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Back to Basics — Why Magnetic Bearings Have Problems

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For many years, I have said that magnetic bearings are a good concept, but their use would be limited to some very specialized applications. Several machines fitted with magnetic bearings have had them removed. While it is true that the U.S. Air Force and NASA are still funding magnetic bearing research, this research applies to very specialized applications with little or no practical application for turbomachinery. Consequently, magnetic bearings will not be a major factor in the design of turbomachinery for the 21st century.

Major machinery manufacturers have been advised by their rotordynamic specialists to avoid significant costs trying to develop successful magnetic bearings.

There are two principal problems with magnetic bearings.

First, the available direct stiffness is severely limited because the laminated permeable core of the shaft is limited.

Secondly, the default for such a bearing is some kind of backup bearing, which, on loss of electric energy or fault of the control system, cannot provide adequate direct damping and quadrature dynamic stiffness in order to prevent machine damage on shutdown.

Let’s take a few minutes and look in more detail at these, and other issues, with magnetic bearings.

1. Weakness–Excessive Heat

Heat is generated by magnetic bearings by two primary mechanisms. First there are eddy current losses in the stator core and rotor laminations. (Refer to Figure 1.)

As the excitation magnetic field varies quickly, the effect of currents induced in ferromagnetic materials will become significant. These currents are known as the ***eddy currents*** and the power loss generated is known as the ***eddy current loss***. The red line in Fig. 1 represents the ideal case as it would appear if there were no power losses. Since the ideal case violates the second law of thermodynamics (entropy) it will never occur in nature and the resultant *B-H* loop will be fatter than the corresponding pure hysteresis loop (red line). With a sinusoidal magnetic flux density, the average eddy current loss in a magnetic core can be expressed by:

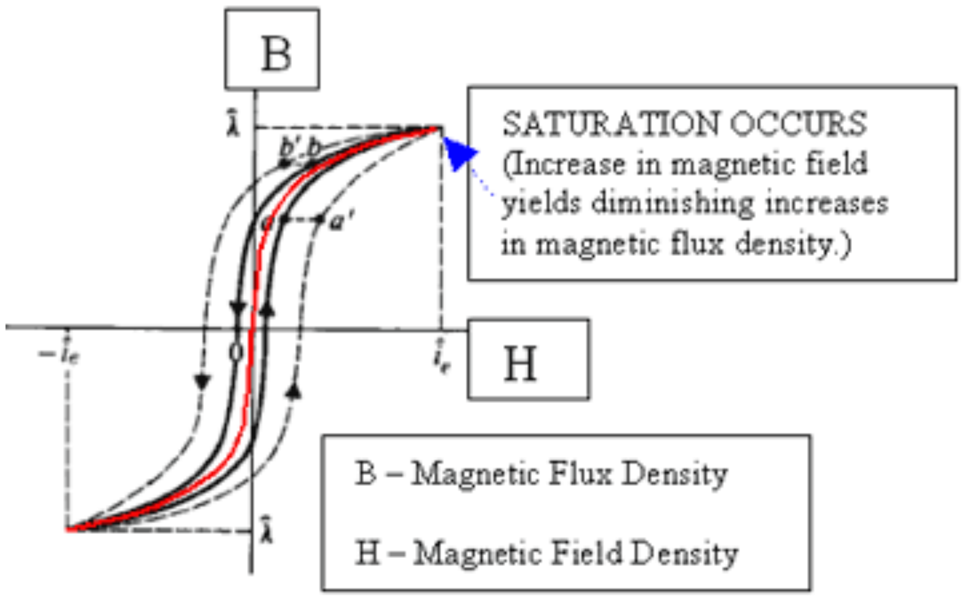

Figure 1

$$\boxed{P_{eddy} = C_e\left(fB_p\right)^2}$$

The resulting heat buildup can cause a number of problems:

Eddy currents are generated in the surface of the stator core and the rotor by the alternating magnetic field and flow in closed paths. Since the paths are resistive, the currents generate heat in the core of the rotor. In an attempt to minimize eddy current losses, modified or new rotors are used that have a continuous spiral of a thin steel lamination in the bearing areas. This generates the additional problem of a unique, matched rotor / bearing system.

- **The heat may eventually destroy the active magnetic bearings, by breaking down the coil insulation and causing electrical short circuits.**

This second heating source comes from the wire resistance in the wound coils. Since normal copper wire has a resistivity that increases with temperature, heating can spiral *out of control* if there is not way to remove the unwanted heat.

- **Inability to "Carry the Load" due to heat generation.**

Large radial or thrust loads in conjunction with the eddy current losses discussed previously, become significant limitations of the magnetic bearing's ability to "carry the load", often resulting in a unit trip due to excessive shaft eccentricity position within the bearing.

The magnetic bearing promise of a "fluid-less bearing system" is often not realized in practice. Many machine users and OEMs are led to believe in elevated reliability claims because magnetic bearing technology eliminates the lubrication system. This potential provides for a wear-free system, thus forecasting longer planned overhaul and maintenance intervals. However, by eliminating fluid lubrication, the ability to remove heat in the bearing region is greatly reduced. There have been cases with magnetic bearings where the flow of coolant gas (typically air) was not enough to control the heat buildup within the bearing, and additional water sprays were required in order to keep the magnetic bearings from failing.

2. Weakness-Limited Fault Protection

When a magnetic bearing system fails for any reason, the rotor and stator could rub. Machines with magnetic bearings always will have some sort of auxiliary (sometimes referred to as a *back up* or *catcher bearing*) bearings installed. Typically, these are rolling element bearings which can create their own set of problems.

- **Placement of the backup bearings can change the machine's rotordynamic behavior.**

Backup bearings are placed outboard of the magnetic bearings, which changes the natural frequencies of the rotor/bearing system when a fault occurs and the rotor drops on to the backup bearings. Consequently, during a "fault" induced shutdown, the rotor's radial displacement may be greater than predicted due to the inherent lack of direct damping in a rolling element bearing.

Pressurized bearings, in contrast, have the inherent benefit of damping. Consequently, the purported savings due to the elimination of the lube oil system may (and often is) more than offset by the increased maintenance costs of maintaining the rotor / bearing system itself.

- **Very limited life of the backup bearing system**

The clearances between the rotor and the inner race of the backup bearing are, by design, large by normal rolling element bearing standards. When the magnetic bearing fails, the backup bearing literally has to "catch up", in speed, to the rotor in a matter of milliseconds. Often, the rotor will bounce around within the clearance boundary of the bearing as it "catches up". The backup bearings can only sustain a limited number of uses before they have to be replaced. Although the number of "rundowns" that a backup bearing can tolerate varies, to some degree, with design, it is not uncommon to find that they can sustain no more that 5 emergency shutdowns before having to be replaced. Once again, the increased maintenance costs may more than offset the initial goal of eliminating the lubrication system.

3. Weakness-Inadequate Direct Stiffness

A significant limitation of the magnetic bearing is its relatively low direct stiffness, which is considerably less than a standard hydronamic bearing, and much less than an externally pressurized bearing. Since the magnetic force is a function of the air gap, the problem compounds when the clearance is increased in order to accommodate the backup bearings. This can result in both design and operating problems.

- **The surface area of the magnetic bearing must be large to support the load**

Magnetic bearings have significantly larger diameters and lengths than a fluid bearing. The differences can be visualized by comparing the load carrying capability of the two. Typically, magnetic bearings are limited to a load of 60 lb_f/in^2, (40 N/cm^2), while both externally pressurized bearings and a typical hydrodynamic bearing are capable of loads in excess of 450 lb_f/in^2, (300 N/cm^2). Therefore, magnetic bearings are very poor choices for machines with either high radial or thrust loads.

4. Weakness–Energy Consumption

Some of the advantages claimed for magnetic bearings are that they are extremely reliable, do not need mechanical maintenance, consume very little energy, and continuously monitor the machine behavior. All of these claims have performance and reliability shortcomings.

- **Energy consumption**

Let's review the claim that a magnetic bearing consumes very little energy. A particular bearing application requires a certain amount of power to support the load and react to dynamic changes. The amount of power required is comparable, whether it is a fluid bearing or a magnetic bearing. A fluid bearing does require additional energy to overcome mechanical losses due to friction. However, this can be greatly minimized by the use of a properly designed externally pressurized bearing. Therefore, the real comparison is between the additional electrical energy needed by the magnetic bearing versus the energy used by pumps that provide the fluid to an externally pressurized bearing.

Conclusions

Magnetic bearings have serious weaknesses that limit their capability. In some cases, they simply are not as good as 20th century hydrodynamic bearing technology. They have not met manufacturers' promises or end users' expectations. They are ***very expensive***, in terms of initial capital investment, maintainability, and operation. Companies have installed magnetic bearings and tried to make them work. Usually, with time, they have become disillusioned and dropped the technology. The technology simply lacks the robustness required by end users.

However, there is a vastly improved answer that provides exceptional performance. The ***Externally Pressurized Bearing***, THE bearing technology of the 21st century, includes clearly stated performance specifications that are determined by control theory. The EPB will revolutionize machine design. Currently, our ongoing work with both Southern California Edison and British Petroleum (Carson Refinery) are significant examples of our future success in the marketplace.