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

(11) **EP 3 904 690 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
03.11.2021 Bulletin 2021/44

(51) Int Cl.:
F04D 17/12 *(2006.01)* ***F04D 27/02*** *(2006.01)*

(21) Application number: **21168518.5**

(22) Date of filing: **15.04.2021**

(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 MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(30) Priority: **27.04.2020 CN 202010346052**

(71) Applicant: **L'AIR LIQUIDE, SOCIETE ANONYME POUR L'ETUDE ET L'EXPLOITATION DES PROCEDES GEORGES CLAUDE**
75007 Paris (FR)

(72) Inventors:
- **GAO, Fei**
  HANGZHOU, 310012 (CN)
- **DAY, Eric**
  HANGZHOU, 310012 (CN)
- **QU, Li**
  HANGZHOU, 310012 (CN)
- **LI, Jian-Wei**
  HANGZHOU, 310012 (CN)

(74) Representative: **Air Liquide**
L'Air Liquide S.A.
Direction de la Propriété Intellectuelle
75, Quai d'Orsay
75321 Paris Cedex 07 (FR)

(54) MULTISTAGE CENTRIFUGAL COMPRESSOR WITH AN ANTI-SURGE SYSTEM AND CONTROL METHOD THEREFOR

(57) An anti-surge system for a centrifugal compressor, the centrifugal compressor including first to Nth compression stages (C1, C2, C3, C4), and an intermediate gas extraction pipeline (IA/PA) being disposed between an (M-1)th compression stage and an Mth compression stage, wherein N is an integer ≥ 2, and M is an integer ≤ N, comprises: a first throttle device (Fa); a first pressure sensor (Pa); a first temperature sensor (Ta; a second pressure sensor (Pb); a second throttle device (Fb); a second temperature sensor (Tb); a third pressure sensor (Pc); a branch pipeline (Bp); an anti-surge backflow valve (ASV); and a control system, comprising a first anti-surge controller (ASC1), a second anti-surge controller (ASC2) and a selector (HY).

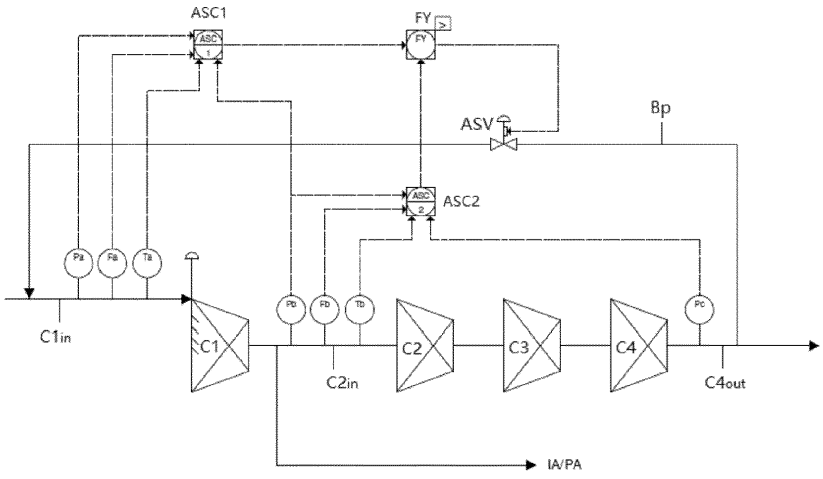

Fig. 1

EP 3 904 690 A1

Description

[0001] The present invention belongs to the field of gas separation equipment, and relates to an anti-surge system and control method for a centrifugal compressor.

[0002] When a centrifugal compressor is running, if the suction flow rate decreases to a certain value, the compressor will exhibit unstable operation. The suction flow rate and outlet pressure thereof will fluctuate rapidly and continuously, and in terms of manifestation, this may be accompanied by high vibration, a rise in temperature and rapid changes in axial thrust. The result is that the compressor experiences fierce vibration, accompanied by a very high level of noise. This phenomenon is known as compressor surge, and might damage the compressor.

[0003] In order to prevent surge, a surge line and a surge control line are usually set in the performance map of a multi-stage compression system, and the surge control line is used to control the multi-stage compression system. The manufacturer or designer of the multi-stage compression system sets the surge line at which surge occurs by subjecting the multi-stage compression system to theoretical analysis and multiple experiments, and sets the surge control line by presetting a 10% safety margin.

[0004] In the prior art, an attempt can be made to stay away from the surge control line by adjusting the ratio of pressures (pressure ratio) of the fluid inputted to the compressor and discharged from the compressor, the fluid flow rate, or other parameters that can be controlled.

[0005] Conventionally, the discharge pressure of the compressor is adjusted by controlling the degree of opening of an inlet guide vane disposed in the compressor, or a backflow valve at the outlet of the compressor is opened, so that some gas discharged from the compressor is returned to the inlet side of the compressor, to achieve the objective of staying away from the surge line and preventing compressor surge.

[0006] An air booster in an air separation apparatus is usually provided with an intermediate gas extraction pipeline, the intermediately extracted gas being used to supply public facilities; the amount of intermediately extracted gas might account for 1 % - 30% of the intake gas flow rate of the air booster. In this case, due to the reduction in the air flow rate through the air booster, the air booster can be regarded as two different centrifugal compressor sections with the intermediate gas extraction pipeline as a boundary. In the prior art, two sets of inlet guide vanes, two backflow pipelines, and backflow valves disposed on the two backflow pipelines respectively are generally provided for anti-surge control, but this is not ideal from an economic perspective.

[0007] In view of the above, the question of how to design a new anti-surge system and control method for a centrifugal compressor, in order to subject a centrifugal compressor with intermediate gas extraction to segmented anti-surge control, is an issue for which relevant technicians in the industry urgently require a solution.

[0008] In order to achieve the abovementioned invention object, the present invention discloses an anti-surge system for a centrifugal compressor, the centrifugal compressor having N compression stages, including first to Nth compression stages, and an intermediate gas extraction pipeline being disposed between an (M-1)th compression stage and an Mth compression stage, wherein N denotes an integer equal to or greater than 2, and M denotes an integer less than or equal to N; the anti-surge system for a centrifugal compressor comprises a first throttle device, disposed on an inlet pipeline of the first compression stage, and configured to measure an inlet flow rate of the first compression stage; a first pressure sensor, disposed on the inlet pipeline of the first compression stage, and configured to measure an inlet pressure of the first compression stage; a first temperature sensor, disposed on the inlet pipeline of the first compression stage, and configured to measure an inlet temperature of the first compression stage; a second pressure sensor, disposed on an inlet pipeline of the Mth compression stage, and configured to measure an inlet pressure of the Mth compression stage; a second throttle device, disposed on the inlet pipeline of the Mth compression stage and disposed after the intermediate gas extraction pipeline, and configured to measure an inlet flow rate of the Mth compression stage; a second temperature sensor, disposed on the inlet pipeline of the Mth compression stage and disposed after the intermediate gas extraction pipeline, and configured to measure an inlet temperature of the Mth compression stage; a third pressure sensor, disposed on an outlet pipeline of the Nth compression stage, and configured to measure an outlet pressure of the Nth compression stage; a branch pipeline, configured to connect the outlet pipeline of the Nth compression stage to the inlet pipeline of the first compression stage; an anti-surge backflow valve, located on the branch pipeline, and configured to adjust a backflow flow rate of backflow from the outlet pipeline of the Nth compression stage to the inlet pipeline of the first compression stage via the branch pipeline; and a control system, comprising a first anti-surge controller, a second anti-surge controller and a high selector; the first anti-surge controller being configured to receive flow rate, pressure and temperature signals inputted by the first throttle device, the first pressure sensor, the second pressure sensor and the first temperature sensor, and to decide via an operation whether to output a first backflow valve opening degree signal; the second anti-surge controller being configured to receive flow rate, pressure and temperature signals inputted by the second throttle device, the second pressure sensor, the third pressure sensor and the second temperature sensor, and to decide via an operation whether to output a second backflow valve opening degree signal; the selector receives and compares the first backflow valve opening degree signal and the second backflow valve opening degree signal, and controls the opening of the anti-surge backflow valve according to the higher of the first and second backflow

valve opening degree signals; if the high selector does not receive any first backflow valve opening degree signal or second backflow valve opening degree signal, the anti-surge backflow valve is not opened.

[0009] Furthermore, the intermediate gas extraction pipeline provides intermediately extracted gas for supplying instrument gas and/or factory gas, and the flow rate of the intermediately extracted gas accounts for 1% - 30% of the intake gas flow rate of the inlet pipeline of the first compression stage. Thus the flow rate in the 1st to M-1 th stages is greater than the flow rate in the Mth to Nth stages.

[0010] Furthermore, when the anti-surge backflow valve is open, at least a portion of gas in the outlet pipeline of the Nth compression stage flows back to the inlet pipeline of the first compression stage via the branch pipeline, thereby increasing the intake gas flow rate of the inlet pipeline of the first compression stage.

[0011] The present invention further discloses an anti-surge system control method for a centrifugal compressor, wherein: the compression stage of the centrifugal compressor that is disposed before the intermediate gas extraction pipeline (i.e. the first to (M-1)th compression stages) is defined as a first compression section; the compression stage of the centrifugal compressor that is disposed after the intermediate gas extraction pipeline (i.e. the Mth to Nth compression stages) is defined as a second compression section; the control method comprises a first anti-surge control associated with the first compression section, and a second anti-surge control associated with the second compression section; the first anti-surge control is based on a first surge control line, and the second anti-surge control is based on a second surge control line; the first anti-surge control and the second anti-surge control are executed together, such that neither one of the first compression section and second compression section of the centrifugal compressor experiences surge.

[0012] Furthermore, the first compression section is subjected to the first anti-surge control via the following steps: a pressure ratio at a first operating point is calculated according to pressure signals inputted by the first pressure sensor and the second pressure sensor, and a first anti-surge flow rate on the first surge control line is determined according to the pressure ratio at the first operating point, and defined as a first set value; a flow rate signal inputted by the first throttle device is defined as a first measured value; when the first measured value is less than the first set value, the first backflow valve opening degree signal is outputted, wherein the opening degree signal is dynamic, opening until the first measured value is equal to the first set value; and when the first measured value is not less than the first set value, the first backflow valve opening degree signal is not outputted.

[0013] Furthermore, the second compression section is subjected to the second anti-surge control via the following steps: a pressure ratio at a second operating point is calculated according to pressure signals inputted by the second pressure sensor and the third pressure sensor, and a second anti-surge flow rate on the second surge control line is determined according to the pressure ratio at the second operating point, and defined as a second set value; a flow rate signal inputted by the second throttle device is defined as a second measured value; when the second measured value is less than the second set value, the second backflow valve opening degree signal is outputted, wherein the opening degree signal is dynamic, opening until the second measured value is equal to the second set value; and when the second measured value is not less than the second set value, the second backflow valve opening degree signal is not outputted.

[0014] Furthermore, the high selector receives and compares the first backflow valve opening degree signal and the second backflow valve opening degree signal, and controls the opening of the anti-surge backflow valve according to the larger backflow valve opening degree signal; at least a portion of gas in the outlet pipeline of the Nth compression stage flows back to the inlet pipeline of the first compression stage via the branch pipeline, thereby increasing the intake gas flow rate of the inlet pipeline of the first compression stage, such that an operating point is on a surge control line or at the right side of the surge control line, to achieve the objective of preventing surge; if the high selector does not receive any first backflow valve opening degree signal or second backflow valve opening degree signal, the anti-surge backflow valve is not opened.

[0015] Compared with the prior art, the technical solution provided in the present invention has the following advantages:

(1) It effectively solves the technical problem of anti-surge control of centrifugal compressors with changing gas flow rate, especially in cases where the amount of intermediately extracted gas accounts for a large proportion of the total intake gas flow rate of the compression stage.

(2) The multi-stage compression system is regarded as two different centrifugal compressor sections with the intermediate gas extraction pipeline as a boundary, such that segmented anti-surge control can be accomplished merely by adding a throttle device and corresponding anti-surge controller to the second compression section.

(3) In conventional practice, two sets of inlet guide vanes, two backflow pipelines, and backflow valves arranged on the two backflow pipelines respectively are usually provided for anti-surge control. However, the present invention can accomplish segmented anti-surge control by retaining one set of inlet guide vanes and one backflow valve.

(4) The anti-surge control of the first compression section and the anti-surge control of the second compression section are relatively independent, but

should be executed together, and control by the same backflow valve ensures that neither one of the first compression section and second compression section of the compressor experiences surge.

[0016] Further understanding of the advantages and spirit of the present invention can be gained through the following detailed description of the invention and the accompanying drawings.

Figure 1 is a structural schematic diagram of an anti-surge system for a centrifugal compressor according to an exemplary embodiment of the present invention.

Figure 2 is a performance map of the present invention for a first compression section, schematically showing a first surge control line associated with first anti-surge control of the first compression section.

Figure 3 is a performance map of the present invention for a second compression section, schematically showing a second surge control line associated with second anti-surge control of the second compression section.

[0017] Specific embodiments of the present invention are explained in detail below in conjunction with the accompanying drawings. However, the present invention should be understood to not be limited to embodiments such as those described below, and the technical concept of the present invention may be implemented in combination with other well-known technologies or other technologies having the same function as those well-known technologies.

[0018] Referring to Fig. 1, an anti-surge system for a centrifugal compressor comprises a first compression stage C1, a second compression stage C2, a third compression stage C3, a fourth compression stage C4, a first throttle device Fa, a first pressure sensor Pa, a first temperature sensor Ta, a second pressure sensor Pb, a second throttle device Fb, a second temperature sensor Tb, a third pressure sensor Pc, an inlet pipeline $C1_{in}$ of the first compression stage, an inlet pipeline $C2_{in}$ of the second compression stage, an outlet pipeline $C4_{out}$ of the fourth compression stage, a branch pipeline Bp connecting the outlet pipeline of the fourth compression stage to the inlet pipeline of the first compression stage, an anti-surge backflow valve ASV installed on the branch pipeline Bp, a first anti-surge controller ASC1, a second anti-surge controller ASC2 and a high selector FY.

[0019] The centrifugal compressor according to the current embodiment is a four-stage compressor comprising the first compression stage C1, the second compression stage C2, the third compression stage C3 and the fourth compression stage C4; the compression pressure increases in sequence from the first stage to the fourth stage. However, this embodiment is not limited to this. The number of stages of the centrifugal compressor of the present invention is not limited; that is, the centrifugal compressor according to an exemplary embodiment may be configured to comprise ten compression stages or more.

[0020] In the present invention, intermediate gas extraction takes place at only one position; in this exemplary embodiment, this is disposed between the first compression stage C1 and the second compression stage C2 (i.e. indicating that M = 2 and N = 4). The centrifugal compressor is divided into two compression sections; a first compression section comprises the first compression stage C1, and a second compression section comprises the second compression stage C2 to the fourth compression stage C4. The intermediately extracted gas is used to supply instrument gas and/or factory gas (IA/PA), and since the amount of intermediately extracted gas accounts for 1% - 30% of the intake gas flow rate of the inlet pipeline $C1_{in}$ of the first compression stage C1, the first compression section before an intermediate gas extraction pipeline and the second compression section after the intermediate gas extraction pipeline exhibit a change in flow rate, and can be regarded as two different centrifugal compressor sections with the intermediate gas extraction pipeline as a boundary; the performance curves thereof and the corresponding surge lines and surge control lines can be regarded as being in different operating conditions, so anti-surge control needs to be performed separately.

[0021] The first throttle device Fa, the first pressure sensor Pa and the first temperature sensor Ta are all disposed on the inlet pipeline $C1_{in}$ of the first compression section; the second throttle device Fb, the second pressure sensor Pb and the second temperature sensor Tb are all disposed on the inlet pipeline $C2_{in}$ of the second compression section (after the intermediate gas extraction pipeline); the third pressure sensor Pc is disposed on the outlet pipeline $C4_{out}$ of the second compression section. Since the outlet pipeline of the first compression section is the inlet pipeline of the second compression section, the second pressure sensor is not only disposed on the outlet pipeline of the first compression section for the purpose of measuring an outlet pressure of the first compression section, but is also disposed on the inlet pipeline of the second compression section for the purpose of measuring an inlet pressure of the second compression section, i.e. the inlet pressure of the second compression section and the outlet pressure of the first compression section share the second pressure sensor, and approximately, the outlet pressure of the first compression section can be considered to be equal to the inlet pressure of the second compression section.

[0022] Preferably, the first throttle device Fa and second throttle device Fb are both orifice plate flow meters; orifice plate flow meter throttle devices are simple in structure and sturdy, with stable and reliable performance, and a long service life; they are instruments that are commonly used in industry for measuring flow rates, are manufactured in accordance with international standards, and undergo rigorous checking and testing. A static

pressure difference arises between the regions before and after the orifice plate flow meter, and a certain functional relationship exists between this pressure difference and flow rate; the greater the flow rate, the greater the pressure difference. A differential pressure signal is transmitted to a differential pressure transmitter, converted to a 4 - 20 ma. DC analog signal for output, and remotely transferred to a flow totalizer, thus achieving measurement of fluid flow rate.

[0023] Preferably, the first pressure sensor Pa, the second pressure sensor Pb and the third pressure sensor Pc are electronic pressure sensors that automatically send measurement signals to a control system, but this embodiment is not limited to this. That is, the first pressure sensor, the second pressure sensor and the third pressure sensor according to an exemplary embodiment may be mechanical pressure sensors. In this case, a user can obtain measurement data from these sensors, and based on the measurement data, he/she performs anti-surge control manually.

[0024] Preferably, the first temperature sensor Ta and the second temperature sensor Tb are electronic temperature sensors that automatically send measurement signals to the control system, but this embodiment is not limited to this. That is, the first temperature sensor and the second temperature sensor according to an exemplary embodiment may be mechanical temperature sensors. In this case, a user can obtain measurement data from these sensors, and based on the measurement data, he/she performs anti-surge control manually.

[0025] Under the control of the control system, the anti-surge backflow valve ASV is opened or closed to control surge. In other words, when the anti-surge backflow valve ASV is opened, at least a portion of gas flowing through the outlet pipeline $C4_{out}$ of the second compression section flows back to the inlet pipeline $C1_{in}$ of the first compression section through the branch pipeline Bp via the anti-surge control valve ASV; the outlet pressure of the second compression section falls and the intake gas flow rate of the inlet pipeline of the first compression section increases, thereby reducing the occurrence of surge.

[0026] In the present invention, the first anti-surge control and the second anti-surge control are executed together. That is, even if surge occurs in only one of the first compression section and the second compression section, the performance of the entire centrifugal compressor is reduced. Therefore, the anti-surge control should be executed such that surge does not occur in either one of the first compression section and the second compression section of the centrifugal compressor.

[0027] In the present invention, the surge control lines (the dotted lines in Figs. 2 and 3) are set by setting a safety margin of about 10% in the surge lines (the solid lines in Figs. 2 and 3), but the permitted safety margin can change according to the demands of the designer or user. The surge lines of different compression sections are different. The surge line is a linear straight line (= AX + Y by supposition) formed by connecting a number of actual surge points, and the surge control line is another linear straight line based on the safety margin. A given pressure ratio on the surge control line has one and only one corresponding flow rate value, which is a set value of the present invention at that pressure ratio. A measured value is directly measured by the throttle device at that pressure ratio. If the measured value is less than the set value, this indicates that the measured value is on the left side of the surge control line; if the measured value is not less than the set value, this indicates that the measured value is on the surge control line or on the right side of the surge control line.

[0028] Fig. 2 is a performance map of the present invention for the first compression section, schematically showing a first surge control line associated with first anti-surge control of the first compression section. The first pressure sensor Pa measures the inlet pressure in the inlet pipeline $C1_{in}$ of the first compression section to be P1, and the second pressure sensor Pb measures the outlet pressure in the outlet pipeline of the first compression section (i.e. the inlet pipeline $C2_{in}$ of the second compression section) to be P2; then the ratio of pressures of gas inputted to the first compression section and discharged from the first compression section, i.e. the pressure ratio at a first operating point, is P2/P1. A first anti-surge flow rate F1 on the first surge control line is determined according to the pressure ratio P2/P1 at the first operating point, and defined to be a first set value; a flow rate signal inputted by the first throttle device Fa is defined to be a first measured value F2; at this time, the first measured value F2 is greater than the first set value F1, i.e. the first operating point is at the right side of the first surge control line, so a first backflow valve opening degree signal is not outputted, and the first compression section operates at the first operating point. For this purpose, the first anti-surge controller comprises an integrated circuit and a circuit device to store data and perform arithmetic operations.

[0029] Fig. 3 is a performance map of the present invention for the second compression section, schematically showing a second surge control line associated with second anti-surge control of the second compression section. The flow rate of the second compression section after the intermediate gas extraction pipeline is about 10% less than that of the first compression section. Therefore, the first compression section and the second compression section can be regarded as two different centrifugal compressor sections with the intermediate gas extraction pipeline as a boundary; the performance curves thereof and the corresponding surge lines and surge control lines can be regarded as being in different operating conditions. The second pressure sensor Pb measures the inlet pressure in the inlet pipeline $C2_{in}$ of the second compression section to be P2, and the third pressure sensor Pc measures the outlet pressure in the outlet pipeline $C4_{out}$ of the second compression section to be P3; then the ratio of pressures of gas inputted to the second compression section and discharged from

the second compression section, i.e. the pressure ratio at a second operating point, is P3/P2. A second anti-surge flow rate F3 on the second surge control line is determined according to the pressure ratio P3/P2 at the second operating point, and defined to be a second set value; a flow rate signal inputted by the second throttle device Fb is defined to be a second measured value F4. At this time, the second measured value F4 is less than the second set value F3, and the second operating point is at the left side of the second surge control line, so a second backflow valve opening degree signal is outputted; the second backflow valve opening degree signal is dynamic, causing the opening of the backflow valve ASV until the second measured value is equal to the second set value. For this purpose, the second anti-surge controller comprises an integrated circuit and a circuit device to store data and perform arithmetic operations.

[0030] In this exemplary embodiment, the selector FY receives and compares the first backflow valve opening degree signal and second backflow valve opening degree signal. Since no first backflow valve opening degree signal is outputted, the value of the first backflow valve opening degree signal is considered to be zero and only the second backflow valve opening degree signal is outputted, opening of the anti-surge backflow valve ASV is controlled according to the larger backflow valve opening degree signal, ie the second backflow valve opening degree signal. The opening degree signal is dynamic, causing the opening of the anti surge backflow valve until the second measured flowrate value is equal to the second set value for the flowrate. Thus, gas in the outlet pipeline $C4_{out}$ of the fourth compression stage with a flow rate of at least I F4-F3 I flows back to the inlet pipeline $C1_{in}$ of the first compression stage via the branch pipeline Bp, thereby increasing the intake gas flow rate of the inlet pipeline $C1_{in}$ of the first compression stage, such that the measured flow rates at the first operating point and second operating point are both no less than the anti-surge flow rates of the corresponding surge control lines, to achieve the objective of preventing surge.

[0031] The four-stage compressor comprising the first to fourth compression stages according to the current embodiment has been described above. However, the compressor is described as having four stages for convenience of explanation but is not limited to four. In other words, the centrifugal compressor may be configured to have N compression stages ($N \geq 2$), but since intermediate gas extraction takes place at only one position according to the present invention, the centrifugal compressor is still regarded as two compression sections with the intermediate gas extraction pipeline as a boundary for the purposes of anti-surge control.

[0032] Unless stated otherwise, qualifiers similar to "first" and "second" appearing herein do not indicate a definition of chronological order, quantity or importance, but are merely intended to distinguish one technical feature in this technical solution from another technical feature. Similarly, qualifiers similar to "a" appearing herein do not indicate a definition of quantity, but describe a technical feature that has not appeared in the preceding text. Similarly, modifiers similar to "about" and "approximately" appearing in front of numerals herein generally include the number itself, and the specific meaning thereof should be understood in conjunction with the meaning of the context.

Claims

1. Centrifugal compressor comprising an anti-surge system , the centrifugal compressor having N compression stages, including first to Nth compression stages, and an intermediate gas extraction pipeline being disposed between an (M-1)th compression stage and an Mth compression stage, wherein N denotes an integer equal to or greater than 2, and M denotes an integer less than or equal to N, **characterized in that** the anti-surge system for a centrifugal compressor comprises:

    • a first throttle device, disposed on an inlet pipeline of the first compression stage, and configured to measure an inlet flow rate of the first compression stage;
    • a first pressure sensor, disposed on the inlet pipeline of the first compression stage, and configured to measure an inlet pressure of the first compression stage;
    • a first temperature sensor, disposed on the inlet pipeline of the first compression stage, and configured to measure an inlet temperature of the first compression stage;
    • a second pressure sensor, disposed on an inlet pipeline of the Mth compression stage, and configured to measure an inlet pressure of the Mth compression stage;
    • a second throttle device, disposed on the inlet pipeline of the Mth compression stage and disposed after the intermediate gas extraction pipeline, and configured to measure an inlet flow rate of the Mth compression stage;
    • a second temperature sensor, disposed on the inlet pipeline of the Mth compression stage and disposed after the intermediate gas extraction pipeline, and configured to measure an inlet temperature of the Mth compression stage;
    • a third pressure sensor, disposed on an outlet pipeline of the Nth compression stage, and configured to measure an outlet pressure of the Nth compression stage;
    • a branch pipeline, configured to connect the outlet pipeline of the Nth compression stage to the inlet pipeline of the first compression stage;
    • an anti-surge backflow valve, located on the branch pipeline, and configured to adjust a backflow flow rate of backflow from the outlet pipeline

of the Nth compression stage to the inlet pipeline of the first compression stage via the branch pipeline; and

• a control system, comprising a first anti-surge controller, a second anti-surge controller;

• the first anti-surge controller being configured to receive flow rate, pressure and temperature signals inputted by the first throttle device, the first pressure sensor, the second pressure sensor and the first temperature sensor, and to decide via an operation whether to output a first backflow valve opening degree signal;

• the second anti-surge controller being configured to receive flow rate, pressure and temperature signals inputted by the second throttle device, the second pressure sensor, the third pressure sensor and the second temperature sensor, and to decide via an operation whether to output a second backflow valve opening degree signal; and means to open the anti-surge backflow valve if one of the first and second backflow valve opening degree signals is received and means to close the anti-surge backflow valve if neither of the first and second backflow valve opening degree signals is received.

2. The compressor of Claim 1 comprising a selector configured to receive and compare the first backflow valve opening degree signal and second backflow valve opening degree signal, and to control the opening of the anti-surge backflow valve according to the higher of the first and second backflow valve opening degree opening degree signals.

3. The compressor as claimed in claim 1 or 2, wherein no pipeline is connected to send gas from the Nth stage to the Mth stage.

4. The compressor as claimed in any of claims 1 to 3, configured such that that when the anti-surge backflow valve is open, at least a portion of gas in the outlet pipeline of the Nth compression stage can flow back to the inlet pipeline of the first compression stage via the branch pipeline, thereby increasing the intake gas flow rate of the inlet pipeline of the first compression stage.

5. The compressor of any preceding claim wherein the first and/or second anti-surge controller is capable of outputting the first and/or second backflow valve opening degree signal respectively if the ratio between the inlet and outlet pressure ratio and the flowrate for the corresponding compression section is greater than a threshold value.

6. A control method for an anti-surge system for a centrifugal compressor centrifugal compressor, the centrifugal compressor having N compression stages, including first to Nth compression stages, and an intermediate gas extraction pipeline being disposed between an (M-1)th compression stage and an Mth compression stage, wherein N denotes an integer equal to or greater than 2, and M denotes an integer less than or equal to N, the anti-surge system for a centrifugal compressor comprising:

• a first throttle device, disposed on an inlet pipeline of the first compression stage, and configured to measure an inlet flow rate of the first compression stage;

• a first pressure sensor, disposed on the inlet pipeline of the first compression stage, and configured to measure an inlet pressure of the first compression stage;

• a first temperature sensor, disposed on the inlet pipeline of the first compression stage, and configured to measure an inlet temperature of the first compression stage;

• a second pressure sensor, disposed on an inlet pipeline of the Mth compression stage, and configured to measure an inlet pressure of the Mth compression stage;

• a second throttle device, disposed on the inlet pipeline of the Mth compression stage and disposed after the intermediate gas extraction pipeline, and configured to measure an inlet flow rate of the Mth compression stage;

• a second temperature sensor, disposed on the inlet pipeline of the Mth compression stage and disposed after the intermediate gas extraction pipeline, and configured to measure an inlet temperature of the Mth compression stage;

• a third pressure sensor, disposed on an outlet pipeline of the Nth compression stage, and configured to measure an outlet pressure of the Nth compression stage;

• a branch pipeline, configured to connect the outlet pipeline of the Nth compression stage to the inlet pipeline of the first compression stage;

• an anti-surge backflow valve, located on the branch pipeline, and configured to adjust a backflow flow rate of backflow from the outlet pipeline of the Nth compression stage to the inlet pipeline of the first compression stage via the branch pipeline;

• the compression stage(s) of the centrifugal compressor disposed upstream the intermediate gas extraction pipeline is defined as a first compression section;

• the compression stage(s) of the centrifugal compressor disposed downstream the intermediate gas extraction pipeline is defined as a second compression section;

• the control method uses a first anti-surge control associated with the first compression section, and a second anti-surge control associated

with the second compression section;

wherein the first anti-surge control generates a first backflow valve opening degree signal if a surge risk in the first compression section is detected, the second anti-surge control generates a second backflow valve opening degree signal if a surge risk in the second compression section is detected and the anti-surge backflow valve is opened if the backflow valve opening degree signal is detected from at least one of the first and second anti-surge controls and is closes if no backflow valve opening degree signal from the first and second anti-surge controls is detected.

7. The method of Claim 6 wherein a selector receives and compares the first backflow valve opening degree signal and second backflow valve opening degree signal, and adjusts the degree of opening of the anti-surge backflow valve according to the higher of the first and second backflow valve opening degree signals.

8. The method as claimed in claim 6 or 7, **characterized in that** the first compression section is subjected to the first anti-surge control via the following steps: a pressure ratio at a first operating point is calculated according to pressure signals inputted by the first pressure sensor and the second pressure sensor, and a first anti-surge flow rate on the first surge control line is determined according to the pressure ratio at the first operating point, and defined as a first set value; a flow rate signal inputted by the first throttle device is defined as a first measured value; when the first measured value is less than the first set value, the first backflow valve opening degree signal is outputted.

9. The method of Claim 8 wherein the first backflow valve opening degree signal causes the backflow control valve to remain open until the first measured value is equal to the first set value.

10. The method of Claim 8 or 9 wherein if the first measured value is not less than the first set value, the first backflow valve opening degree signal is not outputted.

11. The method as claimed in claims 6 to 10, **characterized in that** the second compression section is subjected to second anti-surge control via the following steps: a pressure ratio at a second operating point is calculated according to pressure signals inputted by the second pressure sensor and the third pressure sensor, and a second anti-surge flow rate on the second surge control line is determined according to the pressure ratio at the second operating point, and defined as a second set value; a flow rate signal inputted by the second throttle device is defined as a second measured value; when the second measured value is less than the second set value, the second backflow valve opening degree signal is outputted.

12. The method of Claim 11, wherein the opening degree signal causes the backflow control valve to remain open until the second measured value is at least equal to the second set value.

13. The method of Claim 11 or 12 wherein if the second measured value is not less than the second set value, the second backflow valve opening degree signal is not outputted.

14. The method of any of Claims 6 to 13 wherein the compressor compresses air and the intermediate gas extraction pipeline provides intermediately extracted gas for supplying instrument gas and/or factory gas.

15. The method of any of Claims 6 to 14 wherein the compressor compresses air and the flow rate of the intermediately extracted gas accounts for 1% - 30% of the intake gas flow rate of the inlet pipeline of the first compression stage.

16. The method of any of Claims 6 to 15 wherein no gas is recycled from the Nth compressor stage to the Mth compressor stage.

17. The control method for an anti-surge system of a centrifugal compressor as claimed in one of Claims 6 to 14, **characterized in that** a selector receives and compares the first backflow valve opening degree signal and the second backflow valve opening degree signal, and controls the degree of opening of the anti-surge backflow valve according to the larger backflow valve opening degree signal; at least a portion of gas in the outlet pipeline of the Nth compression stage flows back to the inlet pipeline of the first compression stage via the branch pipeline, thereby increasing the intake gas flow rate of the inlet pipeline of the first compression stage, such that an operating point is on a surge control line or sufficiently distant from the surge control line, to achieve the objective of preventing surge and if the selector does not receive either the first backflow valve opening degree signal or the second backflow valve opening degree signal, the anti-surge backflow valve is not opened.

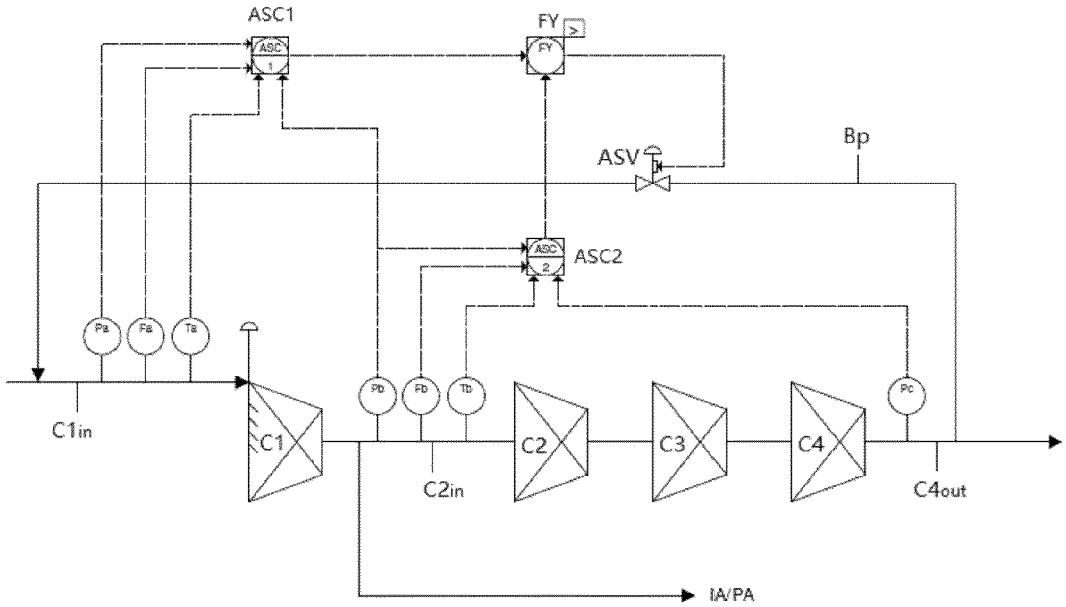
ASC1
FY
ASV
Bp
ASC2
Pa
Fa
Ta
Pb
Fb
Tb
Pc
C1in
C1
C2
C3
C4
C2in
C4out
IA/PA

Fig. 1

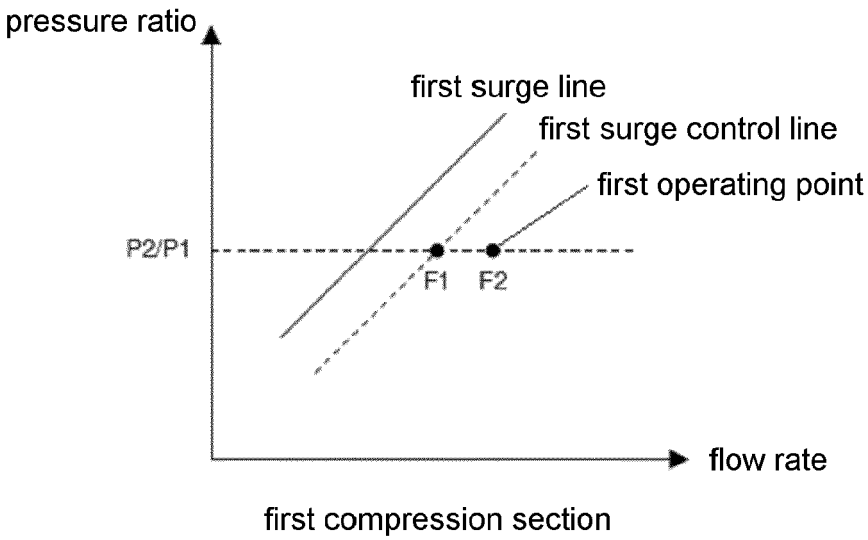
pressure ratio
first surge line
first surge control line
first operating point
P2/P1
F1
F2
flow rate
first compression section

Fig. 2

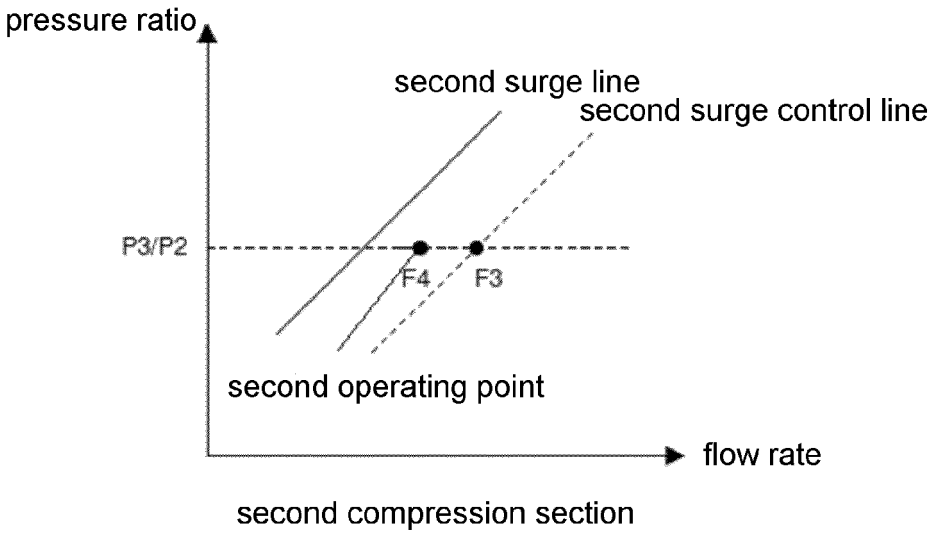
pressure ratio
second surge line
second surge control line
P3/P2
F4
F3
second operating point
flow rate
second compression section

Fig. 3

Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 21 16 8518

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
Y	JP H09 273495 A (HITACHI LTD) 21 October 1997 (1997-10-21) * abstract * * figures 1, 2 *	1-17	INV. F04D17/12 F04D27/02
Y	US 2017/082113 A1 (SHAPIRO VADIM [US] ET AL) 23 March 2017 (2017-03-23) * paragraph [0012] - paragraph [0015] * * paragraph [0043] - paragraph [0061] * * claim 1 * * figures 2-4 *	1-17	
A	US 2007/122272 A1 (GUILLARD ALAIN [FR] ET AL) 31 May 2007 (2007-05-31) * paragraph [0047] * * figure 2 *	1-17	
A	US 9 074 606 B1 (MOORE ROBERT DOAK [US]) 7 July 2015 (2015-07-07) * column 4, line 62 - column 5, line 30 * * figures 1-3 *	1-17	TECHNICAL FIELDS SEARCHED (IPC) F04D

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	26 August 2021	Oliveira, Damien

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 21 16 8518

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.

26-08-2021

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP H09273495 A	21-10-1997	JP 3432674 B2	04-08-2003
		JP H09273495 A	21-10-1997
US 2017082113 A1	23-03-2017	NONE	
US 2007122272 A1	31-05-2007	CN 1890524 A	03-01-2007
		EP 1692443 A1	23-08-2006
		FR 2863348 A1	10-06-2005
		JP 2007518048 A	05-07-2007
		US 2007122272 A1	31-05-2007
		WO 2005057111 A1	23-06-2005
US 9074606 B1	07-07-2015	NONE	

EPO FORM P0459

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