High Performance Large Class Oil-free Screw Compressor

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High-performance, energy-saving equipment is much needed to address the growing concern for the environment. To meet such needs, Kobe Steel has developed high-performance, large class, oil-free screw compressors, the Emeraude-ALE series. This paper introduces the newly developed compressors, which combine the features of high efficiency, economic performance and high reliability.

Introduction

The electric power consumed by air compressors occupies 5% of the total energy consumed in Japan and 20 to 30% of the energy consumed by the manufacturing industry of the country (**Fig. 1**) [1). Large air compressors rated 90kW or greater occupy only 1% in the total number of compressors shipped. However, due to their high power consumption those large compressors consume 20 to 25% of the total energy consumed by all the types of air compressors (**Fig. 2** [1)] and **Fig. 3** [1)]).

Most users of large air compressors are the designated energy management factories specified by the "Law Concerning the Rational Use of Energy" and are conscious about energy-saving. Thus, an increasing number of oil-free screw compressors are used in applications where ratings greater than 90kW are required. This is also the result of an increasing awareness of environmental issues. Among the large machines, the super-large air compressors rated greater than 300kW are used as the base-load machines for industrial plants. Typically, a super-large compressor is either a two-stage screw compressor or a turbo compressor. For base-load compressors, full-load performance is a more important factor in energy-saving.

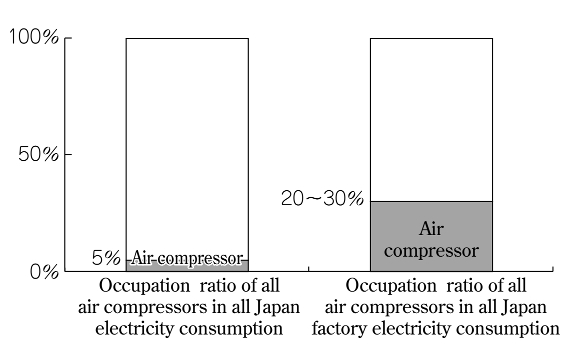


Fig. 1 Electricity consumption ratio of compressor [1)]

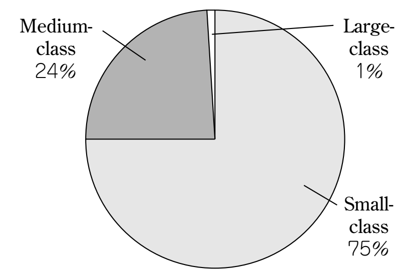


Fig. 2 Shipment ratio of compressor [1)]

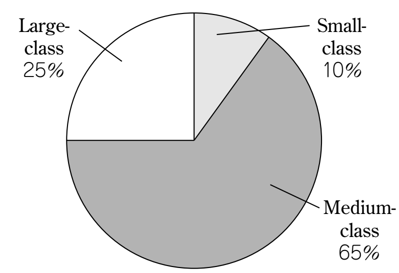


Fig. 3 Electricity consumption ratio of compressor [1)]

In addition to full-load performance, screw compressors also have excellent partial-load performance. Because of this, they are used not only for base-load machines, but also for capacity controllers. In response to such needs, Kobe Steel has developed large oil-free screw compressors with high-performance and excellent energy-saving features.

1. Large oil-free screw compressor, Emeraude® ALE® series

Kobe Steel has a product line-up of oil-free screw compressors for general purposes, namely, the Emeraude FE series rated from 15 to 55kW and the Emeraude ALE series rated from 45 to 290kW. In addition to the existing product line-up, the company has newly developed the large Emeraude ALE series rated from 305 to 400kW. This is in response to the growing need for a large oil-free screw compressor that can be used in both ways as a base-load machine and as a capacity controller. **Table 1** summarizes their specifications and **Fig. 4** shows the appearance of a newly developed compressor.

Table 1 Specifications

TYPE		ALE305W	ALE340W	ALE370W	ALE370WE	ALE400WE
Frequency		50/60				
Motor output	kW	305	340	370	370	400
Discharge pressure	MPa	0.69			0.93	
Discharge air volume	m^3/min	56.9/56.9	63.5/63.6	69.0/69.1	56.8/56.8	63.4/63.5
Shaft power	kW	304.1/304.4	338.8/339.0	367.8/368.4	357.7/357.4	396.3/397.1
Dimensions (W×D×H)	mm	3,500×2,000×2,400				
Weight (3000V type)	kg	7,700	7,900	8,200	8,200	8,500

Fig. 4 New large class oil free compressor Emeraude-ALE

Fig. 5 Plate fin type gas cooler

2. Features of large Emeraude ALE

2.1 Improved full-load performance

Because the air compressors of the 300kW class are frequently used as base-load machines, Kobe Steel placed priority on the full-load performance. Firstly, a two-stage compressor unit was adapted for improved performance. More specifically, the newly developed unit employs a screw rotor larger than the conventional one and rotates it at a low revolution to reduce mechanical loss. Optimized intermediate pressure has reduced the power loss caused by insufficient or excessive compression. This new arrangement has improved the performance by approximately 3%.

Secondly, the newly developed air compressor uses plate fin coolers (**Fig. 5**) to its intercooler and aftercooler. In a plate fin cooler, water passes through a pipe whose outer surface is exposed to air. The plate fin cooler slows down the airflow and reduces pressure loss. Its large heat-transfer surfaces on the air side allow relatively compact design. The plate fin cooler exhibits an air pressure loss of 0.005MPa or less, while a conventional shell-and-tube cooler exhibits a pressure loss of about 0.01MPa or greater. Thus, the plate fin coolers reduce pressure loss and save power. The saved power is utilized for compression work, which improves performance by approximately 4%.

The above improvements have realized a performance improvement of approximately 7% in compound total compared with Kobe Steel's conventional series. The newly developed large compressors perform at the world's highest level, unrivaled by any other large machines (**Fig. 6**).

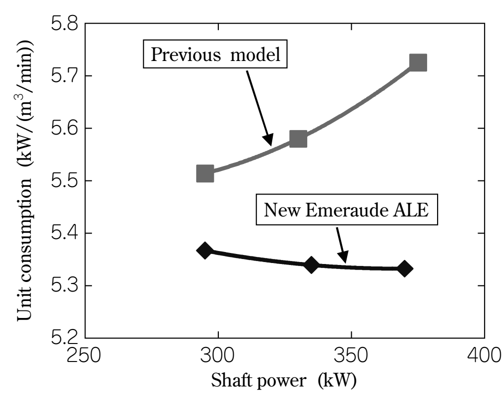


Fig. 6 Performance comparison

2.2 Improved partial load performance

In general, the larger the air compressors the more often they are used as base-load machines. In the case of screw compressors, however, the machines are also used for capacity control on many occasions. This requires the further improvement of partial-load performance, an intrinsic feature of a screw compressor.

Conventionally, a pressure differential of 0.1MPa has been applied to the pressure control. The newly developed compressors have a pressure differential controllable to a minimum of 0.05MPa with their

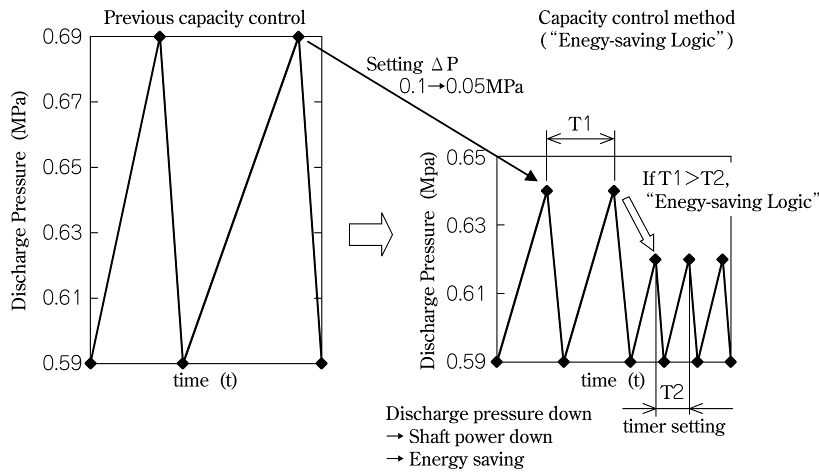


Fig. 7 Capacity control method

robust mechanism for capacity control, including a new capacity control valve. This eliminates the redundant pressure boosting, with a 3% conservation of energy for a given load pressure, compared with the conventional series.

In order to save energy in a load/unload control scheme, the starting pressure for unload operation must be as low as possible while keeping the downstream pressure at the required level. In a conventional oil-free screw compressor, the pressure differential of the control is fixed at the initial setting. As a result, increasing air consumption during the load operation decreases the rate of pressure rise. The decreased rate of pressure rise prolongs the duration in which the machine runs at a high discharge pressure, resulting in an increased consumption of power.

To resolve this issue, each newly developed compressor includes an internal timer. The timer forces the operation to switch from load to unload, depending on the status, such that the pressure differential of the control is kept to the minimum level. The compressors are also equipped with an energy-saving logic which enables operation in an energy saving mode. The internal timer and energy-saving logic are among the standard features of the new compressors. The new features forcibly switch load operation, extending over a certain period, to unload operation, regardless of whether or not the downstream pressure reaches the starting pressure for the unload operation. **Fig. 7** compares the pressure profile of the newly developed capacity control with that of a conventional capacity control. The newly designed capacity control valve decreases the pressure differential of the control from the conventional differential of 0.1MPa to 0.05MPa. This is because the valve can halve the cycle period between the load and unload. In the second cycle and thereafter, the timer switches the load operation to the unload

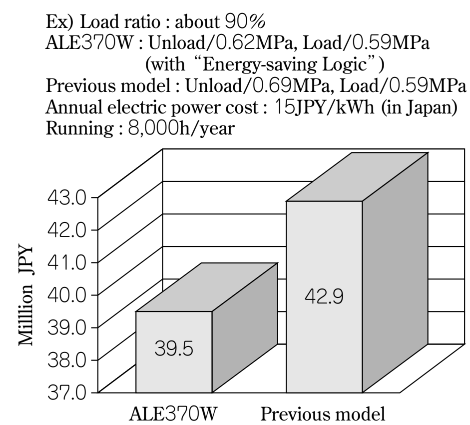
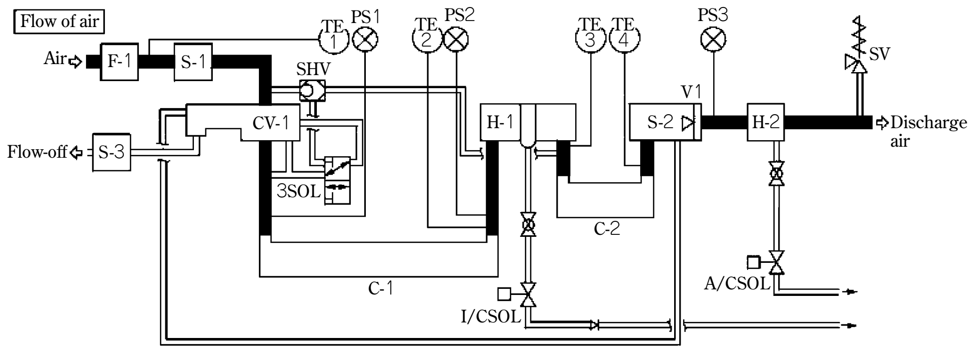


Fig. 8 Power cost comparison

operation even before the starting pressure of the unload operation is reached. This allows the pressure to be maintained at a level above the lower limit, without being increased more than necessary and, thus, saves power.

Fig. 8 compares the electric cost of a large Emeraude ALE compressor with the energy-saving logic and that of a conventional machine, both under standard operating conditions. As shown in Fig. 8, the newly developed compressor saves about 9% of electric power, which corresponds to the saving of 3.4 million yen per year, assuming 8,000 hours/year of operation and 15 yen/kW of electric unit cost. This equates to a power reduction of about 230,000kWh and an emission reduction of about 125 tonne of CO_2/year. The emission reduction is based on the default value, 0.000555t-CO_2/kWh, according to the 2006 ordinance by the Ministry of Economy, Trade and Industry (METI) and Ministry of the Environment (MOE).

Also included in the standard features are an auto start-stop function and a weekly timer. The former feature automatically stops the motor after an extended unload operation and starts the motor



Symbol	Name	Symbol	Name	Symbol	Name	Symbol	Name
C-1	1st stage compressor	H-2	After-cooler	A/C SOL	Solenoid valve for after-cooler drain	TE1	Themocouple for 1st stage suction air temperature
C-2	2nd stage compressor	F-1	Suction filter	V1	2nd stage discharge air check valve	TE2	Themocouple for 1st stage discharge air temperature
CV-1	Volumetric regulator valve	SHV	Shuttle valve	PS1	1st stage suction air pressure sensor	TE3	Themocouple for 2nd stage suction air temperature
S-1	Suction silencer	3SOL	Three-way solenoid valve for volumetric regulator valve	PS2	1st stage discharge air pressure sensor	TE4	Themocouple for 2nd stage discharge air temperature
S-2	Discharge silencer						
S-3	Blow-off silencer	I/C SOL	Solenoid valve for inter-cooler drain	PS3	2nd stage discharge air pressure sensor		
H-1	Inter-cooler						

Fig. 9 Diagram of large class oil-free compressor

when the pressure is decreased to a preset level. The latter feature allows seven patterns to be set for starts and stops. Yet another feature, also standard, allows two of the compressors to be operated alternately without an additional control panel. These features contribute to further energy-saving.

2.3 Improved durability

The compressor units have improved durability and reliability realized by enhanced filtration to clean the lubricant oil poured into the bearings of the units.

The capacity control valves are six times more durable than conventional ones, in term of the number of times of actuation. The conventional valves are less durable because they employ dish-shaped diaphragms in their moving parts. Such a diaphragm has a large pressure-bearing surface which exerts a large force on the fixed parts, lowering the valve's durability. The newly employed capacity control valve uses a rolling diaphragm with a smaller pressure-bearing surface which decreases the force exerted on the fixed parts. With these measures, the newly developed compressors have improved durability, enabling them to operate between load and unload states with half the cycle of the conventional machines. In addition, the maintenance cycle has been extended to three years, as opposed to the one year cycle for the conventional compressors.

Conventional shell-and-tube coolers are made such that water flows outside their pipes. Because of this, the conventional coolers suffer from water scale which can deposit where the water flow stagnates. The plate fin coolers used for the newly developed compressors pass water inside their pipes, which makes the water chamber less susceptible to the water scale compared with the shell and tube coolers and facilitates the maintenance work.

As a result, only lubricant and filters are changed during annual maintenance. The total maintenance costs have been reduced by extending the maintenance cycles of various other parts.

2.4 Enhanced monitoring

An extensive network of sensors (**Fig. 9**) sends information to an intelligent total control system (ITCS) where the information is consolidated. Thus, daily management information (e.g., pressure, temperature and hours of operation) is obtained simply by monitoring this system. The operational status of each unit is constantly monitored, which prevents troubles and unexpected shut-off. For example, a low oil-supply pressure triggers an alarm before emergency shut-off. Emergency shut-off is then avoided by taking appropriate measures, such as raising the pressure and/or changing the lubricant filters, during this alarm stage.

An operational history is recorded including data and alarms, such as for pressure and temperature; this record is logged every hour of the last twenty four hours and every five seconds of the last fifteen minutes, allowing the confirmation of the operational history.

The ITCS monitor displays required maintenance work such as lubricant and/or filter changes. Periodic maintenance ensures long-lasting operation with high reliability.

Optionally, a remote monitoring unit and a communication output (MODBUS) are available to meet the recent needs for central monitoring and laborsaving.

Conclusions

The large Emeraude series consist of oil-free screw compressors that have been developed and modified based on user needs. They also proactively address environmental issues. Kobe Steel will strive to develop compressors which meet future needs for energy-saving.

References

1) M. MATSUKUMA : *Air Compressor (in Japanese), The Energy Conservation Center, Japan*, 2005, pp.30-33.