Evaluation of a Variable-speed Centrifugal Compressor with Magnetic Bearings

Unique compressor with magnetic bearings proves an efficient and effective replacement for conventional compressor technologies.

Photo courtesy of SEI Group, Inc.

Figure 1: An existing 275-ton chiller retrofit with three new 90-ton variable-speed compressors at FISC, San Diego, CA

Summary

The U.S. Navy Technology Validation (Techval) program sponsored a series of demonstrations of a new variable-speed centrifugal chiller compressor. The new compressor uses an internal variable-speed drive with magnetic lift bearings. The combination of variable-speed and 2-stage centrifugal design allows the compressor to operate with high-efficiency, especially at partial load. At three different Navy installations, the new compressors were compared to the existing reciprocating and screw compressors by operating the new and old systems side-by-side. The new compressor technology was found to be more efficient and cost effective in each demonstration. The results of the three Navy demonstrations showed a reduction in chiller energy from 41 to 65% with simple paybacks ranging from 4 to 7 years. The equipment requires no oil because of the compressor's design and use of magnetic bearings. The nominal capacity of the new compressor is 90 tons; however for larger capacity system, multiple compressors can be incorporated on a common chiller frame. The compressor is manufactured by a single company; however, the compressor is available as part of an integrated chiller package through 3 U.S. and 7 international chiller companies.

In this Fact Sheet:

- Summary
- Introduction
- New Compressor Technology
- Conclusion

Introduction

Investigating ways to reduce energy consumption and costs, the Navy Techval program sponsored a series of demonstrations of a new oil-free variable-speed centrifugal compressor with magnetic bearings. The demonstrations involved three Navy locations: the Naval Undersea Warfare Center (NUWC) in Newport, RI; the Fleet Industrial Supply Center (FISC) in San Diego, CA; and the Naval Air Station Jacksonville (NASJAX) in Jacksonville, FL.

The demonstration site at the FISC in San Diego consisted of two 360-ton water-cooled chillers with screw compressors. A dedicated cooling tower served each chiller. The chillers were grossly oversized for the current cooling load, and the cooling system had 100% redundancy. Therefore, one of the existing chillers was retrofitted with two of the new 90-ton variable-speed centrifugal compressors. The existing condenser and evaporator remained in use. To compare the two compressor technologies, the two chiller systems (the chiller modified with the new variable-speed centrifugal compressors and the existing chiller with the screw compressor) were manually cycled each week. Later, because of added electrical equipment cooling loads, a third variable-speed compressor was added to the system. Figure 1 shows the chiller after it was modified for 3 of the new compressors.

> "There clearly is an efficiency improvement here. The FISC San Diego project indicates a 3 year simple payback."
>
> – Paul Kistler, Techval Program Manager, NAVFAC ESC

The demonstration site at the NUWC in Newport consisted of two 100-ton water-cooled chillers, with reciprocating compressors. The chiller plant provides cooling for seasonal space conditioning, as well as year-round cooling for electrical equipment. To assure the new compressor could adequately manage the building load, a new Multistack chiller, equipped with the 90-ton variable-speed centrifugal compressor, was installed (see Figure 2). The Multistack chiller consists of a modular plate-and-frame condenser and evaporator, where additional "stacks" can be added to accommodate future building loads. The two existing chillers remained in service. The two chiller technologies (the new variable-speed centrifugal and the existing reciprocating) were compared by alternating chiller operation every 24 hours.

The NASJAX demonstration site was equipped with two separate water-cooled chillers, each with two reciprocating compressors and a dedicated cooling tower. For this demonstration, one of the chillers was retrofitted with two new variable-speed centrifugal compressors (see Figure 3). The two chiller systems were compared by alternating operation each week.

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Photo courtesy of SEI Group, Inc.

Figure 2: The new chiller with an integrated 90-ton variable-speed compressor used to replace one of the existing 100-ton reciprocating chillers at NUWC, Newport, RI.

Photo courtesy of SEI Group, Inc.

Figure 3: An existing chiller retrofitted with two 90-ton variable-speed compressors at NASJAX, Jacksonville, FL

Project Site	Cooling Capacity (tons)	Electricity Cost ($/kWh)	Annual Electricity Savings (kWh/yr)	Annual Energy Savings ($/yr)	Percent Energy Savings	Installation ($)	Simple Payback (years)
Newport	80	$0.115	227,760	$26,192	65%	$100,783	3.8
San Diego	240	$0.121	210,240	$25,229	47%	$178,687	7.1
Jacksonville	120	$0.053	286,900	$15,358	41%	$99,590	6.5

Table 1: New Chiller Technology Demonstration Summary

New Compressor Technology

The new compressor technology is oil-free, uses magnetic bearings to support the two-stage centrifugal compressor, incorporates an internal variable-speed drive, and digital electronic controls. The compressor is compact and notably quiet compared to conventional compressor equipment with the same cooling capacity. The compressor is designed for use with HFC-134a, a CFC-free refrigerant.

The new chiller technology performed well at all three demonstration locations. The energy savings, installation costs and simple payback associated with each installation are summarized in Table 1.

In addition to energy savings, there is the potential for maintenance savings associated with the new technology. Based on manufacturer recommendations, the required maintenance consists of:

- Quarterly tightening of terminal screws
- Annual circuit board cleaning
- Capacitor change-out every 5 years.

Over 10 years, maintenance labor and costs are estimated to be approximately 96 person-hours in labor and $500 in materials (i.e., the capacitors).

Figures 4, 5, and 6 illustrate the monitored compressor efficiency, in kW/ton, versus chiller load for each demonstration. [For more on kW/ton, see the Side Bar on Chiller Efficiency.] Each figure shows the new compressor technology to be more efficient (i.e., lower kW/ton) than the existing compressor system. As a result, the new compressor technology consumes less energy while providing the same cooling load. The data in Figure 6 illustrates the average chiller compressor and chiller plant (compressor and cooling tower) efficiency versus the chiller load based on the metered data.

The NAXJAX demonstration revealed another opportunity for increased energy savings. The new compressor technology is capable of operating with lower condenser water supply temperatures compared to some conventional compressor systems. This resulted in an additional

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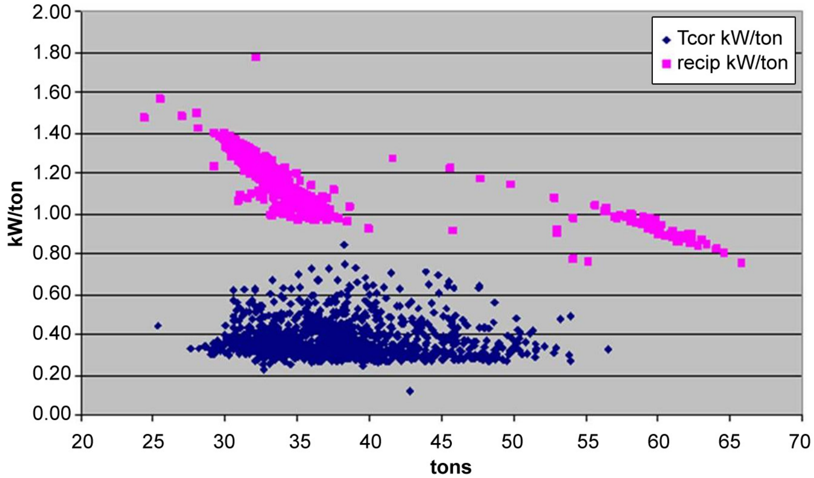

Figure 4: Compressor efficiency (kW/ton) versus chiller load (tons) for new variable-speed and existing reciprocating compressors (NUWC, Newport, RI)

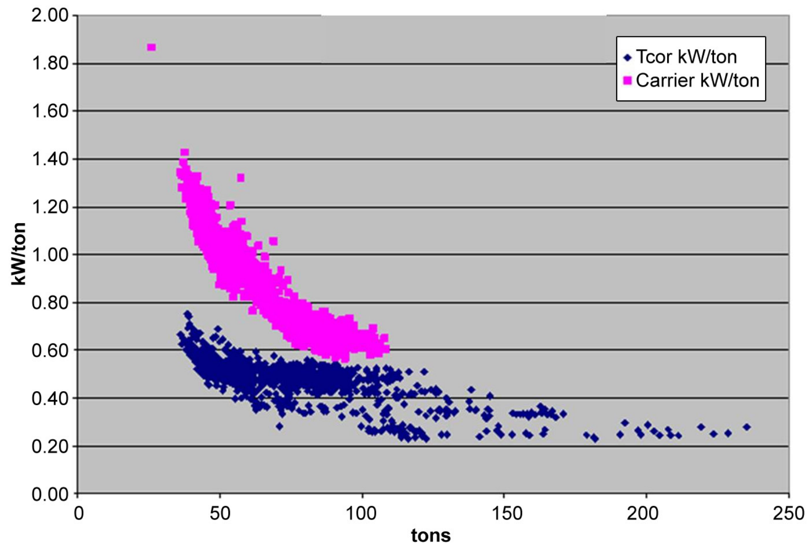

Figure 5: Compressor efficiency (kW/ton) versus chiller load (tons) for new variable-speed and existing screw compressors (FISC, San Diego, CA)

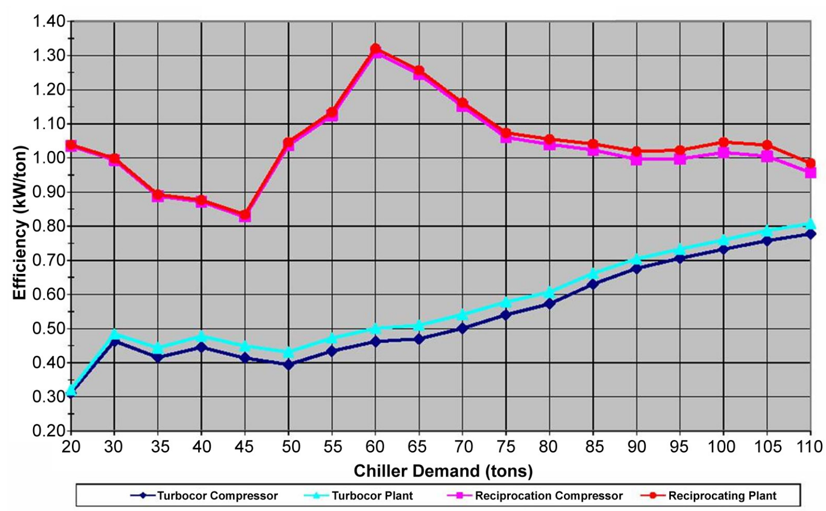

Figure 6: Average compressor efficiency (kW/ton) versus chiller load (tons) for new variable-speed and exisiting reciprocating compressors (NASJAX, Jacksonville, FL)

improvement in efficiency. The relationship between compressor efficiency and the condenser water supply temperature at NASJAX is shown in Figures 7 and 8.

The new compressor technology offers a number of additional advantages over existing technology, including:

- Oil-free
- Expected reduction in maintenance requirements
- 20% lighter than conventional screw or reciprocating compressors
- Quieter than conventional screw or reciprocating compressors
- Low start-up current as a result of the internal variable-speed drive.

Conclusion

The new variable-speed centrifugal compressor technology is a notable improvement over existing reciprocating and screw compressors. In addition to energy and cost savings, the new technology is lighter and quieter. It is also expected to be easier to maintain. Moreover, additional energy savings can be realized by operating the chiller system with lower condenser water supply temperatures.

The new variable-speed centrifugal compressor is available from multiple providers as a fully integrated chiller package. In addition, the new compressor technology can be retrofit on some chillers as a compressor replacement. This new compressor technology is applicable, but not limited, to the following situations:

- Above average electricity costs (> $0.07/kWh)
- Year-round cooling requirements
- Long run time at partial load
- Compressor or full chiller replacements.

These demonstrations were limited to water-cooled chiller systems. However, the manufacturer is expected to release an air-cooled version of the variable-speed centrifugal compressor during 2010.

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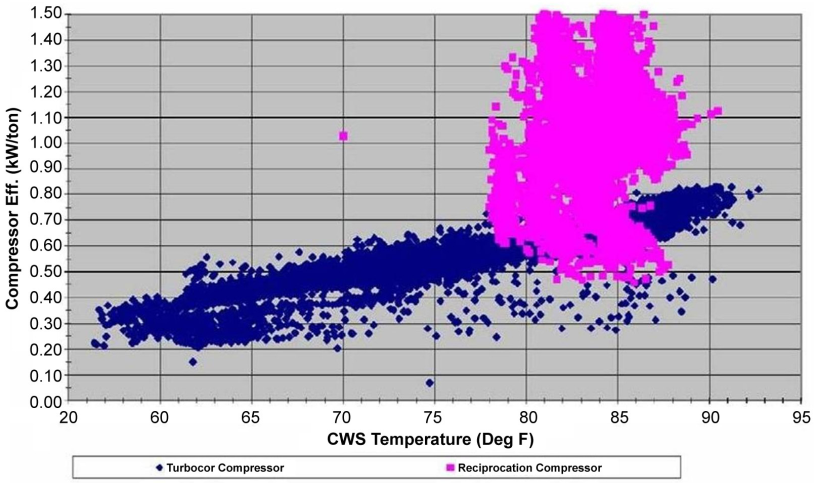

Figure 7: Compressor efficiency (kW/ton) versus condenser water supply temperature (ºF) for new variable-speed and existing reciprocating compressors (NASJAX, Jacksonville, FL)

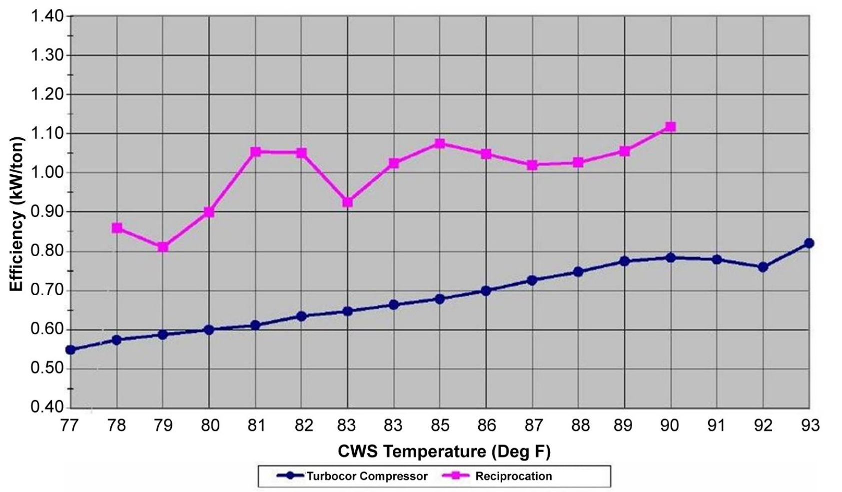

Figure 8: Average compressor efficiency (kW/ton) versus condenser water supply temperature (ºF) for new variable-speed and existing reciprocating compressors (NASJAX, Jacksonville, FL)

Disclaimer

Chiller Efficiency

There are several different ways to express the energy efficiency of a chiller. For chillers, the *coefficient of performance* (COP) is the most common metric cited in codes and standards, as well as by mechanical engineers. COP is defined as the ratio of the cooling capacity (typically in watts or Btu/hr) to the total power input (in the same units of measure as the cooling capacity) at any given set of rating conditions. Because the units of measure for both capacity and power are the same, the resulting ratio is unitless. Like efficiency, when comparing the COP of multiple equipment, the larger COP is more efficient.

Another metric used to express the energy efficiency of a chiller is *power input per capacity*, or kW/ton. kW/ton is defined as the ratio of the total power input to the equipment (in kW) to the net refrigerating capacity (in tons) at any given set of rating conditions. Because power input (kW) and refrigeration capacity (tons) are readily used in the field and in specifications, kW/ton as a measure of energy efficiency for chillers is commonly used by practitioners. When comparing kW/ton, the objective is to reduce the power requirements per ton of cooling delivered; therefore, when comparing the kW/ton of multiple equipment, the smaller kW/ton is more efficient.

For More Information

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Produced for the U.S. Department of Energy, Energy Efficiency and Renewable Energy, by the Pacific Northwest National Laboratory

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PNNL-SA-70614 • June 2010

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