VARIABLE SPEED SCREW COMPRESSOR

RAISING THE BAR FOR VARIABLE SPEED PERFORMANCE

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INTRODUCTION

Today's building owners and managers require well-engineered solutions to keep long-term operational costs under control. The ability to lower heating and cooling costs is critical to this goal. The American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) estimates that 50% of all building energy is consumed by HVAC operation.

VARIABLE FREQUENCY DRIVES

Variable frequency drives (VFDs) prevent wasting energy by precisely matching motor speed with cooling requirements, which results in dramatic reductions in power usage.

Affordable and factory installed in most cases, VFDs are one of the most cost-effective ways to maximize efficiency and reduce operating costs. According to ARI (Air Conditioning and Refrigeration Institute) Standard 550/590-2003, chillers typically run 99% of the time at part-load (off design conditions). Therefore, having your chiller match your building's load profile will provide both efficiency and comfort.

To date, variable speed centrifugal compressors have been the best means to effectively reduce energy consumption during the majority of the operational hours. When variable speed is applied to a screw compressor, the savings are increased, since the variable speed screw chiller always provides the maximum amount of speed reduction.

In order to fully appreciate the benefits of variable speed screw water-cooled chillers, an understanding of centrifugal water-cooled chillers is required.

CENTRIFUGAL COMPRESSORS

Centrifugal air compressors had been in use for 75 years when, in 1916, Dr. Willis H. Carrier recognized their potential for air conditioning applications. Carrier sold the first water-cooled centrifugal chiller in 1924 to the Onondaga Pottery Company in Syracuse, New York. The machine ran for 26 years and provided air conditioning throughout that period. The compressor of that first machine was retired to the Smithsonian Institute in Washington, D.C., where it remains as one of the major technical developments in the history of the United States.

Centrifugal compressors are dynamic compression devices that continuously exchange angular momentum between a rotating impeller and steadily flowing refrigerant. As refrigerant molecules are accelerated outward by centrifugal force, new ones are drawn into the compressor to replace them. The overall effect is one of continuously compressing a stream of refrigerant. (Figure 1.)

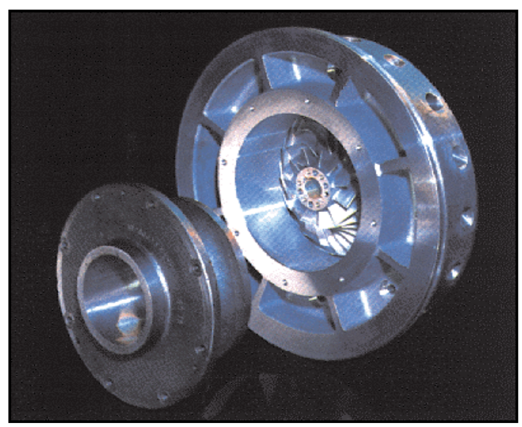


Fig. 1. Centrifugal compressor impeller and diffuser.

Centrifugal compressor performance can be modeled by the following ideal fan laws.

Ideal Fan Laws

Law 1

$$Flow\,Rate_2 \propto Flow\,Rate_1 \times \frac{RPM_2}{RPM_1}$$

Law 2

$$Lift_2 \propto Lift_1 \times \left(\frac{RPM_2}{RPM_1}\right)^2$$

Law 3

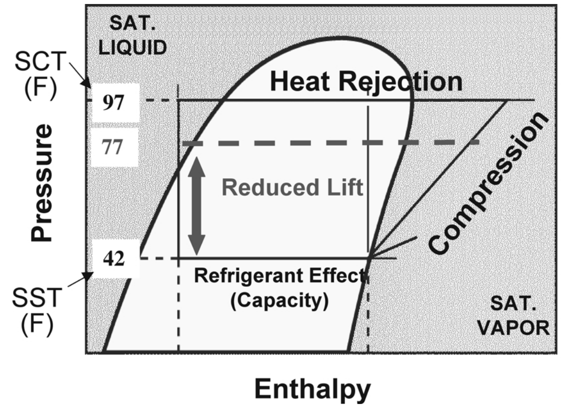
$$Power_2 \propto Power_1 \times \left(\frac{RPM_2}{RPM_1}\right)^3$$

Lift

Lift is defined as the difference between the condensing (discharge) pressure and the evaporating (suction) pressure. Therefore, lift, or the amount of work the compressor performs on the refrigerant, is dependent on the leaving chilled water temperature and condenser water temperature. The compressor only experiences full lift conditions when the wet bulb temperature is at design and refrigeration load is 100%. As the wet bulb temperature decreases, the cooling tower provides colder condenser water to the chiller, reducing the lift required of the compressor. (Figure 2.)

In addition, reductions in load will reduce lift because lower saturated condensing pressure result when less heat is rejected to the condenser. A variable speed chiller responds to changes in lift and refrigeration load by adjusting speed.

As demonstrated by the ideal fan laws, a reduction in speed of the centrifugal compressor will have an exponential (cubic) decrease in compressor power consumption. Given this fact, it is no surprise that to date, variable speed centrifugal compressors have been the best means to effectively reduce energy consumption during the majority of the operational hours.



SST = Saturated Suction Temperature
SCT = Saturated Condensing Temperature

ARI conditions: (2 F approach)
Lift = 97 F - 42 F
With 65 F entering condenser water,
Lift = 77 F - 42 F

Fig. 2. Pressure enthalpy chart.

WHY INLET GUIDE VANES ARE USED IN VARIABLE SPEED APPLICATIONS

The most common form of capacity control for constant speed centrifugal chillers is to modulate guide vanes at the impeller inlet (also called pre-rotation vanes). As load is decreased, the mass flow of refrigerant moving through the compressor must be reduced. On constant speed machines, the guide vanes are closed to match compressor capacity to the load. When centrifugal machines are equipped with VFDs, speed control can also be used to control capacity. In this case, the impeller speed can be reduced to match the compressor capacity to the load.

$$Lift_2 \propto Lift_1 \times \left(\frac{RPM_2}{RPM_1}\right)^2$$

Recalling that the lift produced by a centrifugal compressor is also reduced when speed is reduced, we can determine that speed adjustment alone cannot always be used to regulate the variable speed centrifugal chiller. Under certain lift conditions, the speed is reduced as much as lift requirements will allow and then guide vanes are used to complete the load reduction. Mechanical unloaders of any kind introduce inefficiency. So while speed reduction is almost always obtained with any reduction of lift or load requirements, the question becomes one of magnitude. ***The amount of capacity reduction performed by speed reduction, relative to the amount of capacity reduction performed by guide vanes is an indication of the centrifugal chillers ability to capture all theoretical savings at a given operating point.*** Conversely, the more the guide vanes are closed, the higher the amount of inefficiency introduced into the system.

Given the cubic relationship of speed and power even a small amount of speed reduction yields a significant reduction in energy. However, the more speed reduction possible, the greater the energy savings.

UNDERSTANDING SCREW COMPRESSORS

Heinreich Krigar of Germany developed the first screw compressor in 1878. In the early 1930's, a Swedish engineer by the name of Alf Lysholm developed the profile of the modern screw compressor for gas and steam turbine applications. Screw compressors have been used in HVAC applications for nearly three decades. (Figure 3).

The screw compressor is classified a positive displacement compressor, which simply means that a volume of gas is trapped with an enclosed space whose volume is then reduced. Conventional rotary screw compressors are composed of two parallel rotors with external helical profiles fit into a casing. (Figure 3.) One of the rotors is coupled to the motor (drive rotor) and as it turns it moves the other rotor (driven rotor), similar to a common gear set. The geometric profile of the rotating rotors is difficult to visualize. It is easier to relate the compression process to a reciprocating compressor, if you consider the drive rotor as the piston and the driven rotors as the cylinder. As the drive rotors and driven rotors unmesh, an empty cylinder is created, drawing in suction gas through the synchronized opening on the rotor suction face. As rotation continues, the suction and discharge rotor faces are sealed off, trapping the gas in the cylinder. When this happens, the meshing point moves toward the discharge end of the rotors and drives the gas ahead of it. The discharge port provided for the gas escape is relatively small, compared to the suction port, resulting in positive displacement compression.

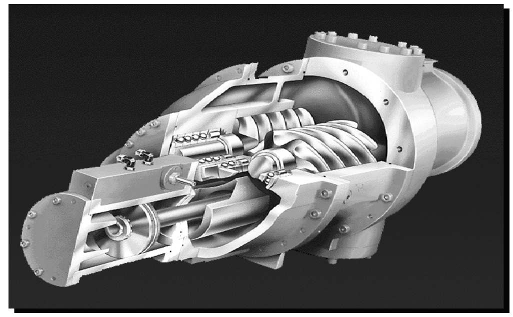


Fig. 3. Conventional twin screw compressor.

Rotary screw compressors are well known for their robustness, simplicity, and reliability. They are designed for long periods of continuous operation, needing very little maintenance. Screw compressors can overcome high lift when speed is reduced, allowing energy savings without the possibility of surge as the compressor unloads.

VARIABLE SPEED SCREW COMPRESSORS

For positive displacement compressors, speed is independent of lift, or worded another way, the compressor can develop the same amount of lift at any speed. Therefore, mechanical loaders can be replaced entirely by speed control. As discussed earlier, centrifugal compressors may require speed control coupled with some closure of the inlet guide vanes. The variable speed screw compressor never has to temper speed control with a guide vane or slide valve, and therefore captures the maximum energy reduction available at a given operating condition. Even small changes in speed create significant changes in energy consumption. Combine this incremental advantage with superior compression efficiencies, and a clear picture of the energy savings potential of this technology emerges.

Variable speed drives used with screw compressors are new to the HVAC industry, but they have been used successfully in various air compression and refrigeration applications. In these applications, screw compressors coupled with VFDs have been utilized to ensure efficient compression at partial and full capacities. Variable speed screw compressors allow a wide range of capacity control while maximizing efficiency.

WHY COMPROMISE?

The variable speed screw chiller combines the best features of positive displacement screw chillers and variable speed technology. The result is a superior chiller with no compromises. A screw compressor with a tri-rotor provides simplicity and reliability. (Figure 4.)

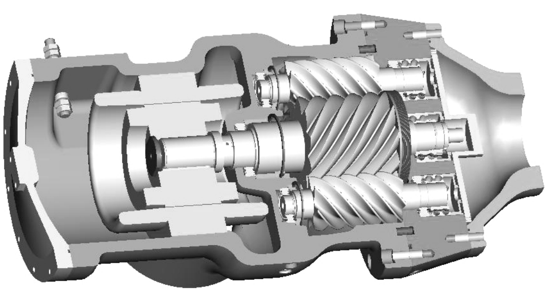


Fig. 4. - Tri-rotor screw compressor.

The direct-drive, tri-rotor design allows for shorter rotors and is about 5 to 10% more efficient than the twin-rotor design. The tri-rotor also balances thrust, which reduces bearing loads.

A VFD CHILLER FOR HUMID CLIMATES

Applications where high lift requirements remain even as cooling loads decrease may favor variable speed screw chillers more significantly. An example of this application is a building located in a hot and humid climate where cooling loads can vary while outdoor-air temperatures (dry bulb/wet bulb) remain high.

A variable speed screw compressor chiller is approximately 10 to 20% more efficient than all variable speed centrifugal compressors with <u>constant 85 F</u> entering condenser water.

CHILLER SELECTION CRITERIA

System part load performance is a crucial factor in chiller selection, since chillers rarely operate at full load design conditions. Consulting engineers and owners should understand the importance of using system part load performance for their specific application as the selection criterion. ***Simply, the unit with the lowest system part load performance will provide the greatest energy savings across its entire operational range.*** The system part load, when multiplied by total annual ton-hours of cooling, provides an estimate of the total annual kilowatt-hour consumption. ***A variable speed screw compressor chiller saves energy in <u>all</u> operating conditions.***

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REFERENCE

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