Magnetic bearings: an update

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Using magnetism to support a shaft within a bearing is an old concept, but it has been put to practical use only in the past 15 years. Now that it has, radically different, magnetic bearings are resulting.


Demonstrator magnetic bearing system by Waukesha Bearings, with digital electronic control and diagnostic equipment.

Originally, magnetic bearing development was done under government research grants for exotic aerospace applications. Later, companies developed the bearings for use by private industry in large custom pieces of turbomachinery. After refining bearings through these efforts, manufacturers are now on the verge of offering standardized, mass-produced magnetic bearings.

The principle behind magnetic bearings is simple: Magnets radially surrounding a shaft levitate the shaft and let it spin in air. It's easy to see there are a multitude of benefits to this.

But because of high cost, the bearings haven't been feasible to date — conventional bearings are still cheaper. Most of the cost is in the controls and the magnets themselves. As technology improves, and acceptance and quantities increase, costs should drop to where magnetic bearings are competitive with conventional ones.

A small group of companies is involved in development and manufacture of magnetic bearings. They're mostly small, R&D-oriented, high-technology firms, and they come from various backgrounds. Presently, the major players are: Advanced Controls Technology (Avcon Inc.), Agoura Hills, Calif.; SatCon Technology Corp., Cambridge, Mass.; Magnetic Bearings Inc. (MBI), Radford, Va.; Mechanical Technology Inc. (MTI), Latham, N.Y.; and Waukesha Bearings Corp., Waukesha, Wis. A few others have come and gone in recent years, and the market continues to shake out. Avcon and MTI have been around longest — since the 1970s.

Avcon was formed on the basis of its expertise in magnetics. Under NASA and Air Force contracts, it has developed magnetic bearings for jet aircraft engines and a cryogenic fuel pump on the space shuttle.

SatCon specializes in active motion control, a larger field which includes magnetic bearings, and was formed by a group of scientists and engineers from MIT. It also has developed bearings for NASA and the military, for refrigeration compressors.

MBI was formed solely to make magnetic bearings. It is partially foreign-owned by the French S2M company, which developed bearings for the French space program in the early 1970s and later licensed the designs to MBI.

MTI comes from a background of producing monitoring, testing, and inspection equipment. Much of this equipment deals with machinery vibration, and the company has extensive experience with turbomachinery.

Waukesha was already a bearing manufacturer, specializing in hydrodynamic bearings for large machinery.

As part of their commercialization, magnetic bearings have been developed for a myriad of common machines including turbines, compressors, machine tools, pumps, and blowers.

MBI and Waukesha have made them for natural gas compressors in pipelines.

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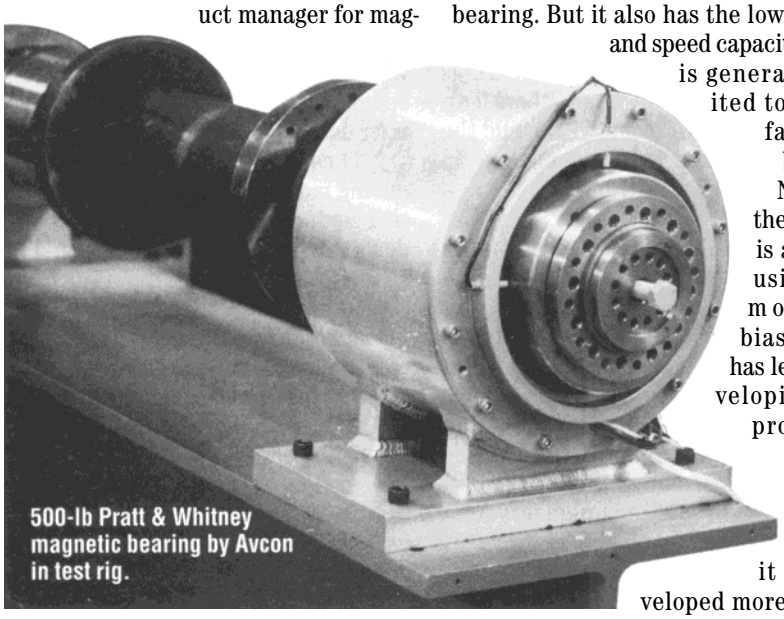
The bearings are more reliable than conventional ones, so they're favored in this application because the compressors are often in remote locations.

Waukesha has also concentrated on magnetic bearings for canned-motor sealless pumps, ranging from 10 to 500 hp. In similar fashion to magnetic-drive pumps, the bearings are sealed, along with the motor, and dynamic shaft seals are eliminated. This greatly reduces leakage and extends pump life.

SatCon sees a big future for its refrigeration compressor bearings in private industry because of the CFC dilemma. Presently, freon is mixed with oil to lubricate compressor bearings. But new refrigerants can't be mixed with oil. With magnetic bearings, there is no oil.

Avcon's bearing designs are being adapted for gas laser fans, printing presses, and data memory devices.

To date, magnetic bearing development has been on a prototype basis only, and manufacturing capacity has been very limited. But most companies are doing what David Weise, Waukesha's product manager for magnetic bearings says his company is: "We're working with customers who have made a commitment to it. It's onesies and twosies for now, with a promise of higher quantities later." Avcon says it is already negotiating production contracts, whereby technology will be licensed to outside manufacturers.



500-lb Pratt & Whitney magnetic bearing by Avcon in test rig.

Basically, a radial magnetic bearing is like conventional bearings in that the shaft rotates inside a ring. Only instead of a sleeve or rolling elements, the ring consists of magnets. The clearance between a centered shaft and bearing is generally 0.015 to 0.020 in. around the periphery. There are three categories of bearing, based on the type of magnets used.

Passive magnetic bearings use permanent magnets. These are unstable in the axial direction and must be used in conjunction with mechanical bearings. They're not very common.

Active bearings use only electromagnets, while hybrids use a combination of permanent and electromagnets.

The reluctance centering hybrid is the simplest and cheapest form of magnetic bearing. But it also has the lowest load and speed capacities, and is generally limited to use on fans and blowers. New on the market is a hybrid using homopolar bias. Avcon has led in developing this promising design, largely because it has developed more-powerful rare-earth permanent magnets. These bearings are lighter, smaller, and more efficient than equivalent all-electromagnet bearings. In this design, permanent magnets levitate the shaft while electromagnets adjust its position under varying load conditions. Avcon claims electrical power consumption is only a few watts when the load is constant, and is overall about 5 W per 100 lb of load.

Magnetic thrust bearings are also available. These use a disc-shaped rotor fixed to the shaft. This disc rotates between two stators, one on either side of the disc.

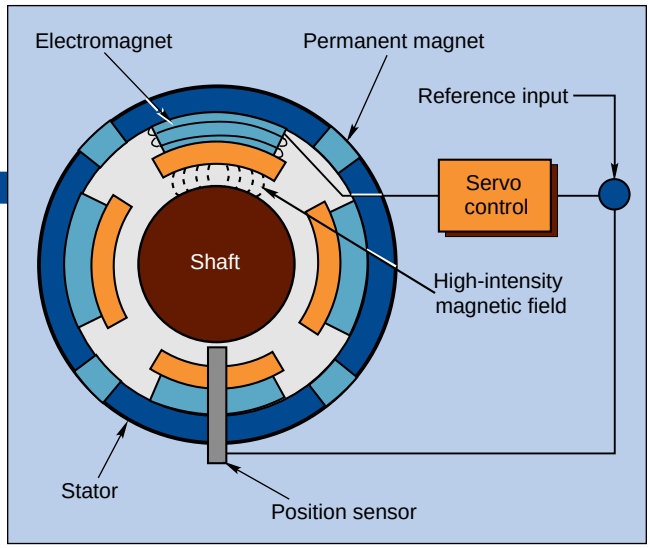
Load capacities of magnetic bearings can be made to match those of conventional bearings.

A typical magnetic bearing system installed on a piece of machinery has a radial bearing at each end of the shaft, just like with conventional bearings, and a thrust bearing at or near one end.

In addition, noncontact proximity sensors are installed at each radial bearing and at the shaft end. The radial-bearing sensors measure shaft displacement in the *X* and *Y* directions; the thrust bearing sensor, axial displacement. Two types of sensors can be used, depending on the operating environment; capacitive and magnetic-field.

Signal outputs from the sensors are fed to electronic servo control amplifiers. Generally, there are five of these; one each for *X* and *Y* directions at both radial bearings, and one for the axial direction. The digital amplifiers use pulse width modulation to compare signals they receive with known values and adjust power to the electromagnets accordingly, to keep the shaft centered. In most applications, electronic controls are in a control-room cabinet away from the machine.

When power is turned off or there's an electrical failure, the shaft comes to rest on mechanical backup bearings. Sleeve



Active bearing basics. Electromagnetic fields support moving parts without contact; servo control system stabilizes suspended element by increasing supporting force in direction opposite that of any displacement, to restore correct position.

or ball bearings are used for this, and there's about 0.02-in. clearance between bearing and shaft, so there's no contact during normal operation.

The biggest advantage of magnetic bearings is near-elimination of friction. Ken Elder, marketing manager at Avcon, says it's estimated to be 1,000 times less than that of conventional bearings. With the new hybrid bearing designs, the power saved from reduced rotating resistance is greater than the power used by the bearings. And with so little friction, there's no need for lubrication.

Also, lack of bearing-to-shaft contact means less wear, heat buildup, and maintenance, and greater reliability and life. Because of reduced heat buildup and fatigue, higher speeds and greater temperature extremes can be accommodated.

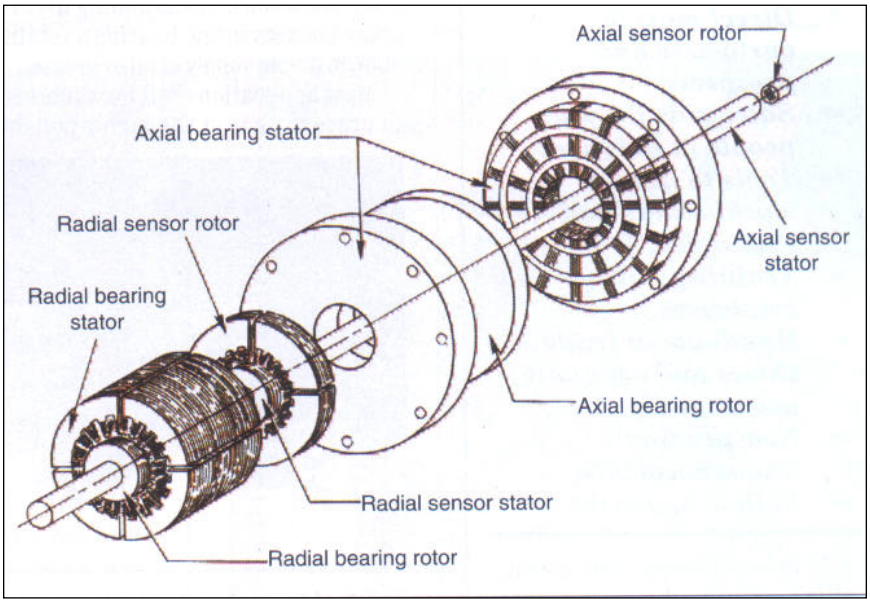
Another big advantage of magnetic bearings is in dealing with shaft vibration caused by rotor imbalance. The rotor's critical speeds can be programmed into the electronic controls so, as the shaft passes through a critical speed, bearing stiffness — in effect, the force holding the shaft centered — is relaxed. The rotor is allowed to rotate about its mass center rather than the shaft's geometric center, resulting in fewer resonant vibrations transmitted to the machine. Also, the shaft sensors can detect unusually excessive vibration, such as that resulting from a turbine-blade break, and the controls can be programmed to stop the machine.

Magnetic bearings can be developed either for new equipment or for retrofitting to existing machinery. For most applications, bearings must be custom-designed. Typically, a bearing manufacturer works with both the owner or end user of a piece of equipment and the OEM who builds it.

The bearing manufacturer will, as Mr. Elder says, first "study and evaluate the customer's design parameters. Then we'll develop models; this can sometimes be quite sophisticated. We do our own rotordynamics analysis on computer. And we can calculate the load. Sometimes the customer doesn't know this." Then the bearing manufacturer will design a system, prototype it, test it in-house, install it in the field and test it there, and train the end user on operating and maintenance procedures.

There's been concern about the complexity of operating machinery with magnetic bearings, but their manufacturers claim that plant personnel can operate them easily once trained.

Looking to the future, Mr. Elder thinks hybrid magnetic bearings will come to dominate the market, and he foresees a time when magnetic bearings will be common on everyday items such as bicycles. Experts say we'll also see them in flywheels of new generations of electric vehicles and also in superconducting devices — the ultimate frictionless situation. ■



Radial magnetic bearing (left) and axial (thrust) magnetic bearing.