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Design and Application of Small Screw Compressors - Part I

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Recent developments in profile geometry, internal oil distribution and production methods now enable the use of small screw compressors in application ranges which are still dominated by reciprocating compressors.

This article deals with some of the major development steps in small screw compressors - with displacements of 84 to 250 m3/h (50 Hz) - and their impact on performance, efficiency and investment cost.

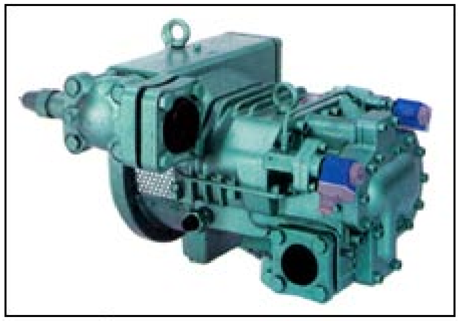
Additional issues are related to the areas of application, the design of single compressor systems and parallel systems and also investment, maintenance and operating costs in comparison with other compressor types.

Background

Until recently reciprocating compressors dominated almost all areas of commercial refrigeration and air conditioning technology. This situation has changed in the past few years and there is now a variety of applications in which a change over to rotating compressors is taking place. A large proportion of this change is accounted for by screw compressors, which since the beginning of the Sixties have become more and more established especially in the area of large industrial systems.

Screws, like reciprocating compressors, belong to the category of positive displacement machines. However, there is an important difference in the method of compression. With screw compressors the sealing of the working chambers is achieved dynamically by means of oil injection. This also explains the interdependence between performance and the tip speed of the rotors, and thus the lower limit of displacement for reasons of economy.


Semi-hermatic screw compressor


Open screw compressor

With pervious screw compressor designs the resulting limit was for a geometrical displacement of above 300 m 3/h, approximately. At the beginning of the Eighties Bitzer was able to make significant progress in the development of profile geometry, production and measuring technology which made the mass production of much smaller, highly efficient screw compressors possible for the first time. Due to intensive research, many years of operating experience and continuous improvements in production methods, it has been possible to optimize this advanced technology further and low capacity screw compressors are therefore more compelling than ever as an alternative to larger reciprocating compressors.

Due to the simple parallel system concept the application range extends to industrial plants; in the low capacity segment of this sector this system is even superior to the usual industrial screws in several respects.

Important Design Features

The high efficiency of twin-shaft screw compressors as described here is due to a profile geometry that has been specially optimised for performance in the low capacity range, a special lubricating system and particularly the use of precision manufacturing with ultra-modern processing centers. Another reason is the extremely demanding quality control by means of automatic measuring equipment.

With a view to minimising essential with industrial refrigeration plants, design and construction have been kept very simple. Oil supply for sealing the profile working chamber and lubricating the bearings, for example, comes from the pressurized reservoir of the oil separator - an oil pump is therefore not necessary for normal areas of application. The main rotor is directly connected to the motor; gearing was deliberately omitted.

Although gears, due to the higher revolutions achieved, make it possible to use smaller rotors and rotor housings and to reduce the number of profile variants within a series (lower production costs), on the other hand they increase the number of working parts and thus also the risk of break-down. Other disadvantages are that they increase sensitivity to slugging (relatively small working chamber in comparison with mass flow), they cause additional flow and transmission losses, they reduce the lifetime of the bearings and create noise emissions at unpleasant frequencies:

The screw compressors under discussion are characterized by extremely stable rotor construction, generously dimensioned roller bearings - thrust bearings in a particularly robust tandem arrangement - and an optimized oil circulation system. With this design principle the overflow of leakage gas from the profile area into the bearing housing on the high pressure sides is seals. The pressure in the bearing housing can thus be reduced almost to suction levels resulting in a minimal proportion of refrigerant being dissolved in the coil and at the same time maintaining high viscosity. An important side effect is a significant reduction on the thrust bearing load. Furthermore, oil supply to the bearings on the suction sides and to the shaft seal (see **Fig 1 and 2**) is carried out in a way that the degassing (by expansion) of the refrigerant that is dissolved in the oil has no significant effect on the compressor's pumping behavior.

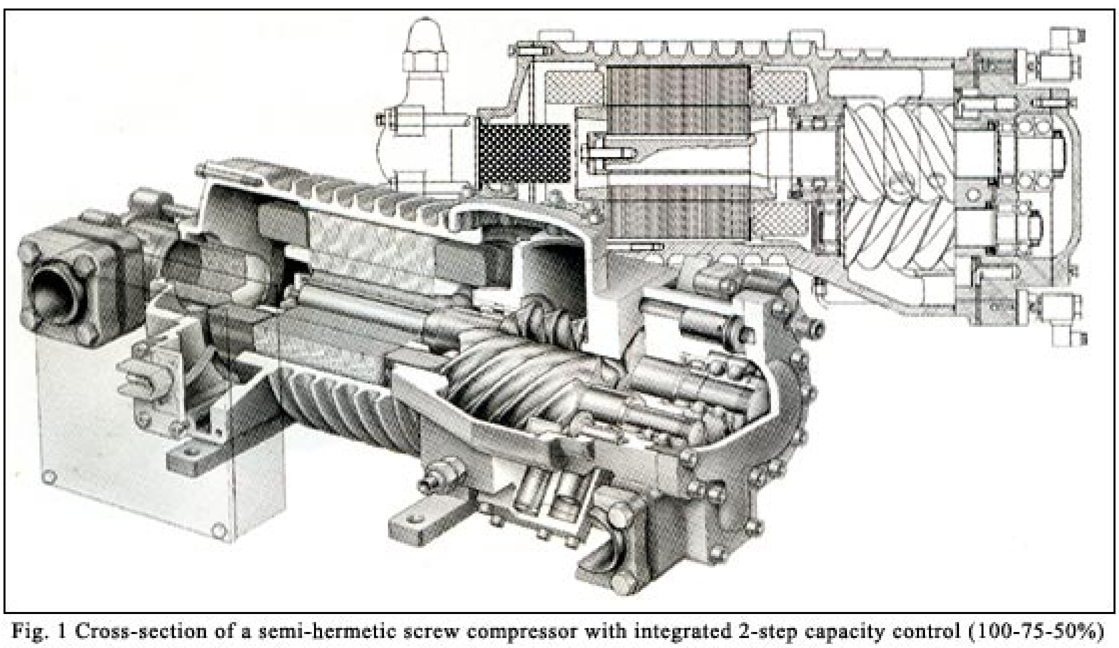


Fig. 1 Cross-section of a semi-hermetic screw compressor with integrated 2-step capacity control (100-75-50%)

All of the new generation compressors are equipped with single-stage or multi-stage capacity control. Control is by means of hydraulically operated pistons which can be activated by solenoid valves. The control units are also used for automatic start unloading and also as additional overload protection against over-compression and in case of liquid slugging. Under such exceptional circumstances the unloader pistons are opened by internal pressure and thus cause the load peaks to be reduced.

Capacity control can also be achieved by altering the motor speed with a frequency inverter. Because of the optimal mass balance (only rotating drive parts) and the stable bearings a frequency range from 25 up to 75 Hz (1450 to 4500 rpm) can be covered, depending on size and application. With parallel systems this technology can be applied with application. With parallel systems this technology can be applied with relatively low cost by modulating the frequency only of the lead compressor.

Because of direct drive (without gearing), as already described, even with trans-synchronous operation there are only negligible effects on bearing life and on noise development.

Semi-hermetic screw compressors

These compressors (**Fig. 1**) are fitted with large volume 2-pole motors. They achieve extremely high efficiency over a wide application range. The motors are suction gas cooled, a principle that has been used successfully for many years with larger reciprocating semi-hermetics. Unlike methods involving liquid injection, suction gas cooling requires no additional control devices and is therefore much simpler to apply. Another advantage is the fact that in this respect there is no difference compared with reciprocating compressors. The stator is fitted in the housing with a sliding fit allowing for replacement using simple tools if necessary. All motors are equipped with integrated devices protecting against (PTC). The monitoring module fixed in the terminal box also has the function of phase sequence monitoring giving protection against operation in the wrong direction.

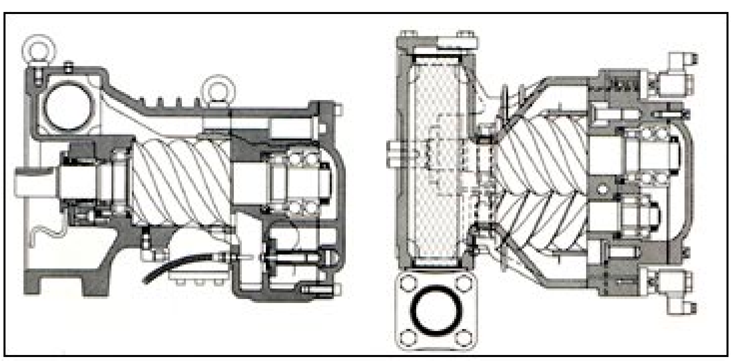


Fig. 2 Cross-section of an open screw compressor

Open compressors

These units (**Fig. 2**) are fitted with an extremely wear resistant shaft seal with a metal bellows, which is also suitable for HFC alternative refrigerants and NH_3. With this construction O-rings have only a static sealing function, which guarantees maximum safety and long life.

Drive takes place by means of the shaft of the main rotor, which is externally accessible. The compressor mounting flange motor (B3/B5) using a coupling housing (**Fig. 3**). This version makes installation simple and ensures that the shaft ends are optimally aligned. Because of he stability of he whole unit and the well-balanced torque behaviors of screw compressors the stresses on couplings and bearings are particularly low.

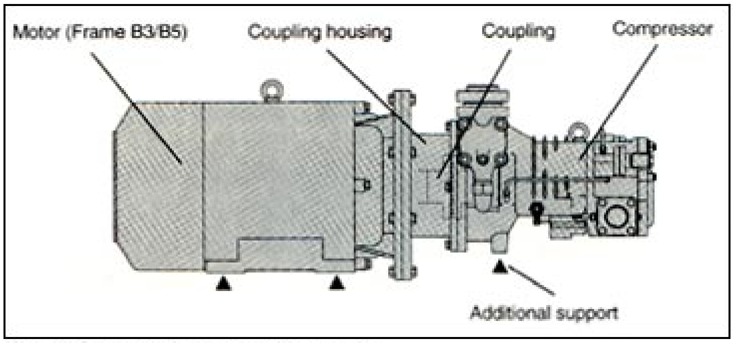


Fig. 3 Open motor-compressor unit

Economiser Operation

The screw compressors under discussion are generally designed for so-called "economiser operation" With this type of operation both refrigerating capacity and system efficiency are improved by means of a sub-cooling circuit or 2-stage refrigerant expansion. The advantages compared with standard operation are especially obvious at high pressure ratio levels.

Unlike the reciprocating working principle of piston compressors, the process of compression with screw compressors takes place only in one direction of flow; as the rotors large turned the refrigerant vapour is compressed by the constant reduction of volume. This characteristic allows an additional intake port on the rotor housing. The position is chosen so that the process of suction (from the direction of the evaporator) is completed and a slight rise in pressure has already taken place (**Fig. 4**). In this way an additional refrigerant mass flow can be transported via a sub-cooling circuit (**Fig. 5**), resulting in liquid sub-cooling and thus higher refrigerating capacity. The power requirement of the compressor does not rise correspondingly as the efficiency of the working process is improved.

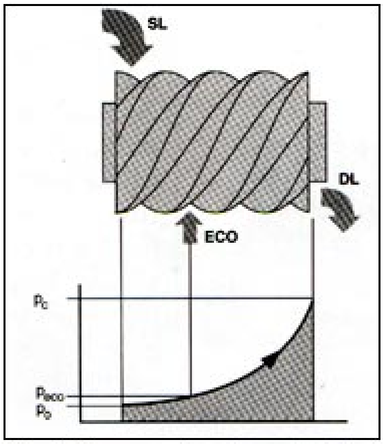


Fig. 4 Compression characteristic with ECO injection

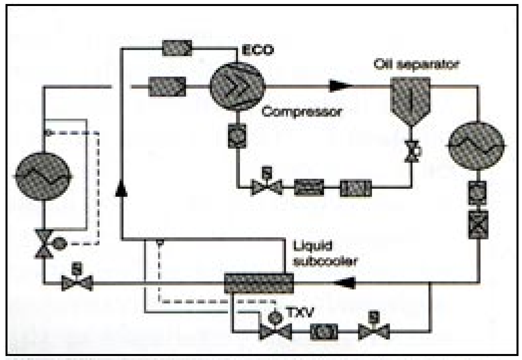


Fig. 5 Economiser system with heat exchanger as liquid sub-cooler

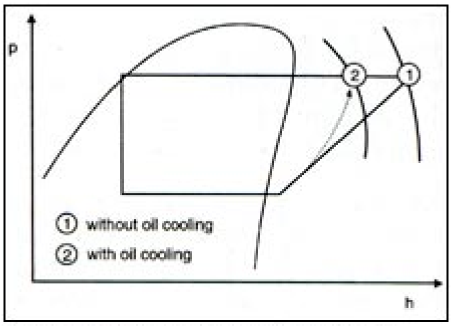


Fig. 6 The influence of oil cooling on discharge gas temperature

In economizer operation a compressor can therefore be used with significantly lower displacement while achieving real energy savings.

Oil Cooling with Screw Compressors

With a view to achieving an economical compression process, sufficient oil viscosity to seal the working chambers and the lubrication of the roller bearings the discharge gas temperature is normally limited to 100°C with screw compressors. Oil cooling may therefore be necessary, depending on refrigerant and application. The additional expense is a disadvantage. However, in comparison with the size and cost of the total system, this is relatively low.

The cheapest option is the direct injection of refrigerant using a capillary tube or expansion valve in a closed working chamber of the profile. Due to the danger of oil dilution and of increased power requirements with large injection volumes this method can only be recommended as a protection device against excessive discharge gas temperature for temporarily high condensing temperature in the medium and high evaporating temperature range.

The classical method of oil cooling is with a water-cooled heat exchanger (**Fig. 7**), as is often used with large industrial systems. Shell and tube or plate type heat exchangers are widely used.

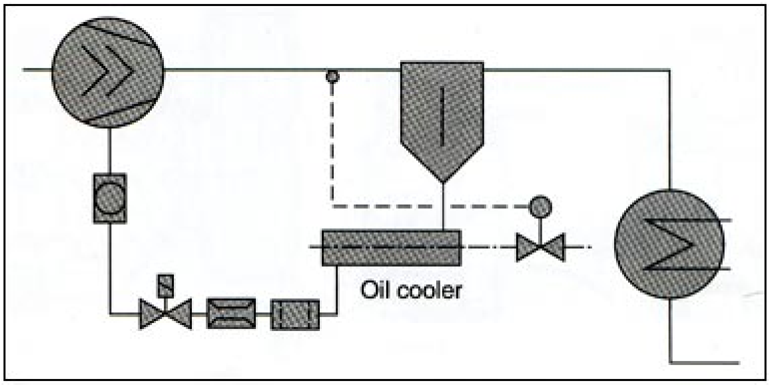


Fig. 7 Water-cooled oil cooler with temperature control

On the other hand, air-cooled heat exchangers (**Fig. 8**) can be applied universally, for example outdoors they can be positioned immediately next tot eh machine room. Under certain conditions the integration of the coil cooler in the condenser coil is also possible. Because of the large fluctuations of the outdoor temperature a by-pass mixing valve is provided for both solutions to control the oil temperature.

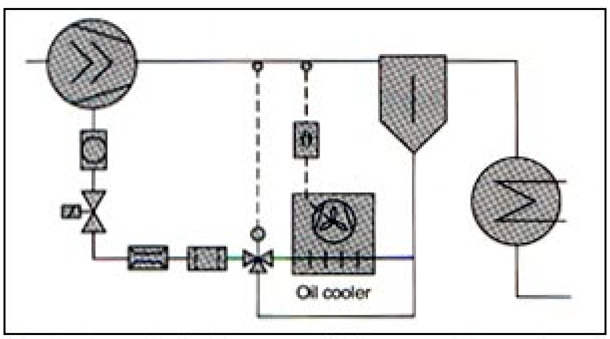


Fig. 8 Air-cooled oil cooler with by-pass mixing valve

The additional space requirement is relatively low as the condenser can be smaller in proportion to the amount of heat given off to the oil cooler. With the version that combines condenser and oil cooler the difference is negligible.

A further, very inexpensive and space-saving possibility is offered by the thermo-syphon principle. With this method, pressurized refrigerant liquid evaporates in a heat exchanger thus cooling the oil in counter flowing (**Fig. 9**). The vapour is fed back into the discharge gas line and condenser again. A precondition for this system is that the condenser is positioned above the oil cooler in order to guarantee a sufficiently high liquid column for the gravity circulation of the refrigerant necessary for oil cooling. Refrigerant circulation can also be supported by means of an injector or circulation pump.

Oil cooling involves additional expense but also brings important advantages:

- The compressors do not need an additional fan (including electrics).

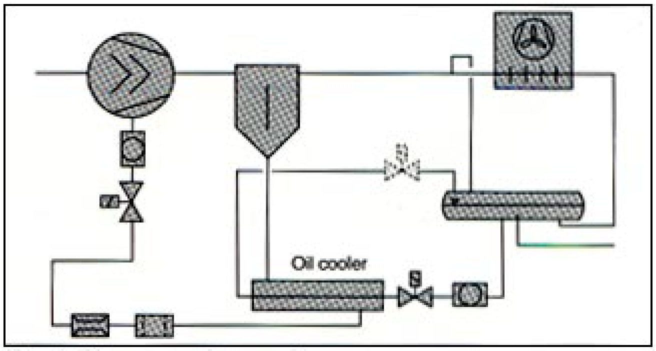


Fig. 9 Thermo-syphon cooling

Mass flow means that a virtually isothermal compression is possible and thus also single-stage operation with very high pressure levels and suction gas temperatures - even when using refrigerants with extremely isentropic compression indices such as R22 and NH_3 (**Fig. 6**)

With the refrigerants R 134a, R404A and R507 thermal loading is comparatively low-due to the low isentropic compression index. Therefore, at least with medium and high evaporating temperatures, oil cooling is not necessary in many applications. With operation near the thermal limit of application or with a required oil cooling capacity up to about 10% of the compressor's cooling capacity, the above mentioned controlled refrigerant injection into the profile area is possible as an alternative cooling method. Suitable expansion valves, which are controlled according to discharge gas temperature, are available from several manufacturers.