High Pressure Oil-flooded EH Series Screw Compressors

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Kobe Steel has developed a line of high pressure, oil-flooded, screw compressors called the "EH series". Discharge pressures up to 6.0 MPa have been achieved through our original technological developments such as new rotor profiles, larger bearings and special mechanical seals. The compressors are characterized by high performance and reliability, and are especially suited for use in fuel gas boosting of gas turbines. The applications of the EH series are expanding. In recent years, the demands for desulfurized gasoline and diesel fuel have increased worldwide. New regulations to protect the environment have forced the oil refinery industry to develop desulfurization processes. The "EH series" also runs on this application and the demand is increasing.

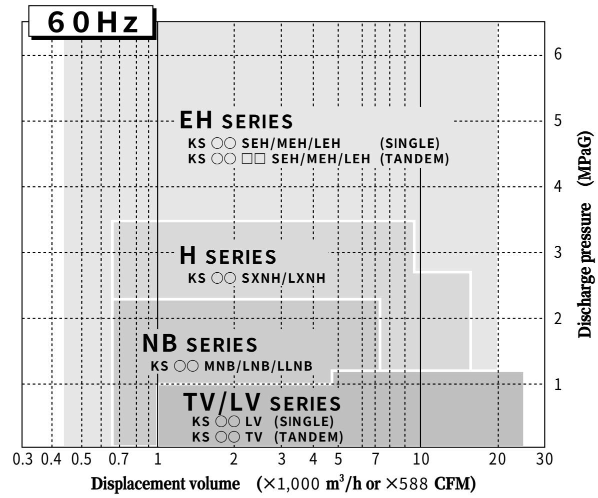

Fig. 1 Range chart of KOBELCO EH series

Introduction

Screw compressors are widely used in industry because, although being volume-type themselves, they have features of rotary-type compressors such as high efficiencies, space savings and prolonged operations. Above all, oil-flooded compressors, which pour oil into compressed gas, are finding more applications, because they can achieve a high discharge pressure with a single step at a high compression ratio, through improvements in application range, lubrication and oil-separation technologies.[1)]

We have developed oil-flooded compressors "EH series" with 17 different rotor sizes, which can compress up to 6 MPa, including the world's largest class oil-flooded compressor. The specifications of "EH series" are summarized in **Table 1**, and a compression range chart is shown in **Figure 1**.

This article describes the compression mechanism and examples of applications of the "EH series" focusing on our original technologies. Also described is the new application and future prospective of the high pressure oil-flooded compressors.

Table 1 Basic specifications of KOBELCO EH series

Max. working discharge pressure	6.0 MPaG
Max. working suction pressure	6.0 MPaG
Max. working differential pressure	6.0 MPaG
Casing design pressure	7.0 MPaG
Capacity range	220～19,000 m^3/h
Capacity control range	approx. 15～100%
Casing	Cast steel
Rotors	Forged steel
Mechanical seal	SiC + Carbon
Bearings : Thrust	Tilting pad type
Journal	Babbittes sleeve type

1. The structure and features of the high pressure oil-flooded "EH Series" compressor[2)]

Figure 2 shows the construction of a tandem-type compressor. Gas is drawn in from the gas-inlet, compressed by the first male/female rotors engaging each other, and discharged from the outlet nozzle after further compression by the second male/female rotors. The two step compression as show in Figure 2 (the tandem-type) is applied for high compression ratio, while the single step type, which does not have the 2nd step of the tandem-type, is applied generally for compression ratio less or equal than 7. Radial bearings are placed at each end of both the rotors, and thrust bearings are placed on the non-rotor side of the radial bearings at the outlet end. A mechanical seal is installed on the axis of the male-rotor preventing the leakage of the compressed gas outside.

1.1 Rotor profile

The main features of our screw compressors are the rotor profiles developed and optimally designed for each field of application. Generally, the compressor performance is optimized by

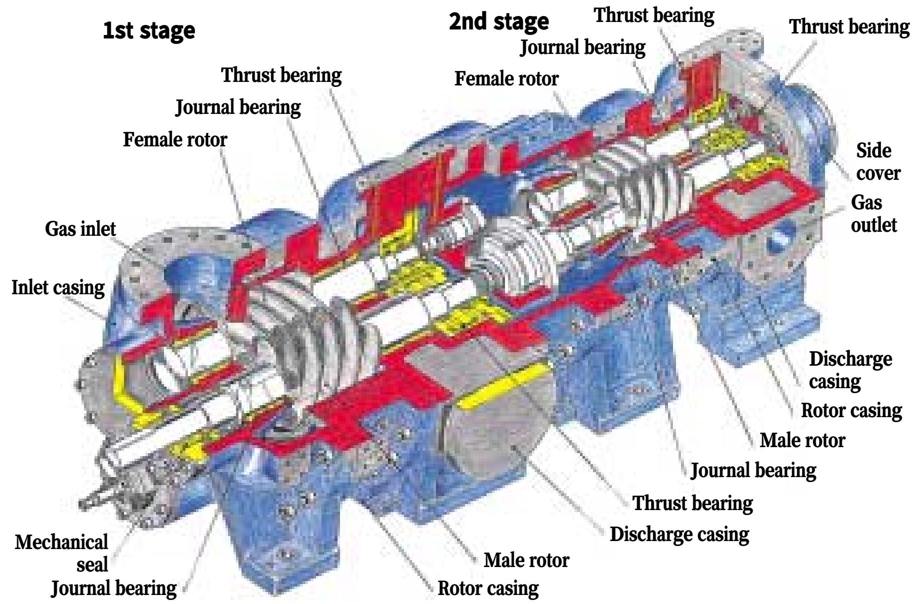

Fig. 2 Construction of tandem-type compressor

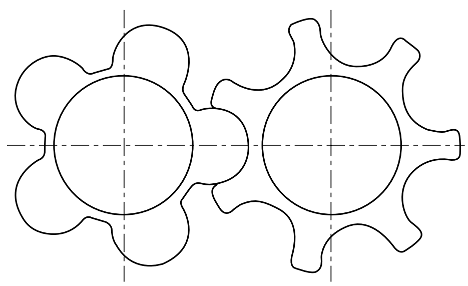

Fig. 3 Rotor profile (5 + 7 lobe numbers)

shortening the rotor seal length per unit stroke-volume, by minimizing the passage way called "blow-hole" between the male/female rotors and casing, and by the twist-angles which determine the pressure ratio between the compression grooves. However, those factors can not be optimized independently at the same time. We have developed simulation programs based on our original rotor-profile theory[3], and have determined the optimal rotor profiles for each application.

The "EH series" has male-rotors with 5 lobes and female-rotors with 7 lobes (5+7 lobes) as shown in **Figure 3**; a combination optimized for high-pressure applications by the simulation programs. Both the gas pressure bearing load and compression performance were simulated for different combinations of rotor numbers and rotor lengths.

1.2 Bearing

The sleeve-type is used for the radial bearings and the tilting-pad type is for the thrust bearings. Both the bearings are larger compared to conventional machines so that they can withstand the higher load caused by the high outlet pressure. Above all, the radial bearings have larger load areas because of the 5+7 lobe configuration. The standard bearing material is white metal, and aluminum bearings are used as an option for an environment containing corrosive gas.

1.3 Mechanical seal

Choices of single-type, double-type and tandem-type are available for the mechanical seal depending on the customer requirements.

In general, the performance of the mechanical seal determines the maximum operating inlet pressure of an oil-flooded compressor, because the construction makes the pressure inside the seal box almost equal to the inlet pressure. The EH series compressors employ high-strength-carbon mechanical seals of which the shapes are optimized for high inlet-pressure utilizing the seal-vendor's technologies and our accumulation of know-how in the field.

2. Application examples of the "EH Series" compressor system

Figure 4 shows a general schematic diagram of an oil-flooded screw compressor system. Gas is compressed after passing the suction filter and check-valve. The oil-flooded screw compressor needs a significant amount of oil to cool the gas and to lubricate the rotors and bearings. The oil is first separated and removed from the gas to an

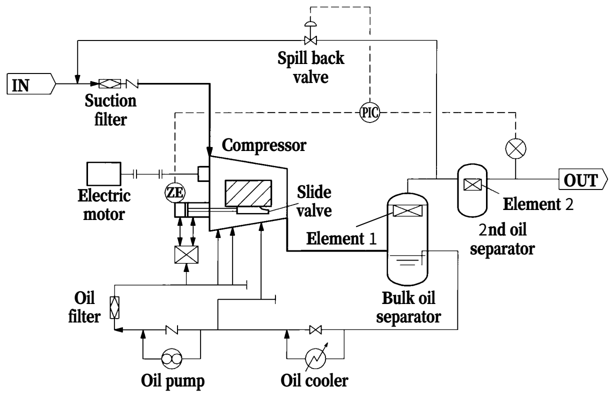

Fig. 4 Schematic diagram of oil flooded screw compressor

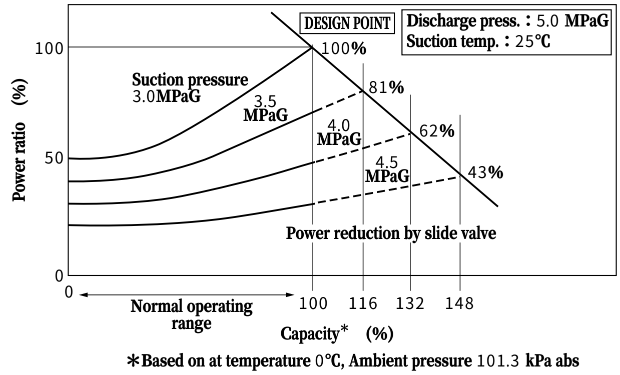

Fig. 5 Typical load characteristics

acceptable limit in the bulk oil separator, and then removed further by the 2nd oil separator. The element employs a special fine fiber filter. The separated oil is re-circulated back to the compressor through the oil cooler.

This chapter describes examples of systems applying the "EH series".

2.1 Gas compressor for gas-turbine fuel

An application exploiting the advantages of the oil-flooded screw compressor is gas turbine fuel gas boosting. The recent increase in the gas-turbine efficiency requires a compressor with high outlet pressure. The "EH series", combined with our conventional series, cover almost all the requirements for flow and pressure by the gas-turbine manufacturers.

The gas turbine compressor is required to have a constant outlet pressure despite the fluctuating gas-turbine load and fluctuating supply (inlet) pressure. Our compressor controls the volume and pressure using both the slide valve and spill-back valve. It takes advantages of both the former having stability and high response, and of the latter having power saving at partial load conditions.

In a condition under which the inlet pressure fluctuates significantly, such as the fluctuation found in the gas pipeline, the actual inlet pressure sometimes exceeds the designed point, forcing the compressor to operate at a low compression ratio with higher inlet pressure with even higher outlet pressure. The oil-flooded screw compressor, especially, reduces the power consumption in such a condition.

Figure 5 shows the typical load characteristics for constant outlet and varying inlet pressures. The oil-flooded compressor operates with reduced power and increased suction flow when the inlet pressure becomes high in a low compression ratio condition. The choice of compressor type is based usually on the minimum inlet pressure, however, in the actual operation, pressures higher than the design-pressure are applied with capacities lower than the designed capacity (100% capacity). The capacity control using a slide valve significantly saves energy in the actual operating conditions.

2.2 Multi-compressor system

Large power plants require systems in which more than one gas turbines are combined with more than one compressors. The pipelines for natural gas have large fluctuations of the source pressure and, in some cases, the maximum source pressure exceeds the fuel-gas pressure (or the compressor outlet pressure) required by the gas-turbine. We deliver fuel-gas compression systems using "EH series" to accommodate those conditions.

An example of the multi-compressor system is shown in **Figure 6**. The system uses 2 compressors to supply fuel gas to 3 gas turbines. A line with a pressure reducer valve bypasses the compressors and directly supplies fuel gas to the turbine when the source pressure is high, thus minimizing the power consumption. The system is featured by the small installation space achieved through the combination of the inlet-pressure control valves and the spill-back valves, and by the ease of site-installation achieved by a single compressed-gas supply-line feeding to 3 gas turbines.

An example of 3 compressors supplying fuel to 2 gas turbines is shown in **Figure 7**, and the appearance of the compressors is shown in **Photo 1**. Three sets of compressors and motors are installed, and while the rest of the system is designed for the flow from the 2 operating sets, one set is used as a standby. The system reduces the space and cost.

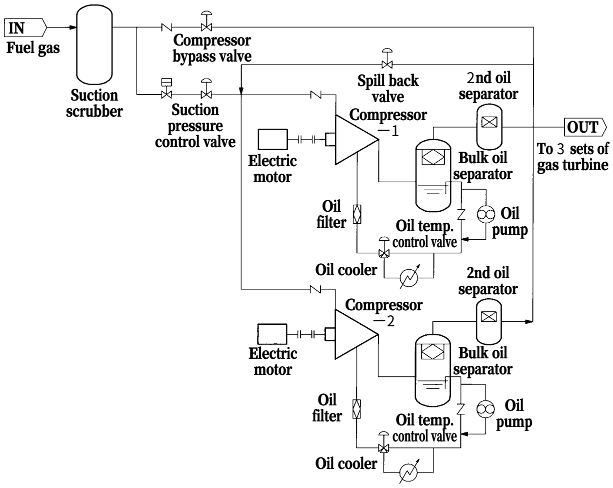

Fig. 6 Oil flooded screw compressor system-1

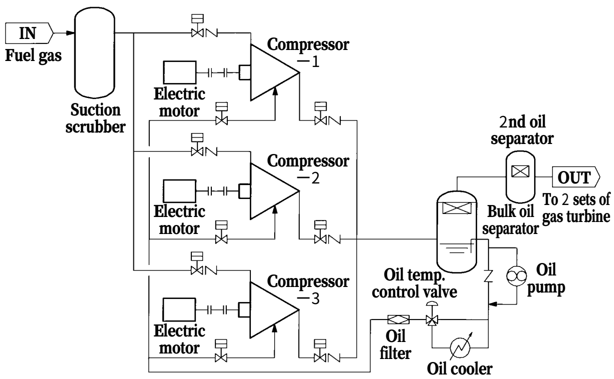

Fig. 7 Oil flooded screw compressor system-2

Photo 1 Screw compressor for gas turbine fuel gas

2.3 Controllability

More sophisticated controls of pressures and temperatures are required for the systems having multiple compressors supplying fuel gas to multiple gas turbines, and for the systems sharing components such as the inlet pressure control valves, separators, and bypass valves. Our experience and simulation technology enable us to respond to those requirements.

We realize a stable system by accounting for such parameters as DSS (Daily Start and Stop), restart and stop of a standby machine, various operation patterns for the varying gas turbine load, and also the piping volumes between the compressors and turbines which are inherent to the installation sites.

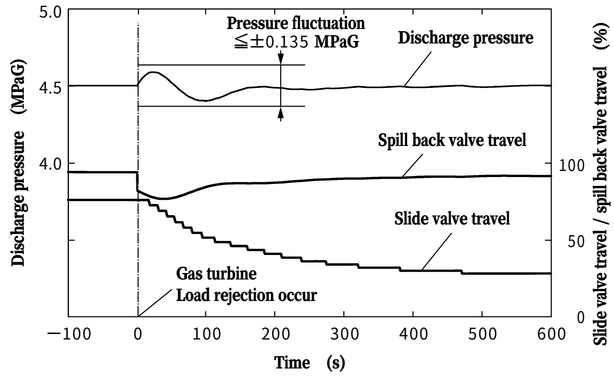

Fig. 8 Simulation for fluctuation of discharge pressure

Figure 8 shows a simulation example of the compressor outlet pressure when a turbine load rejection occurs (100% to 30%). The combination of slide valve and spill-back valve control the outlet pressure even when the gas supply volume to the turbine changes abruptly.

Our compressors for gas turbine fuel have won a good reputation from customers for their excellent controllability and steady operation record. We prioritize customers' needs such as multi-compressor systems which save cost and space, and sharing of separators and bypass valves.

3. New application and future perspective of the "EH Series"

3.1 Ethylene refrigerator compressor

Although our tandem-compressors comprise 2 stages, they can be treated as single stage compressors because the drawn gas is fed into the 2nd stage without being discharged to the outside of the compressor. Thus, only one set of components such as a motor, separator and high order separator is required to achieve the 2 stage compression, enabling the 2 stage compressor to be treated the same as the single stage compressor. Other compressors, in general, tend to increase the number of components to achieve pressures and compression ratios. Our tandem-type compressor provides more space along with the highly efficient 2-stage compression.

We have produced an ethylene refrigerator using a tandem-type "EH series" compressor. The operating condition of the compressor is shown in

Table 2 Specifications of ethylene compressor

Capacity : 1st stage	kg/h	6,500
Side stream	kg/h	3,800
Suction pressure	MPaG	0.22
Suction temperature	℃	−88.4
Discharge pressure	MPaG	3.0
Shaft power	kW	810

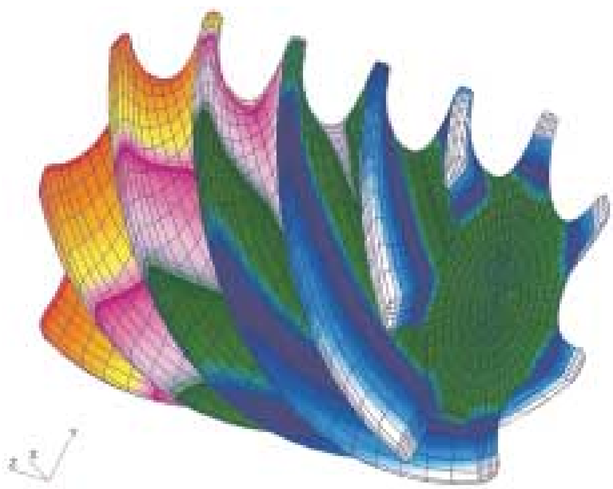

Fig. 9 Simulation for temperature distribution of rotor surface

Table 2. The inlet temperature is so low, at −88.4℃, that a special selection of material is required. In order to meet the condition, a stainless steel is used for the compressor casing, and the rotor uses a special material for low temperature application. **Figure 9** shows the result of a simulation for rotor-surface temperature distribution. The compressor, first in the world of oil flooded screw compressor for a low temperature application at almost −90℃, that symbolizes our technical capability.

3.2 Compressors for desulfurization

The oil companies are working on the sulfur reduction of fuels in response to the global requirement for the low-sulfur automobile gasoline and diesel fuel, which contribute to environmental protection. The desulfurization of fuel generally uses compressed hydrogen gas, and requires a compressor called the recycle-gas compressor.

Although the main constituent of the gas is hydrogen, it contains small amount of sulfur hydride which is corrosive. It also contains heavy hydrocarbons, such as propane and butane, which dissolve into the lubricant-oil reducing the viscosity of the lubricant. The compressor has to correspond to a variety of operating conditions using various gases with different properties

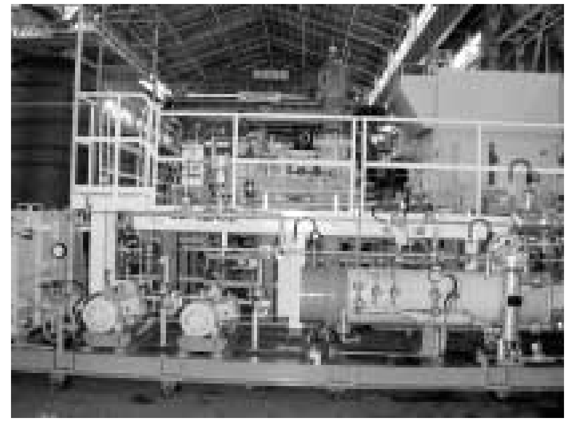

Photo 2 Screw compressor for desulfurization process

including the nitrogen used at the time of the start-up. A high reliability is required for prolonged operation time. Conventionally, compressors of reciprocal and centrifugal types have been used for this application; however, the oil-flooded screw compressors are expanding their applications in this area because of their high reliabilities with their gas-type immune natures inherent to the volume-type compressors.

The oil-flooded screw compressor uses oil inside the compressor to lubricate the rotors, bearings and mechanical seals and to cool the gas. Gas, containing a considerable amount of heavy hydrocarbon which dissolves into lubricant and reduces viscosity, can cause breakage of oil film at the bearings and can cause wear, limiting the application of the oil-flooded compressors. Recent development of synthetic oil (PAG: Poly Alkyl Glycol) dissolves only small amount of heavy hydrocarbon gas, allowing the use of the oil flooded compressor for the application.

Photo 2 shows the appearance of a typical gasoline desulfurization unit. No sound insulation is required because of the low noise nature of the screw compressor, improving the ease of maintenance. Also considered are applications to the desulfurization of diesel fuel and to the net gas booster which is one of the main pieces of equipment for desulfurization process.

3.3 The future prospective

The high-pressure screw compressors "EH series" are now used widely not only in the energy industries but also in the petroleum refineries and petrochemical industries, and have won high reputation as superior process gas compressors. New applications to gas mining and pipelines (Oil and Gas) are also considered. Other new applications include a use for high outlet pressure utilizing the characteristics of the oil-flooded screw compressors. We are developing an oil-flooded screw compressor with outlet pressure 10.0MPa class, and will respond to various needs of the users.

Conclusions

The "EH series" have expanded the application of oil-flooded screw compressors for process gas. We will contribute to the growth of the industry responding to the users' needs by exploiting the characteristics of the screw compressors.

References

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