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(54) **G-M REFRIGERATOR WITH PHASE ADJUSTING MECHANISM**

(57) A G-M refrigerator comprises a compressor (1), a gas inlet valve (2), an exhaust valve (3), a regenerator (4), a cylinder (5), a piston (6), a hot cavity (7), a cold cavity (8), a seal ring (9), a driving mechanism (10-12), an annular gap (13), a heat exchanger (14), an orifice valve (18) and a gas reservoir (19). By introducing a phase modulation mechanism, such as the orifice valve (18), the gas reservoir (19) and the like, the working way of gas in the annular gap (13) is changed to be the same with that of a pulse tube refrigerator with the phase modulation mechanism, expansion of the part of the gas is fully utilized for doing work so as to generate the cold effect, loss caused by gas leakage through the seal ring (9) is further eliminated and the performances of the G-M refrigerator are further improved.

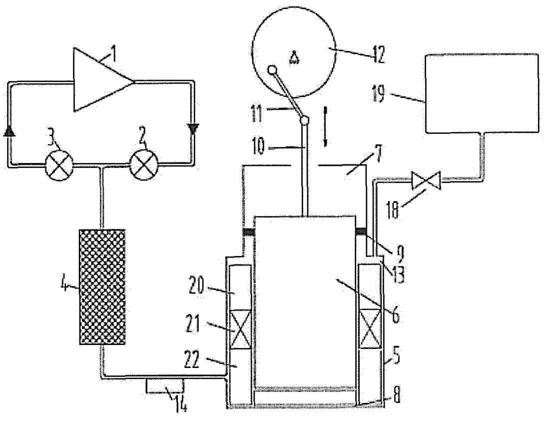

Figure 1

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Description

Technical Field

[0001] The invention relates to a cryogenic refrigerator, particularly relates to a regenerative cryogenic refrigerator and specifically relates to a G-M refrigerator with a phase modulation mechanism.

Background of the Invention

[0002] G-M refrigeration cycle was jointly invented by Gifford and Mcmahon, and the principle of the G-M refrigeration cycle is to utilize deflation of heat insulation gas for refrigeration. At present, a G-M refrigerator has been widely applied in cryogenic pumps and cooling of a variety of superconducting magnets. When in application, a cold head of the refrigerator is generally used for direct contact or a material with high heat conductivity is used as a heat bridge for realizing the cooling effect.

[0003] At present, a gap exists between the cylinder wall and the piston of the G-M refrigerator which is widely used, pressure in the refrigerator changes periodically and the gap can cause pump gas loss. Seal rings are arranged at the hot ends of the piston and the cylinder for sealing, while the cold ends of the piston and the cylinder are open. When a cold cavity is positioned in low pressure, the gas amount in the gap is minimal, when the pressure rises, some cold gas enters into the gap, heat is absorbed from the cylinder wall and the piston till the highest pressure is achieved, when the pressure drops down in the next cycle, the gas returns into the cold cavity and then the absorbed heat is brought to the cold cavity and loss of cold energy is caused.

[0004] In addition, the seal rings can move in the cylinder along with the piston in a reciprocating manner, the sealing between the seal ring and the cylinder, as well as between the seal ring and the piston is non-tight, the high-temperature gas in a hot cavity can be leaked to the cold cavity through the seal rings and the low-temperature gas in the cold cavity can be leaked to the hot cavity through the seal rings, which cause the loss of the cold energy, namely the loss of gas leakage. Along with the increase in operation time of the refrigerator, abrasion of the seal rings will become serious gradually, the sealing between the seal ring and the cylinder, as well as between the seal ring and the piston will become more and more loose, the gas leakage amount through the seal rings will be more and more and the generated loss of the cold energy will also be more and more. In addition, friction heat generated by sliding sealing of the seal rings in the cylinder can also cause the loss of the cold energy.

[0005] The loss of the cold energy seriously affects the performances of the refrigerator, thereby being difficult to meet testing and application requirements of low-temperature superconducting.

Summary of the Invention

[0006] The invention aims at providing a G-M refrigerator with a phase modulation mechanism by introducing the phase modulation mechanism. The G-M refrigerator with the phase modulation mechanism can solve the following technical problems: the working process of gas in a gap between the piston and the cylinder of the G-M refrigerator is changed, expansion of the part of the gas is fully utilized for doing work, loss of gas leakage through a seal ring is further prevented and the G-M refrigerator can further obtain better performances.

[0007] The technical scheme of the invention is as follows:

> A G-M refrigerator with a phase modulation mechanism is characterized by comprising a compressor, a gas inlet valve, an exhaust valve, a regenerator, a cylinder, a piston, a hot cavity, a cold cavity, a driving mechanism, an annular gap and a heat exchanger, wherein the gas outlet end of the compressor is connected with the gas inlet valve, the gas inlet end of the compressor is connected with the exhaust valve, the gas inlet valve, the exhaust valve and the regenerator are communicated and connected, the regenerator is communicated and connected with the cylinder, and the heat exchanger is arranged between the regenerator and the cylinder; the piston is arranged in the cylinder, the cold cavity is arranged below the piston, the hot cavity is arranged above the piston, the annular gap is arranged between the piston and the inner wall of the cylinder, and the driving mechanism is connected on the piston; and the annular gap is communicated with the phase modulation mechanism.

[0008] The annular gap can be divided into hot-end gas, a gas piston and cold-end gas.

[0009] The phase modulation mechanism comprises an orifice valve and a gas reservoir, and the annular gap is communicated with the gas reservoir through the orifice valve; and a seal ring is arranged between the piston and the cylinder in the position above the annular gap.

[0010] The phase modulation mechanism is an orifice gas reservoir structure communicated with the hot end of the cylinder or a two-way gas inlet mechanism or a four-valve mechanism or other phase modulation mechanisms which are more effective.

[0011] The phase modulation mechanism can be built-in type and comprises a built-in orifice valve and the gas reservoir, the built-in orifice valve is placed in the annular gap at the hot end of the piston, and the hot cavity is used as the gas reservoir of the phase modulation mechanism.

[0012] Both the gas inlet valve and the exhaust valve are arranged at room temperature. Regenerative packing is arranged in the regenerator.

[0013] The driving mechanism connected on the piston is a crank and connecting rod driving mechanism and the driving mechanism comprises a piston rod, a connecting rod and a crank.

[0014] The invention has the following benefits:

By introducing the phase modulation mechanism, the working process of the gas in the annular gap is changed, the expansion of the part of the gas is fully utilized for doing work, the loss of the gas leakage through the seal ring is further prevented and the G-M refrigerator can further obtain better performances.

Brief Description of the Drawings

[0015]

Figure 1 is a schematic diagram of G-M refrigerator with phase modulation mechanism of the invention.
Figure 2 is a working process diagram I of gas in annular gap after introducing phase modulation mechanism into G-M refrigerator.
Figure 3 is a working process diagram II of gas in annular gap after introducing phase modulation mechanism into G-M refrigerator.
Figure 4 is a working process diagram III of gas in annular gap after introducing phase modulation mechanism into G-M refrigerator.
Figure 5 is a system diagram of G-M refrigerator with built-in phase modulation mechanism.
Figure 6 is a system diagram of second stage of two-stage G-M refrigerator after introducing phase modulation mechanism.

Detailed Description of the Invention

[0016] In combination of the figures and the embodiment, the invention is further described as follows.

[0017] As shown in Figure 1, a G-M refrigerator with a phase modulation mechanism comprises a compressor 1, a gas inlet valve 2, an exhaust valve 3, a regenerator 4, a cylinder 5, a piston 6, a hot cavity 7, a cold cavity 8, a driving mechanism, an annular gap 13 and a heat exchanger 14, wherein the gas outlet end of the compressor 1 is connected with the gas inlet valve 2, the gas inlet end of the compressor 1 is connected with the exhaust valve 3, the gas inlet valve 2, the exhaust valve 3 and the regenerator 4 are communicated and connected, the regenerator 4 is communicated and connected with the cylinder 5, and the heat exchanger 14 is arranged between the regenerator 4 and the cylinder 5; the piston 6 is arranged in the cylinder 5, the cold cavity 8 is arranged below the piston 6, the hot cavity 7 is arranged above the piston 6, the annular gap 13 is arranged between the piston 6 and the inner wall of the cylinder 5, and the driving mechanism is connected on the piston 6; and the annular gap 13 is communicated with the phase modulation mechanism.

[0018] Gas in the annular gap 13 can be divided into hot-end gas 20, a gas piston 21 and cold-end gas 22.The hot-end gas is arranged above the gas piston 21 and the cold-end gas is arranged below the gas piston 21.

[0019] The phase modulation mechanism comprises an orifice valve 18 and a gas reservoir 19, and the annular gap 13 is communicated with the gas reservoir 19 through the orifice valve 18; and a seal ring 9 is arranged between the piston 6 and the cylinder 5 in the position above the annular gap 13, namely the annular gap 13 is closed by the inner wall of the cylinder 5, the outer wall of the piston 6, the seal ring 9 and the like. The phase modulation mechanism is used for regulating the phase relationship of the working gas in the annular gap 13 so as to improve the performances of the G-M refrigerator.

[0020] The phase modulation mechanism of the invention can also be a two-way gas inlet mechanism which is communicated with the hot end of the cylinder 6 or a four-way mechanism or other phase modulation mechanisms which are more effective.

[0021] The driving mechanism connected on the piston 6 is a crank and connecting rod driving mechanism and the driving mechanism comprises a piston rod 10, a connecting rod 11 and a crank 12.

[0022] Another implementation way of the invention, namely a system diagram of a G-M refrigerator with a built-in phase modulation mechanism, is as shown in Figure 5. The phase modulation mechanism comprises a built-in orifice valve 23 and the gas reservoir, the built-in orifice valve 23 is placed in the annular gap 13 at the hot end of the piston 6, and the hot cavity 7 is used as the gas reservoir of the phase modulation mechanism.

[0023] Both the gas inlet valve 2 and the exhaust valve 3 are arranged at room temperature. A machine is used for controlling the gas inlet valve 2 and the exhaust valve 3 to open and close so as to control the gas flow passing through the regenerator 4 and cylinder 5, as well as cyclic pressure and volume.

[0024] Regenerative packing is arranged in the regenerator 4. Cold gas flow and hot gas flow alternately flow through the regenerator 4 so as to realize the effects of storing and recycling cold energy. The heat exchange purpose between the hot gas flow and the hot gas flow is achieved through the effect, and huge temperature difference between room temperature and the cold end of the refrigerator is further set up.

[0025] The driving mechanism can enable the piston 6 to move up and down in a reciprocating manner in the cylinder 5, which is as shown by a two-way arrow in Figure 1. The piston 6 is arranged in the cylinder 5; and the piston 6 is driven by the crank and connecting rod mechanism to move up and down in the cylinder 5 in a reciprocating manner, which is as shown by a two-way arrow in Figure 6, thereby causing the effective volume hot cavity 7 and the cold cavity 8, which are arranged at the two ends of the cylinder. The two are separated by the seal ring 9, the piston 6 and the cylinder 5.

[0026] The hot cavity 7 is arranged at room temperature and the cold cavity 8 is arranged at low temperature.

Therefore, the piston 6 and the cylinder 5 bear huge longitudinal temperature gradient and are made of materials with poor heat conductivity. The cylinder 5 generally selects stainless steel as the material, thereby having sufficient strength and low heat conductivity; while the piston 6 generally selects bakelite as the material, thereby being capable of reducing heat conduction loss, as the specific gravity of the bakelite is smaller than that of the stainless steel, the weight of the piston 6 is light, the reciprocating inertial force can be reduced; furthermore, the hardness of the bakelite is small, the inner wall of the cylinder 5 can not be scratched. The working process of the G-M refrigerator is briefly described as follows: a control mechanism can enable the piston 6 to be positioned at the bottom of the cylinder 5 at the beginning, and the gas inlet valve 2 is simultaneously opened. The high-pressure gas from the compressor 1 enters into the regenerator 4 and the pressure of the regenerator 4 rises. After the pressure is balanced, the piston moves upwards from the bottom of the cylinder 5, and the high-pressure gas which is cooled by the regenerator 4 simultaneously enters into the cold cavity 8. When the piston 6 moves to the top of the cylinder 5, the gas inlet valve is closed. The exhaust valve is opened so as to communicate the gas of the cold cavity 8 with the low-pressure end via the heat exchanger 14 and the regenerator 4. At this time, the high-pressure gas in the cold cavity is deflated to the low-pressure side, then the cold energy is obtained and the cold energy is transferred to outside via the heat exchanger 14. The gas is heated by the regenerator 4 and then returns to the compressor. At the same time, the piston 6 is returned to the bottom of the cylinder 5 and the exhaust valve is closed. Therefore, the process is repeated again and again, the whole system can work continuously and the cold energy can be obtained continuously.

[0027] In a pulse tube refrigerator, an orifice gas reservoir and other phase modulation structures can regulate the phase relationship between the mass flow and the pressure waves of the working gas and further improve the performances of the pulse tube refrigerator.

[0028] The phase modulation mechanism is introduced into the G-M refrigerator in the invention, as shown in Figure 2, Figure 3 and Figure 4, thereby regulating the working process of the working gas in the annular gap 13. The gas in the annular gap 13 can be divided into thee parts, namely the hot-end gas 20, the gas piston 21 and the cold-end gas 22. When the gas in the annular gap 13 is compressed, the hot-end gas 20 is pressed into the gas reservoir 19 through the gas piston 21, and the position of the gas piston 21 at the end of compression is as shown in Figure 2; in a similar way, during the expansion refrigeration stage, the cold-end gas 22 expands in the cold cavity 8, and the piston of the gas piston 21 at the end of expansion is as shown in Figure 4; and Figure 3 shows the balanced position of the gas piston 21 during the compression or the expansion process. The working process of the annular gap 13 is the same with that of the pulse tube refrigerator with the phase modulation mechanism, the working gas in the annular gap 13 is changed from the original situation of causing the loss of the cold energy to the expansion for doing work so as to generate the cold effect, and then the G-M refrigerator can obtain better performances. In addition, the gas piston 21 also prevents the loss of the gas leakage through the seal ring 9.

[0029] Figure 6 is a system diagram of the second stage of a two-stage G-M refrigerator after introducing a phase modulation mechanism.

[0030] A two-stage G-M refrigerator by introducing a phase modulation mechanism into the second stage comprises a compressor 1, a gas inlet valve 2, an exhaust valve 3, a first-stage cylinder 24, a first-stage piston 25, a first-stage seal ring 26, a first-stage cold cavity 27, a second-stage cylinder 28, a second-stage piston 29 and a second-stage cold cavity 30. The first-stage cold cavity 27 can be regarded as a second-stage hot cavity and a second-stage gas reservoir.

[0031] The compressor 1 is used for providing high-pressure gas refrigerant, such as high-pressure helium.

[0032] Both the gas inlet valve 2 and the exhaust valve 3 are arranged at room temperature, and a machine is used for controlling the gas inlet valve 2 and the exhaust valve 3 to open and close so as to control the gas flow passing through the first-stage piston 25, the second-stage piston 26, the first-stage cylinder 24 and the second-stage cylinder 28, as well as cyclic pressure and volume.

[0033] The first-stage cylinder 24 and the second-stage cylinder 28 are made of stainless steel, and the first-stage cylinder 24 and the second-stage cylinder 28 can form an integral structure.

[0034] The second-stage piston 29 comprises a top cover 31, a bottom cover 32, a second-stage piston barrel 33, second-stage regenerative packing 34, hard silk screens 35-36, a felt 37 and the like; the second-stage piston 29 is in clearance fit with the wall of the second-stage cylinder 28, and the clearance, which is 0.01-0.03mm, can not only ensure the free reciprocating motion of the piston in the cylinder, but also prevent the gas in the second-stage cold cavity 30 from entering into the second-stage hot cavity 27; and the length of the second-stage piston 29 is the same with that of the second-stage cylinder 28.

[0035] A flow passage 38 for communicating the interior of the second-stage piston 29 with the second-stage cold cavity 30 is communicated on the bottom cover 32, the outer diameter of the bottom cover 32 is 0.05mm smaller than the outer diameter of the second-stage piston 29, and then a clearance is formed between the top cover 32 and the wall of the second-stage cylinder 28 so as to enable the working gas to be capable of entering into and getting out of the second-stage cold cavity 30 and the second-stage piston 29.

[0036] A channel 39 is arranged on the top cover 31 and the first-stage piston for communicating the first-stage cold cavity 27 with the interior of the second-stage piston 29 and connected to the first-stage piston 25, and can further move up and down in a reciprocating manner along with the first-stage piston 25;

[0037] A spiral groove 40 is formed on the piston barrel 33, the spiral groove 40 starts from the bottom end of the piston barrel 33 and extends to the position which is about 30mm away from the top end of the top cover 31, and a straight groove 41 is formed from the tail end of the spiral groove 40 to the top end of the top cover 31.

[0038] The second-stage regenerative packing 34, such as a lead ball, is arranged in the second-stage piston 29, the bottom end is firmly sealed by the hard silk screens 35-36 and the felt 37, and the top end is firmly sealed by adopting the same way; and the second-stage regenerative packing 34 can also adopt other types of regenerative packing, such as magnetic regenerative packing and the like, and the second-stage regenerative packing 34 can also adopt multiple layers of different types of the regenerative packing.

[0039] When in specific work, the straight groove 41 can be regarded as the orifice valve 18; the first-stage cold cavity 27 can be regarded as the gas reservoir 19; the volume surrounded by the second-stage piston barrel 33 and the wall of the second-stage cylinder 28 can be regarded as a pulse tube 17; and then the phase modulation mechanism is introduced into the second stage of the two-stage G-M refrigerator, a second-stage seal ring is simultaneously removed, the working process of the annular gap 13 is changed to the working process of the pulse tube refrigerator with the phase modulation mechanism, the expansion of the part of the gas is fully utilized for generating the cold effect, the loss of the gas leakage and friction loss through the seal ring can be further eliminated and the performances of the G-M refrigerator are further improved.

[0040] The embodiment only simply introduces the phase modulation way of the orifice gas reservoir structure, in order to obtain better performances, the sizes of the orifice and the gas reservoir can be precisely calculated, or other more effective phase modulation ways, such as two-way gas inlet, four-valve structure and the like, can be further introduced.

[0041] The non-involved parts are the same with the prior art or can be realized by adopting the prior art.

Claims

1. A G-M refrigerator with a phase modulation mechanism, **characterized by** comprising a compressor (1), a gas inlet valve (2), an exhaust valve (3), a regenerator (4), a cylinder (5), a piston (6), a hot cavity (7), a cold cavity (8), a driving mechanism, an annular gap (13) and a heat exchanger (14), wherein the gas outlet end of the compressor (1) is connected with the gas inlet valve (2), the gas inlet end of the compressor (1) is connected with the exhaust valve (3), the gas inlet valve (2), the exhaust valve (3) and the regenerator (4) are communicated and connected, the regenerator (4) is communicated and connected with the cylinder (5), and the heat exchanger (14) is arranged between the regenerator (4) and the cylinder (5); the piston (6) is arranged in the cylinder (5), the cold cavity (8) is arranged below the piston (6), the hot cavity (7) is arranged above the piston (6), the annular gap (13) is arranged between the piston (6) and the inner wall of the cylinder (5), and the driving mechanism is connected on the piston (6); and the annular gap (13) is communicated with the phase modulation mechanism.

2. The G-M refrigerator with the phase modulation mechanism according to claim 1, **characterized in that** the annular gap (13) can be divided into hot-end gas (20), a gas piston (21) and cold-end gas (22).

3. The G-M refrigerator with the phase modulation mechanism according to claim 1, **characterized in that** the phase modulation mechanism comprises an orifice valve (18) and a gas reservoir (19), and the annular gap (13) is communicated with the gas reservoir (19) through the orifice valve (18); and a seal ring (9) is arranged between the piston (6) and the cylinder (5) in the position above the annular gap (13).

4. The G-M refrigerator with the phase modulation mechanism according to claim 1, **characterized in that** the phase modulation mechanism is an orifice gas reservoir structure communicated with the hot end of the cylinder (6) or a two-way gas inlet mechanism or a four-valve mechanism or other phase modulation mechanisms which are more effective.

5. The G-M refrigerator with the phase modulation mechanism according to claim 1, **characterized in that** the phase modulation mechanism can be built-in type and comprises a built-in orifice valve (23) and the gas reservoir, the built-in orifice valve (23) is placed in the annular gap (13) at the hot end of the piston (6) and the hot cavity (7) is used as the gas reservoir of the phase modulation mechanism.

6. The G-M refrigerator with the phase modulation mechanism according to claim 1, **characterized in that** both the gas inlet valve (2) and the exhaust valve (3) are arranged at room temperature.

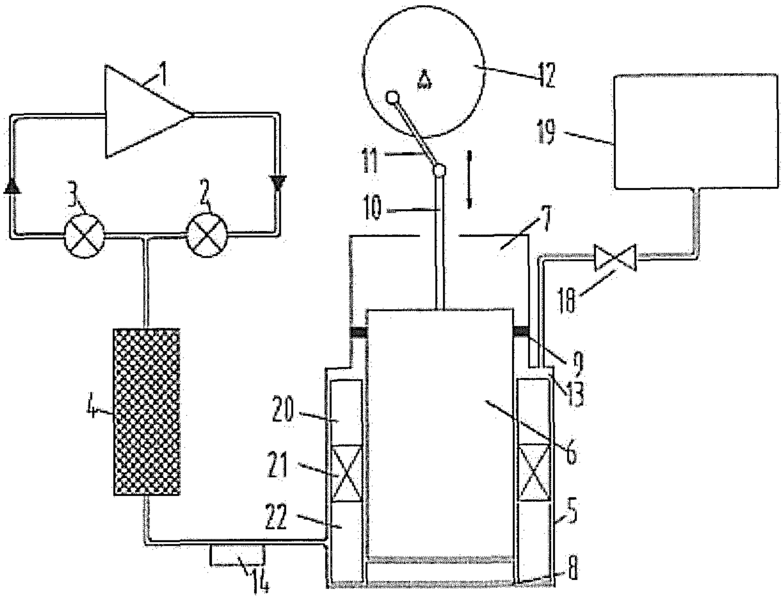

Figure 1

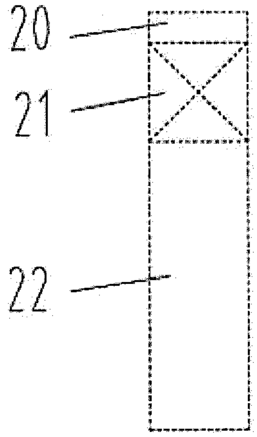

Figure 2

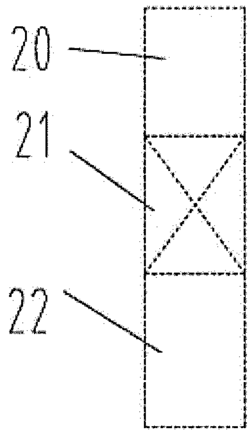

Figure 3

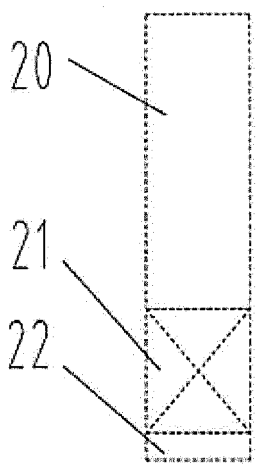

Figure 4

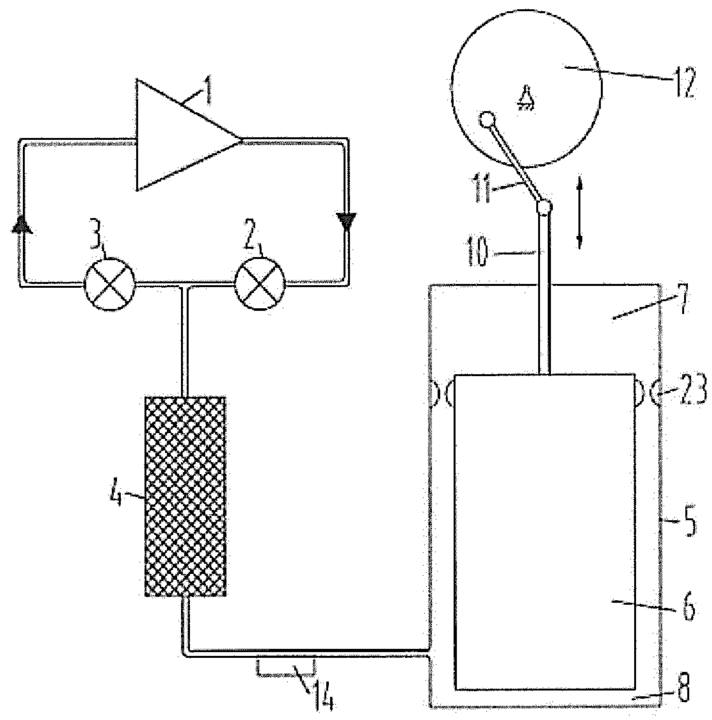

Figure 5

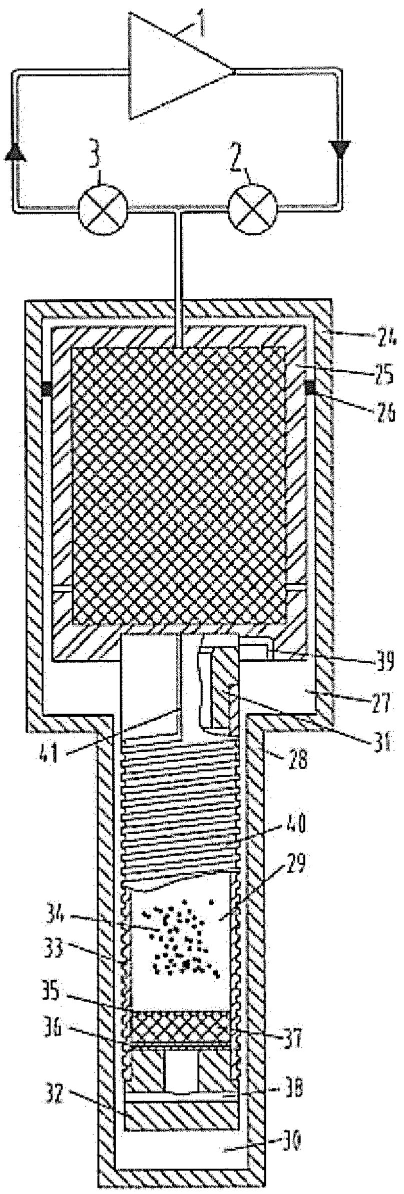

Figure 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2010/077524

A. CLASSIFICATION OF SUBJECT MATTER

F25B 9/14 (2006.01) i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: F25B9, F04C27

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI, EPODOC, CNPAT, CNKI: Gifford, Mcmahon, GM, G w M, phase, adjust+, shift+, modulat+, buffer, tank, reservoir, chamber, vessel, ring, circular, annular, gap, clearance, space, cylinder, piston, displac+, refrigerat+, cryocool+

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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E	CN201764746U (NANJING COOLTECH CRYOGENIC TECHNOLOGY CO LTD) 16 Mar. 2011(16.03.2011) description paragraphs [0006]-[0048] and figures 1-6	1-6

☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"& "document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
06 May 2011(06.05.2011)	**09 Jun. 2011 (09.06.2011)**

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The State Intellectual Property Office, the P.R.China
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2010/077524

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Form PCT/ISA /210 (continuation of second sheet) (July 2009)

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Information on patent family members

International application No.
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