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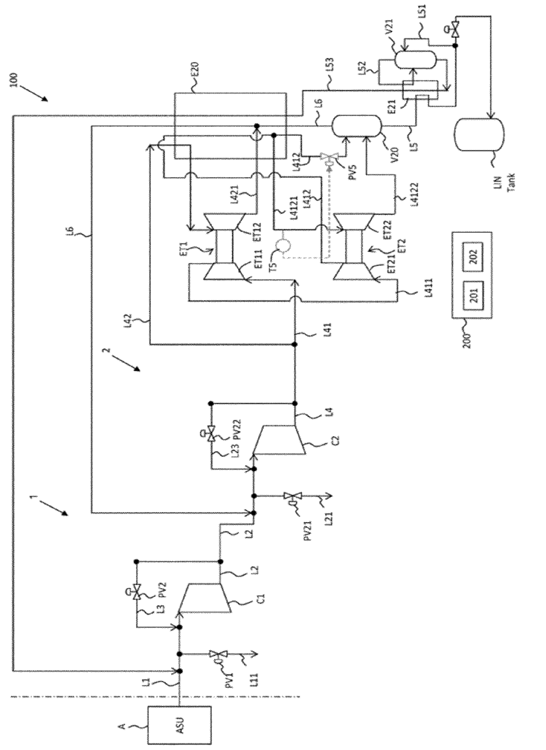
(54) **INLET TEMPERATURE CONTROL FOR TURBINE**

(57) A liquefaction system 100 comprises: a temperature measuring unit T5 for measuring an inlet gas temperature on entry to a turbine; a control valve PV5 for controlling an amount of gas fed to the turbine, correspondingly with an inlet gas temperature T1 measured by the temperature measuring unit T5; and a control unit 200 which compares the inlet gas temperature T1 measured by the temperature measuring unit T5 with a warning temperature set value plus a margin M, and sets a first operating state when the inlet gas temperature T1 is equal to or less than the warning temperature set value plus the margin and also sets an emergency stoppage temperature set value at the warning temperature set value plus the margin, and sets a second operating state when the inlet gas temperature T1 is greater than the warning temperature set value plus the margin.

Figure 1



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Description

[0001] The present invention relates to a liquefaction system, and relates to a method for controlling an inlet temperature of a turbine used in a gas liquefaction system, for example.

Background Art

[0002] A gas liquefaction system generally comprises a compression device, a turbine, and a heat exchanger. A liquefaction process generally involves liquefying a portion of the whole amount of supplied gas and feeding this portion to a product tank, with the remainder being circulated through the liquefaction system and re-treated together with newly supplied gas. The turbine in the liquefaction system is operated so that a gas enters the turbine where it is expanded, and then exits as a gas. In order to avoid liquefaction at a turbine outlet, the system is controlled to output a warning or perform an emergency stoppage (turbine tripping), etc. on reaching a temperature at which liquefaction might occur. The temperature at which liquefaction might occur is calculated from a pressure difference between the turbine inlet pressure and the turbine outlet pressure. The liquefaction system is designed on the basis of normal operation, and is controlled so that the amount of gas fed to the turbine is maximized, while avoiding liquefaction by observing this temperature (the system is operated with the liquefaction process maximized).

[0003] Patent Document 1 describes a liquefaction process comprising: one or more permanent gas compression devices, one or more permanent gas expansion turbines, and a heat exchanger for performing heat exchange between permanent gas and liquefied natural gas.

Prior Art Documents

Patent Documents

Patent Document 1= JP H5-45050A

Summary of the Invention

Problems to be Solved by the Invention

[0004] However, during start-up of the liquefaction system when it is being operated with the liquefaction process maximized, the gas pressure at the turbine inlet increases, and if the turbine inlet temperature reaches the warning output temperature or emergency stoppage temperature, the operator has to intervene each time this occurs. It would also be possible to respond to this situation by operating the turbine at low speed during start-up, but this would delay launching of the liquefaction process and cause lost time.

[0005] Furthermore, the warning output temperature and the emergency stoppage temperature are fixed to correspond to normal operation, and are therefore incompatible with start-up or abnormalities, etc.

[0006] The present disclosure provides a liquefaction system and a method for controlling a turbine inlet temperature of the liquefaction system, which enable a gas temperature at an inlet of a turbine to be measured and enable a warning output temperature set value and an emergency stoppage temperature set value to be varied correspondingly with an operating state.

Means for Solving the Problems

[0007] The present disclosure relates to a liquefaction system for liquefying a product gas provided from an air separation unit, the liquefaction system comprising:

- a temperature measuring unit for measuring an inlet gas temperature on entry to a turbine ;
- a control valve for controlling an amount of gas fed to the turbine, correspondingly with the inlet gas temperature measured by the temperature measuring unit; and
- a control unit capable of, from the beginning of start-up of the liquefaction system, comparing the inlet gas temperature measured by the temperature measuring unit with a warning temperature set value plus a margin, and setting a first operating state when the inlet gas temperature is equal to or less than the warning temperature set value plus the margin and also setting an emergency stoppage temperature set value at the warning temperature set value plus the margin, and setting a second operating state when the inlet gas temperature is greater than the warning temperature set value plus the margin,
- the control unit being capable of performing control in response to the second operating state to make a degree of opening of the control valve greater than a degree of opening during the first operating state in order to lower an inlet pressure of the turbine, and performing control in response to the first operating state to make the degree of opening of the control valve smaller than the degree of opening during the second operating state in order to raise the inlet pressure of the turbine.

[0008] The first operating state means a normal operating state, and the second operating state means an operating state when the system is launched.

[0009] The control unit may comprise:

- a state setting unit which compares the inlet gas temperature measured by the temperature measuring unit with the warning temperature set value plus the margin, and sets the first operating state when the inlet gas temperature is equal to or less than the warning temperature set value plus the margin and also sets the emergency stoppage temperature set value at the warning temperature set value plus the margin, and sets the second operating state when the inlet gas temperature is greater than the warning temperature set value plus the margin; and

- a valve control unit which performs control in response to the second operating state set by the state setting unit to make the degree of opening of the control valve greater than the degree of opening during the first operating state in order to lower the inlet pressure of the turbine, and performs control in response to the first operating state set by the state setting unit to make the degree of opening of the control valve smaller than the degree of opening during the second operating state in order to raise the inlet pressure of the turbine. The "warning temperature set value" is a temperature set value at a timing for warning of the possibility of gas liquefaction at the turbine outlet. The temperature can be deducured from a pressure difference in pressure measuring units provided at the turbine inlet and outlet, and a warning is output when this temperature reaches the "warning temperature set value".

[0010] The "margin" is set while taking account of control responsiveness, and is set in a range from 1°C to 3°C, for example.

[0011] The "emergency stoppage temperature set value" is a temperature set value at a timing for emergency stoppage of the turbine. The temperature can be deduced from the pressure difference in the pressure measuring units provided at the turbine inlet and outlet, and there is an emergency stoppage of the turbine when this temperature reaches the "emergency stoppage temperature set value".

[0012] The liquefaction system may comprise:

- one or more compression devices for compressing a predetermined product gas fed from the air separation unit;
- a compressor of a first expander-compressor to which a compressed gas fed from a post-stage of the compression device is introduced;
- a compressor of a second expander-compressor to which a gas compressed by the compressor of the first expander-compressor is introduced;
- a first heat exchanger to which the gas compressed by the compressor of the first expander-compressor is introduced via a pipe (L412);
- a pipe which branches from the pipe and serves to feed a portion of the gas to an expander (turbine) of the second expander-compressor;
- a first separator (V20) to which the remainder of the gas is fed via the pipe ; and
- a pipe for feeding the gas expanded in the expander (turbine) of the second expander-compressor to the first separator (V20).

[0013] The control valve is provided in the first pipe downstream from the branching position of the second pipe.

[0014] The temperature measuring unit (T5) is provided in the pipe (L4121).

[0015] The present disclosure relates to a method for controlling a turbine inlet temperature of a liquefaction system for liquefying a product gas provided from an air separation unit (A), the method comprising:

- a temperature measuring step in which an inlet gas temperature on entry to a turbine (ET22) is measured;
- a setting step in which, from the beginning of start-up of the liquefaction system, the inlet gas temperature measured in the temperature measuring step is compared with a warning temperature set value plus a margin, and a first operating state is set when the inlet gas temperature is equal to or less than the warning temperature set value plus the margin, and an emergency stoppage temperature set value is also set at the warning temperature set value plus the margin, and a second operating state is set when the inlet gas temperature (T1) is greater than the warning temperature set value plus the margin; and
- a control step in which control is performed in response to the second operating state to lower an inlet pressure of the turbine, and control is performed in response to the first operating state to raise the inlet pressure of the turbine).

[0016] According to the invention, there is provided a liquefaction apparatus for liquefying a product gas provided from an air separation unit, the liquefaction system comprising:

- a temperature measuring unit for measuring a product gas temperature on entry to a turbine;
- a control valve for controlling an amount of gas fed to the turbine, correspondingly with the inlet gas temperature measured by the temperature measuring unit; and
- a control unit which, from the beginning of start-up of the liquefaction system, compares the inlet gas temperature measured by the temperature measuring unit with a warning temperature set value plus a margin, and sets a first operating state when the inlet gas temperature is equal to or less than the warning temperature set value plus the margin and also sets an emergency stoppage temperature set value at the warning temperature set value plus the margin, and sets a second operating state when the inlet gas temperature is greater than the warning temperature set value plus the margin,
- the control unit performing control in response to the second operating state to make a degree of opening of the control valve greater than a degree of opening during the first operating state in order to lower an

inlet pressure of the turbine, and performing control in response to the first operating state to make the degree of opening of the control valve smaller than the degree of opening during the second operating state in order to raise the inlet pressure of the turbine.

[0017] According to other optional features:

> the liquefaction apparatus comprises:

- one or more compression devices for compressing the product gas fed from the air separation unit;
- a compressor of a first expander-compressor to which a compressed gas fed from a post-stage of the compression device is introduced;
- a compressor of a second expander-compressor to which a gas compressed by the compressor of the first expander-compressor is introduced;
- a first heat exchanger to which the gas compressed by the compressor of the first expander-compressor is introduced via a first pipe;
- a second pipe which branches from the first pipe and serves to feed a portion of the gas to the turbine which forms part of the second expander-compressor;
- a first separator to which the remainder of the gas is fed via the first pipe; and
- a third pipe for feeding the gas expanded in the turbine of the second expander-compressor to the first separator.

> the control valve being provided in the first pipe downstream from the branching point of the second pipe.

[0018] According to another aspect of the invention, there is provided a process for controlling a turbine inlet temperature of a liquefaction system for liquefying a product gas provided from an air separation unit, the method comprising:

- a temperature measuring step in which an product gas temperature on entry to a turbine is measured;
- a setting step in which, from the beginning of start-up of the liquefaction system, the inlet gas temperature measured in the temperature measuring step is compared with a warning temperature set value plus a margin, and a first operating state is set when the inlet gas temperature is equal to or less than the warning temperature set value plus the margin, and an emergency stoppage temperature set value is also set at the warning temperature set value plus the margin, and a second operating state is set when the inlet gas temperature is greater than the warning temperature set value plus the margin; and
- a control step in which control is performed in response to the second operating state to lower an inlet pressure of the turbine, and control is performed in response to the first operating state to raise the inlet pressure of the turbine.

[0019] According to other optional features:

- the first operating state corresponds to a normal operating state, and the second operating state corresponds to an operating state when the system is launched.
- wherein the product gas is nitrogen.
- the product gas is liquefied downstream of the turbine.
- the degree of opening of the valve during the second operating state is between 60% and 70% and the degree of opening of the valve during the first operating state is between 50% and 60%.
- the method includes liquefying a portion of the whole amount of product gas and feeding this portion to a product tank, with the remainder being circulated through the turbine and sent to the product tank.

Effects

[0020]

(1) There is no need for the turbine to be operated at low speed during start-up, which enables a rapid transition to normal operation.
(2) The need for operator intervention is eliminated.
(3) The transition from start-up to normal operation can be fully automated.

Brief Description of the Drawings

[0021]

[Fig. 1] illustrates a liquefaction system according to embodiment 1.
[Fig. 2] is a flowchart showing a change of operating mode.

Embodiments of the Invention

[0022] Several embodiments of the present invention will be described below. The embodiments described below illustrate examples of the present invention. The present invention is in no way limited by the following embodiments, and also includes a number of variant modes which are implemented within a scope that does not alter the gist of the present invention. It should be noted that not all of the components described below are essential components of the present invention.

Embodiment 1

[0023] Decompression devices 1 and 2 in a liquefaction system 100 according to embodiment 1 will be described with the aid of fig. 1.

[0024] The liquefaction system 100 utilizes a liquefaction cycle to liquefy a predetermined product gas provided from an air separation unit A, for example a nitrogen-rich gas, oxygen-rich gas, or argon-rich gas, etc.

[0025] The liquefaction system 100 according to this embodiment comprises: first and second compression devices C1, C2; first and second expander-compressors ET1, ET2; first and second heat exchangers E20, E21; first and second separator units V20, V21; and a liquefied gas tank (LIN TANK).

[0026] The nitrogen-rich gas fed from the air separation unit A passes through a pipe L1 and is compressed by the first compression device C1 then compressed by the second compression device C2. A decompression method in these compression devices will be described later.

[0027] A portion of the nitrogen gas compressed in the second compression device C2 is fed to a compressor ET11 of the first expander-compressor ET1 via a first branch pipe L41, then fed to a compressor ET21 of the second expander-compressor ET2 via a pipe L411, and is next fed to the first heat exchanger E20 via a pipe L412 where it is cooled, and a portion thereof arrives at the first separator unit V20. The remainder of this nitrogen gas is fed to an expander ET22 (corresponding to a turbine) of the second expander-compressor ET2 via a branch pipe L4121 branching from the pipe L412 partway through the first heat exchanger E20, and is then fed to the first separator unit V20 via a pipe L4122. A gas component drawn from a column top of the first separator unit V20 passes through the first heat exchanger E20 via a pipe L6, and is fed to a pipe L2 on an intake side of the compression device C2.

[0028] Liquefied nitrogen gas drawn from a bottom of the first separator unit V20 passes, via a pipe L5, through a portion of the second heat exchanger E21 where it is cooled, after which a portion thereof is fed to the liquefied gas tank (LIN TANK). The remainder of this liquefied nitrogen gas is fed to the second separator unit V21 via a pipe L51. Agas component drawn from a column top of the second separator unit V21 is fed to the second heat exchanger E21 via a pipe L52 and then returned to the second separator unit V21. A liquid component drawn from a bottom of the second separator unit V21 passes through a pipe L53 to function as cold in the second heat exchanger E21, then functions as cold in the first heat exchanger E20, and is fed to the pipe L1 on an intake side of the first compression device C1.

[0029] The remainder of the nitrogen gas compressed by the second compression device C2 passes through a portion of the first heat exchanger E20 via a second branch pipe L42 branching from a pipe L4, and is fed to an expander ET12 of the first expander-compressor ET1, then fed via a pipe L421 to partway through the first heat exchanger E20, merging with the pipe L6.

[0030] A first intake-side release pipe L11 for releasing gas, which branches from the pipe L1, is provided on the intake side of the first compression device C1, and a first intake-side release valve PV1 is provided in the first intake-side release pipe L11. A second intake-side release pipe L21 for releasing gas, which branches from the pipe L2, is provided on the intake side of the second compression device C2, and a second intake-side release valve PV21 is provided in the second intake-side release pipe L21.

[0031] A first bypass pipe L3 returning from a discharge side to the intake side of the first compression device C1 is provided, and a first bypass valve PV2 is provided in the first bypass pipe L3. A second bypass pipe L23 returning from a discharge side to the intake side of the second compression device C2 is provided, and a second bypass valve PV22 is provided in the second bypass pipe L23.

Turbine inlet temperature control

[0032] A control valve PV5 is provided in the pipe L412 downstream from the position of the pipe L4121. A temperature measuring unit T5 is provided in the pipe L4121. Fig. 2 shows a flow of operating states.

[0033] After start-up, an inlet gas temperature T1 measured by the temperature measuring unit T5 is compared with a warning temperature set value plus a margin M (S201). During start-up, the inlet gas temperature T1 is greater than the warning temperature set value plus the margin M, and a second operating state is set.

[0034] In response to the second operating state, a valve control unit 202 makes a degree of opening OP1 of the control valve PV5 greater than a degree of opening OP2 during a first operating state in order to lower an inlet pressure of the expander ET22 (turbine) of the second expander-compressor ET2. As a result, the amount of gas fed to the first separator unit V20 is increased and the amount of gas fed to the expander ET22 (turbine) is reduced in relation to this, and it is possible to maintain a state of higher temperature than the warning temperature set value, making it possible to avoid operator intervention during start-up.

[0035] In step S201, the comparison is repeated until the measured inlet gas temperature T1 is equal to or less than the warning temperature set value plus the margin M. When the inlet gas temperature T1 is equal to or less than the warning temperature set value plus the margin M, the operating state transitions from the second operating state to the first operating state, and an emergency stoppage temperature set value is set at the warning temperature set value plus the margin (S202).

[0036] In response to the first operating state, the valve control unit 202 makes the degree of opening OP2 of the control valve PV5 smaller than the degree of opening OP1 during the start-up mode in order to raise the inlet pressure of the expander ET22 (turbine). As a result, the amount of gas fed to the first separator unit V20 is reduced and the amount of gas supplied to the expander ET22 (turbine) is increased in relation to this. This makes it possible to achieve a rapid transition from the state during start-up to operation in the normal state.

[0037] In this embodiment, the degree of opening (OP1) of the valve during the second operating state may be selected from a range of between 60% and 70%, for example. The degree of opening (OP2) of the valve during the first operating state may be selected from a range of between 50% and 60%, for example.

Method for controlling turbine inlet temperature of liquefaction system

[0038] A method for controlling a turbine inlet temperature of a liquefaction system for liquefying a product gas provided from an air separation unit A comprises:

- a temperature measuring step in which an inlet gas temperature (T1) on entry to a turbine (ET22) is measured;
- a setting step in which, from the beginning of start-up of the liquefaction system, the inlet gas temperature (T1) measured in the temperature measuring step is compared with a warning temperature set value plus a margin, and a first operating state is set when the inlet gas temperature (T1) is equal to or less than the warning temperature set value plus the margin, and an emergency stoppage temperature set value is also set at the warning temperature set value plus the margin, and a second operating state is set when the inlet gas temperature (T1) is greater than the warning temperature set value plus the margin; and
- a control step in which control is performed in response to the second operating state to lower an inlet pressure of the turbine (ET22) and thereby relatively reduce the amount of gas supplied to the turbine (ET22), and control is performed in response to the first operating state to raise the inlet pressure of the turbine (ET22) and thereby relatively increase the amount of gas supplied to the turbine (ET22).
- a program for implementing the method for controlling a turbine inlet temperature causes a processor to implement each of the steps of the method for controlling a turbine inlet temperature.

Other Embodiments

[0039]

(1) Functions of the mode setting unit 201 and the valve control unit 202 may be implemented by the single control unit 200.

(2) The control units may be configured to have one or more processors and a memory for storing a control program for operating the processor(s), or may be configured by combining one or more types of firmware, servers, high selectors, and low selectors, etc.

(3) The liquefaction system 100 is not limited to the configuration of embodiment 1, and other components may be added thereto. Furthermore, various types of measurement instruments and other pipes, etc. may also be provided.

Key to Symbols

[0040]

A Air separation unit
200 Control unit
201 Mode setting unit
202 Valve control unit
T5 Temperature measuring unit
PV5 Control valve

Claims

1. Liquefaction apparatus for liquefying a product gas provided from an air separation unit, the liquefaction system comprising:

- a temperature measuring unit (T5) for measuring a product gas temperature (T1) on entry to a turbine;
- a control valve (PV5) for controlling an amount of gas fed to the turbine, correspondingly with the inlet gas temperature (T1) measured by the temperature measuring unit; and
- a control unit capable of, from the beginning of start-up of the liquefaction system, comparing the inlet gas temperature (T1) measured by the temperature measuring unit with a warning temperature set value plus a margin (M), and setting a first operating state when the inlet gas temperature (T1) is equal to or less than the warning temperature set value plus the margin and also setting an emergency stoppage temperature set value at the warning temperature set value plus the margin, and setting a second operating state when the inlet gas temperature (T1) is greater than the warning temperature set value plus the margin,
- the control unit being capable of performing control in response to the second operating state to make a degree of opening of the control valve greater than a degree of opening during the first operating state in order to lower an inlet pressure of the turbine, and performing control in response to the first operating state to make the degree of opening of the control valve smaller than the degree of opening during the second operating state in order to raise the inlet pressure of the turbine.

2. Liquefaction apparatus according to Claim 1 comprising:

- one or more compression devices (C1, C2) for compressing the product gas (L1) fed from the air separation unit (A);
- a compressor (ET11) of a first expander-compressor (ET1) to which a compressed gas (L41) fed from a post-stage of the compression device is introduced;
- a compressor (ET21) of a second expander-compressor (ET2) to which a gas (L411) compressed by the compressor of the first expander-compressor is introduced;
- a first heat exchanger (E20) to which the gas compressed by the compressor of the first expander-compressor is introduced via a first pipe (L412);
- a second pipe (L4121) which branches from the first pipe (L412) and serves to feed a portion of the gas to the turbine (ET22) which forms part of the second expander-compressor;
- a first separator (V20) to which the remainder of the gas is fed via the first pipe (L412); and
- a third pipe (L4122) for feeding the gas expanded in the turbine of the second expander-compressor to the first separator (V20).

3. Apparatus according to Claim 2 wherein the control valve (PV5) being provided in the first pipe (L412) downstream from the branching point of the second pipe (L4121).

4. Method for controlling a turbine inlet temperature of a liquefaction system for liquefying a product gas provided from an air separation unit, the method comprising:

- a temperature measuring step in which an product gas temperature (T1) on entry to a turbine is measured;
- a setting step in which, from the beginning of start-up of the liquefaction system, the inlet gas temperature (T1) measured in the temperature measuring step is compared with a warning temperature set value plus a margin (M), and a first operating state is set when the inlet gas temperature (T1) is equal to or less than the warning temperature set value plus the margin, and an emergency stoppage temperature set value is also set at the warning temperature set value plus the margin, and a second operating state is set when the inlet gas temperature (T1) is greater than the warning temperature set value plus the margin; and
- a control step in which control is performed in response to the second operating state to lower an inlet pressure of the turbine, and control is performed in response to the first operating state to raise the inlet pressure of the turbine.

5. Method according to Claim 4 wherein the first operating state corresponds to a normal operating state, and the second operating state corresponds to an operating state when the system is launched.

6. Method according to Claim 4 or 5 wherein the product gas is nitrogen.

7. Method according to one of Claims 4 to 6 wherein the product gas is liquefied downstream of the turbine.

8. Method according to one of Claims 4 to 7 wherein the degree of opening (OP1) of the valve (PV5) during the second operating state is between 60% and 70% and the degree of opening (OP2) of the valve during the first operating state is between 50% and 60%.

9. Method according to one of Claims 4 to 8 including liquefying a portion (L412) of the whole amount of product gas and feeding this portion to a product tank (V20), with the remainder being circulated through the turbine (ET22) and sent to the product tank.

Figure 1

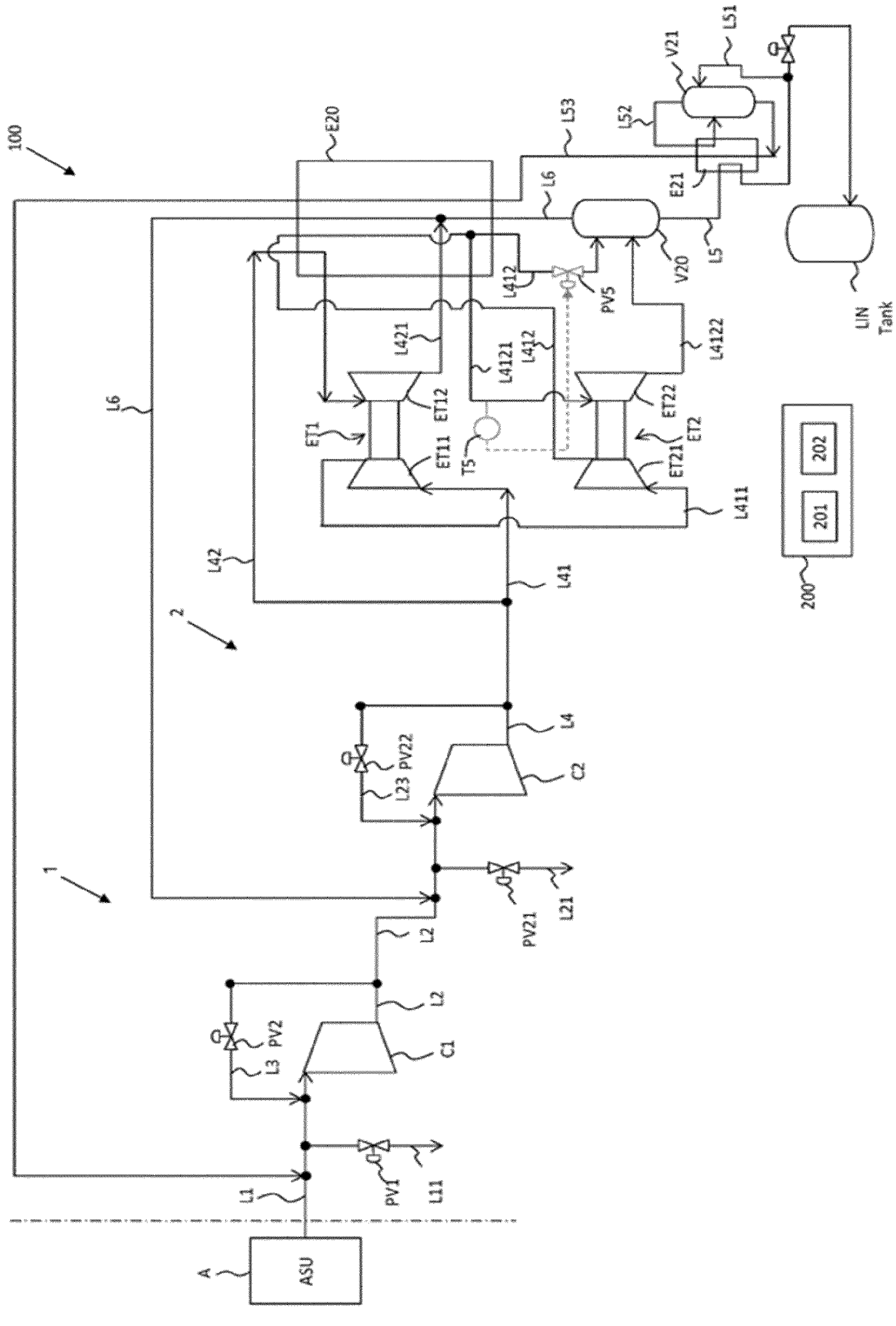
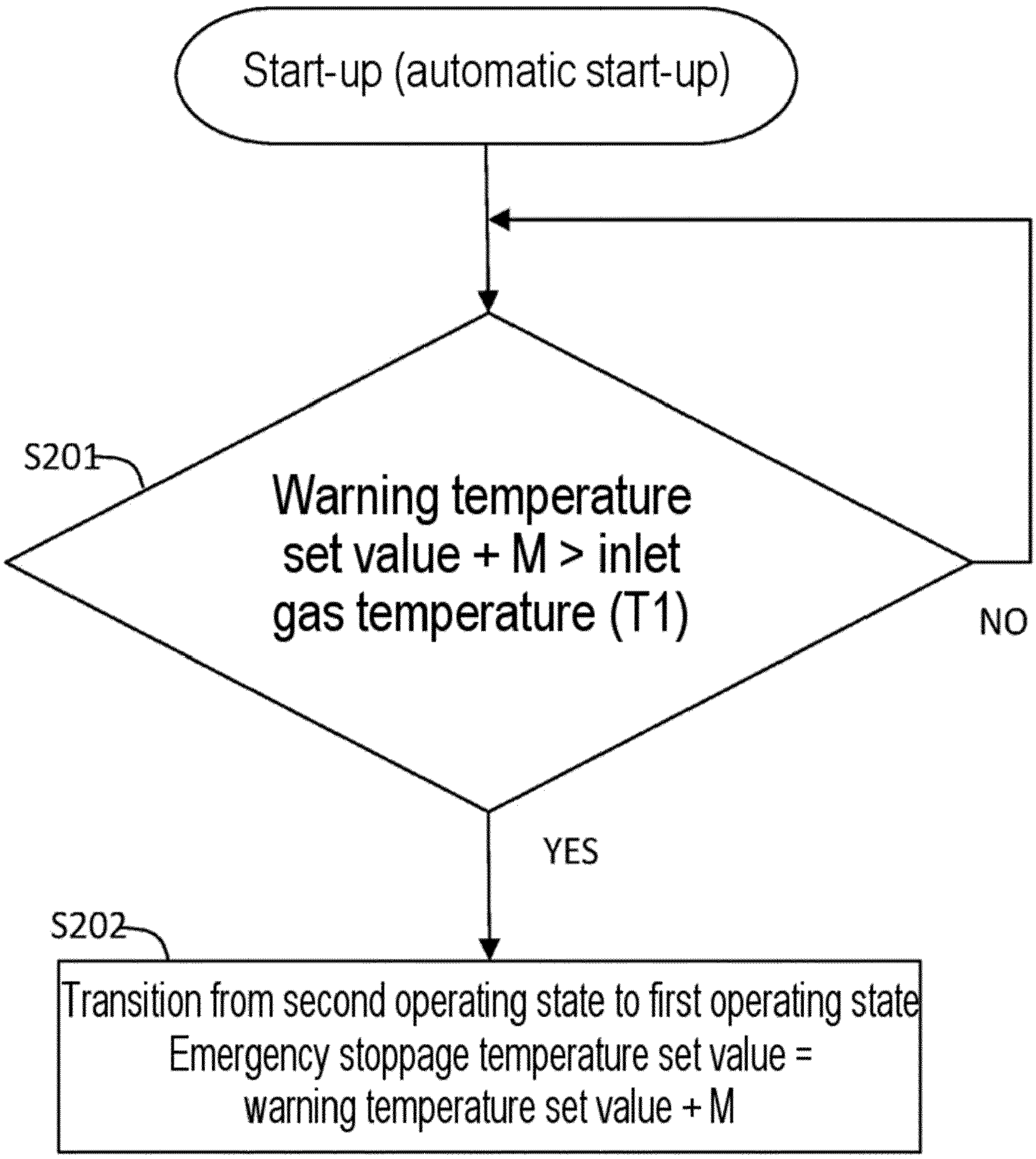

100
1
2
A
ASU
L1
PV1
L11
L3
PV2
C1
L2
L2
PV21
L21
L23
PV22
C2
L4
L41
L42
L6
L6
ET1
ET11
ET12
ET2
ET21
ET22
T5
L411
L4121
L412
L412
L421
L4122
PV5
E20
V20
L5
L53
L52
V21
L51
E21
LIN Tank
200
201
202

Figure 2


Start-up (automatic start-up)
S201
Warning temperature set value + M > inlet gas temperature (T1)
NO
YES
S202
Transition from second operating state to first operating state
Emergency stoppage temperature set value =
= warning temperature set value + M

Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 23 19 2166

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	FR 2 991 758 A3 (AIR LIQUIDE [FR]) 13 December 2013 (2013-12-13) * figure 1 * -----	1-9	INV. F25J1/00
A	CN 113 758 148 A (HANGZHOU OXYGEN PLANT GROUP CO LTD) 7 December 2021 (2021-12-07) * figure 3 * -----	1-9	
A	US 9 890 712 B2 (MORGAN ROBERT [GB]; NELMES STUART [GB] ET AL.) 13 February 2018 (2018-02-13) * figure 5 * -----	1-9	
A	US 7 219 512 B1 (WILDING BRUCE M [US] ET AL) 22 May 2007 (2007-05-22) * column 7, line 61 - column 8, line 9; figure 2 * -----	1,4	
A	US 2006/213223 A1 (WILDING BRUCE M [US] ET AL) 28 September 2006 (2006-09-28) * paragraphs [0069], [0070], [0187], [0188]; figure 18 * -----	1,4	TECHNICAL FIELDS SEARCHED (IPC): F25J

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	2 April 2024	Schopfer, Georg

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
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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 19 2166

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.

02-04-2024

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