view of the structure of FIGURE 10;

FIGURE 13 is an enlarged cross sectional view taken on the line 13—13 of FIGURE 10;

FIGURE 14 is a cross section taken on the line 14—14 of FIGURE 13;

FIGURE 15 is a detail view of a valve component;

FIGURE 16 is an end view of the valve component of FIGURE 16;

FIGURE 17 is another end view of the valve component;

FIGURE 18 is a diagrammatic view of another modified form of gas balancing apparatus; and

FIGURES 19 to 21 illustrate a further modified form of a valve component.

In FIGURES 1 to 5 inclusive, I have illustrated the method of the invention in simplified form and it will be observed that the method as therein illustrated makes use of an enclosure body having a displacer component which is not mechanically actuated by any moving part. By means of this arrangement the displacer is free to move in response to pressure changes exerted on one part or another of the displacer. Cryomatic gas balancing, as carried out in accordance with this invention, is based on the use of a freely disposed displacer whose movement is controlled by predetermined pressure changes induced within the enclosure body for containing the displacer.

As shown in FIGURES 1 to 5, numeral 2 indicates diagrammatically an enclosure body which may consist, for example, of a cylindrical member having a relatively smaller part 4. The cylindrical member includes a confined space in which is supported a displacer 8 formed with a reduced upper end portion 10 extending into the part 4 as shown. Sealing rings as 6 and 12 are supported between the displacer and cylinder in some suitable manner. The displacer 8 is of a size such that it fills a large part of the enclosure body and in the position of the displacer, shown in FIGURE 1, there are formed three separate chamber sections indicated by reference characters C1, C2 and C3 and each of the chamber sections may be of different volumes with volume C1 being much smaller than volume C2 or C3.

The several chamber sections C1, C2 and C3 are connected to a high pressure gas supply source such as a compressor 16 by means of respective conduit portions 17, 18, 20 and 22. Flow of high pressure gas through these conduits is controlled by a special rotary valve structure 24, driven by an electrical motor 26. The valve also has extending away from one side a low pressure or exhaust line 28 which may, if desired, be led back into the intake side of compressor 16. A regenerator member 30 is located between the conduits 20 and 22 and conduit 20 also communicates with chamber section C2.

It will be noted that chamber sections C2 and C3 are in open communication through the regenerator member 30

and the lower pipe section 22, which parts together with the connection of conduit 20 with the chamber section C2 forms an open by-pass.

An important feature of the invention is the manner in which the valve functions to cooperate with the freely displaced displacer and control volumes of gas in the enclosure body. As shown in FIGURES 6 to 9 inclusive, I have devised a specially cored valve rotor 25 which the outer valve body form air passageways P1, P2 and P3. The valve rotor is turned by a motor 26 to open and close the passageways in a definite sequence. The valve body, in one desirable form, is constructed in such a manner that a change occurs with each 90° arc of travel. Thus during the first 90° arc of travel of the rotor body, compressed gas is admitted only through passageways 17 and 18 and rotor 25 to a chamber section C1 and no gas is admitted to chamber sections C2 and C3. Displacer 8 is forced downwardly as shown in FIGURE 2. During the next 90° arc of travel the valve rotor admits compressed gas through 29 to chamber section C2 and C3, while continuing to hold balancing gas pressure in chamber C1 so that the displacer remains in the same position as noted in FIGURE 3. Compressed gas also flows through the regenerator 30 and into conduit 22. In a third 90° arc of travel shown in FIGURE 4, pressure is maintained in chamber section C2 and released in chamber section C1 through 23. This operation unbalances pressures in the system and displacer 8 moves up to reduce the volume of C1 nearly to zero. While the rotor body travels through its last 90° arc of travel, low pressure is maintained in C1 and pressure is released in chamber section C3 and C2 now very small. The gas volume in C3 expands and cools and the cycle is ended as noted in FIGURE 5. At the beginning of a new cycle expanded gas in volume C3 is returned through the regenerator 30 and out through exhaust conduit 23.

In addition to the volume changes illustrated in FIGURES 2, 3, 4 and 5, I have also indicated diagrammatically changes in the position of the valve rotor as noted in FIGURES 6-7. In carrying out these changes under specific working conditions in a typical cryomantic cooling operation, compressed gas, for example, at 100 pounds per square inch or higher, is continuously furnished to the valve 24 from the compressor member 16. Rotation of the valve rotor 25 through the first 90° arc of travel, suggested in FIGURE 6, results in a volume of this compressed gas being admitted through 18 to chamber section C1 and displacer 8 is forced downwardly to reduce the volume of chamber section C3 to nearly zero, while increasing the volume of C2 to a maximum as noted above.

In the next 90° arc of travel, valve body 25 remains open to maintain pressure in chamber section C1 and simultaneously admits pressure to chamber C2 and C3 and also to regenerator 30. During this period the regenerator removes and stores heat from the compressed gas. In the third 90° arc of travel the valve body operates to release pressure in chamber section C1 while maintaining pressure in C2 and C3. This unbalancing of pressure results in displacer 8 moving upwardly and chamber section C1 and chamber section C2 decrease in volume, while chamber section C3 increases to a maximum volume for containing compressed gas. In the fourth 90° arc of travel pressure is released in the chamber sections C3 and C2 and the volume of compressed gas in chamber section C3 expands and cools. As the cycle starts again, expanded cooled gas returns through the regenerator 30, removing heat stored therein, and exhausts out of conduit 23.

Thus it will be seen that pressure which is released or lowered in chamber section C3 generates useful refrigeration in chamber section C3 as the gas pressure therein expands. The regenerator causes the temperature of the hot gas leaving and entering its top to be nearly the same. Therefore, refrigeration generated in chamber section C3

is available for use in some suitable device as a heat exchanger 32 arranged at one side of chamber section C3.

In FIGURES 10-17 inclusive, I have illustrated another desirable form of the invention in which numeral 40 denotes a cylinder having a reduced portion 42. A displacer 48 is mounted in cylinder 40 and includes a threaded cap 59 and another threaded displacer portion 43a secured together as shown in FIGURE 13. These parts define an upper chamber section C4 and intermediate chamber section C5 and a bottom chamber section C6. The cylinder has secured at its upper part a plate 41 to which is bolted another plate member 43 as best shown in FIGURE 13. A sealing means 45 is located between members 41 and 43. The cylinder portion 42 is secured by bolts 47.

Mounted on the plate member 43 is a bracket 56 secured by screws 58 and extending upwardly to support a valve member 60. The valve member 60 is connected to a source of compressed gas furnished through a conduit 62 as suggested in FIGURE 13. Rotatably mounted within the valve casing is a valve rotor body 64 fixed to a shaft 66 which is driven by an electric motor 68 having a switch 69. The latter member is supported in some convenient manner as by a bracket 70 also bolted to a plate member 43.

The valve rotor 64 is formed with passageways which open and close when the rotor is turned by the motor 68. These passageways are indicated in dotted lines in FIGURE 13 and in more detail in FIGURES 14-17 inclusive. Compressed gas delivered from conduit 62 (FIGURE 13) enters an annular recess 80, best shown in FIGURE 16, and is conducted through an orifice 82 to a second semi-annular recess 84. Connected to opening 84 through one side of the valve casing is a conduit 86 whose opposite end extends downwardly into communication with the chamber C4.

Thus during the period in which the rotor 64 makes a 90° arc of travel, as indicated in FIGURE 6, recess 84 is open to receive a flow of the high pressure gas from conduit 62. This flow of gas can exert pressure in chamber C4 but all other passageways are closed. As the valve rotor moves through the next 90° arc of travel (FIGURE 7) a passageway is opened through the conduit 88 which provides for pressurizing chamber C5 while pressure in C4 is maintained. Gas under pressure also passes from 88 through a regenerator 91 and through the conduit 91a to chamber C6.

During the third 90° arc of travel (FIGURE 8) passageway 90 in the cored rotor 64 which is normally separated from passageway 84 by intervening portion 85 as best shown in FIGURE 15 moves into register with the conduit 86. This allows a release of pressure from chamber C4 through passageways 102 and an annular recess 103 and out through an exhaust conduit 104. At this time displacer 48 moves up and chamber section C6 increases in size. In the last 90° cycle (FIGURE 9) the passageway for high pressure gas flow is completely closed and simultaneously pressure is released in chamber C6 and C5 so that the gas expands.

It will be observed that when compressed gas flows downwardly through the regenerator 91, heat is removed and stored and when the flow is reversed heat is given up and carried away. However, by arranging for gas to expand in chamber C6 a net cooling may be realized and be utilized in a heat exchanger 108. The cooling realized is capable of producing temperatures as low as 14° Kelvin and the time required for producing such refrigeration temperature may vary with the compressed gas pressure size of apparatus and other variables.

I may also desire to produce the refrigeration cycle at two or more points as indicated in the modified form of device shown in FIGURE 18. As noted therein a compressor 120 delivers compressed gas to a valve 122 of the type shown in FIGURES 1-5 which valve is driven by a motor 124. The valve controls flow of gas through

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a conduit 126 to a cylinder 128 and to a second cylinder 130.

These cylinders are similar to those of FIGURES 1-5 and include chamber sections 132 and 134, in each of which gas expansion and cooling can take place in the manner already described. A regenerator 136 functions to remove and store heat at the point indicated in the drawings, and in the manner earlier described, and similarly a second regenerator 138, located as shown, may serve a like purpose. Heat exchangers 136a and 138a are provided as shown at the lower left hand side of FIGURE 18 and function in the manner of the heat exchangers earlier described.

In thus using a plurality of expansion chambers to carry out cryomatic gas balancing, temperatures as low as 14° Kelvin may, I find, be produced at the lower stage comprised by chamber 132, while a somewhat higher but desirable range of Kelvin temperatures may be produced at chamber 134. It is pointed out that by using either a single regenerator, as shown in FIGURE 10, or a plurality of regenerators, as shown in FIGURE 18, a desirable gas flow cushioning effect is realized with the regenerator means acting in the nature of a shock absorber to desirably control reciprocating movement of the displacer member so that excessive wear is avoided. I may also employ heat exchangers 143 and 145 in addition to heat exchangers 136a and 138a as shown in FIGURE 18.

In FIGURES 19-21, a modified form of rotor valve is shown in which a valve rotor 140 is formed with passageways 142 and 144. These passageways are connected by a transversely disposed passageway extending between them. In this arrangement compressed gas is conducted through an inlet port 146, for example, as shown in FIGURE 20. It will be understood that the valve rotor body may be received in a valve casing corresponding to that shown in FIGURE 13 and may be rotated by a motor similar to the motor 68 earlier described.

It is intended that other valve arrangements may be utilized in combination with the freely supported displacer apparatus of the invention and the location of the valve means may be varied to control the chamber sections in different ways. In utilizing the thermal regenerator as a shock absorber for displacer motion, it may also be desired to use additional shock absorbing devices, either combined with or utilized separately of the regenerator members. Various other arrangements of heat exchangers may also be employed as, for example, multiple heat exchanger means located between the regenerators.

In practical applications of the invention, I find that a number of controlling factors are to be considered in relation to efficiency of the process in any given application. Thus such factors as required temperature, capacity, operating time, shape of the cold chamber, and various other considerations are to be kept in mind. It is contemplated that the cryomatic gas balancing method disclosed may be employed in connection with a wide range of cryogenic techniques, including such operations as infra red cooling, cryotronic cooling, maser cooling, conditioning of parametric amplifiers, laboratory cold chambers (2°-50° Kelvin) hydrogen liquifiers, helium liquifiers, cryo-pumping refrigerators for super-conducting magnets, refrigerators for super-conducting transformers, refrigerators for super-conducting generators, production of heavy water, and the like.

From the foregoing description it will be seen that I disclosed an important improvement in the field of low temperature refrigeration and I have further provided an efficient and simplified method and apparatus for producing very low temperature refrigeration. I have also devised a combination of cryomatic gas balancing and valve components which can be constructed and operated in the form of relatively small scale equipment having a wide range of use in many fields.

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While I have shown and described preferred embodiments of the invention, it will be understood that the invention may be practiced in various other modified forms within the scope of the appended claims.

I claim:

1. In a method of gas balancing refrigeration in which gas from a high pressure supply source is delivered through valve means to a confined space whose volume is separated into three variable chambers by walls movable under pressure, two of which are connected to one another for the flow of gas therebetween, and said valve means comprising a multipassage rotary inlet and outlet valve for sequentially controlling the flow of fluid into and relieving the pressure from the three chambers, the steps which include introducing a quantity of high pressure gas by movement of said valve to a first position into one of the chambers while a second chamber is increasing in volume, and a third chamber connected to the second chamber is decreasing in volume, then supplying high pressure gas by movement of said valve to a second position to the second chamber in balanced relationship to the first and third chambers, releasing pressure in the first chamber by movement of said valve to a third position while maintaining high pressure of gas in second chamber, conducting high pressure gas from the supply source and from the second chamber through a regenerative path of travel in which heat is removed and stored, and then to a third chamber, then relieving pressure in the third chamber by movement of said valve to its starting position to cause expansion of the gas delivered whereby useful cooling is produced and then returning the expanded gas along the said path of travel and repeating the gas delivery cycle.

2. In a method of gas balancing refrigeration in which gas from a high pressure supply source is delivered through valve means to a confined space whose volume is separated into variable chambers by walls movable under pressure, and the valve means comprising a multipassage rotary inlet and outlet valve for sequentially controlling the flow of fluid into and relieving the pressure from the three chambers, the steps which include introducing a quantity of high pressure gas into one of the chambers while a second chamber is increasing in volume, and a third chamber connected to the second chamber is decreasing in volume by movement of said valve to a first position, then supplying high pressure gas to the second chamber in balanced relationship to the first and third chambers by movement of said valve to a second position, releasing pressure in the first chamber while maintaining high pressure gas in a heated state in communication with the said second chamber and simultaneously admitting high pressure gas to the third chamber whereby balancing of gas pressure occurs and the third chamber increases to its maximum volume while the second chamber decreases to a minimum volume by movement of said valve to a third position, conducting high pressure gas leaving the second chamber as the first chamber pressure decreases, along a regenerative path of travel in which heat is removed and stored, receiving in the third chamber while at maximum volume, high pressure gas from the regenerative path and then relieving pressure in the third chamber by movement of said valve to its starting position while maintaining low gas pressure in the first chamber thereby to expand the volume of gas in the third chamber, and produce useful refrigeration, and returning the expanded gas along the regenerative path to take on and carry away heat.

3. In a method of refrigeration in which a high pressure gas is admitted through valve means to a constant volume confined space having three divided chamber sections capable of being varied in volume, and said valve means comprising a multipassage rotary inlet and outlet valve for sequentially controlling the flow of fluid into and relieving the pressure from the three chambers, the steps which include,

- (a) pressurizing a first section by delivery of a first quantity of gas from a high pressure supply source and simultaneously increasing the volume of the first and second sections while decreasing the volume of a third section by movement of said valve to a first position, 5
- (b) then pressurizing the second chamber by delivery of a second quantity of gas from said high pressure source, said second quantity of gas becoming heated due to pressure increase realized in the second section, by movement of said valve to a second position, 10
- (c) delivering the second quantity of heated gas from the said second section of the confined space to a third section of the confined space along a path of travel extending between the second and third sections and in which path heat is removed and stored and simultaneously drawing gas from the high pressure source and mixing it with the gas from the said second section by movement of said valve to a third position, and 15
- (d) relieving pressure from gas in the third section thereby causing the gas in the third section to expand and cool in said third section and produce useful refrigeration by movement of said valve to its starting position. 20
4. In a method of refrigeration in which a high pressure gas is admitted through valve means to a constant volume confined space having three divided chamber sections capable of being varied in volume by means of a movable displacer member and said valve means comprising a multipassage rotary inlet and outlet valve for sequentially controlling the flow of fluid into and relieving the pressure from the three chambers, the steps which include, 25
- (a) pressurizing a first chamber section by delivery of a first quantity of gas from a high pressure supply source to said displacer and simultaneously increasing the volume of the first and second chamber sections while decreasing the volume of a third chamber section connected to the said second chamber section by movement of said valve to a first position, 30
- (b) then balancing pressure in the second chamber section and the first chamber section by delivery of a second quantity of high pressure gas to the second chamber section, said second quantity of gas becoming heated due to pressure increase realized in the second chamber by movement of said valve to a second position, 40
- (c) relieving pressure on the first chamber part of the displacer to cause it to change position in the first chamber section and simultaneously transferring the second quantity of heated gas from the said second section of the confined space to a third section of the confined space and simultaneously drawing gas from the high pressure source and mixing it with the gas from the said second section along a regenerative path of travel occurring between the second and third sections in which heat is removed and stored, said regenerative path operating to retard rate of flow of gas and provide for cushioning the travel of the displacer by movement of said valve to a third position, 50
- (d) relieving pressure from gas in the third section thereby causing the gas in the third section to expand and cool in said third section by movement of said valve to its starting position, 55
- (e) said expanding gas returning along the said path of travel and regaining the heat previously removed and stored and then exhausting the gas from the system and repeating this cycle. 60
5. A refrigeration method which consists in pressurizing a first chamber of a constant volume enclosed space by delivery through valve means of a quantity of gas from a high pressure supply source, said constant volume enclosed space also having second and third chambers 65

which are connected together and said valve means comprising a multipassage rotary inlet and outlet valve for sequentially controlling the flow of fluid into and relieving the pressure from the three chambers, the pressure induced in said first chamber by movement of said valve to a first position causing means for separation in said enclosed space to move and to increase the size of the second chamber and to decrease the size of the third chamber, then pressurizing the second chamber by delivery of a second quantity of gas from said high pressure supply source by movement of said valve to a second position, relieving pressure in said first chamber by movement of said valve to a third position thereby causing the separation means to move and to transfer high pressure gas from said second chamber to said third chamber and simultaneously drawing additional gas under high pressure from the supply source and conducting this additional gas to the third chamber with the gas from the second chamber, and removing and storing heat from said second and third quantities of gas in transit, and then releasing pressure in said third chamber by movement of said valve to its starting position thereby causing the gas comprised by said second and third quantities to expand and cool in said third chamber. 70

6. A refrigerating apparatus of the class including an enclosure body having a confined space therein and a displacer member of irregular form located within the confined space and movable to define at least three chamber sections, two of said chamber sections being connected through a by-pass for flow of gas therebetween, said displacer member being movable in said confined space to provide an increase in volume of one of the connected chamber sections and a decrease in volume of the other of the connected chamber sections and the third chamber section, means for supplying compressed gas to all of the chamber sections, and a multipassage rotary inlet and outlet valve for sequentially controlling the position of the displacer in the enclosure body by regulating the flow of gas from said gas supply means into and out of the chamber sections. 75

7. A structure according to claim 6 in which the valve means includes a valve casing connected to the means for supplying compressed gas, a valve body rotatably mounted in the casing and a motor member for turning said rotor body within the casing and said rotor body being formed with passageway for conducting compressed gas therethrough.

8. A structure according to claim 6 in which the valve body is formed with means for varying the path of flow of compressed gas during each 90° arc of travel of the rotor body.

9. A structure according to claim 6 in which the valve body includes a gas discharge port and means for conducting discharge gas from the valve to the means for supplying compressed gas.

10. A structure according to claim 6, including regenerator means connected between the valve and the said enclosure body.

11. A structure according to claim 6, including regenerator means located between the enclosure body and the valve and a heat exchanger member located adjacent to one side of the enclosure body.

12. In a method of refrigeration in which gas from a high pressure supply source is delivered through valve means to a confined space whose volume is divided into three variable chambers and said valve means comprising a multipassage rotary inlet and outlet valve for sequentially controlling the flow of fluid into and relieving the pressure from the three chambers, two of which are connected at all times for flow of gas therebetween, and all of which may be varied in size by an unbalancing of gas pressures in said variable chambers, the steps which include exhausting gas out of the chambers to provide expansion and then controlling the pressures of gas admitted to each of the chambers to selectively produce 75

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expansion and cooling in one of the connected chambers, and heating in the other of the said connected chambers as well as the third chamber by moving the rotary valve means to four successive positions of control.

13. In a method of gas balancing refrigeration, in which gas from a high pressure supply source is delivered through valve means to a confined space whose volume is divided into three variable chambers defined by walls movable under pressure, two of said chambers being connected to one another for the flow of gas therebetween at all times and said valve means comprising a multipass rotary inlet and outlet valve for sequentially controlling the flow of fluid into and relieving the pressure from the three chambers, the steps which include introducing quantities of high pressure gas into the chambers in controlled relationship to one another by moving said valve means to first and second positions, exhausting gas from certain of said chambers to provide expansion by successively moving the valve means to third and fourth positions, and controlling the pressures of the gas quantities admitted to the chambers to selectively produce useful cooling in one of the connected chambers, and heating in the other of the said connected chambers as well as the third chamber.

14. In a method of cryogenic gas balancing refrigeration in which gas from a high pressure supply source

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is delivered through valve means to a confined space whose volume is separated into three variable chambers by walls movable under pressure, two of which are connected for the flow of gas therebetween and said valve means comprising a multipass rotary inlet and outlet valve for sequentially controlling the flow of fluid into and relieving the pressure from the three chambers, the steps which include introducing quantities of high pressure gas into the chambers in unbalanced controlled relationship to one another by moving the rotary valve means into first and second positions, expanding the quantities of gas in the chambers in a predetermined sequence by moving the rotary valve means into a third position and then back to a starting position, and controlling the pressures of the gas quantities in said chambers by relieving the pressure in said chambers in a predetermined timed relationship to selectively produce gas expansion and useful refrigeration in one of the connected chambers, and heating in the other of the said connected chambers.

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