Title: FAULT TOLERANT POWER SUPPLY FOR ACTIVE MAGNETIC BEARING

Abstract: The invention provides a rotating machine, such as a subsea pressure boosting compressor or pump, a subsea motor-generator set or a power generator, the machine comprises at least one rotating shaft with at least one active magnetic bearing operatively arranged to a power supply and control system, distinctive in that the rotating machine comprises a power generating means arranged in order to generate and supply power to the active magnetic bearing and control system in a situation of a failure or shutdown of the ordinary active magnetic bearing power supply.
FIELD OF THE INVENTION

The invention relates to rotating machinery such as subsea compressors, multiphase pumps, single phase pumps and motor-generator sets. More specifically, the invention relates to active magnetic bearings arranged in rotating machinery, particularly subsea equipment of the above-mentioned types.

BACKGROUND OF THE INVENTION AND PRIOR ART

Active magnetic bearings can be arranged in rotating machinery in order to have a rotating shaft or another rotating member to rotate contactless on a magnetic field. Active magnetic bearings have advantage in providing very low friction, thereby reducing frictional losses and heat generation, which increases the efficiency of the rotating machinery and allows for a reduction or elimination of utility or support systems. For example, a lubrication oil system for lubricating bearings can be eliminated or reduced. For subsea applications a long supply chain, often tens of kilometers or even more than hundred kilometers away, can thereby be eliminated or reduced.

However, active magnetic bearings require a complex and comprehensive control system and a reliable power supply, particularly for large, expensive subsea equipment for which there is virtually no room for failure without dramatic or very expensive consequences.

If the magnetic bearings fail, for example due to power supply breakage or control system failure, the rotating equipment will very soon be out of function unless contingency or safety systems are included. Currently, a separate local UPS (Uninterruptible Power Supply) containing batteries is usually provided. However, batteries age with time and may require frequent replacement, which can be very expensive, and they may still not be able to support the load when required. Also, the rotating machinery may comprise secondary bearings as
safety bearings, however, these typically have a very limited service life and may withstand only one or a few "hard landings" of the rotating shaft.

A separate 3-phase AC power supply is according to current solutions connected to the magnetic bearings, via a dedicated UPS, a rectifier and the Active Magnetic Bearing (AMB) control amplifier.

A demand exists for better solutions in order to protect the rotating parts of rotating machinery, particularly critical subsea equipment having virtually no room for failure, which equipment can be located far out at deep waters.

Summary of the invention
The invention provides a rotating machine, such as a subsea pressure boosting compressor or pump, a subsea motor-generator set or a power generator, the machine comprises at least one rotating shaft with at least one active magnetic bearing operatively arranged to a power supply and control system, distinctive in that the rotating machine comprises a power generating means arranged in order to generate and supply power to the active magnetic bearing and control system in a situation of a failure or shutdown of the ordinary active magnetic bearing power supply.

The invention is particularly relevant for subsea pressure boosting equipment having magnetic bearings, such as compressors, multiphase pumps and pumps, and power generator sets and step up devices for long subsea step outs or long subsea AC power cable crossing. However, the invention is relevant for any rotating equipment having active magnetic bearings, particularly remotely located or difficult to access equipment for which a very low or negligible friction is crucial, such as windmill power generators and hydropower plants.

The essential part of the invention is recuperating rotational kinetic energy in order to provide a safe landing on safety bearings in a situation of failure, breakdown or shutdown of the active magnetic bearing power supply for any reason when the rotating machine is in rotation and the rotating shaft is
suspended in an active magnetic field by the active magnetic bearings. The power generating means is adapted so as to generate and supply power to the active magnetic bearing and control system in a situation of a failure or shutdown of the ordinary active magnetic bearing power supply at least until the rotation has reduced to a manageable level for the backup bearing surfaces, or until the rotation has stopped.

In a preferable embodiment of the invention the rotating machine comprises an electric motor operatively connected to a two quadrant operable variable speed drive (VSD) able to generate electric power when required, the VSD is connected via a control unit to a rectifier, the rectifier is a part of an ordinary active magnetic bearing power supply as it is connected directly to an input 3 phase AC normal power supply and an output active magnetic bearing (AMB) control amplifier which further is connected operatively to the active magnetic bearings. This embodiment is relevant for motors operated by a single quadrant VSD or similar in normal operation. However, in a situation of breakdown of power to the active magnetic bearings, the VSD switches from motor operation mode, that is 1st quadrant operation, to generator operation mode, that is 2nd quadrant operation.

In a different preferable embodiment, the rotating machine of the invention comprises an electric generator separate from or integrated within the primary rotating machine, operatively connected to the magnetic bearing power supply and control system. In one embodiment the electric generator is arranged on the motor shaft or a pump shaft, for recuperating rotation energy into electrical energy in order to supply the energy, via a control unit to a rectifier, the rectifier is a part of an ordinary active magnetic bearing power supply as it is connected directly to an input 3 phase AC normal power supply and an output active magnetic bearing (AMB) control amplifier which further is connected operatively to the active magnetic bearings.

In a further embodiment the rotating machine of the invention comprises an electric generator operatively connected to a control unit which is connected to a rectifier, the rectifier is a part of an ordinary active magnetic bearing power
supply as it is connected directly to an input 3 phase AC normal power supply and an output active magnetic bearing (AMB) control amplifier which further is connected operatively to the active magnetic bearings. This embodiment is relevant for windmills, hydroelectric power plants and other rotating equipment which may have active magnetic bearings.

The invention also provides a method of providing power supply to a rotating machine active magnetic bearings, particularly a subsea rotating machine, distinctive by recuperating kinetic rotational energy of the rotating machine in order to generate electric power for operation of the active magnetic bearings, by arranging a power generating means so as to generate and supply power to the active magnetic bearing and control system in a situation of a failure or shutdown of an ordinary active magnetic bearing power supply.

In a preferable embodiment of the method, electric energy is generated by arranging a generator on a shaft of the rotating machinery and arranging connections and control devices so as to provide power and control for operation of the active magnetic bearings. This embodiment can be used for virtually any rotating machine.

In another preferable embodiment of the method, electric energy is generated by arranging an electric motor of the rotating machinery operatively to a two quadrant operable variable speed drive (VSD) in order to generate electric power, connecting the VSD via a control unit to a rectifier, the rectifier is connected directly to an input 3 phase AC normal power supply and an output active magnetic bearing (AMB) control amplifier which further is connected operatively to the active magnetic bearings. This embodiment is useful for any motor operated by a VSD or similar device, which VSD or device can switch over to or be adapted to operation in generator mode with the motor.

The power generating means of the machine and method and use of the invention, preferably comprises at least one of an electric motor and an electric generator. Recuperation of rotational kinetic energy is how the power is
generated, using a generator or a motor, the motor can be in addition to the rotating machine motor or be integrated therein.

The invention also provides use of an electric motor of a subsea rotating machine, for generating electric power to active magnetic bearings in a situation with failure or shutdown of an ordinary active magnetic bearing power supply.

In addition, the invention provides use of an electric generator in a subsea rotating machine, for generating electric power to active magnetic bearings in a situation with failure or shutdown of an ordinary active magnetic bearing power supply.

**Figures**

The invention is illustrated with six figures, of which

- Figure 1 illustrates a current system, not of the invention, with a subsea pump with active magnetic bearings and a local VSD,
- Figure 2 illustrates a system of the invention, with a subsea pump with active magnetic bearings and a local VSD,
- Figure 3 illustrates a current system, not of the invention, with a subsea pump with active magnetic bearings and a remote VSD,
- Figure 4 illustrates a system of the invention, with a subsea pump with active magnetic bearings and a remote VSD,
- Figure 5 illustrates detail of the current system, not of the invention, of a subsea motor-compressor set with active magnetic bearings, and
- Figure 6 illustrates a system of the invention, with a subsea motor-generator set with active magnetic bearings, for long subsea step-out.

**Detailed description**

Reference is first made to Figures 1 and 2, illustrating similar systems but according to prior art, that is Figure 1, and according to the invention, that is Figure 2. More specifically, a subsea pump with active magnetic bearings and a local VSD are illustrated in both figures. A three phase AC power supply provides power to a single quadrant variable speed drive (VSD), for operation of the electric motor of a pump, compressor or generator set. In this illustration the
pump is connected to the motor via a common shaft, the pump receives a
process fluid input and delivers a process fluid output at higher pressure. The
shaft of the motor and pump rotates on active magnetic bearings, as illustrated
by three x-y radial active magnetic bearings and one z axial active magnetic
bearing on the figure. More specifically, the active magnetic bearings are
connected to and controlled by an AMB (active magnetic bearing) control
amplifier, in the illustrated embodiment according to Figure 5, a 7 axis control
system is provided (3 times x-y + one z). The AMB control amplifier is supplied
DC from a rectifier which via a dedicated UPS (uninterruptible power supply) is
connected to a separate 3 phase AC power supply. In a situation of interrupted
power supply to the bearings, the UPS provides the power as required.
However, this is a solution that may not be reliable over time, due to battery
faults. More specifically, Fig. 1 illustrates a prior art machine or system, not of
the invention comprising a rotating machine (20) utilising active magnetic
bearings; external power sources (21 & 25); local power backup (23); bearing
control unit (24); local VSD (26) designed for single quadrant operation (motor
drive only).

Reference is made to Figure 2, illustrating in principle the same motor and
pump as for Fig. 1 but adapted according to the present invention. More
specifically, kinetic rotational energy is recuperated in order to provide energy
for control and operation of the active magnetic bearing. To this end, the motor
operation is changed from a motor mode of operation to a generator mode of
operation, by shifting the VSD from a single quadrant mode of operation to a
two quadrant mode of operation whilst also connecting the VSD to the rectifier
of the active magnetic bearing rectifier via a control unit. A connection from the
DC bus of the pump power supply to the control unit is also provided, for further
contingency. In a situation of a breakage or shutdown of the ordinary active
magnetic bearing power supply, power is generated by the motor while the
motor is spinning until the rotational speed drops below a minimum for
generation. The generated power is supplied via the VSD to the control unit and
further to the active magnetic bearing rectifier. Thereby power and control of the
active magnetic bearings are provided when needed, that is when the shaft is
still rotating. The additional control system shall detect a failure of the supply to
the bearing control unit (24) and switch to using power from the motor drive DC
bus. In the event of complete failure of the 3-phase supply, the control system
shall cause the main motor drive to switch from motoring to generating mode.
Recuperated energy from the system inertia will be used to provide power to the
magnetic bearing system, preventing potential damage from a 'hard landing' of
the rotating assembly. More specifically, Fig. 2 illustrates a rotating machine
(20) of the invention, utilising active magnetic bearings; external power sources
(21 & 25); bearing control unit (24); local VSD (27) designed for two quadrant
operation (motoring and generating).

Reference is then made to Figures 3 and 4, illustrating similar subsea pumps
with active magnetic bearings and a remote VSD. Figure 3 illustrates a current
solution, not of the invention, with ordinary active magnetic bearing power and
control system as described above, with a rotating machine (20) utilising active
magnetic bearings; driven from a remote variable speed drive (28). To the
contrary, Figure 4 illustrates an embodiment of the present invention as
implemented for the pump, for recuperating rotational kinetic energy for power
and control for the active magnetic bearing in case of failure or breakdown of
the ordinary supply. More specifically, Fig. 4 illustrates a rotating machine (20)
with internal generator unit (26); local generator control unit (29). Accordingly,
an auxiliary generator is arranged to or on the motor-pump shaft for
recuperating energy when required. The power generated is supplied via a
control unit to the rectifier of the active magnetic bearing power supply. The
additional small generator is only active in the event of a failure of the ordinary
AC supply, which is monitored by the additional control unit. Recuperated
energy from the system inertia will be used to provide power to the magnetic
bearing system, preventing potential damage from a 'hard landing' of the
rotating assembly. This implementation provides complete isolation of the
electrical system if required. Note that the internal generator unit (26) can be
implemented by integrating the generator windings within the main motor
windings and using the same rotor assembly, which represents a preferred embodiment of the present invention.

Fig. 5 is a detailed view of a typical rotating machine assembly showing sealed motor (12) and compressor unit (14), the rotating component supported by three two-axis radial active magnetic bearings (11, 15, 16) and one one-axis axial active magnetic bearing (13). The motor is driven from a three-phase supply (p1, 2, 3); the compressor receives process input (17) and delivers process output (18).

Further reference is made to Figure 6, illustrating a rotating machine of the invention, with active magnetic bearings, for long subsea step-out. More specifically, Figure 6 illustrates an embodiment of the present invention as implemented for the motor-generator set, for recuperating rotational kinetic energy for power and control for the active magnetic bearings in case of disconnection or failure of other supplies. A subsea motor-generator set (20) for long step-out power distribution is illustrated; with a local power controller (29) supplying power to local systems (30) and supporting AMB controller (24) in the event of power failure from remote supplies (21 & 28). Accordingly, the generator is connected via a control unit to the active magnetic bearing controller. In this application the new control system will redirect power from the generator to the magnetic bearing. In the event of a failure of the main supply, recuperated energy from the system inertia will be used to provide power to the magnetic bearing system, preventing potential damage from a 'hard landing' of the rotating assembly.

The rotating machine of the invention can comprise any features described or illustrated in this document, in any operative combination, each such operative combination is an embodiment of the invention. The method of the invention can comprise any features or steps described or illustrated in this document, in
any operative combination, each such operative combination is an embodiment of the invention.
CLAIMS

1. Rotating machine, such as a subsea pressure boosting compressor or pump, a subsea motor-generator set or a power generator, the machine comprises at least one rotating shaft with at least one active magnetic bearing operatively arranged to a power supply and control system, characterised in that the rotating machine comprises a power generating means arranged in order to generate and supply power to the active magnetic bearing and control system in a situation of a failure or shutdown of the ordinary active magnetic bearing power supply.

2. Rotating machine according to claim 1, comprising an electric motor operatively connected to a two quadrant operable variable speed / frequency drive (VSD, VFD) in order to generate electric power when required, the VSD is connected via a control unit to a rectifier, the rectifier is a part of an ordinary active magnetic bearing power supply as it is connected directly to an input 3 phase AC normal power supply and an output active magnetic bearing (AMB) control amplifier which further is connected operatively to the active magnetic bearings.

3. Rotating machine according to claim 1, comprising an electric generator arranged on a rotating shaft, operatively connected to the magnetic bearing power supply and control system.

4. Rotating machine according to claim 3, wherein the electric generator is arranged on the motor shaft or a pump shaft, for recuperating rotating energy into electrical energy in order to supply the energy, via a control unit to a rectifier, the rectifier is a part of an ordinary active magnetic bearing power supply as it is connected directly to an input 3 phase AC normal power supply
and an output active magnetic bearing (AMB) control amplifier which further is
connected operatively to the active magnetic bearings.

5.
5. Rotating machine according to claim 1, comprising an electric generator
operatively connected to a control unit which is connected to a rectifier, the
rectifier is a part of an ordinary active magnetic bearing power supply as it is
connected directly to an input 3 phase AC normal power supply and an output
active magnetic bearing (AMB) control amplifier which further is connected
operatively to the active magnetic bearings.

6.
6. Method of providing power supply to a subsea rotating machine active magnetic
bearings, characterised by recuperating kinetic rotational energy of
the rotating machine in order to generate electric power for operation of the
active magnetic bearings, by arranging a power generating means so as to
generate and supply power to the active magnetic bearing and control system in
a situation of a failure or shutdown of an ordinary active magnetic bearing
power supply.

7.
7. Method according to claim 6, whereby electric energy is generated by arranging
a generator on a shaft of the rotating machinery and arranging connections and
control devices so as to provide power and control for operation of the active
magnetic bearings.

8.
8. Method according to claim 6, whereby electric energy is generated by arranging
an electric motor of the rotating machinery operatively to a two quadrant
operable variable speed / frequency drive (VSD, VFD) in order to generate
electric power, connecting the VFD via a control unit to the active magnetic
bearing control amplifier, reusing the rectifier stage of the standard power
supply if required, the rectifier is normally connected directly to an input 3 phase
AC normal power supply and an output active magnetic bearing (AMB) control amplifier which further is connected operatively to the active magnetic bearings.

9. Use of an electric motor of a subsea rotating machine, for generating electric power to support active magnetic bearings in a situation of failure, breakage or shutdown of the normal active magnetic bearing power supply.

10. Use of an electric generator in a subsea rotating machine, for generating electric power to support active magnetic bearings in a situation of failure, breakage or shutdown of the normal active magnetic bearing power supply.
INTERNATIONAL SEARCH REPORT

International application No.
PCT/NO2014/000034

A. CLASSIFICATION OF SUBJECT MATTER
F04D 29/048 (2006.01), F04D 29/058 (2006.0 1), F16C 32/04 (2006.01), H02K 7/09 (2006.01)
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
F04D, F16C, H02K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
DK, NO, SE, Ft Classes as above.

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPDOC, WPJ, FULDTEKST: ENGELSK, TYSK, FRANSK

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Date of the actual completion of the international search
22/08/2014

Date of mailing of the international search report
25/08/2014

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