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PREDICTION OF THE VALVE STRESSES OF ROTARY COMPRESSOR USING THE FINITE ELEMENT METHOD

Jeongsoo Park\textsuperscript{1}, Jeman Seo\textsuperscript{2}, Huijong Kang\textsuperscript{2}, Joonoh Do\textsuperscript{2}

ABSTRACT

In this study we analyzed both bending and impact stress of the discharge valve of the rotary compressor using a commercial FEM program MSC/NASTRAN and predicted the amount of maximum stress and the location it occurred. We measured the maximum stress of the valve in bolt case compressor using the resistance type strain gages. Good agreement was made by the comparison between the numerical analysis and experiment. To judge the reliability of the discharge valve, the comparison between the maximum stress and the fatigue strength of the valve materials was accomplished. Also using the numerical analysis, we can reduce the time for the design of the valve and estimate the service life of it.

INTRODUCTION

Recently the technology of the compressor has rapidly advanced for the home appliances like refrigerator and air conditioner. Especially rolling piston type rotary compressors are more widely used than reciprocating compressor. The advantages of the rolling piston type rotary compressor are higher efficiency, compact size, and light weight etc. The behavior of the discharge valve of the rotary compressor has effect on performance of it. Also the valve is subjected to the fluctuating bending and impact load about 60 cycles per second. Therefore we have to design the discharge valve in considering both the performance and the service life of the compressor.

To prevent the break of the discharge valve and improve the reliability of the compressor we should find the highest stress of the valve during operation and the location of it. In order to reduce the time for design of the valve we predict the stress using the numerical method and we prove the accuracy of the numerical stress analysis by experiment. We compare the maximum stress of the valve with the fatigue strength of the valve material to assess the reliability of the valve.

ANALYSIS

1. The behavior of the discharge valve

Three states of discharge valve stress are considered in the present study to analyze the stress of the valve, shown in Fig.1\textsuperscript{1}. Fig.1(a) shows the valve which is contact to the backer. In this case the valve is subjected to the bending stress and impact stress. In Fig.1(b) the valve is contact to the valve seat after the refrigerent gas is discharged through the discharge port of the compressor. The valve comes to this position by the spring back of the valve itself. Fig.1(c) shows the valve is subjected to the inflexural force. This force is the results of the difference of the pressure between muffler and cylinder of the compressor. Fig. 2 shows the shape of the discharge valve.

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2. The contact of valve to the backer.

We must know the contact length between the valve and the backer in order to calculate the bending stress and the impact stress in the stage 1, shown in Fig.1 (a). This value is calculated from the equation:

\[
\frac{1}{R} = \frac{6 \times P \times X}{E \times h^3 \times (4.5^2 - X^2)^{0.5}}
\]  

where \( R \) is the radius of the backer, \( P \) is the force of discharge gas, \( X \) is the non-contact length, \( E \) is the Young's Modulus of the valve material, \( h \) is the thickness of the valve.

3. Numerical Stress Analysis

We predict the stress of the discharge valve numerically using MSC/NASTRAN, a commercial Finite Element Method program.  

(1) Bending stress analysis in state 1

The bending stress caused by the discharge gas force has great effect on the maximum stress of the discharge valve. The discharge gas pressure is measured using the pressure gage and the gas force is used as the boundary condition to calculate the maximum stress and the location it occurs. The gas force is the pressure difference between the cylinder and the muffler. The variation of the gas force is shown in Fig. 3. In stress analysis we use the gap element between the valve and the backer along the contact line between the valve and the backer.

(2) Impact stress analysis in state 1

In this case the impact velocity of the valve is used as the boundary condition to calculate the impact stress. We measure the velocity using the gap sensor in normal operation of the compressor.

Fig.4 illustrates the plot of the velocity of the discharge valve versus time.

(3) Impact stress analysis in state 2

In this case we measure the impact velocity of the valve on the valve seat using the gap sensor and use the velocity as the boundary condition for the stress analysis. Fig.4 illustrates the plot of the velocity versus time.

(4) Flexural stress analysis in state 3.

To calculate the flexural stress we use the pressure difference between the muffler and the cylinder. Using the pressure sensor we measure the pressure of the muffler and cylinder, respectively. Fig.5 is the results of the pressure measurement.

EXPERIMENT

In order to verify the numerical predictions, the following experiments are performed. Experimental apparatus is shown schematically in Fig. 6. Table 1 is the specification of the rotary compressor. We assemble the pump of the compressor in the bolt case.

We attach resistance type strain gage at a point where we predict the maximum stress occurs. The strain gage is uniaxial type high temperature gage and gage length is 2 mm. Some special adhesives and coating materials are used because temperature of the discharge gas is about 120 °C and the strain gage is contact to lubricant. Fig. 7 shows the valve and the strain gage attached to it. The experiments are performed with varying the velocity of the compressor and the discharge pressure.

RESULTS
1. Numerical Analysis Results

From the result of the bending stress analysis we can see the maximum stress occurs at the point about 21 mm distance from the rivet joint of the valve and the amount of it is 420 N/mm². Fig. 8 shows the maximum bending stress of each element along the center line of the valve.

The maximum impact stress is equal to 98 N/mm² and it occurs at the point 21 mm distance from the rivet joint of the valve, shown in Fig. 9.

When the discharge valve is contact to the backer the total stress of the discharge valve is the sum of bending stress and impact stress. The value of the total stress is 518 N/mm². Fig. 10 is the plot of three cases above mentioned.

During the contact of the discharge valve to the valve seat, the maximum impact stress is 100 N/mm², shown in Fig. 11. When the valve is subjected to the inflexural force the maximum inflexural stress is 350 N/mm², shown in Fig. 12. In Fig. 13 plots of all stresses are illustrated.

2. Experimental Results

We get some signals from strain measurement, shown in Fig. 14. The strain A is measured during the contact between valve and backer, and the strain B during the contact between the valve and the valve seat. The signal B includes the effect of the inflexural force. The strain values are converted to the stress and we find the maximum value of A and B are 540 N/mm² and 200 N/mm² respectively.

Under varying velocity and discharge pressure we measure the strains of the discharge valve. When the speed of the compressor increases from 3600 rpm to 6000 rpm we can not find the increase of the maximum stress of the discharge valve yet, shown in Table 2. The maximum stress of the valve continuously increases until the discharge pressure reaches a certain value, after that, almost there is no change of it, shown Fig. 15.

DISCUSSION

The stress measured is greater than the stress numerically calculated 4.5% only. The maximum stress is less than the fatigue strength of the valve material and therefore the valve is reliable.

CONCLUSION

In this paper we analyze the stress of the discharge valve of the rolling piston type rotary compressor and perform experiments to measure the stress of the valve. The following conclusions are obtained.

(1) There is a good agreement between the numerical analysis and the experiment.
(2) The maximum stress of the discharge valve is less than the fatigue strength of the valve.

Therefore, the discharge valve is reliable in normal operation.

ACKNOWLEDGEMENT

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![Fig. 1 Stress state of the discharge valve](image1)

![Fig. 2 The shape of the discharge valve](image2)

![Fig. 3Measured gas force as a function of time](image3)

![Fig. 4 The plot of velocity of the discharge valve versus time](image4)

![Fig. 5 Measured pressure of cylinder and muffler as a function of time](image5)
Fig. 6 The simplified schematic of the experimental setup

Fig. 7 The discharge valve and the strain gage attached to it

Fig. 8 The maximum bending stress of each element in state 1

Fig. 9 The maximum impact stress of each element in state 1

Fig. 10 The maximum bending and impact stress in state 2

Fig. 11 The maximum impact stress of each element in state 2
Fig. 12 The maximum impact stress of each element in state 2

Fig. 13 The mixed stress of state 2 and state 3

Fig. 14 The signal of the strain gage

Fig. 15 Variation of maximum stress with discharge pressure

Table 1 Specifications of the rotary compressor

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<tbody>
<tr>
<td>Compressor</td>
<td>Capacity</td>
<td>11000 Btu/hr</td>
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<tr>
<td></td>
<td>Weight</td>
<td>127.5 N</td>
<td></td>
</tr>
<tr>
<td>Motor</td>
<td>Speed</td>
<td>3600 rpm</td>
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<tr>
<td></td>
<td>Power</td>
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Table 2 Variation of maximum stress with speed of compressor

<table>
<thead>
<tr>
<th>Compressor Velocity(rpm)</th>
<th>3600</th>
<th>5400</th>
<th>6000</th>
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<td>The Signal of Strain Gage(v)</td>
<td>2.6054</td>
<td>2.6287</td>
<td>2.6803</td>
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