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Frictionless-Compressor Technology

New compressor makes chillers cleaner, quieter, and more energy-efficient

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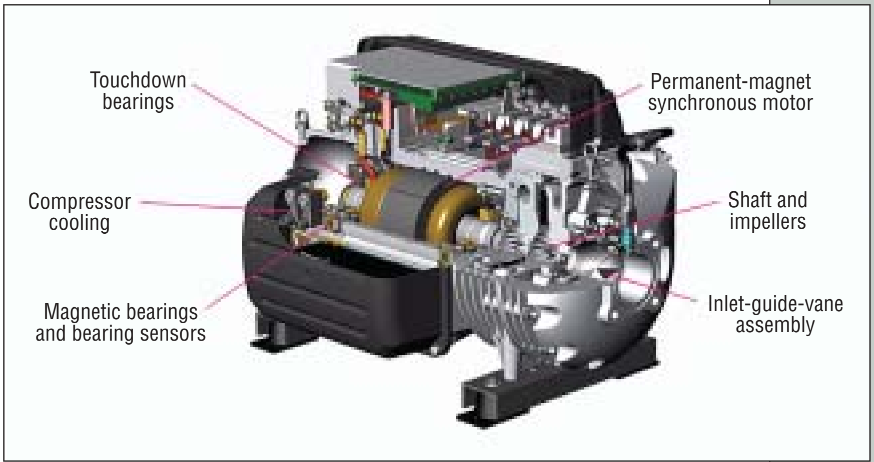
A new compressor technology introduced during the 2003 International Air-Conditioning, Heating, Refrigerating Exposition (AHR Expo), held last January in Chicago, may have a significant effect on the future of mid-range chillers and rooftop applications in water-cooled, evaporatively cooled, and air-cooled chilled-water and direct-expansion (DX) systems. Designed and optimized to take full advantage of magnetic-bearing technology, the compressor was awarded the first AHR Expo Innovation Award in the energy category, as well as Canada's Energy Efficiency Award for its potential to reduce utility-generated greenhouse-gas emissions. The compressor is key to a new water-cooled centrifugal-chiller design, with Air-Conditioning and Refrigeration Institute (ARI) tests indicating integrated part-load values (IPLVs) not normally seen with conventional chillers in this tonnage range.

This article describes this new compressor technology and its first use in an ARI-certified chiller design.

THE BEARINGS

Traditional centrifugal compressors use roller bearings and hydrodynamic bearings, both of which consume power and require oil and a lubrication system. Recently, ceramic roller bearings, which avoid issues related to oil and reduce power consumption, were introduced to the HVAC industry. The lubrication of these bearings is provided by the refrigerant itself.[1]



The TT300 compressor's onboard digital electronics manage operation while providing external control and Web-enabled access to a full array of performance and reliability information.

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Magnetic-bearing technology is significantly different. A digitally controlled magnetic-bearing system, consisting of both permanent magnets and electromagnets, replaces conventional lubricated bearings. The frictionless compressor shaft is the compressor's only moving component. It rotates on a levitated magnetic cushion (Figure 1). Magnetic bearings—two radial and one axial—hold the shaft in position (Figure 2).

When the magnetic bearings are energized, the motor and impellers, which are keyed directly to the magnetic shaft, levitate. Permanent-magnetic bearings do the primary work, while digitally controlled electromagnets provide the fine positioning. Four positioning signals per bearing hold the levitated assembly to a tolerance of 0.00002 in. As the levitated assembly moves from the center point, the electromagnets' intensity is adjusted to correct the position. These adjustments occur 6 million times a minute. The software has been designed to automatically compensate for any out-of-balance condition in the levitated assembly.

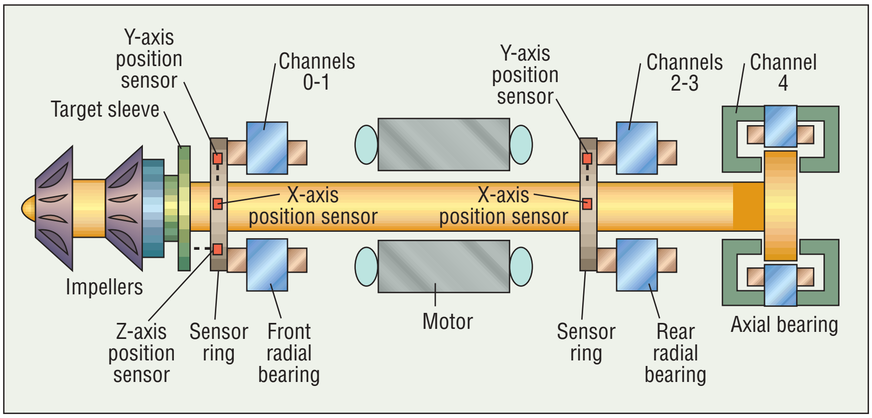

FIGURE 2. A digitally controlled magnetic-bearing system consisting of two radial and one axial bearing levitate the compressor's rotor shaft and impellers during rotation.

SHUTDOWNS AND POWER FAILURES

When the compressor is not running, the shaft assembly rests on graphite-lined, radially located touchdown bearings. The magnetic bearings normally position the rotor in the proper location, preventing contact between the rotor and other metallic surfaces. If the magnetic bearings fail, the touchdown bearings (also known as backup bearings) are used to prevent a compressor failure.

FIGURE 1. Electromagnetic cushions continually change in field strength to keep the rotor shaft centrally positioned.

The compressor uses capacitors to smooth ripples in the DC link in the motor drive. Instantaneously after a power failure, the motor becomes a "generator," using its angular momentum to create electricity (sometimes known as back EMF) and keeping the capacitors charged during the brief coastdown period. The capacitors, in turn, provide enough power to maintain levitation during coastdown, allowing the motor rotor to stop and delevitate. This feature allows the compressor to see a power outage as a normal shutdown.

OIL-FREE DESIGN

Oil management, particularly as it pertains to the lubrication of compressor bearings, is a critical issue in refrigeration-system design. But with magnetic bearings, this issue is avoided. Only a very small amount of oil is required to lubricate other system components, such as seals and valves; often, however, experience shows that even this small amount of oil is not needed. Avoiding oil-management systems means avoiding the capital cost of oil pumps, sumps, heaters, coolers, and oil separators, as well as the labor and time required to perform oil-related services. Reports indicate that for many installations, compressor-maintenance costs have been cut by more than 50 percent.

Most air-cooled products (including chillers, rooftop units, and condensing units) use DX evaporators. Most DX systems allow oil to travel through the refrigeration circuit and back to the compressor oil sump. Great care must be taken during design to provide oil return, particularly at part load, when refrigerant flow rates are reduced.

Water-cooled chillers often use flooded evaporators. In a flooded evaporator, even small amounts of oil can coat evaporator tubes and significantly diminish chiller performance. This can lead to an elaborate oil-recovery system. Magnetic bearings eliminate the need for these systems and oil management in general. In fact, the only required regular maintenance of the compressor is the quarterly tightening of the terminal screws, the annual blowing off of dust and cleaning of the boards, and the changing of the capacitors every five years. Complete service agreements and extended maintenance contracts can be provided by the manufacturer.

THE MOTOR

Most hermetic compressors use induction motors cooled by either liquid or suction-gas refrigerant. Induction motors have copper windings that, when alternating current is run through them, create the magnetic fields that cause the motor to turn. These copper windings are bulky, adding size and weight to the compressor.

Two-pole, 60-Hz induction motors operate at approximately 3,600 rpm. A higher number of revolutions per minute can be obtained by increasing the frequency. Compressors that require higher shaft speeds tend to use gears. While gears are a proven technology, they create noise and vibration, consume power, and require lubrication.

The magnet-bearing compressor features a synchronous permanent-magnet brushless DC motor with a completely integrated variable-frequency drive (VFD). The stator windings found on conventional induction motors are replaced with a permanent-magnet rotor. Alternating current from the inverter energizes the armature windings. The stator (excitation) and rotor (armature) change places. No commutator brushes are required. The motor and key electronic components are internally refrigerant-cooled, so no special cooling is required for the VFD or the motor.

The use of permanent magnets instead of rotor windings makes the motor smaller and lighter than induction motors. Using magnetic-bearing technology, a 75-ton compressor weighs 265 lb—about one-fifth the weight of a conventional compressor.

A variable-speed drive (VSD) is required for the motor to operate. The VSD varies the frequency between 300 and 800 Hz, which provides a compressor-speed range from 18,000 to 48,000 rpm. This avoids a gear set. The VSD is integrated into the compressor housing, avoiding long leads and allowing key electronic components to be refrigerant-cooled. The VSD also acts as a soft starter; as a result, the compressor has an extremely low startup in-rush current: less than 2 amps, compared with 500 to 600 amps for a traditional 75-ton, 460-v screw compressor with a cross-the-line starter.

With the integration of the motor, VSD, and magnetic-bearing system, the capacitors required for the motor and drive can be used as a backup power source for the bearings in the event of a power outage or emergency shutdown.

CAPACITY AND EFFICIENCY

Among the key parameters affecting performance are capacity (tons) and efficiency (kilowatts per ton). The compressor's capacity ranges from 60 to 90 tons, depending on the operating conditions. Plans call for that range to be extended to 150 tons water-cooled and 115 tons air-cooled by the end of 2004 with the use of R-134a refrigerant. An R-22 version is planned for retrofit applications.

Efficiency improvements stem from a combination of the centrifugal compressor, permanent-magnet motor, and magnetic bearings. Within the compressor, efficiency is affected by the compressor isentropic efficiency (the efficiency of the wheels), the motor, and the bearings. Traditional induction motors of this size typically are in the 92-percent efficiency range. This compressor's permanent-magnet motor has an efficiency of 96 to 97 percent.

Efficiency is further enhanced with the use of magnetic bearings, which avoid the friction of rubbing parts associated with traditional oiled bearings. Conventional bearings can use as much as 10,000 w, while magnetic bearings require only 180 w. That amounts to 500 times less friction loss. Current development projects are expanding the range and duty of the compressor wheels and promise to offer even greater efficiency for water-cooled and air-cooled duties and different capacities.

> **Magnetic-bearing compressors offer economic, energy, and environmental benefits, including increased energy efficiency, the elimination of oil, and considerably less noise and vibration.**

CONTROLS

The new compressor effectively is a computer. It provides diagnostic and performance information through Modbus to the refrigeration system, which then communicates to the building automation system through Modbus, LonWorks, or BACnet.

CHILLER APPLICATION

The compressor manufacturer and a major chiller manufacturer teamed up to develop a line of ARI-certified water-cooled chillers, which were expected to be introduced in January 2004. The combination of flooded-evaporator technology and an oil-free system has allowed very close approaches and, subsequently, enhanced performance. The integrated VFD allows excellent part-load performance as power consumption drops off, depending on the head relief, near the cube root of the shaft speed.

The compressor includes wheels tuned for water-cooled duty in the dual-compressor format, which further enhances part-load performance. Tested in accordance with ARI Standard 550/590-98, *Water Chilling Packages Using the Vapor Compression Cycle*, a 150-ton (nominal) chiller has a full-load performance of 0.629 KW per ton (5.6 COP) and an IPLV of 0.375 KW per ton (9.4 COP).

All IPLVs are weighted for standard operating conditions and the time spent at those conditions. Specific operating points for a 150-ton nominal-capacity chiller are shown in Figure 3.

SOUND AND VIBRATION

Because the rotating assembly levitates, there essentially is no structure-borne vibration. The magnetic bearings create an air buffer that prevents the only major moving part—the motor rotor—from transmitting vibration to the structure.

Similarly, sound levels are extremely low, primarily because of refrigerant-gas movement through the compressor and the rest of the refrigeration system. There are no tonal issues, such as those found with some screw compressors, and the noise occurs in the higher octave bands, where it is easier to attenuate. When two magnetic-bearing compressors were integrated into a chiller, the sound pressure was 77 dBA at 3.3 ft under ARI Standard 575-94, *Method of Measuring Machinery Sound Within an Equipment Space.*

Location	Phoenix	Chicago	Tampa, Fla.	New York
Machines	Reciprocating vs magnetic-bearing	Reciprocating vs magnetic-bearing	Reciprocating vs magnetic-bearing	Centrifugal vs. magnetic-bearing
Building type	Three-story office	Three-story office	Three-story office	Three-story office
Square footage	58,200	69,000	67,800	69,600
Design cooling load (tons)	150	149	150	150
Annual cooling ton-hours	241,121	116,256	312,305	119,521
On-peak charge	6 cents per KWH	5 cents per KWH	6.4 cents per KWH	10.9 cents per KWH
Off-peak charge	6 cents per KWH	2.1 cents per KWH	4.4 cents per KWH	10.9 cents per KWH
Summer demand	$1.75 per KW	$16.41 per KW	$8.12 per KW	$20 per KW
Winter demand	$1.75 per KW	$12.85 per KW	$8.12 per KW	$20 per KW
Capital-cost difference	$18,000	$18,000	$18,000	$12,000
Interest rate	6 percent	6 percent	6 percent	6 percent
Energy savings	$5,197	$5,035	$9,919	$4,587
Simple payback	3.46 years	3.57 years	1.81 years	2.62 years
Net present value	$96,278	$92,872	$195,914	$87,880
Internal rate of return	36.72 percent	35.8 percent	63.3 percent	46.27 percent

TABLE 1. Estimated operating costs and payback times.

MODELED ENERGY SAVINGS

Chiller applications were modeled for Phoenix; Chicago; Tampa, Fla.; and New York to estimate operating costs and payback times. The program compared an hourly analysis of a 150-ton frictionless chiller with that of a water-cooled reciprocating chiller (Phoenix, Chicago, and Tampa) and a water-cooled centrifugal chiller (New York). Each city showed an annual energy savings of more than $4,500 and a two- to three-year payback (Table 1).

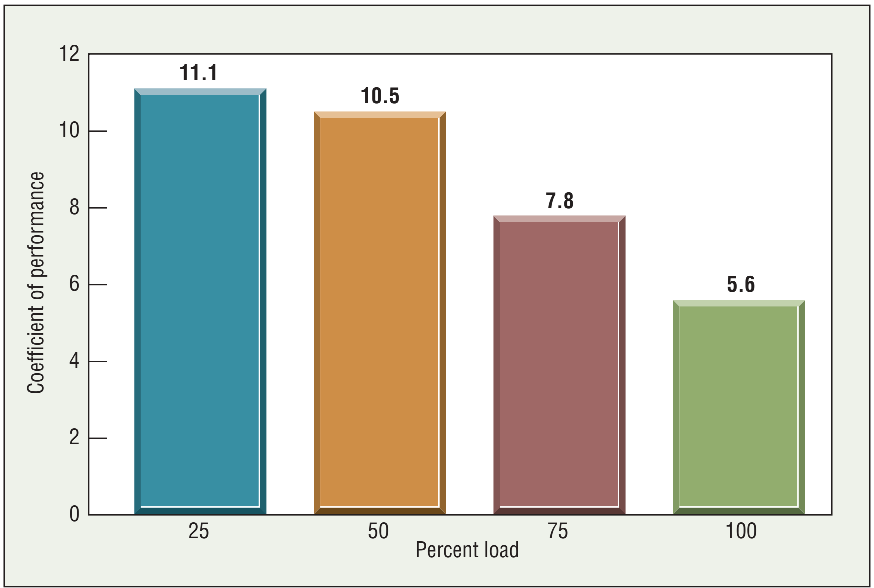

FIGURE 3. According to ARI testing, a 150-ton frictionless chiller has a full-load performance of 0.629 KW per ton (5.6 COP) and an IPLV of 0.375 KW per ton (9.4 COP).

SUMMARY

After 10 years of development, magnetic-bearing compressors offer economic, energy, and environmental benefits. Chief among them are increased energy efficiency, the elimination of oil and oil management, and considerably less weight, noise, and vibration. This initial mid-range package offers centrifugal-compression efficiencies previously reserved for large-tonnage systems only.

REFERENCE

1) Ivanovich, M.G. (2002, June). The market for chillers: drives, controls, simplicity. *HPAC Engineering*, pp. 11, 12, 15, 17.

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