Kirloskar-Howden Screw Compressor

KIRLOSKAR-HOWDEN SCREW COMPRESSOR

Principle of Operation:

In order to fully realise the advantages of Screw Compressor over reciprocating it is firstly essential to understand the working of the Screw Compressors.

Short History

The Screw Compressor, that is a compressor with two rotors having helical lobes on them and the whole unit having internal compression, was first invented by A.J.R.Lysholm in Sweden in middle of 1930s. It is interesting to note that at the time he was working on the development of gas turbine and he was having troubles with the centrifugal compressor involved.

He developed Screw Compressor as a replacement, the aim being to have a positive displacement compressor thereby eliminating the possibility of surging and being capable of operating at a high rotational speed above that possible with reciprocating designs.

The initial development work was carried out by a Swedish research organisation now known as Svenska Rotor Maschines (S.R.M.)

In the year 1946 James Howden from Scotland took the licence for manufacture and sale of Screw Compressor, the first licence in the world.

Howden was the first to install oil injected refrigeration screw compressor in the world in 1961. In 1966 change in female rotor addendum was introduced. This change from 2% to 3% of diameter changed torque split between male to female from 90%:10% to 85%:15% resulting in avoiding vibrations at low duties and hence timing gears could be eliminated. This change explains unusual rotor dia. e.g.204 and 255 which were 200 and 250 mm earlier. Unsymetric profile rotors were introduced in 1970 which reduced the blow hole area to 10% of previous designs resulting in improvement in performance.

Principles of Operation

Screw compressor is a positive displacement machine with entirely rotary action.

The screw compressor consists basically of two rotors enclosed in a casing. The rotors differ in shape and are identified as 'male' and 'famale'. If these are rotated, a space is formed due to the helix angle of the rotor lobes. This space is enclosed by the rotors and the casings. This volume increases as the rotor rotates and gas is drawn in to fill the low pressure area formed.

A useful anology in understanding this process is to consider the male rotor lobes as pistons and the female flutes as cylinder rotation of the rotors causes the piston to slide along the cylinder and draw in gas.

Continued rotaton results in the lobes remeshing and expelling the gas out of the far end of the casing. However if the cover is placed over the discharge end of the machine then the remeshing of the lobes results in the volume of gas which has been drawn into the set being reduced in volume, i.e.compressed between the meshing rotors and the casing.

At a particular point along the length of the casing a discharge port is positioned which will permit the gas to pass out of the compressor. The amount of internal compression which occurs before release is therefore a characteristic which can be varied by positioning and shaping of the discharge port. This feature is known as the 'Built in compression ratio' of the set.

It can thus be seen that the principle of the compressor is positive displacement with rotary motion and that only moving components are the rotors themselves. There are no valves at either suction or discharge.

Advantages of lubricated compressors over oil free compressors particularly for refrigeration, air conditioning industry.

The fundamental difference between the oil free and the lubricated types is that the former compress the gas without any lubrication of the compression chamber. The rotors are fitted with timing gears so that there is no rotor to rotor contact, so that they can run totally dry in compression chamber.

They are fitted with normally lubricated bearings outside the compression chamber area.

The lubricated or oil injected screw compressor is supplied with oil injected into the compression space to carry out three functions: 1) lubrication, 2) cooling and 3) sealing.

Lubrication:

Oil is supplied to the rotors and there is no longer any necessity to incorporate timing gears to keep the rotors apart. Owing to the geometry of the meshing rotor shapes the male rotor absorbs 85% input power and female only 15%.

As a result the oil provides an effective film **preventing metal to metal** contact and no wear occurs.

A further advantage being it is no longer necessary to incorporate seals between the rotor bearings and the compression chamber and the bearings can be positioned directly besides the rotor body. This is important in that it considerably reduces the rotor bending effect and permits much greater pressure difference across the machine.

Cooling

In compressing any gas the thermodynamic process absorbed in increasing the pressure levels appears as heat in the gas after compression. In dry compression high temperartures result from even reasonable compression ratios.

For example, ammonia compression over a pressure ratio 10/1 i.e.-23°C/+40°C. The adiabetic temperature rise is 315°F (173°C). If adiabatic efficiency is 85% then the final temperature would be 182°C(360°F).

In case of oil injected compressor, oil is added in sufficient (and controlled) quantity to reduce the discharge temperature to be within a predetermined level. This is normally in the range of 60°C to 100°C maximum.

The volume of injected oil is relatively small, normally less than 1% of the compressor suction volume, but its heat capacity is relatively high as it is in the liquid phase and its heat absorption capacity is proportionately greater than an equivalent volume of gas. Thus with this relatively small addition of approx 1% by volume of oil the final discharge temperature is accurately controlled.

This enables a wide variation of suction and discharge pressures to be handled with complete freedom from temperature limitations.

(3) Sealing

The rotors in order to mesh smoothly and capable of some temperature variations, must have clearances between them. When operating 'dry' gas would leak- back thro' these clearances reducing the compressor performance particularly at high pressure differences . When oil is injected into the compressor, these clearances are effectively sealed. This means not only the gas leakage is reduced but much higher pressure differences are possible with high efficiencies.

ADVANTAGES OF SCREW COMPRESSORS OVER RECIPROCATING COMPRESSOR

Simplicity in compressor design and increased reliability.

Reliability is inherent in the screw compressor design concept since the basic design consists of two rotors, one being driven directly by motor and the second driven by the first. The inlet/outlet ports are opened and closed by moving rotors without any valves whatsoever, and since the bearings are very close to rotor bodies there is virtually no rotor deflection. As the rotors are fully lubricated and act as cycloidal gears, there is no requirement for timing gears as used in oil free screw compressors.

Since the maximum temperature occuring anywhere in the compressor never exceeds $100^{o}C$ there is no requirement for casing cooling by water jacket or any other means.

Reliability of compressor is therefore increased both due to low operating temperatures and reduction in compressor components. The screw compressors uses approximately 1/10th the moving parts of reciprocating compressors. The components such as the pistons, connecting rods, valve plates which need periodic meintenance are totally absent in screw compressor. Similarly, friction intensive piston rings and anti-friction bearing construction results in lower frictional power.

No metallic contact occurs between the rotors. As a result oil passing provides effective film and nowhere metal to metal contact occurs.Howden claims that there are many installations which have run in excess of 80,000 hours with no evident wear on the rotors.

This is very important advantage for critical industrial processes which are often continuous in operation and handle large quantities of chemical materials. In order to ensure economic operation of the plant involved, it is important that all the various items of equipment are as reliable as possible and easy to repair and overhaul and it should be possible to add means of predicting problems before actual failure occurs.

The Mean Time Before Failure of machine (MTBF) is directly related to the number of moving items involved in compressor operation. Less the number of components, the less possibility there is to go wrong. The screw compressors therefore meet above requirements idally. The reliability of the compressor is such that recommended overhaul period is after 50,000 hours of operation which is equivalent to six years.

As against this reciprocating compressor needs periodical replacement of valves, piston rings, bearings, shaft seal, springs O rings and number of other components.

Efficiency in operation

No matter how reliable any machine might be, it is of little consequence if it does not operate efficiently. Fortunately the screw compressor is efficient and further more since the various components do not touch each other in operation and therefore do not wear the efficiencies maintained throughout the operation. Reciprocating machines give high efficiencies when they are new and drop drastically over a period.

The presence of oil in the rotors during compression forms an effective seal between the rotors and between the rotor and rotor housing thus greatly reducing the leakage of gas from high pressure side to low pressure side of the rotors. This means the ability to handle high pressure ratio, cool operation and improved sealing resulting in higher efficiency. As there is no clearance volume in screw compressor compared to reciprocating compressors, the screw compressor draws in, compresses and discharges the gas by virtue of the helical shape of the meshed rotors, the shape of rotor casings and the gas ports. No gas volume is left in the machine at the end of compression cycle which normally would be associated with any reciprocating compressor having valves. This ensures that the limiataions due to residual clearance volume and associated re-expansion and re-compression do not occur and very high operating pressure ratios are quite feasible and practical. The volume handled by screw compressor is therefore directly proportional to rotor speed.

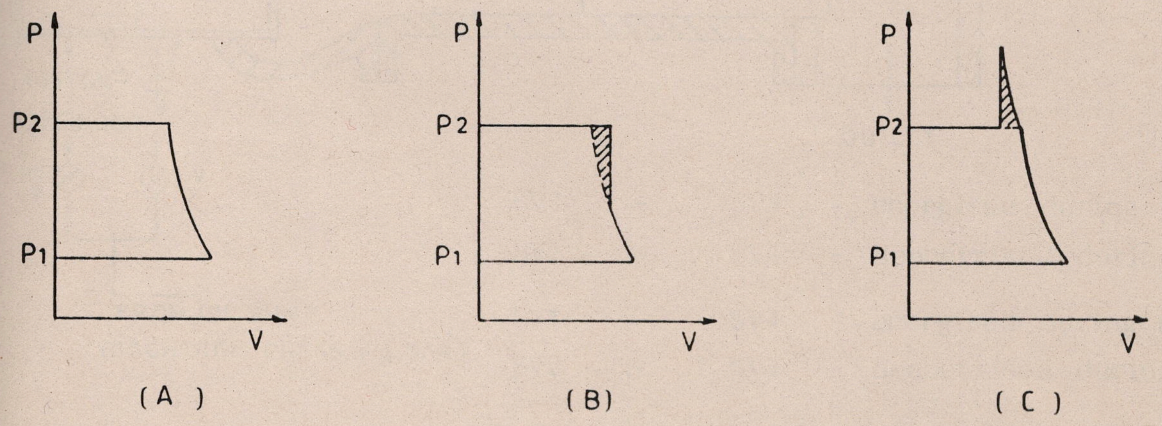
The low temperature of oil also makes it possible to operate with very small rotor clearance and this minimises leakage in the compressor thus ensuring high efficiency both volumetric and total C.O.P.

The screw compressor has relatively flat efficiency characteristics as compared to reciprocating compressors since there is no residual clearance volume.

Also since in screw compressor there are no valves, there is no wear or leakage and hence the basic design efficiency is not reduced over a period.

Built in compression ratio is another important variable in screw compressor which greatly assists in ensuring high efficiency. The discharge port in the casing is sized to determine how much compression matches the overall duty requirement as shown below

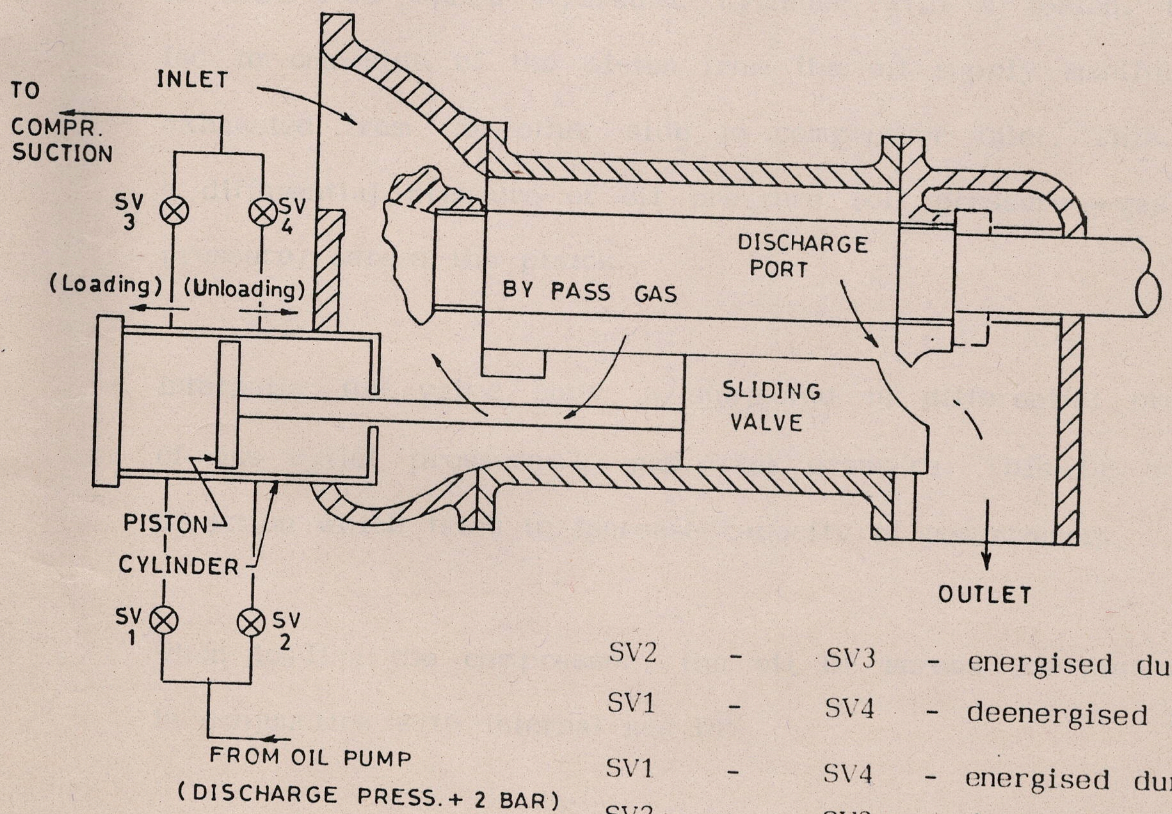
Effect of internal compression



p - v diagrams of internal compression

Condition A is ideal whereas B and C would result in losses and reduction in efficiency. A number of different discharge port sizes and hence built in compression ratios may be used on any given size compressor to enable high efficiency to be obtained at any operating pressure ratio within the compressor range.

Capacity Control Arrangement



SV2 - SV3 - energised during loading
SV1 - SV4 - deenergised during loading
SV1 - SV4 - energised during unloading
SV2 - SV3 - deenergised during unloading

The major feature of screw compressor compared to reciprocating compressors is fully variable stepless capacity control as against step control.

In many processes and particularly for refrigeration systems some means of efficiency and simply varying the compressor output is highly desirable. This has been achieved in screw compressor by means of integral slide valve.The effect of this is to vary the effective length of the rotor being used. This enables to adjust the output of the compressor to match the system demand at any given time.The movement of slide valve is controlled via a hydraulic cylinder with a piston. Oil is fed to one side of the piston from the oil supply manifold and exhausted from the other side to compressor inlet. This gives a differential pressure of oil pressure (oil pressure — gas inlet pressure) across the piston.

Internally the valve body is subjected to differential pressure of gas outlet pressure to gas inlet pressure. This DP acts in direction which tries to increase capacity of compressor.

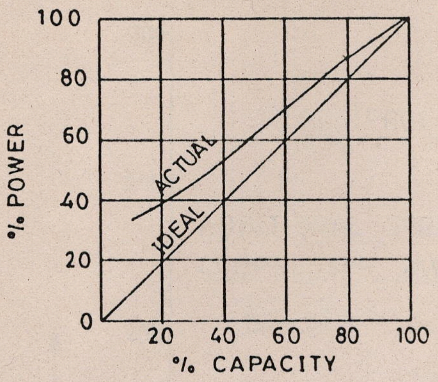
When loading the compressor, the oil DP across the piston acts in conjunction with internal gas DP.

When unloading the compressor the oil DP across piston must overcome the internal gas DP.

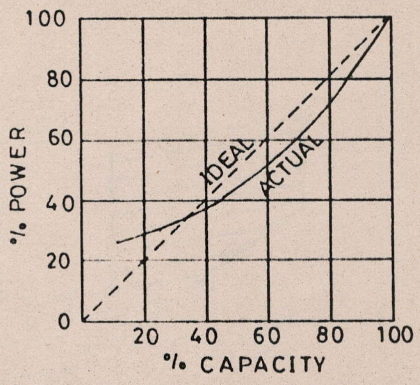
Hence it is easier to load than unload.

Note oil pressure = Gas outlet pressure + 2 Bar.

PART LOAD CHARACTERISTIC
Constant discharge pressure



PART LOAD CHARACTERISTIC
Falling discharge pressure



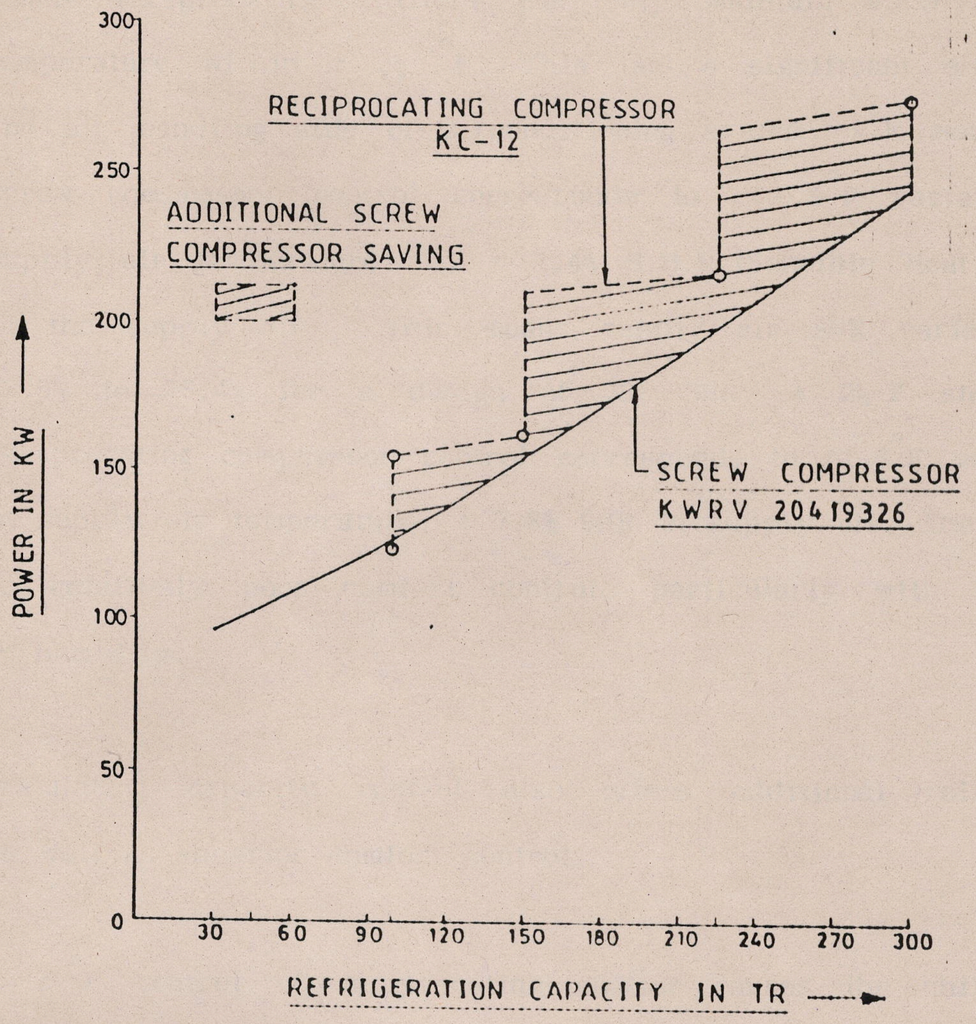
Insome installations the discharge pressure of the compressor falls off with reducing mass flow. For example, in refrigeration plants this usually happens and this further enables part load characteristics to improve. The condensing pressure falls as the condenser with its fixed heat exchange surface area and constant water flow becomes more effective at the reduced gas mass flow at part load. Similarly the suction pressure increases slightly as the heat exchanger (evaporator) also becomes more effective for the same reasons.

A comparison between screw compressors and reciprocating compressor having similar capacities is enclosed from which it is evident that screw compressor installation saves power during its yearly operation.

The proportional integral and derivative logic control available with screw packages allows to maintain temperatures within ± ½°F accuracy. This is extremely important in maintaining comfort conditions. Reciprocating compressors are commonly supplied with 3/4 steps of capacity control depending upon the compressor design controlled from return water and

TYPICAL PART LOAD PERFORMANCE FOR SCREW V/S RECIPROCATING COMPRESSOR

REFRIGERATION CAPACITY V/S POWER CONSUMPTION WITH R 22
BASED ON 0°C EVAPORATING & 40°C CONDENSING TEMP.



PERCENTAGE REFRIGERA-TION CAPACITY	POWER CONSUMPTION IN KW		DIFFERANCE IN KW	NO. OF HOURS OPERATION	TOTAL POWER SAVING IN KW
	SCREW	RECIPROCATING			
100	243·26	272·79	29·53	300	8859
90	226·23	250·53	24·30	1500	36450
80	206·77	228·28	21·51	1500	32265
70	187·31	206·03	18·72	1200	22464
60	170·28	183·78	13·50	900	12150
50	153·25	161·54	8·29	300	2487
40	136·22	139·29	3·07	300	921
			TOTAL-	6000	115596

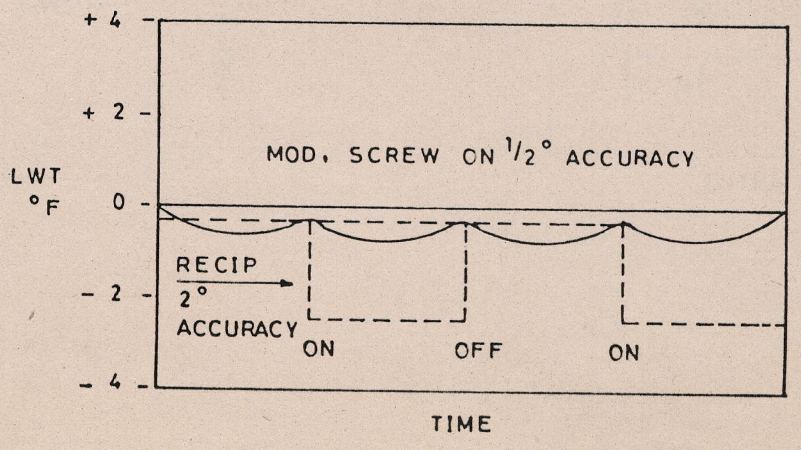
100% CAPACITY REPRESENTS 300 TR FOR BOTH

300 TR FOR BOTH

10°F differential between supply and return temperatures. This means reciprocating chillers can only maintain supply water temperature within ± 2½ $^{\circ}$F. This has a significant effect on the air handling side of airconditioning system. ½ $^{\circ}$F modulating screw compressor control corresponds to ± 0.4 $^{\circ}$F variation in supply air temperature and ± 1.4% S.H.R.(Sensible Heat Ratio) in the supply air. This means supply air SHR varies from 73.6% to 76.4% for a design of 75% SHR. ± 2½ $^{\circ}$F stepped reciprocating compressor control corresponds to ±1.8 $^{\circ}$F variation in supply air temperature, ± 7.8% SHR in supply air. The result is relatively poor comfort control, particularly with respect to humidity.

Modulating capacity control also offers additional reliability as well as superior comfort control.

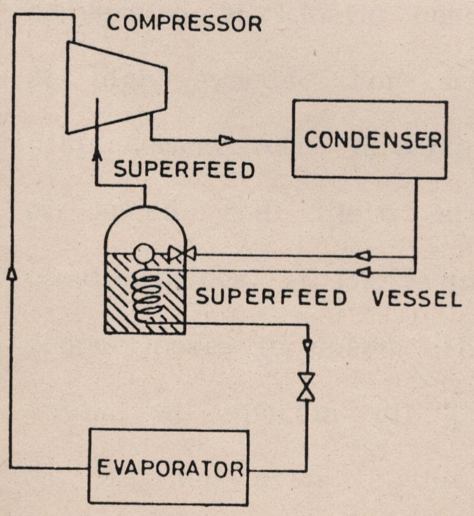
A 2½ $^{\circ}$F control of reciprocating chiller causes the chiller to continually cycle between the stages in a futile attempt to match load. The additional compressor cycling along with problems in thermal expansion valve operation are a maintenance liability totally eliminated in screw compressors.

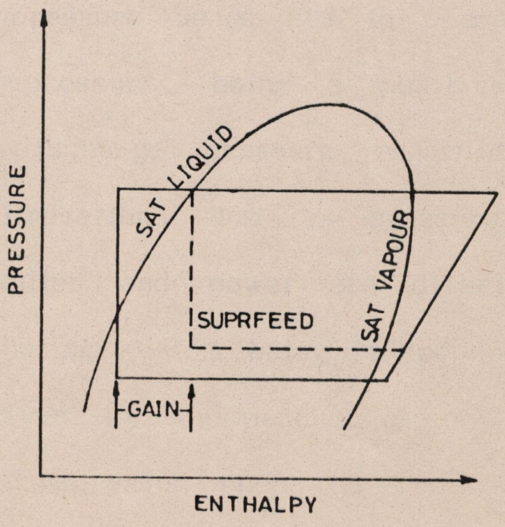


SuperFeed System

One of the more recent developments is the super feed system which means the efficiency of a single stage screw compressor upto a level comparable to a two stage unit. It is therefore of particular significance in high pressure ratio applications.(low temp)

The basic principle is that an additional port is provided in the casting which connects into the rotor after the normal suction phase has been completed. Therefore if higher pressure ratio (that is higher suction) requirement is available, an additional charge will be taken in by the compressor through this port. This is arranged by the super feed vessel sub cooling the liquid leaving the condenser while the gas generated going on to the suction port. The figure below illustrates this action:





The beneficial effects of vapour compression are most pronounced at high pressure ratios i.e., for low temperature applications.

For a reciprocating compressor this result can be only partially accomplished by mechanical subcooling. Subcooling increases only the compressor capacity and not the isentropic efficiency. Mechanical subcooling requires not only additional hardware but also sometimes requires addition of a separate compressor.

Variable speed

It is undisputed fact that maximum efficiency is achieved when the speed is varied proportionately to load requirements. This however, is not feasible with reciprocating or centrifugal compressors. In reciprocating machines lowering of speed affects the lubricating system whereas in centrifugal compressors, not being a positive displacement, works on the principle of conversion of kinetic energy to pressure hence has to operate at high speeds. For screw compressors, being a positive displacement can develop full discharge pressure regardless of speed and there are no limitations due to pressure considerations. The volume handled and power are directly proportionate to speed. The lubricating system being independent having a separate oil pump driven by independent motor is not affected even if the screw compressor speed is reduced. With the advancement of electronic Thyrister control speed reducers the system is bound to become more popular in not too distant future as the cost of the speed reducers is falling rapidly and would become an economically viable alternative.

Wide range of application

Since the volumetric efficiency remains more or less constant at all pressure ratios and since it is determined only by the clearance between the rotors and the housing, the single stage screw compresor can operate efficiently upto -55 °C., a temperature which is impossible for reciprocating compressors to achieve without multi-stage application involving complicated and expensive system design.

Also due to high compression ratio involved in low evaporating temperature applications, discharge temperatures in reciprocating machines would be extremely high if single stage compression is envisaged hence one has to go for multi-stage. This is not so in screw compressor since the discharge temperature of refrigerant is not dependent on the pressure ratio and is controlled by a separate oil cooling circuit.

Ability to handle liquid

It occasionally happens that some liquid is passed directly into the compressor either due to a fault developing in the overall system or due to mal-function. The reciprocating or centrifugal compressors cannot handle liquid, even minute drops can damage the machine.In the reciprocating compressors if the liquid stroke occurs, it can lead to major breakdown and even the minute droplets can damage valve plates.

The screw compressor can and does handle amazingly large quantities of liquid without this even being evident and causes absolutely no damage. The compressors are capable of handling wet refrigerant or even ramdom slugs of liquid without any effect on compressor whatsoever. The compressor has no valves to be broken, there are no sliding surfaces to be washed clear of luricant and there are no excessive loads which get applied to any of the component. When liquid refrigerant enters the suction port a certain amount of liquid separation occurs at the inlet. This means that the certain amount of gas is sucked into compressor together with liquid refrigerant and and since the built in volume ratio of refrigeration screw compressor is normally less than 5, the volume of the inter lobe space at the outlet is large enough to pump out the gas liquid refrigerant mixture without any liquid hammer and without any mechanical stresses and strains.

As an added advantage one can state that this eliminates the need for additional suction line accumulator in the system altogether which is required at times in reciprocating installations.

Lubricating system and oil foaming

It is interesting to note that unlike reciprocating compressors the oil system is at discharge pressure and not at suction pressure. Therefore the problem of oil foaming and thereby passing out of the crankcase into the gas system at start up cannot occur in screw compressor.

Oil is supplied to all working parts at an elevated pressure. This ensures the margin of safety above the dilution point (saturation) so that "flashing",a known case of bearing failures does not occur. Also high side oil system avoids excessive dilution of the oil with liquid refrigerant either during shut down or operation.

Steady flow operation

In screw compressors the process of compression is continuous rather than cyclical as equilibrium condition can then be reached which are relatively stable in operation. In reciprocating compressors the suction gas is drawn in on downward stroke of piston then the suction valve closes, compression takes place after which discharge valve opens and the gas is discharged. This being a cyclic process having continuous pulsations and variations.

Speed of Operation

In oil injected compressors the sealing effect of oil results in much lower minimum speed resulting in operating range of 15 to 60 metres per second without affecting the efficiency.The efficiency of screw compressors increases at higher speeds. This is due to the fact that at low operating speeds the back leakage through the operating clearances becomes too high a percentage of total. In reciprocating compressors the efficiency and reliability drops at higher speeds.

This offers another advantage in that it means that the majority of compressors are directly driven by electric motors either two or four pole, no speed increasing gear box being required. This eliminates gear box frictional losses which are part of centrifugal designs and also the belt drive losses, belt slippage losses inherent with reciprocating design.

The overall efficiency is also high since two pole motor designs have higher efficiencies (upward of 90%) than 4 pole and also improves power factor.

Vibration Levels

The inherent balanced compression without cyclic variation results in smooth operation with the compressor vibration levels much lower compared to reciprocating machines. The reciprocating compressor has higher vibrations since it is virtually impossible to balance any reciprocating machine and smoothen unbalanced forces/movements as also unbalanced at partial loads due to compressor cylinder arrangements and cyclic pulsating gas pressure waves.

Foundation requirements.

Since the operation of screw compressor is entirely rotary operation, there are no unbalanced forces or movements leading to extremely smooth operation. Hence screw compressors do not need heavy foundation and can be mounted on simple load bearing floor.

As against this, reciprocating compressors of necessity involves additional loads and forces in accelerating and decelerating oscillating masses.The reciprocating compressors can never be fully balanced and therefore require proper foundation design along with large fly wheel to take care of unbalanced inertia forces.

Inspection check during routine operation

In normal operation the only routine attention is required for compressors of this type is to control oil temperature (which also get controlled by an automatic valve). To check oil filter pressure drop and change when necessary and to check oil level.

The normal inspection check can be carried out once in a year by opening the end cover only to check axial movement of the rotor. During this inspection check only PTFE seal, slide valve guide block and the thrust bearings need inspection.

If the compressors are fitted with condition monitoring equipment it would give continuous indication of the condition of the thrust bearings and the inspection check then can be extended once every two years.

As against this, reciprocating compressors have to be monitored continuously for various parameters like performance of oil pump, safety valves, compressor head temperatures, water cooling jackets, belt slippages, oil level, oil cleanliness, valve leakage etc needing full time plant operators.

In view of screw compressors reliability of routine operation and practically no inspection requirements most of the installations have found that operators do not have full time requirement and they can be eliminated, thereby considerably reducing plant operating costs.

Skills required for overhaul.

Oil injected refrigeration screw compressors are very simple machines with very few components as a result any skilled tradesman is capable of fully dismantling and rebuilding them with the assistance of manufacturers Instruction Manual.

All components are interchangeable in the field including rotors and casings .

Standby requirements.

With all above mentioned inherent features of the screw with reliability in design, less components, smooth operation, recommended period of service between overhaul equivalent to 50,000 hours in continuous operation, ability to handle liquid and other features, normally screw compressors do not require standby machines even for critical applications thereby reducing the capital investment to a great extent. As against this it is unthinkable to have reciprocating plant without a standby compressor.

Noise Level

The screw compressor noise also occurs at lower vibration frequency. The compressor operation is quieter due to double wall construction greater amount of rotor surface area. This becomes an extremely important feature on an indoor chillers designs and typically forced to use heavier more expensive equipment,room walls and foundation or else sacrifice the adjacent space due to excessive noise. Thus the quiet operation of screw compressor offers considerable savings.

Safety protection

The oil injected screw compressor is very robust simple machine with large safety reserves on all operating parameters.

The compressor systems are normally fitted with protections to ensure the safety of the compressor in the event of any fault occuring. These are oil pressure, compressor discharge pressure & compressor discharge temperature. Other protective devices such as low suction pressure and oil temperature are fitted to suit the characteristics of the plants concerned.

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