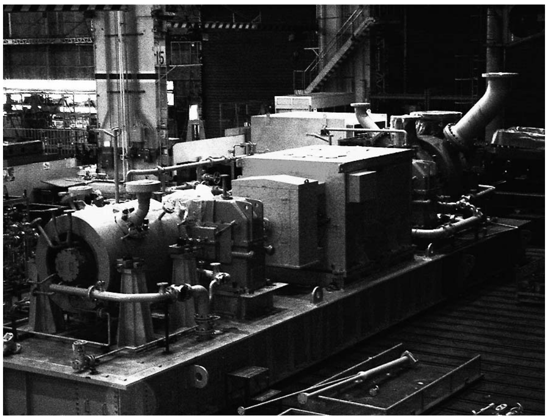

Re-injection Compressors for Greenhouse Gas (CO_2)

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Various methods have been proposed recently to deal with CO_2 because it is one of the greenhouse gases causing global warming. These methods include injection of CO_2 into the ground to increase petroleum production, and sequestration of CO_2 into aquifers. High-efficiency, large-sized CO_2 re-injection centrifugal compressors have been developed for the purpose of subterranean sequestration of CO_2. This paper discusses the features of the compressor and its shop test results at full pressure and full load.

1. Introduction

In addition to the technology for decreasing production of CO_2 (one of the greenhouse gases causing global warming) by reducing energy consumption, the technology for not releasing CO_2 into the atmosphere draws an attention. Mitsubishi Heavy Industries, Ltd. (MHI) has put flue gas CO_2 recovery plants and high-efficiency re-injection compressors into practical use. The flue gas CO_2 recovery plant recovers CO_2 from boiler exhaust gas in power plants with high efficiency and low energy consumption. The high-efficiency re-injection compressor injects CO_2 into the ground, causing the increase of petroleum production and the sequestration of CO_2 into aquifers.

2. Specifications and features

2.1 Health, Safety and Environment (HSE)

In the whole process of design and manufacture of the compressor, every aspect has been studied from the viewpoint of HSE in order to achieve the purpose of the global environment conservation. With this in mind, hazard and operability (HAZOP) study and system integration level (SIL) analysis have been carried out. And safety measures and environmental effects in case of compressor failure have been carefully discussed.

2.2 Composition

The compressor train is composed of two compressors: low pressure and high pressure, for raising the pressure of CO_2 from atmospheric pressure up to 203 bar, and is driven by a synchronous motor of 11.7 MW. As compared with CO_2 compressors used in existing fertilizer plant, it provides about 1.3 times the final discharge pressure and 1.5 times the specified required power, and it is the world's largest class CO_2 compressor.

Discharge pressure: 203 bar
Suction volume flow rate: 37 100 m^3/h (77.6 t/h)
Required shaft horse power: 11.7 MW

2.3 Features

(1) Machine configuration

The compressor train consists of a both ends drive motor (capable of providing motor output at both ends of the shaft) installed in the center of the train, two speed increasing gears provided at outer ends, and two compressors outside them. All the units are integrated into a skid framework, including a lubricating oil system, for ease of transportation and installation (**Fig. 1**). By this configuration, the power loss from speed increasing gears is suppressed to a minimum.

The compressor can be opened by drawing out the cartridge in the axial direction, and it is not required to disassemble the compressor casing. Therefore, maintenance of the compressor is possible without disassembling the main gas piping connected to the compressor casing. In the case of a conventional tandem configuration of two compressors of low pressure and high pressure arranged side by side, the cartridge of the compressor cannot be drawn out in the axial direction. The cartridge maintenance can be started only after removing either of the compressors by crane. By contrast, in this configuration, since the compressors are located at both ends of the train, the cartridge can be opened without removing either compressor to realize easy maintenance.

(2) Soft starter

A so-called soft starter is used in the starting mechanism of the synchronous motor of the driving unit of the compressor train. Since the compressor train is installed in a place having no allowance in power source equipment (power source capacity), a large current flows on direct online start, causing voltage drop and other adverse effects in other power appliances in the district. Accordingly, the soft starter is used to minimize the starting current so as to avoid effects on other facilities.

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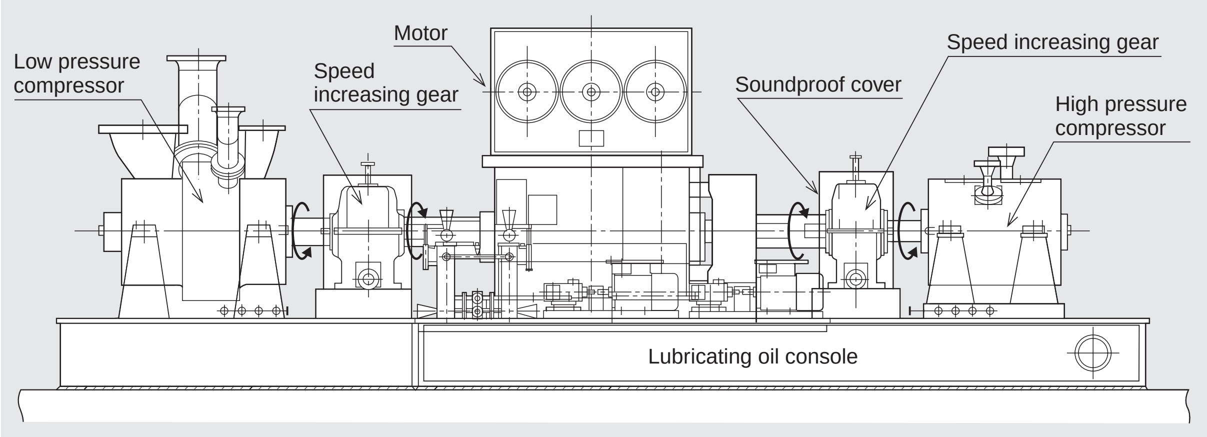

Fig. 1 CO_2 re-injection compressor train configuration
A both ends drive motor is installed in the center of the train, two speed increasing gears are provided at outer ends, with two compressors outside them.

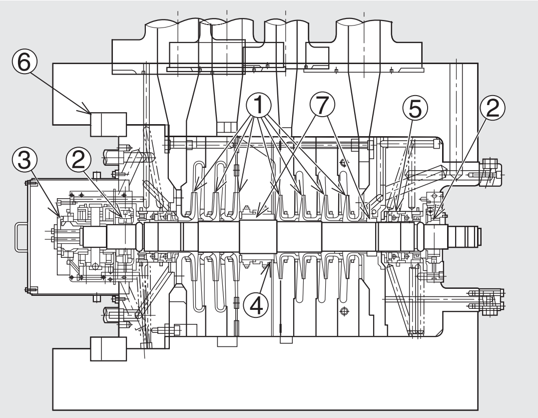

Fig. 2 A sectional view of CO_2 re-injection compressor
Required advanced technology, and health, safety and environment protection features are shown in a sectional view of the CO_2 re-injection compressor.

(3) Compressor

The compressor has the advanced technology required in the world's largest CO_2 compressor, and has features effective for HSE (**Fig. 2**).

All stages of the compressor have impellers with three-dimensional blade profile and static gas passages optimized by conditions of use. A high efficiency of 85% is achieved in the 1st stage section, resulting in saving of power consumption. At the same time, a wide operation range is realized by the use of a three-dimensional blade shaped impeller, and the compressor has sufficient flexibility to cope with changes in the local conditions of use.

The molecular weight of CO2 is relatively large among gases handled by a centrifugal compressor (**Table 1**). Accordingly, in high pressure conditions, as in this compressor, the specific gravity may become about 1/3 that of water, and the compressor rotor may vibrate unstably, and technology for preventing this phenomenon is required.

For this purpose, the compressor has a damper with squeeze film mechanism, called an overhang damper, installed at the shaft end at the outside of the bearing, in order to enhance the vibration damping characteristics of the rotor. The compressor also has a tilting pad bearing to prevent occurrence of unstabilizing force in the bearing. In labyrinth seals of the division wall, where the differential pressure is large, it is necessary to prevent unstabilizing force caused by swirl of passing gas. A swirl canceller is used to guide the high pressure gas into the opposite direction from the gas swirl in the midst of the labyrinth seals. As a result, sufficient stability of the rotor is assured, even in high pressure conditions[1].

Table 1 Discharge gas condition of CO_2 re-injection compressor

Discharge pressure (bar)	203
Discharge temperature (°C)	172.7
Gas molecular weight	43.96
Gas density (kg/m^3)	291

Further, owing to the high pressure gas, thrust force in axial direction acting on the rotor, changes significantly with change in operation point. As a countermeasure, the impellers are arranged as back to back, and two balance pistons are installed for canceling the thrust force, and hence the thrust force is mostly stabilized, regardless of the state of operation.

The seal is a tandem dry gas seal. The system organization, parts and materials are determined in consideration of gas properties in all conditions (start, operation, stop).

2.4 Technology applicable to high density gas

In high density gas, as compared with normal atmosphere, the natural frequency of the impeller is lowered, and impeller resonance may occur. On sufficient analysis, it has been found that the natural frequency is lowered to about 60% of that of normal atmosphere, and a design for preventing impeller resonance is required.

A small flow rate of high density gas such as CO_2 is likely to cause rotating stall near the impeller outlet. To prevent increase of rotor vibration of sub-N components due to such rotating stall, the range of continuous operation must be narrowed. In this compressor, the point of rotating stall has been designed to occur at a smaller flow rate by controlling the ratio of the impeller outlet width and static gas passage width.

For prediction of the aerodynamic performance of a compressor, precision of prediction of gas properties is very important, but under high pressure conditions it is very difficult to predict the properties of CO_2 because it is near the critical point. The Mitsubishi centrifugal compressor has been proved by sufficient use as a CO_2 compressor for fertilizer plant and 235 bar shop tests, and this technology is fully applied in the new compressor.

3. Shop test of equipment at full load and full pressure

3.1 Purpose

In order to confirm the rotor stability, point of rotating stall, impeller resonance, and design validity for prediction of gas properties, shop tests were conducted using CO_2 at full pressure and full load as inspected in field operation (**Fig. 3**).

3.2 Test equipment specification

A high voltage power source facility of 14 MVA capacity was prepared in the outdoor test stand for the shop tests. The soft starter of 5 000 kW specification, which would be used only at the time of starting in the field, was modified to a specification of 11.7 MW for continuous use as a frequency converter (shop specification of 60 Hz to local specification of 50 Hz) in shop tests.

Tests and measurements conformed to API-617 and ASME PTC-10, and further, as a special measurement, pressure sensors were installed in the compressor final discharge nozzle passage. Rotating stall for small pressure fluctuations could be observed. Antimagnetic measures were taken to avoid noise effect on measured signals due to high voltage power source lines.

4. Shop test results

4.1 Aerodynamic performance

The performance was tested in ASME PTC-10 type 1 conditions, equivalent to the field operation conditions, and desired results were obtained, and the design verification technique was proved to be correct (**Fig. 4**).

4.2 Impeller rotating stall

Increase of rotor vibration caused by occurrence of rotating stall took place at 28% smaller flow rate (23% larger flow rate from surge prediction point) than the normal operating point (design point). It was confirmed that operation is possible from the rotor vibration value limit to 33% smaller flow rate (13% larger flow rate from surge prediction point) than the normal operating point (design point). It was also confirmed that the planned operation rate is assured, and no problem is expected for field operation (Fig. 4).

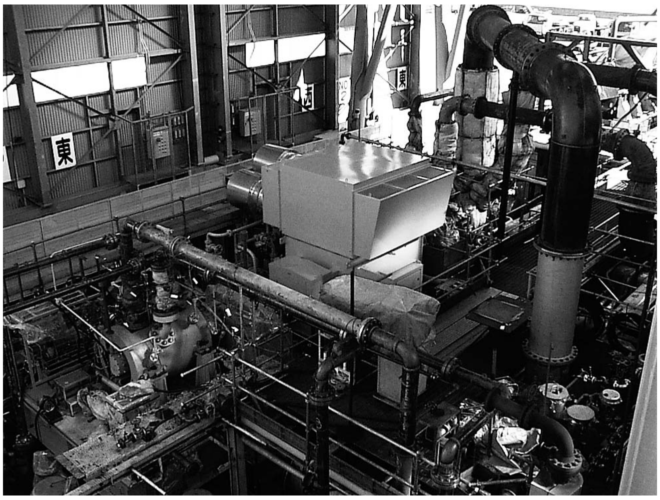

Fig. 3 Shop test at full load and full pressure before shipping

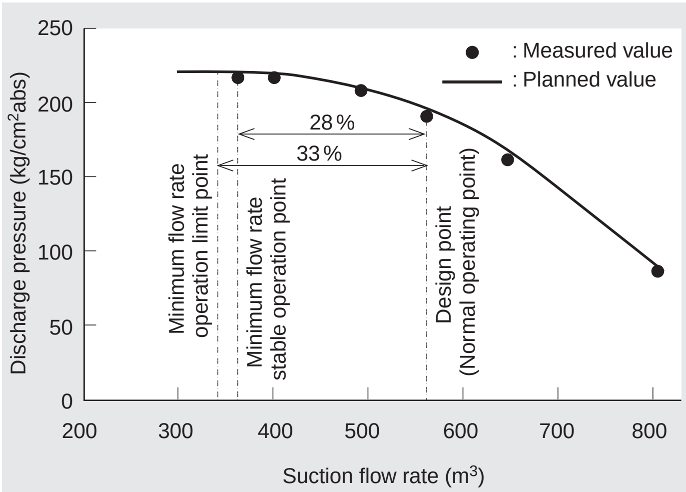

Fig. 4 Shop performance test result of final section
Shop test results at full load and full pressure in final section.

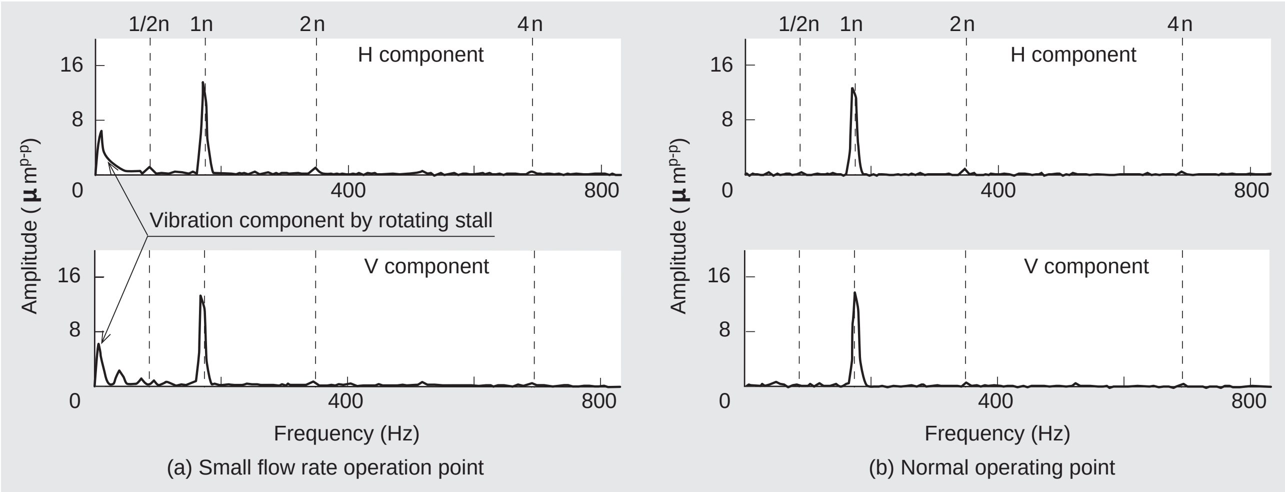

Fig. 5 Vibration characteristics (rotating stall occurrence point and normal operating point).
Spectrum analysis result of rotor vibration. In small flow rate region, vibration at smaller than components of rotating speed (N) occurs due to rotating stall.

As to frequency components at small flow rate, it is understood that rotating stall occurred due to increase of rotor vibration smaller than the components of rotating speed (N) (**Fig. 5**).

4.3 Rotor vibration characteristics

Rotor vibration value at normal operating point is lower than the tolerance of API-617, and asynchronous vibration components were not caused (Fig. 5).

5. Conclusions

The world's largest CO_2 re-injection centrifugal compressor has been developed, and its high aerodynamic performance, rotor stability (low rotor vibration), shifting of rotating stall occurrence point to smaller flow rate side, impeller resonance prevention, and design validity of prediction of gas properties have been studied and confirmed in shop tests at full pressure and full load.

The technology for recovering CO_2 and not releasing it to the atmosphere will become more important in the future, and a huge CO_2 recovering plant of 5 000 to 15 000 t/d scale will possibly be needed.

MHI continues to concentrate their efforts to meet social needs and contribute to achieving a better global environment.

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