High-pressure 100 barG Oil-flooded Screw Compressor

Yasushi AMANO Rotating Machinery Engineering Department, Compressor Division, Machinery Business

Kobe Steel has developed a series of oil-flooded screw compressors for high-pressure. The company's original rotor technology, along with larger bearings and special mechanical seals, has enabled discharge pressures up to 100 barG. The compressors, with their high performance and reliability, are suitable for fuel gas boosting and, in particular, for high-efficiency gas turbines. They are finding an increasing number of applications, such as the desulfurization of fuels, and further increases are anticipated.

Introduction

Screw compressors are positive displacement compressors, but also have characteristics of rotary compressors. Screw compressors are widely used across the industry for their characteristics of high efficiency, a small footprint and long-lasting features. Oil-flooded screw compressors, in which oil is poured into the gas being compressed, can achieve high discharge pressures in one stage with high pressure ratios. The oil-flooded compressors are finding increasing applications, as their technology is improved for higher pressures, larger gas volumes, better lubrication and advanced oil separation.

Kobe Steel has developed a series of oil-flooded screw compressors, the "EH series", which are applicable to discharge pressures up to 100 barG. **Fig. 1** is a range chart for the oil-flooded screw compressors, including the conventional series, developed by Kobe Steel. **Table 1** summarizes their specifications.

This paper introduces an oil-flooded screw compressor with a maximum discharge pressure of 100 barG. Also included are the examples of applications using the newly developed compressors and their future applications, which are expected to increase in number [1) - 3)].

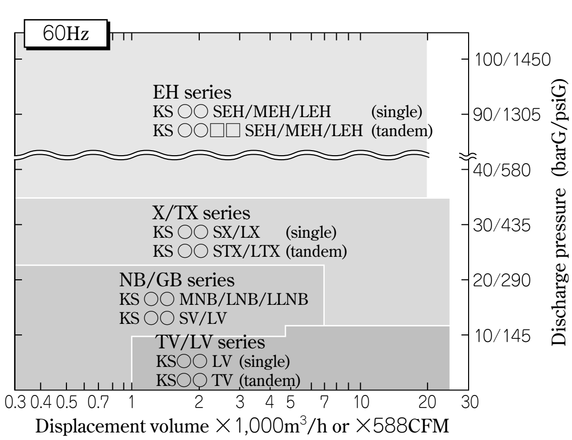

Fig. 1 Range chart for KOBELCO EH series

Table 1 Basic specifications of 100 barG oil-flooded screw compressor

Max. working discharge pressure (barG)	100
Max. working suction pressure (barG)	100
Casing design pressure (barG)	115
Capacity range (m^3/h)	200～20,000
Rotor material	Forged steel
Casing material	Cast steel
Mechanical seal	SiC＋SiC
Bearings : Radial	Babbittes sleeve type
Thrust	Tilting pad type
Capacity Control	Step less 100～15%

1. Construction and features of 100 barG oil-flooded screw compressor

Fig. 2 is a cut-away view of an oil-flooded screw compressor having a discharge pressure of 100 barG. Gas is introduced into a suction nozzle, compressed by a pair of male and female rotors engaging each other and discharged from an outlet. Each rotor has radial bearings on both of the sides along the shaft and a thrust bearing installed on the discharge side of the radial bearing away from the rotor. A mechanical seal, disposed at the portion of the male rotor passing through the casing, prevents the compressed gas from leaking outside.

1.1 Rotor tooth profile

The most important feature of Kobe Steel's screw compressors is their tooth profiles, which have been continually developed and adapted for various applications. The following conditions must be met in order to achieve high volume efficiency:
- shortening the seal line between the rotors for each unit of displacement volume,
- minimizing the size of the passage way called "blow-whole" created by the male/ female rotors and the casing,

and
- optimizing the rotor wrap angles for minimizing the pressure ratio in each of the grooves.

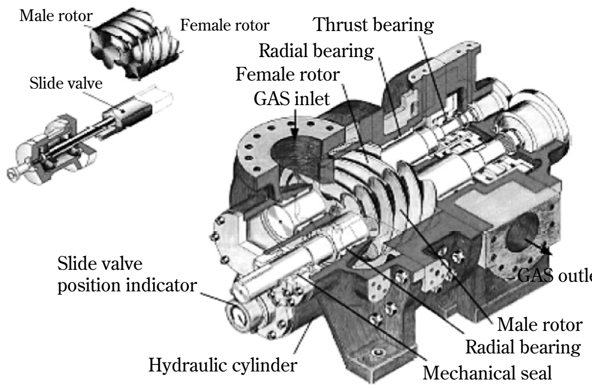

Fig. 2 Construction of 100 barG oil-flooded screw compressor

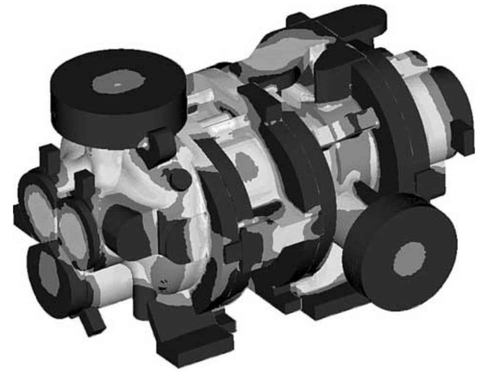

Fig. 3 FEM analysis of casing stress

These conditions, however, cannot easily be met simultaneously. To this end, Kobe Steel has developed a simulation program based on a unique theory on tooth profiles. The simulation program allows the designing of the most suitable tooth profiles for various applications. The tooth profile of the 100 barG oil-flooded screw compressor was designed using this program. The program includes bearing load simulation and performance simulation based on gas pressure and other parameters, including the number of teeth and rotor lengths. The simulations lead to a rotor combination, most suitable for a high load, consisting of a male rotor having five teeth and a female rotor having seven teeth (5 + 7 tooth profile).

1.2 Bearings

The compressor adopts sleeve-type radial bearings and thrust bearings of the tilting pad type. The high discharge pressure is supported by the bearings, which are selected to be large enough to bear the load. Adopting the "5 + 7 tooth profile" has enabled the radial bearings to have large enough bearing surfaces. The standard material for the bearings is white metal, with an alternative use of aluminum for the bearings exposed to corrosive gas.

1.3 Mechanical seal

The mechanical seal of a compressor is single-type, double-type or tandem-type, depending on the customer's needs.

The pressure inside the box of a mechanical seal becomes almost equal to the suction pressure during the run. This means the mechanical seal strongly affects the maximum suction pressure of an oil-flooded screw compressor.

All the seal components are made of silicon carbide (SiC) which endures high suction pressure and assures durability.

1.4 Casing

An FEM stress analysis was conducted to optimize the casing for high discharge pressure. Included in the analysis were wall thickness and rib shapes. **Fig. 3** shows the result of the casing stress analysis.

A casing was designed, based on the above analysis, and was tested for its mechanical strength. A compressor using the casing was test-run to ensure operation at the discharge pressure of 100 barG. The performance measurement was conducted using a testing apparatus built in-house. In addition, the gas discharged at the pressure of 100 barG was analyzed for its oil content to verify the effectiveness of oil separation.

2. Applications of the oil-flooded screw compressor with 100 barG discharge pressure

Fig. 4 is a schematic diagram of a typical oil-flooded screw compressor. After passing a suction filter and check valve, gas is compressed to a high pressure. The oil-flooded screw compressor uses a large amount of oil for lubricating the rotors and bearings and for removing compression heat. The oil has to be separated and removed from the compressed gas to an acceptable level. The oil is recovered in a first separator and then fed into the compressor via an oil-cooler. The oil remaining in the compressed gas is removed further by high-order separators employing a special filter made of fine fibers.

The following describes the practical applications which can fully exploit the features oil-flooded screw compressors having discharge pressures up to 100 barG.

<Petroleum refining>
- Compressors for desulfurization
- Net-gas booster compressors
- Off-gas compressors

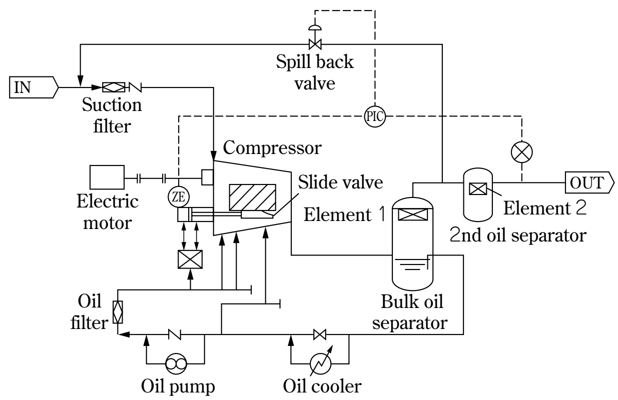

Fig. 4 Schematic diagram of oil-flooded screw compressor

<Petrochemical>
- Hydrogen compressors
- Carbon dioxide compressors

<Energy>
- Fuel gas compressors for gas turbine

<Oil & Gas>
- Gas-lifting compressors for offshore rigging
- Booster compressors for LNG pipelines

Conventionally either reciprocal compressors or centrifugal compressors have been used for those applications; however, an increasing number of oil-flooded screw compressors are being used for pressure ranges up to 60 barG. This is because the oil-flooded screw compressors have the advantages of positive displacement compressors which are highly reliable and unaffected by the type of gas. The following section introduces typical applications that can employ oil-flooded screw compressors.

2.1 Compressors for desulfurization

Sulfur in gasoline and diesel fuels is a global environmental concern, and reducing the sulfur content poses challenges to petroleum companies around the world. Desulfurization is a process for removing sulfur from fuel using hydrogen and requires a hydrogen compressor, commonly known as a "recycled gas compressor". The gas consists mainly of hydrogen, but also contains a small amount of hydrogen sulfide, which is corrosive. Occasionally, the gas also contains heavy hydrocarbons, such as methane, propane and butane, which can dissolve into the lubricant and lower the oil's viscosity. Nitrogen may be used during the start-up of a plant. The gas content can be affected by the desulfuration process. Thus, the compressors must be able to respond to various gas and operation patterns. In addition, the compressors are required to achieve high reliability and to run continuously for extended periods.

As described above, the lubricating oil poured into the interior of an oil-flooded screw compressor may have a viscosity decreased by the dissolved gas i.a., heavy hydrocarbons. This can deplete the oil film in the bearings and mechanical seals, causing the parts to wear. This limits the use of oil-flooded screw compressors for those applications; however, a newly developed synthetic oil, polyalkyl glycol (PAG), which has resistance to heavy hydrocarbon, enables the use of the compressors for hydrocarbon containing gases.

Fig. 5 shows a typical compressor used for desulfurization. The compressor is being used as a net-gas booster, a major apparatus for desulfurization, which requires even higher reliability. Going forward, the compressor is expected to be used for desulfurizing diesel fuel, which requires a discharge pressure at the 100 barG level.

2.2 Hydrogen compressor

Hydrogen is widely used in the petroleum refining and petrochemical fields and is purified by various methods, including pressure swing adsorption (PSA), membrane separation and electrolysis. Hydrogen is usually produced at a low pressure (near atmospheric pressure) and, usually, is sucked into a compressor at that low-pressure. Compressing hydrogen from a state of such low pressure to the high pressure specified by each application requires a compressor with a high pressure ratio. However, hydrogen, with its small molecular mass, is prone to leak, making it difficult to boost the gas with a high pressure ratio. Thus, hydrogen is conventionally compressed in more than one stage. **Fig. 6** shows a hydrogen compressor.

The lubricating oil poured into the rotor chamber of an oil-flooded screw compressor during the run decreases the gas leakage from the rotors and suppresses the temperature rise caused by gas compression. This enables single stage compression with a high pressure ratio. In addition, Kobe Steel's

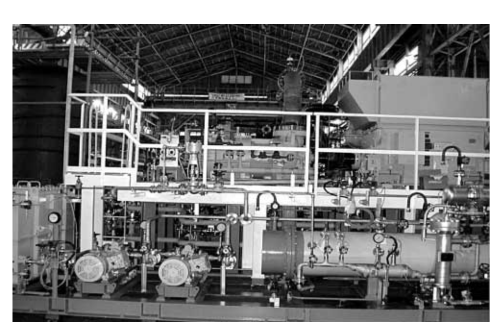

Fig. 5 Screw compressor for desulfurization process

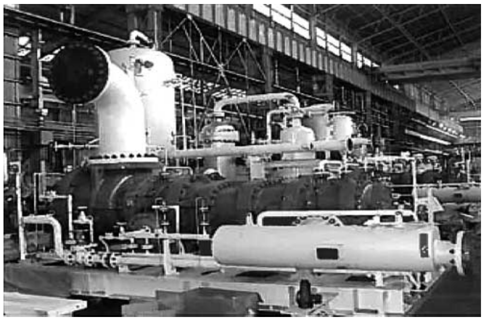

Fig. 6 Screw compressor for hydrogen process

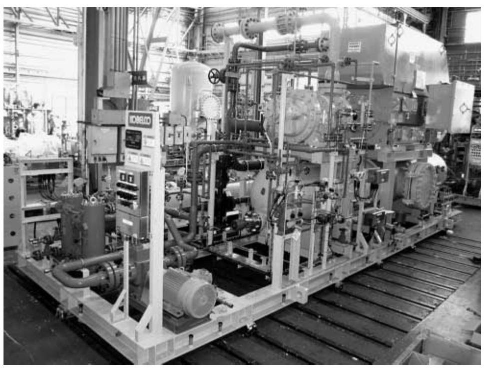

Fig. 7 Screw compressor for gas turbine fuel gas

original tandem arrangement enables dual stage compression in a single casing using neither connecting piping, nor an intermediate gas cooler. The new arrangement simplifies the entire compressor, improves the reliability, eliminates the need for reserve machines and decreases the footprint.

The newly developed oil separation technology using a coalesce filter does not affect the downstream of the compressors and enables oil purification by activated carbon adsorption up to a 50 ppb level if required.

2.3 Screw compressor for gas turbine fuel gas

Another example of an application taking the advantages of the oil-flooded screw compressors is fuel gas compressors for gas turbines. Recent fuel gas compressors require high discharge pressure to improve turbine efficiency. The series of oil-flooded screw compressors made by Kobe Steel, including the newly developed compressor with 100 barG discharge pressure, achieve the gas volumes and pressures required by almost all the modern gas turbines. **Fig. 7** shows the appearance of a fuel gas compressor unit.

A fuel gas compressor for gas turbines must be able to maintain a constant discharge pressure regardless of the variations in the turbine load and supply pressure (suction pressure). Kobe Steel exploits the combined features of two valves, slide valves and spill-back valves, for controlling the gas volume and pressure. Slide valves decrease power consumption during partial loading, while spill-back valves have improved stability and load following capability.

Now, an increasing number of oil-flooded screw compressors are being used for gas compression for gas turbines.

3. Advantages of oil-flooded screw compressors

3.1 Pressure fluctuation and capacity control

Fig. 8 shows the typical load characteristics of an oil-flooded compressor running at a constant discharge pressure with fluctuating suction pressure. In an oil-flooded screw compressor running at a low pressure ratio, increased suction pressure decreases power and increases the gas volume processed. The compressor type is usually selected based on the minimum suction pressure. In reality, however, the compressors run with higher suction pressures and at lower capacities than the designed conditions (100%).

Kobe Steel's oil-flooded screw compressors, with their volume control capability using the slide valves, save energy during operations.

3.2 Energy-saving

Under the conditions where the suction pressure fluctuates significantly, as in the case of the source pressure of gas pipeline, compressors often operate with higher suction pressures and with lower pressure ratios than the designed points. In addition, the source pressure may vary greatly and may exceed the discharge pressure of a compressor. Oil-flooded screw compressors consume less power in such situations where the pressure conditions vary significantly.

Fig. 9 shows an example of a system employing

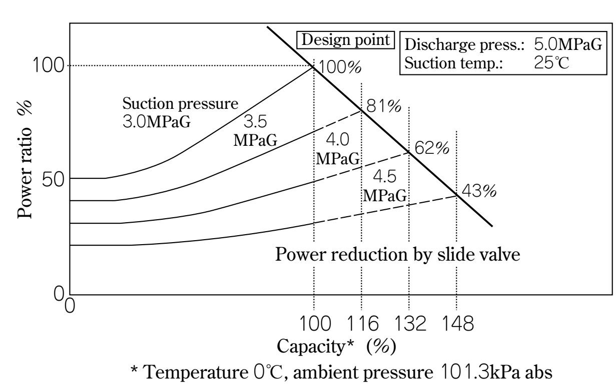

Fig. 8 Typical load characteristics of an oil-flooded compressor

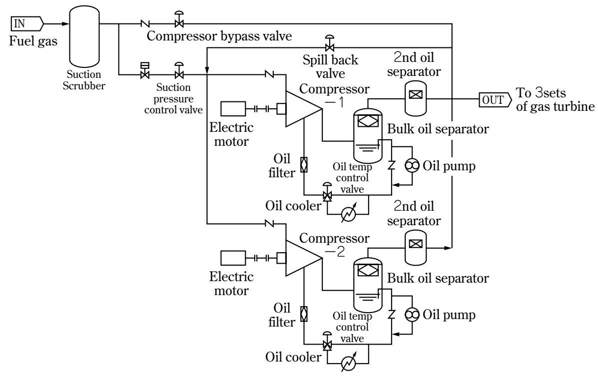

Fig. 9 Oil-flooded screw compressor system (case 1)

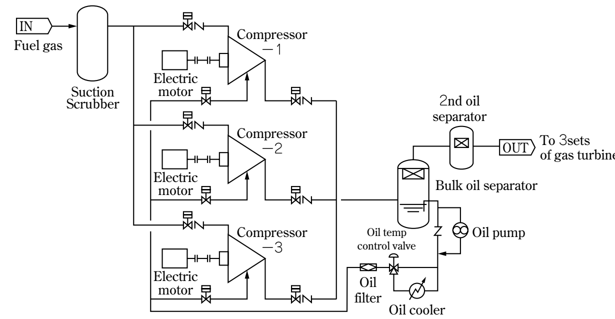

Fig.10 Oil-flooded screw compressor system (case 2)

more than one compressor. The depicted system employs two compressors supplying fuel gas to three gas turbines. A bypass line allows the fuel gas to be fed direct, without passing through the compressors, when the source pressure becomes high. The system integrates a suction pressure control valve with a spill-back valve to achieve a small footprint. The unified pipeline, connecting the two compressors and the three gas turbines, simplifies the site installation work.

3.3 Cost-saving

Fig. 10 shows a system having three compressors for supplying fuel gas to three gas turbines, one of which is for reserve. Thus the three compressors share apparatuses, such as an oil recovery tank, separator and lubricant pump, designed for the gas volume for two turbines. This construction decreases the system cost, as well as the footprint.

3.4 Adding values to the process gas

Coke oven gas (COG) is a by-product of the coking process and is commonly used, for example, for hydrogen Pressure Swing Adsorption (PSA), gas cutting and fuel. COG contains a considerable amount of impurities, e.g., tar, naphthalene, BTX (benzene, toluene and xylene) and hydrogen sulfide, which must be removed before use. Kobe Steel's oil-flooded screw compressor has been adopted in this COG application, which has attracted attention because this has not been done anywhere else in the world.

The lubricating oil, flooded into the rotor chamber of the screw compressor, serves to clean the tar and dust in the COG being compressed. The oil separator and lubricant filter on the discharge side remove the dust and pass the cleaned gas to the downstream.

Injecting the lubricant into the compressed gas not only cools, but also cleans the gas and thus adds value to it. This application is an exemplary case, exploiting the features of oil-flooded screw compressors, and indicative of the future.

Conclusion

Kobe Steel will continue to expand the applications by further improving the intrinsic features of oil-flooded screw compressors, as well as their applicability to high discharge pressures. Furthermore, Kobe Steel will strive to develop new applications exploiting their features and thus contribute to the industry.

References

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