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Development of a piston and vane connected assembled vane compressor

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ABSTRACT

Rotary compressors, which are widely used in air conditioning equipment, can generate collision noises between the vane and piston during low speed operation. To avoid this noise when operating at low capacity, the compressor in the air conditioning equipment is stopped intermittently, resulting in inefficient operation. This paper introduces an assembled vane compressor in which the piston and vane are mechanically connected, achieving low-speed operation while maintaining quiet performance and improved energy efficiency.

Keywords: Rotary Compressor, Low-capacity, Assembled vane, Piston

1. INTRODUCTION

Recently, as residential and commercial buildings have evolved toward higher airtightness and improved thermal insulation, air conditioning systems are required to operate at high capacity during startup to handle the initial load. However, once the indoor temperature stabilizes, they tend to run for extended periods at low capacity and under low-load conditions. As a result, improving energy efficiency and comfort under low-load operation has become increasingly important for air conditioning equipment.

Rotary compressors, which are widely used in air conditioning systems, compress refrigerant by pressing a vane against a rolling piston that is mounted on a crankshaft and rotates during operation, thereby forming a sealed compression chamber. However, rolling piston type compressors face limitations on achieving high efficiency under low-capacity conditions due to vane separation, which causes refrigerant leakage and re-expansion, as well as collision noise upon recontact.

This report introduces the development of a compressor equipped with an assembled vane type mechanism (hereinafter referred to as the “assembled vane compressor”), which the vane is mechanically linked to the piston. This design eliminates collision noise between the vane and piston during low-speed operation and enables higher efficiency compared to conventional compressors.

2. STRUCTURE OF THE ASSEMBLED VANE COMPRESSOR

The assembled vane compressor shares the basic operating principle with conventional rotary compressors employing a rolling piston mechanism. The assembled vane compressor operates by rotating a crankshaft with an internal motor, which drives the piston inside the compression chamber. As the piston moves, the volume of the compression chamber decreases, compressing the refrigerant drawn from the evaporator. The compressed refrigerant is then discharged into the sealed container and subsequently delivered to the outside of the compressor.

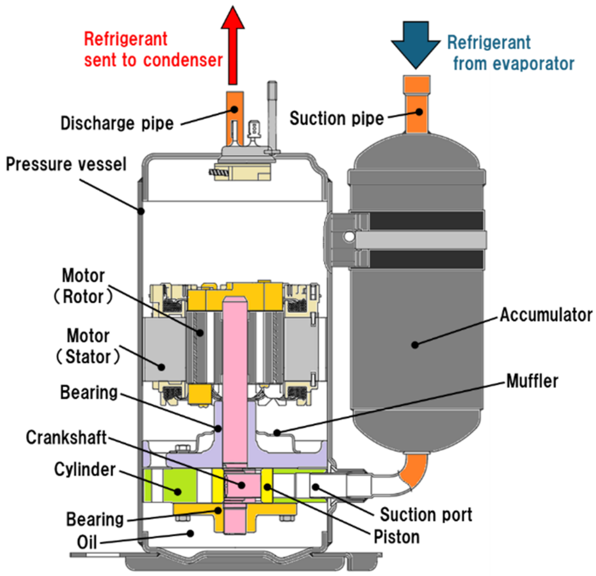


Fig.1 Cross section of compressor

Figure 2 shows the piston and vane movement during crankshaft rotation and the associated volume changes in the suction and compression chambers. As the piston rotates once within the cylinder, the volume of the suction chamber increases, drawing refrigerant in through the suction port. During the subsequent rotation, the refrigerant trapped in the compression chamber is compressed as the chamber volume decreases. Once the refrigerant reaches the specified pressure level, the refrigerant pushes open the valve (check valve) at the

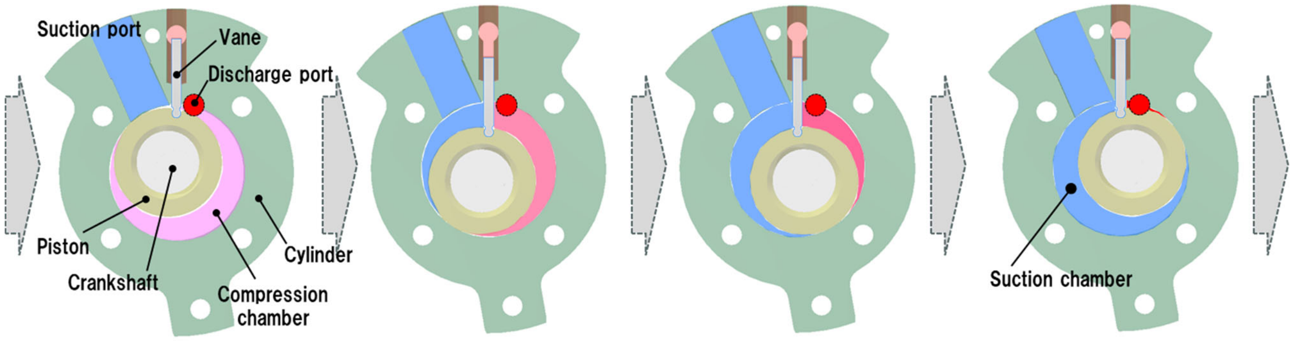
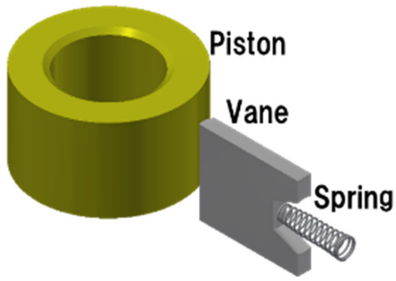


Fig. 2 Compression process of the assembled vane type

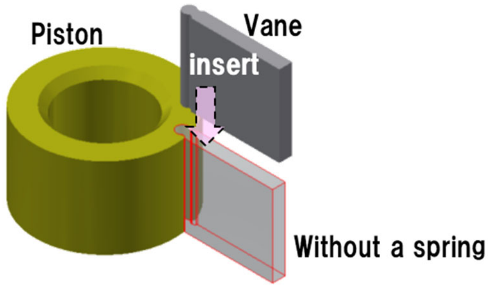
discharge port and is expelled into the discharge space within the muffler. From there, it is discharged into the sealed container and then sent to the condenser via the discharge pipe. Refrigeration oil located at the lower part of the sealed container lubricates sliding components such as bearings during compressor operation, contributing to the reliability against abnormal wear.

Figure 3 compares the assembled vane type mechanism with the conventional rolling piston type. In the conventional mechanism, a spring is applied to the back of the vane to keep it in contact with the piston during operation. Additionally, during compressor operation, the pressure difference between the compressed refrigerant discharged into the sealed container and the uncompressed refrigerant drawn into the suction chamber also contributes to maintain the vane in contact with the piston.

As shown in figure 4, under low-load conditions, the decrease in pressure difference reduces the force acting on the back of the vane. Combined with variations in piston speed during low-speed operation, this may cause the vane to lose contact with the piston, leading to refrigerant leakage into the suction chamber during compression. If the vane separates from the piston during the compression process, the subsequent movement of the piston toward the vane may result in contact, generating a collision noise. To avoid such operating conditions, conventional rotary compressors with rolling piston type in air conditioners were compelled to employ intermittent operation to limit output during low-capacity operation.



(a) Rolling-piston type



(b) Assembled vane type

Fig. 3 Comparison of compression parts

In contrast, the assembled vane type replaces the spring that presses the vane against the piston with a

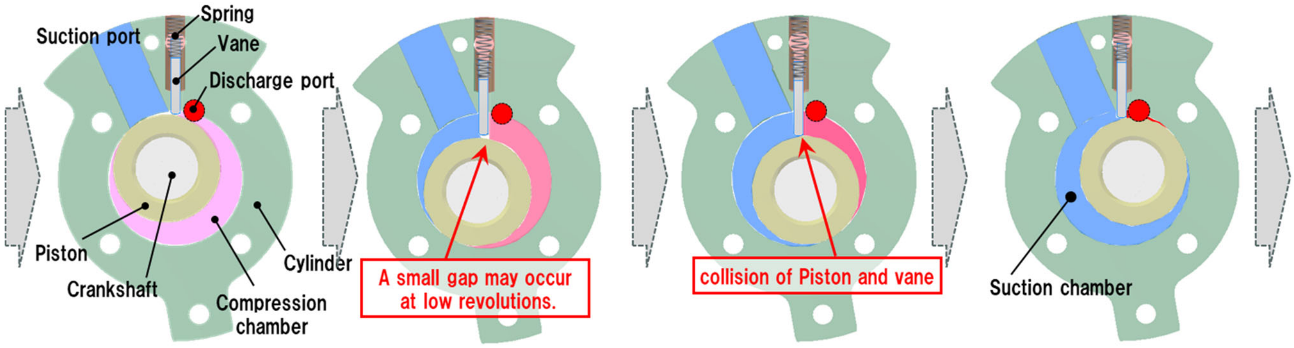


Fig. 4 Compression process of the rolling piston type

cylindrical vane tip whose central angle exceeds 180°. This cylindrical section is fitted into a groove on the piston, allowing the vane to remain mechanically linked to the piston and follows its motion. As a result, the vane does not separate from the piston during operation, ensuring smooth movement and eliminating both separation and collision noise.

3. CHARACTERISTICS OF THE ASSEMBLED VANE COMPRESSOR

3.1 Vane Retention during Operation

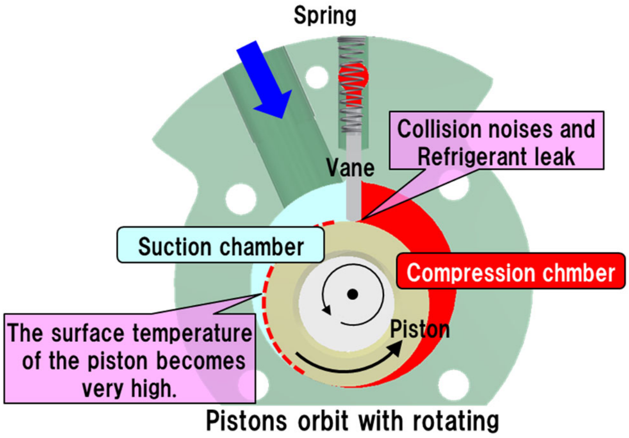
Under Low-load and low-capacity operation, the compressor operates at low rotational speeds, and the pressure difference between the evaporator and condenser is relatively small. In rotary compressors with rolling piston type, this results in a reduced force pressing the vane against the piston. Combined with fluctuations in rotational speed due to compression torque variations, the vane often fails to follow the piston's motion during certain segments of a crankshaft revolution, leading to gaps between the vane and piston. As previously mentioned, such gaps can cause refrigerant leakage during compression and collision noise due to contact between the vane and piston. Therefore, air conditioners using this type of compressor have had to avoid such operating conditions.

In contrast, the assembled vane type maintains a mechanical connection between the vane and piston, ensuring synchronized movement even during low-load and low-speed operation. Compared to rotary compressors with rolling piston type, this enables efficient operation at lower rotational speeds and contributes to an expanded operational range for compressors in air conditioning systems.

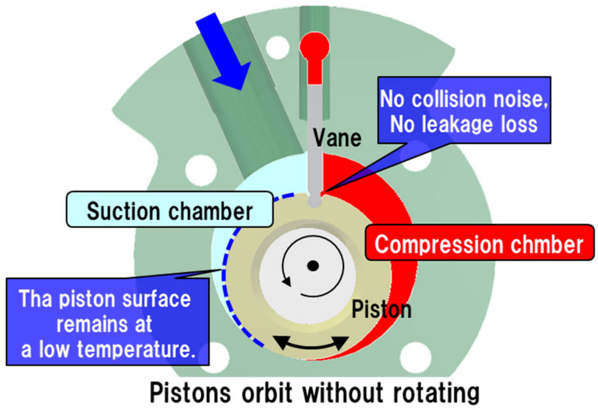
3.2 Piston Rotation Prevention

In conventional rotary compressors with rolling piston type, the piston is not constrained against self-rotation and rotates within the cylinder while also spinning due to frictional forces with the crankshaft. Figure 5 compares the advantages and disadvantages between the rolling piston type and the assembled vane type. In contrast, the assembled vane type restricts piston rotation through its structural connection with the vane, preventing the piston from rotating during compressor operation.

The temperature difference between the low-temperature refrigerant drawn into the suction chamber and the high-temperature refrigerant after compression is significant. Since the outer surface of the piston is constantly exposed to both refrigerants, the surface near the discharge port becomes hot, while the surface near the suction port remains cold. In rolling piston type compressors, the piston rotates, which facilitates heat transfer from the high-temperature refrigerant in the compression chamber to the low-temperature refrigerant in the suction chamber via the piston surface. This heat transfer reduces refrigerant density in the suction chamber and increases the required compression power. However, the assembled vane type prevents piston rotation, effectively minimizing the thermal loss caused by such heat transfer.



(a) Rolling piston type



(b) Assembled vane type

Fig.5 Advantages and disadvantages of compressor types

3.3 Contact Characteristics between Piston and Vane

Figure 6 compares the contact stress and hardness requirements between conventional rotary compressors with rolling piston type and those employing the assembled vane type. In conventional rotary compressors with rolling piston, the arc- shaped vane tip is pressed against the cylindrical piston surface during compression, generating high contact stress between these components. Since the piston also rotates during compression, surface treatments such as hardening are applied to both the piston and vane to prevent wear at the contact points. In contrast, the assembled vane mechanism allows the vane tip to contact the piston along a cylindrical surface, which significantly reduces contact stress and eliminates the need for hardening treatments.

According to the findings of Sawai et al. [1][2], a smaller diameter of the cylindrical tip of the vane improves the mechanical efficiency of the compressor. Considering manufacturing feasibility, the diameter of the cylindrical section was designed to be smaller than the thickness of the vane body.

4. EVALUATION OF THE ASSEMBLED VANE COMPRESSOR EFFICIENCY

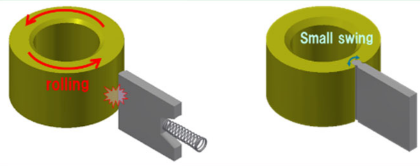
The efficiency of the compressor equipped with the assembled vane type described in this report was compared with that of a conventional rolling piston type rotary compressor. Both compressors were constructed using identical components, except for the piston, vane, and the inclusion of a vane spring. Figure 7 (a) shows the comparison of volumetric efficiency between the two compressors. In the conventional rolling piston type, as previously mentioned, under low-load conditions where the rotational speed decreases and the pressure difference between the condenser and evaporator also drops, the pressure load from the rear of the vane is reduced, and the rotational speed fluctuation of the piston increases. As a result, the vane fails to follow the piston movement, leading to a significant drop in volumetric efficiency.

In contrast, the assembled vane compressor exhibited no significant reduction in volumetric efficiency during low- speed operation. It operated efficiently with minimal refrigerant leakage, and no collision noise between the vane and piston was observed. Figure 7 (b) shows the compressor efficiency ratio compared to the conventional rolling piston type. In addition to improved volumetric efficiency, the assembled vane compressor also achieved a reduction in losses equivalent to the energy associated with refrigerant leakage during the compression process in the rolling piston type. These improvements in compressor efficiency were also confirmed under both rated operating conditions (40 r/s) and half-load conditions (15 r/s).

5. CONCLUSIONS

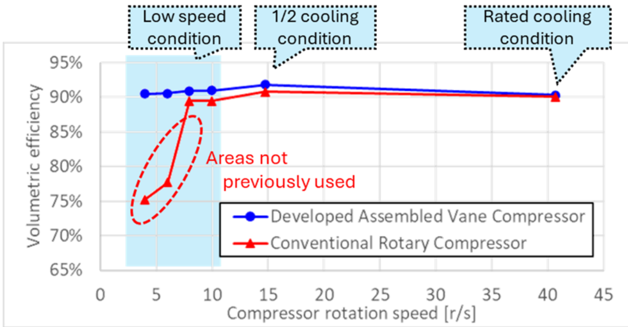
To improve compressor efficiency during low-load and low-capacity operation, this study introduced and evaluated the assembled vane compressor, in which the vane is mechanically linked to the piston. Compared to conventional rotary compressors, the assembled vane compressor demonstrated higher volumetric and total compressor efficiency. It significantly improved performance in the low-load, low-speed operating range, where conventional rotary compressors tend to suffer from vane collision noise and reduced efficiency.

The compressor incorporating the assembled vane type described in this report has been adopted in our residential air conditioning systems. It enables continuous low-capacity operation with high energy efficiency, maintaining high energy performance even under low-load conditions where conventional models typically required intermittent operation. This advancement contributes to both improved energy efficiency and enhanced user comfort.

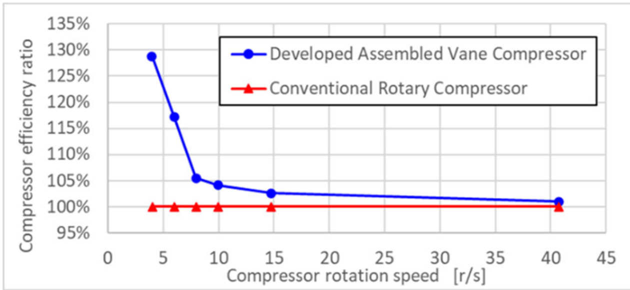


	Rolling piston	Assembled Vane
Surface pressure at the contact point	High	Low
Sliding speed	Hight	Low
Abrasion resistance	×	○
Hardness of piston	Over Hv500	Under Hv400
Hard coating of vane tip	Necessary	Unnecessary

Fig.6 Comparison of contact stress and hardness requirements



(a) Volumetric efficiency



(b) Compressor efficiency ratio

Fig.7 Comparison of compressor performance

RFFERENCES

[1] K. Sawai, et al.: Compressor with turning-paired vane and piston. International Compressor Engineering at Purdue, 1418, (2014)

[2] K. Sawai, et al.: Trans. of JSRAE, Vol.33, No.2, p93-104 (2016). (in Japanese)