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

(11) EP 4 361 527 A1

(12) # EUROPEAN PATENT APPLICATION

(43) Date of publication:
01.05.2024 Bulletin 2024/18

(21) Application number: **23202568.4**

(22) Date of filing: **10.10.2023**

(51) International Patent Classification (IPC):
F25B 9/14 *(2006.01)* ***F25B 49/00*** *(2006.01)*

(52) Cooperative Patent Classification (CPC):
F25B 9/14; F25B 9/145; F25B 49/005;
F25B 2309/003; F25B 2309/1405; F25B 2309/1411;
F25B 2309/1413; F25B 2309/1418

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC ME MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA
Designated Validation States:
KH MA MD TN

(30) Priority: **27.10.2022 JP 2022172326**

(71) Applicant: **SUMITOMO HEAVY INDUSTRIES, LTD.**
Tokyo 141-6025 (JP)

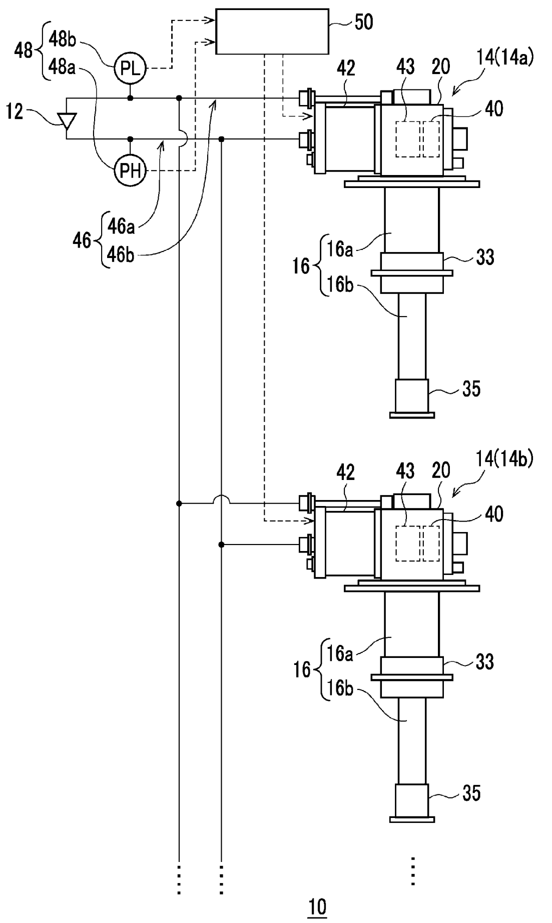
(72) Inventor: **OYAMA, Shuji**
Tokyo 188-8585 (JP)

(74) Representative: **Louis Pöhlau Lohrentz**
Patentanwälte
Postfach 30 55
90014 Nürnberg (DE)

(54) **CRYOCOOLER AND METHOD FOR OPERATING CRYOCOOLER**

(57) There is provided a new technology which can operate a plurality of cold heads (14) at the same time asynchronously. A cryocooler 10 includes: a compressor 12; a plurality of cold heads 14 connected in parallel to the compressor 12; a pressure sensor 48 that measures a pressure of a working gas on a supply side from the compressor 12 to the plurality of cold heads 14 or on a collection side from the plurality of cold heads 14 to the compressor 12; and a controller 50 that acquires individual pressure waveform data measured by the pressure sensor 48 when the cold heads 14 are individually operated for each of the plurality of cold heads 14, and operates the plurality of cold heads 14 at the same time asynchronously based on the individual pressure waveform data.

FIG. 1



EP 4 361 527 A1

Description

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates to a cryocooler and a method for operating a cryocooler.

Description of Related Art

[0002] In a multi-system cryocooler including a plurality of cryocoolers, when the opening and closing timings of the pressure switching valves of the respective cryocoolers coincide with each other when the cryocoolers are operated at the same time, the refrigerating performance may deteriorate. In the related art, in order to avoid this, it is known that an inverter provided in each cryocooler is used to make the operating frequencies of the cryocoolers different and make the valve timing asynchronous (for example, Japanese Unexamined Patent Publication No. 2003-49770) .

SUMMARY OF THE INVENTION

[0003] The above-mentioned method cannot be applied to a cryocooler without an inverter.

[0004] It is desirable to provide a new technology which can operate a plurality of cold heads at the same time asynchronously.

[0005] According to an aspect of the present invention, there is provided a cryocooler including: a compressor; a plurality of cold heads connected in parallel to the compressor; a pressure sensor that measures a pressure of a working gas on a supply side from the compressor to the plurality of cold heads or on a collection side from the plurality of cold heads to the compressor; and a controller that acquires individual pressure waveform data measured by the pressure sensor when the cold heads are individually operated for each of the plurality of cold heads, and operates the plurality of cold heads at the same time asynchronously based on the individual pressure waveform data.

[0006] According to another aspect of the present invention, there is provided a method for operating a cryocooler. The cryocooler includes a compressor and a plurality of cold heads connected in parallel to the compressor. The method includes measuring a pressure of a working gas on a supply side from the compressor to the plurality of cold heads or on a collection side from the plurality of cold heads to the compressor during individual operation of the cold heads for each of the plurality of cold heads; and operating the plurality of cold heads at the same time asynchronously based on a pressure waveform obtained by measurement.

[0007] Any combination of the components described above and any replacement of the components and expressions of the present invention between methods, devices, systems, and the like are also effective as aspects of the present invention.

[0008] According to the present invention, a plurality of cold heads can be operated at the same time asynchronously.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009]

Fig. 1 is a view schematically illustrating a cryocooler according to an embodiment.
Fig. 2 is a view schematically illustrating the cryocooler according to the embodiment.
Fig. 3 is a flowchart illustrating an example of the method for operating the cryocooler according to the embodiment.
Fig. 4 is a flowchart illustrating another example of the method for operating the cryocooler according to the embodiment.

DETAILED DESCRIPTION OF THE INVENTION

[0010] Hereinafter, embodiments for carrying out the present invention will be described in detail with reference to the drawings. In the description and drawings, the same or equivalent components, members, and processes will be assigned with the same reference symbols, and redundant description thereof will be omitted as appropriate. The scales and shapes of each illustrated part are set for convenience in order to make the description easy to understand, and are not to be understood as limiting unless stated otherwise. The embodiments are merely examples and do not limit the scope of the present invention. All characteristics and combinations to be described in the embodiment are not necessarily essential to the invention.

[0011] Figs. 1 and 2 are views schematically illustrating a cryocooler 10 according to an embodiment. As an example, the cryocooler 10 is a two-stage Gifford-McMahon (GM) cryocooler. Fig. 1 illustrates the appearance of the cryocooler 10, and Fig. 2 illustrates the internal structure of the cryocooler 10.

[0012] The cryocooler 10 includes a compressor 12 and a plurality of cold heads 14 connected in parallel to the compressor 12. The compressor 12 is configured to collect the working gas of the cryocooler 10 from the cold head 14, pressurize the collected working gas, and supply the working gas to the cold head 14 again. The plurality of cold heads 14 may include at least two cold heads 14, that is, a first cold head 14a and a second cold head 14b. The cold head 14 is also called an expander. The working gas is also referred to as a refrigerant gas and is usually a helium gas, but other suitable gas may be used.

[0013] The cold head 14 includes a cryocooler cylinder 16, a displacer assembly 18, and a cryocooler housing 20. The cryocooler housing 20 is coupled to the cryocooler cylinder 16, thereby forming a hermetic container that accommodates the displacer assembly 18. The internal volume of the cryocooler housing 20 may be connected to the low pressure side of the compressor 12 and maintained at a low pressure.

[0014] The cryocooler cylinder 16 has a first cylinder 16a and a second cylinder 16b. As an example, the first cylinder 16a and the second cylinder 16b are members having a cylindrical shape, and the second cylinder 16b has a diameter smaller than that of the first cylinder 16a. The first cylinder 16a and the second cylinder 16b are coaxially disposed, and a lower end of the first cylinder 16a is rigidly connected to an upper end of the second cylinder 16b.

[0015] The displacer assembly 18 has a first displacer 18a and a second displacer 18b. As an example, the first displacer 18a and the second displacer 18b are members having a cylindrical shape, and the second displacer 18b has a diameter smaller than that of the first displacer 18a. The first displacer 18a and the second displacer 18b are disposed coaxially with each other.

[0016] The first displacer 18a is accommodated in the first cylinder 16a, and the second displacer 18b is accommodated in the second cylinder 16b. The first displacer 18a can reciprocate in the axial direction along the first cylinder 16a, and the second displacer 18b can reciprocate in the axial direction along the second cylinder 16b. The first displacer 18a and the second displacer 18b are connected to each other and move integrally.

[0017] In this specification, in order to describe the positional relationship between the components of the cryocooler 10, for convenience, the side close to the top dead center of the axial reciprocation of the displacer is "upper", and the side close to the bottom dead center is "lower". The top dead center is the position of the displacer where the volume of the expansion space is maximum, and the bottom dead center is the position of the displacer where the volume of the expansion space is the minimum. Since a temperature gradient is generated in which the temperature drops from the upper side to the lower side in the axial direction during the operation of the cryocooler 10, the upper side can be referred to as a high temperature side and the lower side can be referred to as a low temperature side.

[0018] The first displacer 18a accommodates a first regenerator 26. The first regenerator 26 is formed by filling a tubular main body portion of the first displacer 18a with a wire mesh such as copper or other appropriate first regenerator material. The upper lid portion and the lower lid portion of the first displacer 18a may be provided as members separate from the main body portion of the first displacer 18a, the upper lid portion and the lower lid portion of the first displacer 18a may be fixed to the main body by appropriate means such as fastening or welding, and accordingly, the first regenerator material may be accommodated in the first displacer 18a.

[0019] Similarly, the second displacer 18b accommodates a second regenerator 28. The second regenerator 28 is formed by filling a tubular main body portion of the second displacer 18b with a non-magnetic regenerator material such as bismuth, a magnetic regenerator material such as $HoCu_2$, or other appropriate second regenerator material. The second regenerator material may be formed in a granular shape. The upper lid portion and the lower lid portion of the second displacer 18b may be provided as members separate from the main body portion of the second displacer 18b, the upper lid portion and the lower lid portion of the second displacer 18b may be fixed to the main body by appropriate means such as fastening or welding, and accordingly, the second regenerator material may be accommodated in the second displacer 18b.

[0020] The displacer assembly 18 forms an upper portion chamber 30, a first expansion chamber 32, and a second expansion chamber 34 inside the cryocooler cylinder 16. The cold head 14 includes a first cooling stage 33 and a second cooling stage 35 for heat exchange with a desired object or medium to be cooled by the cryocooler 10. The upper portion chamber 30 is formed between the upper lid portion of the first displacer 18a and the upper portion of the first cylinder 16a. The first expansion chamber 32 is formed between the lower lid portion of the first displacer 18a and the first cooling stage 33. The second expansion chamber 34 is formed between the lower lid portion of the second displacer 18b and the second cooling stage 35. The first cooling stage 33 is fixed to the lower portion of the first cylinder 16a to surround the first expansion chamber 32, and the second cooling stage 35 is fixed to the lower portion of the second cylinder 16b to surround the second expansion chamber 34.

[0021] The first regenerator 26 is connected to the upper portion chamber 30 through a working gas flow path 36a formed in the upper lid portion of the first displacer 18a, and is connected to the first expansion chamber 32 through a working gas flow path 36b formed in the lower lid portion of the first displacer 18a. The second regenerator 28 is connected to the first regenerator 26 through a working gas flow path 36c formed from the lower lid portion of the first displacer 18a to the upper lid portion of the second displacer 18b. In addition, the second regenerator 28 is connected to the second expansion chamber 34 through a working gas flow path 36d formed in the lower lid portion of the second displacer 18b.

[0022] The working gas flow between the first expansion chamber 32, the second expansion chamber 34, and the upper portion chamber 30 is not the clearance between the cryocooler cylinder 16 and the displacer assembly 18, but a first seal 38a and a second seal 38b may be provided to be guided to the first regenerator 26 and the second regenerator 28. The first seal 38a may be mounted to the upper lid portion of the first displacer 18a to be disposed between the first displacer 18a and the first cylinder 16a. The second seal 38b may be mounted to the upper lid portion of the second displacer 18b to be disposed between the second displacer 18b and the second cylinder 16b.

[0023] Further, the cold head 14 includes a pressure switching valve 40 and a driving motor 42. The pressure switching valve 40 is accommodated in the cryocooler housing 20, and the driving motor 42 is attached to the cryocooler housing 20.

[0024] As illustrated in Fig. 2, the pressure switching valve 40 includes the high pressure valve 40a and the low pressure valve 40b, and is configured to generate periodic pressure fluctuation in the cryocooler cylinder 16. The working gas discharge port of the compressor 12 is connected to the upper portion chamber 30 via the high pressure valve 40a, and the working gas suction port of the compressor 12 is connected to the upper portion chamber 30 via the low pressure valve 40b. The high pressure valve 40a and the low pressure valve 40b are configured to selectively and alternately open and close (that is, when one is open, the other is closed). A high pressure (for example, 2 to 3 MPa) working gas is supplied from the compressor 12 to the cold head 14 through the high pressure valve 40a, and a low pressure (for example, 0.5 to 1.5 MPa) working gas is collected from the cold head 14 to the compressor 12 through the low pressure valve 40b. For the sake of understanding, the flow direction of the working gas is indicated by an arrow in Fig. 2.

[0025] The driving motor 42 is provided to drive the reciprocating motion of the displacer assembly 18. The driving motor 42 is connected to a displacer drive shaft 44 via a motion conversion mechanism 43 such as a Scotch yoke mechanism. The motion conversion mechanism 43 is accommodated in the cryocooler housing 20 similar to the pressure switching valve 40. The displacer drive shaft 44 extends from the motion conversion mechanism 43 into the upper portion chamber 30 through the cryocooler housing 20, and is fixed to the upper lid portion of the first displacer 18a. A third seal 38c is provided in order to prevent leakage of the working gas from the upper portion chamber 30 to the cryocooler housing 20 (which may be maintained at a low pressure as described above). The third seal 38c may be mounted to the cryocooler housing 20 to be disposed between the cryocooler housing 20 and the displacer drive shaft 44.

[0026] When the driving motor 42 is driven, the rotational output of the driving motor 42 is converted into axial reciprocation of the displacer drive shaft 44 by the motion conversion mechanism 43, and the displacer assembly 18 reciprocates in the cryocooler cylinder 16 in the axial direction. Further, the driving motor 42 is connected to the pressure switching valve 40 to selectively and alternately open and close the high pressure valve 40a and the low pressure valve 40b.

[0027] In addition, the cryocooler 10 includes a working gas line 46 that connects the compressor 12 and the plurality of cold heads 14. The working gas line 46 includes a high pressure line 46a for supplying the high pressure working gas from the compressor 12 to the plurality of cold heads 14, and a low pressure line 46b for collecting the low pressure working gas from the plurality of cold heads 14 to the compressor 12. The high pressure line 46a extends from a working gas discharge port of the compressor 12, branches in the middle, and is connected to a pressure switching valve 40 of each cold head 14. The low pressure line 46b extends from a working gas suction port of the compressor 12, branches in the middle, and is connected to a pressure switching valve 40 of each cold head 14. In this manner, as described above, the working gas discharge port of the compressor 12 is connected to the high pressure valve 40a of each cold head 14, and the working gas suction port of the compressor 12 is connected to the low pressure valve 40b of each cold head 14.

[0028] According to the above-described configuration, the cryocooler 10 generates periodic volume fluctuations in the first expansion chamber 32 and the second expansion chamber 34 and pressure fluctuations of the working gas synchronized therewith when the compressor 12 and the driving motor 42 are driven to operate the displacer assembly 18 and the pressure switching valve 40, and accordingly, the refrigeration cycle is configured, and the first cooling stage 33 and the second cooling stage 35 are cooled to a desired cryogenic temperature. The first cooling stage 33 can be cooled to a first cooling temperature in the range of, for example, approximately 20K to approximately 40K. The second cooling stage 35 can be cooled to a second cooling temperature (for example, approximately 1K to approximately 4K) lower than the first cooling temperature.

[0029] In addition, the cryocooler 10 includes a first pressure sensor 48a, a second pressure sensor 48b, and a controller 50. The first pressure sensor 48a measures the pressure of the working gas on the supply side from the compressor 12 to the plurality of cold heads 14, that is, on the high pressure line 46a. The second pressure sensor 48b measures the pressure of the working gas on the collection side from the plurality of cold heads 14 to the compressor 12, that is, on the low pressure line 46b. Hereinafter, for convenience of description, the first pressure sensor 48a and the second pressure sensor 48b may be collectively referred to as a pressure sensor 48. The pressure sensor 48 is connected to be capable of communicating with the controller 50 by wire or wirelessly, and can transmit the measured pressure waveform data to the controller 50.

[0030] The first pressure sensor 48a can be installed at any place on the high pressure line 46a. For example, the first pressure sensor 48a may be disposed inside the housing of the compressor 12 and may measure the pressure of the high pressure line 46a inside the compressor 12. Alternatively, the first pressure sensor 48a may be installed in the working gas pipe connecting the compressor 12 and the cold head 14 as the high pressure line 46a. Similarly, the second pressure sensor 48b can be installed at any place on the low pressure line 46b.

[0031] The periodic operation of the pressure switching valve 40 (that is, the periodic alternating opening and closing of the high pressure valve 40a and the low pressure valve 40b) may cause a periodic pressure fluctuation (pulsation) in the working gas line 46. For example, in the high pressure line 46a, when the high pressure valve 40a is opened, the working gas flows from the high pressure line 46a into the cold head 14, and thus the pressure of the high pressure line 46a may decrease to some extent. When the high pressure valve 40a is subsequently closed, this pressure drop is restored by supplying a working gas from the compressor 12 to the high pressure line 46a. Such a pressure fluctuation in the high pressure line 46a can be detected by the first pressure sensor 48a. That is, periodic pressure fluctuations may appear in the pressure waveform data measured by the first pressure sensor 48a. Similarly, in the pressure waveform data measured by the second pressure sensor 48b, a periodic pressure fluctuation that may occur in the low pressure line 46b due to the periodic opening and closing of the low pressure valve 40b may appear.

[0032] Such a periodic pressure fluctuation reflects the valve timing of the pressure switching valve 40, and thus the phase of the refrigeration cycle of the cold head 14. Therefore, by monitoring the pressure waveform of the working gas line 46 (at least one of the high pressure line 46a and the low pressure line 46b) by using the pressure sensor 48 (at least one of the first pressure sensor 48a and the second pressure sensor 48b), the valve timing of the pressure switching valve 40 can be identified. By acquiring the valve timings of the pressure switching valves 40 for each cold head 14 and starting each cold head 14 such that the valve timings are not synchronized with each other, a plurality of cold heads 14 can be operated at the same time asynchronously.

[0033] Therefore, in the present embodiment, the controller 50 is configured to acquire individual pressure waveform data measured by the pressure sensor 48 when the cold heads 14 are individually operated for each of the plurality of cold heads 14, and operate the plurality of cold heads 14 at the same time asynchronously based on the individual pressure waveform data.

[0034] The controller 50 is realized as a hardware configuration by elements or circuits such as a central processing unit (CPU) or memory of a computer, and is realized by a computer program or the like as a software configuration. In the drawing, these are drawn as functional blocks realized by their cooperation as appropriate. It is understood by those skilled in the art that the functional blocks can be realized in various forms by combining hardware and software.

[0035] Fig. 3 is a flowchart illustrating an example of the method for operating the cryocooler 10 according to the embodiment. The processing illustrated in Fig. 3 is executed by the controller 50 in preparation for the normal operation prior to the normal operation of the cryocooler 10 in which the plurality of cold heads 14 are operated at the same time. As will be described below, the controller 50 may operate the plurality of cold heads 14 at the same time asynchronously based on the comparison between the individual pressure waveform data.

[0036] As illustrated in Fig. 3, the first cold head 14a is started (S10). The controller 50 starts the operation of the first cold head 14a by turning on the driving motor 42 of the first cold head 14a. At this time, the first cold heads 14a are individually operated. That is, only the first cold head 14a is operated, and the operation of the other cold heads 14 including the second cold head 14b is stopped.

[0037] The controller 50 acquires individual pressure waveform data measured by the pressure sensor 48 for the first cold head 14a during the individual operation of the first cold head 14a (S11). The individual pressure waveform data is acquired over the refrigeration cycle of at least one or a plurality of cold head 14. The individual pressure waveform data may be the pressure waveform data of the high pressure line 46a measured by the first pressure sensor 48a, or may be the pressure waveform data of the low pressure line 46b measured by the second pressure sensor 48b.

[0038] When the individual pressure waveform data is acquired for the first cold head 14a, the first cold head 14a is stopped (S12). The controller 50 ends the operation of the first cold head 14a by turning on the driving motor 42 of the first cold head 14a.

[0039] Subsequently, in the same manner, the second cold head 14b is started (S13), individual pressure waveform data is acquired for the second cold head 14b during the individual operation of the second cold head 14b (S14), and then the second cold head 14b is stopped (S15).

[0040] Next, the acquired individual pressure waveform data are compared with each other (S16). The controller 50 compares the individual pressure waveform data of the first cold head 14a with the individual pressure waveform data of the second cold head 14b, and determines the phase difference between the two pressure waveforms. The controller 50 determines the generation timing of the pressure fluctuation caused by the same specific valve timing from the individual pressure waveform data of the first cold head 14a and the second cold head 14b, and determines the phase difference between the two pressure waveforms from the time difference thereof. For example, when the individual pressure waveform data is measured by the first pressure sensor 48a, the controller 50 can detect the generation timing of pressure drop of the high pressure line 46a corresponding to the opening timing of the high pressure valve 40a from each of the individual pressure waveform data of the first cold head 14a and the second cold head 14b, and determine the phase difference between the two pressure waveforms from these.

[0041] Then, the normal operation of the cryocooler 10 is started (S17). The controller 50 operates the plurality of cold heads 14 at the same time asynchronously based on the comparison between the individual pressure waveform data.

[0042] For example, the controller 50 determines whether or not the phase difference of the determined pressure waveform is non-zero. When the determined phase difference is non-zero, the controller 50 starts the first cold head 14a and the second cold head 14b at the same time. In this manner, the cold heads are started to operate while the phase difference between the pressure waveforms of the first cold head 14a and the second cold head 14b is kept. Therefore, the valve timings of the two cold heads can be made asynchronous.

[0043] On the other hand, when the determined phase difference is zero, the controller 50 starts the first cold head 14a and the second cold head 14b with a time difference. That is, one cold head is started first, and the other cold head is started later. The delay time may be a non-integer multiple of one refrigeration cycle of the cold head 14 (that is, one cycle of the pressure waveform). In this manner, the operation of the two cold heads is started with a phase difference corresponding to the delay time. Therefore, the valve timings of the two cold heads can be made asynchronous.

[0044] In a case where the cryocooler 10 has three or more cold heads 14, by repeating the same processing, the controller 50 can acquire individual pressure waveform data measured by the pressure sensor 48 when the cold heads 14 are individually operated for each of the plurality of cold heads 14, and operate the plurality of cold heads 14 at the same time asynchronously based on the comparison between the individual pressure waveform data.

[0045] Therefore, according to the embodiment, the cryocooler 10 can be provided by operating the plurality of cold heads 14 at the same time asynchronously. In particular, even in the cryocooler 10 in which each cold head 14 is not equipped with an inverter and the driving motor 42 is operated at a fixed operating frequency, the plurality of cold heads 14 can be operated at the same time asynchronously.

[0046] Fig. 4 is a flowchart illustrating another example of the method for operating the cryocooler 10 according to the embodiment. Similar to the processing of Fig. 3, the processing illustrated in Fig. 4 is executed by the controller 50 in preparation for the normal operation prior to the normal operation of the cryocooler 10 in which the plurality of cold heads 14 are operated at the same time.

[0047] As will be described below, the controller 50 acquires total pressure waveform data measured by the pressure sensor 48 when the plurality of cold heads 14 are operated at the same time, acquires a total pressure amplitude from the total pressure waveform data, acquires a total sum of individual pressure amplitudes from the individual pressure waveform data of the plurality of cold heads 14, and operates the plurality of cold heads 14 at the same time asynchronously based on comparison between the total pressure amplitude and the total sum of the individual pressure amplitudes.

[0048] As illustrated in Fig. 4, the first cold head 14a is started (S10), individual pressure waveform data is acquired for the first cold head 14a during the individual operation of the first cold head 14a (S11), and then the first cold head 14a is stopped (S12). In addition, the second cold head 14b is started (S13), and individual pressure waveform data is acquired for the second cold head 14b during the individual operation of the second cold head 14b (S14). When the cryocooler 10 has three or more cold heads 14, individual pressure waveform data is acquired for each of the cold heads 14 in the same manner. The acquisition of the individual pressure waveform data can be executed in the same manner as in the processing of Fig. 3.

[0049] Subsequently, the plurality of cold heads 14 are operated at the same time (S20). For example, when the cryocooler 10 has two cold heads 14, the first cold head 14a is started again after the individual pressure waveform data of the second cold head 14b is acquired. The first cold head 14a and the second cold head 14b are operated at the same time. When the cryocooler 10 has three or more cold heads 14, the stopped cold heads 14 are started again, and all the cold heads 14 are operated at the same time.

[0050] The controller 50 acquires the total pressure waveform data measured by the pressure sensor 48 during the simultaneous operation of the plurality of cold heads 14 (S21). The total pressure waveform data is acquired over the refrigeration cycle of at least one or a plurality of cold head 14. The total pressure waveform data may be the pressure waveform data of the high pressure line 46a measured by the first pressure sensor 48a, or may be the pressure waveform data of the low pressure line 46b measured by the second pressure sensor 48b.

[0051] The controller 50 acquires a pressure amplitude from the acquired total pressure waveform data (also referred to as a total pressure amplitude in this specification) (S22). In addition, the controller 50 acquires the pressure amplitude from the individual pressure waveform data of the plurality of cold heads 14 (also referred to as the individual pressure amplitude in this specification), and calculates the total sum of the individual pressure amplitudes (S23).

[0052] Next, the total pressure amplitude and total sum of the individual pressure amplitudes are compared (S24). The controller 50 compares the total pressure amplitude and the total sum of the individual pressure amplitudes, and determines the magnitude relationship between the two. It is considered that, when the valve timings of the plurality of cold heads 14 are synchronized, the total pressure amplitude becomes equal to the total sum of the individual pressure amplitudes, and conversely, when the valve timings of the plurality of cold heads 14 are asynchronous, the total pressure amplitude is smaller than the total sum of the individual pressure amplitudes.

[0053] For example, a case where the cryocooler 10 has two cold heads 14 is considered. The individual pressure amplitudes of the first cold head 14a are represented by A, the individual pressure amplitudes of the second cold head 14b are represented by B, and the total pressure amplitude when these two cold heads 14 are operated at the same time is represented by C. While C = A + B is established when the valve timings of the two cold heads 14 are synchronized, C < A + B should be established when the valve timings of the two cold heads 14 are asynchronous.

[0054] When it is assumed that the plurality of cold heads 14 have the same individual pressure amplitude (for example, when the plurality of cold heads 14 are cold heads having the same specifications), since the individual pressure amplitudes of a certain cold head can also be used for another cold head, it is not essential to acquire an individual pressure amplitude for each cold head. For example, considering a case where the individual pressure amplitudes of the two cold heads 14 are equal, when the valve timings of the two cold heads 14 are synchronized, C = 2A should be established and when the valve timings of the two cold heads 14 are asynchronous, C < 2A should be established.

[0055] Therefore, when the total pressure amplitude is smaller than the total sum of the individual pressure amplitudes (for example, C < A + B or C < 2A), the controller 50 continues the operation of the plurality of cold heads 14 at the same time (S25). In this case, the valve timings of the cold heads of the plurality of cold heads 14 are asynchronous.

[0056] On the other hand, when the total pressure amplitude is equal to the total sum of the individual pressure amplitudes (for example, C = A + B or C = 2A), the controller 50 stops one cold head 14 (for example, the second cold head 14b) once and is started again after a lapse of waiting time (S26). The waiting time may be a non-integer multiple of one refrigeration cycle of the cold head 14 (that is, one cycle of the pressure waveform). In this manner, the operation of the two cold heads is operated with a phase difference corresponding to the waiting time. Therefore, the valve timings of the two cold heads can be made asynchronous.

[0057] When the cryocooler 10 has three or more cold heads 14, the controller 50 can operate the plurality of cold heads 14 at the same time asynchronously based on the comparison between the total pressure amplitude and the total sum of the individual pressure amplitudes by the same processing.

[0058] According to the embodiment, the cryocooler 10 can be provided by operating the plurality of cold heads 14 at the same time asynchronously. In particular, even in the cryocooler 10 in which each cold head 14 is not equipped with an inverter and the driving motor 42 is operated at a fixed operating frequency, the plurality of cold heads 14 can be operated at the same time asynchronously.

[0059] Above, the present invention was described based on examples. It will be understood by those skilled in the art that the present invention is not limited to the above-described embodiment, various design changes are possible, various modification examples are possible, and such modification examples are also within the scope of the present invention. Various characteristics described in relation to one embodiment are also applicable to other embodiments. A new embodiment generated through combination also has the effects of each of the combined embodiments.

[0060] In the above-described embodiment, a case where the cryocooler 10 has one compressor 12 is described as an example. However, the cryocooler 10 may include a plurality of (for example, two) compressors 12.

[0061] In the above-described embodiment, a case where the cryocooler 10 is a two-stage GM cryocooler was described as an example, but the present invention is not limited thereto. The cryocooler 10 may be a single-stage or multistage GM cryocooler, and may be another type of cryocooler such as a pulse tube cryocooler.

[0062] Above, the present invention was described based on examples. It will be understood by those skilled in the art that the present invention is not limited to the above-described embodiment, various design changes are possible, various modification examples are possible, and such modification examples are also within the scope of the present invention.

Brief Description of the Reference Symbols

[0063]

- 10 Cryocooler
- 12 Compressor
- 14 Cold head
- 14a First cold head
- 14b Second cold head
- 46 Working gas line
- 46a High pressure line
- 46b Low pressure line
- 48 Pressure sensor
- 48a First pressure sensor
- 48b Second pressure sensor
- 50 Controller

Claims

1. A cryocooler (10) comprising:

a compressor (12);
a plurality of cold heads (14) connected in parallel to the compressor (12);
a pressure sensor (48) that measures a pressure of a working gas on a supply side from the compressor (12) to the plurality of cold heads (14) or on a collection side from the plurality of cold heads (14) to the compressor (12); and
a controller (50) that acquires individual pressure waveform data measured by the pressure sensor (48) when the cold heads (14) are individually operated for each of the plurality of cold heads (14), and operates the plurality of cold heads (14) at the same time asynchronously

based on the individual pressure waveform data.

2. The cryocooler (10) according to claim 1, wherein the controller (50) operates the plurality of cold heads (14) at the same time asynchronously based on comparison between the individual pressure waveform data.

3. The cryocooler (10) according to claim 1, wherein the controller (50)

acquires total pressure waveform data measured by the pressure sensor (48) when the plurality of cold heads (14) are operated at the same time,
acquires a total pressure amplitude from the total pressure waveform data,
acquires a total sum of individual pressure amplitudes from the individual pressure waveform data of the plurality of cold heads (14), and
operates the plurality of cold heads (14) at the same time asynchronously based on comparison between the total pressure amplitude and the total sum of the individual pressure amplitudes.

4. A method for operating a cryocooler (10), in which the cryocooler (10) includes a compressor (12), and a plurality of cold heads (14) connected in parallel to the compressor (12), the method comprising:

measuring a pressure of a working gas on a supply side from the compressor (12) to the plurality of cold heads (14) or on a collection side from the plurality of cold heads (14) to the compressor (12) during individual operation of the cold heads (14) for each of the plurality of cold heads (14); and
operating the plurality of cold heads (14) at the same time asynchronously based on a pressure waveform obtained by measurement.

FIG. 1

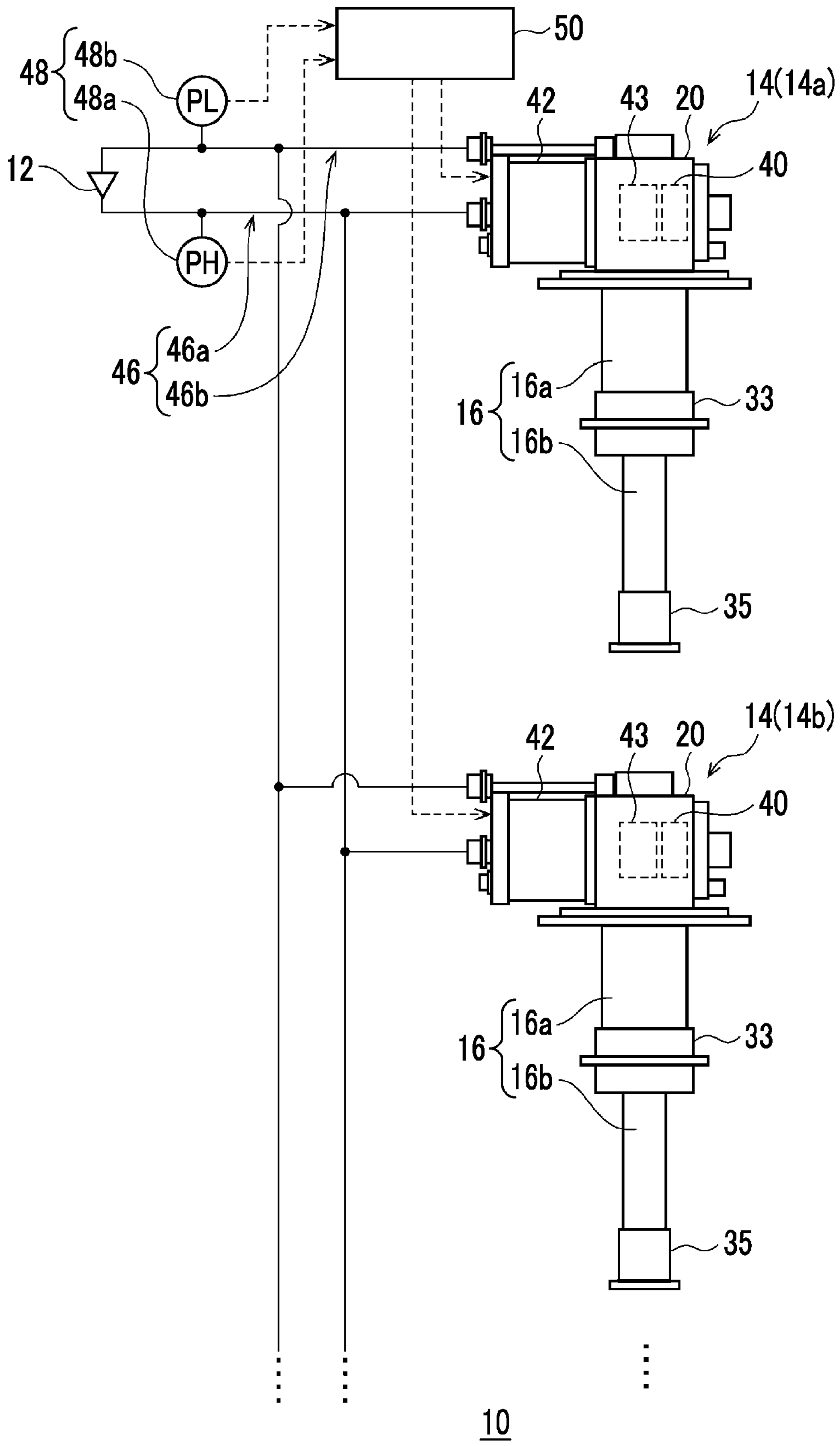

50
48
48b
48a
PL
PH
12
42
43
20
14(14a)
40
46
46a
46b
16
16a
16b
33
35
42
43
20
14(14b)
40
16
16a
16b
33
35
10

FIG. 2

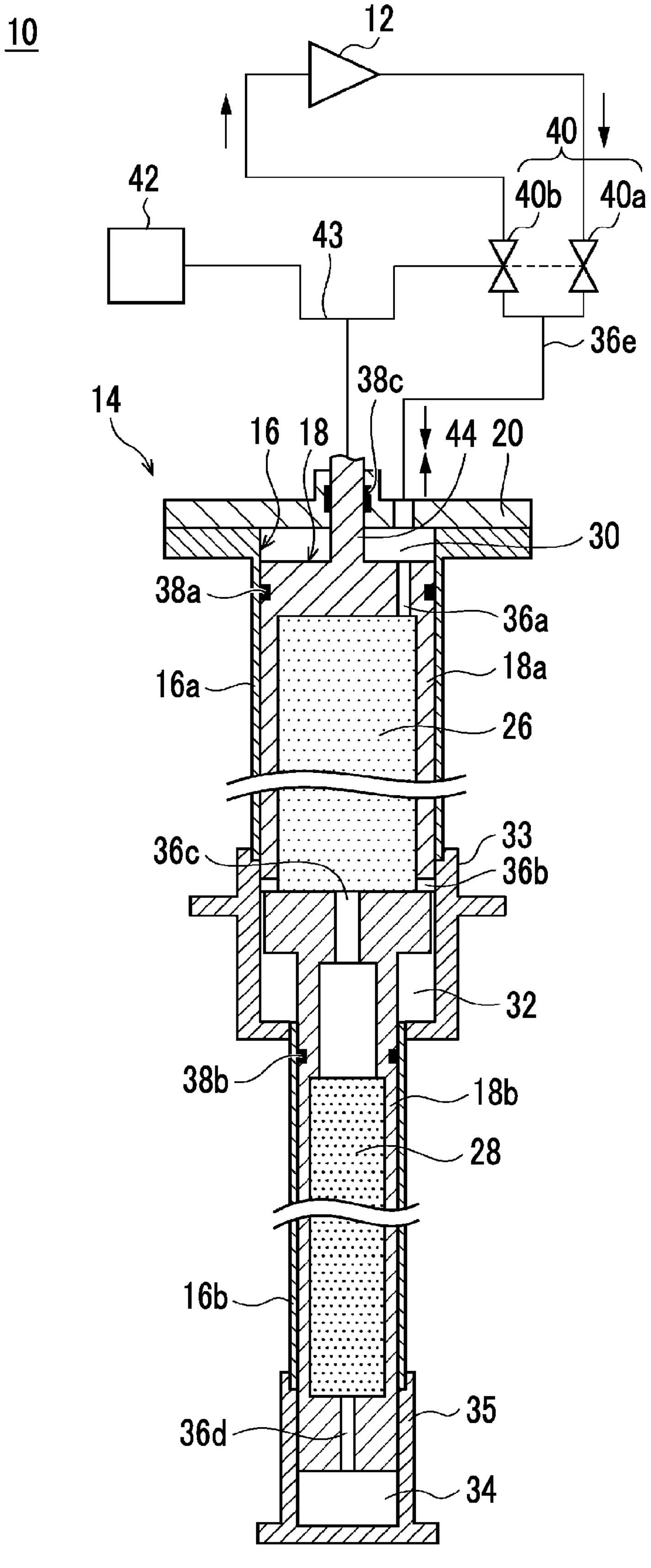

10
12
40
40b
40a
42
43
36e
38c
14
16
18
44
20
30
38a
36a
16a
18a
26
36c
33
36b
32
38b
18b
28
16b
35
36d
34

FIG. 3

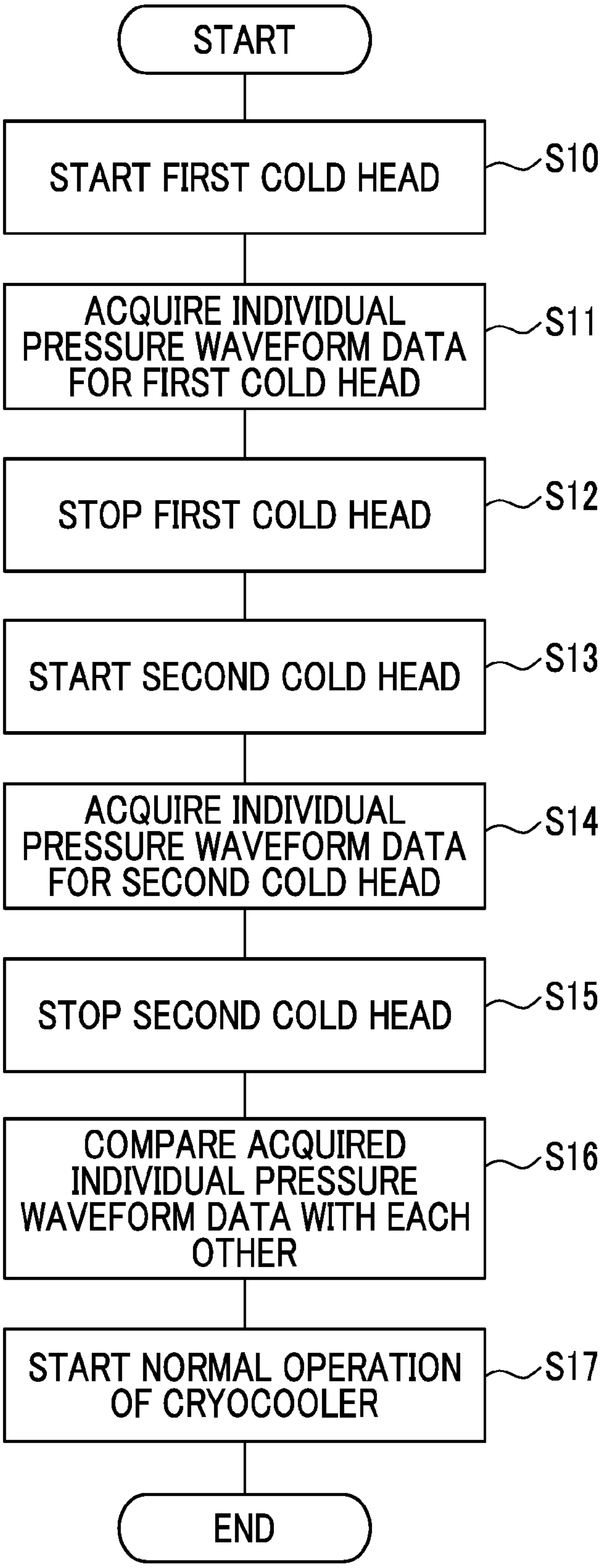
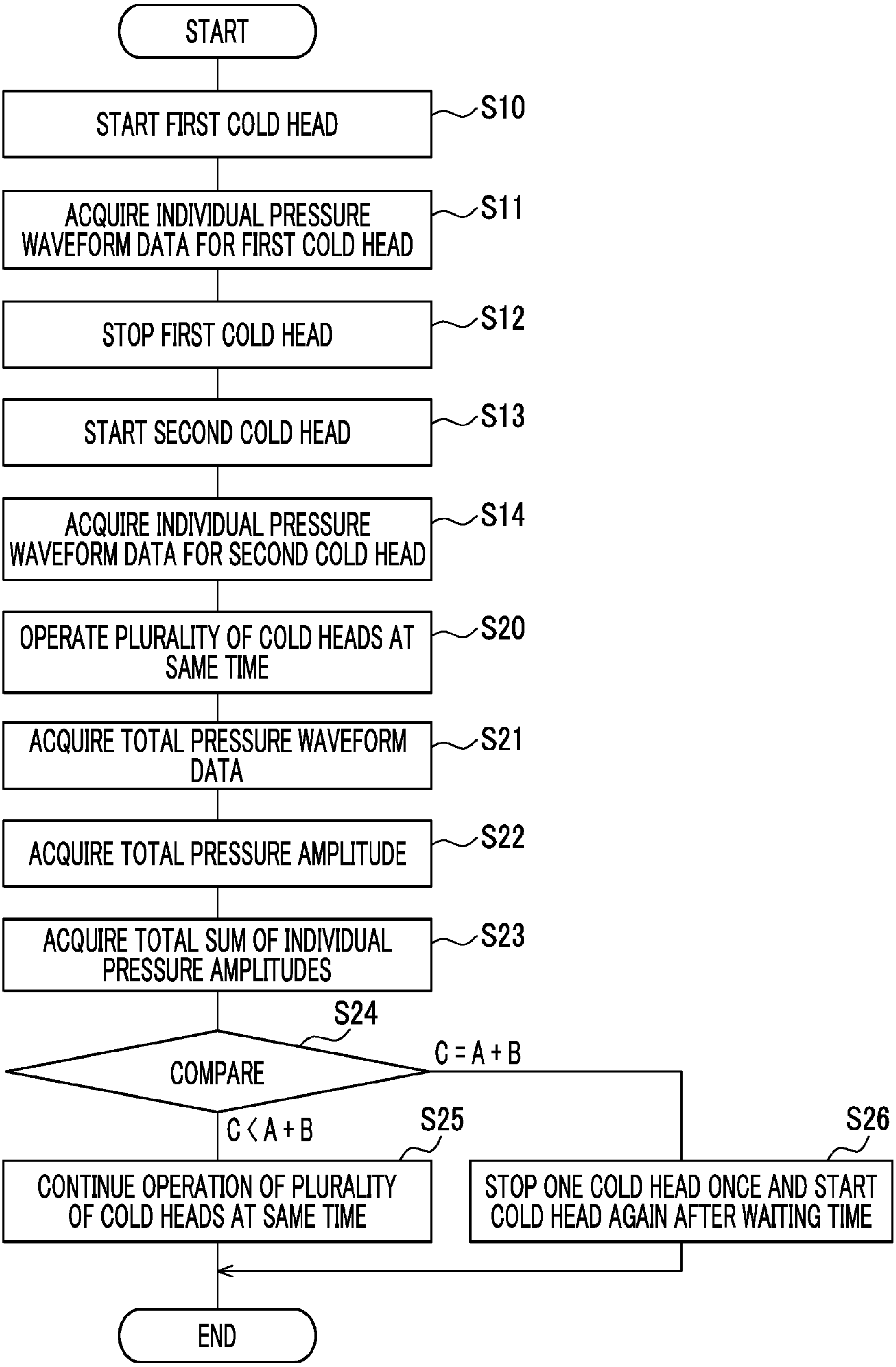

START
START FIRST COLD HEAD
S10
ACQUIRE INDIVIDUAL PRESSURE WAVEFORM DATA FOR FIRST COLD HEAD
S11
STOP FIRST COLD HEAD
S12
START SECOND COLD HEAD
S13
ACQUIRE INDIVIDUAL PRESSURE WAVEFORM DATA FOR SECOND COLD HEAD
S14
STOP SECOND COLD HEAD
S15
COMPARE ACQUIRED INDIVIDUAL PRESSURE WAVEFORM DATA WITH EACH OTHER
S16
START NORMAL OPERATION OF CRYOCOOLER
S17
END

FIG. 4


START
START FIRST COLD HEAD
S10
ACQUIRE INDIVIDUAL PRESSURE WAVEFORM DATA FOR FIRST COLD HEAD
S11
STOP FIRST COLD HEAD
S12
START SECOND COLD HEAD
S13
ACQUIRE INDIVIDUAL PRESSURE WAVEFORM DATA FOR SECOND COLD HEAD
S14
OPERATE PLURALITY OF COLD HEADS AT SAME TIME
S20
ACQUIRE TOTAL PRESSURE WAVEFORM DATA
S21
ACQUIRE TOTAL PRESSURE AMPLITUDE
S22
ACQUIRE TOTAL SUM OF INDIVIDUAL PRESSURE AMPLITUDES
S23
S24
COMPARE
C = A + B
C < A + B
S25
S26
CONTINUE OPERATION OF PLURALITY OF COLD HEADS AT SAME TIME
STOP ONE COLD HEAD ONCE AND START COLD HEAD AGAIN AFTER WAITING TIME
END

Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 23 20 2568

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	US 2003/024252 A1 (FUNAYAMA SHIN [JP] ET AL) 6 February 2003 (2003-02-06) * the whole document * -----	1-4	INV. F25B9/14 F25B49/00
A	US 2019/277541 A1 (HIRAYAMA TAKASHI [JP]) 12 September 2019 (2019-09-12) * the whole document * -----	1-4	
A	US 2019/316574 A1 (XU MINGYAO [JP] ET AL) 17 October 2019 (2019-10-17) * the whole document * -----	1-4	
A	US 2022/235984 A1 (MORIE TAKAAKI [JP]) 28 July 2022 (2022-07-28) * the whole document * -----	1-4	
A	JP H09 130964 A (SANYO ELECTRIC CO) 16 May 1997 (1997-05-16) * the whole document * -----	1-4	
			TECHNICAL FIELDS SEARCHED (IPC)
			F25B

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	14 March 2024	Lucic, Anita

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons
& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO.

EP 23 20 2568

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

14-03-2024

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2003024252 A1	06-02-2003	CN 1405521 A	26-03-2003
		JP 3754992 B2	15-03-2006
		JP 2003049770 A	21-02-2003
		KR 20030013298 A	14-02-2003
		TW 584698 B	21-04-2004
		US 2003024252 A1	06-02-2003
US 2019277541 A1	12-09-2019	CN 110168292 A	23-08-2019
		JP 6727723 B2	22-07-2020
		JP 2018115778 A	26-07-2018
		US 2019277541 A1	12-09-2019
		WO 2018131376 A1	19-07-2018
US 2019316574 A1	17-10-2019	CN 109997003 A	09-07-2019
		JP 6781678 B2	04-11-2020
		JP 2018091601 A	14-06-2018
		US 2019316574 A1	17-10-2019
US 2022235984 A1	28-07-2022	CN 114585867 A	03-06-2022
		JP WO2021075274 A1	22-04-2021
		KR 20220079525 A	13-06-2022
		TW 202117243 A	01-05-2021
		US 2022235984 A1	28-07-2022
		WO 2021075274 A1	22-04-2021
JP H09130964 A	16-05-1997	NONE	

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- JP 2003049770 A **[0002]**