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(54) ANTI-SURGE CONTROL OF A SUBSEA COMPRESSOR

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COMMANDE ANTI-EMBALLLEMENT D'UN COMPRESSEUR SOUS-MARIN

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Description

TECHNICAL FIELD OF THE INVENTION

[0001] The present invention refers to the prevention of surge in a compressor that is arranged to be operated and used in the transport of gas from a subsea hydrocarbon fluid deposit. In particular, the invention refers to a method by which a subsea compressor, the rotor of which is supported by active magnetic bearings for contact-free rotation, is arranged to be switched from normal operation into anti-surge operational mode, such as in a case of insufficient flow in a fluid processed by the compressor. In accordance herewith, the invention also refers to a subsea compression system arranged for implementation of the method.

BACKGROUND AND PRIOR ART

[0002] In subsea hydrocarbon production compressors can be used to aid in transport of gas from a subsea hydrocarbon fluid deposit via an offshore pipeline to a surface platform, e.g. Suitable for compression of gas in the subsea environment, the radial or centrifugal compressor comprises a rotor equipped with wheels or impellers, operated in rotation by an electric motor. The compressor is capable of achieving a rise in pressure in a gaseous fluid that is fed continuously through the compressor.

[0003] The operation of a gas compressor can be described in terms of three operating parameters: speed, head and flow. At a given speed the compressor delivers a maximum head and a corresponding flow, defining a state of stable operation. Stable operation can be maintained as long as a reduction in head is compensated by an increase in flow. If flow is reduced when the compressor has reached its maximum head capability, the compressor rotor spins idling in the gas which is no longer propelled forward by the rotor. The system pressure that is build up at the compressor outlet may force the gas to pass the rotor backwards, reversing the flow through the compressor. At a point where the compressor can no longer add to the fluid the energy required to overcome the backpressure, the compressor is going into surge.

[0004] In other words, a compressor's performance can be defined as a relation between pressures at compressor inlet and outlet, or pressure ratio (discharge pressure divided by suction pressure) over the compressor, and flow at a given rotor speed. For each compressor its performance can be quantified and illustrated in a diagram wherein the horizontal axis represents the flow or amount of uncompressed gas passing the compressor inlet. The vertical axis represents compression pressure ratio that occurs inside the compressor. For each rotor speed there is one relation between pressure ratio and flow at which the operation is stable. At a point where the flow no longer matches the pressure ratio and the relation is broken the compressor leaves the region of stable op-

eration, going into a region characterized as the surge zone. A line connecting the surge points for the whole range of operational rotor speeds represents the surge limit in a compressor map that illustrates and quantifies the performance of the subject compressor.

[0005] In a state of surge, the compressor will be subject to overheating, strong vibration, rapid changes in axial thrust and shaft movements, eventually causing damage to rotating parts, rotor seals, rotor bearings etc. Accordingly there is a requirement to prevent the compressor from going into surge, not the least in the subsea environment where maintenance and repair is more complicated.

[0006] Preventing a compressor from operating in the surge zone usually involves recycling of the processed fluid from the compressor outlet to the compressor inlet to supplement an insufficient flow via the compressor inlet. A valve normally closed in the recycle line is arranged to be shifted into open state in case of insufficient flow, switching the compressor from normal operation into what can be called an anti-surge operational mode.

[0007] An anti-surge control system is arranged to maintain the recycle valve, also called anti-surge valve (ASV), in closed position as long as the compressor operates well outside the surge zone. If the compressor gets close to the surge limit the anti-surge control system shifts the valve into the open position thus increasing the flow at the compressor inlet.

[0008] The anti-surge control system may be arranged to generate a valve operating command based on several parameters which are monitored by appropriate sensors and meters. The monitored parameters are typically the inlet and outlet pressures and temperatures, the differential pressure over the compressor, and the rotor speed.

[0009] In the prior art, US patent no. 4464720 discloses an anti-surge control based on sensing the inlet and outlet pressures and calculating an actual differential pressure that is compared with a desired set-point.

[0010] US patent no. 4971516 discloses an anti-surge control based on sensing the flow and the rotor speed and calculating the actual flow/speed ratio which is compared with the corresponding ratio at surge.

[0011] US patent no. 7094019 discloses an anti-surge control system that calculates the actual pressure ratio and the pressure ratio at surge based on monitoring speed, inlet and outlet pressures in order to operate the recycle valve when the actual pressure ratio is safely distanced from the pressure ratio at surge.

[0012] WO 2009/055878 A2 discloses measuring the electric currents flowing through the coils of magnetic bearings to calculate the forces on the bearings.

[0013] The gas compressor in general is very sensitive to disturbances in the flow and the demands are high on the anti-surge control system to react rapidly to changes in the process. Anti-surge control systems, wherein the valve operating command is generated topside from a main control system and based on input from sensors and transmitters that monitor the process parameters of

flow, pressure and temperature in a compression system located at the sea floor, run the risk of being too slow to safeguard the compressor against surge. The delay in reaction increases with increasing length of signal pathways between the subsea compression system and the topside facility hosting the main control system and its central logic.

[0014] One earlier solution aiming for short signal pathways and fast response in the control and operation of the recycle valve is disclosed in EP 2042743A1. This document describes a land based gas compression system wherein the input voltage to the compressor motor drive unit is monitored, and a control unit adapted to determine whether there is a risk of surge based on the measured input voltage, and if that is the case, to generate a valve opening command.

[0015] Another attempt to reduce response times in an anti-surge control system, known from the subsea environment, involves the arrangement of a dedicated closed loop control system handling the anti-surge control through a compression system control module located at the site.

[0016] The present invention provides another solution for fast anti-surge valve response to be applied in conjunction with gas compressors wherein the compressor rotor is supported for contact free rotation by active magnetic bearings (AMB). Active magnetic bearings can be arranged for contact-free support of the compressor rotor in both radial and axial directions of the rotor.

[0017] In the active magnetic bearing, briefly, a magnetic conductive rotor is journaled in a stator that is magnetized by the current fed through appropriate electric windings. The magnetic field generated by the stator windings induces the magnetic force needed to support the rotor. Stator winding's currents are actively modulated on the basis of a feedback rotor position signal. The feedback rotor position signal is provided by a sensor (i.e. inductive or eddy current) which is reacting to changes in the position of the rotor relative to the sensors and other non-rotating parts of the compressor. The detected change in position is used in an AMB controller that controls the supply of current to the electric windings in the stator correspondingly, this way forcing the rotor to return to a centered position in the bearing. The AMB controller is usually located short distance from the bearing for short signal pathways and fast response.

[0018] As long as the compressor maintains stable operation well outside the surge zone the AMB controller will not register much change in the position of the rotor which then rotates substantially free from vibration and under substantially constant load from the processed fluid. Should the compressor get close to or pass the surge limit the AMB controller will react to vibration and changes in the rotor's position resulting from changing loads applied to the rotor from the processed fluid.

[0019] The design, implementation and testing of an active surge controller in a centrifugal compressor was previously presented by Se Young Yoon et al. in Control

of Surge in Centrifugal Compressors by AMB, published by Springer Verlag, London, 2013. In this document, Se Young Yoon et al. suggest employing the thrust magnetic bearing to modulate the impeller tip clearance in order to compensate for flow disturbances occurring during an initial state of surge.

[0020] Because a shift from stable operation to surge can take place within a few seconds it is crucial that the anti-surge valve can be opened rapidly, and as early as possible from a first indication that the compressor is approaching the surge limit. In this aspect even a delay in the order of milliseconds may result in a failure to detect and avoid an impending surge condition in time.

15 SUMMARY OF THE INVENTION

[0021] It is an object of the present invention to provide a fast responding anti-surge control and shift from normal operation into anti-surge operational mode in a subsea compressor having a compressor rotor that is supported by active magnetic bearings.

[0022] It is another object of the present invention to provide redundancy in the anti-surge control of the subsea compressor having a compressor rotor that is supported by active magnetic bearings.

[0023] The first mentioned object is met in a method comprising:

- arranging an anti-surge valve (ASV) normally closed in a recycle line setting a compressor outlet in flow connection with a compressor inlet in an open state of the anti-surge valve,
- arranging an active magnetic bearing (AMB) controller to maintain the position of the compressor rotor relative to non-rotating parts of the compressor,
- determining a value representing a force (hereafter referred to force representing value) acting on the compressor rotor from the process load by using magnetic bearing control data,
- comparing the force representing value to a threshold value indicative of a surge condition, and in response to the force representing value exceeding the threshold value switching the anti-surge valve into the open state.

[0024] The first and second objects are both met in a method which further comprises:

- arranging an anti-surge controller (ASC) to control the state of the anti-surge valve in response to at least one of a detected flow, pressure and temperature in the processed fluid, wherein in response to the force representing value exceeding the threshold value:

- overriding the valve control provided by the anti-surge controller and switching the anti-surge valve into the open state.

[0025] The AMB control data used in determination of the force representing value comprises at least one of i) rotor position data, ii) amount of current fed through magnetic bearing coils, iii) amplitude in magnetic flux generated in the magnetic bearings.

[0026] Rotor position data can be acquired from position sensors, such as inductive or eddy current sensors arranged about the rotor. The amount of current supplied to the magnetic bearing coils can be acquired from the active magnetic bearing controller. The amplitude in the magnetic flux can be acquired by means of dedicated sensors, such as a Hall-effect sensor e.g., or can be estimated by the AMB controller based on the magnetic bearing characteristics and a combination of: i) the current signal, ii) the position signal, iii) the power amplifier voltage. A possible method for the magnetic flux estimation is described by Gerhard Schweitzer . Eric H. Maslen in the section 4.5.3 of the book Magnetic Bearings published by Springer Verlag, Berlin, 2009.

[0027] In one embodiment the method foresees that the force representing value can be evaluated by detecting the low frequency (LF) harmonic content in at least one of: i) a rotor position signal, ii) a current signal, iii) a magnetic flux signal, iv) a magnetic flux estimation. Another embodiment involves the provision of an anti-surge valve switching actuator (VSA) arranged to control the state of the anti-surge valve based on input command either from i) the flow and/or pressure and/or temperature based anti-surge controller, or from ii) the active magnetic bearing controller. The valve switching actuator is then configured to execute the valve control in accordance with the following condition:

if AMB controller command = TRUE then valve command = open valve, else valve command = ASC command.

[0028] The valve switching actuator is further configured to evaluate the AMB controller command in accordance with the following condition:

if the force representing value exceeds the threshold value, then AMB controller command is TRUE, else AMB controller command is FALSE.

[0029] The threshold value can be predetermined while running the compressor in calibration. For example, threshold values can be determined while mapping the performance of the compressor during commissioning. More precisely, a set of threshold values related to different compressor rotor speeds can be compiled in a compressor map.

[0030] In a similar way the LF harmonic content threshold value can be predetermined in a calibration process. For example, the content of LF harmonic oscillation and amplitude in the position signal, current signal or magnetic flux signal can be recorded for a range of rotor speeds with the rotor levitated by the magnetic bearings.

[0031] The first mentioned object of the present inven-

tion is likewise met in a subsea compression system comprising a compressor having a compressor rotor supported for contact-free rotation by active magnetic bearings, and further comprising:

- an anti-surge valve normally closed in a recycle line setting a compressor outlet in flow connection with a compressor inlet in an open state of the anti-surge valve,
- an active magnetic bearing (AMB) controller arranged to regulate the amount of current supplied to electromagnets in the bearing in response to forces acting on the compressor rotor from the process load, wherein
- the AMB controller is operatively connected to the anti-surge valve.

[0032] Embodiments of the compression system comprises:

- an anti-surge controller arranged to control the state of the anti-surge valve in response to at least one of a detected flow, pressure and temperature in the processed fluid, wherein the active magnetic bearing controller is operatively connected to the anti-surge valve in parallel with the anti-surge controller.

[0033] Embodiments of the compression system further comprises an anti-surge valve switching actuator (VSA) that is interposed between the anti-surge valve on the one hand and the active magnetic bearing and anti-surge controllers, respectively, on the other hand.

[0034] The valve switching actuator in turn comprises an evaluation unit configured to generate a valve switching command based on input from either of the active magnet bearing controller or the anti-surge controller.

[0035] The actuation of the anti-surge valve can be achieved through a quick opening function activated by the active magnetic bearing controller. In another embodiment the actuation of the anti-surge valve can be achieved through a quick opening function activated by the active magnetic bearing controller which overrides the anti-surge controller.

[0036] Further advantages as well as advantageous features of the method and system of the present invention will appear from the following description and the dependent claims.

SHORT DESCRIPTION OF THE DRAWINGS

[0037] The invention will be further explained below with reference made to the accompanying schematic drawings. In the drawings,

Fig. 1 is a system overview of a subsea compression system incorporating anti-surge control in accord-

ance with the state of the art,

Fig. 2 is a corresponding overview of a subsea compression system incorporating anti-surge control in accordance with a first embodiment,

Fig. 3 is a corresponding overview of a subsea compression system incorporating anti-surge control in accordance with a second embodiment,

Fig. 4 is a diagram illustrating parallel chains of input commands to the anti-surge control,

Fig. 5 is a flow chart showing the steps through a process for evaluation of input commands to the anti-surge control,

Fig. 6 is a diagram illustrating signal pathways for process parameters used in formation of an input command to the anti-surge control, and

Fig. 7 is a flow chart showing the steps through a process for testing the validity of an input command to the anti-surge control.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0038] Fig. 1 illustrates a compression system 1 situated on the seafloor. The subsea compression system 1 comprises a compressor 2 having a rotor 3 driven in rotation by a drive means, such as a motor 4, via a rotor shaft 5. The motor and compressor assembly 2-5 is operable for raising the pressure in gas recovered from a subsea hydrocarbon fluid deposit for transport to a topside, land based or floating station, in the drawings illustrated as a surface platform 6 by way of example, via pipeline sections 7 and 8. The compressor 2 is connected to the pipeline through a compressor inlet 9 via which the fluid is sucked and through a compressor outlet 10 via which the fluid is discharged at higher pressure and elevated temperature. In Fig. 1, the flow direction is illustrated through arrows F_{IN} and F_{OUT} .

[0039] Power and process control is supplied from the topside station and distributed via a power/control umbilical 11 which connects a topside umbilical termination unit (TUTU) 12 to a subsea umbilical termination assembly (UTA) 13. Basically, power and process control is governed by the main control system (MCS) 14 that is arranged topside, and which communicates with a compression system control module (CSCM) 15 arranged subsea. The CSCM 15 comprises control logic and communication capacity to the topside controls via the power/control umbilical 11.

[0040] Through the CSCM 15, a number of process parameters can be monitored and controlled, either directly in the CSCM 15 or indirectly from the topside located MCS 14.

[0041] Electrical power to the compressor motor and other subsea power consumers is supplied via a power distribution module (PDM) 16. Reference number 17 refers to a variable speed drive (VSD) unit by which the motor power and rotor speed can be regulated. The functionality included in the PDM 16 and VSD 17 units and their controls may entirely or in part be located in the CSCM 15, or located topside such as in the MCS 14, e.g.

[0042] Transformers, converters, circuit breakers and other electric and electronic devices, which are usually found in a subsea compression system, are omitted from the drawings of Figs. 1-3 for reasons of simplification. For the same reason upstream located equipment, such as production valves, coolers, separators, sand traps etc., have been omitted since their description is not necessary in order to explain or understand the present invention.

[0043] In a description of the general layout of a compression system it can be noted that the depth at which the compression system may be located typically is in the range of several hundred meters up to the order of kilometers, whereas the distance from the compression station to a land based receiving station 6 may amount to one hundred kilometers or more.

[0044] The compressor rotor 3 is supported by active magnetic bearings in which it is levitated for contact-free rotation. The rotor position is monitored by position sensors 18 that continuously detect the rotor's position relative to electromagnets 19. In the compression system layout depicted in Fig. 1 the rotor 3 is journaled in radial bearings 20 and 21 supporting the rotor and counteracting the weight of the rotor (in horizontal orientation) and the radial loads and forces acting on the rotor from the process load. The rotor 3 is further levitated in thrust bearing(s) 22 which hold(s) the rotor in levitation while compensating for and counteracting the weight of the rotor (in vertical orientation) and the axial load acting on the rotor from the processed medium.

[0045] The electromagnets 19 of the thrust bearing 22 are arranged on opposite sides of a radial disc 23 which is fixed onto the rotor shaft 5.

[0046] The principal structure of active magnetic bearings is a well-known technology per se, and need not be further discussed here. It shall however be noted that realizations of the subsea compression system may require other numbers of bearings, electromagnets and sensors, as well as different types of sensors and electromagnets. In other embodiments, obviously, the compressor rotor may be supported to have a horizontal orientation.

[0047] Auxiliary bearings will typically be arranged to protect the magnetic bearings from contact with the rotor during start and stop procedures or in case of excessive displacements of the rotor. Auxiliary bearings are omitted from the drawings of Figs. 1-3 for simplicity reasons.

[0048] Based on the rotor position detected by the position sensors 18, an active magnetic bearing (AMB) controller 24 regulates and supplies the amount of current

to the electromagnets 19 that is required to maintain the rotor in contact-free rotation, compensating and counteracting a change or deviation in the rotor's position relative to ideal positions in the electromagnet bearings 20-22.

[0049] In order to avoid the compressor from going into a condition of surge, flow communication from the outlet 10 to the inlet 9 can be established outside the compressor 3 via a valve 25 that controls the flow in a recycle line 26 connecting the outlet and inlet sides of the compressor. The valve 25 is normally closed and shifted into an open state in case the compressor is about to go into surge. In open state the valve permits recirculation of fluid that is returned to the compressor via the compressor inlet 9, driven by the higher fluid pressure on the discharge side. In the following, the valve 25 will be named an anti-surge valve 25 or ASV.

[0050] In prior art solutions the state of the anti-surge valve 25 can be controlled by an anti-surge controller (ASC) 27. The anti-surge controller 27 comprises control logic configured to process information on dedicated process parameters in order to generate an ASC command that determines the state of the anti-surge valve 25.

[0051] In the system layout depicted in Fig. 1, an ASC command is based on inputs received from pressure transmitters 28 and 29 monitoring the fluid pressure respectively at both suction and discharge of the compressor and based on input received from a flow transmitter 30 used to measure or to calculate the flow at the compressor inlet. Alternatively or additionally, the temperature in the discharged fluid may be monitored and transmitted to the anti-surge controller 27.

[0052] During stable operation the anti-surge valve 25 is closed or held in the closed state by a corresponding ASC command (or by the absence of an ASC command). As a consequence of an insufficient flow at the compressor inlet 9 the anti-surge controller 27 produces an ASC command which results in opening of the anti-surge valve 25, thus permitting recirculation of process fluid in order to restore and maintain the relation between flow and pressure ratio which is required for stable compressor operation.

[0053] The anti-surge controller 27 may form an integrated part of the compression system control module 15 as illustrated in Fig. 1.

[0054] The anti-surge controller 27 may alternatively be located topside in association with the main control system 14. The anti-surge controller 27 can also alternatively be arranged as a separate module as illustrated in Fig. 3.

[0055] However, the anti-surge controller 27 and its associated transmitters for flow, pressure or temperature may all be omitted in a method for anti-surge control described with reference to an embodiment of a subsea compression system 100, illustrated in Fig. 2.

[0056] Except where otherwise stated the compression system 100 corresponds to the compression system 1 in respect of structural components and operation.

[0057] However, in the embodiment 100 to be de-

scribed below with reference to Fig. 2, the AMB controller 24 is arranged to control the state of the anti-surge valve 25. To this purpose the AMB controller 24 comprises control logic configured to process information on compressor operation parameters in order to generate an AMB controller command which is communicated to the anti-surge valve 25 via communication line 31.

[0058] A change in the process that eventually moves the compressor towards the surge zone leads to a change in the forces acting on the compressor rotor from the process load. Unless the compressor speed is adapted to the changed condition the compressor rotor will be subject to relative displacement and vibration in the form of axial and/or radial oscillation. The magnitude of the displacement or vibration reflects the magnitude of change in the force or forces acting on the compressor rotor from the process load.

[0059] A rotor vibration can be recognized as low frequency (LF) harmonic oscillation that is superimposed on the position signal transmitted from the position sensors 18. The amplitude of the LF harmonic oscillation reflects the magnitude in the forces acting on the compressor rotor. The LF harmonic oscillation can be extracted from the position signal by commonly used signal processing techniques such as filtration/modulation/demodulation, e.g.

[0060] Other operation parameters besides the rotor position may form an underlying base for the AMB controller command that controls the state of the anti-surge valve 25. The amount of current that is required to maintain the rotor in the desired position can be an early indicator of an imminent surge condition. As an alternative or as supplement to the position signal input, variations in the current can be monitored to detect low frequency dynamic forces generated as the compressor approaches the surge zone. Another alternative or supplementary input to the AMB controller can be the magnetic flux generated by the electromagnets. Variations in the magnetic flux can be detected through dedicated sensors, such as a Hall-effect sensor, or can be estimated by the AMB controller.

[0061] Thus, in the embodiment 100, the anti-surge valve 25 is instantaneously reacting to a change in the compressor's operation that is processed in the AMB controller 24 and sent via communication line 31 as an AMB command which determines the state of the anti-surge valve 25.

[0062] In another embodiment 200 to be described with reference to Fig. 3, the anti-surge valve 25 is actuated via an anti-surge valve switching actuator (VSA) 32.

[0063] Except where otherwise stated the compression system 200 corresponds to the compression systems 1 and 100 in respect of structural components and operation.

[0064] In the embodiment 200, the valve switching actuator 32 is responsive to inputs transmitted from the anti-surge controller 27 via communication line 33.

[0065] In addition the valve switching actuator 32 is

responsive also to inputs received from the AMB controller 24, transmitted via communication line 31.

[0066] The valve switching actuator 32 comprises an evaluation unit equipped with data processing capacity configured to evaluate the input received from the anti-surge controller 27 and from the AMB controller 24 respectively, to decide which input, the ASC command or the AMB controller command that shall be determinative for the state of the anti-surge valve 25. In particular the valve switching actuator 32 is arranged to overrule the ASC command under a certain condition at which the AMB controller command takes precedence over the ASC command. The evaluation process performed by the valve switching actuator 32 is illustrated in the block diagrams of Figs. 4 and 5.

[0067] Fig. 4 illustrates the parallel input of the AMB controller command and the ASC command to the valve switching actuator 32. As default, the valve switching actuator 32 generates a valve switching command based on the ASC command during stable operation. The AMB controller command is repeatedly read and evaluated in a process loop through the steps of Fig. 5, by which the valve switching actuator 32 is programmed and preset to permit the AMB controller command to take preference over the ASC command under the following condition: if the AMB controller command is found to be true, then the valve switching actuator 32 shifts the anti-surge valve 25 into open state (i.e. regardless of the valve status information contained in the ASC command), and if the AMB controller command is found to be false, the valve switching actuator 32 sets the valve position in accordance with the ASC command.

[0068] Fig. 6 illustrates the signal pathways for the process parameters which form the base for the AMB controller command.

[0069] The validity of the information contained in the AMB controller command is assessed in a process loop through the steps of Fig. 7. One input to the validity test of Fig. 7 is the AMB axial force, which is a value representing the axial force acting on the compressor rotor. The AMB axial force can be calculated based on the rotor position data, the amount of current supplied to the electromagnets in the magnetic bearings and the amplitude in magnetic flux generated in the magnetic bearings. Alternatively or in addition, the AMB axial force can be estimated by the amplitude of the position signal, the current signal, and the magnetic flux signal in the frequency domain especially at low frequency where the effect of the surge is noticeable.

[0070] The AMB controller command is accepted as a TRUE indicator of the operational status of the compressor if:

the value representing the force acting on the compressor rotor exceeds a threshold value.

[0071] Thus the valve switching actuator 32 switches the anti-surge valve into the open state. If none of the above conditions is fulfilled, then the AMB controller command is considered as FALSE, in response to which the

valve switching actuator 32 ignores the AMB controller generated command.

[0072] The axial force threshold value can be calculated or determined through running of the compressor in test or in calibration. In particular, a set of threshold values for various rotor speeds can be compiled and memorized by the valve switching actuator 32 in the form of a compressor map while the operating point is approaching the surge area.

[0073] In a similar way the LF harmonic content threshold value can be predetermined by running of the compressor in test or calibration. In particular, a set of threshold values for various rotor speeds can be compiled and stored by the valve switching actuator 32 in the form of a compressor map while the operating point is approaching the surge area.

[0074] Actuation of the anti-surge valve 25 may be achieved through a quick opening function activated by the active magnetic bearing controller command. This function may be implemented by means of a power switch that controls the supply of power to the anti-surge valve.

[0075] If the AMB controller fails to detect an imminent surge at an early stage, the anti-surge valve 25 will be actuated on command from the anti-surge controller 27 based on the input from the flow and/or pressure and/or temperature transmitters 28, 29. On the other hand the AMB control can be expected to react just as rapid as the flow/pressure/temperature activated anti-surge control or even faster. In all cases the embodiment 200, as shown in Fig. 3, provides back up and redundancy in the anti-surge control of a subsea compression system.

[0076] In all embodiments disclosed the anti-surge valve 25 can be reset into its normally closed state once the processed flow has been reestablished or the risk for surge being removed or avoided. Reset of the anti-surge valve can follow an automatic procedure, relying for example on a valve body that is biased towards a closed position or a valve actuator biased towards a closing state, and can alternatively follow upon a closing command generated in a subsea control unit, such as the AMB controller, or from the topside control, e.g. Notwithstanding the obvious necessity to provide for reset of the anti-surge valve after an anti-surge operational mode, the invention is focused on the shift from stable operation towards surge which is the critical end of the process.

[0077] The invention is of course not in any way restricted to the embodiments described above. On the contrary, many possibilities to modifications thereof will be apparent to a person with ordinary skill in the art without departing from the scope of the invention which is defined in the appended claims.

Claims

1. A method by which a subsea compressor, the rotor (3) of which is supported by active magnetic bearings (20, 21, 22) for contact-free rotation, is arranged to

be switched from normal operation into an anti-surge operational mode, the method comprising:

arranging an anti-surge valve (25) normally closed in a recycle line (26) setting a compressor outlet (10) in flow connection with a compressor inlet (9) in an open state of the anti-surge valve (25),
arranging an active magnetic bearing (AMB) controller (24) to maintain the position of the compressor rotor (3) relative to non-rotating parts of the compressor,
characterized by the active magnetic bearing (AMB) controller:

determining, using bearing control data, a value representing a force acting on the compressor rotor from the process load, comparing the force representing value to a threshold value indicative of a surge condition, and in response to the force representing value exceeding the threshold value:

switching the anti-surge valve into the open state.

2. The method of claim 1 further comprising:

arranging an anti-surge (ASC) controller (27) to control the state of the anti-surge valve (25) in response to at least one of a detected flow, pressure and temperature in the processed fluid, wherein in response to the force representing value exceeding the threshold value:

overriding the valve control provided by the anti-surge controller (27) and switching the anti-surge valve into the open state.

3. The method of claim 1 or 2, wherein the bearing control data used in determination of the force representing value comprises at least one of:

- i) rotor position data,
- ii) amount of current fed through magnetic bearing coils (19),
- iii) amplitude in magnetic flux generated in the magnetic bearing.

4. The method of any of claims 1-3, wherein the force representing value is determined by the low frequency (LF) harmonic content in at least one of:

- i) a rotor position signal,
- ii) a current signal,
- iii) a magnetic flux signal,
- iv) a magnetic flux estimation.

5. The method of claim 4, comprising:
providing a valve switching actuator (32) arranged

to control the state of the anti-surge valve (25) based on input command from either of:

- i) a flow and/or pressure and/or temperature based anti-surge controller (27), or
- ii) an active magnetic bearing controller (24),

wherein the valve switching actuator (32) is configured to execute the valve control in accordance with the following condition:

if AMB controller command = TRUE then valve command = open valve, else valve command = ASC command.

6. The method of claim 5, wherein the valve switching actuator (32) is configured to evaluate the AMB controller command in accordance with the following condition:

If the force representing value exceeds the threshold value, then AMB controller command = TRUE, else AMB controller command = FALSE.

7. The method of any previous claim, wherein the threshold value is predetermined while running the compressor in calibration.

8. The method of claim 7, wherein a set of threshold values related to different compressor rotor speeds are compiled in a compressor map.

9. A subsea compression system (100; 200) arranged to be switched from normal operation into an anti-surge operational mode in a method according to any one of the preceding claims, the compression system comprising:

a compressor, having a compressor rotor (3) supported for contact-free rotation by active magnetic bearings (20, 21, 22),
an anti-surge valve (25) normally closed in a recycle line (26) setting a compressor outlet (10) in flow connection with a compressor inlet (9) in an open state of the anti-surge valve,
an active magnetic bearing (AMB) controller (24) to maintain the position of the compressor rotor (3) relative to non-rotating parts of the compressor,
wherein the active magnetic bearing controller (24) is operatively connected to the anti-surge valve (25).

10. The subsea compression system (200) according to claim 9 further comprising:

an anti-surge controller (27) arranged to control the state of the anti-surge valve (25) in response to at least one of a detected flow, pressure and

temperature in the processed fluid,
wherein the active magnetic bearing controller
(24) is operatively connected to the anti-surge
valve (25) in parallel with the anti-surge control-
ler (27).

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11. The subsea compression system of claim 10, comprising an anti-surge valve switching actuator (32) interposed between the anti-surge valve (25) on the one hand and the anti-surge and active magnetic bearing controllers (27; 24), respectively, on the other hand.
12. The subsea compression system of claim 11, wherein the valve switching actuator (32) comprises an evaluation unit configured to generate a valve switching command based on input from either of the active magnetic bearing controller (24) or the anti-surge controller (27).
13. The subsea compression system of any of claims 9-12, wherein the actuation of the anti-surge valve (25) is achieved through a quick opening function activated by the active magnetic bearing controller (24).
14. The subsea compression system of any of claims 10-13, wherein the actuation of the anti-surge valve (25) is achieved through a quick opening function activated by the active magnetic bearing controller (24) which overrides the anti-surge controller (27).

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Patentansprüche

1. Verfahren, durch das ein Unterwasserverdichter, dessen Rotor (3) durch aktive Magnetlager (20, 21, 22) zur berührungslosen Drehung gelagert ist, angeordnet wird, um von Normalbetrieb in einen Pumpschutzbetriebsmodus geschaltet zu werden, wobei das Verfahren umfasst:

Anordnen eines normalerweise geschlossenen Pumpschutzventils (25) in einer Rückföhrleitung (26), die in einem offenen Zustand des Pumpschutzventils (25) einen Verdichterauslass (10) in Strömungsverbindung mit einem Verdichtereinlass (9) setzt,
Anordnen einer Steuerung des aktiven Magnetlagers (AMB) (24), um die Position des Verdichterrots (3) relativ zu nicht rotierenden Teilen des Verdichters aufrechtzuerhalten,
dadurch gekennzeichnet, dass die Steuerung des aktiven Magnetlagers (AMB):

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unter Verwendung von Lagersteuerdaten einen Wert bestimmt, der eine Kraft darstellt, die von der Prozesslast auf den Ver-

dichterroter wirkt,
den Kraft darstellenden Wert mit einem Schwellenwert vergleicht, der einen Pumpzustand anzeigt, und in Abhängigkeit davon, dass der Kraft darstellende Wert den Schwellenwert überschreitet:
das Pumpschutzventil in den geöffneten Zustand schaltet.

2. Verfahren nach Anspruch 1, ferner umfassend:
Anordnen einer Pumpschutz-Steuerung (ASC-Steuerung) (27), um den Zustand des Pumpschutzventils (25) in Abhängigkeit von mindestens einem von einem erfassten Fluss, einem erfassten Druck und einer erfassten Temperatur in dem verarbeiteten Fluid zu steuern, wobei in Abhängigkeit davon, dass der Kraft darstellende Wert den Schwellenwert überschreitet:
Umgehen der von der Pumpschutzsteuerung (27) bereitgestellten Ventilsteuerung und Schalten des Pumpschutzventils in den offenen Zustand.

3. Verfahren nach Anspruch 1 oder 2, wobei die Lagersteuerdaten, die bei Bestimmung des Kraft darstellenden Werts verwendet werden, mindestens eines von Folgendem umfassen:

- i) Rotorpositionsdaten,
- ii) Strommenge, die durch Magnetlagerspulen (19) eingespeist wird,
- iii) Amplitude des im Magnetlager erzeugten Magnetflusses.

4. Verfahren nach einem der Ansprüche 1-3, wobei der Kraft darstellende Wert durch den Niederfrequenz-Oberschwingungsgehalt (LF-Oberschwingungsgehalt) in mindestens einem von Folgendem bestimmt wird:

- i) einem Rotorpositionssignal,
- ii) einem Stromsignal,
- iii) einem Magnetflusssignal,
- iv) einer Schätzung des Magnetflusses.

5. Verfahren nach Anspruch 4, umfassend:
Bereitstellen eines Ventilschaltstellglieds (32), das angeordnet ist, um den Zustand des Pumpschutzventils (25) basierend auf einem Eingabebefehl von einem der Folgenden zu steuern:

- i) einer strömungs- und/oder druck- und/oder temperaturbasierten Pumpschutzsteuerung (27) oder
- ii) einer Steuerung eines aktiven Magnetlagers (24),

wobei das Ventilschaltstellglied (32) konfiguriert ist, um die Ventilsteuerung gemäß

- der folgenden Bedingung auszuführen:
wenn AMB-Steuerungsbefehl = WAHR,
dann Ventilbefehl = offenes Ventil, sonst
 Ventilbefehl = ASC-Befehl.
6. Verfahren nach Anspruch 5, wobei das Ventilschaltstellglied (32) konfiguriert ist, um den AMB-Steuerungsbefehl gemäß der folgenden Bedingung zu bewerten:
Wenn der Kraft darstellende Wert den Schwellenwert überschreitet, dann AMB-Steuerungsbefehl = WAHR, sonst AMB-Steuerungsbefehl = FALSCH.
7. Verfahren nach einem der vorstehenden Ansprüche, wobei der Schwellenwert vorbestimmt wird, während der Verdichter in Kalibrierung betrieben wird.
8. Verfahren nach Anspruch 7, wobei ein Satz von Schwellenwerten, die sich auf verschiedene Verdichterrotordrehzahlen beziehen, in einem Verdichterkennfeld zusammengestellt wird.
9. Unterwasser-Verdichtungssystem (100; 200), das angeordnet ist, um in einem Verfahren nach einem der vorstehenden Ansprüche von normalem Betrieb in einen Pumpschutz-Betriebsmodus geschaltet zu werden, wobei das Verdichtungssystem umfasst:
- einen Verdichter mit einem durch aktive Magnetlager (20, 21, 22) berührungslos drehbar gelagerten Verdichterrotor (3),
 ein normalerweise geschlossenes Pumpschutzventil (25) in einer Rückführleitung (26), die in einem offenen Zustand des Pumpschutzventils einen Verdichterauslass (10) in Strömungsverbindung mit einem Verdichtereinlass (9) setzt,
 eine Steuerung des aktiven Magnetlagers (AMB) (24), um die Position des Verdichterrotors (3) relativ zu nicht rotierenden Teilen des Verdichters zu bewahren,
 wobei die Steuerung des aktiven Magnetlagers (24) mit dem Pumpschutzventil (25) wirkverbunden ist.
10. Unterwasser-Verdichtungssystem (200) nach Anspruch 9, ferner umfassend:
- eine Pumpschutzsteuerung (27), die angeordnet ist, um den Zustand des Pumpschutzventils (25) in Abhängigkeit von mindestens einem von einem erfassten Fluss, einem erfassten Druck und einer erfassten Temperatur in dem verarbeiteten Fluid zu steuern,
 wobei die Steuerung des aktiven Magnetlagers (24) mit dem Pumpschutzventil (25) parallel zu der Pumpschutzsteuerung (27) wirkverbunden ist.

11. Unterwasser-Verdichtungssystem nach Anspruch 10, umfassend ein Pumpschutzventil-Umschaltstellglied (32), das zwischen dem Pumpschutzventil (25) einerseits und der Pumpschutzsteuerung bzw. der Steuerung des aktiven Magnetlagers (27; 24) andererseits angeordnet ist.
12. Unterwasser-Verdichtungssystem nach Anspruch 11, wobei das Ventilschaltstellglied (32) eine Auswertungseinheit umfasst, die dafür konfiguriert ist, einen Ventilschaltbefehl basierend auf einer Eingabe von entweder der Steuerung des aktiven Magnetlagers (24) oder der Pumpschutzsteuerung (27) zu erzeugen.
13. Unterwasser-Verdichtungssystem nach einem der Ansprüche 9 bis 12, wobei die Betätigung des Pumpschutzventils (25) durch eine Schnellöffnungsfunktion erreicht wird, die durch die Steuerung des aktiven Magnetlagers (24) aktiviert wird.
14. Unterwasser-Verdichtungssystem nach einem der Ansprüche 10 bis 13, wobei die Betätigung des Pumpschutzventils (25) durch eine Schnellöffnungsfunktion erreicht wird, die durch die Steuerung des aktiven Magnetlagers (24) aktiviert wird, die die Pumpschutzsteuerung (27) übersteuert.

Revendications

1. Procédé selon lequel un compresseur sous-marin, dont le rotor (3) est supporté par des paliers magnétiques actifs (20, 21, 22) pour une rotation sans contact, est agencé pour être commuté d'un fonctionnement normal en un mode de fonctionnement anti-surpression, le procédé comprenant :
- la disposition d'une soupape anti-surpression (25) normalement fermée dans une conduite de recyclage (26) établissant une sortie de compresseur (10) en communication fluide avec une entrée de compresseur (9) dans un état ouvert de la soupape anti-surpression (25),
 l'agencement d'un dispositif de commande (24) de palier magnétique actif (AMB) pour maintenir la position du rotor de compresseur (3) par rapport aux parties non-rotatives du compresseur, **caractérisé en ce que** le dispositif de commande de palier magnétique actif (AMB) :
- détermine, en utilisant des données de commande de palier, une valeur représentant une force agissant sur le rotor de compresseur à partir de la charge de processus, compare la valeur représentant la force à une valeur de seuil indicative d'une condition de surpression, et en réponse à la va-

- leur représentant la force dépassant la valeur de seuil :
commute la soupape anti-surpression à l'état ouvert.
2. Procédé selon la revendication 1, comprenant en outre :
l'agencement d'un dispositif de commande (27) anti-surpression (ASC) pour commander l'état de la soupape anti-surpression (25) en réponse à au moins l'un d'un écoulement, d'une pression et d'une température détectés dans le fluide traité, dans lequel en réponse à la valeur représentant la force dépassant la valeur de seuil :
le contournement de la commande de soupape fournie par le dispositif de commande anti-surpression (27) et la commutation de la soupape anti-surpression à l'état ouvert.
3. Procédé selon la revendication 1 ou 2, dans lequel les données de commande de palier utilisées pour la détermination de la valeur représentant la force comprennent au moins l'une parmi :
- i) des données de position de rotor,
 - ii) une quantité de courant introduit par des bobines de palier magnétiques (19),
 - iii) l'amplitude du flux magnétique généré dans le palier magnétique.
4. Procédé selon l'une quelconque des revendications 1 à 3, dans lequel la valeur représentant la force est déterminée par la teneur en harmoniques basse fréquence (LF) dans au moins l'un parmi :
- i) un signal de position du rotor,
 - ii) un signal de courant,
 - iii) un signal de flux magnétique,
 - iv) une estimation de flux magnétique.
5. Procédé selon la revendication 4, comprenant :
la fourniture d'un actionneur de commutation de soupape (32) agencé pour commander l'état de la soupape anti-surpression (25) sur la base d'une commande d'entrée provenant de l'un ou l'autre de :
- i) un dispositif de commande anti-surpression basé sur l'écoulement et/ou la pression et/ou la température (27), ou
 - ii) un dispositif de commande de palier magnétique actif (24),
dans lequel l'actionneur de commutation de soupape (32) est configuré pour exécuter la commande de soupape selon la condition suivante :
si la commande du dispositif de commande AMB = VRAI alors la commande de soupape = soupape ouverte, sinon la commande de soupape
- = commande ASC.
6. Procédé selon la revendication 5, dans lequel l'actionneur de commutation de soupape (32) est conçu pour évaluer la commande du dispositif de commande AMB conformément à la condition suivante :
si la valeur représentant la force dépasse la valeur de seuil, alors la commande du dispositif de commande AMB = VRAI, sinon la commande du dispositif de commande AMB = FAUX.
7. Procédé selon l'une quelconque des revendications précédentes, dans lequel la valeur de seuil est prédéterminée tout en exécutant le compresseur en étalonnage.
8. Procédé selon la revendication 7, dans lequel un ensemble de valeurs de seuil relatives à différentes vitesses de rotor de compresseur est compilé dans une carte de compresseur.
9. Système de compression sous-marin (100 ; 200) agencé pour être commuté d'un fonctionnement normal en un mode de fonctionnement anti-surpression dans un procédé selon l'une quelconque des revendications précédentes, le système de compression comprenant :
- un compresseur, doté d'un rotor de compresseur (3) supporté en rotation sans contact par des paliers magnétiques actifs (20, 21, 22),
 - une soupape anti-surpression (25) normalement fermée dans une conduite de recyclage (26) réglant une sortie de compresseur (10) en communication fluïdique avec une entrée de compresseur (9) dans un état ouvert de la soupape anti-surpression,
 - un dispositif de commande (24) de palier magnétique actif (AMB) pour maintenir la position du rotor de compresseur (3) par rapport aux parties non rotatives du compresseur,
 - dans lequel le dispositif de commande de palier magnétique actif (24) est connecté de manière opérationnelle à la soupape anti-surpression (25).
10. Système de compression sous-marin (200) selon la revendication 9, comprenant en outre :
- un dispositif de commande anti-surpression (27) agencé pour contrôler l'état de la soupape anti-surpression (25) en réponse à au moins l'un d'un écoulement, d'une pression et d'une température détectés dans le fluide traité,
 - dans lequel le dispositif de commande de palier magnétique actif (24) est connecté de manière opérationnelle à la soupape anti-surpression (25) en parallèle avec le dispositif de commande

anti-surpression (27).

11. Système de compression sous-marin selon la revendication 10, comprenant un actionneur de commutation de soupape anti-surpression (32) interposé entre la soupape anti-surpression (25) d'une part et les dispositifs de commande de palier magnétique actif et anti-surpression (27 ; 24), respectivement, d'autre part.
12. Système de compression sous-marin selon la revendication 11, dans lequel l'actionneur de commutation de soupape (32) comprend une unité d'évaluation configurée pour générer une commande de commutation de soupape sur la base d'une entrée provenant de l'un ou l'autre du dispositif de commande de palier magnétique actif (24) ou du dispositif de commande anti-surpression (27).
13. Système de compression sous-marin selon l'une quelconque des revendications 9 à 12, dans lequel l'actionnement de la soupape anti-surpression (25) est réalisé par une fonction d'ouverture rapide activée par le dispositif de commande de palier magnétique actif (24).
14. Système de compression sous-marin selon l'une quelconque des revendications 10 à 13, dans lequel l'actionnement de la soupape anti-surpression (25) est réalisé par une fonction d'ouverture rapide activée par le dispositif de commande de palier magnétique actif (24) qui contourne le dispositif de commande anti-surpression (27).

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Fig. 1
(Prior Art)

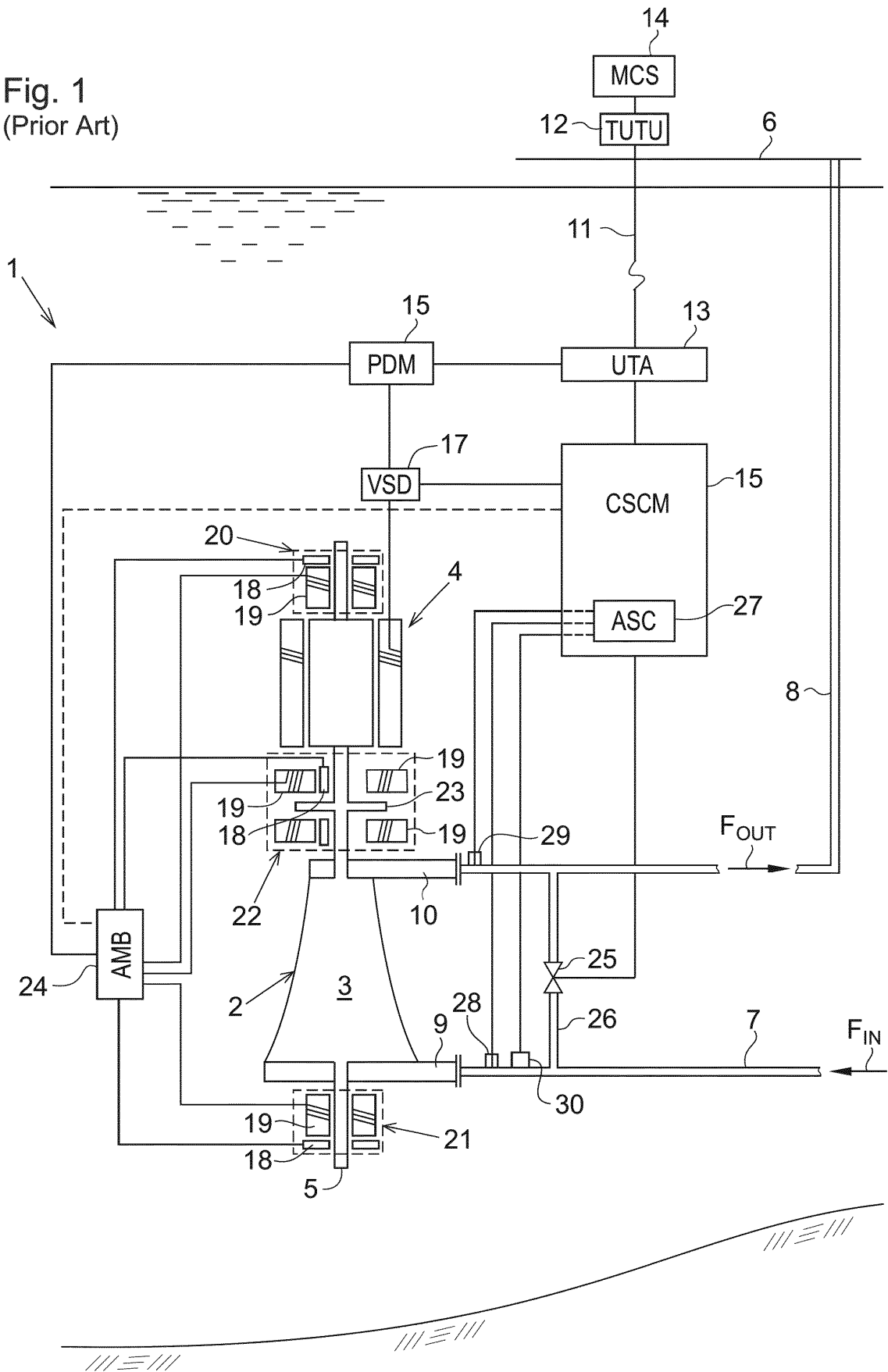


Fig. 2

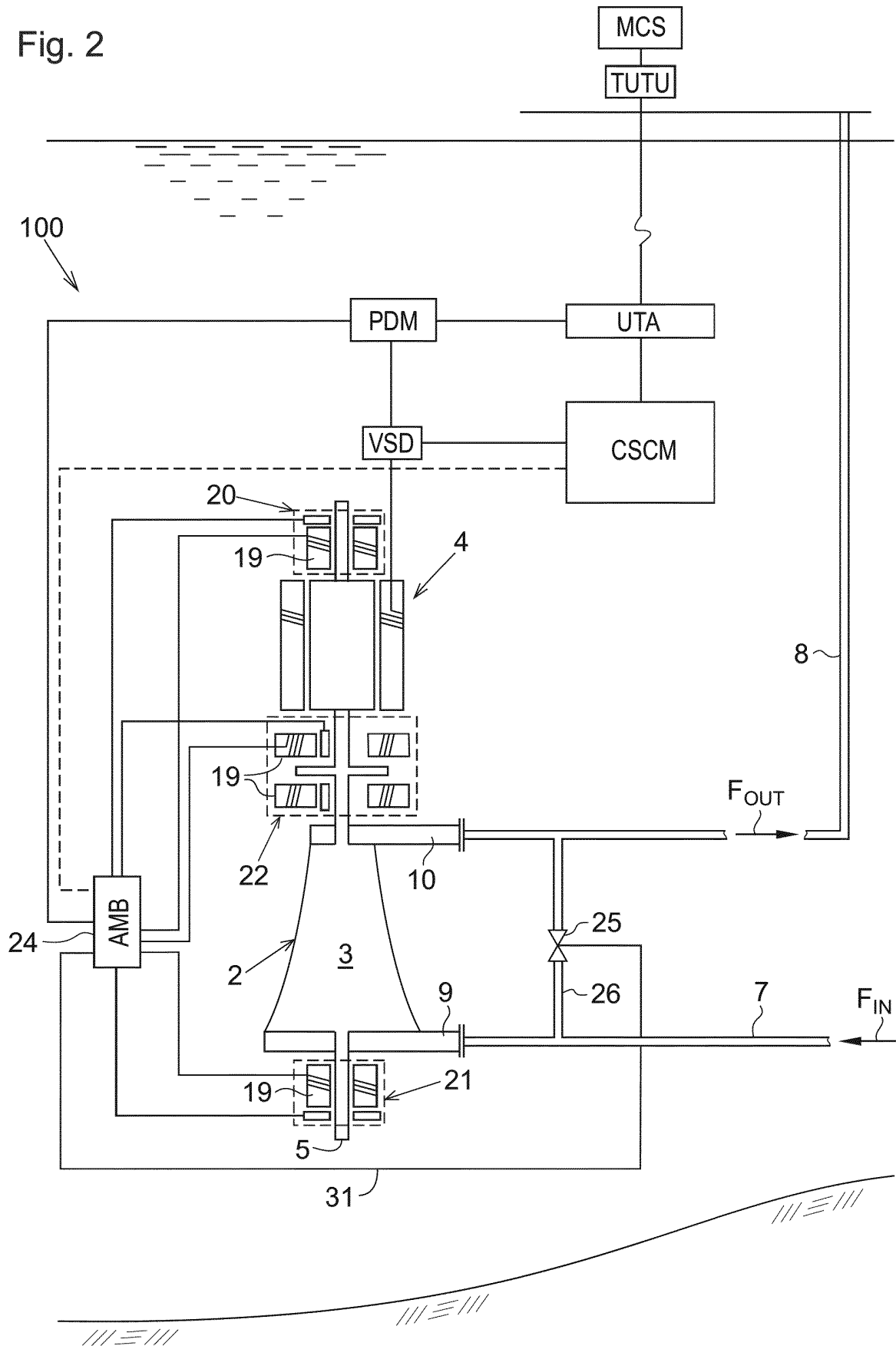


Fig. 3

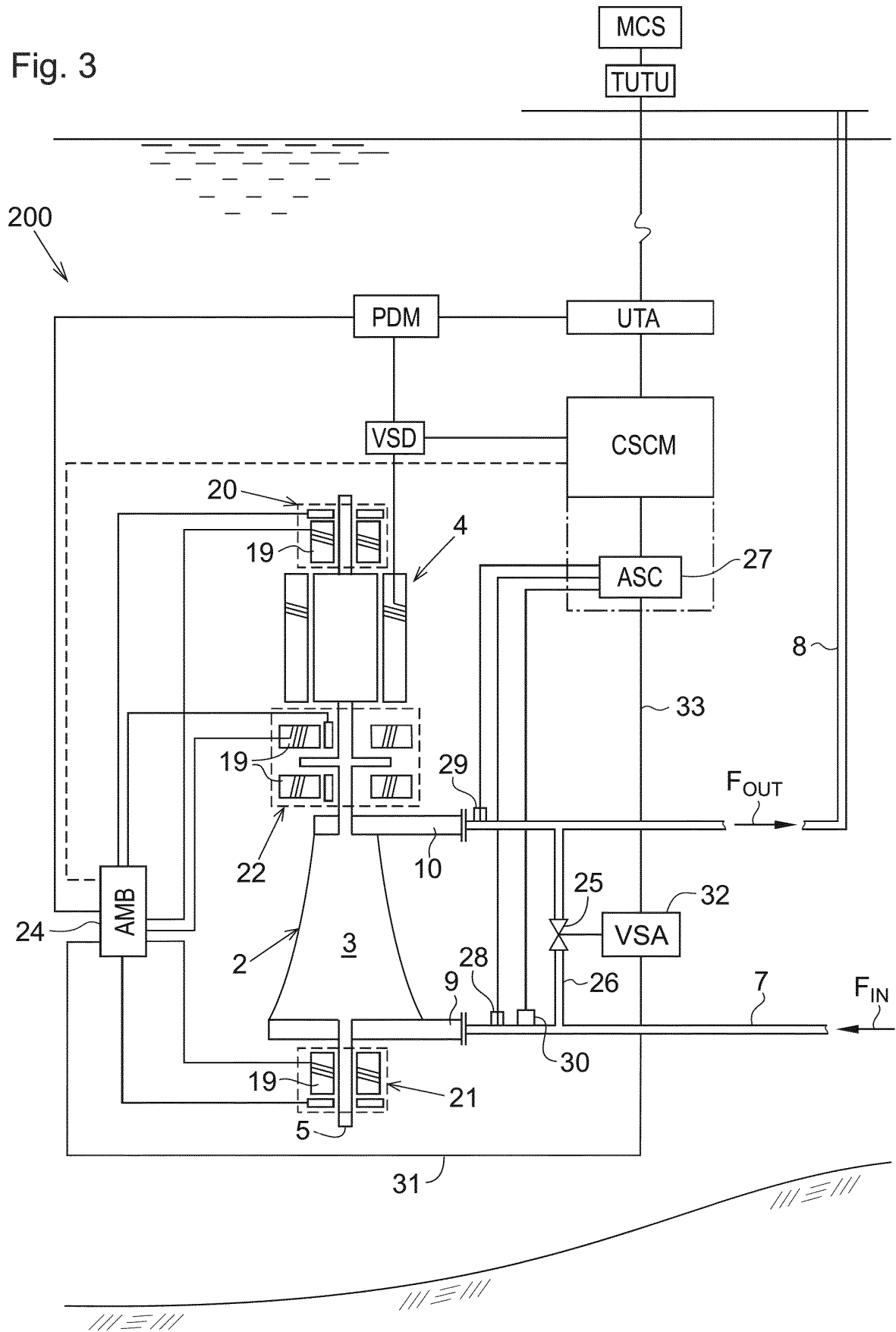


Fig. 4

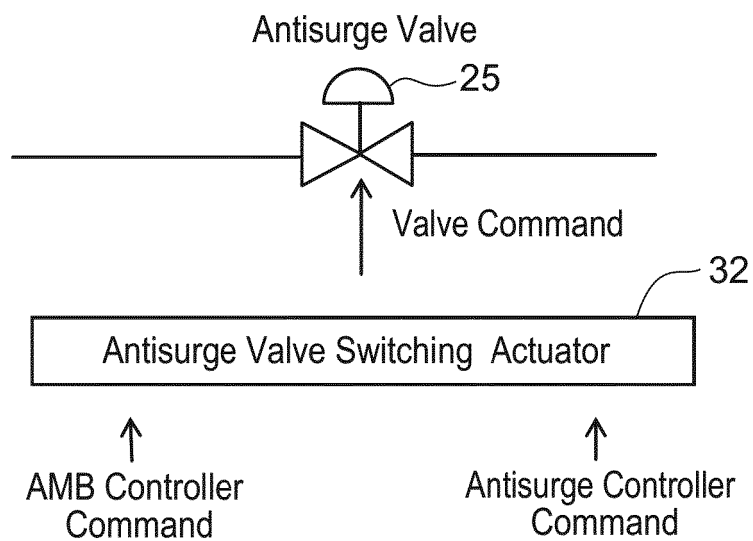


Fig. 5

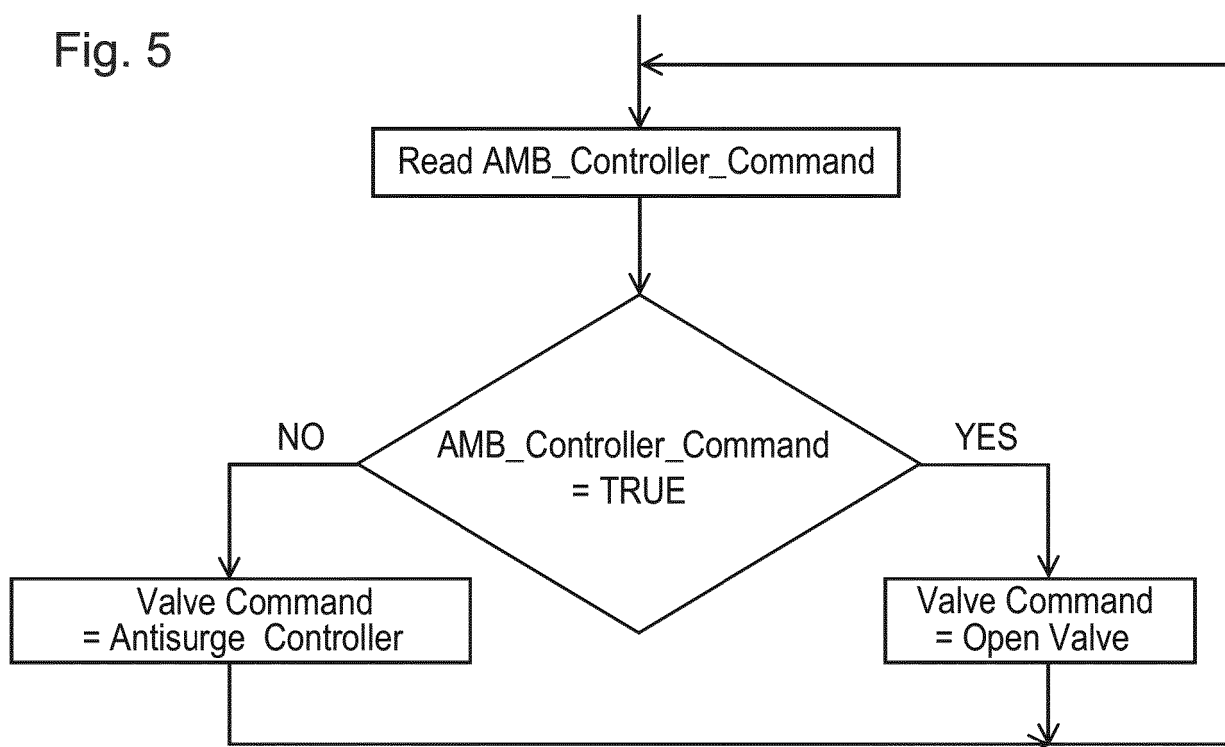


Fig. 6

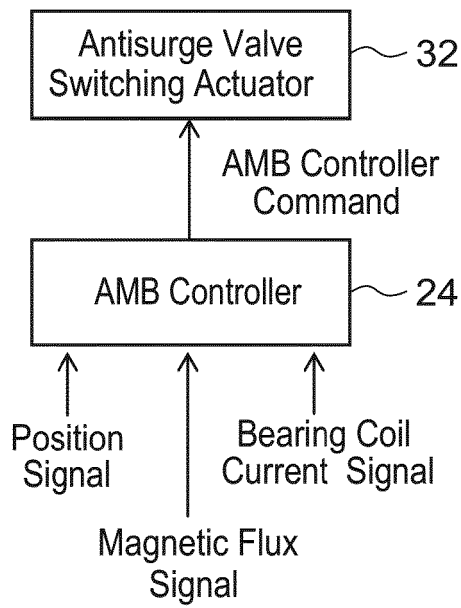
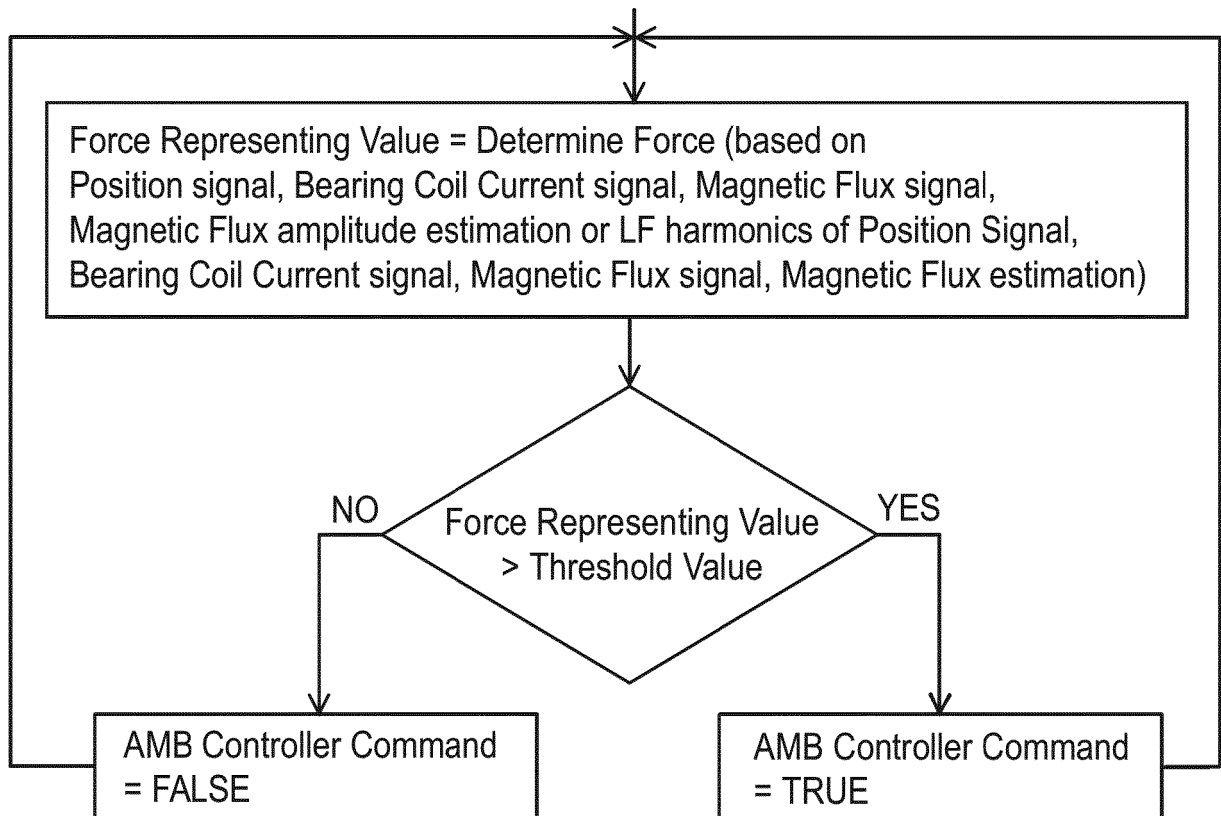


Fig. 7



REFERENCES CITED IN THE DESCRIPTION

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