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The Design of Compressor Valve to Consider the Flexibility and Reliability

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ABSTRACT

This paper presents a qualitative introduction to the compressor valve design and development efforts by considered flexibility and reliability. Flexibility that is related to compressor efficiency and structural reliability are two main important factors in compressor valve design. In this study, we have designed the optimal CO₂ compressor valve considered these factors. To obtain optimal valve flexibility we performed to system simulation of compressor. From this simulation, we could get some important data at valve design like the optimal natural frequency and the height of retainer. For each case bending stress, contact stress and natural frequency were obtained by finite element analysis. Also we studied the fatigue stability to obtain optimal valve shape that ensured to reliability.

1. INTRODUCTION

In compressor, suction and discharge valve are one of the key components which maintain constant pressure by enabling the move of refrigerant at a certain pressure. As the refrigerant enters to cylinder at low pressure, it is compressed by piston. As pressure gets higher, it is send to discharge room by discharge valve.

Therefore, consistent suction and discharge of refrigerant is the key factor, which determines the performance of compressor. There are several design factors to consider in suction and discharge valve design. But, two most significant factors are optimal reliability and flexibility. While the leakage or backflow of refrigerant is minimized, the maximum suction and discharge is necessary to guarantee optimum performance. That is, optimal flexibility is the necessary condition for smooth opening and closing of valve. As automotive compressor are under high speed loading condition while driving, suction and discharge valve need to stand for loaded impact and bending fatigue. Therefore, the design with strength reliability is requested. In this study, several important design factors in designing suction and discharge valve of CO₂ refrigerant are considered to propose the optimal design process. Unlike R134, CO₂ refrigerant compressor is mostly under high pressure condition, so valve should be thoroughly tested before exposing of severe loading condition.

Among two different methodology tried in this study, first, design factor of valve system is obtained by performance simulation of compressor. Natural frequency and stopper height are determined to maximize the performance of swash plate type CO₂ refrigerant compressor.

Secondary, based upon the results of performance simulation, finite element analysis is conducted to ensure the reliability of valve. After several iterations, design factors are finally determined.

2. PERFORMANACE SIMULATION

To determine the optimal height of valve stopper and natural frequency, the following simulation is performed. The compressor consists of six cylinders and three control volumes. Each could be represented as twenty 1st order differential equations with respect to mass and temperature and six 2nd order kinetic equations for suction and

discharge valve. To solve twenty 1st order differential equations and 2nd order kinetic equations simultaneously, twelve 2nd order differential equations are transformed to twenty-four 1st order differential equations, and then forty-four ordinary differential equations are solved using Runge-kutta method.

3. FINITE ELEMENT METHOD

The finite element analysis is performed to test the reliability of valve under loading. The figure 1 shows the valve movement of compressor.

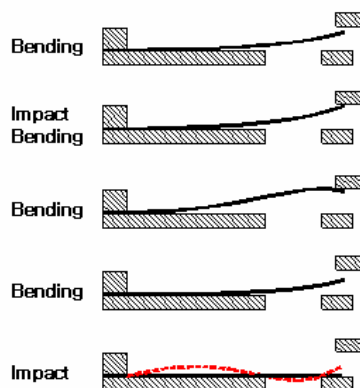


Figure 1: The valve movement of compressor (1)

As shown in figure 1, valve mechanism is quite complex, which could accompany various phenomena in opening and closing. For two most severe cases in terms of the safety, valve structure is analyzed in this study. I-DEAS analysis program is utilized, and 3D shell element is used. The thickness is set to 0.305mm and 0.381mm, as these two are only available in the market. The bending stress, contact stress, and natural frequency of valve is obtained as a result.

Table 1. Mechanical Properties(1)

Material	Tensile Strength , Mpa	Fatigue limit, Mpa	Impact fatigue, m/s
Sandvik20C	1900	800	8

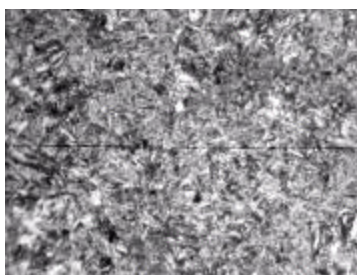


Figure 2: Microstructure of Sandvik 20C

Sandvik 20C is selected for this analysis, and its properties are listed in Table 1. Looking upon microstructure image (figure 2), it is found that the main structure is needle type martensite. The shape of suction and discharge is shown in figure 2.

3.1 Determination of natural frequency and stopper height

The lower the natural frequency of valve is, the higher the performance of compressor is. But, if the natural frequency is too low, the safety of structure is in danger. Therefore, the determination of optimal natural frequency is very important. Since stopper height is also closely related to the compressor performance, its optimal length is determined by performance simulation. The short stopper is better in terms of reliability, but the opposite is preferred for the better performance of compressor. Therefore, the optimal natural frequency and stopper height should be determined considering the performance of compressor. In this study, two key factors are determined to maintain 70% volume efficiency at 1800 rpm like R134 case. Table 2 shows the results from performance simulation for natural frequency and stopper height.

Table 2 Design Factor of Valves

	Natural Frequency(w_1)	Height of Stopper (H)
Suction	1100	0.57 mm
Discharge	1300	0.5 mm

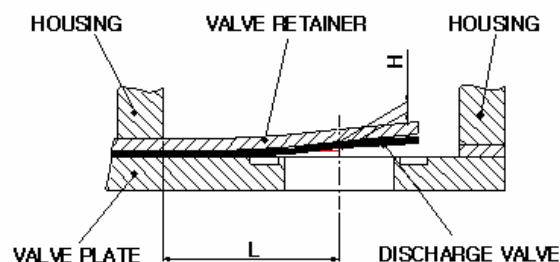


Figure 3: Basic shape of Valve

To obtain optimal natural frequency, several different design cases (figure 3) are simulated. Mostly the width of suction and discharge valve is varied. But, if the width variation is too big to lower the reliability, the area of valve head is changed to vary its mass for optimal natural frequency. The final shape of valve after simulation is shown in figure 4.

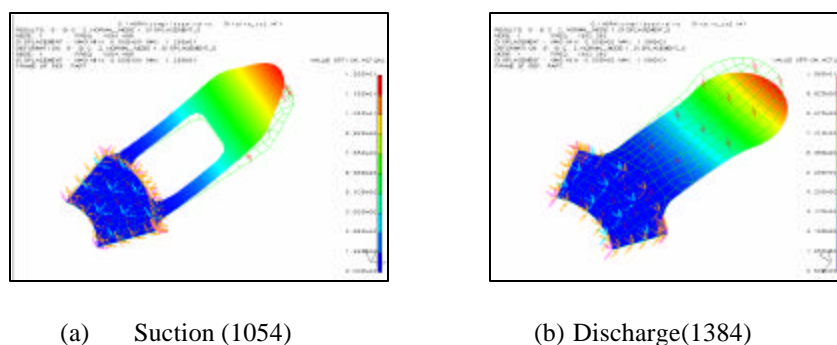


Figure 4: Natural frequency and Valve shape

3.2 Bending stress

When suction and discharge valve reach to stopper, its displacement is maximum. The bending stress is also calculated under this condition. Though contact and fatigue stress is more significant in value design, bending stress is also important design factor. For suction valve analysis, constraint condition is applied to contact area between valve plate and gasket. The loading is set for maximum displacement, where the pressure difference between suction chamber and cylinder is maximum value. After the performance simulation, the maximum pressure difference is determined to be 0.7 MPa. The loading condition for discharge valve is set to the maximum displacement where the end of valve reaches to retainer. The bending Stress distribution of suction valve is shown in figure 5.

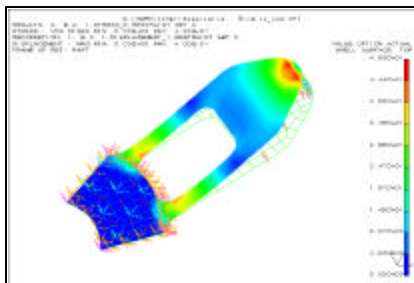


Figure 5: Bending stress of suction valve

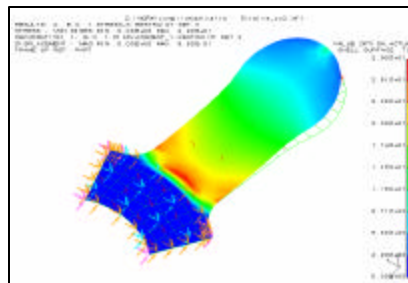


Figure 6: Bending stress of discharge valve

Maximum bending stress for suction valve resulted at $50 \text{ kg}/\text{mm}^2$, and stress is mainly distributed around valve root. It is slightly higher than the fatigue strength of material ($65 \text{ kg}/\text{mm}^2$). But, stress is usually higher right after valve opening and gets lowered as refrigerant enters from suction muffler to cylinder. Taking account this fact, we could conclude that suction valve is structurally safe. The bending stress distribution of suction valve is shown in figure 6. Its maximum bending stress is $40 \text{ kg}/\text{mm}^2$, and it lower than the fatigue strength of material.

3.3 Impact Fatigue

Most of reported cases for valve fracture, especially for discharge valve under high pressure, are due to impact fatigue. From the structural point of view, bending fatigue fracture is critical for the suction valve, and impact fatigue fracture is critical for the discharge valve. In this study, valve velocity at opening and closing is calculated by performance analysis at 5000rpm condition. Table 3 and figure 7 show the valve velocity results.

Table 3 Valve velocity at 5000 rpm

	Stopper height [mm]	Velocity [m/sec]	
		open	close
Suction	0.57	5.08	0.927
Discharge	0.5	5.58	1.69

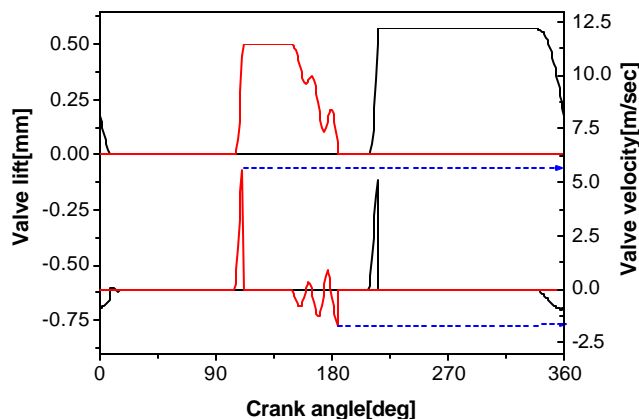
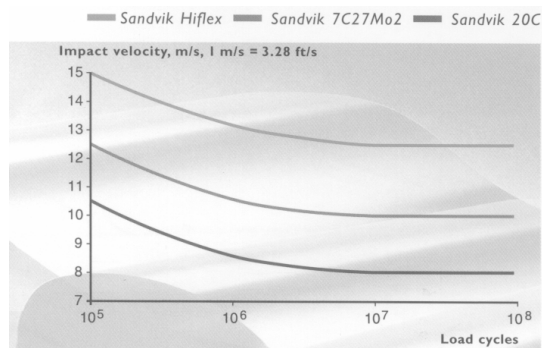


Figure 7 Valve velocity at 5000 rpm

To consider impact fatigue reliability, the above analysis result is compared with the material data. The impact fatigue of Sandvik 20C is listed in figure 8.

Figure 8 Impact Fatigue ⁽¹⁾

Though the analysis result (5.58 m/sec) at 5000rpm condition is lower than the material data (8 m/sec), we need to consider changing with new material with higher impact fatigue value to ensure impact fatigue reliability at higher driving condition

4. CONCLUSION

The finite element analysis is performed to determine the optimal design for suction and discharge valve of CO₂ compressor. At first, the optimal design target for volume efficiency is set by performance simulation. Then, design shape which converges to design target is obtained by several iterations of finite element analysis. As a result, optimal design shape with natural frequency and stress distribution, which ensures flexibility and reliability, is determined. But, new material needs to be considered for impact fatigue reliability at higher driving condition.

REFERENCE

1. Sandvik Material brochure, 2004.