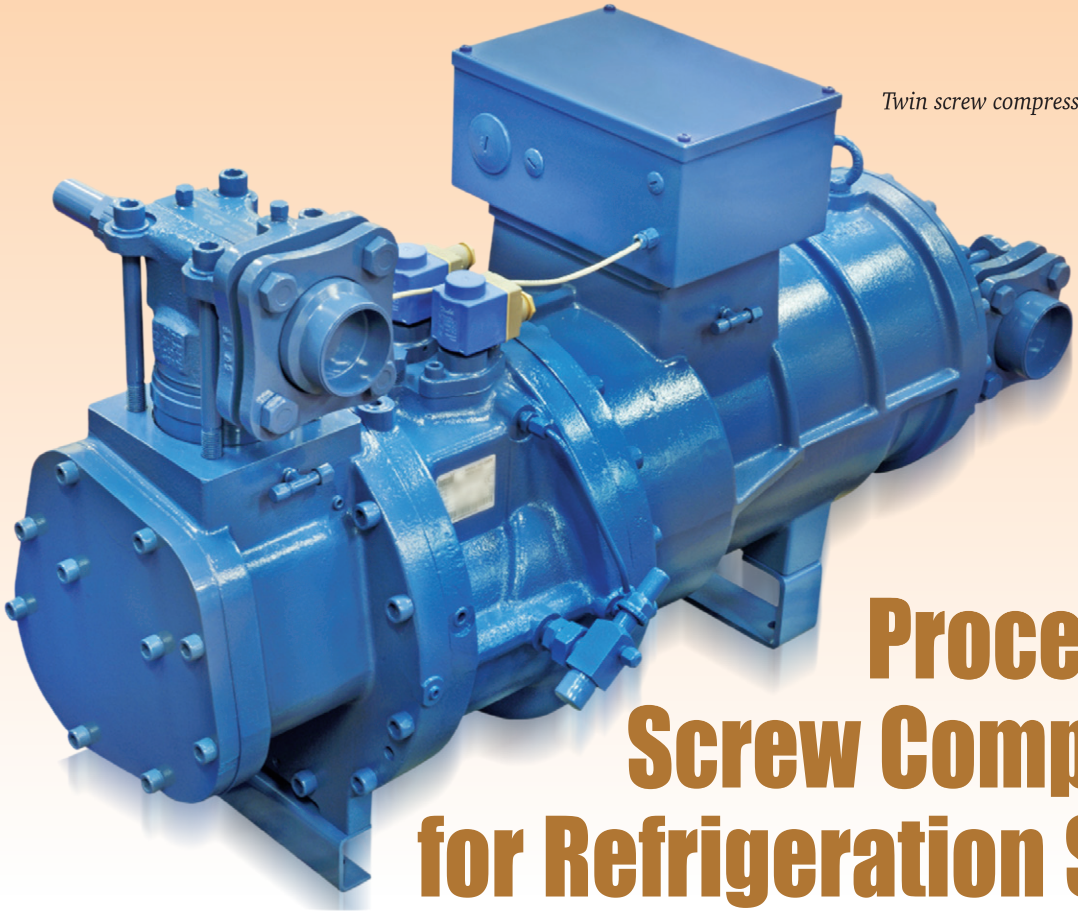

Twin screw compressor

Design Procedure for Screw Compressors for Refrigeration Systems

By Deobrat Barat

Introduction

The main components of the screw compressor are male and female rotors mounted on bearings that fix their position so as to mesh together along with their helical lobes. In the refrigeration system, the driving device is generally connected to the male rotor with four to five lobes, which drives the six- to seven-lobed female rotor.

About the Author

Deobrat Barat passed his B.E. (Hons.) in mechanical engineering from Govt. Engineering College, Jabalpur in 1962. He worked in Heavy Engineering Corporation, Ranchi and Projects & Development India Limited, before joining Frick India Limited as head of R&D in 1997 where he worked on the design and development of screw compressors, liquid ammonia pumps, ice flake machine and valves for refrigeration system. Since 2014, he has been working as a consultant.

Design Basics

Rotors are designated with diameter D of the screw profile and ratio L/D, where L is the length of screw profile. As an example, a 163 dia rotor that has L/D equal to 1.7 and lobes 4/6 (4 lobes in male and 6 lobes in female) will be designated as *163-4/6, L/D 1.7*.

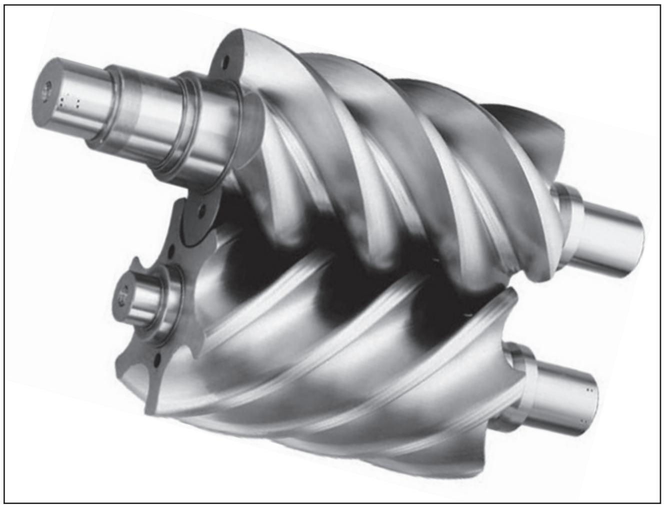

Figure 1: Male and female rotors

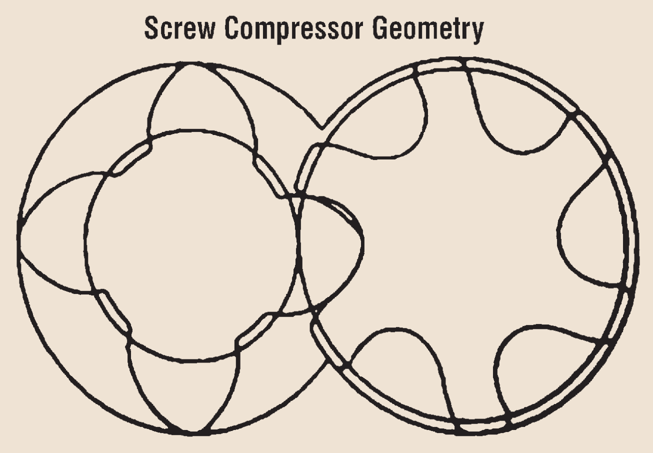

Figure 2: Rotors in 4-6 configuration

The displacement per revolution 'Q' by the rotors can be expressed by the following equation:

$$Q = D^3 (L/D) / C$$

where

D is the diameter of rotor profile,

L/D is the ratio explained above, and

C is a typical profile constant; for asymmetric profiles generally used in a refrigeration system, C can be taken as 1.98 to 2.

The screw compressor model can be specified either by the designation of rotors being used in it or the swept volume of the compressor.

Most screw compressors in India are directly driven by a 2-pole motor (2950 rpm at 50Hz).

The suggested procedure for screw compressor design and development is:

1. Design, manufacturing or procurement of rotors.
2. Design of screw compressor housing and pattern making.
3. Antifriction bearing selection and design of balancing piston.
4. Calculation of bearing preloading and disc spring selection.
5. Lubrication system and sealing system – shaft seal, O-rings etc.
6. Selection of machine tools for machining the housing and components.

The details of each step are given below.

Design, Manufacturing or Procurement of Rotor

Rotor design was patented in Germany in the name of SRM in 1951. SRM is known worldwide for its rotor design and has issued manufacturing licences to almost every rotor manufacturer.

With a view to reducing the initial development cost, instead of taking up the design and manufacturing of rotors, it is recommended that rotors be procured from a renowned rotor manufacturer. After finalizing a vendor for the rotor, a Purchase Order can be issued to the party for the supply of rotors suitable for the refrigeration system and compatible with refrigerants – ammonia, R134a, R22, R404, etc. The vendor should be asked to provide technical details of the rotor profile, axial and radial force generated by the rotors at the extreme load condition using ammonia as refrigerant (evaporating temperature -5.5°C and condensation temperature +40°C) at 3600 rpm.

So as to assist the vendor in the procurement of material and for taking up manufacture of rotor shafts as per your requirement, it is necessary that you provide him provisional dimensional drawings (male and female) of rotors. Regarding the material of construction, it is recommended to use low carbon steel material with C between 0.35 and 0.50, Mn between 0.35 and 1.0, P maximum 0.04, S maximum 0.08 and hardness in the range of 180 -230 Brinell. However, you may discuss the matter with the vendor and finalize a suitable material.

On completion of the rotor profile design, the rotor manufacturer should forward you all the technical details of the screw profile as mentioned above. You may then finalize the rotor drawing as well as drawings of other components related to the rotor shaft. Copies of working drawings of the rotor shafts may then be handed over to the rotor vendor to enable him commence manufacturing.

Design of Screw Compressor Housing and Pattern Making

The castings for housing of the screw compressor are designed for the maximum discharge pressure of 350 psig considering use of ammonia as the refrigerant. It is recommended to use cast iron ASTM-A 48, Class 40 for all the housing castings. After finalizing the material of casting, you can find out the minimum thickness of the housing component castings, which will be needed in their design, using formulas given in ASME, Section VIII.

The housing of a screw compressor consists of the following casting components:

1. Rotor cover casting
2. Inlet cover casting
3. Discharge cover casting
4. Cylinder casting for capacity and volume ratio control
5. Castings of sliding valves, sliding valve guide, pistons and covers, etc.

While preparing the casting drawings, maximum care should be taken to fix tolerances on the dimensions in accordance with

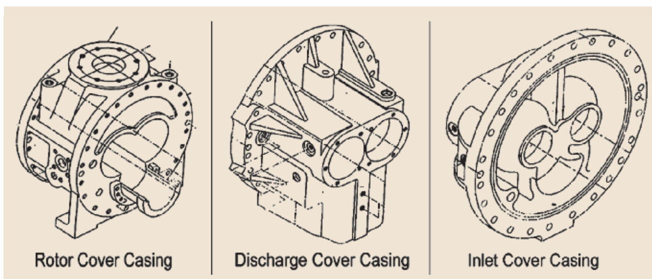

Figure 3: Rotor cover, discharge cover and inlet cover casings

the desired fits. As the speed of the rotors is very high (3600 rpm), close tolerances are needed for satisfactory operation of the screw compressor.

Regarding radial and axial clearance of rotor with respect to rotor cover casting, it is recommended that radial clearance be kept in the range of 0.100 to 0.125 mm, whereas axial clearance be kept based on the following calculation:

Axial clearance = (coefficient of linear thermal expansion x length of rotor profile x temperature difference between suction and discharge)

Regarding bearing fittings and tolerances, the bearing catalogue may be referred to.

It is recommended that the fabrication of the pattern of the following casting components may be looked into on completion of their working drawings:

1. Rotor cover casting
2. Inlet cover casting
3. Discharge cover casting

Several castings should be made from these patterns and their surfaces inspected along with the foundry manager before taking up rough machining of the castings. While rough machining is in progress, machinability as well as hardness of the castings may be checked and, if necessary, addition of alloying elements such as Ni and Cu may be decided in consultation with the foundry manager. After rough machining is completed, the next step is to conduct hydrostatic and pneumatic testing of the castings. The inlet cover and discharge cover should be assembled on both sides of rotor cover by using fasteners to make one unit for conducting the tests, after closing all the remaining openings. Hydrostatic test pressure should be 350 psi, and pneumatic test pressure should be 250 psi air under water. After the tests, the components may be disassembled and arrangement for final machining may be taken up.

Selection of Antifriction Bearing

As refrigerant gas is compressed in the screw compressor along the length of the rotors, the rotors are forced in radial and axial directions. In order to maintain the rotors in their position and to reduce frictional forces, antifriction bearings with L10 rated bearing life in excess of 100,000 hours are selected.

In order to calculate and select suitable bearings, you may first decide on the brand of bearings to be used. Based on your bearing brand selection, you may refer to either the SKF or the FAG catalogue and use the formulas recommended in them for selecting suitable bearings. In case you go for SKF bearings, you can also use the SKF bearing software to select and calculate bearing life.

Cylindrical roller bearings are used to control radial load (up and down and sideways). With this type of bearing, the cage is secured in the outer race and maintains the position of the rollers. The outer race is fitted snugly in the compressor housing whereas the inner race is secured to the rotor shaft by interference fit.

For controlling axial (back and forth) movement of the rotors, four-point contact ball bearings are used, designed to take the axial force in both the directions.

Balancing Piston System

While selecting the correct size of thrust bearings with life in excesses of 100,000 hours, it is noticed in some cases that due to high discharge pressure, the calculated sizes of some bearings are much higher than the bearings selected for the inlet side of the rotor shaft. It is not feasible to accommodate these higher size bearings in the assembly of the screw compressor. In such cases, with a view to reducing the axial bearing size, you may reduce the axial force generated by the rotors at the discharge end. This is possible by using the 'Balancing Piston System' device *(Figure 4)*. Subsequently, at a reduced axial force, a proper size of thrust bearing can be selected.

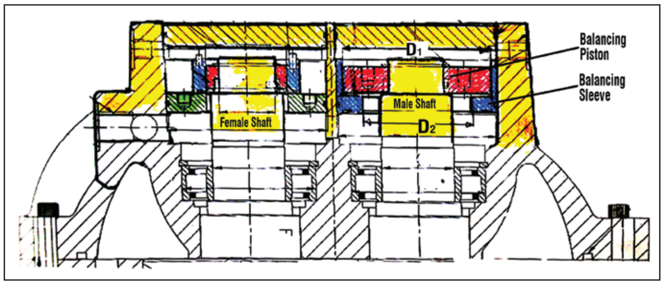

Figure 4: Balancing piston system fitted on male rotor shaft at discharge end

The formula used in the Balancing Piston System can be derived by equating the difference of forces acting on the balancing piston and the counter-balancing piston. This is expressed as:

$F = 1/8\ (P_2 - P_1)\ (D_1 + D_2)\ \pi$

where

D_1 is the diameter of balancing piston,

D_2 is the inner diameter of counter-balancing piston,

P_1 is the compressor suction pressure, and

P_2 is the pressure of oil entering the compressor.

Calculation of Bearing Pre-loading and Disc Spring Selection

For satisfactory operation of the installed bearings, they must always be subjected to a given minimum load, particularly if they run at high speed. This is required to improve the 'run-out precision' of the rotating axis and to reduce vibration as well as noise at high speed. One can calculate the minimum load to be applied to the bearings using the formulae provided in the bearing catalogue. If an SKF bearing is used, it may also be calculated by using the SKF bearing software.

As regards pre-loading of roller bearings that are intended for controlling the radial load, rollers are already pre loaded as the inner race of the bearing has an interference fit on the rotor shaft. As regards pre-loading of four point contact ball bearing meant for controlling the axial load, a special device is needed

continued on page 40

continued from page 38

to provide the minimum axial force. Accordingly, a sleeve is provided over the bearing to transmit the required axial force by using a disc spring. The selection of the disc spring that can provide the requisite axial force can be done by referring to the disc spring catalogue.

Lubrication System

Lubrication is vital for the successful operation of oil flooded screw compressors. The major functions of lubricating oil are:

1. To lubricate rotors, bearings, and mechanical seal.
2. To seal the gaps between the rotor and the wall of rotor housing, and the internal running clearance between the rotors.
3. To lubricate the O-ring to seal the escape of refrigerant outside the housing.
4. To absorb the heat of compression.

In order to carry out these functions, oil is directly injected into the screw compressor housing at the following locations:

1. Mechanical seal,
2. Bearings installed on the rotors at suction and discharge end,
3. High pressure discharge region, and
4. Balancing piston systems (male and female).

All the oil required to be injected for lubrication is provided by the positive gas differential pressure during normal operation. However, during the period of start-up to normal operation, a pre-lube pump is used; it is shut down on reaching the required differential pressure as per the PLC setting. The oil injected into the screw compressor housing absorbs heat generated in it and flows out from the discharge port along with the refrigerant through a pipe in the oil separator. The hot oil separated from the refrigerant is cooled down and is again used after filtration.

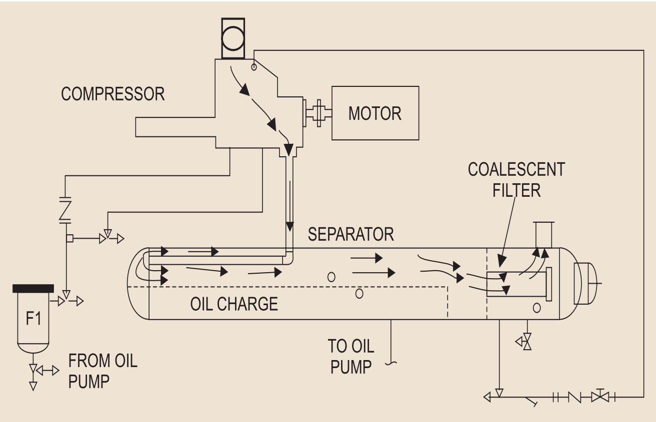

Figure 5: Screw compressor oil separator function

The refrigerant gas, after shedding most of the oil, is passed through a coalescing filter to get rid of residual oil down to 1 micron. It is then used for the refrigeration process.

It is recommended to use lubrication oil as per ISO VG 68.

Shaft Seal

As the driving device is connected to the male rotor, a sealing device is required to prevent the leakage of oil and gas from and around the rotor shaft. The sealing device is designated as shaft seal, a mechanical device comprising of two components (*Figure 6*). The first component, the carbon ring, is either stationary or rotating. It is mounted over either a Belleville wave (*Figure 7*) or helical springs. The second component is the hard metal bush. Considering the case where the carbon ring is stationary, arrangements are made to rotate the metal bush along with the rotor shaft. The mating surface of the carbon ring is kept pressed to its working height against the hard face of the metal bush for its proper working.

Shaft seals of foreign as well as indigenous makes are available.

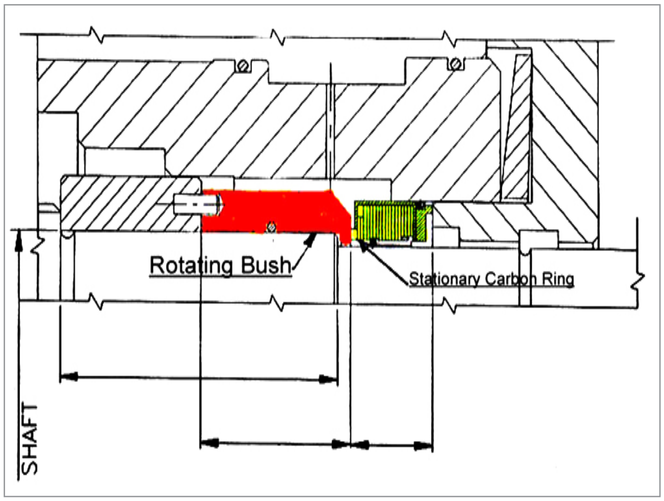

Figure 6: Mechanical shaft seal

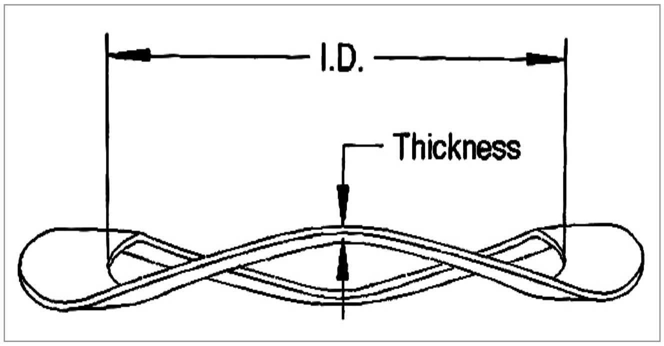

Figure 7: Belleville wave spring

O-Ring Sealing

O-rings are generally used for static sealing in the refrigeration system. As neoprene is compatible with ammonia gas and liquid, O-rings made out of neoprene are used to seal all the static joints of the screw compressor, such as the assembly joints of inlet cover and discharge cover with rotor cover casing and all other static joints of the screw compressor.

continued on page 42

continued from page 40

With regard to dynamic sealing, such as sealing of the piston that moves to and fro inside the cylinder full of oil used in the capacity and volume ratio control system of the screw compressor, a special sealing device that consists of a rectangular section ring mounted over the O-ring is used.

Figure 8: O-ring

It is recommended to use only branded O-rings and other sealing devices in the screw compressor.

Machine Tool Selection

As mentioned earlier, a screw compressor is a high-speed machine, and therefore machining of its components to close tolerances is essential. Some of the tolerances and dimensional accuracies to be maintained during machining of screw compressor components are given below:

- Centre distance (CD) of rotor bores should be within +0.012 and –0.024 mm.
- Taper of centerlines of the rotor bore from inlet end to discharge end should be within 0.009 mm.
- Concentricity of bores of male and female rotors should be within 0.008 mm.

In order to achieve the machining of the rotor bore with the above accuracies, the selection of proper machine tools is required. After considering the most probable inaccuracies that you may have to face when machining the components of the screw compressor (inaccuracies in clamping the job to be machined, inaccuracy in holding the cutting tool, etc.), it is recommended to use a Horizontal Machining Center (HMC) with an accuracy of ±1 micron for machining all the components of the screw compressor housing.

Regarding the machining of other screw compressor components, it is recommended to use a CNC lathe with an accuracy of ±2 micron.

Conclusion

This article gives the suggested procedure for the development of a screw compressor. It would be advisable for a designer to open three or four screw compressors of any make under the guidance of an experienced mechanic and try to learn the function of each component, and thereafter to re-assemble the compressors. To get further insight, you may visit some dairy and refrigeration plants using screw compressors and try to understand their working through discussion with the operations personnel. This can enhance your knowledge and instill confidence.