(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 469 261 B1

(12) EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent:
17.12.2008 Bulletin 2008/51

(51) Int Cl.:
F25B 9/10 *(2006.01)* ***F28F 3/08*** *(2006.01)*

(21) Application number: **03076111.8**

(22) Date of filing: **15.04.2003**

(54) **A helium cooling system and a method of operating the same**

Helium- Kühlanlage und zugehöriges Betriebsverfahren

Système de refroidissement à l' helium et procédé pour son opération

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IT LI LU MC NL PT RO SE SI SK TR

(43) Date of publication of application:
20.10.2004 Bulletin 2004/43

(73) Proprietor: **L'AIR LIQUIDE, Société Anonyme pour l'Etude et l'Exploitation des Procédés Georges Claude**
75007 Paris (FR)

(72) Inventor: **Ravex, Alain**
38240 Meylan (FR)

(74) Representative: **Le Moenner, Gabriel et al**
L'AIR LIQUIDE
75, Quai d'Orsay
75321 Paris Cédex 07 (FR)

(56) References cited:
US-A- 2 856 756
US-A- 3 372 554
US-A- 5 101 894
US-A- 5 259 197
US-A- 5 298 337
US-A- 5 609 034
US-B1- 6 173 761

- **PATENT ABSTRACTS OF JAPAN vol. 2002, no. 07, 3 July 2002 (2002-07-03) -& JP 2002 071236 A (AISIN SEIKI CO LTD), 8 March 2002 (2002-03-08)**

EP 1 469 261 B1

Description

[0001] This invention relates to cryogenic cooling systems and, in particular, to helium cooling systems embodying a regenerator.

[0002] It is often desirable to cool devices, *e.g.*, semiconductor electronics, superconducting electronics, superconducting magnets, sub-Kelvin cooling stages, and the like, to low temperatures, such as temperatures near absolute zero. The cooling systems that provide cooling to such devices are inherently thermally linked to a room-temperature environment and/or intermediate temperature environments via various structures, *e.g.*, mechanical structures, electrical cabling and leads. The cooling capacity of such systems is also impacted by thermal radiation from the environment. These extraneous thermal sources result in a parasitic thermal load on the cooling system in addition to the thermal load created by the device or devices to be cooled. Additional thermal loads can cause power loss, cooling inefficiencies, and other problems that could be detrimental to a process or manufacturing operation.

[0003] Generally, such cooling systems are generally two-stage pulse tube, Stirling, or Gifford-McMahon type cooling systems having a first stage operating within a range of about 40K to about 100K and a second stage operating in the liquid helium temperature range, *i.e.*, about 2K to about 6K. It is generally desirable to reduce the parasitic heat load on the lowest temperature cooling stage to increase the overall efficiency of the system. Conventionally, this problem has been addressed by operating the first stage of the cooling system at the lowest achievable temperature, resulting in less heat being transferred to the second, or lower temperature, stage. Success by this method, however, is generally limited by the cooling capacity of the first, or upper temperature, stage. Furthermore, more inefficiency (*e.g.*, power and thermal inefficiencies) may result from this approach.

[0004] The problem has also been addressed by utilizing a three-stage cooling system having a second stage operating in the range of about 10K to about 20K. Such a system, however, is more costly and complex than a two-stage cooler and may have lower reliability.

[0005] The present invention is directed to overcoming, or at least reducing, the effects of one or more of the problems set forth above.

[0006] The invention concerns a cooling system according to claim 1.

[0007] The invention, concerns also a method of operating a cooling system according to claim 11.

[0008] A system or method according to the preamble of claims 1 and 11 is known from document JP(A) 2002071236.

[0009] The invention may be understood by reference to the following description taken in conjunction with the accompanying drawings, in which the leftmost significant digit(s) in the reference numerals denote(s) the first figure in which the respective reference numerals appear, and in which:

Figure 1 is a stylized diagram of an illustrative embodiment;

Figure 2 is a stylized diagram of the cooling system of Figure 1 having a heat intercept thermally linked to the heat exchanger according to the invention;

Figure 3A is a front view of a first illustrative embodiment of a heat exchanger according to the present invention;

Figure 3B is a side view of the heat exchanger of Figure 3A;

Figure 3C is a front view of a second illustrative embodiment of a heat exchanger according to the present invention;

Figure 3D is a side view of the heat exchanger of Figure 3C;

Figure 3E is a front view of a third illustrative embodiment of a heat exchanger according to the present invention;

Figure 3F is a side view of the heat exchanger of Figure 3E; and

Figures 4A-4D are block diagrams representing various illustrative embodiments of a method of extracting cooling power from helium in a regenerator.

[0010] Figure 1 depicts an illustrative embodiment of a cooling system 100. The cooling system 100 includes a compressor 102 in fluid communication with various helium gas flow control components, which are indicated generally as 104 in Figure 1. The flow control components 104 may include valves, orifices, reservoirs, and the like for controlling the flow of gaseous helium through the cooling system 100. The cooling system 100 further includes a first regenerator 106 in fluid communication with at least some of the flow control components 104 and with a first pulse tube 108 via a tube or line 110.

[0011] The first regenerator 106, and regenerators in general, is a type of heat exchanger that absorbs heat from the helium during a first part of the pressure cycle and returns heat to the helium during a second part of the pressure cycle to enhance the cooling power of the helium. The first pulse tube 106, and pulse tubes in general, function to cool the helium via changes in helium pressures therein. Generally, the first regenerator 106, the first pulse tube 108, and the line 110 comprise an upper stage 112 of the cooling system 100.

[0012] Generally, helium gas flows through the first regenerator 106, the line 110, and into the first pulse tube 108. In some embodiments, the gas may also flow through an orifice and into a reservoir, which are included in the flow control components 104. As the helium is compressed, heat in the helium gas is moved from a first end 114 of the first pulse tube 108 toward a second end 116 of the first pulse tube 108, where it is removed. Typically, temperatures proximate the first end 114 of the first pulse tube 108 may be greater than about 20K.

[0013] Still referring to Figure 1, the cooling system

100 further includes a second regenerator 118 in fluid communication with the first stage 112 and with a second pulse tube 120 via a line 122. The first regenerator 106 and the second regenerator 118 are shown in Figure 1 as being disposed in-line. However, those skilled in the art having benefit of the present disclosure would appreciate that the scope of the present invention is not so limited but rather may have any chosen spatial relationship between the first regenerator 106 and the second regenerator 118. In a similar fashion to that of the first stage, helium gas flows through the second regenerator 118, the line 122, and into the second pulse tube 120. In some embodiments, the gas may also flow through an orifice and into a reservoir, which are included in the flow control components 104. As the helium is compressed, heat in the helium gas is moved from a first end 124 of the second pulse tube 120 toward a second end 126 of the second pulse tube 120, where it is removed. Typically, temperatures proximate the first end 124 of the second pulse tube 120 may be within a range of about 2K to about 4K.

[0014] In the illustrated embodiment, a heat exchanger 128 is disposed between a first portion 130 and a second portion 132 of the regenerator 118. In one embodiment, the heat exchanger 128 is disposed with a physical area or zone of the regenerator 118 that operates within a temperature of about 8K to about 20K. The enthalpy difference of the helium is generally greatest within a temperature range of about 8K to about 20K. Generally, variations in the helium enthalpy may lead to thermal irreversibilities as the regenerator 118 is operated based upon temperature gradients. Thus, the regenerator 118 can become a source of cooling, via the heat exchanger 128, and the heat exchanger 128 extracts cooling power from helium flowing through the regenerator 118. In such an embodiment, the second regenerator 118, the line 122, the second pulse tube 120, and the heat exchanger 128 comprise a lower stage 134 of the cooling system 100.

[0015] One or more various components 136, such as mechanical structures, electrical cabling, leads, thermal shields, and/or other components linking the second stage 134 and the first stage 112 or linking the second stage 134 and the surrounding environment may be thermally linked to the heat exchanger 128 via a thermal link 138. Referring now to Figure 2 disclosing an embodiment of the claimed invention, the heat exchanger 128 may also be thermally coupled via a thermal link 202 to a thermal intercept 204 that is attached to, or inserted within, the second pulse tube 120. The thermal intercept 204 is generally designed for transmitting heat from the second pulse tube 120 to the thermal link 202. In one embodiment, the thermal intercept 204 is attached to the second pulse tube 120 within a physical area or zone thereof that operates within a temperature range of about 8K to about 20K. Generally, the thermal intercept 204 comprises a high thermally conductive material (e.g., copper, a copper alloy, aluminum, an aluminum alloy, or the like) wrapped around the second pulse tube 120 and/or inserted within the second pulse tube for more efficient thermal exchange. In one embodiment, the thermal intercept 204 has a configuration corresponding to that of the heat exchanger 128. In other words, the thermal intercept 204 may be disposed between two portions of the second pulse tube 120.

[0016] The thermal link 138 may comprise any desired thermally conductive structure for transmitting heat from the component 136 to the heat exchanger 128. For example, the thermal link 138 may comprise a metallic (*e.g.*, copper, a copper alloy, aluminum, an aluminum alloy, or the like) portion extending between the component 136 and the heat exchanger 128. In other embodiments, the thermal link may comprise a metallic (e.g., copper, a copper alloy, aluminum, an aluminum alloy, or the like) braid covering at least a portion of a cable or lead and extending to the heat exchanger 128. The thermal link may, in one embodiment, comprise a heat pipe extending between the component 136 and the heat exchanger 128. Generally, a heat pipe comprises a sealed container made of a high thermal conductivity material having inner surfaces with a capillary wicking material.

[0017] The heat exchanger 128 may comprise various configurations, such as those shown in Figures 3A-3F. For example, a first illustrative embodiment of the heat exchanger 128, shown in Figures 3A (front view) and 3B (side view), may comprise a plurality of plates 302 (only one is labeled for ease of illustration) defining a plurality of openings 304 (only one is labeled for ease of illustration) therethrough. In such an embodiment, the openings 304 defined by each plate 302 are generally aligned to allow fluid flowing through the second regenerator 118 to communicate therethrough, so that heat may be transferred to the helium from the walls of the openings 304.

[0018] Alternatively, a second illustrative embodiment of the heat exchanger 128, is shown in Figures 3C (front view) and 3D (side view). This second embodiment may comprise a block 306 defining a plurality of openings 308 (only one is labeled for ease of illustration) therethrough, such that fluid flowing through the second regenerator 118 may communicate through the openings 308. The second embodiment may, in certain situations, have greater thermal exchange capabilities and than the first embodiment, since the second embodiment omits interfaces between the plates 302. In each of the first and second embodiments, the heat exchanger 128 comprises a high thermal conductivity material, such as copper, a copper alloy, aluminum, or an aluminum alloy.

[0019] Figures 3E (front view) and 3F (side view) depict a third illustrative embodiment of the heat exchanger 128, which comprises a grid 310 of thermally conductive material (*e.g.*, copper, a copper alloy, aluminum, an aluminum alloy, or the like). The grid 310 defines openings 312 (only one indicated) that allow fluid flowing through the second regenerator 118 to communicate therethrough. The third embodiment may, in certain situations, have greater thermal exchange capabilities over the first and second embodiments due to a greater amount of surface area over which helium may flow.

[0020] The thermal intercept 204, in various embodiments, may have configurations corresponding to the embodiments of the heat exchanger 128 depicted in Figures 3A-3F. In other words, the thermal intercept 204 may be disposed within the pulse tube 120 and comprise a plurality of plates defining a plurality of openings therethrough, a block defining a plurality of openings therethrough, or a grid defining a plurality of openings therethrough. In each case, openings allow helium to flow therethrough and a thermal exchange occurs between the helium and the walls of the openings.

[0021] While the heat exchanger 128, the thermal links 138, 202, and the thermal intercept 204 are shown in Figures 1-3F as being used with a pulse tube type cooling system, the present invention is not so limited. Rather the heat exchanger 128, the thermal links 138, 202, and the thermal intercept 204 may be used with any cooling system having a regenerator-type device, such as Stirling cooling systems and Gifford-McMahon cooling systems.

[0022] Figure 4A depicts a first illustrative embodiment of a method of extracting cooling power from helium in the regenerator 118. The method includes flowing helium through the first portion 130 of the regenerator 118 (block 402) and flowing the helium through the heat exchanger 128 disposed between the first portion 130 and the second portion 132 of the regenerator 118 (block 404). The method further includes transferring heat from the component 136 via the thermal link 138 to the heat exchanger 128 (block 406).

[0023] Figure 4B depicts a second illustrative embodiment of a method of extracting cooling power from helium in the regenerator 118 according to the present invention. The method includes blocks 402, 404 as described above concerning Figure 4A. The method according to the claimed invention further includes transferring heat from the thermal intercept 204 coupled with the pulse tube 120 to the heat exchanger 128 via the thermal link 202 (block 408). In this way, heat may be extracted from the pulse tube 120 to enhance its cooling capabilities.

[0024] Figure 4C depicts a third illustrative embodiment of a method of extracting cooling power from helium in the regenerator 118 according to the present invention. The method includes blocks 402, 404 as described above concerning Figure 4A. The method further comprises transferring heat from the thermal intercept 204 coupled with a zone of the pulse tube 120 capable of operating within a temperature range of about 8K to about 20K to the heat exchanger 128 via the thermal link 202 (block 410). In this way, the cooling capability of the pulse tube 120 may be enhanced by taking advantage of the greatest enthalpy difference of helium within the pulse tube 120, which is within a temperature range of about 8K to about 20K.

[0025] Figure 4D depicts a fourth illustrative embodiment of a method of extracting cooling power from helium in the regenerator 118. The method includes blocks 402, 406 as described above concerning Figure 4A. The method further includes flowing helium having a temperature within a range of about 8K to about 20K through the heat exchanger 128, which is disposed between the first portion 130 and the second portion 132 of the regenerator 118. In this way, the cooling capability of the helium within the regenerator 118 may be enhanced by taking advantage of the greatest enthalpy difference of helium therein, which is within a temperature range of about 8K to about 20K.

[0026] While the embodiments concerning Figures 4A-4D have been described in relation to particular elements shown in Figures 1-3, the present invention is not so limited. Rather, the scope of the present invention encompasses the use of the various method embodiments disclosed herein with any chosen elements of a cooling system according to the claims.

[0027] Implementing the multi-stage cooling system illustrated by embodiments of the present invention to extract cooling power from helium provides for improved thermal efficiencies over the prior art systems by using previously unutilized cooling power of helium flowing through the regenerator 118 to cool one or more related components, thus decreasing the parasitic thermal load on the cooling system.

[0028] While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof have been shown by way of example in the drawings and are herein described in detail. It should be understood, however, that the description herein of specific embodiments is not intended to limit the invention to the particular forms disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the scope of the invention as defined by the appended claims.

Claims

1. A cooling system (100), comprising:

at least one regenerator (118) capable of allowing helium to flow therethrough;
a heat exchanger (128) disposed within the regenerator and being capable of extracting cooling power from the helium; and
a thermal link (138) coupled to the heat exchanger for thermally coupling the heat exchanger with a component (136), wherein the cooling system (100) further comprises :

a pulse tube (120) ; and **characterized by**
a heat intercept (204) thermally coupled with the pulse tube (120); and
a thermal link (202) coupling the heat exchanger (128) and the heat intercept (204).

2. A cooling system, according to claim 1, wherein the regenerator (118), the heat exchanger (128), and the thermal link (138) are part of a lower stage of the cooling system, which system further comprises an upper stage for delivering cooled helium to the lower stage.

3. A cooling system, according to claim 1 or 2, wherein the component (136) comprises a component of the cooling system.

4. A cooling system, according to any of claims 1-3, wherein the heat exchanger (128) comprises a material selected from the group consisting of copper, a copper alloy, aluminum, and an aluminum alloy.

5. A cooling system, according to any of claims 1-4, wherein the heat exchanger (128) comprises a structure defining a plurality of openings therethrough for communication of the helium so that cooling power may be extracted from the helium.

6. A cooling system, according to any of claims 1-5, wherein the thermal link (138) comprises a heat pipe.

7. A cooling system, according to any of claims 1-6, wherein the heat exchanger (128) is disposed within a zone of the regenerator capable of operating within a temperature range of about 8K to about 20K.

8. A cooling system, according to any of claims 1-7, wherein the cooling system (100) comprises a pulse tube cooling system.

9. A cooling system, according to any of claims 1-8, wherein the cooling system (100) comprises a Stirling cooling system.

10. A cooling system, according to any of claims 1-9, wherein the cooling system (100) comprises a Gifford-McMahon cooling system.

11. A method of operating a cooling system (100) using helium as a working fluid for cooling a device (136), the cooler having first and second cooler stages each having a regenerator (106, 118), the pressure in the second stage oscillating between about 1×10^5 Pa and 1×10^6 Pa in a temperature range between 2 K and 50 K, comprising the step of establishing heat exchange relationship between a zone of the regenerator (128) of the second stage having a temperature within a first temperature range and a mechanical link linking the cooler to the device (136) and having a mean temperature greater than the first temperature range, wherein the cooling system (100) further comprises :

a pulse tube (120) ; and **characterized by**
a heat intercept (204) thermally coupled with the pulse tube (120); and
a thermal link (202) coupling the heat exchanger (128) and the heat intercept (204).

12. The method of claim 11, wherein the zone of the second stage regenerator is selected to be at a working temperature between 8 and 20 K.

Patentansprüche

1. Kühlsystem (100), das Folgendes umfasst:

mindestens einen Regenerator (118), der einen Durchfluss von Helium **dadurch** gestatten kann;
einen in dem Regenerator angeordneten Wärmetauscher (128), der Kühlleistung aus dem Helium extrahieren kann; und
eine an den Wärmetauscher gekoppelte thermische Verbindung (138) zur thermischen Kopplung des Wärmetauschers an eine Komponente (136), wobei das Kühlsystem (100) weiterhin ein Pulsationsrohr (120) umfasst;
gekennzeichnet durch
eine Wärmeunterbrechung (204), die thermisch an das Pulsationsrohr (120) gekoppelt ist; und
eine an den Wärmetauscher (128) und an die Wärmeunterbrechung (204) gekoppelte thermische Verbindung (202).

2. Kühlsystem nach Anspruch 1, wobei der Regenerator (118), der Wärmetauscher (128) und die thermische Verbindung (138) Teil einer unteren Stufe des Kühlsystems sind, wobei das System weiterhin eine obere Stufe zur Zufuhr von gekühltem Helium zur unteren Stufe umfasst.

3. Kühlsystem nach Anspruch 1 oder 2, wobei die Komponente (136) eine Komponente des Kühlsystems umfasst.

4. Kühlsystem nach einem der Ansprüche 1 - 3, wobei der Wärmetauscher (128) ein aus der aus Kupfer, einer Kupferlegierung, Aluminium und einer Aluminiumlegierung bestehenden Gruppe ausgewähltes Material umfasst.

5. Kühlsystem nach einem der Ansprüche 1 - 4, wobei der Wärmetauscher (128) eine Struktur umfasst, die mehrere Öffnungen **dadurch** zur Übertragung des Heliums definiert, so dass Kühlleistung aus dem Helium extrahiert werden kann.

6. Kühlsystem nach einem der Ansprüche 1 - 5, wobei die thermische Verbindung (138) ein Wärmerohr umfasst.

7. Kühlsystem nach einem der Ansprüche 1 - 6, wobei der Wärmetauscher (128) in einem Bereich des Regenerators angeordnet ist, der in einem Temperaturbereich von ca. 8 K bis ca. 20 K betrieben werden kann.

8. Kühlsystem nach einem der Ansprüche 1 - 7, wobei das Kühlsystem (100) ein Pulsationsrohrkühlsystem umfasst.

9. Kühlsystem nach einem der Ansprüche 1 - 8, wobei das Kühlsystem (100) ein Stirling-Kühlsystem umfasst.

10. Kühlsystem nach einem der Ansprüche 1 - 9, wobei das Kühlsystem (100) ein Gifford-McMahon-Kühlssystem umfasst.

11. Verfahren zum Betrieb eines Helium als Arbeitsfluid zum Kühlen einer Vorrichtung (136) verwendenden Kühlsystems (100), wobei der Kühler eine erste und eine zweite Kühlstufe aufweist, die jeweils einen Regenerator (106, 118) aufweisen, wobei der Druck in der zweiten Stufe in einem Temperaturbereich zwischen 2 K und 50 K zwischen ca. 1 x 10^5 Pa und 1 x 10^6 Pa schwankt, mit dem Schritt des Herstellens einer Wärmeaustauschbeziehung zwischen einem Bereich des Regenerators (128) der zweiten Stufe, der eine Temperatur in einem ersten Temperaturbereich aufweist, und einer mechanischen Verbindung, die den Kühler mit der Vorrichtung (136) verbindet und eine mittlere Temperatur aufweist, die höher ist als der erste Temperaturbereich, wobei das Kühlsystem (100) weiterhin ein Pulsationsrohr (120) umfasst und **gekennzeichnet ist durch** eine Wärmeunterbrechung (204), die thermisch an das Pulsationsrohr (120) gekoppelt ist, und eine thermische Verbindung (202), die den Wärmetauscher (128) an die Wärmeunterbrechung (204) koppelt.

12. Verfahren nach Anspruch 11, wobei der Bereich des Regenerators der zweiten Stufe so ausgewählt wird, dass er eine Arbeitstemperatur zwischen 8 und 20 K aufweist.

Revendications

1. Système de refroidissement (100), comprenant:

   au moins un régénérateur (118) capable de permettre un écoulement d'hélium à travers celui-ci;
   un échangeur de chaleur (128) disposé à l'intérieur du régénérateur et capable d'extraire une puissance de refroidissement de l'hélium; et
   une liaison thermique (138) couplée à l'échangeur de chaleur pour relier thermiquement l'échangeur de chaleur à un composant (136),
   dans lequel le système de refroidissement (100) comprend en outre:

   un tube à pulsion (120),
   et **caractérisé par**:

   un intercepteur de chaleur (204) relié thermiquement au tube à pulsion (120); et
   une liaison thermique (202) reliant l'échangeur de chaleur (128) et l'intercepteur de chaleur (204).

2. Système de refroidissement selon la revendication 1, dans lequel le régénérateur (118), l'échangeur de chaleur (128) et la liaison thermique (138) font partie d'un étage inférieur du système de refroidissement, ledit système comprenant en outre un étage supérieur pour délivrer l'hélium refroidi à l'étage inférieur.

3. Système de refroidissement selon la revendication 1 ou 2, dans lequel le composant (136) comprend un composant du système de refroidissement.

4. Système de refroidissement selon l'une quelconque des revendications 1 à 3, dans lequel l'échangeur de chaleur (128) comprend une matière sélectionnée dans le groupe comprenant le cuivre, un alliage de cuivre, l'aluminium et un alliage d'aluminium.

5. Système de refroidissement selon l'une quelconque des revendications 1 à 4, dans lequel l'échangeur de chaleur (128) comprend une structure qui définit à travers elle une pluralité d'ouvertures pour la communication de l'hélium de telle sorte qu'une puissance de refroidissement puisse être extraite de l'hélium.

6. Système de refroidissement selon l'une quelconque des revendications 1 à 5, dans lequel la liaison thermique (138) comprend un caloduc.

7. Système de refroidissement selon l'une quelconque des revendications 1 à 6, dans lequel l'échangeur de chaleur (128) est disposé à l'intérieur d'une zone du régénérateur qui est capable de fonctionner à l'intérieur d'une plage de température d'environ 8 K à environ 20 K.

8. Système de refroidissement selon l'une quelconque des revendications 1 à 7, dans lequel le système de refroidissement (100) comprend un système de refroidissement à tube de pulsion.

9. Système de refroidissement selon l'une quelconque des revendications 1 à 8, dans lequel le système de refroidissement (100) comprend un système de re-

froidissement Stirling.

10. Système de refroidissement selon l'une quelconque des revendications 1 à 9, dans lequel le système de refroidissement (100) comprend un système de refroidissement Gifford - McMahon.

11. Procédé de fonctionnement d'un système de refroidissement (100) qui utilise de l'hélium comme fluide de travail pour refroidir un dispositif (136), le refroidisseur comprenant un premier étage de refroidisseur et un deuxième étage de refroidisseur comprenant chacun un régénérateur (106, 118), la pression dans le deuxième étage oscillant entre 1 x 10^5 Pa et 1 x 10^6 Pa dans une plage de température comprise entre 2 K et 50 K, comprenant l'étape consistant à établir une relation d'échange de chaleur entre une zone du régénérateur (128) du deuxième étage dont la température se situe à l'intérieur d'une première plage de température, et une liaison mécanique qui relie le refroidisseur au dispositif (136) et qui présente une température moyenne supérieure à la première plage de température, dans lequel le système de refroidissement (100) comprend en outre:

un tube à pulsion (120),
et **caractérisé par**:

un intercepteur de chaleur (204) relié thermiquement au tube à pulsion (120); et
une liaison thermique (202) reliant l'échangeur de chaleur (128) et l'intercepteur de chaleur (204).

12. Procédé selon la revendication 11, dans lequel la zone du régénérateur du deuxième étage est sélectionnée pour se trouver à une température de travail comprise entre 8 K et 20 K.

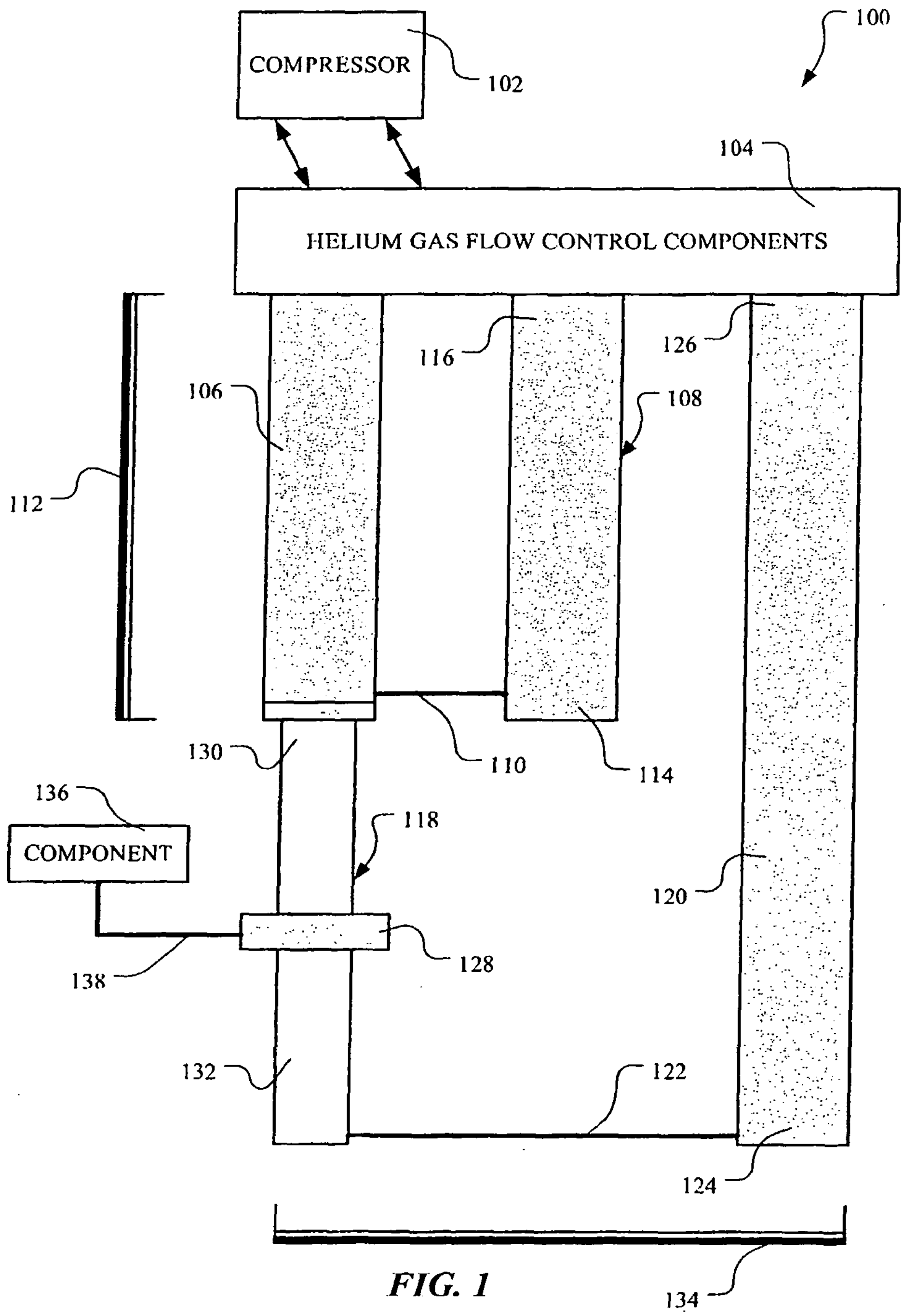
COMPRESSOR
102
100
104
HELIUM GAS FLOW CONTROL COMPONENTS
116
126
106
108
112
130
110
114
136
118
COMPONENT
120
128
138
132
122
124
134

FIG. 1

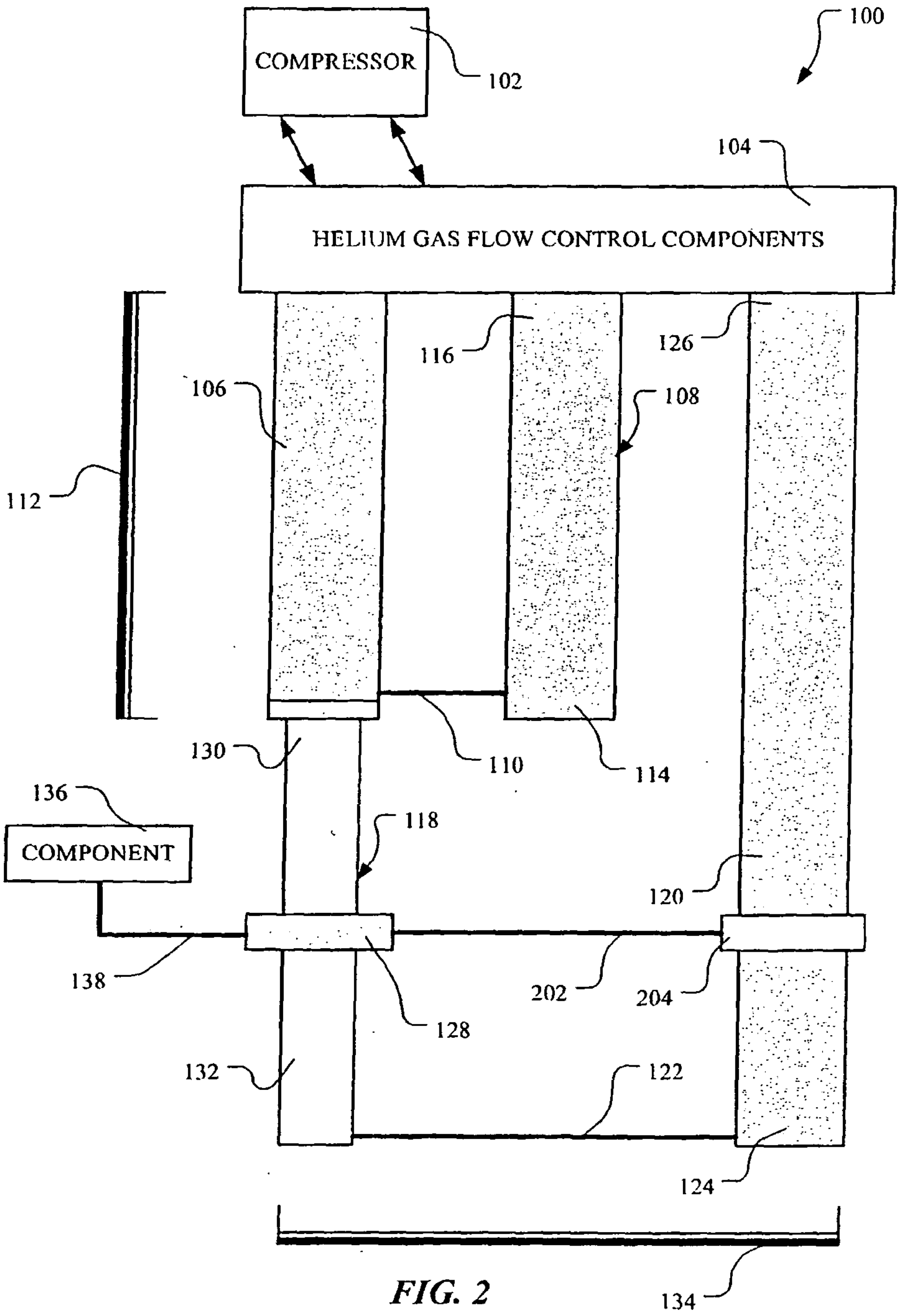
100
COMPRESSOR
102
104
HELIUM GAS FLOW CONTROL COMPONENTS
116
126
106
108
112
130
110
114
136
118
COMPONENT
120
138
202
204
128
132
122
124
134

FIG. 2

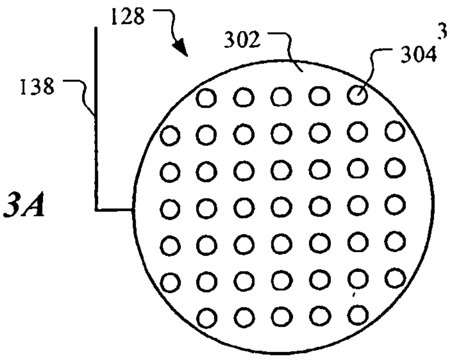

FIG. 3A

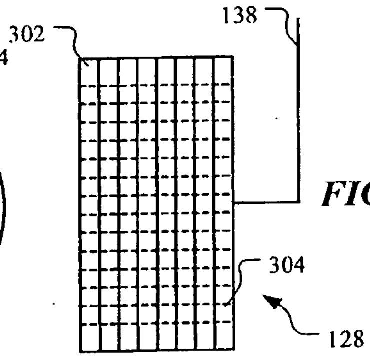

FIG. 3B

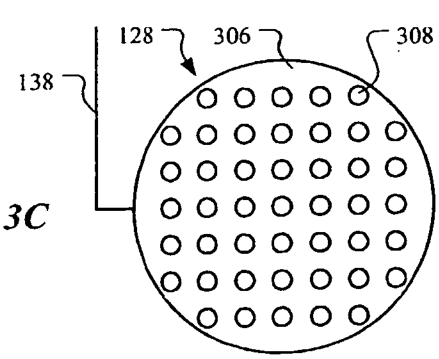

FIG. 3C

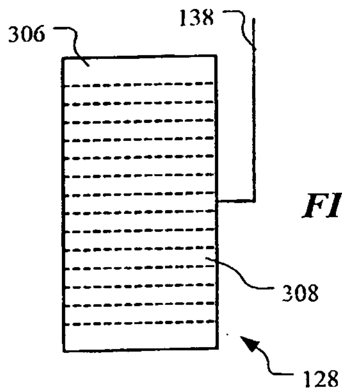

FIG. 3D

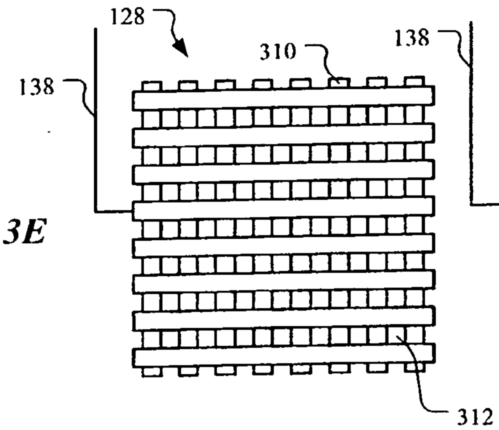

FIG. 3E

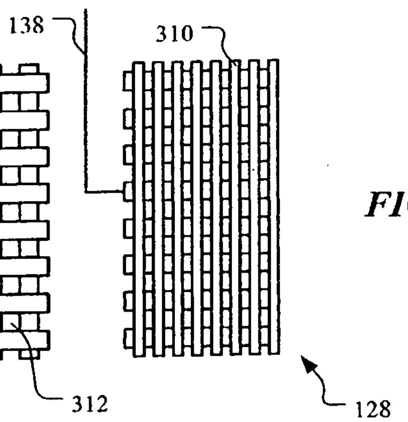

FIG. 3F

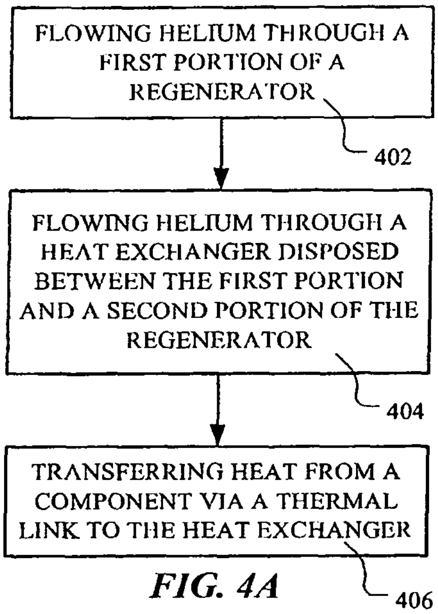

FIG. 4A

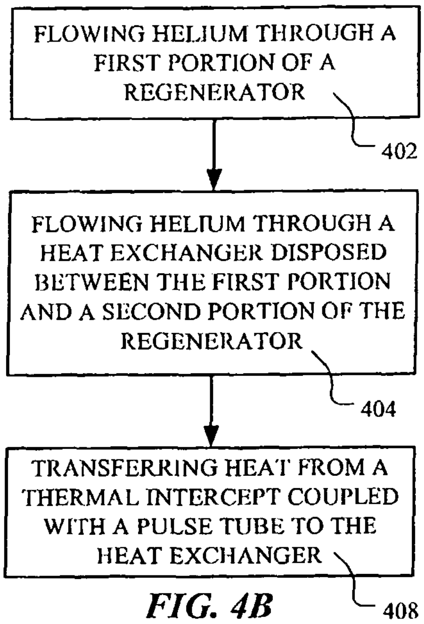

FIG. 4B

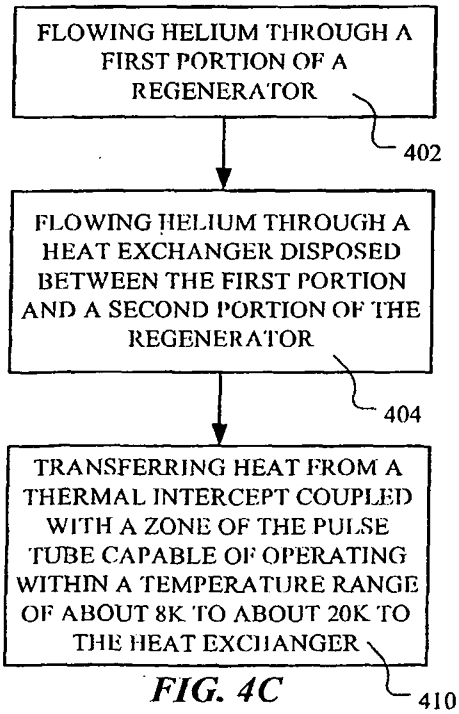

FIG. 4C

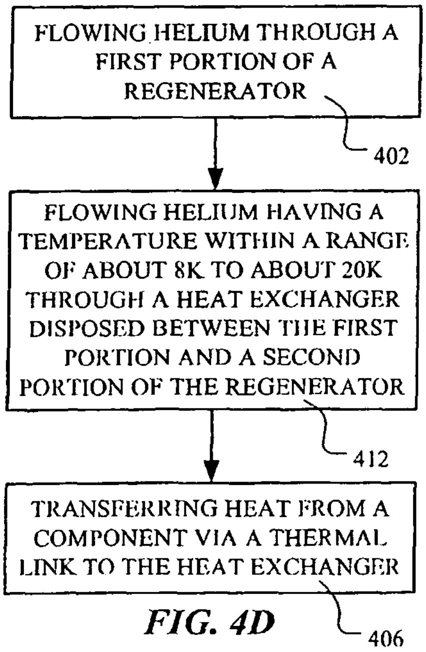

FIG. 4D

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP 2002071236 A **[0008]**