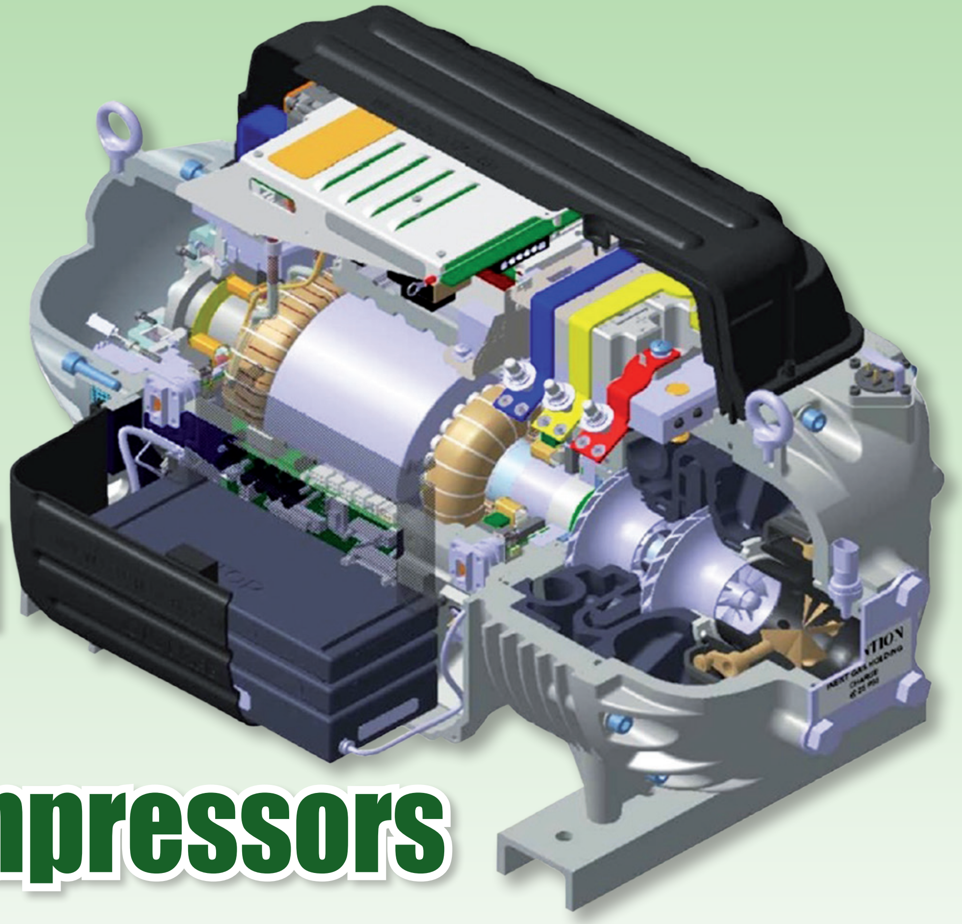

A Danfoss Turbocor compressor

Technical Trends in Large Compressors

By Akira Otsuki
Senior Consultant for Centrifugal & Screw Chillers
Kyoto, Japan

Introduction

The current technical development of large compressors for heating, ventilation, air conditioning and refrigeration (HVAC&R) applications is focused on improving overall efficiencies, maintaining a wide operating range, and shifting to next-generation low global warming potential (GWP) refrigerants.

In the past, centrifugal and reciprocating compressors were the mainstream large compressors for HVAC&R applications. During the 1980s, semi-hermetic screw compressors in capacities of 40–300 tons were developed and replaced reciprocating compressors and some small centrifugal compressors in chiller applications.

With the advent of a new oil-free centrifugal concept, small centrifugal compressors extended their capacity into the range of screw compressors. From the other direction, the development of larger scroll compressors up to 60 hp has also extended their capacity into the range of screw compressors.

With the technical advancement of various compressor technologies, the boundaries of the respective compressor types have been changing over time.

This article was first published in the February 2016 issue of JARN. Reprinted with permission.

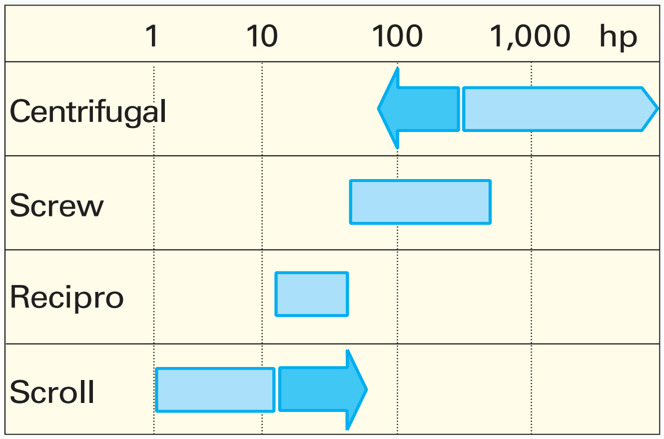

Figure 1: Compressor capacity range

Centrifugal Compressors

Centrifugal compressors compress gases by converting kinematic energy into static pressure. Therefore the characteristics

About the Authors

Akira Otsuki has worked at a Japanese manufacturer for 40 years, mainly engaged in designing and development of screw chillers, centrifugal chillers and large compressors. He is a member of ASHRAE and JSRAE(Japan Society of Refrigerating and Air-Conditioning Engineers).

continued on page 40

continued from page 38

and operating ranges are different from positive-displacement type compressors.

As shown in *Figure 2*, the rotational speed (rpm) of impellers increases as the capacity becomes smaller. If pressure is higher, it significantly increases the mechanical loss from step-up gears and bearings in smaller capacity ranges. This reduces the competitiveness of centrifugal compressors compared with screw compressors in terms of both cost and performance.

However, the advent of oil-free compressors with frictionless magnetic bearings, in which mechanical loss is negligible even at higher impeller rotational speeds, has solved this technical issue of centrifugal compressors.

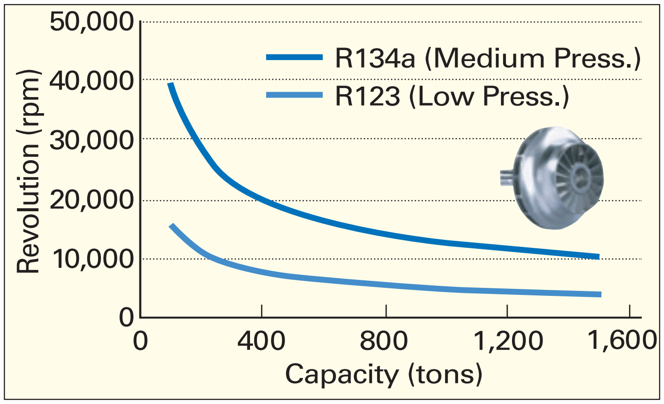

Figure 2: Revolution vs. capacity, centrifugal compressor (single-stage)

Advancement of Oil-free Compressors

The development and start of production of a small 70-ton oil-free centrifugal compressor with magnetic bearings by Danfoss Turbocor in the early 2000s was a significant technical innovation in refrigeration compressors. Daikin Applied has developed large oil-free compressors with capacity of 500–700 tons and has since released a 1,500-ton chiller. York has developed large compressors with capacity of 210–1,000 tons, with the recent release of a single compressor 1,000-ton oil-free chiller. Mitsubishi Heavy Industries (MHI) has also developed oil-free compressors in the range of 350–500 tons. In 2014, Gree released a two-stage oil-free compressor with 1,000 tons of capacity. Oil-free compressors with magnetic bearings started with small capacity but have rapidly extended their range to higher capacities.

The basic technology of magnetic bearings is not new. A company specializing in research and manufacturing of magnetic bearings was established about 40 years ago. But the high cost of magnetic-bearing systems was an issue in commercializing them for air conditioning and refrigeration compressors. The control system also included controllers and required advanced control technologies to obtain stable operation over the wide operating conditions of chiller systems.

In addition, typical oil-free compressors require a motor attaining high rotational speed directly coupled with the impeller. For larger compressors, the development of large permanent magnet (PM) motors and cost-competitive variable frequency drives (VFDs) were also critical issues. The recent technical advancements in controls, electric devices, and semiconductors have made magnetic-bearing systems more compact and cost effective. As oil-free chillers mounted with magnetic-bearing compressors have been recognized in the HVAC market and production increased, the cost of oil-free compressors has fallen to a competitive level compared with conventional compressor costs.

LG oil-free inverter centrifugal chiller

Meanwhile, oil-free compressors that do not use magnetic bearings but refrigerant-lubricated ceramic bearings have also been released in the market. In addition, LG recently released a 300-ton oil-free chiller that utilizes 100-ton oil-free compressors with refrigerant-gas-lubricated bearings. These refrigerant-lubricated oil-free compressors do not require a complicated control system unlike magnetic-bearing systems and have lower friction loss than oil lubrication by using a low-viscosity fluid for lubrication, which improves efficiency.

It is well known that centrifugal compressors can obtain dramatic efficiency improvements with the use of VFDs at off-design conditions. The operating range of VFD, however, is limited to low capacity, and a conventional inlet guide vane (IGV) is generally required to further extend the capacity range, or possibly the addition of a diffuser control system at the impeller exit. These have increased the complexity of the control mechanism for centrifugal compressors. Danfoss Turbocor has recently developed and commercialized a new control system that can extend the operating range through a combination of variable-speed control with diffuser passage control using gas injection without using IGV.

Expanding the Operating Range with Two-stage Compression

Centrifugal chillers were originally developed in the United States for applications in rather mild climates and have used a single-stage design for many years. In the 1990s when conventional R11 refrigerant was phased out and replaced with R134a refrigerant, most Asian and particularly Japanese manufacturers developed two-stage chillers to compensate for the reduced

continued on page 42

continued from page 40

cycle efficiency with R134a refrigerant. Two-stage centrifugal chillers with an economizer are now major products in Asian and Japanese markets.

By using an economizer system with two-stage compression, cycle efficiency can be increased by 5–7% under Asian cooling-water temperature conditions. The effect of the economizer cycle is further increased at higher lift conditions such as in Middle Eastern climates or for heat pump applications and can also expand the operating range.

Table 1: Low GWP alternatives for large capacity chillers

Current Refrigerant	Application	Alternative	GWP	ASHRAE Class	Performance	
					Capacity	Efficiency
R123	Centrifugal	HFO-1233zd(E)	1	A1	40% higher than R123	1% lower than R123
R134a	Centrifugal & Screw	HFO-1234ze(E)	6	A2L	26% lower than R134a	Similar or higher than R134a
	Screw	R513A (HFO/HFC Blend)	631	A1	Similar to R134a	2% lower than R134a
	Screw	R450A (HFO/HFC Blend)	604	A1	13% lower than R134a	1% lower than R134a

Note: Performance is based on thermodynamic calculation

Following the recent growth of centrifugal chillers in Asian markets and increasing demand for district heating and cooling systems, heat pumps, ice storage systems, and more efficient air conditioning systems, two-stage centrifugal chillers are expected to increase their market share.

Carrier released a large two-stage centrifugal chiller in 2013 and expanded it to 3,000 tons in 2015. Mitsubishi Heavy Industries has recently started to release two-stage 2,500-ton centrifugal chillers for district cooling in the Middle East.

Screw Compressors

Screw compressors are different from centrifugal types and have much less limitation on high lift conditions, allowing their use in broad applications including water-cooled chillers, air-cooled chillers, heat pumps, and low-temperature refrigeration systems. A wide variety of refrigerants are used with screw chillers, including HFC refrigerants as well as natural refrigerants.

There are currently three types of screw compressors used in HVAC&R applications, namely single, twin, and tri-rotor. Twin-type compressors are most widely used. The single screw compressor for HVAC&R applications was developed in the 1970s, and the tri-rotor compressor was developed in the 2000s for air conditioning applications. A special feature of both types of compressors is their structure, consisting of a main rotor with a pair of mating rotors, which are shorter in length and are balanced for pressure, thus reducing rotor deflection and allowing tight rotor clearance.

For the respective three types of compressors, analyses to identify optimum profiles and losses have been carried out to improve compressor efficiency. Under current market trends emphasizing Integrated Part Load Value (IPLV) for HVAC equipment, the VFD variable-speed control system has become widely used in screw compressors.

Variable-speed Control and PM Motors

Conventional capacity control of screw compressors using a slide valve causes significant loss due to bypass flows during part-load operation, which results in poor part-load performance. Screw compressors with variable-speed control systems, which eliminate the slide valve, were released around 2005 and are now supplied by most major manufacturers.

Since the rotational speed of the screw rotor is not as high as that of centrifugal compressors, a conventional alternating current (AC) induction motor can be used to increase the rotational speed to above 90 Hz, allowing capacity to be increased. Meanwhile, the rotational speed of centrifugal compressors cannot be increased further due to the limitation of the acoustic velocity of gas flow in the compressor.

Screw compressors mounted with permanent magnet (PM) motors have been developed to further improve part-load performance. At this time, the maximum capacity of PM motors is around 200 hp, as the capacity is determined by the trade-off between motor cost increases and performance improvement benefits.

Expanding the Use of Screw Compressors

As environmental issues become more of a concern, the shift from fuel combustion heating to heat pump heating is progressing. Screw compressors are being used not only for HVAC heat pumps but for various industrial applications such as manufacturing process heating/drying, where the supplied hot water temperature is more than 90°C instead of the conventional 60–70°C.

For refrigeration applications, Mycom has released a NH_3/CO_2 cascade refrigeration system using semi-hermetic screw compressors with a VFD-driven PM motor. In the case of energy recovery systems using the Organic Rankin Cycle (ORC), semi-hermetic screw compressors are often used as an expander in the system. Screw compressors are becoming more widely used not only for HVAC&R systems but also for various thermal energy systems.

Alternative Refrigerants

The main refrigerants currently used for HVAC centrifugal compressors are R134a and R123. Screw compressors also use R134a refrigerant. When using new alternative refrigerants, most centrifugal compressors require design changes, such as changes to the impeller diameter and rotational speed according to the properties of the respective refrigerant. Screw compressors also require design modifications. Compressor and chiller manufacturers are now exploring solutions for new refrigerants considering performance, compressor cost, and investment.

Promising alternative low-GWP refrigerant candidates for large compressors are listed in *Table 1*. Since compressor performance is determined not only by refrigerant cycle efficiency, but also the combination of cycle efficiency and compressor efficiency, it is important to consider compressor efficiency when using new refrigerants. For screw compressors for refrigeration applications, various blends of hydro-fluoro-olefin (HFO), HFCs and natural refrigerants have been proposed.