High Efficiency and Large Capacity 3D Scroll Compressor GU Series

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Scroll compressor features high efficiency and low vibration, and is adopted in wide variety of refrigerating and air-conditioning products. For the purpose of meeting the demand for further efficiency improvement and large capacity, MHI developed the three-dimensional scroll compressors (3D scroll) for commercial air-conditioner "GU series". By realizing three-dimensional compression which is impossible for the conventional scroll, 5.5% improvement of efficiency, 35% smaller size and 26% lighter weight compared with the conventional compressor were archived, so that substantial energy-saving effect and improvement of unit-mounting capacity are obtained.

1. Introduction

The demand for saving energy in refrigerating and air-conditioning systems is increasing in terms of environmental conservation against global warming. Since most energy in refrigerating and air-conditioning systems is consumed in compressor to compress refrigerant, the efficiency improvement in compressor is indispensable.

Mitsubishi Heavy Industries, Ltd. (MHI) has so far adopted scroll compressors featuring high efficiency and low vibration to main refrigerating and air-conditioning products to meet the demand for saving energy. For the purpose of further energy improvement, we developed the three-dimensional scroll compressor (3D scroll compressor) by adding an axial compression to the conventional radial compression.

This paper describes the efficiency improvement technology of the 3D scroll compressor and the development of the 3D scroll compressor for commercial air-conditioner (GU series).

Note: "3D scroll" is a registered trademark of MHI.

2. Structure of 3D scroll

2.1 Features of 3D scroll

Fig. 1 shows a sectional view of the newly developed the 3D scroll compressor for commercial air-conditioner. Scroll compressors compress refrigerant by orbiting motion, accompanied with mutual eccentricity of a pair of scrolls (fixed scroll and orbiting scroll) composed of end plates and scroll blades (wrap). In the case of conventional scrolls, the wrap height is constant throughout the compression process. Therefore, refrigerant is compressed two-dimensionally from the outer side to the inner side. For the 3D scroll, on the other hand, the outer wrap is higher than the inner one by installing steps in scroll tips and end plates. Consequently, the 3D scroll made possible to compress refrigerant three-dimensionally (**Fig. 2**).

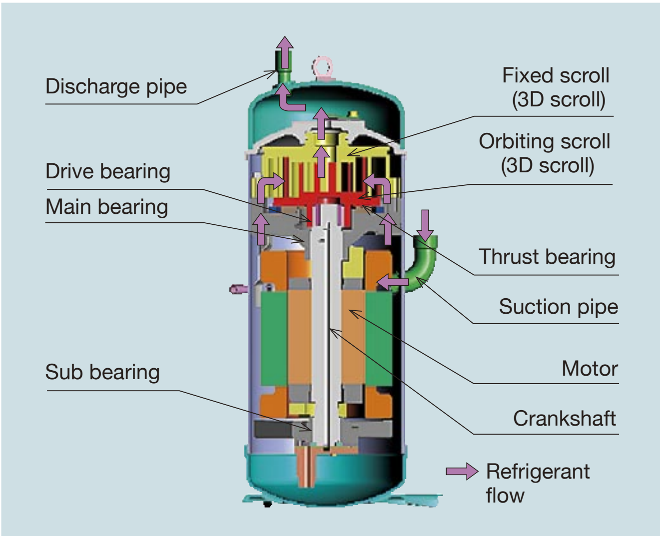

Fig. 1 3D scroll compressor

The 3D scroll features the following.

- The high compression ratio is obtained by compressing refrigerant not only radially but also axially.
- The strength of scroll is improved and higher reliability is obtained by reducing the height of inner wrap, which acts heavy load.
- The large capacity is obtained without extension of the outer diameter of scroll by increasing the height of outer wrap, and thus the 3D scroll has smaller size and lighter weight.

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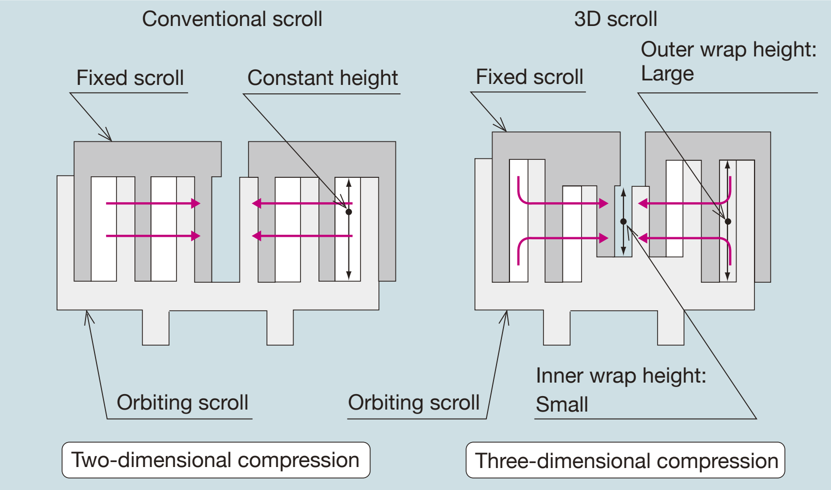

Fig. 2 Sectional view of conventional scroll and 3D scroll
Introduction of 3D scroll made possible three-dimensional compression.

Table 1. Performance requirements for compressors and effects of 3D scroll

Performance requirements	Commercial air-conditioner	GHP	Refrigeration unit for trucks	Refrigeration unit for marine transport
High efficiency (high compression ratio)	◎	◎	◎	◎
High reliability (enhanced scroll strength)	◎	◎	○	○
Low noise and low vibration	○	○	○	○
Small size and light weight	○	○	◎	◎
Large capacity	◎	◎	○	○

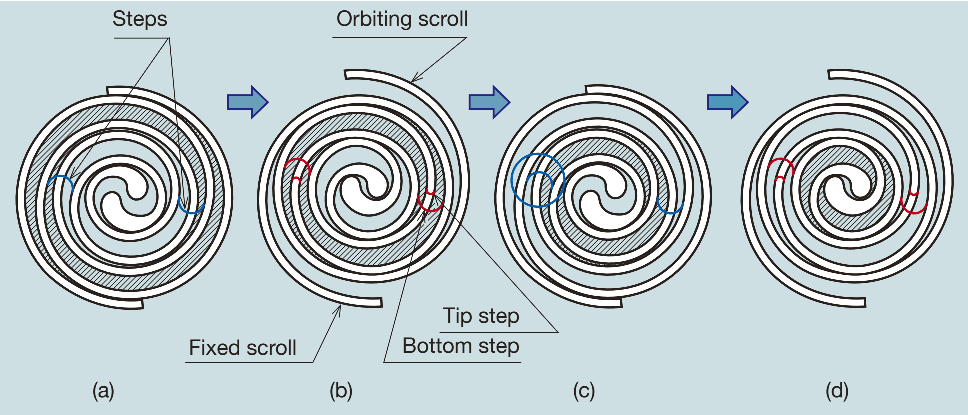

Fig. 3 Compression mechanism of 3D scroll
The seal line is formed by engagement of the tip step and the bottom step.

Table 1 shows performance requirements of compressors and effects when the 3D scroll is introduced in each product. The introduction of the 3D scroll satisfies various requirements specific to each product such as large capacity and high reliability in commercial air-conditioners, the operation under high compression ratio in refrigeration units, and so on.

2.2 Compression mechanism and leakage clearances in 3D scroll

The compression mechanism of 3D scroll is shown in **Fig.3**. Compression chambers are composed of fixed scroll and orbiting scroll, and the volume of compression chamber is reduced by orbiting motion of orbiting scroll. As for the 3D scroll, steps are installed in scroll tips and end plates. When the bottom step and the tip step are not engaged (b)(d), compression chambers across the step have the same pressure, and there is no leakage at steps. On the other hand, when the bottom step and tip step are engaged (a)(c), the seal line is formed by engagement of the tip step and the bottom step.

Fig. 4 shows the enlarged view of the step and sectional view in the longitudinal direction of orbiting scroll. Leakage clearances at the step can be broadly classified into tip clearance and side clearance, and the gas leakage from the higher-pressure chamber to the lower pressure chamber occurs through these clearances. The key point of efficiency improvement in the 3D scroll is to minimize the gas leakage at steps by optimization of tip and side clearances.

3. Efficiency improvement technology for 3D scroll compressor

3.1 Optimization of clearances at steps

Fig. 5 shows the variation of efficiency with the leakage clearance at step. The efficiency is improved with a decrease of the clearance. However, the efficiency is saturated in the region that the clearance is small. It is because the clearance is filled with the oil when the clearance is sufficiently small, and thus the gas leakage is decreased. Consequently, the reduction of leakage loss in the 3D scroll can be obtained by setting the clearance at steps between the minimum value determined from the tolerance of profile, thermal deformation, pressure deformation, etc. and the maximum value determined from the permitted limit of performance as shown in the shaded are of Fig. 5.

3.2 Visualization of step

In order to investigate the behavior of leakage flow in the step clearance, a prototype compressor which is able to observe the behavior of leakage flow was made, and visualization tests are performed.

Fig. 6 shows the variation of the behavior of leakage flow with the oil circulation ratio. Focusing on the clearance at step marked with circles, in the case that the oil circulation ratio is small (a), there is no oil in the clearance and the gas leakage occurs through the clearance. On the other hand that the oil circulation ratio is large (b)(c), the clearance is filled with the oil and the oil flow along the bottom step was also observed.

Based on the result of visualization tests, clearances at steps and the oil content in refrigerant were optimized, and the leakage loss at steps was minimized.

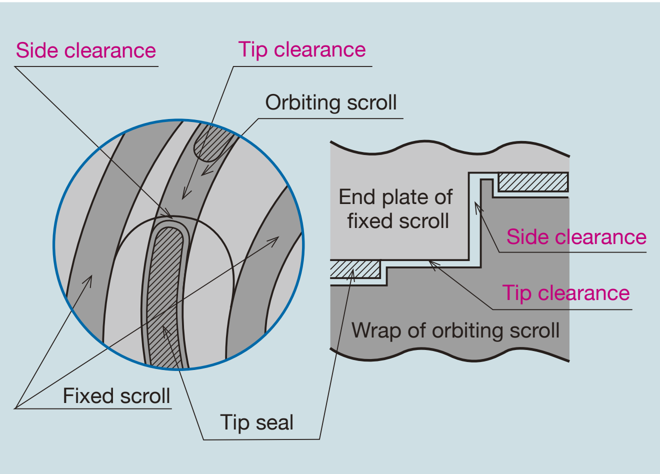

Fig. 4 Schematic diagram of step
It is important for efficiency improvement to reduce the gas leakage at steps.

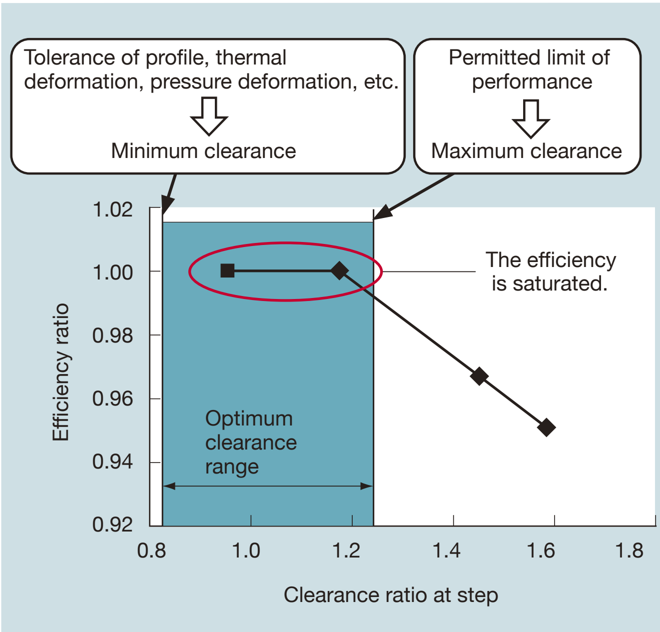

Fig. 5 Variation of efficiency with the clearance at step
The efficiency is saturated in the region that the clearance is small.

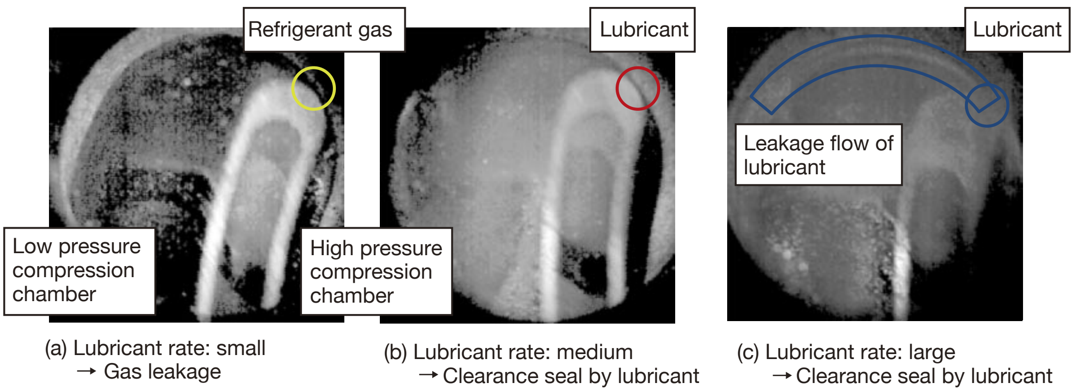

Fig. 6 Visualization of steps
Optimization of clearance size and lubricant content leads to reduction of refrigerant leakage.

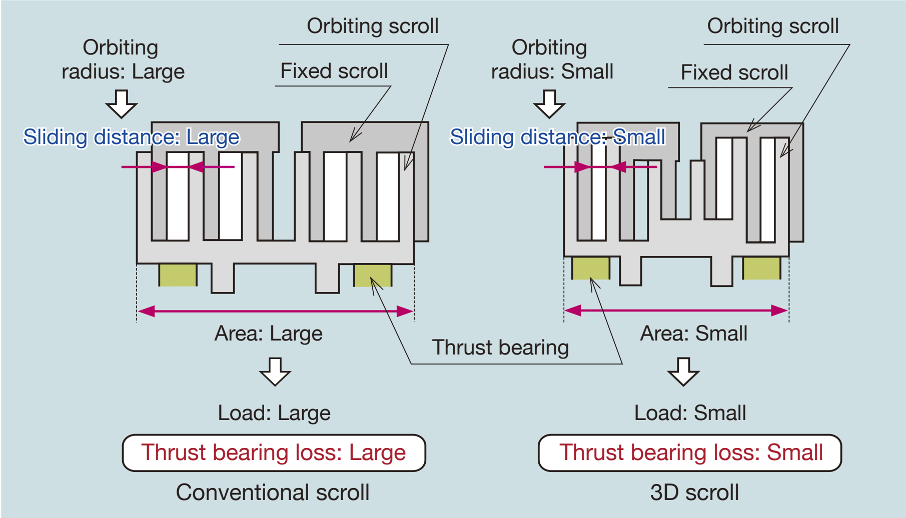

Fig. 7 Thrust bearing loss in scroll compressor.
The reduction of thrust bearing loss is obtained by introducing 3D scroll.

3.3 Reduction of thrust bearing loss

Thrust bearing loss occupies a large part of total mechanical loss in scroll compressor, and it is necessary for performance improvement to decrease the thrust bearing loss.

As shown in **Fig. 7**, the wrap height can be set higher by introducing 3D scroll, so the outer diameter can be reduced compared with the conventional scroll which has the same capacity. Therefore, the area which acts pressure reduced and thus thrust-bearing load is reduced. Moreover, the orbiting radius can be also set smaller and the sliding distance is reduced. As a result, a substantial reduction of thrust bearing loss is archived.

4. Features of the developed 3D compressor

4.1 Smaller size and lighter weight

The outline of the newly developed 3D scroll compressor (GU series) and the conventional one for 10HP commercial air-conditioner are shown in **Fig.8**. Introducing 3D scroll enabled the miniaturization of scroll, and the outer diameter of compressor was reduced by 17% (from 221 mm to 183 mm). As a result, 35% reduction of volume and 26% reduction of weight were obtained.

4.2 High efficiency and low noise

Fig.9 shows the loss classification of the developed compressor. The developed 3D scroll compressor resulted in 14% loss reduction (5.5% efficiency improvement) by the following.

(1) Indicative loss reduction by the optimization of compression ratio with the 3D scroll and the optimization of leakage clearances

(2) Mechanical loss reduction by miniaturization of compressor with the 3D scroll

(3) Motor loss reduction by introducing high efficiency motor.

Moreover, 6dB noise reduction compared with the

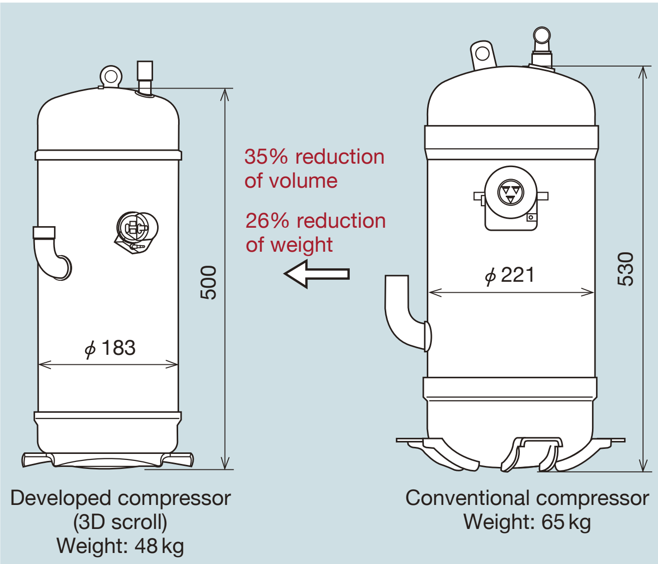

Fig. 8 Outline of 3D scroll compressor and conventional one
35% reduction of volume and 26% reduction of weight are archived.

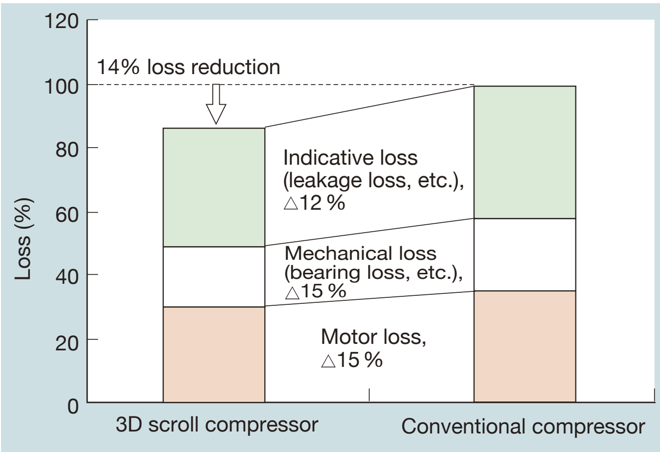

Fig. 9 Effect of loss reduction in 3D scroll
Realization of 14% loss reduction compared with the conventional type.

conventional compressor was obtained by the increase of stiffness.

5. Conclusions

The development of the 3D scroll brought dramatically improvement of efficiency and reliability, smaller size and lighter weight compared with the conventional scroll. As for the newly developed compressor "GU series."

- 35% smaller size, 26% lighter weight
- 5.5% improvement of efficiency
- 6dB reduction of noise

were archived by introducing the 3D scroll.

We have commercialized 3D scroll compressors for gas heat pump (GHP) air-conditioners in addition to GU series, and planning to introduce 3D scrolls in refrigeration units, etc. in the future. MHI is determined to contribute to the conservation of the global environment through the promotion of energy-saving activities in refrigerating and air-conditioning systems.

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