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A Study on High Efficiency Wing-vane Compressor - Part.3: Experimental Evaluation of the Prototype -

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A Study on High Efficiency Wing-vane Compressor - Part 3: Experimental Evaluation of The Prototype -

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ABSTRACT

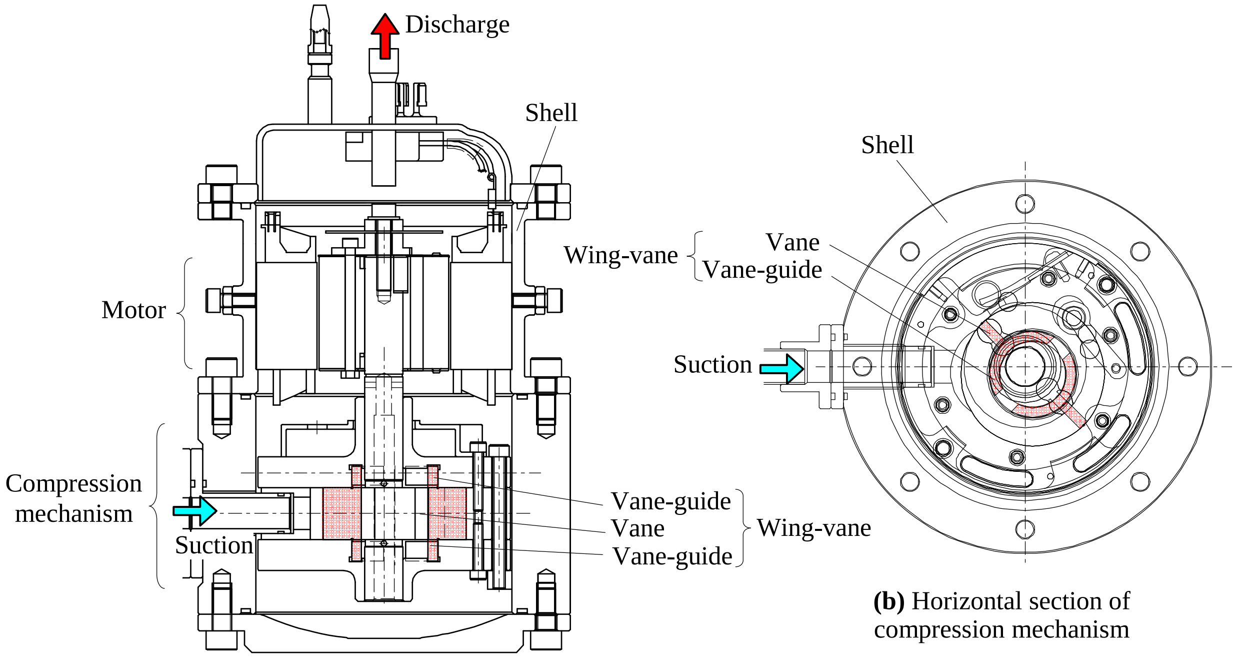
Low global warming potential refrigerants such as HFO (hydro fluoro olefin) -1234yf are attractive as alternative working fluids in air-conditioning and cooling systems to address global warming. However, larger compressor sizes were required due to the lower fluid density compared with conventional refrigerants such as R410A. Thus, a new wing-vane compressor which has no contact between the vane and the cylinder has been developed to prevent an increase in size without performance degradation. The structure of the wing-vane compressor is different from a conventional sliding-vane compressor. Therefore, a prototype of the wing-vane compressor was operated using R134a refrigerant to simulate HFO-1234yf refrigerant. The results were as follows: (1) the APF (annual performance factor) ratio of the prototype of the wing-vane compressor was 100.2% with respect to the twin-rotary compressor. (2) Stable operation was confirmed without problems in the process from suction to discharge. (3) There were no serious abrasions and scratches in the friction parts of the wing-vane compressor after 100 hours of operation under high load operating conditions. (4) The vane-guide, whose arc angle is over 60 degrees, operates stably in low load conditions which are the most worrying conditions for instability of a vane-guide.

1. INTRODUCTION

Low global warming refrigerants such as HFO-1234yf are attractive as alternative working fluids in air-conditioning and cooling systems to address global warming. However, larger compressor sizes were required due to the lower fluid density compared with conventional refrigerants such as R410A. Thus, a new wing-vane compressor which has no contact between the vane and the cylinder was developed to prevent an increase in the size without performance degradation. The structure of the wing-vane compressor is different from a conventional vane compressor. The basic structure and dynamics model were described in Part 1, and the lubrication characteristic of the partial arc guide bearing of the vane-guide in Part 2. In this paper, a prototype of the wing-vane compressor was operated using R134a refrigerant to simulate HFO-1234yf refrigerant. The results of the experimental evaluation of the prototype are compared with the conventional twin-rotary compressor.

2. SPECIFICATION OF THE PROTOTYPE

Figure 2.1 shows the overall configuration of the 1st prototype of the wing-vane compressor. Figure 2.1a shows the longitudinal section of entire structure and Figure 2.1b shows the horizontal cross-section of the compression mechanism. Figure 2.2 shows the appearance of 1st prototype. Table 2.1 shows the basic specifications of the 1st prototype. The refrigerant is R134a to simulate HFO-1234yf, and the stroke volume of the compressor is 28.5 cc. The number of vanes is two, and the shell is a high-pressure type. The flow of the refrigerant is described as follows. First, low-pressure refrigerant is sucked into the compression mechanism. The refrigerant is pressurized from low pressure to high pressure in the compression mechanism and it is discharged into the interior of the shell. Next, the refrigerant is discharged to the outside of the compressor through the gap of the motor.



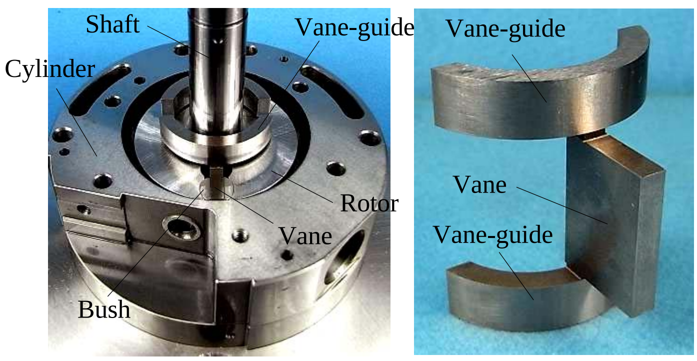
(a) Longitudinal section of entire structure

(b) Horizontal section of compression mechanism

Figure 2.1: Overall configuration of 1st prototype

Table 2.1: Basic specifications of 1st prototype

Refrigerant	R134a
Stroke Volume	28.5cc
Number of vanes	2



(a) Compression mechanism **(b)** Wing-vane

Figure 2.2: Appearance of 1st prototype

3. EVALUATION OF BASIC RELIABILITY

3.1 Operation check test

In order to confirm the stable operation of compressor, the pressure waveform of the prototype was measured under the specific operating conditions (evaporation temperature 52℃, condensation temperature 5℃, rotational speed 30rps). Figure 3.1 shows the pressure waveform measured in the above condition. As a result of the measurement, stable operation was confirmed without problems in the process from suction to discharge. It should be noted that the range without a waveform (over 320 degrees) is out of measurement range.

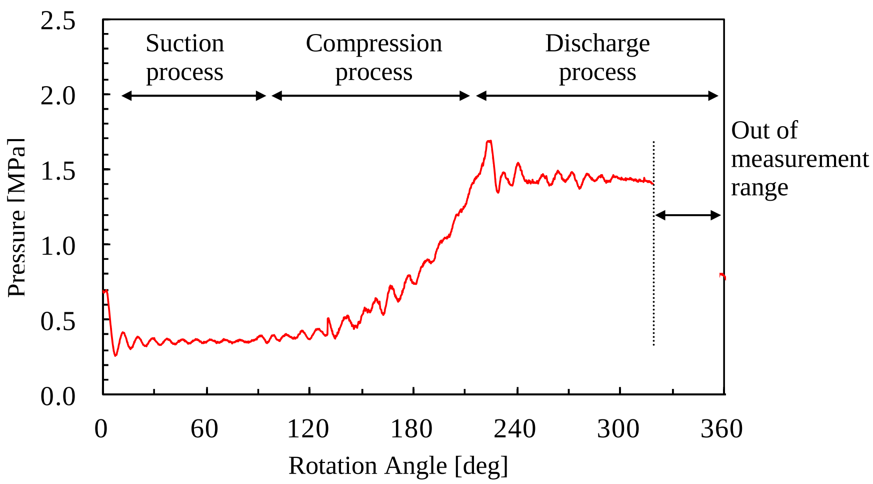


Figure 3.1: Pressure waveform of compression chamber

3.2 Durability test of the friction parts

In order to confirm the durability of the friction parts, the 1st prototype was operated for 100 hours under high load operating conditions (evaporation temperature 68℃, condensation temperature 12℃, rotational speed 60rps). Figure 3.2 shows the typical friction parts of the wing-vane compressor after operation under the above conditions. As shown in Figure 3.2, there are no serious abrasions and scratches. Therefore, it can be said that the structure of the wing-vane has high reliability under normal operating conditions.

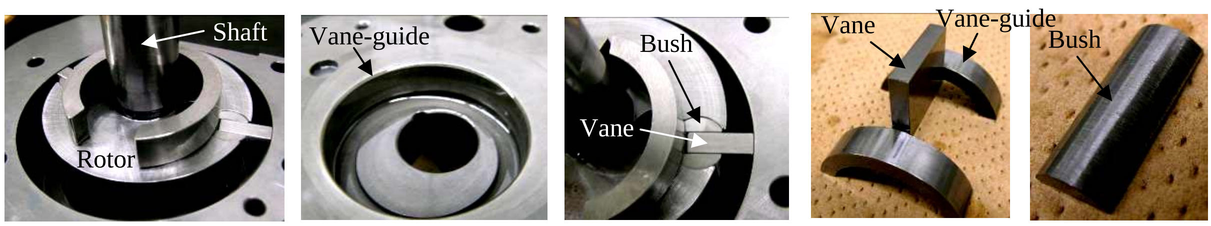


Figure 3.2: Appearance of friction parts after operation

3.3 Stable Operation of Vane

The stability of the vanes described in Part 2 were evaluated in the actual 1st prototype compressor. To confirm the stability limits of the arc angle of the vane-guide, the pressure waveform was compared in the arc angle range from 50 degrees to 135 degrees. From the evaluation, when the arc angle was over 60 degrees, the vane-guide operated stably under low load conditions (evaporation temperature 35℃, condensation temperature 20℃, rotational speed 20rps) which is the most worrying condition of the unstableness of the vane-guide.

Figure 3.3 shows the pressure waveform in the unstable specification of the vane-guide (arc angle was 50 degrees). If the arc angle of the vane-guide is small, the vane-guide operates unstably. In this case, the vane-guide separated from the bearing and the vane separated from the cylinder inside. For this reason, the compression chamber is no longer sealed and the chamber pressure is reduced to the range between 250 deg to 280 deg shown in Figure 3.3.

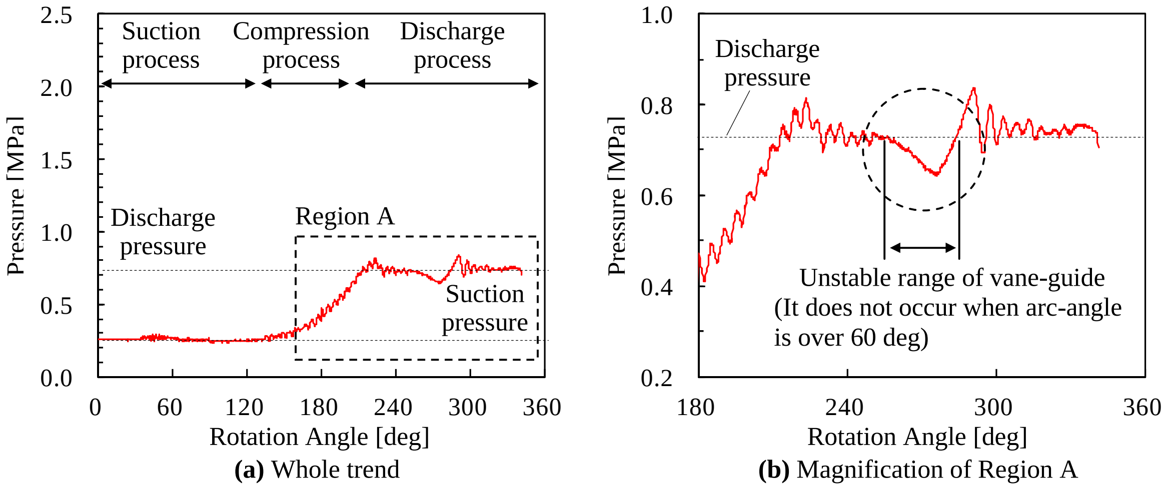


Figure 3.3: Pressure waveform in the unstable condition of the vane (arc angle is 50 deg)

4. EXPERIMENTAL EVALUATION OF PERFORMANCE

4.1 Evaluation of 1st Prototype

Figure 4.1 shows the performance evaluation results of the 1st prototype in comparison with the twin-rotary type. The stroke volume of the twin-rotary type is 28.5cc which is the same as the wing-vane 1st prototype. According to the results of the evaluation, the APF (annual performance factor) ratio of the 1st prototype is 88.4% with respect to the twin-rotary type. The APF is a closer condition to the actual usage of air-conditioners in Japan.

Figure 4.2 shows the loss analysis of the 1st prototype in comparison with the twin-rotary type under specific operating conditions (evaporation temperature 52℃, condensation temperature 5℃, rotational speed 60rps). In comparison with the twin-rotary type, 1st prototype has large indicative losses. A pressure loss and a leakage loss accounts for the vast majority of them. It is necessary to reduce these losses to improve the performance of the wing-vane compressor. The improved items for reducing these losses are described in the next section.

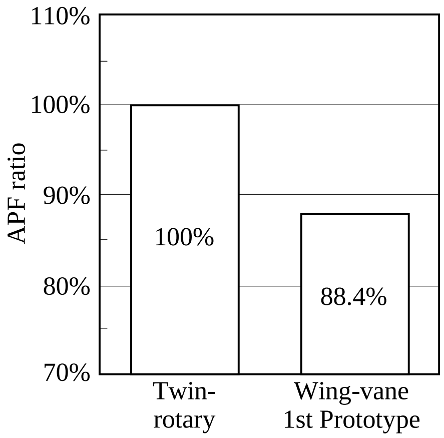


Figure 4.1: Performance evaluation results of 1st prototype

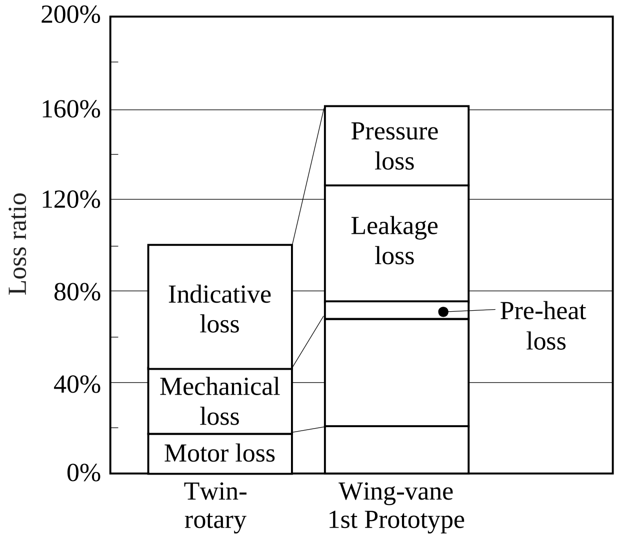
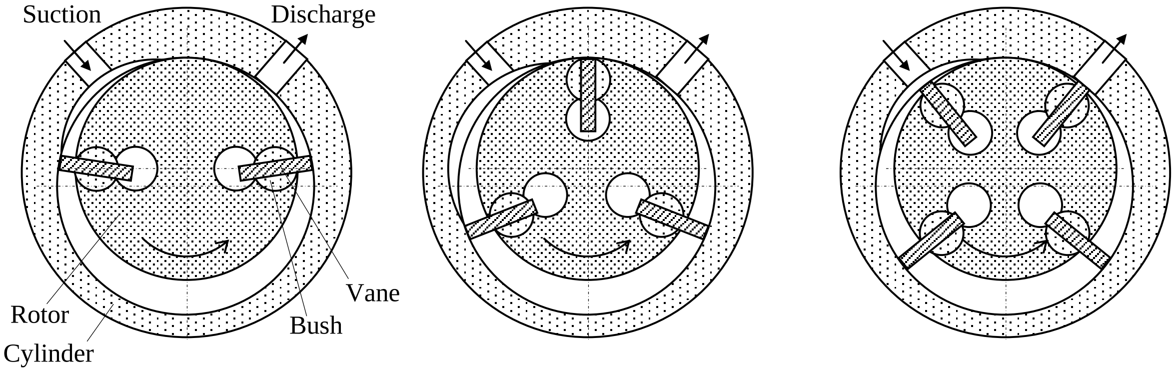


Figure 4.2: Loss analysis of 1st prototype

4.2 Improvement for Loss Reduction

(1) Selection of the number of vanes

In order to reduce the leakage loss, the influence of the number of vane against leakage loss was examined in actual evaluation. As shown in Figure 4.3, the performance (compression efficiency) was compared by changing the number of vanes between 2 and 4. Figure 4.4 shows the influence of the number of vane under specific operating conditions (evaporation temperature 52℃, condensation temperature 5℃, rotational speed 60rps). The performance was improved by using 3 vanes and 4 vanes compared with 2 vanes. This improvement is caused by reducing the pressure difference between the adjacent compression chambers due to increasing the number of vanes. There is no significant difference in the performance of 3 vanes and 4 vanes. This result means that the leakage loss is sufficiently reduced using 3 vanes. Therefore, we selected the specification of 3 vanes using less parts than 4 vanes. In addition, the arc angle of the vane-guide was 135 degrees in the 2-vane type, 95 degrees in the 3-vane type, and 65 degrees in the 4-vane type.



(a) 2-vane type
1st Prototype

(b) 3-vane type

(c) 4-vane type

Figure 4.3: Compressor arrangement when changing the number of vanes

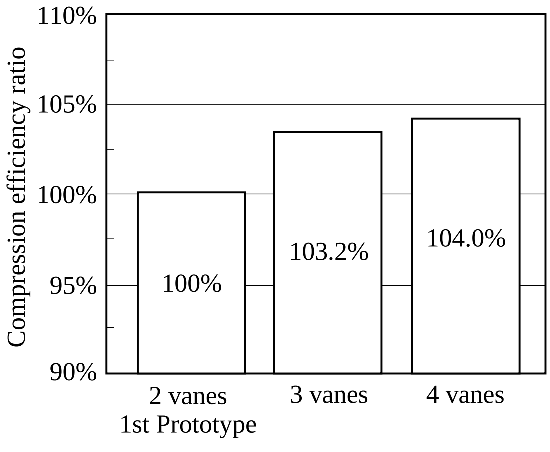
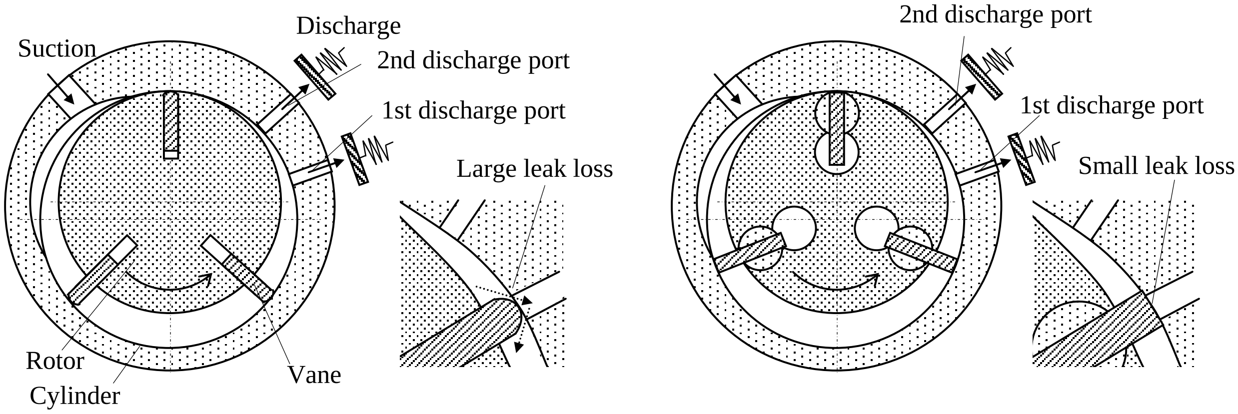


Figure 4.4: Influence of the number of vanes

(2) Adoption of a two-step discharge method

In order to reduce the discharge pressure loss, a new discharge method for the compression chamber was devised for dividing the discharge process into two steps. In the sliding-vane type and the wing-vane type, there is a problem that the flow passage area in the compression chamber is decreased at the end of the compression process and the discharge pressure loss is increased. Therefore, the 1st discharge port was placed at the point with a large flow passage area and the 2nd discharge port was placed behind the 1st discharge port to discharge the rest of the refrigerant with a small flow passage area. Figure 4.5 shows the structure of two-step discharge method applied to the sliding-vane type and the wing-vane type. In the sliding-vane type, since the vane tip curvature is small, a leakage loss occurs at the timing when the vane passes the 1st discharge port as show in Figure 4.5a. In the wing-vane type, since the vane tip curvature is large and it is the same as the curvature of cylinder inside, the leakage loss is smaller than the sliding-vane type as show in Figure 4.5b.

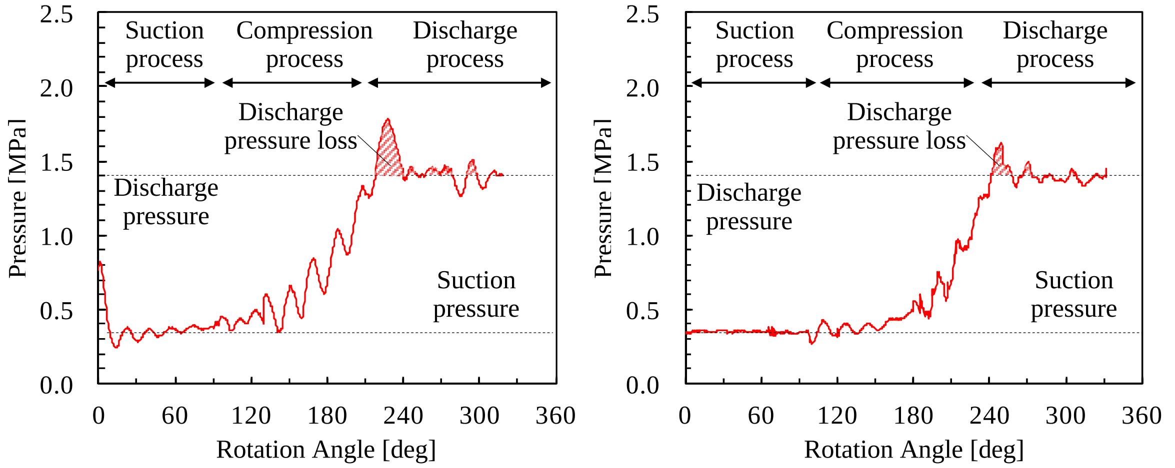
Figure 4.6 shows the pressure loss improvement by the two-step discharge method under specific operating conditions (evaporation temperature 52℃, condensation temperature 5℃, rotational speed 60rps). Figure 4.6a shows the pressure waveform of the conventional discharge method (1 port), and Figure 4.6a shows that of the two-step discharge method. In Figure 4.6, the hatching range over the discharge pressure is the discharge pressure loss. By applying the two-step discharge method, it was possible to suppress the discharge pressure loss to about 1/3.



(a) Sliding-vane

(b) Wing-vane

Figure 4.5: Structure of two-step discharge method



(a) Conventional discharge method (1 port)

(b) Two-step discharge method

Figure 4.6: Pressure loss improvement by two-step discharge method

4.3 Evaluation of 2nd Prototype

Figure 4.7 shows the performance evaluation results of the 2nd prototype mainly applying the improvement items in the previous section. The Stroke volume of the 2nd prototype is 28.5 cc which is the same as the 1st prototype. The APF ratio of the 2nd prototype is improved by 11.8% from the 1st prototype. In the breakdown of this improvement, 5.1% is due to the two-step discharge method, 4.1% is due to the optimization of the number of vanes, and 2.6% is due to other improvements. As the result of these improvements, the APF ratio of the 2nd prototype is 100.2% with respect to the twin-rotary type. In other words, the wing-vane type can achieve both high performance and miniaturization.

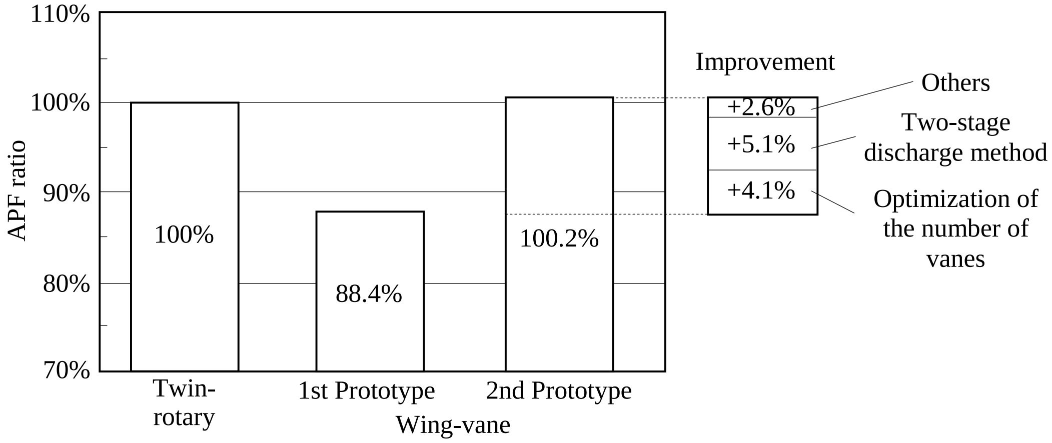


Figure 4.7: Performance evaluation results of 2nd prototype

5. CONCLUSIONS

A wing-vane compressor which can achieve both high efficiency and downsizing has been proposed. In this paper, prototypes of the wing-vane compressor were operated using R134a refrigerant to simulate HFO-1234yf refrigerant. The evaluation results in the prototype are as follows.

(1) Performance

By optimizing the number of vanes and improving the discharge method, the APF ratio of the prototype of the wing-vane compressor is 100.2% with respect to the twin-rotary compressor.

(2) High Reliability

・From the pressure waveform, stable operation was confirmed without problems in the processes from suction to discharge

・There were no serious abrasions and scratches in the friction parts of the wing-vane compressor after 100 hours of operation under high load operating conditions.

・The vane-guide, whose arc angle is over 60 degrees operates stably under low load conditions which is the most worrying condition for instability of the vane-guide.