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AODD pumps are the workhorse of choice for oil and gas operators

Getting into position

Use of independent position transmitters can improve the performance of a control loop

Magnetic bearings installed at Europe's largest natural gas field have resulted in 99.9% availability

May the magnetic force be with you

Groningen, Europe's largest natural gas field, was discovered in 1959. Production began in 1963, and by the end of the decade nearly 50% of the field's reserves were depleted with free-flow operation. Nederlandse Aardolie Maatschappij (NAM), a joint venture between Royal Dutch Shell and ExxonMobil, was created in the mid-1990s to find the most cost-effective way to extract gas from the field and extend the life of its reserves.

By upgrading the field's equipment, including installation of motors and compressors, the field could supply gas to all of the Netherlands, Germany, and Belgium for an additional 40 years. The challenge was to achieve at least 87% availability and a low total cost of ownership.

Magnetic bearings are a proven technology for large standalone motor compressor strings, like the ones at Groningen, to provide both high availability and a low total cost of ownership, as well as lower power consumption (due to decreased rotating losses), lower maintenance costs, and lower CAPEX costs compared to conventional bearings.

Operating principles of magnetic bearings

Magnetic bearings maintain levitation of a machine shaft using electromagnets, which apply controlled attractive forces to the shaft. A schematic of a typical configuration for control of 1° of freedom is shown in figure 1. The actuators for the radial and thrust magnetic bearings comprise stationary electromagnets mounted to the machine housing, and rotor sleeves and disks mounted to the machine shaft. The typical system has two

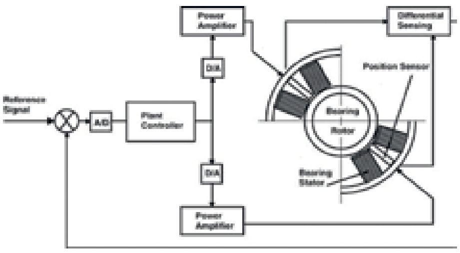

Figure 1: Schematic of a typical active magnetic bearing configuration for control of 1° of freedom

radial bearings and one thrust bearing. With this system, a rotating shaft can be held in stable levitation with control of 5° of freedom, with 2° of freedom controlled by each radial bearing, and 1° of freedom controlled by the thrust bearing.

Each actuator is paired with a position sensor, which is mounted in a housing adjacent to the actuator and measures the position of the shaft. The shaft position is used as a feedback signal to the magnetic bearing controller. A control algorithm is applied to the position signal in the digital controller and generates a demand signal for the power amplifiers when the shaft position changes. In response, the power amplifiers change the current in the electromagnets, creating forces on the rotor to pull the shaft back into a perfectly centred position.

The position sensors can also be used to monitor machine vibrations, eliminating the need for a separate vibration monitoring system. With the position sensors and bearing currents as inputs, the digital controller can be programmed to act as a condition monitoring system, trending vibration levels and bearing forces.

Since the active magnetic bearing (AMB) system contains actuators that can excite the dynamics of the machine shaft and sensors that can measure the resulting response, the AMB system can be used to measure the dynamics of the rotor/bearing system at zero speed. This is a significant advantage for magnetic bearings compared to fluid film bearings, as the data can be used to predict the

Figure 2: Inside a digital control cabinet for an active magnetic bearing system

vibration characteristics of the machine before it is put into operation. This can save valuable time on the test stand and increase the reliability of the machine, since any anomalies in the assembled machine that would have caused vibration problems can be corrected before the machine is tested or placed in operation.

While the actuators and sensors are located within the machine casing, the digital controller and the power amplifiers are contained in a cabinet (figure 2) located in a control or switchgear room. The power to the magnetic bearing system is backed up by an uninterruptable power supply (UPS), so levitation is maintained during any site power failures. An auxiliary bearing system supports the machine shaft when the AMB system is switched off or if the magnetic bearings are overloaded during operation.

Auxiliary bearings are almost never utilised but are critical to a robust AMB system. They are available in two primary designs: rolling element and bushing style. Rolling element auxiliary bearings have angular-contact ball bearings either mounted on the shaft of the machine or fixed to the stator housing of the bearing. The shaft-mounted design and the stator-mounted design each offer optimum characteristics for certain applications.

Bushing-style auxiliary bearings, such as the patented Rotor Delevitation System (RDS) bearings (figure 3) from magnetic bearing supplier Waukesha Magnetic Bearings (WMB), a Dover company, typically use an articulated multi-pad plain bearing which makes contact with a metallic landing sleeve protecting the rotor. The plain bearing is fixed to the machine casing, while the landing sleeve is fixed to the shaft. The pad material

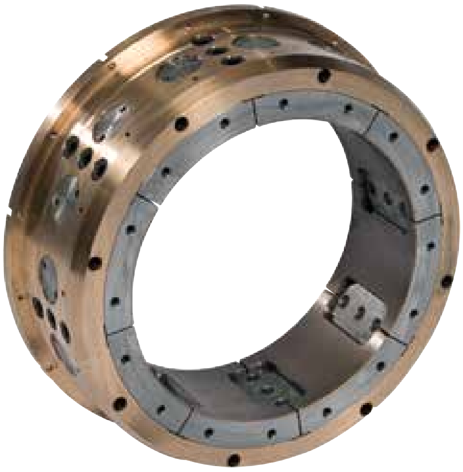

Figure 3: RDS radial auxiliary bearing

Figure 4: The Zephyr (top), Chinook (left) and Elephanta (right) magnetic bearing control cabinets from Waukesha Magnetic Bearings

has embedded dry lubricants, eliminating maintenance. An engineered matching of materials for the stator pad lining and the rotor landing sleeve surface yields an optimum sliding coefficient of friction to maintain good rotordynamic performance.

Designed for performance

The design practice for applying magnetic bearings to specific machine applications is a mature process, with guidelines provided in new sections of API Standard 617. The process follows an outline similar to the application of conventional bearings, but there are some distinct design tasks for magnetic bearing systems. First, two bearing systems must be designed, the magnetic bearings and the auxiliary bearings. Second, a control system analysis and a transient analysis for the auxiliary bearing landing event must be included in the rotordynamic analysis. Finally, a control cabinet must be selected.

As would be expected, larger machines with heavier rotors require larger magnetic bearings. Larger magnetic bearings require higher power amplifiers to maintain good dynamic performance. The line of control cabinets (figure 4) from WMB – based in Worthington, UK – accommodates machine power ratings ranging from 50MW to less than 1MW and rotor masses ranging from more than 9 tonnes to less than 50kg. The controllers all allow for remote monitoring and diagnostics and can be fully automated to allow remote startups.

The natural gas compression equipment at the Groningen field (figure 5) uses 23MW of electric power to drive a flexible compressor rotor and extract the gas from the underground wells. High reliability and energy efficiency are required across a wide compressor speed range, with minimal vibration and noise.

When WMB joined the Groningen project, it set out to solve a problem that had generally been deemed impossible because of the wide speed range involving several critical rotor speeds. In fact, NAM was told 'it cannot be done' by the other manufacturers it approached.

WMB partnered with Siemens to install three radial active magnetic bearings for the motor, two radial and one thrust active magnetic bearing on the compressor, and a digital controller with analogue amplifiers. The robust bushing-style auxiliary bearings were selected for higher investment protection and they provided the added benefit of remote condition observability.

There are a total of 20 AMB-equipped motor compressor strings at the Groningen field, and magnetic bearings from WMB have been installed in each of them. Although the machines have varied significantly in the number of stages, hence the dynamics of the rotor, the bearing hardware has remained the same on each. WMB was able to adjust for the different rotordynamics through software changes in the controllers.

The financial case

Compared to conventional oil-lubricated bearings, the magnetic bearing solution, despite a seemingly higher bearing-to-bearing comparison cost, is a less expensive investment and yields a lower total cost of ownership. Several application configurations were analysed for the Groningen field: a gas turbine drive and compressor with oil-lubricated bearings, an electric motor drive and compressor with oil-lubricated bearings, and an electric motor drive and compressor with magnetic bearings. The magnetic bearing solution offers significant savings in both the initial investment and operating costs, especially when multiplied by 20 installations.

Using an electric motor drive instead of a gas turbine eliminated emissions and noise concerns, and the removal of oil lubrication also did away with the need for additional building construction to house the lubrication system. This reduced costs and provided a simpler, cleaner, more efficient design to lessen the environmental footprint.

Figure 5: NAM motor (right) and compressor bundle (left) being installed at the Groningen site

Performance in the field

NAM's original goal was to provide 87% availability with the lowest total cost of ownership. Analysing the results after 17 years, the magnetic bearings from WMB exceeded expectations, providing over 99.9% availability and an investment cost savings of 35%, all the while saving on energy costs.

'In the end it is the performance that counts and when I look at the performance, it is amazing,' says Wim de Groot, retired rotating equipment engineer, NAM GLT. The success of the magnetic bearing systems for NAM GLT was so great that it prompted seven other sites in the region to adopt similar systems from WMB.

Magnetic bearing systems are able to accommodate a wide variety of rotating equipment, so applications other than large natural gas fields can reap the benefits of magnetic bearing technology. Depending on the application, magnetic bearings can increase efficiency, improve safety, decrease the total cost of ownership, reduce maintenance, provide enabling technology for paradigm shifts, and eliminate fluid lubrication. Magnetic bearings have achieved high availability, cost savings, and environmentally responsible operation in steam turbines, generators, turbo-expanders, pumps, blowers, compressors, and motors in natural gas production and pipelines, oil fields, the chemical industry, the refrigeration industry, and more.

For more information:
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