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(54) **A gas compression system and a method for controlling a gas compression system.**

Gaskompressionssystem und Verfahren zur Steuerung eines Gaskompressionssystems.

Système de compression de gaz et procédé pour le contrôle d'un système de compression de gaz.

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Description

FIELD OF THE INVENTION

[0001] The present invention relates to a gas compression system comprising a compressor for compressing a gas fed to the compressor, an electric motor driving the compressor, a compressor motor drive unit producing current to said motor, a pipe for feeding back gas from the outlet of the compressor to the inlet of the compressor, a recycle valve controlling the gas flow in the pipe, an actuator for actuating the recycle valve, and a control unit generating a control signal to said actuator for controlling the opening of the recycle valve.

[0002] The invention also relates to a device for controlling opening and closing of a recycle valve in a gas compression system.

[0003] Further, the invention relates to a method for controlling such a gas compression system.

[0004] The present invention is useful in gas processing industries using compressors to compress gases, such as chemical and petrochemical plants. The invention is particularly useful in plants producing Liquefied Natural Gas (LNG).

PRIOR ART

[0005] Compressors are widely used worldwide in industrial applications to compress gases. Centrifugal compressors, sometimes referred to as radial compressors, are a special class of compressors. They are a sort of dynamic compressors. The centrifugal compressor is one of the most commonly used for gas compression. A centrifugal compressor includes a rotating wheel, also called an impeller, for increasing the velocity of the gas. A diffuser section converts the velocity energy to pressure energy. When the compressor wheel rotates fast enough, the wheel draws gas in through the inlet into the wheel, where the gas is accelerated away from the center of the wheel. When this accelerated gas enters the diffuser section of the compressor housing, its velocity decreases whereas static pressure of the gas increases. This process increases both the temperature and pressure of the gas according to rules of adiabatic compression and limitations of the design of the compressor. The compressor wheel is driven by an electric motor.

[0006] It is known that the operation of dynamic gas compressors can become unstable due to changes in various operating conditions, such as flow rate or pressure. This causes rapid pulsations in flow, known as surge. The surge phenomenon is inherent in all dynamic compressors.

[0007] Operation of centrifugal gas compressors can be defined by three operating parameters: speed, head and flow. Centrifugal compressors have a maximum head that can be achieved at a given speed. At that peak head there is a corresponding flow. This is a stability limit. The system is stable as long as reductions in head result in increases in flow. Surge occurs when the peak head capability of the compressor is reached and flow is further reduced. When a centrifugal compressor approaches its surge limit, the gas in the compressor stops being propelled forward by the impeller and is simply spinning around with the wheel. When this happens, the pressure build-up at the discharge opening forces the gas back through the impeller, causing a reversal of gas flow through the compressor. It is said that the compressor is gone into surge, which is the point at which the compressor cannot add enough energy to overcome the system resistance. Considerable mechanical damage can be done to a compressor, which has gone into surge, due to vibrations, noise, shaft axial movements and overheating. Thus, operation of a compressor close to its surge limit must be be avoided.

[0008] The performance of a compressor is quantified using a compressor map. Figure 1 shows an example of a compressor map for a centrifugal compressor. The horizontal axis represents the amount of uncompressed gas entering the compressor, either as volume flow or as mass flow. The vertical axis represents the amount of compression that occurs inside the compressor. It may, for example, be the ratio of the pressure at the outlet of the compressor and the pressure at the inlet of the compressor; or it may be the differential pressure (or head) between inlet and outlet. For each speed of the compressor wheel (in rpm) there is one relation between head and flow. The compressor map shows a plurality of performance curves for different wheel rotation speeds. The locus of the surge points for all compressor speeds is called the surge limit line, and the area to the left of this line is called the surge zone. The surge line divides a stable operating region from the region where surge can occur.

[0009] To prevent a compressor from operation in the surge zone a recycle valve is used to recycle flow from the outlet of the compressor to the inlet of the compressor. Alternatively, the recycle valve is called a bypass valve or an anti-surge valve. A surge control system is normally used, separated from the compressor's other controls because of response-speed requirements. The surge control system keeps the recycle valve closed as long as the operating point is well away from the surge line. If operation gets too close to the surge line, the controller opens the recycle valve to increase the flow through the compressor and move away from the surge line.

[0010] The surge control system commanding the operation of the recycle valve can be designed in many different ways; however, in general it normally receives the following signals :

- Inlet pressure
- Temperature
- Flow
- Head across the compressor
- Compressor speed.

[0011] US patent no. 4464720 shows a surge control system based on sensing the pressure at the inlet and outlet and calculating an actual differential pressure that is then compared with the desired head, and a regulator that reduces the difference to zero.

[0012] US patent no. 4971516 shows a method and a device for operating compressors to avoid surge based on sensing the flow Q and the speed *N* and calculating the actual ratio *Q*/*N* that is then compared with the ratio *Q*/*N* at surge.

[0013] US patent no. 7094019 describes a surge control system calculating the actual pressure ratio and the pressure ratio at surge based on monitoring speed, inlet pressure, outlet pressure, temperature and finally operating a recycle valve when the actual pressure ratio is within a defined safety margin from the pressure ratio at surge.

[0014] US patent no. 0661426 discloses a gas turbine apparatus having a bypass valve for recycling the gases on the outlet of the compressor. The flow rate sucked by the compressor is monitored, and when the flow rate reaches a lower limit the bypass valve is opened.

[0015] Gas processing industries are very sensitive to any disturbances in the process. Therefore, the demands on the recycle valves are very high. The recycle valves are operated between two positions: an open position and a closed position. Looking at the demands for the recycle valves, the speed of the opening of the valve is crucial to protect the gas compressor. Preferably, the valve is opened within 2-3 s. The faster the valve can open, the more likely that it will catch and prevent an impending surge in time.

[0016] Traditionally, gas turbines are used for driving the gas compressor. However, variable speed drive (VSD) of compressors through an electric motor and a frequency converter is more and more common today because of a number of advantages. For a compressor that is driven by a VSD, there is a risk of surge due to disturbances in the electric power supply to the compressors. During normal operation, the torque supplied by the motor corresponds to the torque used by the compressor. Depending on the type of VSD used, a sudden, short-duration drop in the supply voltage to the VSD, known as a voltage dip or voltage sag, can result in a transient reduction of the currents to the motor from the frequency converter. Voltage dips can have any duration between 50 ms up to hundreds of ms.

[0017] If the supply voltage dips, the current to the compressor is blocked or reduced, causing the motor torque to fall to zero and as a consequence the speed of the compressor starts to fall. How fast the speed falls depends on the compressor work being performed by the compressor and the stored rotational energy in the motor, gear and compressor. Although the speed will change gradually and this is a dynamic phenomenon, it can be interpreted in the compressor map as a sudden 'jump' from one head-flow characteristic to another at lower speed. Considering that momentarily the pressure will not change, this means that the operating point will suddenly jump to the left, with an ensuing risk of entering the surge area. If the voltage dip lasts long enough, the compressor will lose so much speed that it will enter surge.

[0018] All types of anti-surge controllers mentioned above will react against a surge caused by the sudden drop in torque and speed due to a voltage dip: however, a certain delay is accumulated since the controller will only react when the consequences of the voltage disturbance appear at the compressor in the form of a change in speed or in flow.

[0019] Liquefied Natural Gas (LNG) is natural gas that, when cooled to temperatures of about -160°C, condenses into a liquid. For large distances liquefying and shipping natural gas is cheaper than transporting the gas by off-shore pipelines. During the liquefying process the gas is compressed in several steps. A liquefaction system comprises a plurality of compressors compressing the gas until it is liquefied. The compressor is one of the most expensive pieces of equipment for an LNG plant. A compressor can go into surge if the flow drops below 80 % of the rated flow. In order to protect the compressor from surge, a surge protection system is provided.

[0020] Figure 2 shows an example of a part of a prior art natural gas liquefaction system including a surge protection system. The liquefaction system comprises a compressor 1 which receives cold gas through an inlet pipe 2 and provides compressed hot gas through an outlet pipe 3. The compressor 1 is driven by a variable speed drive including an electric motor 4 and compressor motor drive unit 5 such as a frequency converter. A power source 6 supplies the frequency converter 5 with AC voltage. The motor shaft is connected to the compressor directly or via a gear system (not shown in the figure). The hot gases from the compressor are cooled in a cooler 8. The surge protection system comprises a cold gas recycle loop including a recycle pipe 10 and an anti-surge recycle valve 11. The cold gas recycle loop feeds cold gas back from the cooler to the inlet of the compressor in order to keep a steady gas flow through the compressor. A disadvantage with the cold gas recycle loop is that the anti-surge valve 11 is quite slow, and cannot respond fast enough to protect the compressor against surge if the flow rate quickly drops to zero.

[0021] In order to protect the compressor from going into surge when the flow rate quickly drops to zero, a hot gas recycle loop is provided. The key function of the hot gas recycle loop is to respond quickly to a process upset and avoiding sending the compressor into surge by recycling the hot gas from the outlet of the compressor. The hot gas recycle loop includes a pipe 13 for feeding hot gases from the outlet 3 of the compressor back to the inlet 2 of the compressor, and a hot gas recycle valve 14, determining the amount of hot gases feed back to the inlet of the compressor.

[0022] The surge protection system further comprises a plurality of sensors (only two sensors 15a-b are shown in the figure) for measuring the gas pressure on the inlet of the compressor, for measuring inlet flow, for measuring discharge pressure, for measuring outlet gas temperature, and for measuring compressor speed. A control unit 16 generates a control signal for controlling the opening of the hot gas recycle valve. The control unit 16 receives measured values from the sensors 1 and generates a signal for opening the hot gas recycle valve upon detecting that the compressor is dangerously close to surge. As there is no cooling in the hot gas recycle loop, the compressor can not operate for longer than a few seconds with the hot gas recycle valve open before the temperature becomes so high that it can damage the compressor. Therefore, opening of the hot gas recycle valve will initiate a power shutdown function, tripping the compressor. Accordingly, opening of a hot gas recycle valve will cause a standstill of the liquefying process, and shall thus be avoided, except in cases when it is absolutely necessary.

[0023] In recent years, the industry has moved from hydraulic actuators to pneumatic actuators for recycle valves. Thus, today pneumatic actuators are used for actuating hot gas recycle valves in an LNG process. The actuators are today built with a spring that provides the opening action. In order to close the valve, air is supplied to the valve. The hot gas recycle valve can, for example, be opened by releasing air from an actuator pilot valve via either of two solenoid valves When either of the solenoids is opened, the pilot valve is opened and three quick exhaust valves are activated. When enough air has left the actuator, so that the air pressure within the actuator falls below the pressure required to hold the spring in position, the actuator will start to open. However, when the quick exhaust valves have been activated, a certain amount of air, and thus time, is required to reverse the pilot valve, closing the quick exhaust valves, if the process of opening the hot gas recycle valve is to be reversed. This happens if the supply voltage is restored before the compressor gets too close to surge making the bypass unnecessary. Within the time required to supply the air through the solenoid, the quick exhaust valves will have released so much air from the actuator that it will open regardless of having reenergized the solenoid. Therefore, when the solenoid has moved, the action of opening the hot gas recycle valve is considered as having passed a "point of no return", i.e. reenergizing the solenoid before it has released will reverse the action of opening the hot gas recycle valve, but reenergizing the solenoid afterwards will not stop the hot gas recycle valve from opening, even though it will still take some time before the valve starts to open.

[0024] If the supply voltage is restored soon enough, the motor will re-accelerate the compressor back to normal speed before it goes into surge. In this case the opening command to the recycle valve should be aborted or if the valve has opened already, it should be reclosed quickly. Re-accelerating the compressor also takes a certain time due to inertia of the compressor/motor system. Therefore, if the compressor is to be protected against surge during a voltage dip, the sum of the voltage dip duration, the time to re-accelerate the compressor and the time to take protective actions must not exceed the time to surge, i.e. the time until the compressor is damaged due to the low gas flow.

[0025] Figure 3 illustrates the relationship between time to surge, the time to take protective actions, and maximum voltage dip duration. A dip in the voltage supply to the frequency converter occurs at a point in time t1. The voltage dip causes the motor torque to become zero, and consequently the gas pressure on the inlet of the compressor will become zero. At a point in time t2, the surge control unit 16 detects that the gas pressure on the inlet of the compressor has dropped below a threshold value. A signal to open the hot gas recycle valve is generated at a point in time t3. At a point in time t4, the solenoid is released and opening of the hot gas recycle valve can no longer be stopped. At a point in time t5, the hot gas recycle valve starts to opening, and at a point in time t6, the hot gas recycle valve is sufficiently open to protect the compressor.

[0026] $\Delta T1$ is the time period from when the voltage dip occurred until the compressor has entered into surge due to the low gas flow. The time period $\Delta T2$ is the time required to re-energize the solenoid, the time period $\Delta T3$ is the time required to re-accelerate the compressor to normal speed, and thus the time period $\Delta T4$ is the maximum time before a signal to abort the opening of the hot gas recycle valve has to be given, if opening of the valve is to be avoided, i.e. the maximum voltage dip duration allowed in order to avoid opening of the hot gas recycle valve. As can be seen from the figure, the maximum voltage dip duration allowed before generating the signal to open the hot gas recycle valve can be rather short.

[0027] A problem with the pneumatic actuators used today for actuating the hot gas recycle valve is that it is difficult to provide a fast and accurate regulation of the position of the valve. Another problem is the long time required between the initiation of the opening action and the actual opening of the valve. A further problem is that the maximum time before an order to reverse the opening of the valve has to be given, after opening has been initiated, is very short. This is a disadvantage since short voltage dips occur now and then and if they lead to a signal to open the hot gas valve being generated, and the opening cannot be stopped, this will cause a shutdown of the compressor. A compressor trip will cause loss of production for several hours, and each trip increases the required maintenance and shortens the life of the compressor. Compressor shutdowns due to voltage dips can be in the range of 20 - 25 times per year, particularly if the load on the compressors is increased.

[0028] US patent application with publication number US 2006/0102864 proposes to use an electric motor drive for actuating a valve. By using an electric motor drive for actuating a valve, it is possible to achieve an accurate regulation of the position of the valve. The electric drive disclosed in this document comprises a gear provided between the motor and the valve. This means that the motor makes a plurality of revolutions while the valve only rotates about 180°. However, the electric drive proposed in this document is not fast enough to be suitable for controlling a hot gas recycle valve in an LNG process. The requirement on the hot gas recycle valve is that it is changed from open to closed in less than two seconds.

[0029] EP03688567 discloses a method for detecting surge for a compressor driven by an electric motor. The method comprises sensing the motor current, calculating with some filtering its average value, and detecting deviations of the instantaneous current value from the average value, and based thereon detecting surge of the compressor.

[0030] WO97/38270 discloses a method for detecting surge for a compressor driven by an electric motor with a drive system, based on sensing the differential pressure between inlet and discharge and the motor current, or sensing the inlet pressure and discharge pressure and the motor current, or sensing only the differential pressure, or sensing only the motor current and calculate accordingly to conclude if there is a risk of surge

[0031] US5971712 discloses a method for detecting surge for a compressor driven by an electric motor, based on calculating the rate of change in time of the discharge pressure, calculating the rate of change in time of the discharge pressure and the motor current, and comparing with a set-point value to detect surge.

OBJECTS AND SUMMARY OF THE INVENTION

[0032] Accordingly, it is an object of the present invention to provide improvements in surge control for compressors, which overcome many of the abovementioned drawbacks of the prior art. It is particularly an object of the present invention to reduce the above described problem of compressor trips due to short voltage dips in the power supply to the motor drive unit.

[0033] This object is achieved by a gas compression system as defined in claim 1.

[0034] The invention is **characterized in that** the actuator for actuating the recycle valve comprises an electric motor controlling the opening and closing of the recycle valve. The present invention proposes to use an electric motor drive actuating the recycle valve. By using an electric motor for actuating the recycle valve, it is possible to achieve a fast, accurate and well-controlled motion of the position of the valve. The electric motor reduces the important closing speed without causing bouncing. The use of an electric motor significantly reduces the long time required between the initiation of the opening action and the actual opening of the recycle valve. Furthermore, due to the different type of actuator, it is possible to achieve partial opening of the valve, if desired, and to reverse the valve opening practically at any time.

[0035] The invention is further **characterized in that** the gas compression system comprises measuring equipment for measuring the input voltage to the compressor motor drive unit, and the control unit is adapted to determine whether there is a risk of surge of the compressor based on the measured input voltage to the compressor motor drive unit, and to generate said control signal if it is determined that there is a risk of surge of the compressor. Here it is proposed to complement the standard anti-surge voltage controller with an additional function that monitors continuously the voltage at the supply to the compressor motor drive unit and reacts at fast changes of the supply voltage by quickly opening the recycle valve when the disturbance is such that there is a risk of surge. An advantage with this is that it enables a fast response against voltage dips that might lead to surge. Another advantage is that it is possible to detect the duration of a voltage dip at an early stage and accordingly avoid opening of the recycle valve if the voltage dip is short enough to not cause compressor surge. The early detection of the duration of a voltage dip also makes it possible to reverse the opening of the valve if it is detected that the duration of the voltage dip is too short to cause surge of the compressor. Accordingly, unnecessary compressor trips due to short voltage dips in the power supply to the compressor motor drive unit are avoided.

[0036] According to an embodiment of the invention, the motor of the actuator is arranged rotatable between a first angular position in which the valve is closed and a second angular position in which the valve is opened, the actuator comprises a shaft operatively connected between the motor and the recycle valve for opening and closing the recycle valve, and the motor is rotatable less than one revolution between said first and second angular position. No gear is provided between the motor and the valve. Such an actuator is very fast and can move the valve from closed to an open position in less than 2 seconds, and is accordingly suitable for controlling a hot gas recycle valve in an LNG process.

[0037] According to an embodiment of the invention, said control unit is adapted to generate the control signal such that the actuator opens the recycle valve according to a predefined opening curve. This is advantageous in that the opening and closing of the recycle valve can be made soft and safe without any bounces.

[0038] According to an embodiment of the invention, said control unit is adapted to compare the measured input voltage to the compressor drive unit with a predefined threshold value and to generate said control signal to the actuator if the measured input voltage is lower than the threshold value during a predefined time period. The time period is selected such that if the voltage returns with the defined time period there should be no risk of compressor surge. The time period is, for example, selected to be 150ms. The threshold value for the input voltage is, for example, selected to be 80% of its nominal value. This embodiment avoids unnecessary openings of the recycle valve due to short voltage dips.

[0039] According to an embodiment of the invention, said control unit is adapted to predict the rotational speed of the compressor based on the measured input voltage and a mathematical model of the compressor drive unit and the motor of the compressor, and said control unit is adapted to determine where in the compressor map the compressor is operating based on the predicted rotational speed of the compressor, and based thereon determine whether there is a risk of surge of the compressor, and to generate said control signal if it is determined that there is a risk of surge of the compressor. Depending on where in the compressor map the compressor is operating, a reduction in speed from the same initial value will cause a larger or smaller reduction in flow, based on the slope of the flow versus head curves, at given speeds. At lower heads the slope is steeper and a fall in speed causes a relatively small reduction in flow compared to the situation at higher loads, where the curves are flatter. By using the predicted compressor speed to determine where in the compressor map the compressor is operating, it is possible to make an accurate prediction of how close to surge the compressor will be. Further, it is faster to predict the reduction in compressor speed due to the voltage dip compared to waiting until the voltage dip actually results in reduced compressor speed or flow. An early detection of the risk of surge enables an early generation of the command for opening the recycle valve, which is advantageous since it achieves more time available for opening the valve. More time available for opening the valve enables a gradual and smooth opening of the valve, thereby avoiding fast and strong changes in the flow.

[0040] According to an embodiment of the invention, the gas compression system further comprises measuring equipment for measuring at least two of the following quantities: compressor inlet flow, compressor outlet flow, compressor inlet temperature, compressor outlet temperature, compressor inlet pressure, compressor outlet pressure, and head across the compressor, and the control unit is adapted to determine where in the compressor map the compressor is operating based on said at least two measured quantities.

[0041] According to an embodiment of the invention, said pipe is adapted to feed hot gas from the outlet of the compressor back to the inlet of compressor, said recycle valve is a hot gas recycle valve, and the system further comprises a second pipe adapted to feed cold gas back to the inlet of compressor and the second pipe is provided with a cold gas recycle valve controlling the gas flow in the pipe. The invention is particularly suitable for solving the above-mentioned problems in relation to hot gas recycle valves in a Liquefied Natural Gas system.

[0042] According to an embodiment of the invention, the control unit is adapted to detect the end of a voltage dip based on the measured input voltage to the compressor motor drive unit, and to generate a control signal for closing the recycle valve if the end of the voltage dip is detected. This embodiment enables an early detection of a reduced risk of surge, and to close the hot recycle valve as soon as possible, thereby avoiding unnecessary trips of the compressor.

[0043] According to an embodiment of the invention, the opening position of the valve is calculated based on a model of the anti-surge recycle valve, the predicted speed of the compressor and a desired flow to avoid surge. This embodiment enables a gradual and smooth opening of the valve, thereby avoiding fast and strong changes in the flow. Advantageously, a control signal to the actuator is generated such that the flow through the compressor is kept essentially constant during the voltage dip.

[0044] This object is also achieved by a device for controlling opening and closing of a recycle valve in gas compression system as defined in claim 9.

[0045] This object is also achieved by a method for controlling a gas compression system as defined in claim 10.

BRIEF DESCRIPTION OF THE DRAWINGS

[0046] The invention will now be explained more closely by the description of different embodiments of the invention and with reference to the appended figures.

Fig. 1 shows an example of a compressor map for a centrifugal compressor.

Fig. 2 shows schematically a part of a natural gas liquefaction system including a prior art surge protection system.

Fig. 3 illustrates the relationship between time to surge, the time to take protective actions, and the maximum voltage dip duration in a gas liquefaction system including a prior art surge protection system.

Fig. 4 shows a gas compression system including a device for controlling the opening of a recycle valve according to an embodiment of the invention.

Fig. 5 shows an example of an opening curve for the recycle valve.

Fig. 6 shows an example of an actuator for actuating the recycle valve according to an embodiment of the invention.

Figs. 7a-c show an example of a transmission component for transferring the rotational movement of the motor shaft to the recycle valve.

Fig. 8 shows a Natural Gas Liquefaction system including a device for controlling the opening of a hot gas recycle valve according to an embodiment of the invention.

Fig. 9 shows a surge control unit according to a first embodiment of the invention.

Fig. 10 shows a surge control unit according to a second embodiment of the invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

[0047] The invention is useful for gas compression systems having one or more recycle valves. Figure 4 shows a gas compression system according to an embodiment of the invention having one recycle valve. The gas compression system comprises a compressor 1 which receives gas through an inlet pipe 2 and provides compressed gas through an outlet pipe 3. The compressor 1 is driven by a variable speed drive including an electric motor 4 and a motor drive unit 5, such as a frequency converter. The motor drive unit 5 provides the motor with current and controls the speed of the motor. The motor drive unit 5 is supplied with AC voltage from a power source 6. A motor shaft 7 is connected to the compressor. The system further comprises a gas recycle loop including a recycle pipe 20 and an anti-surge recycle valve 22. The gas recycle loop feeds back compressed gas from the compressor 1 to the inlet of the compressor in order to keep a steady gas flow through the compressor.

[0048] The gas compression system is provided with a device for controlling the opening of the recycle valve 22 comprising an anti-surge control unit 24 generating a control signal for controlling the opening of the recycle valve 22. The opening and closing of the recycle valve 22 is actuated by an actuator 25 comprising an electric motor 26 and a drive unit 28 controlling the motion of the electric motor 26 in response to a control signal Φ_{ref} received from the control unit 24. The control signal Φ_{ref} is a reference value for the motor angle. The recycle valve 22 is provided with a sensor 30 sensing the position of the recycle valve. The measured position Φ_m of the recycle valve is transferred to the control unit 24, which comprises a control loop for controlling the position of the recycle valve 22 based on the measured position of the valve and a predefined opening curve. Figure 5 shows an example of an opening curve for the recycle valve. The opening curve describes the degree of opening of the valve during the opening time in the form of the desired motor angle Φ_{ref} versus the time t. For example, the motor angle Φ_{ref} varies between 0 and 180°, and the recycle valve is closed when the motor angle is 180° and the recycle valve is completely open when the motor angle is zero.

[0049] The device for controlling the opening of the recycle valve further comprises measuring equipment 32 for measuring the input voltage to the compressor motor drive unit 5. The output from the voltage measuring equipment 32 is transferred to the control unit 24, which is adapted to determine whether there is a risk of the compressor entering into surge based on the measured input voltage to the compressor drive unit and to generate the control signal Φ_{ref} for opening the recycle valve in order to avoid compressor surge. If the control unit decides that there is a risk of surge, the control signal Φ_{ref} to the recycle valve actuator 25 is controlled according to the predefined opening curve until the recycle valve 22 is opened. If the control unit decides that there is no risk of surge of the compressor, the recycle valve is kept closed. Although not shown in figure 4, it is obvious that the gas compression system can be provided with sensors measuring one or more input and output quantities of the compressor, such as temperature, flow, pressure and head. The measured values of those quantities are supplied to the control unit 24. The measured quantities are used for determining where in the compressor map the compressor is operating at present and accordingly to determining how close to the surge line the compressor is. This is necessary since the compressor can go to surge for other reasons than voltage dips in the compressor drive unit. Several methods to achieve this are known from the prior art.

[0050] Figure 6 shows an example of an actuator 25 for actuating the recycle valve 22. The actuator 25 comprises a drive unit 28 including a charger 34, a capacitor 35 arranged in parallel with the charger, and a frequency converter 36. The actuator drive unit 28 provides the electric motor 26 with a variable current in dependence on the reference value Φ_{ref} received from the control unit 24. The motor 26 is rotatable between a first Φ_1 and a second Φ_2 angular position, i.e. $\Phi_1 < \Phi_{ref} < \Phi_2$, and the motor is rotatable less than one revolution between said first and second angular position, i.e. $\Phi_1 - \Phi_2 < 360°$. Preferably, the motor is rotatable about half a revolution between the first and second angular position, i.e. $\Phi_1 - \Phi_2$ is about 180°.

[0051] The actuator 28 comprises a shaft 38 operatively connected between the motor 26 and the recycle valve for opening and closing the recycle valve. The actuator is further provided with a transmission component 40 for transferring the rotational movement of the motor shaft 38 to the recycle valve. Figure 7 shows an example of a transmission component for transferring the rotational movement of the motor shaft 38 to the recycle valve 22. The transmission component 40 comprises a rotating disc 41 connected to the motor shaft 38. The rotating disc 41 is rotatable about half a revolution, i.e. from 0° to about 180°. The rotating disc 41 is connected to the valve 22 by means of a rod 42. The rod 42 is connected to the rim of the rotating disc 41.

[0052] Figure 7a shows the valve 22 in a closed position. In the closed position the angle Φ of the motor shaft 38 is defined to be 180°. Figure 7b shows the recycle valve during opening of the valve. The valve is about half way through the opening of the valve and the angle Φ of the motor shaft 38 is about 90°. During the entire opening procedure, the motor shaft 38 is moved half a revolution, i.e. the angle Φ is changed from 180° to zero. Figure 7c shows the recycle valve 22 in an opened position. In the open position, the motor shaft 38 and accordingly the rotating disc 41 have moved half a revolution.

[0053] The electric motor is dimensioned to be run for a very short period of time with very high power. A similar drive unit, including a rotating electric motor, for operating an electric component, such as an electrical switch, is shown in the international patent application WO 2005/024877. The motor is arranged for providing a movement of the electrical component during a limited predetermined angular motion of the rotor of the motor. The electrical drive unit proposed in this document can be rapidly activated, accelerated and decelerated for a short time during which an operation movement of the electrical component is to be carried out.

[0054] Figure 8 shows a Natural Gas Liquefaction system including an for controlling the opening of a hot gas recycle valve according to an embodiment of the invention. Elements corresponding to the ones shown in figures 2 and 4, are given the same reference numbers as the corresponding elements of those figures. The surge protection system comprises a cold gas recycle loop including a recycle pipe 10 and an anti-surge recycle valve 11 and a hot gas recycle loop including a recycle pipe 13 for feeding hot gases from the outlet 3 of the compressor back to the inlet 2 of the compressor, and a hot gas recycle valve 14, determining the amount of hot gases feed back to the inlet of the compressor. The opening and closing of the hot gas recycle valve 14 is actuated by an actuator 25 comprising an electric motor 26 and a drive unit 28 controlling the motion of the electric motor 28 in response to a control signal Φ_{ref}.

[0055] A control unit 43 is adapted to generate the control signal Φ_{ref} to the actuator 25 of the hot gas recycle valve 14. In this embodiment, the gas compression system further comprises measuring equipment 15a-b for measuring at least two quantities of the compressor. The quantities measured are at least two of the following quantities: the compressor inlet flow, the compressor outlet flow, the compressor inlet temperature, the compressor outlet temperature, the compressor inlet pressure, the compressor outlet pressure, or the head across the compressor. A sensor 15a measures a quantity at the inlet of the compressor and a sensor 15b measures a quantity at the outlet of the compressor. Those quantities are used for determining where in the compressor map the compressor is operating at present and accordingly to determining how close to the surge line the compressor is. Where in the compressor map the compressor is operating is continuously determined in the control unit 43 based on the measured quantities. The control unit 43 receives measured values of the two quantities and the measured input voltage to the compressor motor drive unit 5 measured by the equipment 15a-b and 32.

[0056] Figure 9 and 10 show two different embodiments of the control units 24 and 43. The control unit 24 and 43 showed in figure 9 comprises a voltage dip detection unit 50 receiving measured values of the voltage supply to the compressor drive unit. It is possible to use any known voltage dip detection method, for example the method described by E. Styvaktakis, I.Y.H. Gu and M.H.J. Bollen in "Voltage Dip Detection and Power System Transients", proceedings of IEEE Power Engineering Society Summer Meeting 2001, pp.683-688, or described by O. C. Montero-Hernandez and P. N. Enjeti, in "A fast detection algorithm suitable for mitigation of numerous power quality disturbances," presented at IEEE Industry Applications Conference 2001.

[0057] If it is detected that the supply voltage falls below a predetermined value, for example, below 80 % of its nominal value, a voltage dip is detected. If the voltage dip detection unit 50 detects a voltage dip it sends a signal to an anti-surge controller 54 notifying it of the fact that a voltage dip has been detected. The anti-surge controller 54 determines the risk of surge by comparing the duration of the voltage drop with a predefined threshold value and commanding opening of the recycle valve if the voltage is lower than the predefined threshold value for a predefined time period. The threshold is for example set off-line by doing simulations. A safety margin should be considered since the method is not based on real time monitoring of the compressor operating point. The anti-surge controller 54 is adapted to determine whether the voltage dip has duration longer than a predefined threshold value, such as a specified time interval, for example 135 ms. The predefined threshold values for input voltage and the duration of the voltage dip are stored in a memory unit 52. If a voltage dip having a duration longer than the threshold value is detected, the anti-surge controller 54 generates an opening signal to the recycle valve.

[0058] Figure 10 shows another embodiment of the control unit 24 and 43. The control unit comprises a voltage dip detection unit 50 detecting if there is a voltage dip. The same threshold value can be used as in the previous embodiment, and the threshold value can be stored in memory unit 52. If a voltage dip is detected a signal is sent to a prediction module 56 together with the measured voltage. The prediction unit 56 predicts in real time the resulting compressor speed due to the voltage dip by using a model of the compressor drive unit and the electric motor and the measured input voltage. Thereafter an anti-surge controller 58 evaluates the risk of surge if the compressor moves from the current operating point to the new one at a lower predicted speed in the compressor map. Here it is assumed that the compressor map is known and that the operating point is monitored continuously, which is normally done by a standard anti-surge controller. The compressor map is provided based on the measured input and output properties. The anti-surge controller 58 is adapted to determine where in the compressor map the compressor is operating based on the predicted speed of the compressor and the at least two measured quantities, and based thereon determine whether there is a risk of surge of the compressor and to generate a control signal for opening the recycle valve if it is determined that there is a risk of surge of the compressor.

[0059] The voltage detection unit 50 is also adapted to detect the end of a voltage dip based on the measured supply voltages. The anti-surge controller 54,58 is notified accordingly. The anti-surge controllers 54,58 are adapted to generate a control signal to the actuator 25 commanding it to close the recycle valve upon receiving information of that the end of the voltage dip is detected.

[0060] When using the method including real-time prediction of the compressor speed described above, a further improvement of the method comprises including a model of the anti-surge recycle valve, so that from the predicted speed and a desired flow to avoid surge, the necessary opening position of the valve is calculated, and the electric valve actuator is used for accurately controlling partial opening of the valve, as opposed to a pure ON/OFF control of the valve. For example, the control signal to the actuator is generated such as to keep an essentially constant flow through the compressor.

[0061] To achieve the above performance, the control of the proposed system must fulfill the following during normal operation:

- Monitor continuously the supply voltages to the compressor drive unit
- Monitor continuously the operating point of the compressor
- Detect voltage dips in the supply voltage
- Predict drop in compressor speed due to voltage dip
- Calculate the risk of compressor surge from operating point and predicted speed

[0062] If no risk of surge, then do nothing. If risk of surge: calculate the desired flow to avoid surge based on current operating point and predicted speed, calculate the necessary opening position of the valve to achieve desired flow (alternatively, to keep flow constant despite the speed drop), and command the actuator accordingly.

[0063] The control of the proposed system must fulfill the following during voltage dips:

- Monitor continuously the supply voltages to the compressor drive unit
- Monitor continuously the operating point of the compressor
- Monitor continuously the position of the recycle valve
- Detect end of voltage dip in supply voltage
- Predict increase in compressor speed and temperature;
- Calculate necessary opening position of the valve to keep even flow through the compressor, or alternatively, to keep temperature lower than given maximum value
- command actuator accordingly to close the recycle valve gradually avoiding over temperature

[0064] The advantage of this method as opposed to the traditional anti-surge controller is that by sensing the supply voltages the reaction can be faster, as opposed to waiting for the voltage dip to cause reduction or blocking of the current to the motor with a consequential drop in speed. As long as the speed does not drop too much, the compressor does not go into surge, but knowing before the speed starts to drop that it is likely to go into surge means that there is more time to react, and if desired counteract the drop in speed by gradually opening the valve to keep flow constant as the speed decreases. With the same reasoning, by sensing the supply voltages the controller will detect the end of a voltage dip and thereby avoid unnecessary trips of the compressor drive unit and the compressor.

[0065] The present invention is not limited to the embodiments disclosed but may be varied and modified within the scope of the following claims. For example, in a gas compression system having a plurality of parallel compressors it is enough to measure the voltage of the power supply at one point, for example, at the collecting bar, since the input voltage is the same for all compressors. It is possible to have a centralized control of all compressors, which detects dips in the supply voltage, and when a voltage dip has been detected a signal is sent to the control unit of each compressor.

Claims

1. A gas compression system comprising:

a compressor (1) for compressing a gas fed to the compressor,
an electric motor (4) driving the compressor,
a compressor motor drive unit (5) producing current to said motor,
a pipe (20;13) for feeding back gas from the outlet of the compressor to the inlet of the compressor,
a recycle valve (22;14) controlling the gas flow in the pipe,
an actuator (25) for actuating the recycle valve, and
a control unit (24;43) generating a control signal to said actuator for controlling the opening and closing of the recycle valve, **characterized in that** said actuator comprises an electric motor (26) controlling the opening and closing of the recycle valve, the gas compression system further comprises measuring equipment (32) for

measuring the input voltage to the compressor motor drive unit, and said control unit is adapted to determine whether there is a risk of surge of the compressor based on the measured input voltage to the compressor motor drive unit, and to generate a control signal for opening the recycle valve if it is determined that there is a risk of surge of the compressor.

2. The gas compression system according to claim 1, wherein the motor (26) of the actuator is arranged rotatable between a first angular position in which the valve is closed and a second angular position in which the valve is opened, and the actuator comprises a shaft (38) operatively connected between the motor and the recycle valve for opening and closing the recycle valve, and the motor is rotatable less than one revolution between said first and second angular position.

3. The gas compression system according to claim 1 or 2, wherein said control unit (24;43) is adapted to generate said control signal such that the actuator opens the recycle valve according to a predefined opening curve.

4. The gas compression system according to any of the previous claims, wherein said control unit is adapted to compare the measured input voltage with a predefined threshold value and to generate said control signal to the actuator if the measured input voltage is lower than the threshold value during a predefined time period.

5. The gas compression system according to any of claims 1-4, wherein said control unit (24;43) is adapted to predict the rotational speed of the compressor based on the measured input voltage and a mathematical model of the compressor drive unit and the motor of the compressor, and said control unit is adapted to determine where in the compressor map the compressor is operating based on the predicted rotational speed of the compressor, and based thereon determine whether there is a risk of surge of the compressor, and to generate said control signal for opening the recycle valve if it is determined that there is a risk of surge of the compressor.

6. The gas compression system according to claim 5, wherein the gas compression system further comprises measuring equipment (15a-b) for measuring at least two of the following quantities: compressor inlet flow, compressor outlet flow, compressor inlet temperature, compressor outlet temperature, compressor inlet pressure, compressor outlet pressure, and head across the compressor, and the control unit is adapted to determine where in the compressor map the compressor is operating based on said at least two measured quantities.

7. The gas compression system according to any of the previous claims, wherein said pipe (20;30) is adapted to feed hot gas from the outlet (3) of the compressor back to the inlet (2) of compressor, said recycle valve is a hot gas recycle valve (14), and the system further comprises a second pipe (10) adapted to feed cold gas back to the inlet of compressor and the second pipe is provided with a cold gas recycle valve (11) controlling the gas flow in the pipe.

8. The gas compression system according to any of the previous claims, wherein the system is a Liquefied Natural Gas system.

9. A method for controlling a gas compression system comprising a compressor (1) for compressing a gas fed to the compressor, an electric motor (4) driving the compressor, a compressor motor drive unit (5) producing current to said motor, a pipe (20;13) for feeding back gas from the outlet of the compressor to the inlet of the compressor, a recycle valve (22;14) controlling the gas flow in the pipe, and an electric actuator for actuating the recycle valve, **characterized in that** the method comprises:

measuring the input voltage to the compressor motor drive unit,
determining whether there is a risk of surge of the compressor based on the measured input voltage to the compressor motor drive unit, and
generating a control signal for opening the recycle valve if it is determined that there is a risk of surge of the compressor.

10. The method according to claim 9, wherein said control signal is generated such that the actuator opens the recycle valve according to a predefined opening curve.

11. The method according to claim 9 or 10, wherein the method comprises detecting the end of a voltage dip based on the measured input voltage to the compressor motor drive unit, and generating a control signal for closing the recycle valve if the end of the voltage dip is detected.

12. The method according to any of claims 9-11, wherein the method comprises:

comparing the measured input voltage with a predefined threshold value, and
generating said control signal to the actuator for opening the recycle valve if the measured input voltage is lower than the threshold value during a predefined time period.

13. The method according to any of claims 9-11, wherein the method comprises:

predicting the rotational speed of the compressor based on the measured input voltage and a mathematical model of the compressor drive unit and the motor of the compressor,
determining where in the compressor map the compressor is currently operating
predicting the new operating point of the compressor based on the predicted rotational speed of the compressor, and the current operating point of the compressor in the compressor map,
determining whether there is a risk of surge of the compressor based on the current operating point and the new predicted operating point in the compressor map, and
generating said control signal to the actuator if it is determined that there is a risk of surge of the compressor.

14. The method according to claim 13, wherein the method further comprises:

measuring at least two of the following quantities: compressor inlet flow, compressor outlet flow, compressor inlet temperature, compressor outlet temperature, compressor inlet pressure, compressor outlet pressure, and head across the compressor, and
determining where in the compressor map the compressor is operating based on said at least two measured quantities.

15. The method according to claim 13, wherein the opening position of the valve is calculated based on a model of the anti-surge recycle valve, the predicted speed of the compressor and a desired flow to avoid surge.

16. The method according to any of claims 9-15, wherein said control signal to the actuator is generated such as to keep an essentially constant flow through the compressor.

17. Use of the method according to any of claims 9-16 for controlling the opening of a hot gas recycle valve in a Liquefied Natural Gas system.

Patentansprüche

1. Gaskompressionssystem, umfassend:

einen Kompressor (1) zum Komprimieren von Gas, das dem Kompressor zugeführt wird,
einen Elektromotor (4), der den Kompressor antreibt,
eine Kompressormotor-Antriebseinheit (5), die Strom für den Motor erzeugt,
eine Rohrleitung (20; 13) zum Zurückführen von Gas von dem Auslass des Kompressors zu dem Einlass des Kompressors,
ein Rücklaufventil (22; 14), das die Gasströmung in der Rohrleitung steuert,
ein Stellglied (25) zum Betätigen des Rücklaufventils, und
eine Steuereinheit (24; 43), die ein Steuersignal für das Stellglied zum Steuern des Öffnens und Schließens des Rücklaufventils erzeugt, **dadurch gekennzeichnet, dass** das Stellglied einen Elektromotor (26) umfasst, der das Öffnen und Schließen des Rücklaufventils steuert, wobei das Gaskompressionssystem des Weiteren Messinstrumente (32) zum Messen der Eingangsspannung zu der Kompressormotor-Antriebseinheit umfasst, und die Steuereinheit eingerichtet ist, aufgrund der gemessenen Eingangsspannung zu der Kompressormotor-Antriebseinheit zu bestimmen, ob ein Risiko des Pumpens für den Kompressor besteht, und um ein Steuersignal zum Öffnen des Rücklaufventils zu erzeugen, wenn bestimmt wird, dass ein Risiko des Pumpens für den Kompressor besteht.

2. Gaskompressionssystem nach Anspruch 1, wobei der Motor (26) des Stellgliedes zwischen einer ersten Winkelposition, in welcher das Ventil geschlossen ist, und einer zweiten Winkelposition, in welcher das Ventil geöffnet ist, drehbar angeordnet ist und wobei das Stellglied eine Stange (38) umfasst, die zwischen dem Motor und dem Rücklaufventil zum Öffnen und Schließen des Rücklaufventils wirkverbunden ist, und wobei der Motor um weniger als eine Umdrehung zwischen der ersten und der zweiten Winkelposition drehbar ist.

3. Gaskompressionssystem nach Anspruch 1 oder 2, wobei die Steuereinheit (24; 43) eingerichtet ist, um das Steuersignal dergestalt zu erzeugen, dass das Stellglied das Rücklaufventil gemäß einer zuvor definierten Öffnungskurve öffnet.

4. Gaskompressionssystem nach irgendeinem der vorhergehenden Ansprüche, wobei die Steuereinheit eingerichtet ist, um die gemessene Eingangsspannung mit einem zuvor definierten Schwellenwert zu vergleichen und um das Steuersignal für das Stellglied zu erzeugen, wenn die gemessene Eingangsspannung während einer zuvor definierten Zeitdauer niedriger als der Schwellenwert ist.

5. Gaskompressionssystem nach irgendeinem der Ansprüche 1 bis 4, wobei die Steuereinheit (24; 43) eingerichtet ist, um die Drehgeschwindigkeit des

Kompressors auf der Basis der gemessenen Eingangsspannung und eines mathematischen Modells der Kompressor-Antriebseinheit und des Motors des Kompressors vorauszusagen, und die Steuereinheit eingerichtet ist, um aufgrund der vorausgesagten Drehgeschwindigkeit des Kompressors zu bestimmen, wo in der Kompressorabbildung der Kompressor momentan arbeitet, und aufgrund dessen zu bestimmen, ob ein Risiko des Pumpens für den Kompressor besteht, und um das Steuersignal zum Öffnen des Rücklaufventils zu erzeugen, wenn bestimmt wird, dass ein Risiko des Pumpens für den Kompressor besteht.

6. Gaskompressionssystem nach Anspruch 5, wobei das Gaskompressionssystem des Weiteren Messinstrumente (15a bis b) zum Messen von mindestens zwei der nachfolgenden Mengen umfasst: Kompressor-Einlassströmung, Kompressor-Auslassströmung, Kompressor-Einlasstemperatur, Kompressor-Auslasstemperatur, Kompressor-Einlassdruck, Kompressor-Auslassdruck und Druckhöhe im Kompressor, und wobei die Steuereinheit eingerichtet ist, um aufgrund der mindestens zwei gemessenen Mengen zu bestimmen, wo in der Kompressorabbildung der Kompressor momentan arbeitet.

7. Gaskompressionssystem nach irgendeinem der vorhergehenden Ansprüche, wobei die Rohrleitung (20; 30) eingerichtet ist, heißes Gas von dem Auslass (3) des Kompressors zu dem Einlass (2) des Kompressors zurückzuführen, wobei das Rücklaufventil ein Heißgas-Rücklaufventil (14) ist, und das System des Weiteren eine zweite Rohrleitung (10) umfasst, die eingerichtet ist, um kaltes Gas zu dem Einlass des Kompressors zurückzuführen, und die zweite Rohrleitung mit einem Kaltgas-Rücklaufventil (11) versehen ist, das die Gasströmung in der Rohrleitung steuert.

8. Gaskompressionssystem nach irgendeinem der vorhergehenden Ansprüche, wobei das System ein System für verflüssigtes Erdgas ist.

9. Verfahren zum Steuern eines Gaskompressionssystems, umfassend einen Kompressor (1) zum Komprimieren von Gas, das dem Kompressor zugeführt wird, einen Elektromotor (4), der den Kompressor antreibt, eine Kompressormotor-Antriebseinheit (5), die für den Motor Strom erzeugt, eine Rohrleitung (20; 13) zum Zurückführen von Gas von dem Auslass des Kompressors zu dem Einlass des Kompressors, ein Rücklaufventil (22; 14), das die Gasströmung in der Rohrleitung steuert, und ein elektrisches Stellglied zum Betätigen des Rücklaufventils, **dadurch gekennzeichnet, dass** das Verfahren umfasst:

Messen der Eingangsspannung zu der Kompressormotor-Antriebseinheit,
Bestimmen, auf der Basis der gemessenen Eingangsspannung zu der Kompressormotor-Antriebseinheit, ob ein Risiko des Pumpens für den Kompressor besteht, und
Erzeugen eines Steuersignals zum Öffnen des Rücklaufventils, wenn bestimmt wird, dass ein Risiko des Pumpens für den Kompressor besteht.

10. Verfahren nach Anspruch 9, wobei das Steuersignal dergestalt erzeugt wird, dass das Stellglied das Rücklaufventil gemäß einer zuvor definierten Öffnungskurve öffnet.

11. Verfahren nach Anspruch 9 oder 10, wobei das Verfahren das Erfassen des Endes eines Spannungseinbruches auf der Basis der gemessenen Eingangsspannung zu der Kompressormotor-Antriebseinheit und das Erzeugen eines Steuersignals zum Schließen des Rücklaufventils umfasst, wenn das Ende des Spannungseinbruches erfasst wird.

12. Verfahren nach irgendeinem der Ansprüche 9 bis 11, wobei das Verfahren umfasst:

Vergleichen der gemessenen Eingangsspannung mit einem zuvor definierten Schwellenwert, und
Erzeugen des Steuersignals für das Stellglied zum Öffnen des Rücklaufventils, wenn die gemessene Eingangsspannung während einer zuvor definierten Zeitdauer niedriger als der Schwellenwert ist.

13. Verfahren nach irgendeinem der Ansprüche 9 bis 11, wobei das Verfahren umfasst:

Voraussagen der Drehgeschwindigkeit des Kompressors auf der Basis der gemessenen Eingangsspannung und eines mathematischen Modells der Kompressor-Antriebseinheit und des Motors des Kompressors,
Bestimmen, wo in der Kompressorabbildung der Kompressor momentan arbeitet,
Voraussagen des neuen Arbeitspunktes des Kompressors auf der Basis der vorausgesagten Drehgeschwindigkeit des Kompressors und des aktuellen Arbeitspunktes des Kompressors in der Kompressorsabbildung,
Bestimmen, auf der Basis des aktuellen Arbeitspunktes und des neuen vorausgesagten Arbeitspunktes in der Kompressorabbildung, ob ein Risiko des Pumpens für den Kompressor besteht, und
Erzeugen des Steuersignals für das Stellglied, wenn bestimmt wird, dass ein Risiko des Pum-

pens für den Kompressor besteht.

14. Verfahren nach Anspruch 13, wobei das Verfahren des Weiteren umfasst:

Messen von mindestens zwei der nachfolgenden Mengen: Kompressor-Einlassströmung, Kompressor-Auslassströmung, Kompressor-Einlasstemperatur, Kompressor-Auslasstemperatur, Kompressor-Einlassdruck, Kompressor-Auslassdruck und Druckhöhe im Kompressor, und
Bestimmen, auf der Basis der mindestens zwei gemessenen Mengen, wo in der Kompressorabbildung der Kompressor momentan arbeitet.

15. Verfahren nach Anspruch 13, wobei die Öffnungsposition des Ventils auf der Basis eines Modells des Pumpenschutz-Rücklaufventils, der vorausgesagten Geschwindigkeit des Kompressors und einer gewünschten Strömung zur Vermeidung von Pumpen berechnet wird.

16. Verfahren nach irgendeinem der Ansprüche 9 bis 15, wobei das Steuersignal für das Stellglied dergestalt erzeugt wird, dass im Wesentlichen eine konstante Strömung durch den Kompressor hindurch beibehalten wird.

17. Verwendung des Verfahrens nach irgendeinem der Ansprüche 9 bis 16 zum Steuern des Öffnens eines Heißgas-Rücklaufventils in einem System für verflüssigtes Erdgas.

Revendications

1. Système de compression de gaz comportant :

un compresseur (1) servant à comprimer un gaz amené jusqu'au compresseur,
un moteur électrique (4) entraînant le compresseur,
une unité (5) d'excitation du moteur de compresseur fournissant un courant audit moteur,
une conduite (20 ; 13) servant à renvoyer du gaz de la sortie du compresseur à l'entrée du compresseur,
une soupape (22 ; 14) de recyclage commandant l'écoulement de gaz dans la conduite,
un actionneur (25) servant à actionner la soupape de recyclage, et
une unité (24 ; 43) de commande générant un signal de commande vers ledit actionneur pour commander l'ouverture et la fermeture de la soupape de recyclage,
caractérisée en ce que ledit actionneur comporte un moteur électrique (26) commandant l'ouverture et la fermeture de la soupape de recyclage, **en ce que** le système de compression de gaz comporte en outre un équipement (32) de mesure servant à mesurer la tension d'entrée vers l'unité d'excitation du moteur de compresseur, et **en ce que** ladite unité de commande est prévue pour déterminer s'il existe un risque de pompage du compresseur sur la base de la tension d'entrée mesurée vers l'unité d'excitation du moteur de compresseur, et pour générer un signal de commande afin d'ouvrir la soupape de recyclage s'il est déterminé qu'il existe un risque de pompage du compresseur.

2. Système de compression de gaz selon la revendication 1, the moteur (26) de l'actionneur étant disposé de façon à pouvoir pivoter entre une première position angulaire dans laquelle la soupape est fermée et une deuxième position angulaire dans laquelle la soupape est ouverte, et l'actionneur comportant un arbre (38) relié fonctionnellement entre le moteur et la soupape de recyclage pour ouvrir et fermer la soupape de recyclage, et le moteur pouvant tourner de moins d'un tour entre ladite première et ladite deuxième position angulaire.

3. Système de compression de gaz selon la revendication 1 ou 2, ladite unité (24 ; 43) de commande étant prévue pour générer ledit signal de commande de telle façon que l'actionneur ouvre la soupape de recyclage selon une courbe d'ouverture prédéfinie.

4. Système de compression de gaz selon l'une quelconque des revendications précédentes, ladite unité de commande étant prévue pour comparer la tension d'entrée mesurée à une valeur seuil prédéfinie et pour générer ledit signal de commande vers l'actionneur si la tension d'entrée mesurée est inférieure à la valeur seuil pendant une durée prédéfinie.

5. Système de compression de gaz selon l'une quelconque des revendications 1 à 4, ladite unité (24 ; 43) de commande étant prévue pour prédire la vitesse de rotation du compresseur sur la base de la tension d'entrée mesurée et d'un modèle mathématique de l'unité d'excitation de compresseur et du moteur du compresseur, et ladite unité de commande étant prévue pour déterminer l'endroit de la carte de compresseur où fonctionne le compresseur sur la base de la vitesse de rotation prédite du compresseur, et déterminer sur cette base s'il existe un risque de pompage du compresseur, et pour générer ledit signal de commande afin d'ouvrir la soupape de recyclage s'il est déterminé qu'il existe un risque de pompage du compresseur.

6. Système de compression de gaz selon la revendication 5, le système de compression de gaz comportant en outre un équipement (15a-b) de mesure servant à mesurer au moins deux des grandeurs suivantes : débit d'entrée du compresseur, débit de sortie du compresseur, température d'entrée du compresseur, température de sortie du compresseur, pression d'entrée du compresseur, pression de sortie du compresseur, et charge piézométrique à travers le compresseur, et l'unité de commande étant prévue pour déterminer l'endroit de la carte de compresseur où fonctionne le compresseur sur la base desdites au moins deux grandeurs mesurées.

7. Système de compression de gaz selon l'une quelconque des revendications précédentes, ladite conduite (20 ; 30) étant prévue pour renvoyer un gaz chaud de la sortie (3) du compresseur à l'entrée (2) de compresseur, ladite soupape de recyclage étant une soupape (14) de recyclage de gaz chaud, et le système comportant en outre une deuxième conduite (10) prévue pour renvoyer du gaz froid vers l'entrée du compresseur et la deuxième conduite étant munie d'une soupape (11) de recyclage de gaz froid commandant l'écoulement de gaz dans la conduite.

8. Système de compression de gaz selon l'une quelconque des revendications précédentes, le système étant un système de gaz naturel liquéfié.

9. Procédé de commande d'un système de compression de gaz comportant un compresseur (1) servant à comprimer un gaz amené jusqu'au compresseur, un moteur électrique (4) entraînant le compresseur, une unité (5) d'excitation du moteur de compresseur fournissant un courant audit moteur, une conduite (20 ; 13) servant à renvoyer du gaz de la sortie du compresseur à l'entrée du compresseur, une soupape (22 ; 14) de recyclage commandant l'écoulement de gaz dans la conduite, et un actionneur électrique servant à actionner la soupape de recyclage, **caractérisé en ce que** le procédé comporte les étapes consistant à :

mesurer la tension d'entrée à l'unité d'excitation du moteur de compresseur,
déterminer s'il existe un risque de pompage du compresseur sur la base de la tension d'entrée mesurée vers l'unité d'excitation du moteur de compresseur, et
générer un signal de commande afin d'ouvrir la soupape de recyclage s'il est déterminé qu'il existe un risque de pompage du compresseur.

10. Procédé selon la revendication 9, ledit signal de commande étant généré de telle façon que l'actionneur ouvre la soupape de recyclage selon une courbe d'ouverture prédéfinie.

11. Procédé selon la revendication 9 ou 10, le procédé comportant les étapes consistant à détecter la fin d'une baisse de tension sur la base de la tension d'entrée mesurée vers l'unité d'excitation du moteur de compresseur, et à générer un signal de commande pour fermer la soupape de recyclage si la fin de la baisse de tension est détectée.

12. Procédé selon l'une quelconque des revendications 9 à 11, le procédé comportant les étapes consistant à :

comparer la tension d'entrée mesurée à une valeur seuil prédéfinie, et
générer ledit signal de commande vers l'actionneur afin d'ouvrir la soupape de recyclage si la tension d'entrée mesurée est inférieure à la valeur seuil pendant une durée prédéfinie.

13. Procédé selon l'une quelconque des revendications 9 à 11, le procédé comportant les étapes consistant à :

prédire la vitesse de rotation du compresseur sur la base de la tension d'entrée mesurée et un modèle mathématique de l'unité d'excitation de compresseur et du moteur du compresseur,
déterminer l'endroit de la carte de compresseur où fonctionne actuellement le compresseur,
prédire le nouveau point de fonctionnement du compresseur sur la base de la vitesse de rotation prédite du compresseur, et le point de fonctionnement actuel du compresseur sur la carte de compresseur,
déterminer s'il existe un risque de pompage du compresseur sur la base du point de fonctionnement actuel et du nouveau point de fonctionnement prédit sur la carte de compresseur, et
générer ledit signal de commande vers l'actionneur s'il est déterminé qu'il existe un risque de pompage du compresseur.

14. Procédé selon la revendication 13, le procédé comportant en outre les étapes consistant à :

mesurer au moins deux des grandeurs suivantes : débit d'entrée du compresseur, débit de sortie du compresseur, température d'entrée du compresseur,
température de sortie du compresseur, pression d'entrée du compresseur, pression de sortie du compresseur, et charge piézométrique à travers le compresseur, et
déterminer l'endroit de la carte de compresseur où fonctionne le compresseur sur la base desdites au moins deux grandeurs mesurées.

15. Procédé selon la revendication 13, la position d'ouverture de la soupape étant calculée sur la base d'un modèle de la soupape de recyclage anti-pompage, de la vitesse prédite du compresseur et d'un débit souhaité pour éviter le pompage.

16. Procédé selon l'une quelconque des revendications 9 à 15, ledit signal de commande vers l'actionneur étant généré de façon à maintenir un débit essentiellement constant à travers le compresseur.

17. Utilisation du procédé selon l'une quelconque des revendications 9 à 16 pour commander l'ouverture d'une soupape de recyclage de gaz chaud dans un système de gaz naturel liquéfié.

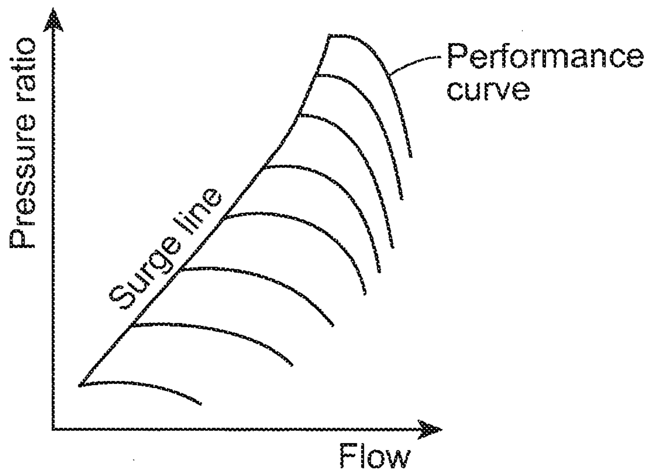

Fig.1

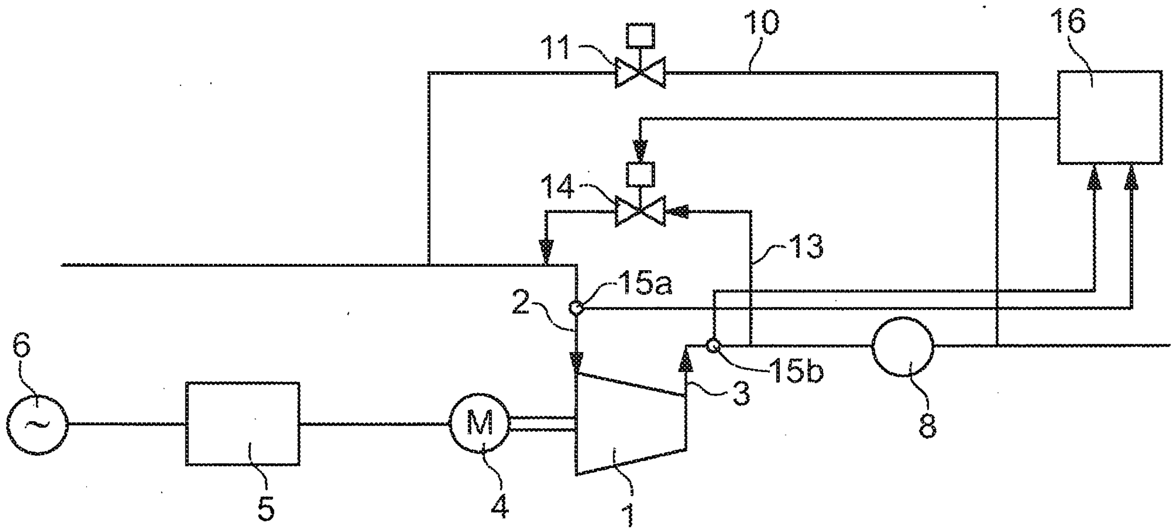

Fig.2

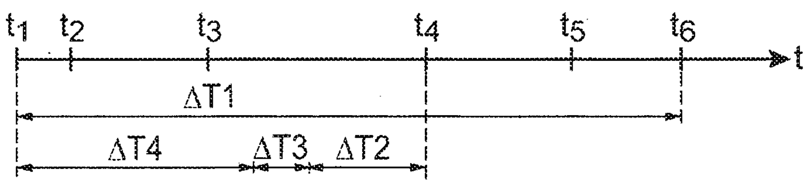

Fig.3

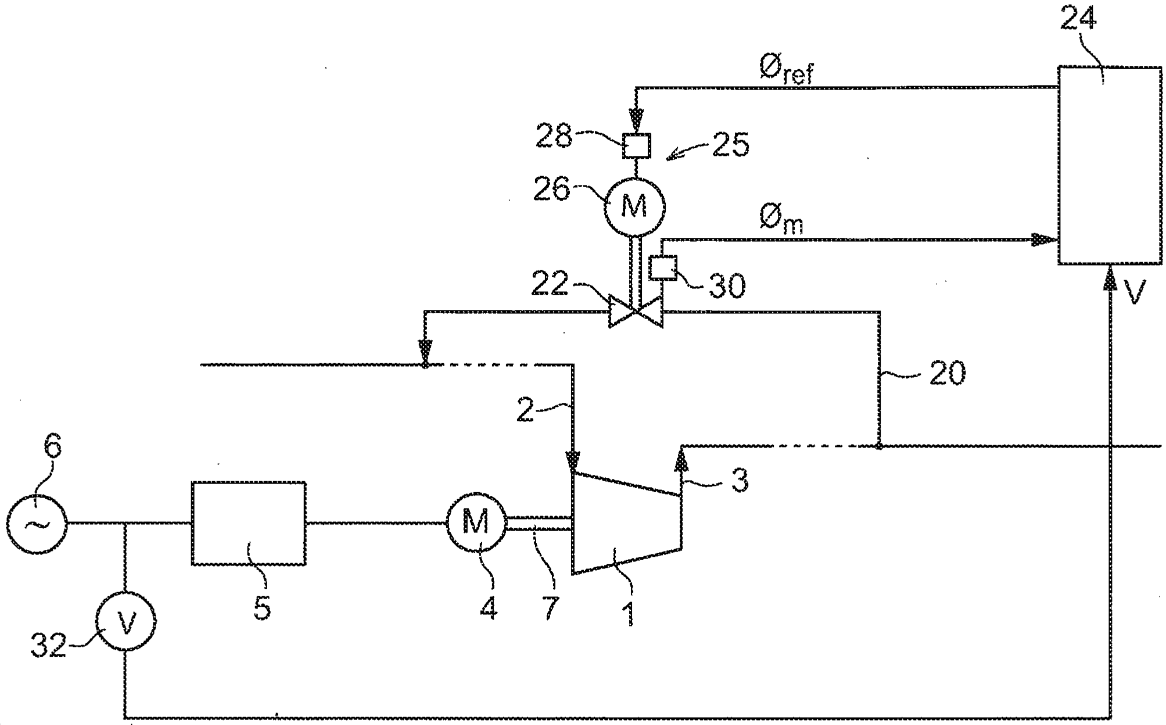

Fig.4

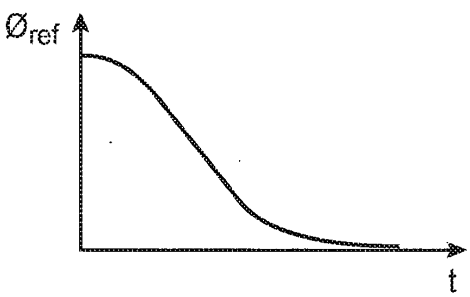

Fig.5

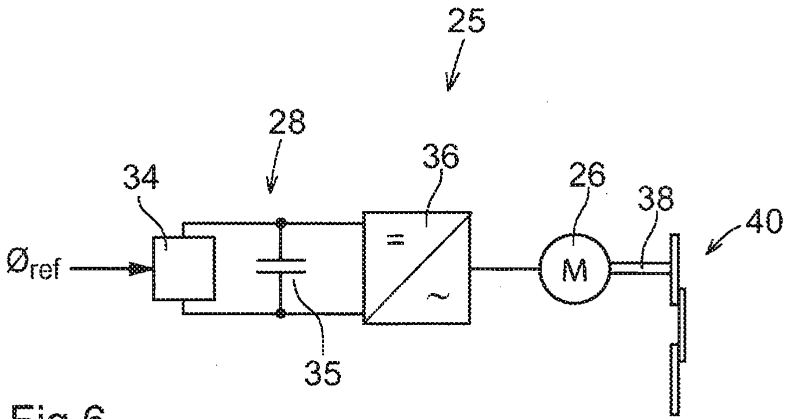

Fig.6

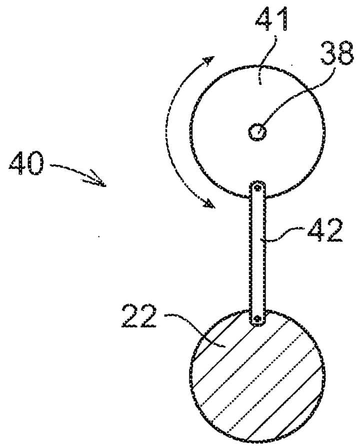

Fig. 7a

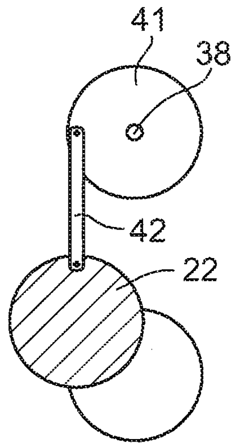

Fig. 7b

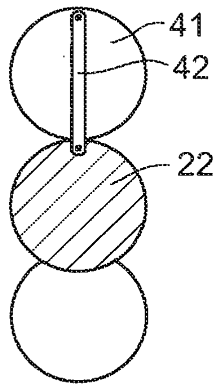

Fig. 7c

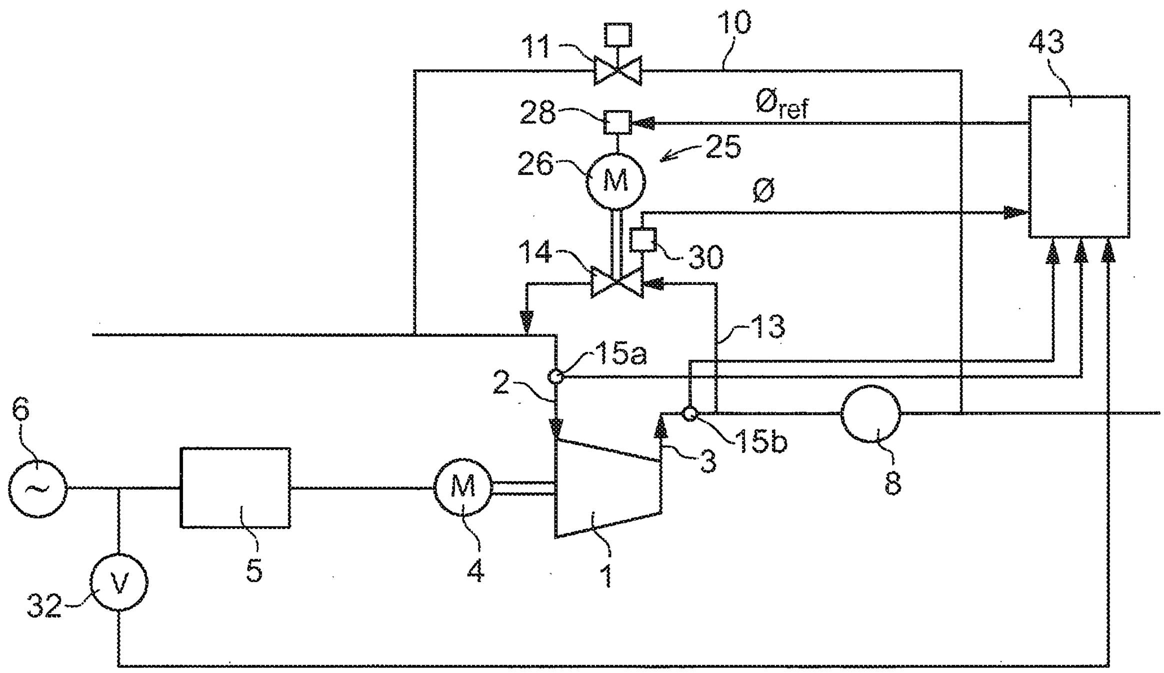

Fig. 8

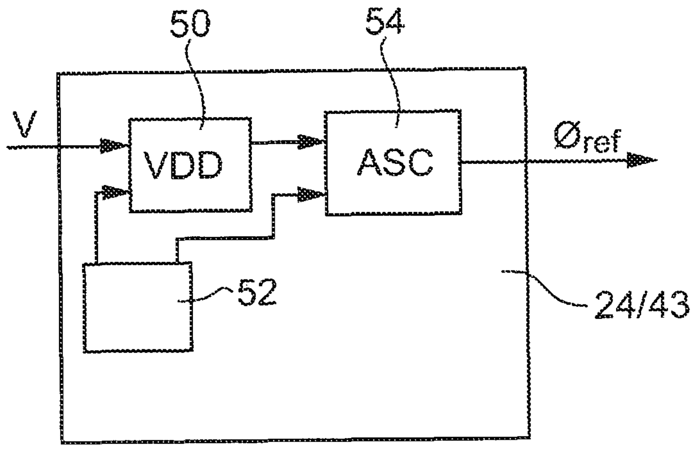
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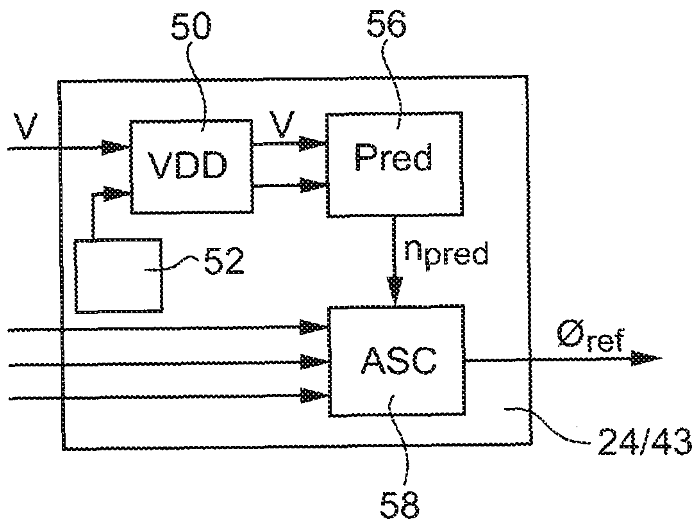
Fig.9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58

Fig.10

REFERENCES CITED IN THE DESCRIPTION

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