Small High Speed

Centrifugal Compressors

By Mildred Hastbacka; John Dieckmann, Member ASHRAE; **Antonio Bouza,** Associate Member ASHRAE

This month, we are revisiting small high speed centrifugal compressors, which were first covered in Emerging Technologies in October 2003.[1] In 2003, there had been technically successful development of a 25 ton (88 kW) capacity, two-stage centrifugal compressor for R-134a that could be used in either water-cooled chiller applications or air-cooled chiller or unitary air-conditioning applications.

The two centrifugal impellers were direct-driven by a permanent magnet rotor dc motor on a common shaft. The compressor operated at variable speeds between 35,000 and 50,000 rpm and used refrigerant-lubricated ball bearings to support the shaft. With refrigerant lubrication of the bearings, no oil lubrication was required, eliminating circulating oil through the rest of the refrigeration loop. At this high speed, the impeller diameter is quite small, on the order of 3 in. (75 mm). Despite the potential advantages, this technology did not advance to commercial production.[2]

Since then, another configuration of small high speed centrifugal compressor has emerged and become an established commercial product. As with the previous development, the compressor has been designed for R-134a, with two stages to provide sufficient pressure ratio and temperature lift to allow it to be used in air-cooled applications. The motor and impellers are on a common shaft, with variable rotating speed on the order of 30,000 rpm, with impeller diameters between 3 and 4 in. (75 and 100 mm).

A significant difference is that the bearings are magnetic bearings, which levitate the shaft on a magnetic field, with no contact with a stationary bearing half. This eliminates mechanical friction loss and allows lubricant-free operation. While these compressors have extended the range of competitive performance of centrifugal compressors to lower capacities than traditional centrifugal chillers—down to 60 tons (211 kW), the technology has proven to be scalable, with high speed centrifugal chiller products on the market with capacities up to 700 tons (2460 kW).

This compressor configuration contributes to increased energy efficiency in several ways. From the perspective of scaling laws, the combination of small impeller diameter and high rotating speed is optimum for a centrifugal compressor in this relatively small capacity range. The variable operating speed provides excellent part-load efficiency, with the speed being varied to match the condensing temperature.

The two-stage design allows a refrigerant economizer cycle to be incorporated; the condensed refrigerant is expanded in two stages from the condensing pressure to the evaporating pressure, and vapor flashed after the first expansion stage is directed to the second compressor stage, requiring approximately half of the energy for compression compared to the full compression from the evaporating to the condensing pressures.

Typical energy savings from the refrigerant economizer cycle range from 5% to 7%. The magnetic bearings allow unlubricated operation with low friction loss. Eliminating lubricating oil from the system results in incrementally better refrigerant-side heat transfer performance, particularly in the evaporator.

Energy Savings

The U.S. Department of Energy, Federal Energy Management Program has included water-cooled oil-free magnetic bearing compressor technology among its "top 20 technologies for deployment."[3,4] Annual cooling energy savings ranging from about 40% to more than 60% have been achieved with this technology as documented by the Navy Technology Validation (Techval) Program.[5,6] Three project sites were involved in the Navy evaluation: San Diego, Newport, and Jacksonville.[6] Projects included a compressor retrofit as well as a new chiller and an added compressor.

Table 1 presents a high level summary of each project, as well as energy savings results and payback based on the total project cost. In the San Diego project, three existing chillers, with and without the new compressors, were used as the basis of the energy savings comparison. Baselines for the Jacksonville project and for the Newport project were existing compressors.[7]

A significant contributor to the energy savings is the technology's excellent efficiency at partial loads, typical of chiller operation.[3,4,5] The longer the compressor is run at part load and the higher the electric rate (e.g., > $0.07/kWh), the greater the advantage offered by magnetic bearing chiller compressors.[5]

The incremental costs for these three projects were reported as $24,000; $8,000; and $13,000, respectively. Using this incremental project cost for payback calculations yields payback periods of 1.1 years for San Diego; 0.3 years for Newport; and 0.8 years for Jacksonville.[6]

Project/Type	Tons	Utility Rate ($/kWh)	Annual Energy Savings	Percent Energy Savings	Project Cost	Payback (Years)
San Diego/ Third Compressor Added	240	$0.121	$21,206	40%	$178,787 (Design Through Installation)	8.4
Newport/ New Chiller	80	$0.115	$26,192	65%	$100,783 (Design Through Installation)	3.8
Jacksonville/ Compressor Retrofit	120	$0.054	$15,358	41%	$107,592 (Installation, Including Compressor)	7.0

Table 1: Summary results from Navy Technology Validation Program, oil-free magnetic bearing technology.[6]

Market Potential

Small centrifugal compressors are now commercially available from multiple sources and are expected to replace reciprocating and screw compressors for chilled-water systems in the 25 to 80 ton (88 to 281 kW) range.[8] Comparatively high first cost can be, and has been, substantially offset by improved energy efficiency.

Mechanical contractors serving the school construction market report that magnetic bearing chillers are among the new technologies of interest to this market.[9] With overall school construction demand down by 50% from prerecession levels, the major drivers for selection of building products and technologies in this market have been life-cycle costs and return on investment, rather than LEED or sustainability.

In New England, with electric rates hovering around $0.15/kWh, data storage centers with water-cooled chillers are realizing reduced power consumption as well as lower maintenance costs and high reliability from use of oil-free, magnetic bearing compressors.[10] Both data center users and data center service providers are concerned about shutdown risks. Many data center users have migrated from leases based on cost/ft^2 to leases based on "service levels agreements" (SLAs), which compensate data center users for time periods in which they cannot access critical data.

Cooling system reliability affects shutdown risk. Given 80% of chiller field problems have been attributed to failures in compressor-oil return, oil-free compressors are an attractive option for data center service providers.[10] Also, data center applications benefit from the low inrush current required to start a magnetic bearing compressor, which permits downsizing of standby generator equipment.

References

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Mildred Hastbacka is a director and emerging technologies scout for TIAX LLC and John Dieckmann is a director in the Mechanical Systems Group of TIAX LLC, Lexington, Mass. Antonio Bouza is a technical manager with the U.S. Department of Energy, Washington, D.C. ■