EnergyIdeas Clearinghouse

PTR #14
April 2006

Product & Technology Review

Turbocor

A frictionless, oil-free, variable speed, centrifugal compressor designed for mid-size chiller applications (60-90 tons) that compares favorably to the most efficient standard compressors at full load, and offers significant savings at part load.

Product

Turbocor TT 300 Compressor, available in 60-, 70-, 80-, and 90-ton capacities. The manufacturer has plans to unveil a TT400 model in the near future with capacities in the 110- to 160-ton range.

Manufacturer

Danfoss Turbocor
1850 Trans-Canada Hwy.
Dorval, Québec H9P 2N4 Canada

Phone: (514) 421-0523
Fax: (514) 421-4277
E-mail: *smitty@turbocor.com*
Website: *www.turbocor.com/*
[Note: According to a press release on their website, Danfoss "plans to move its headquarters and manufacturing plant from Montreal, Canada, to Tallahassee, Florida … by June, 2006."]

Distributor

Turbocor compressors are used primarily as components by original equipment manufacturers (OEMs). The Danfoss Turbocor website has a list of manufacturers that currently use their compressors at *www.turbocor.com/distribution/*.

Danfoss Turbocor also has a division for aftermarket and retrofit sales, and keeps a current list of certified installers for the Northwest. For more information, contact:

Dan Thatcher
Aftermarket/Retrofit Sales
(805) 267-1224
E-mail: *dthatcher@turbocor.com*

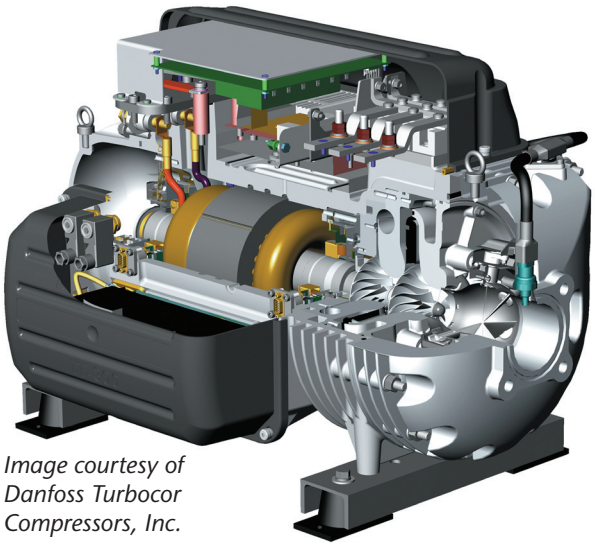

Image courtesy of Danfoss Turbocor Compressors, Inc.

Product History

The product debuted in the United States (in California) in 2001.

Product Application and Function

The following information was primarily provided by the manufacturer and is not evaluated in this section. Turbocor compressors are designed for mid-size heating, ventilation, and air conditioning (HVAC) chiller and

Product & Technology Reviews (PTR) are developed for Northwest electric utilities. EnergyIdeas Clearinghouse engineers review published literature for objective, independent test results. No primary testing was conducted by the reviewer for the preparation of this document. PTR factsheets describe the technology, discuss available data, and suggest additional testing needed to verify energy saving claims.
For more information: ***www.EnergyIdeas.org/ptr***

Managed by
Washington State University Extension Energy Program

With support from
Northwest Energy Efficiency Alliance
www.nwalliance.org

rooftop applications. They are not designed for medium- and low-temperature applications, such as refrigerated storage or freezer applications. They can be used as a single compressor or ganged together in parallel for larger applications. Features of the Turbocor include:

Magnetic Bearings
The compressor uses magnetically levitated bearings on the single rotating part – the rotor shaft – eliminating the need for oil. Having no oil eliminates the need for oil pumps, sumps, heaters, coolers, and oil separators.

The rotating compressor shaft is suspended in a magnetic field. The bearing system uses permanent magnets for the primary work and electro-magnets for fine-tuning. An internal digital control system senses and repositions the shaft with the electro-magnets six million times each minute. The digital control can sense shaft movement of less than 0.00005 inches on five axes.

Motor
The Turbocor compressor uses a high efficiency permanent-magnet synchronous motor that is refrigerant-cooled and operates at speeds up to 48,000 rpm. Using permanent magnets instead of stator windings makes the motor smaller and lighter than conventional induction motors. Though not specifically rated by the manufacturer, the motor delivers about 75 hp at full load, but is approximately the size of a 15-hp three-phase induction motor.

Variable Speed Drive (VSD)
Turbocor's inverter was developed for speed control. Power comes in between 50 and 60 hertz (Hz) alternating current (AC) and is converted to DC. The inverter reconstructs the AC wave to vary it between 300-800 Hz. This gives an operating range for the compressor of between 18,000 and 48,000 rpm. The VSD is integrated into the compressor housing. This allows the electronics to be refrigerant-cooled. The VSD also serves as a soft-start that reduces the initial starting current to less than five amps.

Centrifugal Compressor
The compressor uses two open-shrouded ("semi-open") impellers and uses R-134a as the refrigerant. The compressor uses inlet guide vanes to pre-swirl the gaseous refrigerant before entering the compressor. This pre-swirl imparts a rotation to the refrigerant in the same direction as the impeller rotation before it enters the first stage of the compressor. This reduces some of the work needed to compress the refrigerant, particularly at part load. The inlet vanes are also adjustable to help balance the load. There is a side-stream inlet port between the two compressor stages to allow for economizing. After the second stage, the refrigerant passes through the discharge with an integrated check-valve to prevent short-circuiting or reversal of the shaft.

Digital Control
The electronics and controls have been fully integrated into the system. They were designed to be easy to access and maintain and offer plug-and-play ease. The high-voltage and low-voltage systems are separated for ease of maintenance and troubleshooting. The controls can be integrated with a building management system for automation and data logging. The user interface is available in several different communication protocols for use with almost any system.

Energy Saving Claims

The following information was provided primarily by the manufacturer and is not evaluated in this section.

The magnetic bearings eliminate the need for oil. According to the manufacturer, a conventional lubrication system can use up to 10,000 watts, but the magnetic bearings only use 180 watts. The elimination of oil also increases the efficiency of heat exchange surfaces. Oil entrained in chiller refrigerant can significantly reduce performance. Oil recovery systems (used in conventional refrigeration installations) can also be eliminated.

The compressor motor is a permanent-magnet motor rather than a conventional induction

motor. While older induction motors have a nominal 92% efficiency and newer induction motors have a nominal 95%, the permanent-magnet motor used with Turbocor has an efficiency of 96% to 97%.

The Turbocor coefficient of performance (COP) has been measured at over 5.6 at full load in water-cooled applications, which translates to a cooling efficiency of 0.62 kilowatts per ton (kW/ton), and at part load measured at 9.4 (0.375 kW/ton). McQuay International, an OEM, did comparison testing of their chillers using a 156.7-ton screw (Model WGS160A) as the base condition. The results show the full-load performance of the screw compressor to be 0.715 kW/ton and of the 150-ton Turbocor compressor (Model WMC035T) to be 0.645 kW/ton. The Integrated Part-Load Value (IPLV) performance was measured at 0.546 kW/ton and 0.371 kW/ton for the screw and frictionless chillers, respectively. This is an improvement of 10.9% at full-load and 47.2% at IPLV in this one example.

Non-Energy Benefits

Eliminating oil in the system reduces compressor maintenance costs. Most air-cooled units use Direct Exchange (DX) evaporators and allow oil to migrate through the system and back to the compressor sump. A designer of these systems must consider carefully the part-load requirements of the system in order to maintain the necessary velocity of the refrigerant that will allow this migration of oil back to the sump. Many water-cooled chillers use flooded evaporators. In these systems, oil can coat the evaporator tubes, diminishing the performance of the chiller. Sophisticated oil-recovery systems are often required to help alleviate this problem. The oil-free design of Turbocor eliminates the need for these systems and issues.

The permanent-magnet synchronous motor offers several advantages. Compressors that require high shaft speeds usually use gears. The combination of the permanent-magnet motor and the integrated VSD eliminates the need for gears and their associated noise, vibration, and lubrication issues. With a permanent-magnet motor there are no commutator brushes to be maintained, as there are with a typical motor. Permanent-magnet motors are smaller and lighter than induction motors, greatly reducing weight. A Turbocor 75-ton compressor weighs only 265 pounds (roughly 1/5 the weight of a conventional compressor) and is roughly half the size of a conventional compressor, making installation and retrofits easier.

The VSD is also used as a soft start that gives a low starting current of less than 5 amps and ramps gradually to full current over a two-minute period. The current would slightly exceed full-load amperage (about 60 amps) as it reaches full speed. Without a soft start, a conventional compressor of this size could have an inrush current of up to 500 amps. This inrush current can affect electrical components adversely, causing the tripping of circuit breakers and fuses. The high current can also cause momentary contact bouncing in switches or relays that may pit the contact from arcing or may even weld the contacts together.

The integrated controls offer a variety of outputs and diagnostics. Performance information and diagnostics can communicate with many building automation systems, and can be used for automatically logging the performance of the compressor.

The Turbocor compressor also has some other interesting and notable features:

- The sound level is less than 77 decibels (dB) at 3.3 feet. (ARI Standard 575-94), or about one-fourth as loud as a conventional compressor (typically 83 dB).
- The compressor shaft is the only rotating part.
- At power down, or in the case of loss of power, the motor turns into a generator to keep the capacitors charged to maintain shaft levitation while coasting to a stop.

Independent Testing Results

McQuay International is currently the only manufacturer that is licensed to bear the Air-Conditioning and Refrigeration Institute (ARI) label for this style compressor on a standard packaged chiller. Each McQuay Model WMC has been independently tested to ARI 550/590 requirements for water cooled chillers. Equipment catalog and computer selection program data are published in compliance with ARI requirements.

Cost

Cost for retrofits will vary based on the project, but should be in the range of $550-600 per ton installed, according to the Turbocor manufacturer. For new chiller installations, McQuay gives a relative price comparison of their (approximately) 150-ton chillers as shown below:

	Compressor Type			
	Screw	Centrifugal – Solid State	Centrifugal with VFD	Turbo-cor
Chiller Model #	WGS160A	WSC050M	WXC050M	WMC035T
No. compressors	2	1	1	2
VFD	No	No	Yes	Yes
Capacity (tons)	156.7	148.3	150	150
Price Difference	Base	+8.81%	+27.80%	+13.56%

Alternative Products and Strategies

We know of no other compressors that are directly comparable to Turbocor. That is, we know of no other centrifugal compressors in this size range with an integrated VSD, a permanent-magnet motor, and magnetic bearings. The alternatives in most of these applications would be conventional screw or scroll compressors. For the new chiller installations described above under "Cost," McQuay gives the following performance information:

	Compressor Type			
	Screw	Centrifugal – Solid State	Centrifugal with VFD	Turbo-cor
Chiller Model #	WGS160A	WSC050M	WXC050M	WMC035T
Full Load kW/ton	0.715	0.630	0.668	0.645
IPLV	0.546	0.559	0.492	0.371

Which option to choose would depend on the circumstances and your buying philosophy. Putting together the cost and performance tables above, you can see that the chiller with Turbocor compressors is 32% more efficient than the chiller with screw compressors in terms of IPLV, but has a 14% price premium. If the application calls for a compressor that is operated frequently, and often at part load, the price premium for the Turbocor will very likely have a short payback, especially if electricity prices are high.

The price of the chiller with a solid state centrifugal compressor is less than the one with Turbocor compressors, and it is about the same efficiency at full load, but is less efficient at part load. Thus, in an application where the compressor is being baseloaded – that is, running at full load most of the time – the centrifugal compressor is better. In a more typical HVAC situation (running at part load much of the time), a Turbocor compressor may be better.

In the most direct comparison – a centrifugal compressor with a VFD added – Turbocor is the clear winner. Not only is it more efficient at full load and part load, but it costs less. It should also be noted that the comparison given by McQuay is for two Turbocor compressors in parallel compared to a single centrifugal. There are currently no

manufacturers of centrifugal compressors in the range of a single Turbocor compressor.

To determine which option is best in a particular situation, a full engineering analysis is recommended.

Case Studies

1. "AMP Place, Brisbane: Compressor Retrofit" (McGowan 2005).
Compressor failure in an 1850 kW chiller at AMP Place in Brisbane, Australia, reduced plant capacity by 40%. A retrofit replaced the failed compressor with Turbocor compressors. With the retrofit there is a general increase in heat exchange efficiency due to lack of oil in the refrigerant. Chiller capacity matches building loads due to electronic expansion valves. Compressors have a low noise level of less than 75 dB. Full-load current is reduced from 720 amps to 595 amps and the retrofit chiller comes within 20 kW of the 1850 kW design capacity of the original system. The original equipment was designed to operate at a COP of 3.87; the new system has been recorded with a COP of 4.92. Site verification showed 20% savings at full load and 55% savings at 50% load, compared to the original chiller. Actual capacity (as opposed to design capacity) has increased 15%.

2. "Advanced compressor technology solves no-cool problem in SoCal offices" (Engineered Systems 2005).
In this building in Pasadena, California, two 40-ton units were replaced with one 80-ton unit with a Turbocor compressor. The 30-year-old units weighed a total of 6,400 pounds and the Turbocor compressor weighs 265 pounds. The previous units used R-22 and the Turbocor uses R-134a. Energy savings from January through June 2004 averaged 32%. Tenants have also experienced an increase in comfort level.

3. Energy Performance Report: Turbocor Compressor, Wests Leagues Club, Newcastle (Building Controls Management 2003).
Energy performance tests were conducted on a new retrofit at this facility in Australia. A single Turbocor unit replaced two of four Trane reciprocal compressors. Both the new and existing equipment were run in parallel on the same chilled water loop. The system was set up so that each system did the same amount of work. Logging was averaged over two-minute intervals for the testing period. The average reduction in energy of the Turbocor versus the existing system for the operating conditions was 58%. The minimum reduction was 28% and the maximum reduction was 75%.

4. Ultra-Efficient HVAC Design and Control: Major Heating, Ventilating and Air-Conditioning Replacement at the County of San Diego Crime Lab (San Diego Regional Energy Office 2005).
In analyzing a conventional air-cooled chiller retrofit option compared to one using two 150-ton McQuay frictionless chillers using the Turbocor compressors, this case study determined that the McQuay system would save about $48,500 per year, for a simple payback of the incremental cost of the frictionless chiller (compared to the next best alternative) of about five years, or 1.8 years after utility rebates. A summary of the case study can be found on the McQuay International website (see reference: San Diego Regional Energy Office). Note that McQuay uses the Turbocor compressors in their frictionless chillers and thus has a marketing interest in Turbocor.

Suggestions for Further Research and Testing

The technologies used for the components and the overall designs are impressive and should yield significant energy savings. Several case studies seem to indicate significant savings, but the manufacturer is strongly encouraged to pursue independent testing under more controlled conditions. In case study #2 above, a 30-year-old chiller was replaced with a new chiller that happened to contain a Turbocor compressor; how much of the resulting savings can be attributed to the compressor is not clear. Also, the case studies were not documented by impartial organizations who specialize in

such comparisons and who can isolate the contributions of various factors.

Controlled independent performance testing under various conditions will assist utilities and energy engineers to more accurately predict savings in the future.

Additional Reviewer Comments

Turbocor is specifically targeted to the largest market for chillers. This allows the manufacturer to concentrate all their resources on designing a product well. They stepped back from improving current systems and looked at designing a system from the ground up. After success in this market, they plan to extend the line of compressors to include those for larger and smaller chillers, as well as, perhaps, applications in other temperature ranges.

Turbocor has won the following awards.

- 2004 Environmental Protection Agency's Climate Protection Award – Corporate & Governmental
- 2003 Air-Conditioning Heating and Refrigerating (AHR) Expo Energy Innovation Award
- 2003 Canadian Energy Efficiency Award – Equipment & Technology

Conclusion

Turbocor is a frictionless, oil-free, variable speed, centrifugal compressor designed for mid-size chiller applications. The permanent magnet motor with built-in variable speed drive allows the system to match the compressor output to the load. The magnetic bearings allow frictionless operation of the impeller shaft and eliminate the need for any oil and related components. The control system allows for the ability to monitor and optimize performance, as well as integration with many building automation systems.

In several case studies, compared to standard chillers, those with the Turbocor compressor have demonstrated significant energy savings at full load and even higher savings at part-load. However, in all cases old equipment was replaced by new equipment containing Turbocor and it is not clear how much of the savings can be attributed to the new equipment and how much to the Turbocor compressors. Therefore, independent testing under more controlled conditions should be performed.

Utilities should consider Turbocor as an option for retrofits on HVAC chillers due to its impressive part-load operation, controllability, weight, monitoring, and ease of integration.

References

Building Controls Management Pty Ltd., *Energy Performance Report: Turbocor Compressor, Wests Leagues Club, Newcastle*, June 2003. Available online (April 2006) at *www.turbocor.com/literature/pdfs/articles/performance_report.pdf*

Conry, Ron, "Dissecting Success: The Anatomy of a Compressor," sales literature from Danfoss Turbocor. Available online (April 2006) at *www.turbocor.com/literature/pdfs/articles/anatomy.pdf*

Crowther, Hugh, and Eugene Smithart, "Frictionless-Compressor Technology," *HPAC Engineering*, January 2004.

Engineered Systems, "Advanced compressor technology solves no-cool problem in SoCal offices," *Engineered Systems*, January 2005. Available online (April 2006) at *www.esmagazine.com/CDA/Archives/a98d0ba2b1ea8010VgnVCM100000f932a8c0____*

McGowan, Sean, "AMP Place, Brisbane: Compressor Retrofit," EcoLibrium®, Australian Institute of Refrigeration Air Conditioning and Heating. Melbourne, Australia. July 2005. Available online (April 2006) at *www.airah.org.au/downloads/2005-07-P03.pdf*

McQuay International, "Efficient, quiet and oil-free: Frictionless chiller technology sets new standard for efficiency and quiet operation," *McQuay International Bulletin*, 2005. Available online (April 2006) at *www.mcquay.com/mcquaybiz/literature/lit_ch_wc/Brochures/Frictionless_Comp_Chiller.pdf*

McQuay International, McQuay Frictionless Centrifugal Compressor Chillers. McQuay International sales literature, January 2005. Available online (April 2006) at *www.mcquay.com/eprise/main/mcquaybiz/Lit_CH_WC/Brochures/ASP_WMC_0105.pdf*

San Diego Regional Energy Office, *Ultra-Efficient HVAC Design and Control: Major Heating, Ventilating and Air-Conditioning Replacement at the County of San Diego Crime Lab*, December 30, 2005. Available online (April 2006) at *www.mcquay.com/mcquaybiz/marketing_tools/mt_ch_wc/RefJob/SanDiegoCrimeLab-WMC.pdf*

Sine, Jack, "Excess Oil: Problem Solved," *Air Conditioning, Heating, & Refrigeration News*, 2004.

Additional Information

Northwest businesses and electric utilities can contact the EnergyIdeas Clearinghouse for additional information on this or other energy technologies or products. Contact:

Phone: 1-800-872-3568
E-mail: *Info@EnergyIdeas.org*
Website: *www.EnergyIdeas.org*

The EnergyIdeas Clearinghouse is a technical assistance service managed by the WSU Extension Energy Program with support from the Northwest Energy Efficiency Alliance.

Reviewer

Craig Meredith, P.E.
WSU Extension Energy Program

Note: Product & Technology Reviews are peer reviewed by objective industry professionals prior to publishing.