6. Хмельницкий, Р.С. Анализ конструкций технологического оснащения для точения выпуклых сферических поверхностей на универсальных токарных станках / Р.С. Хмельницкий, А.С. Максимчук // Тр. молодых специалистов Полоц. гос. ун-та. Вып. 68. Промышленность. – 2013. – С. 89–91.
7. Анализ способов обработки сферических поверхностей деталей / Р.С. Хмельницкий, А.С. Максимчук // Тр. молодых специалистов Полоц. гос. ун-та. Вып. 68. Промышленность. – 2013. – С. 92–94.
8. Справочник технолога-машиностроителя. В 2 т. Т. 2 / под ред. А.Г. Косиловой и Р.К. Мещерякова. – 4-е изд., перераб. и доп. – М. : Машиностроение, 1986. – 496 с. : ил.
9. Ящерицин, П.И. Теория резания : учеб. / П.И. Ящерицин, Е.Э. Фельдштейн, М.А. Корниевич. – Минск : Нов. изд., 2005. – 512 с.: ил. – (Техническое образование).
10. Попок, Н.Н. Теория резания : учеб. пособие для студентов машиностр. специальностей / Н.Н. Попок. – Новополоцк : ПГУ, 2006 – 228 с.

UDC 62-121

OIL-FREE PISTON COMPRESSORS

VADZIM SIDAROVICH, INNA YELSHINA
Polotsk State University, Belarus

This thesis describes the development on long lifetime and an efficient piston compressor operating in a clean environment where oil lubrication must be excluded. No oil lubricant and tight piston/cylinder fit leads to higher demands with respect to design specifications. The engineer is often confronted with various effects that occur during operation, e.g. tribology, material deformation, heat transfer, fluid flow. An accurate prediction of those processes is important to be able to analyze any newly invented design.

A lubricant can be defined as a substance, which introduced between sliding surfaces, reduces the friction between them, improves efficiency and reduces surface wear. Commonly used lubricants are different types of liquids, mainly oils. Such lubricants however, need to be avoided in this design. Other substances like gases or dry lubricants are acceptable in the analyzed system. In general, piston compressors must fulfill specific requirements due to their inherent use. First of all, lifetime and reliability requirements which are mainly related to material wear and the compressor design. A major challenge in the design is to reduce the potential of material wear in the critical components. The second requirement is an energy efficient gas compression [1].

1. Piston compressors technology

During the compression process, the piston should form a sliding seal so that the gas is compressed without any or with acceptable leakage. This means that a very close fit to the cylinder bore is needed. Because of temperature and other engineering and economical reasons this is not practical. Naturally, maximum piston leakage occurs as the piston approaches the end of its stroke because differential pressure across the piston is the highest at this point. This leakage causes both volumetric and power losses. Piston rings are therefore used. Piston rings have many variations, but all follow the same principle of a thin metallic ring, which tends to push out against the cylinder wall and make a tight sliding fit.

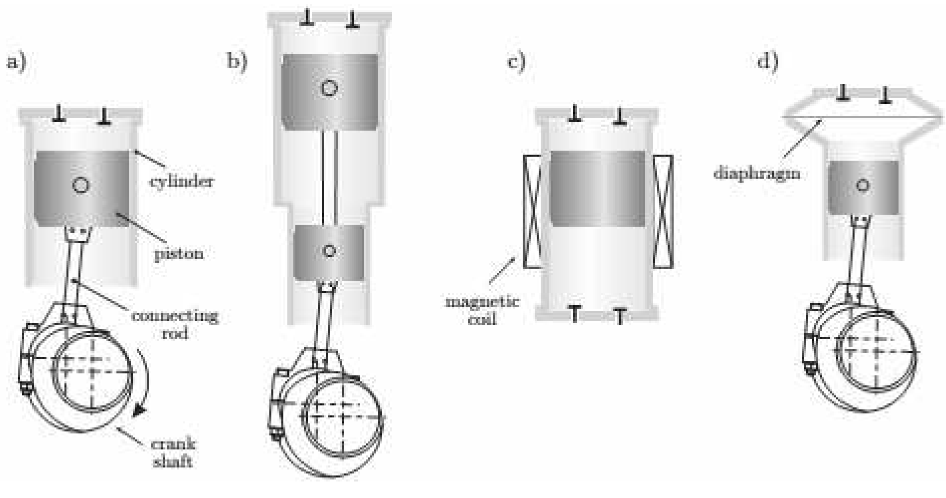

Fig. 1. Different compressor types:
a – crank driven, *b* – crosshead, *c* – free moving piston, *d* – diaphragm

The basic piston reciprocating compressor is a single cylinder with the compression space on one side of the piston, see figure 1.1a. The construction is similar to an automotive engine and uses the piston skirt to guide it in the cylinder. The piston is mechanically attached to a driving mechanism, a crank shaft, via the connecting rod. Its motion is constrained by the motion of the driver, thus stroke and the main position of the piston is predefined. During operation side forces are generated on the sliding surfaces. Generally the bearings, wrist pin and piston rings are 'splash' lubricated by oil. In some other cases, an oil pump is added and the components are pressure lubricated. Some compressors are designed with a separate crosshead to guide the piston in the cylinder instead of depending on the piston skirt to provide the guiding, see figure 1.1b. This design has many advantages. First it eliminates contact stresses on the piston skirt. Further, it separates the crankcase from the cylinder allowing control of oil migration to the working piston cylinder assembly. This necessitates a longer piston rod on which a collar or oil defector is installed. The disadvantage is the limit in rotating speed. In addition, those compressors are heavier and more expensive.

Free piston compressors include those where the piston is supported with either a gas or flexure bearing, see figure 1.1c. With a gas bearing the piston and cylinder surfaces are separated by a thin layer of gas under pressure. The piston is floating on the gas which is the same as the working fluid. Flexure bearings suspend the moving piston by mechanical springs that offer a high radial stiffness and allow easy movement in axial direction. In free piston devices, energy is supplied or removed by an electrical linear alternator. This excludes the need for a linkage and reduces the number of moving parts. Due to the unconstrained piston motion, both the stroke and mean piston position can be modulated during operation. It makes the device more versatile since the piston motion can be adjusted continually to achieve an optimum performance. Another advantage is the lack of side forces since all driving forces act along the line of motion. In some designs friction and wear are nearly eliminated by the use of non-contact gas or flexure bearings. This reduces the high friction losses and wear rates associated with crank devices. Such a solution extends substantially compressor's lifetime and reliability. In practice, the electromagnetic driving forces cannot efficiently generate enough power to drive the piston. To enhance the motion, the piston is mounted using an elastic element so that its natural frequency is close to the intended operating frequency. By driving the system close to resonant frequency less power is needed. However, if the driving frequency or natural frequency changes, the system will move away from resonance and require more input power [2].

2. Lubrication problem

A new lubrication concept for piston compressors is needed which excludes oil lubricants. The functional performance of a lubrication system is determined by friction and surface wear. Lubrication failure can be determined by these two parameters. A lubricant is defined as a substance that reduces friction and wear providing smooth movement between sliding surfaces and a satisfactory lifetime for the machine. Most often liquid lubricants are used such as mineral oils, synthetic esters or water. The lubricant may also be in solid state, like teflon, various greases used in rolling bearings, or gases for use in gas bearings. In principle failure will take place when the lubrication no longer fulfills the function for which it was designed. In the case of a piston compressor the sliding components can rub destructively over each other, thereby generating heat or causing vibrations leading to damage and, in the end, to failure.

3. Piston design

A candidate ringless piston design concept is shown in figure 2b. The piston consists of two main parts; the crown and rod are one part, the skirt is the second. The two parts are in contact along a seating surface and are held there by a spring. During running the piston crown operates at higher temperature than the skirt. The skirt temperature is held low by ceramic inserts that reduce the heat flux to the skirt. By this means, the skirt temperature is made to be approximately the same as the liner wall; this is because the skirt is isolated from heat flux from the crown and is in close proximity to the liner wall. This encourages heat flow between wall and skirt by convection and radiation and tends to make their temperatures equal. The crown thermally expands, but its expansion does not change the minimum clearance between piston and wall, since the minimum clearance is between skirt and wall. When the crown expands radially, it slides on the contact surface with the skirt and compresses the spring, but the clearance is unchanged. Therefore, the clearance change is a function only of the temperature of the skirt and the liner. Since these temperatures are always approximately equal, the clearance is always approximately constant if the thermal expansion coefficients of the materials are the same. The following drawback of this concept is that the skirt may become unseated at the crown interface under high operating speed due to inertia loads. For compressors with large pistons the concept is feasible; however, for smaller pistons the assembly can be more problematic. Further, a small amount of gas leak is tolerated in this concept.

The second alternative design having the potential to suppress the gas leak is depicted in figure 2c. The piston is constructed similar to the traditionally used elastic lip seals in hydraulic systems. The sealing element could be designed as an integrated part of the piston. The circumferential slot allows the piston skirt to adjust elastically to the liner surface. The rising pressure in the slot during compression and thermal expansion would give rise to the sealing effect. The main advantage is that the gas leakage is almost totally suppressed. Since the sliding surface will be continuously in Gas spring test sliding contact it must be covered with a wear protective coating. The application of DLC coating may reduce the coefficient of friction down to 0.02 [3].

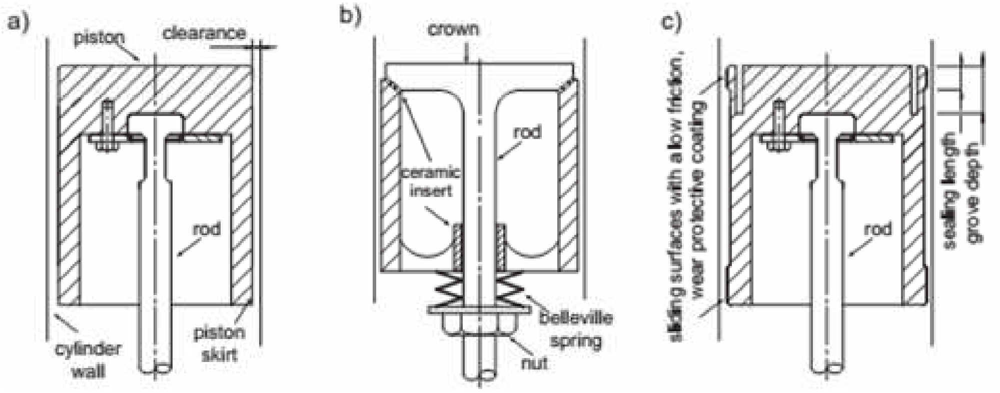

Fig. 2. Candidate ringless piston designs for an oil-free piston compressor:
a – clearance seal, *b* – the T-piston [3] and *c* – the U-piston

Conclusion

The piston will be designed as a self-lubricating (aerodynamic) piston and the working gas will be used as the lubricant. Low viscosity of the gas offers virtually frictionless operation. In order to fully benefit from the low friction potential of gas lubrication any contact between the piston skirt and cylinder liner must be avoided. However, because of unbalanced forces acting on the piston, it will also move laterally in the cylinder and occasionally hit the cylinder wall. These occasional contacts cause friction, wear and also noise eventually leading to failure. A good design must therefore provide a smooth and stable reciprocating motion of the piston and ensure that the gas film separating the surfaces is maintained during operation. At the same time the gas leakage along the piston needs to be limited. The sealing of the compressed gas in this case is obtained by the small radial clearance between piston and cylinder only, also called a clearance seal. To optimize the piston design a complete dynamic analysis of the reciprocating piston is needed.

REFERENCES

1. Yamaguchi. Motion of the piston in piston pumps and motors (Experiments and theoretical discussion) / Yamaguchi // JSME International Journal. Series B. – 2001.
2. Dickey, D.W. Thermal Engineering / D.W. Dickey, Ch.D. Wood // Analitical and experimental investigation of ringless piston concept : Technical report. – Gas Research Institute, 1998.
3. Beaty, K.D. Long-life engine design : Technical report / K.D. Beaty. – 2005.

UDC 665.662.5

DEWAXING OF LUBRICANT BASE OILS

ILYA BOROVIK , INNA YELSHINA
Polotsk State University, Belarus

Most paraffinic crude oils contain a significant amount of wax across the entire lube fraction viscosity range. Since the wax in base oil has a high melting point, as temperatures drop, the wax crystallises and thickens the lubricant until it finally stops flowing. Therefore, dewaxing processes are used during lube refining to remove waxy components from base oils to ensure that lubricants formulated with these base oils will continue to flow at low temperatures. Dewaxing is achieved by cooling the oil to below the crystallisation temperature of its waxes. The crystallised waxes are then removed by filtration. One of the most common dewaxing processes is solvent dewaxing [1].