BENEFITS OF SELECTING CHILLERS WITH SCREW COMPRESSORS FOR AIR CONDITIONING SYSTEMS

by

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This paper describes the advantages of using screw chiller packages vs. centrifugal and reciprocating chillers. In Sri Lanka, most of the large installations still prefer to use centrifugal chillers rather than screw chillers merely due to lack of awareness of the benefits available with the modern machinery.

Chillers with screw compressors provide better part load efficiencies and energy efficiency. Therefore substantial power cost savings can be achieved when chillers with screw compressors are installed in large and medium buildings.

This article intends to help building managers/engineers and end-users in the engineering field.

Screw Compressor

There are two types available in the refrigeration & air conditioning field namely Mono Screw and Twin-Screw compressors. Although both types are used in Refrigeration & Air conditioning systems, Mono screw is widely used in the refrigeration applications. Twin screw is a popular item in the air conditioning chillers.

The distinct advantage of a screw compressor is, that it consists of less parts. There are only three moving parts in the twin-screw compressor compared to several moving parts in the reciprocating type. The total number of parts in a screw compressor is one tenth of that in a similar capacity reciprocating compressor.

Re-expansion is eliminated in the screw compressor, and complete flute volume will be filled with suction gas. Due to this reason volumetric efficiency increases. There are no suction and delivery valves thus no wire drawing takes place during passage through the suction and delivery ports.

In screw compressors, high compression ratios, up to 20:1 is achieved with single stage compression. This is a great advantage in refrigeration duties, where multi compression is avoided by using screw type compressors.

However, in a reciprocating compressor compression ratio increases approximately beyond 9:1 therefore multi stage compression is required.

Mono Screw Compressor

Mono screw compressor is a positive displacement machine, which is designed, for compression of all refrigerant gases in industrial refrigeration, air conditioning and heat pump systems. Usually it is driven by either 2 pole, 50 or 60 Hz electric motors. It also operates on turbines, internal combustion, gas or diesel engines.

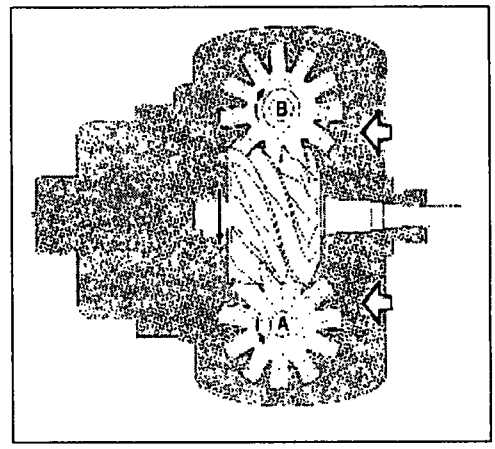

Fig.1 Mono Screw Compressor (Curtsey of J & E Hall limited UK)

Mono screw consists of a main rotor, which meshes with two diametrically opposed star wheels that seal the rotor grooves. The same sequence of suction, compression & delivery take place simultaneously in the top half and the bottom half. When the main rotor rotates (anti clockwise from the rotor end), suction gas enters the cavity space axially on the top half and the bottom half. Gas compression begins when further rotation of the rotor, causes gas to be pushed toward the end of the main rotor, where it reduces the volume of the groove. Finally, reduced space exposes the delivery cavity, where gas is delivered to the discharge line.

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The same sequence of operation occors on the under side of the rotor.

Twin Screw Compressor

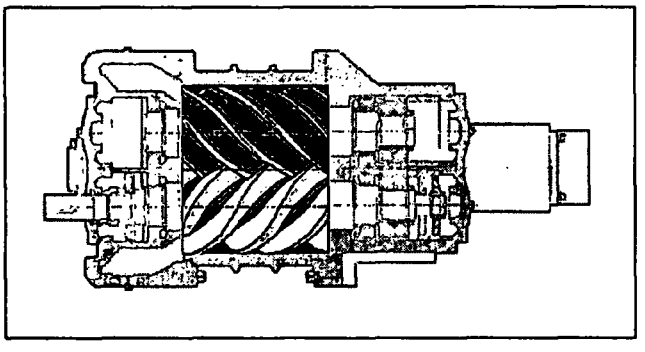

Fig.2 Twin Screw Compressor

Out of two types, compressors twin-screw is regarded as the most popular version both in the refrigeration and air-conditioning field.

Twin screw has two helical rotors. They are identified thus; the "male", (which is driving), and the "female", (which is driven). Usually, the male rotor has 4 lobes and the female has 6 flutes. As shown in the figure above, two helical gears are intermeshed and suction gas fills through the uncovered lobe spaces. Further rotation of the screws, and interlobe spaces increases its volume and suction continues. Gas moves along with rotors to the end of the intermesh where interlobe space volume gradually decreases and compression begins. Compression continues until the delivery port is uncovered which is located at the bottom of the rotor on the opposite end.

The rotor and compressor housing do not contact each other, except at the point where the driving action between the male and the female rotor occurs. Oil sprayed along the top of the compressor rotor section completely lubricates both rotors, along with the compressor-housing interior. The primary purpose of the oil injection is to seal the clearance spaces that exist between the rotors and compressor housing. Effective seals between these internal parts enhance compressor efficiency by limiting leakage between the high and low-pressure cavities.

The driving electrical motor is directly coupled and rotors are driving in two speeds. If the male rotor speed is N, the female rotor would be driven at 2 N/3 due to 4 + 6 combination of rotors.

Swept volume rate is given by

$$V_{sw} = K \pi N D^2 L \qquad (1)$$

$$k = \frac{a_m + a_f}{\pi D^2 / 4} \qquad (2)$$

Where;

N = rotational speed of the male rotor
L = Length of rotors
D = diameter of the rotors
a_m, a_f = Cross sectional areas of rotors

In machines with asymmetric rotors, K is about 0.155

Total Volumetric Efficiency;

$$\eta_v = m v_1 / V_{sw} \qquad (3)$$

Where;

m = mass flow rate
v_1 = specific volume at entry to the compressor
V_{sw} = swept volume

Since high-pressure vapour remains at the end of the delivery stroke is smaller, the volumetric efficiency is higher. Screw compressors can have higher compression ratios without loss of volumetric efficiency.

Capacity control

A slide valve between two rotors is used for capacity control. Unlike in reciprocating compressors, this has a continuous modulation from 100% capacity to less than 10%. The slide valve is driven by a piston/cylinder along an axis parallel to rotors.

Capacity control slide valve by-passes the gas being compressed to the suction manifold thus decreasing the capacity. In some compressors in addition to the slide valve the discharge port also regulates. This gives better part load efficiency of the compressor. Step-less modulation of capacity is a unique feature of screw compressors. The screw type the comp ressors are the most efficient among compressors due to this factor. Therefore, chiller packages with screw compressors in air conditioning industry are more efficient than any of the other chillers at load and part load conditions.

Built in Volume Ratio

This is a unique term, in screw compressors technology. Built-in volume ratio is defined as the ratio of volume of the interlobe space at the start of the compression to the volume of the same interlobe when it first begins to open to the discharge port. In the refrigeration industry there are fixed volume ratio machines and variable volume ratio machines.

Vertical Hermetic Compressor

The latest additions to the screw compressor range are the Hermetic and Semi Hermetic vertical compressors. As shown in figure 3, Hermetic Compressor motor is on top of the housing, which is under the high-pressure side of the system. This is known as high side crankcase, which eliminates any mechanical oil pump. Since suction vapour is not used for Hermetic motor cooling, there is no superheating of suction gas.

These compressors are reported to run more than 75,000 hours without any compressor overhaul.

Features of Screw Compressors Chillers

Fig.3 Vertical Hermetic Screw Compressor used in chiller packages
(Courtesy of Dunham-Bush)

There are three primary features, which customers look for when selecting a chiller package for air conditioning . These are

1. Reliability
2. Performance
3 Low price

Key elements for the reliability and low price would be, low-speed direct drive configuration with only three moving parts and precise rotor tip clearences.

Direct drive compressors

Direct drive configuration benefits the compressor performance by eliminating the need for speed, increasing gears and their transmission losses which range from 3%~4%. Since these losses are fairly constant, over the full load range, losses increase as the gear driven machine unloads. For example, at 50% load, these losses would be 6%~8% and at 25% load, losses would be 12%~16%.

Precise Rotor Tip Clearences

Like in vane axial fans, closer rotor tips clearences in the helical rotary compressor areas are critical in maintaining performance, high efficiency and low noise levels. Excessive tip clearances result in refrigerant gas leakage between rotor cavities, thus reducing full and part load performance. To minimise leakage and achieve optimum performance, the screw compressor utilises machining techniques and machine tools similar to those used in the production of watches, jet aircraft engines and military applications.

Following are some of the features found in screw compressors in water chillers for air conditioning duty;

1. **Class-5 Bearing Design-** a critical component in the design of rotating equipment is the bearings. Modern screw compressors utilise four bearing assemblies consisting of long life class-5 rolling element bearings to locate and support the rotors. Clas-5 bearings are the type typically used in precision machine tool applications requiring rigid tolerances and long life.

2. **Oil Separator-** Screw compressors utilise modern oil separators to ensure that the oil remains in the compressor where it belongs.

3. **No Oil Pump-** Compressor utilises high pressures shells where pressure difference maintains the oil flow thus eliminating the need for an oil pump.

4. **Fixed Orifice Flow Control-** With flooded evaporator utilisation, no thermostatic expansion valves are necessary. Typical low side float valves used in flooded evaporator application are also eliminated by using the fixed orifice system, because there are no moving parts thus enhancing the reliability.

5. **Microprocessor control-** Microprocessor controls allow self-diagnostic features with control strategies for smooth efficient and uninterrupted cooling comfort.

Energy Efficiency

Energy efficiency is calculated on a screw chiller package is similar to that of a reciprocating chiller.

1. **Coefficient of Performance (COPref)**

   a. A Ratio of refrigerating Effect KJ/Kg to the work done KJ/Kg

   b. A Ratio of the cooling capacity in Watts, to the Power input in Watts at any given rating conditions

2. **Energy Efficiency Ratio (EER)**

   a. **A Ratio of the cooling** capacity in Btu/hr to the total power input in watts at any given set of rating condi tions.

3. **Power Input per Ton (kW/Ton)**

   a. A Ratio of the total power input to the unit, including controls, in kW to the net refrigerating capacity in tons at any given rating condition.

ARI Ratings

When selecting chillers, it is advisable to check whether the equipment is "Performance Certified" and complied with certain standards such as ARI standard 550-90. Air conditioning and Refrigeration Institute (ARI) in America has different standards and certification programmes for performance testing of chillers. Therefore it is advisable to select ARI rated equipment, which would have at least been tested for correct equipment capacity and eventually offer safeguards to the customer.

Fig.4 ARI seal found in Certified Documents (Courtesy of ARI)

Under the ARI standard 550-90 certification programmes, screw chiller packages are tested in strict compliance. This provides an independent, third party verification of the chiller performance.

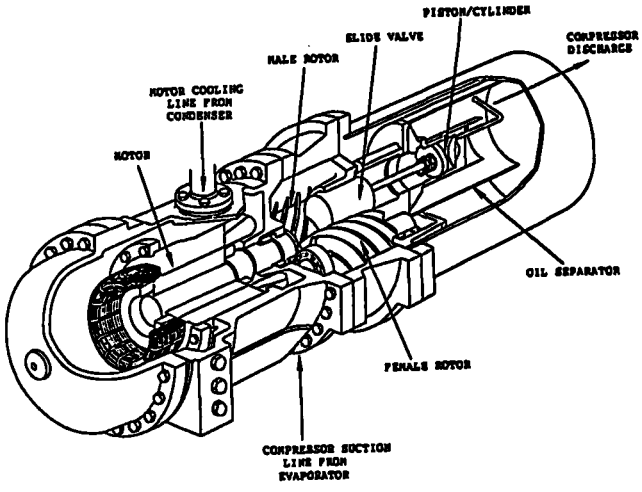

Fig 5 - Components of Twin Screw Compressor (Courtesy of the Trane Company)

Integrated Part Load Value (IPLV)

Although we select chillers for peak heat load, they are not operating at peak capacity through out the day. Most chillers operate at lower load conditions and lower condensing temperatures. It is not uncommon for chillers with the same full load kW/TR to have an operating cost difference of over 10% due to part load operation.

Part load information can be easily and accurately generated by use of a computer. Since it is so important to an owner's operating budget, this information has now been standardised within the ARI Certification programme in the form of Integrated Part-Load Value *(IPLV)*.

The following equation is used when efficiency is expressed as EER or COP

$$IPLV = 0.01A + 0.42B + 0.45C + 0.12D \quad (4)$$

Where:

A = EER or COP at 100% capacity
B = EER or COP at 75% capacity
C = EER or COP at 50% capacity
D = EER or COP at 25% capacity

The following equation is used when efficiency is expressed in kW/Ton

$$IPLV = \frac{1}{\frac{0.01}{A} + \frac{0.42}{B} + \frac{0.45}{C} + \frac{0.12}{D}} \quad (5)$$

Where:

A = kW/ton at 100% capacity
B = kW/ton at 75% capacity
C = kW/ton at 50% capacity
D = kW/ton at 25% capacity

(Above equations are taken from the ARI Standard 550/590)

Actual data from chiller tests are used to derive the IPLV values for particular chillers, which are manufactured and ready for delivery from the factory. When we order a chiller for a particular duty, the factory, which manufactures the particular chiller, will issue the IPLV at given conditions.

A typical screw chiller with 0.73kW/Ton efficiency at full load has an IPLV of 0.528 as determined in accordance with ARI 550-90 Standard.

Selection of Screw Chillers

In practice most designing engineers, contractors and building owners prefers the reciprocating chillers for loads upto100 TR. Centrifugal chillers are available above 100TR capacity and they are more efficient and economical to use for larger capacities.

However, with the advent of screw chiller packages, it is evident that enormous power savings could be achieved utilising the screw compressor. Retrofit applications are best examples for power savings in Sri Lanka.

The efficiency of screw chillers, compared to reciprocating chillers is much grater. Reciprocating chillers usually have 1.04 kW/TR at full load where screw chillers range from 0.75 to .83 kW/TR approximately at full load.

Reasons for higher efficiency and reliability of screw chillers are:

1. Low IPLV available for screw chillers. This is mainly due to step-less capacity control down to 10%.
2. Less moving parts and low wear & tear of mechanical parts. Less number of overhauling for the life cycle and lower service cost.
3. Volumetric efficiency is higher due to low clearance volume and no valve leakages.
4. Adaptable for high compression ratios, where multi stages are required with reciprocating compressors.
5. Very high overhaul limits; if properly maintained. It can run without any major overhauls for at least 50,000 hrs operation.
6. Constant gas flow. As there is no pulsation present, this will reduce piping noise and reduce maintenance in general for piping and controls due to less leaks and piping stresses

Factors considered for selection of Screw Chillers

Generally chiller packages consist of a compressor, condenser, water cooler or shell & tube chiller, expansion device, inter connecting piping, controls and motor starting device.

To obtain the maximum efficiency, reliability and economical operation, of a screw chiller package, following items should be considered during equipment selection among various product manufacturers.

1. Screw compressor should have a capacity control system with continuous modulation from 100% to 10%.
2. Compressors shall be open type or semi-hermetic design for easy maintenance
3. If fully hermetic compressors are used, a minimum of two compressors per chiller are required and isolation of compressors for repairs while the others in operation should be provided.
4. The evaporator or the chiller should be of flooded shell & tube version for better heat transfer
5. Microprocessor controlled equipment for chiller operation, which monitors functions, conditions and displays operating status and diagnostic messages for improved operator control.

Conclusion

Screw chillers are designed to provide the greatest amount of cooling for the least kilowatt input over the entire operating range of a building load.

All building owners, architects, consultants and maintenance engineers should consider the installation of screw chiller packages as the better bid for new installations as well as retrofit applications.

Therefore we shall make use of modern advancements in engineering such as screw chillers to minimise energy waste and optimise the comfort conditions of air conditioning systems.

CEB should encourage all commercial and industrial building owners to utilise chillers with screw compressors for better utilisation of the national grid.

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