High-pressure Oil-free Screw Compressor

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Kobe Steel's screw compressors for process gas are widely used in the fields of petrochemistry, general chemistry, oil refining, gas businesses, etc., and, more recently, are being used not only in on-land factories, but also in oceanic platforms and offshore applications such as FPSO. In recent applications that require relatively high discharge pressure, such as flare gas recovery and off-shore VRU, for which small compressors have conventionally been used, medium-sized compressors are needed to respond to the users' requirements for an increased gas flow rate. Now, Kobe Steel has lined up medium sized, high-pressure oil-free screw compressors, whose advantages and concepts are introduced in this paper.

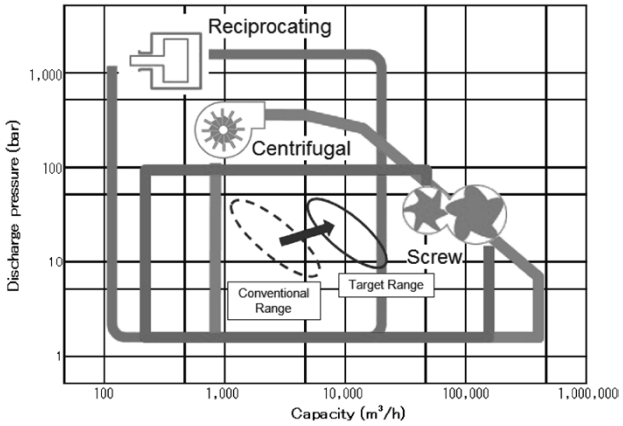

Fig. 1 Range chart for compressors

Introduction

Kobe Steel's oil-free screw compressors for process gas are widely used in the fields of petrochemistry, general chemistry, oil refining, gas business, etc.,[1] and more recently, are being used not only in on-land plants, but also in oceanic platforms and offshore applications such as floating production, storage and offloading (FPSO).

Particularly in the cases of flare-gas recovery and offshore vapor recovery units (VRUs), which require relatively high discharge pressure, medium-sized compressors are more and more often needed. This is because these applications, which have conventionally employed small-sized compressors, have recently come to require an increased gas flow rate due to customer demand. In response to such market needs, Kobe Steel has included in its lineup a series of medium-sized oil-free screw compressors for high-pressure specifications. This paper introduces the concept and advantages of these compressors.

1. Applications and applicable range of high-pressure oil-free screw compressors

Fig. 1 shows the range chart of Kobe Steel's compressors. In the cases where oil-free screw compressors are applied with a relatively high required discharge pressure, a multistage compressor of a two- or three-stage arrangement is commonly used. In those cases, a compressor specified for high-pressure is required on the side of the high-pressure stage. In flare-gas recovery, offshore VRUs, etc., a medium-sized compressor with a high-pressure and a relatively large capacity is often required. Against this backdrop, Kobe Steel has developed a medium-sized oil-free screw compressor that can cope with a maximum discharge pressure up to 40 barG, whereas the conventional machines could handle only up to approximately 20 barG.

2. Compressor structure

A typical structure of Kobe Steel's oil-free screw compressor is shown in **Fig. 2**, and the whole system is shown in **Fig. 3**. The major parts of an oil-free screw compressor include a screw rotor, casing, shaft seal, bearing and timing gear. The design specifications of some major parts such as the rotor, casing, and bearing, have been changed because the load generated by gas compression increases under high-pressure operating conditions. A high-performance silencer has also been developed in order to reduce the acoustic energy, which increases with increasing operating pressure. The following describes the features of each component for the high-pressure oil-free screw compressor.

2.1 Compressor casing

There are two types of casing structures for Kobe Steel's oil-free screw compressors, i.e., a horizontally split type and a cylindrical type, which are selected according to the compressor size. A large-size compressor, used in relatively low-pressure applications, employs a horizontally split type that emphasizes maintainability, whereas, compact to

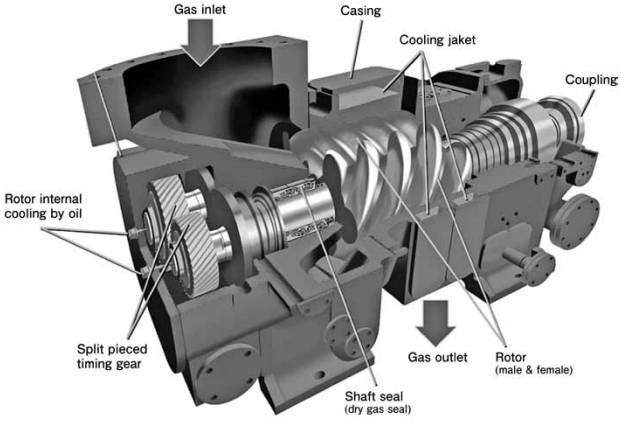

Fig. 2 Structure of oil-free screw compressor

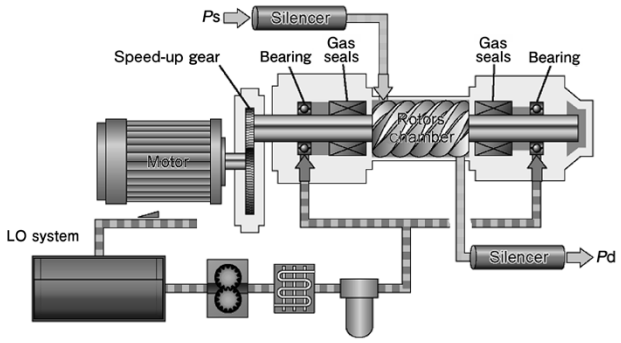

Fig. 3 Typical system of oil-free screw compressor

medium-sized compressors, which are often used in high-pressure conditions, employ cylindrical types with a view to the pressure resistance. For the high-pressure specifications, revisions have been made on the wall thickness and flange rating of the conventional casing.

The standard casings are made of cast carbon steel. For a water injection application, an option is available to improve erosion resistance by overlaying several-millimeter-thick welding of austenitic stainless steel on the inner surface of the rotor chamber of a horizontally split casing. This overlaying welding is a technology established as a result of Kobe Steel's long-standing trial and error efforts. This technology has been used in large-sized screw compressors for styrene monomer applications, in which excellent resistance against erosion has been confirmed.

More recently, casings of cast stainless steel are also being made at customer request.

2.2 Screw rotors

The profile of a screw rotor is an important factor that directly affects the performance of the screw compressor. Hence, Kobe Steel selects, from several types of profiles including proprietary types,[2] the optimal rotor profile for the customer's specifications. The rotor is made of either forged carbon steel or forged stainless steel, depending on the applications or customer's requirements.

The rotor length of each Kobe Steel screw compressor is selected from the short type or the long type on the basis of the specified gas flow rate, so as to enable optimum designing for the compressor capacity. For high-pressure specifications, a shaft with an outer diameter greater than that of the conventional specifications is used to secure the rigidity of the rotor shaft.

2.3 Shaft seal system

The shaft seal system is regarded as one of the most important technologies for process-gas compressors. In the case of Kobe Steel's oil-free screw compressors, an optimum shaft-seal system can be selected from several options in accordance with the specifications, application or customer requirements. The following describes a typical shaft seal system used for Kobe Steel's oil-free screw compressors:

(1) Dynamic type dry gas seal (tandem or double arrangement)
(2) Hydrostatic type dry gas seal (single or tandem arrangement)
(3) Mechanical seal
(4) Carbon ring seal
(5) Bearing oil film seal

Dynamic-type dry gas seals or mechanical seals are applicable to high-pressure oil-free screw compressors.

2.4 Bearing (journal bearing, thrust bearing)

Kobe Steel's oil-free screw compressors mainly employ plain bearings. Recently, a lineup of Advanced series, adopting roller bearings, is also available.

Journal bearings are mainly based on cylindrical bearings, in which the positions and shapes of oil grooves, bearing clearance, etc., are optimally designed in accordance with the lubrication conditions and operating conditions. In recent years, tilting-pad journal bearings, having a high vibration-damping effect, are also used for high rotational speed specifications to stabilize the shaft vibration. The high-pressure oil-free screw compressor, however, employs conventionally used cylindrical bearings to support relatively large bearing loads.

The thrust bearing normally adopts a highly reliable tilting-pad bearing on the active load side (**Fig. 4**). The lubrication type for the thrust bearing adopts the direct lubrication type, which is effective

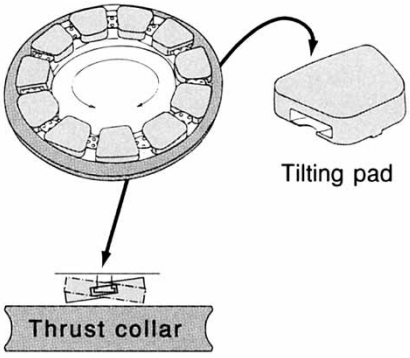

Fig. 4 Tilting pad thrust bearing

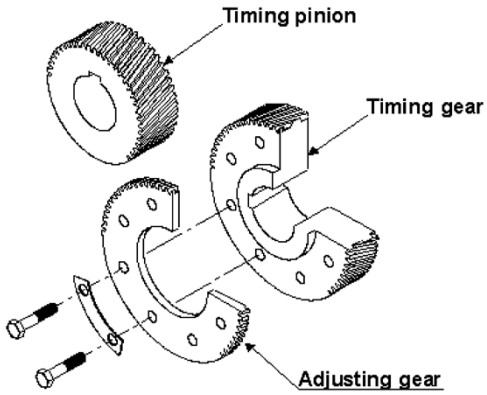

Fig. 5 Exploded view of timing gear

in reducing the mechanical loss during high-speed operation. In the cases of high-pressure and relatively high rotational speed conditions, a self-equalizing thrust bearing is occasionally used, due to the high thermal load on the bearings.

2.5 Balance piston

Kobe Steel's oil-flooded screw compressors normally adopt balance pistons to reduce the gas load in the thrust direction. Whereas oil-free screw compressors bear thrust loads that are relatively small and have the problem that the hydraulic oil of balance pistons, if used, generates heat during high-speed operation. Therefore, balance pistons have not been used so far. In high-pressure applications, however, oil-free screw compressors may be operated under conditions where the thrust load is high. Therefore oil-free screw compressors also need to reduce the thrust load by balance piston or some other way, if the allowable thrust-bearing load is exceeded. In general, the mechanisms for reducing thrust load include not only balance pistons, but also the utilization of the meshing reaction force of a single helical gear. Kobe Steel has developed a proprietary balance piston for high-speed operation that can be applied to an oil-free screw compressor.[3)]

2.6 Timing gear

The timing gear of a Kobe Steel's oil-free screw compressor normally has the split structure shown in **Fig. 5**, which makes it possible to adjust the backlash of the gear. The backlash of the gear, if made smaller than that of the rotors, prevents the rotors from contacting each other at the time of an emergency stop of the compressor, for example, and thereby helps improve the reliability of the compressor.

A high-strength material is selected for the timing gear so as to ensure that its dimension in the axial direction is just enough to secure the necessary strength without becoming excessively large. As a result, the weight increase of the gear is suppressed, which contributes also to the stability improvement of the rotor during operation. Thanks to the improvement in the machining accuracy of gears in recent years, a precision gear without adjusting gear may be used, especially in cases where high strength is required.

2.7 Water/liquid injection system

In some Kobe Steel's oil-free screw compressors, water or liquid may be injected into the casing, depending on their applications and specifications. For this purpose, a water injection nozzle has been designed such that water is sprayed for easy evaporation. Water is also injected in the direction opposing the gas flow to ensure the homogeneous distribution of water in the process gas. Such water injection methods can significantly reduce the erosion of casings and rotors.

2.8 Silencer

For Kobe Steel's oil-free screw compressors, there are two silencer configurations to reduce acoustic energy in process gas piping, i.e., one silencer installed in the nozzle on the discharge side, and two silencers installed in the nozzles on the suction side and discharge side, respectively. In the case of screw compressors, generally, the acoustic energy on the discharge side is greater than that on the suction side due to the effect of discharge pulsation. Hence, it is important to design measures to reduce the discharge pulsation, especially the low-frequency pulsation. Kobe Steel has technologies to design optimum silencers in accordance with the type of gas and required acoustic characteristics. The company makes the arrangement and optimum design of silencers suitable for the respective applications and specifications.

Fig. 6 Appearance of developed silencer

On the other hand, the pulsation characteristics of a screw compressor may change in flare-gas recovery, which is one of the applications of high-pressure oil-free screw compressors. This is because flare-gas, i.e., the gas accompanying crude oil extraction, may change in composition and concentration over time, depending on the condition of the reserves. This occasionally affects the performance of the silencers.

Hence, in developing high-pressure oil-free screw compressors, Kobe Steel also worked on the development of a silencer that can be used for the above application (**Fig. 6**).

The newly developed silencer has a reducing effect on the pulsation in a wide frequency band and exerts that effect even when the frequency characteristics of pulsation change as described above. For the development of the silencer, a case study was conducted using acoustic analysis, and the performance was verified by a speaker test using a prototype silencer. In the actual machine test of the high-pressure oil-free screw compressor, as described below, the prototype silencer was installed to verify its performance.

3. Verification by actual machine operation

During the development of the high-pressure oil-free screw compressor, a high-pressure operation by closed-loop was carried out at Kobe Steel's 20 MW test bench (**Table 1**, **Fig. 7**, **Fig. 8**). The discharge pressure was raised to the maximum 40 barG to verify the mechanical stability of the compressor under high-pressure conditions. The following items were also checked:

(1) The performance of the compressor was confirmed by operating with gases having different molecular weights.

(2) The bearing temperature, the shaft vibration, etc., at the maximum load operation, were confirmed to be within the allowable limits specified by Kobe Steel's design standard and the API standard.

(3) The load acting on the thrust bearing was monitored by a load cell embedded in the thrust bearing pad (**Fig. 9**).

(4) The change value of the thrust load with the use of the balance piston was checked

Table 1 Specifications and test conditions of developed compressor

Model	KS40SNZ
Test gas media	N_2, CO_2
Discharge pressure (barG)	Max. 40
Rotational speed (rpm)	Max. 4,700
Suction volume (m^3/h)	Max. 10,000

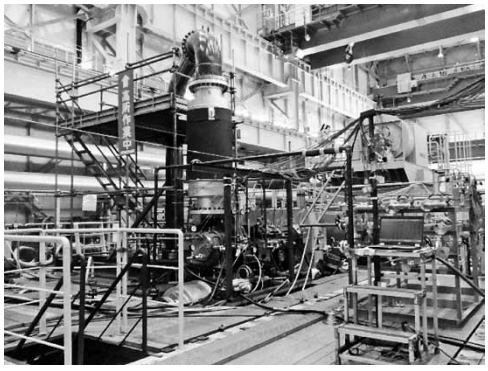

Fig. 7 View of test bench

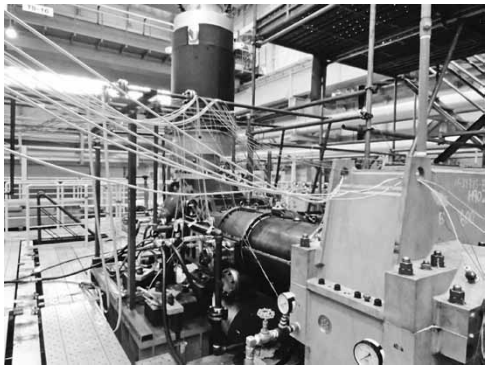

Fig. 8 Prototype model of developed high-pressure screw compressor

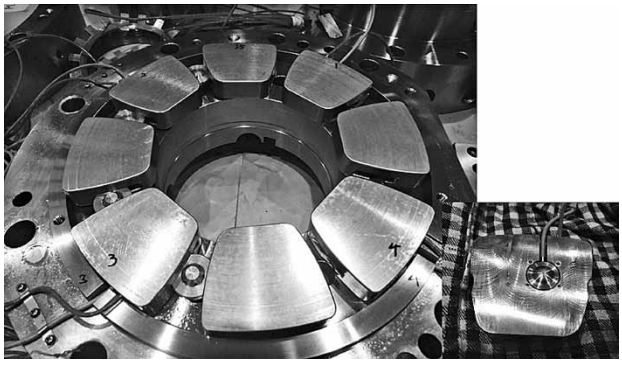

Fig. 9 Thrust bearing with embedded load cell

to confirm that the balance piston was functioning normally.

(5) The sound pressure inside the silencer was measured to confirm that the acoustic energy in the silencer was reduced.

(6) Disassembly inspections after high pressure operation confirmed that there were no abnormalities in the internal parts of the compressor.

4. Future perspectives

Kobe Steel is capable of designing not only the oil-free screw compressor for high-pressure specifications, introduced in this paper, but also oil-free screw compressors for high-speed specifications and for high/low temperature applications.

The company not only supplies customers with bare screw compressors, but also with compressor units as shown in **Fig.10**.

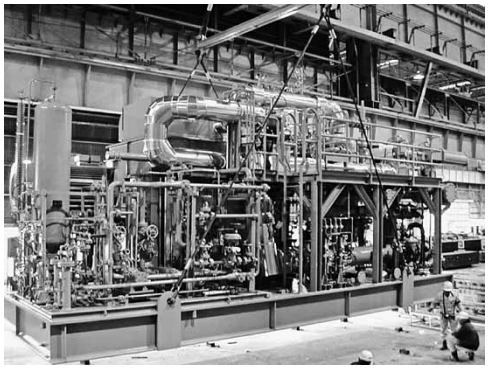

Fig.10 Oil-free screw compressor unit

Kobe Steel will continue to produce cutting-edge screw compressors in accordance with the market needs.

Conclusions

Kobe Steel has designed and manufactured oil-free screw compressors for more than 60 years and has many deliveries on record. Exploiting the experience it has gained so far, the company will continue to expand the scope of its oil-free screw compressors by developing new technologies and new models that are adapted to market needs, as well as improving existing models. In addition, it will focus on developing new fields and new applications and thus contribute to the development of the industry through its oil-free screw compressors.

References

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2) E. Fujita et al. R&D Kobe Steel Engineering Reports. 1999, Vol.49, No.1, p.36.
3) Kobe Steel, Ltd. COMPRESSOR. Japanese Patent No. 6019003. 2 Nov. 2016.