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STUDY ON IMPROVEMENT OF THE SUCTION VALVE OF A COMPRESSOR FOR AN AUTOMOTIVE AIR-CONDITIONER

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ABSTRACT

The simplified test model of the commercial reciprocating compressor for an automotive air-conditioner is used to measure the displacement of the suction valves using a strain gauge and to investigate the velocity distributions of the discharge flow from the valves using the particle image velocimetry sytem. This paper is focused on the effects of shape of the suction valve on the vibration-reduction. The size of the suction valve hole and the width of the tip of the suction valve are changed as main parameters of the valve shape. First, the size of the conventional valve hole and the width of the tip of the conventional valve are changed and seven new valves are manufactured to reduce the vibration of the valve. Next, the influence of the natural frequency on the vibration-reduction is investigated using one shape of the new valves by changing the material and the thickness of the valve. Finally, the reason of the vibration-reduction for one shape of the new valves is discussed from the results of the flow analysis around the valve. The vibration-reduction for one of the new valve is confirmed by measurement of the displacement of the valve in the reciprocating compressor.

KEY WORDS

Key words, Flow Visualization, PIV, Vibration, Suction Valve, Compressor, Automotive Air-conditioner

INTRODUCTION

The noise is usually caused from the evaporator for an automotive air-conditioner because the evaporator resonates with the pressure-pulsation in the commercial reciprocating compressor. Therefore the decrease of the pressure-pulsation is one of the important problems in the reciprocating compressor for the automotive air-conditioner. Tsukiji et al. [1] found through the previous studies that the vibration of the suction valve affects the pressure-pulsation. Sato et al. [2,3] conducted the flow visualization of the discharge flow from the suction valve using the commercial compressor, which is improved to observe inside it under the actual condition.
Chung et al. [4] and Myung et al. [5] investigated only the flow analysis around the suction valve using PIV system with the test facility for the flow visualization. On the other hand, Ishii et al. [6] and En et al. [7] performed only the measurement of the vibration using

the strain gauge for the suction valve. Despite the above-mentioned studies, it is not done about the reduction of valve vibration.

This paper is focused on the effects of shape of the suction valve on the vibration-reduction. The size of the suction valve hole and the width of the tip of the suction valve are changed as main parameters of the valve shape. First, this paper describes the relevant fundamental studies employing a cylinder with one suction valve on the valve plate as a test model instead of the reciprocating compressor for the automotive air-conditioner. The test model was designed to measure the displacement of the suction valve and to visualize the discharge flow from the suction valve inside the cylinder. The valve vibrations of the conventional valve and the improved valve were measured using a strain gauge. On the other hand the measurement of the velocity distributions was performed to analyze the flow field around the suction valve using the PIV(Particle image velocimetry) system. Next, the size of the conventional valve hole and the width of the tip of the conventional valve are changed and seven new valves are manufactured to reduce the vibration of the valve. Consequently, it is found that one shape of the new valves is the most effective for the vibration reduction. Next, the influence of the natural frequency on the vibration-reduction is investigated using one shape of the new valves by changing the material and the thickness of the valve. Finally, the reason of the vibration-reduction for one of the new valves is discussed from the results of the flow analysis around the valve. The vibration reduction for one of the new valves is confirmed by measurement of the displacement of the valve in the reciprocating compressor for the automotive air-conditioner.

TEST APPARATUS

Experimental set up

The schematic layout of the test model designed in this study is shown in Fig.1. An air as a working fluid is compressed using the air compressor and the inlet pressure is kept constant to reduce the pressure from the compressor with the pressure-reducing valve. The solenoid valve is used to stop or flow the air. The pressure difference between the upstream and the downstream parts of the suction valve is set with the downstream valve of the test model. Moreover, the inlet pressure and the differential one are measured by the pressure transducer.

The test model is shown in Fig.2. In the figure, the right-hand side of the figure is the upstream direction, and left-hand side is the downstream direction. The valve plate, the suction valve and the cylinder are arranged in the test model. A commercial reciprocating compressor for an automotive air conditioner has usually seven cylinders. However one cylinder was used to simplify the experimental device in our experiments. The cylinder made of acrylic resin was designed to visualize the flow around the valve inside the cylinder. The diameters of the suction port and the cylinder, and the depth of the valve stopper are same as a commercial reciprocating compressor for an automotive air-conditioner. The diameter of the suction port is 9 mm in order to make the same influence of the suction port on the vibration of the suction valve and the flow around the valve. In our experiments the air is used instead of refrigerant to visualize the flow clearly in the valve.

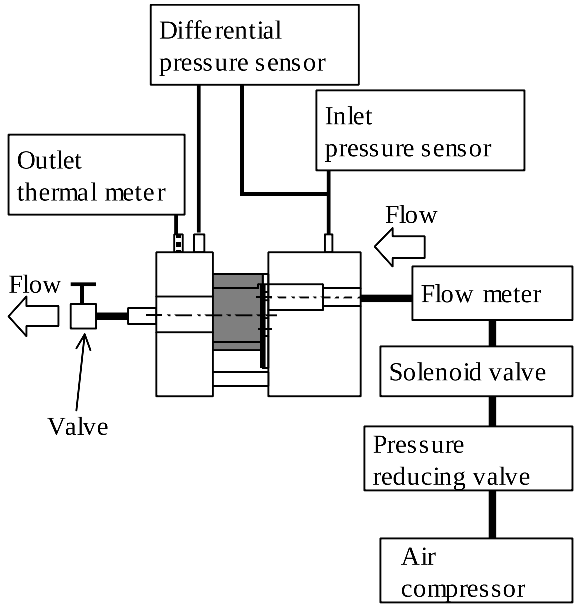


Figure 1 Experimental apparatus

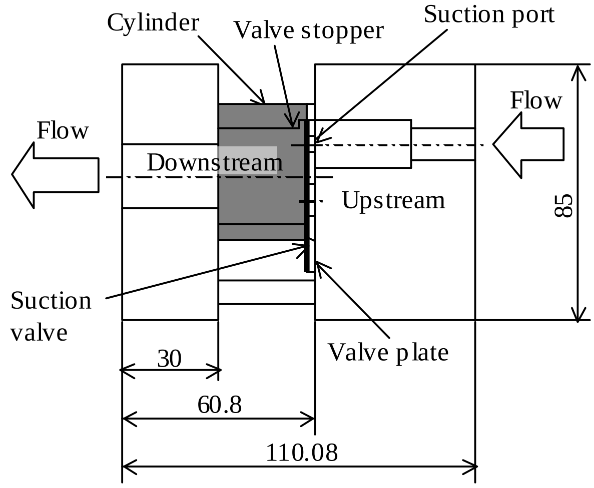


Figure 2 Test model

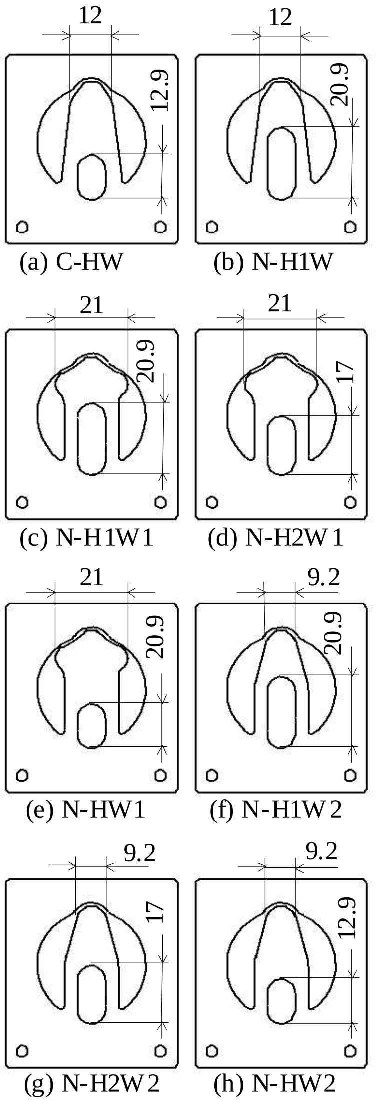


Figure 3 Suction valves

Figure3 (a) shows a conventional valve of the type C-HW. Moreover, seven kinds of the improvement valves are shown in Figures 3 (b) ~ (h). The size of valve hole and the width at the tip of a valve for the improved valves are changed to compare with the conventional valve C-HW. In this experiment, seven kinds of valves were manufactured as the first stage of our study.

Measurements of the displacement of the suction valves

The strain gauge is pasted on the part of the valve, which is expected to be deformed largely with quick drying glue. As shown in Figure 4, the output signals from the strain gauge are amplified through the bridge box and the voltage amplifier and are recorded to the data recorder. The relation between the valve displacements measured using a laser sensor and the output voltages using a strain gauge is obtained.

Flow visualization using PIV (Particle Image Velocimetry) system

The PIV system is used to visualize the flow field around the suction valve and to obtain the velocity distributions for the conventional valve C-HW and the improved valve without the vibration. The light sheet using the double-pulsed YAG laser is used as a light source. The positions of the laser light sheets are shown in Figure 4. The laser light sheets are placed on the sections perpendicular to the valve plate including the axes A-A of a suction port. The tracer particles DEHS are introduced in the tube between the mass flow meter and the test model, as shown in Figure 1. DEHS is a liquid and becomes the mist phase using the pressurized tank. The mist of the DEHS is introduced into the experimental circuit.

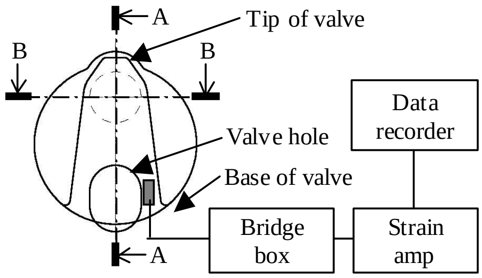


Figure 4 Position of strain gauge and Laser sheet

Test condition

The upstream pressure is kept constant at 0.2MPaG in the present experiments because the suction pressure of the reciprocating compressor for an automotive air conditioner is also about 0.2MPaG. The mass flow rate is changed from 3.0kg/h to 10.5kg/h in our experiments.

RESULTS

Displacement of the suction valve

Figure 5 shows the displacement for the conventional valve C-HW and new valve N-H2W1 for 3.0kg/h of the mass flow rate as one of the typical example. Time is shown in the horizontal axis and the displacement of a suction valve is shown in the vertical axis.

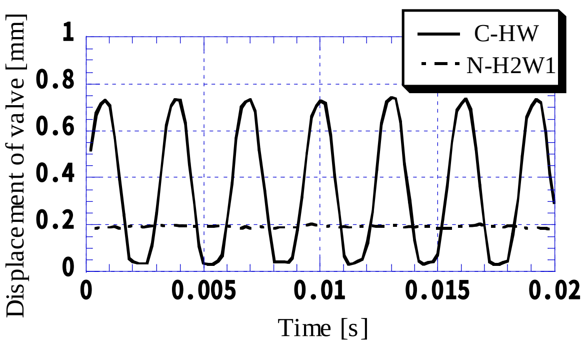


Figure 5 Valve vibration (Flow rate=3.0kg/h)

Figure 6 shows the amplitude and the frequency of the seven suction valves, respectively. The flow rate is shown in a horizontal axis and the amplitude of a suction valve is shown in a vertical axis. As shown in Figure 6, the amplitude of the new valve N-H2W1 was 0.01mm or less. Therefore, there is almost no vibration for the new valve N-H2W1. Furthermore, the valves (C-HW,N-H1W,N-H1W2,N-H2W2,N-HW2) vibrated for 3.0 kg/h of the low flow rate. Therefore the experiments were not conducted for other parameters of the flow rate except it. For new valves, the frequency of the valves N-H1W1 and N-HW1 is about 200Hz and is about 320~340Hz except it.

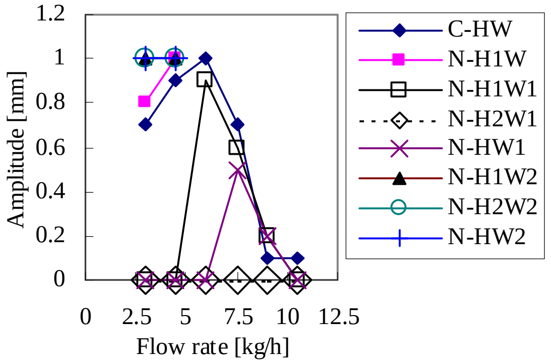


Figure 6 Amplitude of the suction valves

The natural frequency fn Hz and mass m g of the valves used in our experiments are shown in Table 1.

Table 1 Characteristics of the suction valves

	f_n[Hz]	m[g]
C-HW	216	0.87
N-H1W	205	0.72
N-H1W1	167	0.83
N-H2W1	165	0.91
N-HW1	165	0.99
N-H1W2	199	0.66
N-H2W2	193	0.74
N-HW2	201	0.81

The natural frequencies are about 165Hz or 200Hz. The frequencies of the valves during the vibration in the experiment are 200Hz. The natural frequencies of each new valves N-H1W1, N-H2W1 and N-HW1 are almost 165Hz. But we have found that some these valves vibrate and the other do not vibrate.

Next, we changed the natural frequency of the vibration-reduced new valve N-H2W1 with 165Hz of the natural frequency by changing its material and thickness keeping its shape, in order to investigate the influence of natural frequency. The natural frequency fn Hz and the mass m g of seven kinds of valves manufactured are shown in Table 2.

Table 2 Characteristics of the suction valves (N-H2W1 Type)

	f_n[Hz]	m[g]
PK0.2	113	0.61
PK0.3	165	0.91
PK0.4	223	1.0
G0.2	119	0.61
G0.3	177	0.91
G0.4	230	1.0
PK-200	200	1.06

Furthermore, it was found from the previous experimental results that the valve tends to vibrate for 200Hz of the natural frequency. We made the valve PK-200 with 200Hz of the natural frequency by changing the thickness of the valve N-H2W1. On the same experimental conditions shown in Figure 6, the mass flow rate was changed between 3.0 and 10.5 kg/h. As for the experimental results, the oscillating amplitude was about 0.3mm only for 9.0 kg/h of the valve G0.3, and frequency was about 200Hz. But the other valve's amplitudes were 0.01mm or less almost without the vibration. Therefore, in the mass flow range of this experiment, the valves were without the vibration and it turns out that there is less influence of the natural frequency. It is effective to enlarge width of tip of a valve, and it turns out that the optimal size for the valve hole also exists. It is because the size of the valve hole changes the influence of the flow on the valve. Even if we change the material's quality and thickness, keeping the valve shape of the valve N-H2W1, it turns out that the vibration of the valve can be suppressed mostly. From the above results, the important factors for designing the suction valve are both the shape of the suction valve and the size of valve hole. Then, we paid attention to the valve PK-200 of the same shape of the valve N-H2W1. The pressure drop is investigated using the pressure drops $\Delta P_{PK\text{-}200}$ of the valve PK-200 divides by the pressure drops $\Delta P_{C\text{-}HW}$ of the conventional valve C-HW. The results are shown in Figure 7.

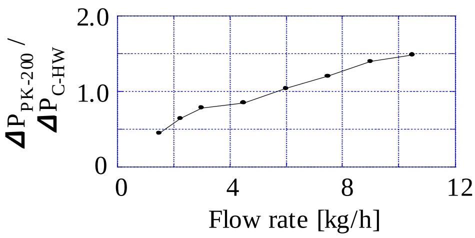
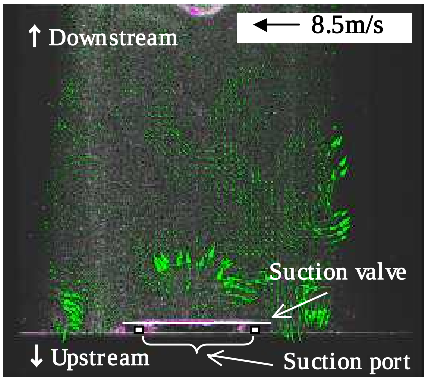


Figure 7 Pressure loss of the valve PK-200

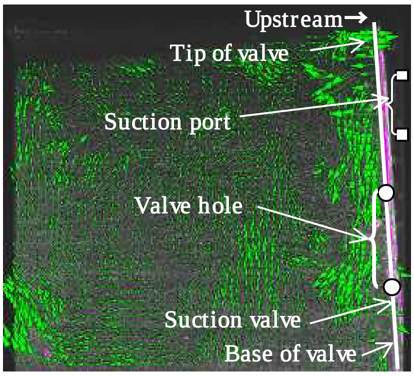
The pressure drop of the valve PK-200 in low mass flow rate is smaller than the pressure drop for the valve C-HW. If the mass flow rate increases to 6.0kg/h or more, the pressure drop of the valve PK-200 is higher than the pressure drop of the conventional valve. Therefore, it turns out that the effect of the shape of the valve N-H2W1 without vibration is effective in the range of the low mass flow rate.

Velocity distributions around the valve

Figure 8 shows the velocity distributions obtained using the PIV technique for the valve C-HW when the flow rate is 3.51kg/h. The displacement of the valves changes between 0mm and 0.8mm during the vibration as mentioned in the section 'Displacement of the suction valve'. In the image shown in Figure 8 the displacement of the valve is almost 0.4mm and it is increasing.



(a) section A-A



(b) section B-B

Figure 8 Visualized results of conventional valve (Flow rate=3.51kg/h)

Figure 8(a) shows the velocity distributions in the section A-A and Figure 8(b) shows those in the section B-B. The magnitudes of instantaneous velocity vector obtained are from 4m/s to 7m/s. In the Figure 8(a) the direction of the downstream velocity vectors from the suction port is the same direction of the movement of the valve because the valve is opening and going up. From the Figure 8(b) it is found that the fluid flows from the suction port along the surface of the suction valve to the bottom of the valve and the flow structure is random and turbulent in the downstream region from the suction valve. The velocity vectors are obtained at the several times and the flow structures observed in the section B-B are almost same. In this experimental range, the valve N-H2W1 did not almost vibrate as mentioned in the section 'Displacement of the suction valve'. Figure 9 shows the velocity distributions of downstream direction for the valve N-H2W1 obtained using the PIV technique.

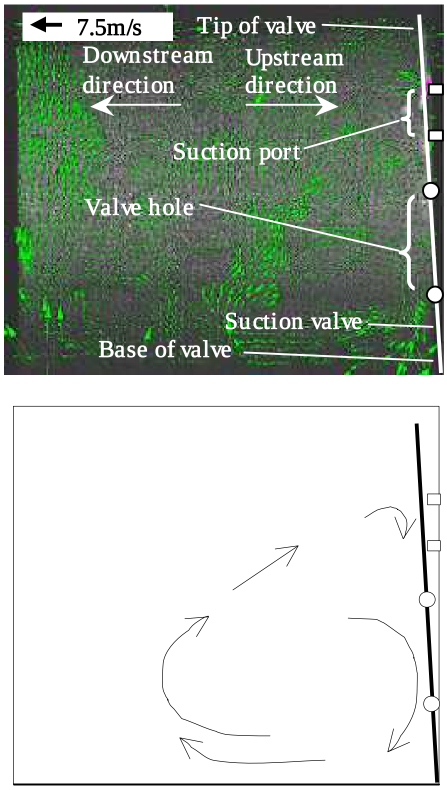


Fig.9 Visualized results of new valve (top:using PIV technique, bottom:sketched figure, Flow rate=3.0kg/h)

The bottom figure of Figure 9 is the sketched figure in the section A-A. From the figure 9 the vortex exists in the downstream region of the new valve without the vibration. It was confirmed that the design to generate the steady large vortex near the suction valve is useful to prevent the vibration of the valve. The generating of the two-dimensional flow in the width direction near the center of the valve N-H2W1 is useful to exist the vortex and the vortex has the influence on the vibration reduction.

Displacement of the suction valve in the reciprocating compressor for the automotive air-conditioner

From the results using the test model, it is found that the shape of the valve N-H1 has most effective to reduce the vibration. To investigate the effect of the vibration-reduction for the valve N-H2W1 the valve is set in the reciprocating compressor for the automotive air-conditioner and the displacements of the suction valves are measured using the strain gauge. The results are shown in Figure 10.

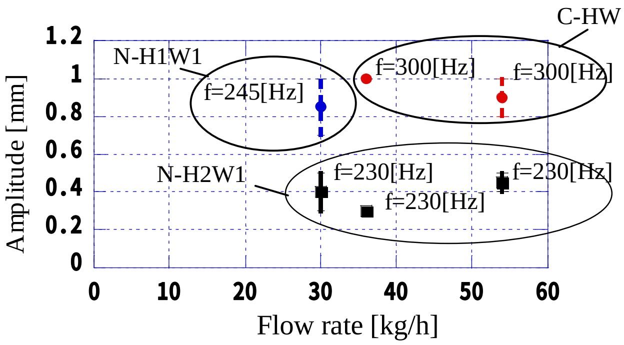


Figure 10 Amplitude and frequency of the valve in reciprocating compressor

In order to compare it, the valves C-HW and N-H1W1 were also investigated. The mass flow rate for the circuit of refrigerate is shown in a horizontal axis and the amplitude of the vibration is shown in a vertical axis. The frequency f Hz was also shown in the left or right-hand side of each data. Although the valve N-H2W1 vibrates compared with the results using the simplified test model, the vibration was reduced compared with the valves C-HW and N-H1W1. It is confirmed that the shape of the valve N-H2W1 is the most effective for the vibration-reduction.

CONCLUSIONS

To perform the vibration-reduction of the suction valve of the reciprocating compressor for the automotive air-conditioner, the simplified test model is designed to improve the conventional valve. Detailed study is conducted by measurement of the displacement for the valves using the strain gauge. And the velocity distributions around the suction valves without vibration are measured using PIV technique. Furthermore, the new valve is set in the reciprocating compressor for the automotive air-conditioner and the displacement of the suction valves is measured using the strain gauge. It is confirmed that the shape of the valve N-H2W1 is the most effective for the vibration-reduction.

Summary of this paper is itemized as follows;

1. The generating of the two-dimensional flow in the width direction near the center of the valve N-H2W1 is useful to obtain the two-dimensional vortex flow and the vortex has the influence on the vibration reduction of the valve. Moreover, the optimal size for the valve hole exists.
2. Even when the natural frequencies of the valves are the same, we have found that the valves vibrate or do not vibrate according to the shape of the valve. Therefore, it was found that the vibration was affected by the three-dimensional flow.
3. The new valve with the optimal shape obtained to reduce the vibration using this simplified test model showed good result for the case of the compressor of the commercial system.
4. The pressure loss for the new valve N-H2W1 without the vibration was compared to the conventional valve C-HW with the vibration. The pressure loss of the new valve is small in the range of low mass flow rate. When the mass flow rate increases, the pressure loss of the conventional valve is less than that of the new valve .

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