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[54] **METHOD OF REFRIGERATION COMBINING TWO THERMODYNAMIC CYCLES AND A CORRESPONDING CRYOGENIC MACHINE**

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July 6, 1973 France 73.24991

[52] **U.S. Cl.** **62/6**; 62/86

[51] **Int. Cl.**^{2} **F25B 9/00**

[58] **Field of Search** 62/6, 86

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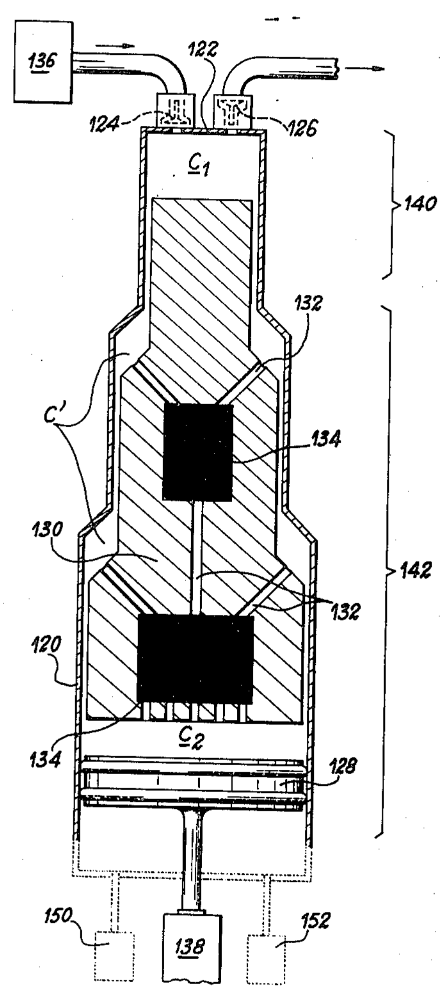
[57] **ABSTRACT**

Two separate circulating fluids undergo different thermodynamic cycles in two coupled cryogenic machines, at least one of the operations of each cycle being intended to initiate one of the operations in the other cycle.

16 Claims, 11 Drawing Figures



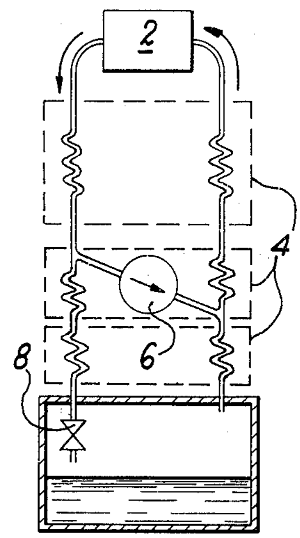


FIG. 1

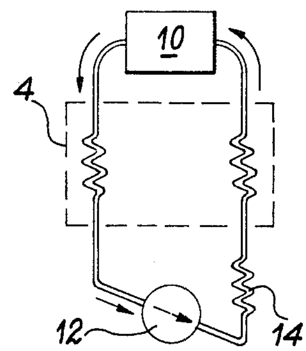


FIG. 2

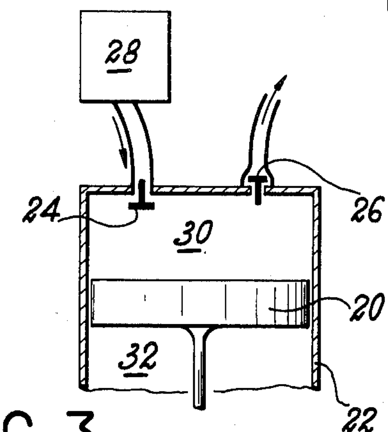
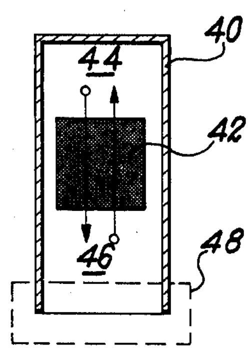


FIG. 3

FIG. 4



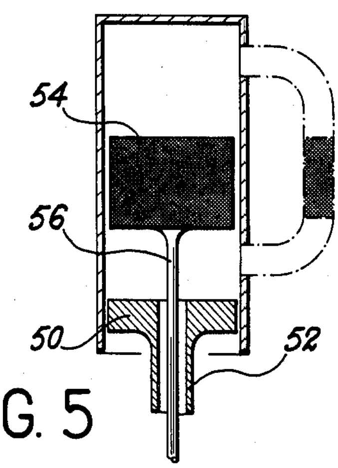


FIG. 5

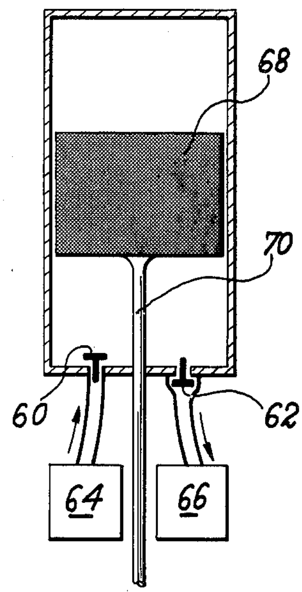


FIG. 6

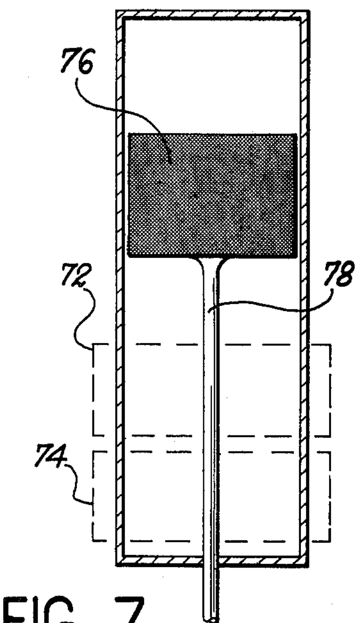


FIG. 7

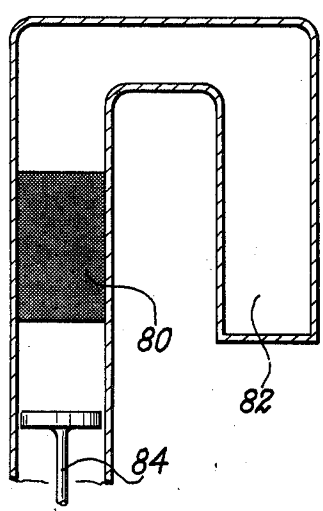


FIG. 8

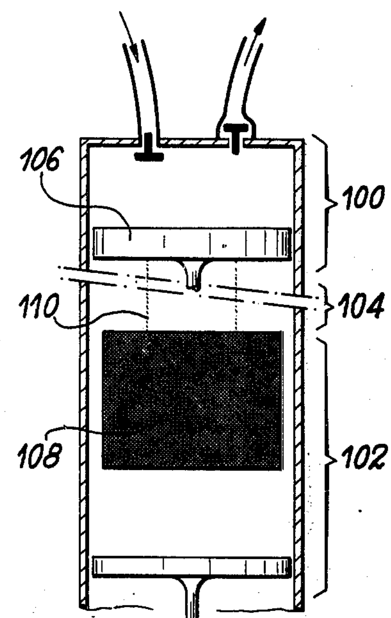


FIG. 9

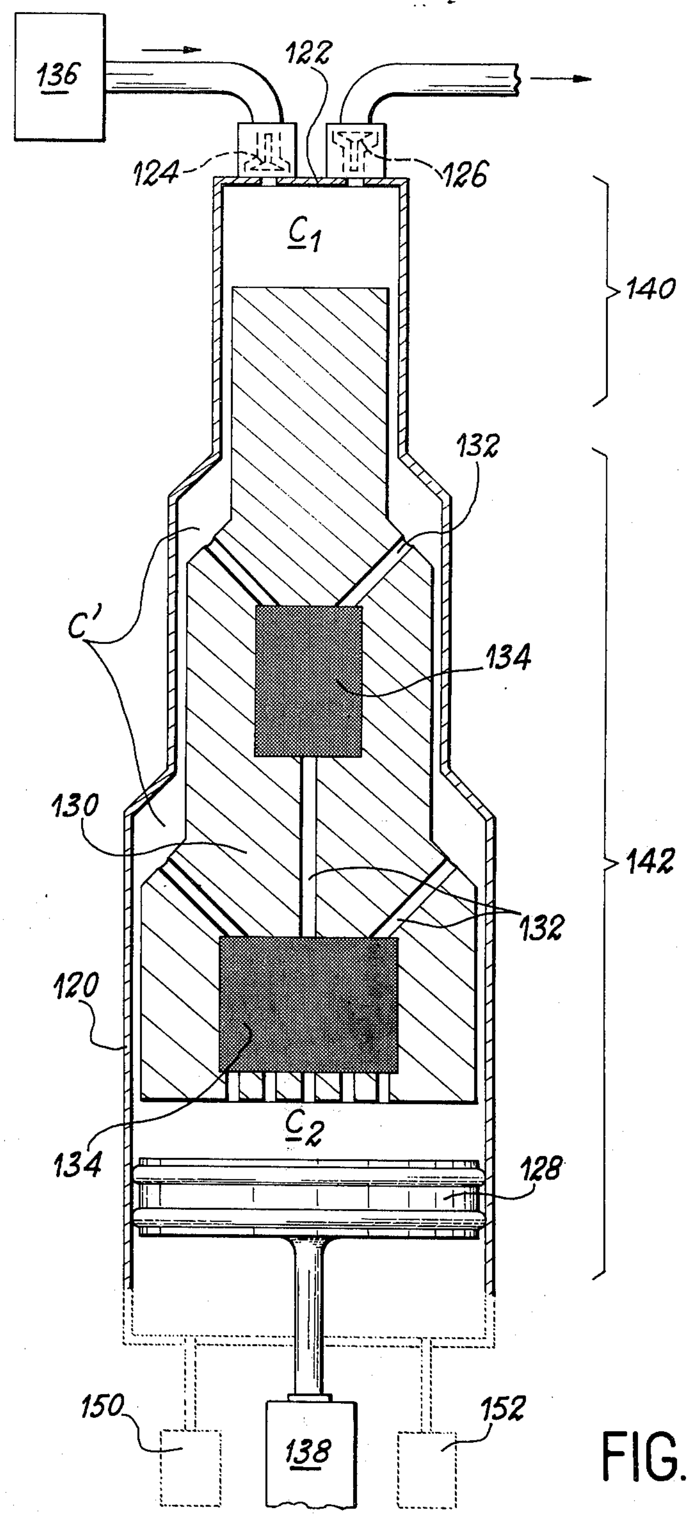

136
122
124
126
C1
140
132
C'
134
130
142
132
120
134
C2
128
150
138
152

FIG. 10

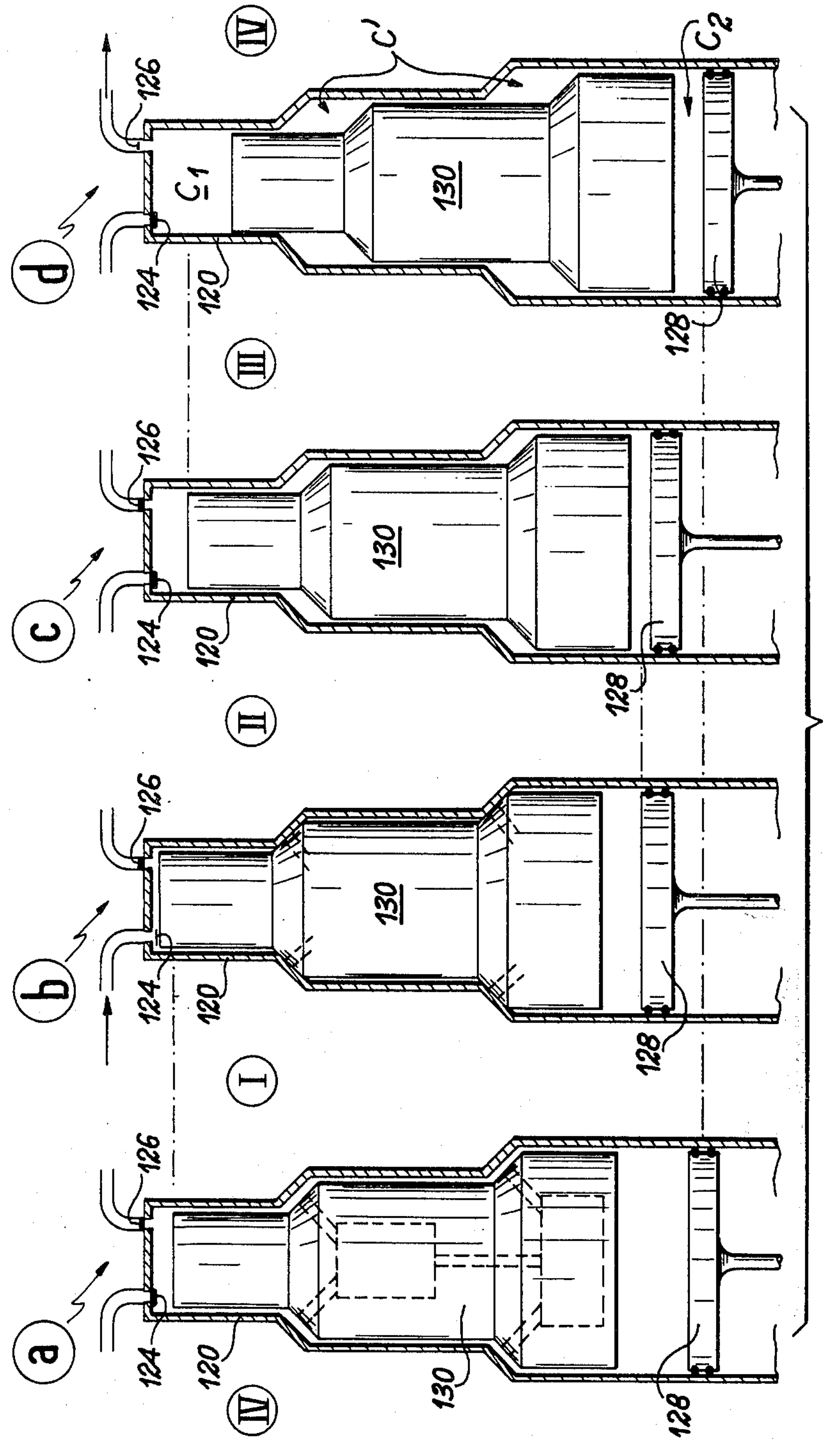


FIG. 11

METHOD OF REFRIGERATION COMBINING TWO THERMODYNAMIC CYCLES AND A CORRESPONDING CRYOGENIC MACHINE

This invention relates to a method of refrigeration which combines two thermodynamic cycles and a cryogenic machine for carrying out said method. One notable application of the invention is in the field of cryogenics.

Theoretical thermodynamic cycles which permit power extraction at low temperature usually entail four basic operations, namely: compression, cooling, expansion and reheating.

Each of these operations can be carried out in different ways. Compressions and expansions can accordingly be either isothermal or adiabatic whilst reheating and cooling operations can be carried out either by counter-current heat transfer or by means of a thermal reservoir which stores or restores heat. The many possible combinations lead to a large number of practical cycles which can be placed in two main categories according to whether they make use of a continuous circulation fluid or an alternate circulation fluid.

In many of these cycles, the theoretical efficiency is that of the Carnot cycle or is close to this latter. In practice, no cycle is either better or worse than another but each cycle is more or less suited to the desired power range or to a given application.

For example, the Claude cycle which belongs to the first category of continuous circulation cycles is of interest in medium-power and high-power installations since it has high efficiency and permits direct utilization of the continuously circulating gas for the extraction of power. In this cycle, the cold gas is expanded and supplies mechanical work which is taken off either on a turbine shaft when the installation is of large size or by means of a piston machine. The expansion unit is always of very delicate design and often limits the practical applications of this cycle.

In regard to the alternate fluid-circulation cycles, they do not entail the need for any delicate component in the cold portion and thus permit the construction of rugged units which are capable of operating over long periods of time but have acceptable efficiency only within the range of low or medium power outputs. These cycles suffer from a further disadvantage in that they do not readily permit external utilization of the cold which is produced. In fact, the power produced by the gas is yielded to a wall on which another gas can be cooled only by accepting accumulated temperature differences which impair the efficiency of the entire system to a marked degree. The effect of this disadvantage is demonstrated for example in pre-cooling of helium prior to liquefaction.

With a view to combining the inherent advantages of each cycle in a single method and a single unit without incurring the associated disadvantages, the invention proposes a composite solution in which two different cycles are employed in close conjunction with each other so that certain operational stages of one cycle control operational stages of the other cycle.

In more precise terms, the present invention is directed to a method of refrigeration of the type which consists in causing a fluid to undergo a thermodynamic cycle comprising the operations of compression, cooling, expansion and reheating. The method essentially consists in subjecting two distinct fluid circulations to different but coupled thermodynamic cycles, the effect of at least one operation in each cycle being such as to initiate one operation of the other cycle.

The two cycles which are combined in accordance with the invention are clearly chosen so as to ensure that their respective advantages are complementary. To this end, the invention preferably combines a cycle of the continuous fluid-circulation type with an alternate-circulation cycle. Among the cycles of the first category, the invention contemplates the use of the Claude or Brayton cycles; in the case of the cycles of the second category, the invention recommends the use of the Stirling or Gifford-McMahon cycles or the Taconis or Vuilleumier cycles or alternatively the so-called pulse-tube cycle.

The cooling power delivered by means of a method of this type can be extracted from one of the cycles such as, for example but not exclusively, from the continuous fluid-circulation cycle. The cooling power delivered by the other cycle is employed for the purpose of balancing the temperatures between the different parts of the machine but can also be partially extracted.

In a cryogenic machine which, in accordance with the invention and by way of example, combines the Claude and Stirling cycles, it is possible to maintain continuous equilibrium of pressures and temperatures on each side of the expansion unit employed in the machine which operates in accordance with the Claude cycle. In that case there is no longer either leakage of gas, friction or addition of heat in this machine. This accordingly results in enhanced efficiency of the first cycle and in disappearance of the delicate nature of the expansion unit which is an essential component. At the same time, the alternate-circulation cycle in which the power delivery may not be extracted and may serve solely to compensate losses operates at low power and consequently retains its inherent efficiency and endurance. Since the extraction of the power produced by the second cycle is no longer necessary, the disadvantage attached to this cycle is removed.

The present invention is also directed to a cryogenic machine for carrying out the method which has just been defined. Said machine essentially comprises two coupled cryogenic machines which operate in accordance with different thermodynamic cycles with separate fluids, at least one of the operations performed in each machine being intended to control elements belonging to the other machine.

One of the machines is preferably of the type involving continuous circulation of a first fluid and comprises in particular an alternating expansion unit and the other machine is preferably of the type in which provision is made for alternate circulation of a second fluid, the variations in pressure of said second fluid being such as to control said alternating expansion unit pneumatically.

In one advantageous alternative embodiment, said alternating expansion unit is of the expansion piston type. The alternate-circulation machine can be of the heataccumulator type and can further comprise a displacer piston, in which case said displacer piston is coupled to the expansion piston of the continuous-circulation machine.

The characteristic features and advantages of the invention will become more readily apparent from the following description of exemplified embodiments which are given by way of explanation without any limitation being implied, reference being made to the accompanying drawings, wherein:

FIG. 1 is a schematic diagram of a cryogenic machine which operates in accordance with the Claude cycle;

FIG. 2 is a schematic diagram of a cryogenic machine which operates in accordance with the Brayton cycle;

FIG. 3 is a diagram of an alternating piston-type expansion unit;

FIG. 4 is a schematic diagram of an alternate-circulation cryogenic machine;

FIGS. 5, 6, 7 and 8 represent alternative forms of alternate-circulation machines which operate respectively in accordance with the Stirling cycle, the Gifford-McMahon type, the Taconis type or the Vuilleumier type and of the pulse-tube type;

FIG. 9 is a schematic diagram of the cryogenic machine in accordance with the invention;

FIG. 10 is a diagram of an alternative embodiment in which an expansion-piston machine and a displacerpiston machine are combined;

FIG. 11 shows the different positions of the expansion and displacer pistons during the operating cycle of the machine shown in FIG. 10.

Before describing the cryogenic machine in accordance with the invention, the principles of a few known thermodynamic cycles and the structures of machines which make use of said cycles will be briefly recalled in order that the advantages and different embodiments of the method and the machine according to the invention may become more readily apparent.

There is shown in FIG. 1 a general diagram of a cryogenic installation which operates in accordance with the Claude cycle. There can be seen in this figure a compressor 2 and heat exchangers 4. An expansion unit 6 produces action on a portion of the circulating fluid whilst the other portion is directed towards a valve 8 in which the Joule-Thomson expansion which takes place therein results in liquefaction of the gas.

FIG. 2 shows diagrammatically a cryogenic machine which operates in accordance with the Brayton cycle and differs from the previous machine in that the entire quantity of fluid compressed by the compressor 10 passes through the expansion unit 12, the cooling power being utilized through the element 14.

The expansion units 6 and 12 of the installations referred-to above can be alternating and each comprise a piston as shown in FIG. 3. Said piston is designated by the reference 20 and is capable of displacement within a cylinder 22, the top end of which is fitted with gas intake and exhaust means 24 and 26 (disc-valves, poppet valves, check-valves and the like). The intake means 24 are connected to means 28 for supplying fluid under the conditions of temperature and pressure which are adapted to a cryogenic machine of the continuous-circulation type, that is to say in actual fact under conditions of high pressure and low temperature.

In a piston-type alternating expansion unit, the pressures within the chambers 30 and 32 located on each side of the piston 20 are not balanced, with the result that gas leakages which are detrimental to good operation of the unit take place between the piston 20 and the cylinder 22. Special care must therefore be devoted to the provision of a pressure-tight seal between the piston and the cylinder. However, since pressure-tightness must be achieved at very low temperatures, it is a matter of considerable difficulty to obtain satisfactory solutions.

Moreover, the chambers 30 and 32 are at very different temperatures, thus giving rise to a transfer of heat to the chamber 30 and impairing the performances of the machine to an even greater extent.

The improvements which have already been made in this type of cryogenic machine make it possible to limit these conditions of pressure and temperature disequilibrium but do not make it possible to eliminate these latter completely. One of the objects of the invention is precisely to eliminate these disequilibria by virtue of the incorporation of a second machine which is preferably of the alternate-circulation type and so designed that the conditions of pressure and temperature of the fluid within the chamber 32 which is located beneath the alternating piston are close to the conditions of temperature and pressure of the fluid within the chamber 30 which forms part of the continuous-circulation machine.

In order that the whole advantage of this combination of machines of different types may be more completely understood, the known principle of alternate-circulation machines will also be briefly recalled.

The different forms which can be given to these machines have a common structure which is shown diagrammatically in FIG. 4. In this figure, an enclosure 40 comprises a heat accumulator 42 located between two chambers 44 and 46 between which a fluid circulates in an alternate flow motion. This flow motion is produced by means 48 which can assume a number of different forms illustrated by the following figures. In FIG. 5, said means comprise a piston 50 actuated by a stem 52 which is controlled by mechanical means (not illustrated in the figure); a displacer piston 54 is actuated by a piston-rod 56 which is controlled by mechanical means (also omitted from the figure). The heat accumulator can be located either within the displacer piston 54 or in an associated connecting-tube which is shown on the righthand side of the figure in chain-dotted lines. This diagram corresponds to a machine which operates in accordance with the so-called Stirling cycle. As a result of their combined movements, the moving displacer piston and the lower piston 50 controls the alternate flow of gas through the heat accumulator.

In FIG. 6, the means 48 shown in FIG. 4 are constituted by gas intake means 60 and gas discharge means 62, by a high-pressure gas reservoir 64 and by a low-pressure gas reservoir 66; a displacer piston 68 which contains the heat accumulator is also actuated by a piston-rod 70 controlled by mechanical means (not shown). This figure corresponds to the diagram of a machine which operates in accordance with the so-called Gifford-McMahon cycle.

FIG. 7 shows a third alternative embodiment in which the means for producing alternate circulation of the fluid are constituted by a moderately hot source 72 and a very hot source 74 between which the thermal compressions take place. The displacer 76 is also endowed with an alternating movement by means of the piston-rod 78 which is controlled in a suitable manner.

FIG. 8 also shows an alternate-circulation machine but no longer comprises a displacer piston. This is replaced by a pulse-tube comprising a stationary heat accumulator 80 and a dead space 82. The means for producing alternating pressure variations beneath the accumulator 80 can be of several different types as shown in FIGS. 5 to 7; by way of explanation, FIG. 8 shows an alternative embodiment in which said means are constituted by a moving piston **84.**

Having now recalled a few elements of the state of the art, the cryogenic machine in accordance with the invention will now be described and will accordingly serve to define the method of refrigeration which is employed by this machine.

The general diagram of the cryogenic machine in accordance with the invention is illustrated in FIG. **9.** There are shown in this figure in a highly diagrammatic form a first cryogenic machine **100** and a second cryogenic machine **102** which utilize different thermodynamic cycles such as a Claude cycle in the case of the machine **100** and a Stirling cycle in the case of the machine **102,** these cycles being mentioned solely by way of example. The two machines aforesaid are closely coupled together by means which are indicated schematically by the stage **104,** with the result that at least one operation performed within each machine controls elements which form part of the other machine.

In order to provide an explanation which is not intended to imply any limitation whatsoever, it is postulated in more exact terms that, if the cryogenic machine **100** is of the continuous-circulation type and comprises an expansion piston **106** and if the cryogenic machine **102** is of the alternate-circulation type and comprises a displacer piston **108,** the coupling element **104** can be simply constituted by a member **110** which couples the piston **106** and **108** in rigidly fixed relation. In this manner, the variations in the pressures of the fluid contained in the machine **102** which result in displacement of the displacer piston **108** will have the effect of initiating the movement of the piston **106** at the same time. Similarly, the injection of the first fluid into the cryogenic machine **100** under high pressure which has the effect of moving the piston **106** downwards also has the effect of displacing the piston **108** of the second machine **102.** If the zone **104** is given a suitable shape, the fluid of the machine **102** which follows a thermodynamic cycle can by substantially under the same conditions of temperature and pressure as the fluid of the machine **100,** with the result that the disequilibria mentioned in the foregoing in connection with the machine of the first category are eliminated.

A better understanding of this characteristic feature of the machine according to the invention will be gained by referring to FIG. **10.** An expansion-piston machine is combined with a displacer-piston machine in the embodiment shown in this figure, in which the cryogenic machine comprises:

a casing **120** in which the walls are constituted by cylinders having different diameters and which are closed at one end by a cover **122** fitted with means **124** and **126** respectively for admission and discharge of a first fluid and at the other end by a moving piston **128;**

an expansion-displacer piston **130** which corresponds in shape to said walls and is capable of back-and-forth motion within the casing; said piston delimits at one end a chamber C_1 which is filled with said first fluid and at the other end a chamber C_2, at least one chamber C' being delimited in the intermediate portion of said piston at the level of the changes in diameter of said cylinders; the chambers C' and C_2 are filled with a second fluid;

ducts **132** providing a communication between the chambers C' and C_2;

heat accumulators **134** placed in the flow paths of the ducts aforesaid;

means **136** for supplying a first fluid under the conditions which are adapted to a continuous-circulation machine;

mechanical means **138** for actuating the moving piston **128.**

The machine aforesaid therefore comprises a first cryogenic machine **140** of the type which operates in accordance with the Claude cycle and a second cryogenic machine **142** of the type which operates in accordance with the Stirling cycle, these machines being provided with a common piston **130** which performs at the same time the function of expansion piston for the Claude-type machine and of displacer piston for the Stirling-type machine.

The operation of this machine is illustrated in FIG. **11** which shows the positions of the different components during the operating cycle. Four instantaneous positions are designated by the references *a, b, c, d,* between which there are four operational stages designated respectively by the references I, II, III and IV.

The stage I is the compression stage for the fluid contained in the chamber C_2; compression is produced by the upward motion of the piston **128.** In the position *a,* the heat accumulators are cold as a result of the previous stage IV. The admission and discharge valves **124** and **126** are closed. The upward motion of the piston **128** causes the upward motion of the displacer-expansion piston **130,** thereby compressing the fluid contained in the chamber C_1. The end of stage I is illustrated in the diagram *b.* When the pressure within the chamber C_1 attains the high pressure of the Claude cycle, the admission valve **124** opens and this is the beginning of stage II.

The opening of the admission valve **124** initiates the admission of the first fluid under a high pressure, thereby causing the expansion-displacer piston **130** to return downwards; this movement results in transfer of the fluid which was contained in the chamber C_2 to the chambers C'. During the downward motion of the expansion-displacer piston **130,** the mean temperature of the second fluid is reduced by reason of the fact that it has passed over the cold heat accumulators. In consequence, the volume of said second fluid decreases and this has the effect of moving the displacer-expansion piston **130** towards the piston **128,** this effect being enhanced by the admission of the first fluid under high pressure. At the end of stage II, the positions of the components are as shown in FIG. *c.*

The closure of the admission valve and the downward motion of the piston **128** give rise in stage III to expansion of the gases contained in the chambers C_1, C' and C_2. At the end of stage III, the expansion-displacer piston **130** is in the bottom position and, at the end of travel, the exhaust valve **126** is open as shown in FIG. *d.*

In stage IV, the beginning of upward motion of the piston **128** causes the upward return of the expansion-displacer piston **130** and the transfer of the cooled fluid from the chambers C' and the chamber C_2. This fluid increases in volume at the time of reheating and accordingly permits the continued upward motion of the expansion-displacer piston, which also results in discharge of the first fluid contained in the chamber C_1, until the instant of closure of the exhaust valve **126.** The piston **128** which had moved only to a slight extent is restored to the position shown in FIG. *a* and the cycle continues.

It may be observed that the cycles of the two machines of different types are interrelated throughout the performance of these operations and that the operations of one of the cycles control the operation of the other cycle and conversely. Thus the beginning of the upward displacement of the piston **128** initiates compression in the Stirling cycle but causes discharge in the Claude cycle; the admission in the Claude cycle causes transfer of the gas through the heat accumulator in the Stirling cycle; the expansion is common in the Claude and Stirling cycles.

The advantage of the method and the machine according to the invention is also apparent from this example. Accordingly, the pressure is the same at any moment (subject to pressure drops) at all points of the casing **120.** In consequence, it is only necessary to obtain between the chambers C_1 and C' a low standard of pressure-tightness which does not give rise to a substantial degree of friction. Moreover, the heat losses to the chamber C_1 are completely eliminated if the general dimensions of the circuits are such that the temperature of the fluid within the chamber C_1 is equal to the temperature of one of the chambers C', namely the nearest chamber C', for example.

The cooling power need be extracted only from the first fluid but may also be extracted from the second fluid either wholly or in part. If the machine **142** comprises a plurality of stages at different temperatures, the power can be extracted at different temperature levels. In some alternative forms of construction, the dimensions of the machines **140** and **142** can be such that the alternate-circulation machine supplies the cooling power whislt the power delivered by the continuous-circulation machine is employed only for the purpose of ensuring equilibria.

In FIGS. **10** and **11,** there is shown by way of explanation an expansion-displacer piston **130** which contains the ducts **132** and the heat accumulators **134** but it would not constitute any departure from the scope of the invention if said ducts and accumulators were placed outside the casing **120.** Similarly, FIG. **5** had shown an alternative form of construction in which the heat accumulator was located outside the main casing.

It is also by way of illustration that the means for varying the pressure of the fluid contained in the chamber C_2 are shown in FIG. **10** and **11** in the form of a piston **128.** As already mentioned in connection with FIGS. **5, 6** and **7,** said means can take different forms and can in particular comprise sets of check-valves or control valves which put the chamber C_2 alternatively in communication with two reservoirs at different pressures (as shown in dotted lines in FIG. **10** and designated by the references **150** and **152**) in order to utilize the Gifford-McMahon cycle; but it would also be possible to employ a cryogenic machine **142** of the Taconis or Vuilleumier type or alternatively a pulse-tube machine.

Similarly, the expansion chamber C_1 which is fitted with intake and exhaust valves and shown diagrammatically in FIGS. **10** and **11** can be of the type described in French Pat. No. 2,123,611, issued Jan. 25, 1971.

Finally, the two gases of the cryogenic machines can advantageously be the same.

The length of service life of the cryogenic machine according to the invention is now dependent only on the portion which operates at ambient temperature. In point of fact, this portion is even more simple than in the alternate-circulation machines of the prior art which are employed alone since it is no longer necessary to control the displacer piston by means of a rod and mechanical means. The service life is therefore appreciably longer than that of known machines.

The foregoing description makes constant reference to a method of refrigeration or to a cryogenic machine but it is possible in accordance with known practice to operate this type of machine in reverse (especially machines which utilize the Stirling cycle) so that work may accordingly be supplied by these latter. There would therefore not be any departure from the scope of the invention if the directions of energy conversion were reversed in the method and the device hereinabove described so as to obtain a method of conversion of heat energy to mechanical energy and a corresponding engine.

What we claim is:

1. A method of refrigeration of the type which consists in causing a fluid to undergo a thermodynamic cycle comprising the operations of compression, cooling, expansion and reheating, wherein two distinct fluid circulations are subjected to different but coupled thermodynamic cycles, the effect of at least one operation in each cycle being such as to initiate one operation of the other cycle.

2. A method according to claim **1,** wherein one of the cycles is of the continuous fluid-circulation type and the other cycle is of the alternate fluid-circulation type.

3. A method according to claim **2,** wherein said continuous-circulation fluid is subjected to any one of the cycles of the group comprising the Claude and Brayton cycles and wherein said alternate-circulation fluid is subjected to one of the cycles of the group comprising the Stirling cycle, the Gifford-McMahon cycle, the Taconis cycle, the Vuilleumier cycle and the pulse-tube cycle.

4. A method according to claim **1,** wherein the cooling power is extracted only from one of the cycles for subsequent utilization.

5. A method according to claim **1,** wherein the cooling power is extracted at levels of said circulations which are at different temperatures.

6. A compound machine combining two coupled cryogenic machines which operate in accordance with different thermodynamic cycles with separate fluids, comprising:

first thermodynamic means for causing a first compressible refrigerating fluid medium to undergo a cycle in which it is subjected to the operations of, successively, compression, cooling, expansion, and reheating;

means for utilizing said reheating operation of said first thermodynamic means to extract a refrigerating effect from the compound machine; and

second thermodynamic means for causing a second compressible refrigerating fluid medium to undergo a cycle in which it is subjected to the operations of, successively, compression, cooling, expansion, and reheating;

said first and second thermodynamic means being so constituted and equipped so as to provide coupling means for coupling said first and second thermodynamic means in such a way that at least one of said operations of each of said first and second thermodynamic means brings about one of said operations of the other of said thermodynamic means.

7. A cryogenic machine according to claim 6, wherein said first thermodynamic means is of the type involving continuous circulation of said first fluid and comprises in particular an alternating expansion unit and wherein said second thermodynamic means is of the type involving alternate circulation of said second fluid, and in which said coupling means provided in said thermodynamic means is constituted by means for causing the variations in pressure of said second fluid to control said alternating expansion unit pneumatically.

8. A cryogenic machine according to claim 7, wherein said second thermodynamic means is of the heat accumulator type.

9. A cryogenic machine according to claim 8, wherein said first thermodynamic means comprises in particular an expansion piston and wherein said second thermodynamic means further comprises a displacer piston, said displacer piston being rigidly fixed to said expansion piston.

10. A cryogenic machine according to claim 9, wherein said machine comprises:

a casing for said first and second thermodynamic means in which the side walls of said casing are constituted at one end by a cover fitted with means for admission and discharge of said first fluid and at the other end by a moving piston;

an expansion-displacer piston, constituting in combined form said expansion piston and said displacer piston, which expander-displacer piston corresponds in shape to said casing walls and is capable of back-and-forth motion within said casing, said expansion-displacer piston being so arranged as to delimit at one end with said cover a first chamber (C_1) which is filled with said first fluid and at the other end with said moving piston a second chamber (C_2), at least one intermediate chamber (C') being delimited in the intermediate portion of said expansion-displacer piston at the level of the changes in diameter of said cylinders, said intermediate and second chambers (C' and C_2) being filled with said second fluid;

ducts providing a communication between said intermediate and second chambers (C' and C_2);

heat accumulators placed in the flow paths of said ducts;

means for supplying said first fluid under the conditions which are adapted to a continuous-circulation machine; and

mechanical means for actuating said moving piston.

11. A cryogenic machine according to claim 9, wherein said machine comprises:

a casing for said first and second thermodynamic means in which the side walls of said casing are constituted by cylinders having different diameters and which is closed at one end by a cover fitted with means for admission and discharge of said first fluid and at the other end by means for admission and discharge of said second fluid;

an expansion-displacer piston constituting in combined form said expansion piston and said displacer piston, which expansion-displacer piston corresponds in shape to said walls and is capable of back-and-forth motion within said casing, said expansion-displacer piston being so arranged as to delimit at one end with said cover a chamber (C_1) which is filled with said first fluid and at the other end with means for supplying said second fluid to a chamber (C_2), at least one chamber (C') being delimited in the intermediate portion of said expansion-displacer piston at the level of the changes in diameter of said cylinders;

ducts providing a communication between said intermediate and second chambers (C' and C_2);

heat accumulators located in the flow paths of said ducts;

means for supplying said first fluid under the conditions which are adapted to a continuous-circulation machine;

means for supplying said second fluid under the conditions which are adpated to an alternate-circulation machine.

12. A cryogenic machine according to claim 6, wherein the first and second fluids aforesaid are identical in composition.

13. A cryogenic machine according to claim 10, wherein said communication ducts between said intermediate and second chambers (C' and C_2) and the heat accumulators are located within the expansion-displacer piston.

14. A cryogenic machine according to claim 10, wherein the heat conducting and insulating portions of said first and second thermodynamic means are so disposed as to maintain the temperatures of said first chamber (C_1) and of one of said intermediate chambers (C') substantially equal.

15. A cryogenic machine according to claim 11, wherein said communication ducts between said intermediate and second chambers (C' and C_2) and the heat accumulators are located within the expansion-displacer piston.

16. A cryogenic machine according to claim 11, wherein the heat conducting and insulating portions of said first and second thermodynamic means are so disposed as to maintain the temperatures of said first chamber (C_1) and of one of said intermediate chambers (C') substantially equal.

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