Compressors

Selection of gas compressors: part 3

In this continuing series of articles, Eduardo Larralde and Rafael Ocampo survey the current state of the art concerning gas compressors. Parts 1 and 2 explained the principles of compression processes and the classification of compressors, respectively. Part 3 explains the physical structure of one key class – the piston compressors.

The use of piston compressors with horizontal cylinders is very extensive. They are representative of piston compressors as a whole, and can be taken as a model to explain the main constituent parts (Figure 3.1).

Crankcase

The crankcase is the main frame of the compressor and should have high stiffness to maintain the correct alignment of all moving and stationary parts. Figure 3.2 shows a crankcase with crosshead extensions and transverse spacers. The compressor crankcase is typically a single-piece cast iron casting. Heavily ribbed high-strength ductile iron may be considered for superior designs for advanced performance.

All medium- and high-power frames and four- or six-cylinder small-power frames are equipped with tight-tolerance transverse spacers, fitted above the bearing housings between the two sides of the frame. This solution creates an extremely stiff, closed body, with an even distribution of stresses and strains. Large openings are provided in the crankcases, to cut the time and cost of maintenance procedures.

Crosshead extension or sliding body

This component connects the crankcase and distance piece. The crosshead moves inside this part.

The crosshead extension is made of cast iron and machined to exacting tolerances, to ensure optimum alignment of crosshead, cylinder and piston assembly. The crosshead guide is made of ductile iron with external ribbing.

In small and high-speed compressors the crosshead extensions are integral with the crankcase, while in larger frames they are separate components.

Distance piece

The distance piece connects the crosshead extension and the cylinder. Distance pieces are available in many different configurations, among them single or double, pressurized or purged with inert gas, and vented to the atmosphere. The optimum configuration is selected according to the process needs and customer specifications.

Cylinder

The design of the cylinder depends on the working pressure, the flow of gas and the compressor application. For pressures below 5 MPa, cylinders are made of cast iron or nodular cast iron. For pressures between 5 MPa and 15 MPa, they are made of cast steel. For higher pressures, forged carbon steel or forged alloy steel is used. Cast iron or Perlite cast steel inner liners are usually installed on cylinders in order to obtain a very smooth machined surface and to provide...
a renewable wear surface. Liners made of Ni-Resist cast iron (high nickel content) are not recommended due to problems such as permanent distortions\(^5\). In small- and medium-sized compressors, cylinders are made in one piece with the distance piece. In large compressors they are bolted together. Suction and discharge valves are fitted on the cylinder walls.

The design of process cylinders includes full water jackets around the cylinder bore. The major benefits of water cooling come from its role in reducing gas temperature rise during compression, so extending the life of the piston rings, rider bands and packing rings, permitting better lubrication, reducing deposits on valves, increasing the life of the valves, decreasing the risk of fire in discharge piping and also dissipating heat during unloaded operation. Another benefit of lower gas temperatures is higher efficiency and lower power requirements\(^6\).

The cylinders should be designed to achieve the highest reliability and key design features include:

- The ability to house different types of valves for maximum efficiency and life of valve internals.
- Wide gas passages to minimize pressure drop.
- Optimization of cooling passages to reduce thermal stress and distortion, and to control operating temperature.
- Replaceable liners, in a wide range of materials, for specific applications\(^4\).

Crankshaft

This is the main component of any piston compressor. It is a cranked shaft provided with counterweights to reduce unbalanced rotating inertial forces and moments. The crankshaft is supported on the main bearings. Figure 3.1 shows all the moving parts of a horizontal compressor, namely, the crankshaft, connecting rod, crosshead, piston rod and piston.

All crankshafts are precision-ground, single-piece, high-strength steel forgings. Counterweights of high-speed machines are integral with the shaft, while others are bolted on\(^3,4\). In order to reduce stress concentration and avoid fatigue failures, all lube oil holes and discontinuities on the crankshaft are carefully smoothed and polished\(^5\).

Connecting rod

The connecting rod links the crankshaft to the crossheads. The big end rotates with the crankshaft while the small end moves back and forth in a linear fashion with the crosshead.

The connecting rod is made of die-forged steel. An internal axial channel through the rod ensures reliable lubrication at the small end\(^4\).

Crosshead

The small end of the connecting rod and one end of the piston rod are both connected to the crosshead, which transmits the movement from the connecting rod to the piston rod. The crosshead is equipped with amply-sized replaceable shoes. The body is made of fully machined forged steel. Specific loads are kept to a minimum, resulting in an extremely long working life. Shoes are completely machine-finished and interchangeable\(^3,4\).

On large compressor units the traditional threaded connection between the piston rod and crosshead has been replaced by a flanged crosshead design with hydraulically tensioned bolts.

Piston rods

These die-forged induction-hardened steel or stainless steel alloy rods are used to join the crosshead to the piston. Because the piston rod comes through the sliding body, distance piece and cylinder end wall, an oil wiper packing in the sliding body and a pressure packing in the cylinder end wall should be provided to avoid the leaking of oil and gas, respectively.

A relatively recent advancement rapidly increasing in use over the past 15 years is the application of tungsten carbide coatings with the purpose of increasing reliability\(^7\).

Pistons

The pistons are key components in compressors because their rectilinear movement provides the means for suction, compression and discharge of the gas. The material of construction depends on the final discharge pressure and the chemical composition of the gas being handled. For low pressures they are usually made of cast iron but in the case of large diameters they can be made of structural welded steel. For high pressures, the pistons are made of forged steel. Aluminium alloys can be selected for some applications and special alloys are used for aggressive gases.
Piston rings and rider bands

The piston rings and rider bands are fitted on circular slots machined around the piston perimeter to provide sealing between pistons and cylinders. For general service the piston rings are made of cast iron. For non-lubricated cylinders, the piston rings are made of phosphorus alloyed bronze or filled Teflon (PTFE) materials (carbon, bronze, glass and molybdenum). Other piston ring and rider band materials such as textile–phenolic resin laminate textolite and some engineering thermoplastics are also used.

In advanced designs, rider band grooves are eccentric with respect to the axis of the piston rod, so that there is a higher protrusion of the rider band in the bottom part of the piston. This feature has many advantages, among them a greater thickness available for wear and a lower average rod run-out.

Bearings

As main bearings, small compressors use rolling bearings and large compressors use plain bearings with a steel body and Babbitt metal working surface. The contact surface of connecting rod bearings is made of Babbitt metal and can be removable or weld-deposited according to compressor size.

Advanced design reciprocating compressor bearings show the following features:

- Tri-metal (steel shell, leaded bronze layer, galvanic white metal flash) main and connecting rod bearings or newer aluminium–tin bi-metallic main and big-end bearings with important improvements incorporated.
- Split in the vertical plane.
- No geometrical discontinuity in the highest loaded area.
- Bearings can be replaced without removing the shaft.
- Big-end bearings are identical to journal bearings for spare optimization.

Valves

The valves are the most critical component in terms of piston compressor reliability and also strongly influence the efficiency. They allow or prevent the passage of gas to and from the cylinder. All the valves are of the self-acting type whose opening and closing occurs because of the pressure difference across the sealing element. Closing is helped by a set of springs that ensure an effective contact between the plates and the seat. The valves should be designed to hold power losses to a minimum, while ensuring the longest possible life for internal parts.

The valves can be classified into four general types as can be seen in Figures 3.3 to 3.6:

- Poppet
- Ported plate
- Concentric ring and
- Channel.

Valve materials

Seat and guard

The seats and guards are generally made of the same material. Many of them are castings, usually of nodular iron. Others are fully machined from bar stock. The most common materials for non-corrosive environments are nodular iron and low carbon steel. For highly corrosive environments, 17-4 PH, 410 or 300 series stainless steel are used.

Spring

The spring is the most highly stressed component of the compressor valve, and is typically one of the largest causes of valve failures.

Chrome silicon and chrome vanadium have very good mechanical properties. Both are available in spring quality wire. Hastelloy and Inconel are commonly used in corrosive environments.
applications, but they are relatively weak in dynamic applications. High cobalt materials such as Elgiloy and MP35N are also used in corrosive environments. These materials have good corrosion-resistant properties and better mechanical properties than Hastelloy or Inconel, but are also more expensive.

Moving elements

The moving elements may be subjected to corrosive substances and high stress levels, as well as to high impacts. Therefore, material selection is very important to the success of the valve. This is where the most significant improvements have been made over the past two decades.

Early valve designs used metallic plates, which are inexpensive, able to withstand high differential pressures and are not affected by high temperatures. However, they are prone to impact fatigue, susceptible to corrosion damage and are very unforgiving of dirt and debris.

Plastic materials offer several advantages over metallic elements, such as:

- They are able to withstand higher impact velocities than metal plates. This allows them to be applied at higher lifts and speeds, and makes them more tolerant of liquids often present in the gas.
- They are resistant to most corrosive elements commonly found in process gas streams.
- Plastic elements help reduce wear on the seat.
- Small pieces of dirt or metal can embed in a plastic element without causing a failure.
- A plastic element that breaks and falls into the cylinder is less likely to cause damage to other components such as the cylinder liner, piston rings and rider bands.

Pure nylon is too weak to withstand the discharge temperatures of most compressors. Nylon plates tend to change their shape in service by swelling or distorting. PEEK (poly ether ether ketone) is currently the most commonly used material for valve elements and is the standard material for rings up to 35 MPa. It offers several advantages over nylon:

- PEEK has temperature thresholds that ensure retention and stability of load-bearing properties and dimensions at high temperatures.
- Tensile, flexural and compressive strengths are maintained at high temperatures.
- It resists flex fatigue.
- It has lower water absorption rates to ensure dimensional integrity.
- It resists deformation at high temperatures.

However, standard PEEK has the disadvantage of been very difficult to mould. A low-viscosity variant called ‘Easy Flow’ was developed to allow moulding of PEEK at lower pressures. It is as strong as standard PEEK but, at low impact velocities, Easy Flow plates fail by brittle fracture.

Although PEEK is a more expensive material, it is recommended not to use ‘regrind’ because experience shows that it greatly weakens a valve element.

Piston rod packing

The piston rod seal is the second important area regarding the reliability of reciprocating compressors and the most likely path for potentially hazardous process gas leakage. A complete range of state-of-the-art materials, including PEEK, is available to ensure the best performance under any condition.
Lubricated packings above 2.5 MPa and all non-lubricated packings are cooled. Packing cups are made of stainless steel. The packing assembly may be configured with one or two gas recovery lines or with inert or sweet gas purging. A zero-leakage arrangement is also possible when necessary.

Packing rings are usually made of the same plastic material as the piston rings and rider bands.

**Lubrication system**

The cylinder bore and stuffing box may be lubricated, mini-lubricated or non-lubricated, according to process needs and customer specification. Cylinder lubrication is of the forced-feed type. Single pump to point, divider block or a combination of the two systems may be used.

The crank gear is lubricated by a forced-feed system. It consists of a tank, pumps, filters and coolers. The oil is pumped to the crankshaft main bearings, connecting rods' big- and small-end bearings, crosshead pin and slippers via channels bored through both crankshaft and connecting rod.

**Gas coolers**

These components are used to cool the gas after the compression stages (intercoolers) or at the end of the compression process (final coolers).

Different types of coolers are available but the most used is the shell and tube model in a variety of designs (straight or U tubes, fixed or floating heads, horizontal or vertical shell). Figure 3.7 shows an example. Usually the cooling medium is fresh water and occasionally sea water. It is common practice to use air as the cooling fluid in small compressors although it can be used in other applications too. Some other modern designs are available such as shell and plate circular coolers.

**Separators**

Separators are vessels installed after the gas coolers to separate the oil and water from the compressed gas. Inertial separation occurs by changing the direction and abruptly decreasing the velocity of the gas flow. The most used design is the cyclonic type.

It is also a good practice to install a suction drum, with a drain provision, upstream of the first-stage cylinder.

**Pulsation dampeners**

The pulsation dampeners are large capacity pipes where the compressed gas coming from each stage is discharged. Pulsation vessels should be sized properly to control the effects of pulsations inherent in the gas flow into and out of reciprocating compressor cylinders.

The pulsed energy input can cause pipe failures, inefficiency and capacity limitations. Pulsation can also alter the timing of the valve motion and decrease efficiency and reliability.

Nozzle placement should be optimized in such a way that residual shaking forces are minimized. An orifice located at a point with high dynamic flow modulations can frequently control the pulsation levels effectively and conveniently in the associated acoustic mode of response.

However, the full cost-effectiveness of an orifice needs careful consideration, particularly when fuel usage is a significant contributor to life cycle costs.

Part 4 will move on to discuss the physical structure and some important operational features of a second major class of gas compressors – the centrifugal compressors.