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Bo Huang
huangb@shec.com.cn

Hao Yuan
Shanghai Highly Electrical Appliances Co., LTD., China, People's Republic of, yuanh1@shec.com.cn

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Noise And Cycle Performance Of A New Damping Valve For Compressor

Huang Bo, Yuan Hao

Shanghai Highly Electrical Appliances Co., Ltd.
Shanghai, China
Phone:+86 21 50554560*5340; E-mail: huangb@shec.com.cn

ABSTRACT

A new design of damping valve which contain two steel valve and one piece of silica gel is proposed in this paper. This new structure is considered effectively in the valve noise improvement especially in the mid-low speed which can lead the flutter response of valve. 6 case damping valves of different height are assembled in compressors. Noise and cycle performance experiments are carried out with the same working condition cases. One optimal damping valve is selected and its sound pressure level of compressor is gotten about 2dB improvement comparing with the traditional product in the mid-low speed as 3210rpm and 1380rpm. Meanwhile, cycle performance's result is at the same level with the traditional product.

1. INTRODUCTION

Valve noise is thought to be one of the most complicated noise inside compressor. Valve's movement locus can't be observed by regular equipment, so it's hard to give the improvement of valve noise by experiment method directly. Also, the temperature and pressure of refrigerant near the valve is different with irregular. Simulation method describes inaccuracy valve's movement and vibration form. Noise generated by valve is too difficult to monitor and improve. In this paper, valve's movement mechanism is introduced. The physical model based on the basic structure of the valve is established and differential equations of motion is derived. A serial of improved valves are designed and applied in compressors. Noise and cycle performance is compared with the traditional valve.

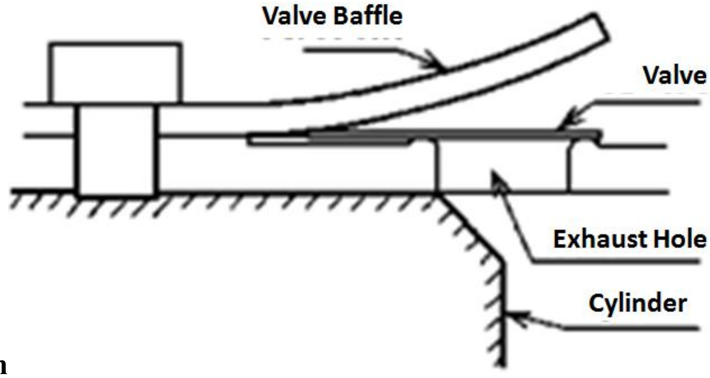
2. MOVEMENT MECHANISM OF VALVE

The panel flutter is a classical supersonic aeroelastic phenomenon on the valve of high-speed refrigerant fluid, which can lead the fatigue failure of the valve and a harmful influence on the cycle performance of compressor. The phenomenon is concerned to the special frequency which always correspond a rotating speed. In traditional fix-speed compressor, the rotating speed is constant. By adjusting the valve-assembly's property, the special rotating speed can be skipped to the normal movement situation. But in the inverter compressor, rotating speed covers a huge range, which makes the skipping process much harder.

2.1 Valve Assembly

The classical valve-assembly is shown in Figure 1 which contains valve baffle, valve, exhaust hole and cylinder. The refrigerant flow coming from the compress chamber is introduced to the exhaust hole. Huge pressure crushes the valve and lifts it up. After crushing, the valve falls down to the original position. In one cycle, the mechanical and aerodynamic noise is generated and radiating from the valve assembly. The height of valve lifting is decided by the valve's shape, valve's stiffness coefficient, refrigerant's pressure and so on. Of course there is no directly concern between valve's lifting height and noise. Valve baffle supply a limit height of lifting in case of valve cracking.

Figure 1: Valve-assembly



2.2 Movement Form

One cycle of valve lifting is containing three main process: rising, holding and falling. In the rising process, valve rises quickly to the highest position by the instant pressure. After a small moment of spring-back, the holding process is upcoming. In this period, the valve keep a position for a while until the pressure drops down. As pressure dropping down, the valve falls to the original position. Normally, it is suggested that valve is rising quickly to the holding position, keeping stable in the holding position, falling directly to the original position(Figure 2: Left chart). But in some case, the holding valve is not stable because of the flutter effect(Figure 2: Mid chart). Delay valve movement in the right side of Figure 2 means valve falls slowly to the original position, which is maybe caused by the weak stiffness of the valve.

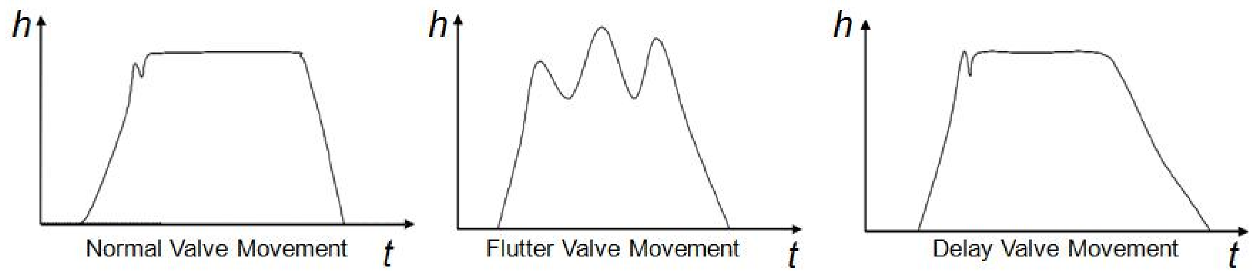


Figure 2: Three movement form

In the 3 cases of movement form, delay movement will affect the cycle performance due to the backflow when valve falls down. Flutter movement will affect not only the cycle performance because of the unstable refrigerant flow rate, but also the noise. Flutter valve will lead secondary aero-acoustic source. Flutter valve will impact the valve baffle which can generate mechanical noise. It should avoid or decrease the possibility for the flutter phenomenon when compressor is working.

2.2 Movement Model

A simplified vibration model is introduced in Figure 3. The vibration/movement form is represented by two springs, the upper and lower vibration of the spring response the valve in the vertical direction, and the other stands for the torsional motion. This model has two degrees of freedom and acts on G point of mass center. One is the vertical displacement h of the center of mass, the other is the angular displacement θ around the center of mass. E is the point of rigid center of the model, which is located in front of the center of mass.

It is easily introduced two-dimension valve's differential equation of flutter motion in generalized coordinate system:

$$\begin{bmatrix} m & 0 \\ 0 & J \end{bmatrix} \begin{Bmatrix} \ddot{h} \\ \ddot{\theta} \end{Bmatrix} + \begin{bmatrix} C_{11} & C_{12} \\ C_{21} & C_{22} \end{bmatrix} \begin{Bmatrix} \dot{h} \\ \dot{\theta} \end{Bmatrix} + \begin{bmatrix} K_h + K_{11} & -K_h x_e + K_{12} \\ -K_h x_e + K_{21} & K_h x_e{}^2 + K_{22} \end{bmatrix} \begin{Bmatrix} h \\ \theta \end{Bmatrix} = \begin{Bmatrix} 0 \\ 0 \end{Bmatrix} \tag{1}$$

Suppose:

$$M = \begin{bmatrix} m & 0 \\ 0 & J \end{bmatrix},\ C = \begin{bmatrix} C_{11} & C_{12} \\ C_{21} & C_{22} \end{bmatrix},\ \begin{Bmatrix} h \\ \theta \end{Bmatrix} = \begin{Bmatrix} h_0 \\ \theta_0 \end{Bmatrix} e^{pt},\ q_0 = \begin{Bmatrix} h_0 \\ \theta_0 \end{Bmatrix},\ S = \begin{bmatrix} K_h + K_{11} & -K_h x_e + K_{12} \\ -K_h x_e + K_{21} & K_h x_e{}^2 + K_{22} \end{bmatrix} \tag{2}$$

Simplify the equation (1):

$$\left[p^2M + pC + S\right]\{q_0\} = 0 \tag{3}$$

To make equation exist zero solution:

$$\left|p^2M + pC + S\right| = 0 \tag{4}$$

In equation (4), if make sure a bigger damping *C*, it is more possible to get the convergence solution.

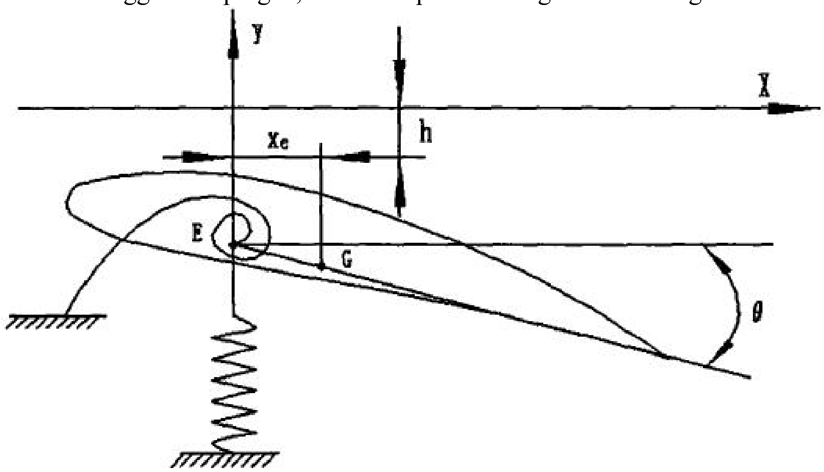


Figure 3: 2-Dimension vibration model of valve

3. Damping Valve And Its Performance

3.1 Damping Valve

In section 2, it is suggested a bigger damping *C*. So a damping valve is designed to optimize the noise generated by the compressor valve.

The shape of new damping valve is similar with the original valve. But in the section, it is composed by three layers(Figure 5). The first and the third layers are original valve, the second layer is the rubber made by damping material.

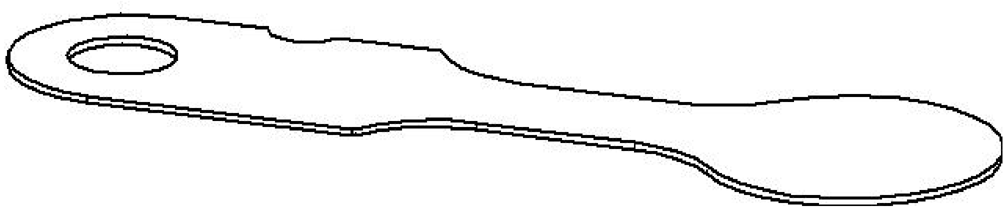


Figure 4: 3-Dimension model of valve

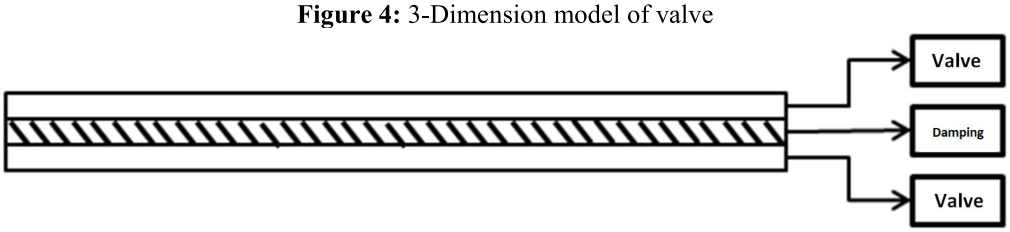


Figure 5: Section of damping valve

Several compressor using different height valve is testing the noise and cycle performance.

Case1: traditional sample 0.3mm valve;

Case2: 0.3mm valve+0.1mm damping+0.3mm valve

Case3: 0.3mm valve+0.1mm damping+0.2mm valve

Case4: 0.3mm valve+0.1mm damping+0.15mm valve

Case5: 0.2mm valve+0.1mm damping+0.2mm valve

Case6: 0.2mm valve+0.1mm damping+0.15mm valve

Case7: 0.15mm valve+0.1mm damping+0.15mm valve

3.2 Noise Performance

The noise test is carried to compare the noise performance for each cases. The test cycle condition is refer to the actual system for different rotating speed and they are same in different cases. Noise points are monitored around the compressor. The distance to the surface of compressor for both points is 1 meter.
The total noise shown on Figure 6

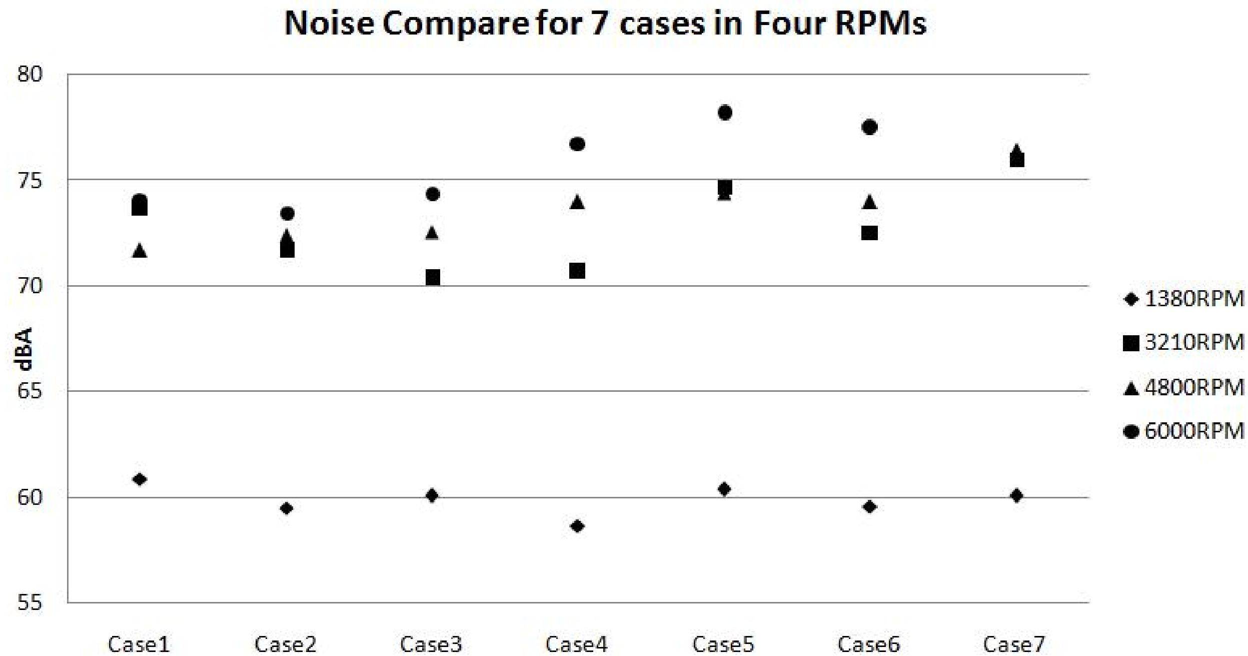
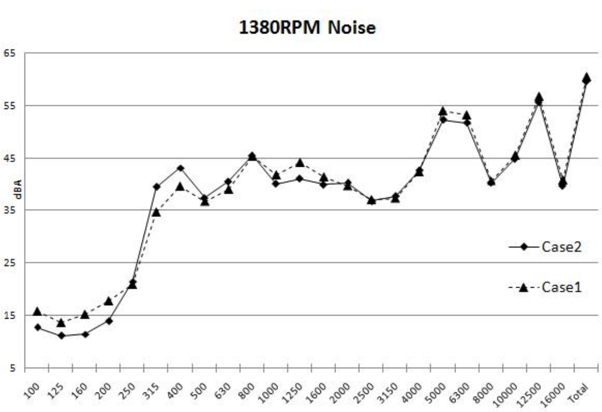
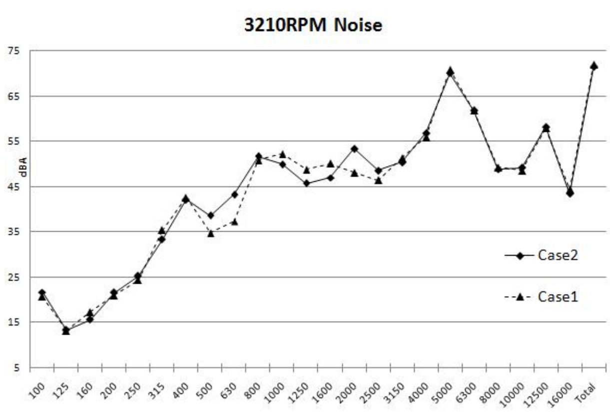


Figure 6: Total noise data for each cases in four operating condition

Case2 has a comprehensive improvement comparing the traditional product.
In lower rotating rpm(1380/3210rpm), total noise is improving comparing to the traditional product, maximum about 2dB. In higher rpm(4800/6000rpm), total noise is similar. The detail frequency is shown below. It is easily found 800-1600Hz, 5000-6300Hz is the main improving frequency range.





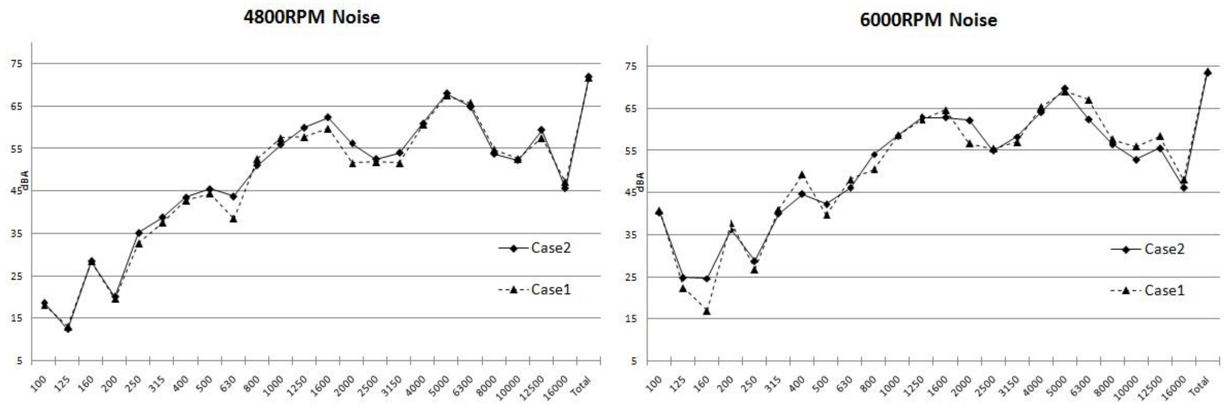


Figure 7: Noise spectrum(1/3 Octave) compare in four operating condition

3.3 Coefficient of Performance

Cycle performance is compared to check the COP coefficient. The operating conditions for different RPMs are in Table 1.

Parameter	Pd(MPa[abs])	Ps(MPa[abs])	Ts(℃)
1380RPM	2.41	1.22	30
3180RPM	2.69	1.023	20
6000RPM	3.431	0.638	6.1

Table 1

Refer the COP performance in Figure 9, case2 has the same level of COP in all rpm range compare with case1. Case4 has a bigger COP than case1.

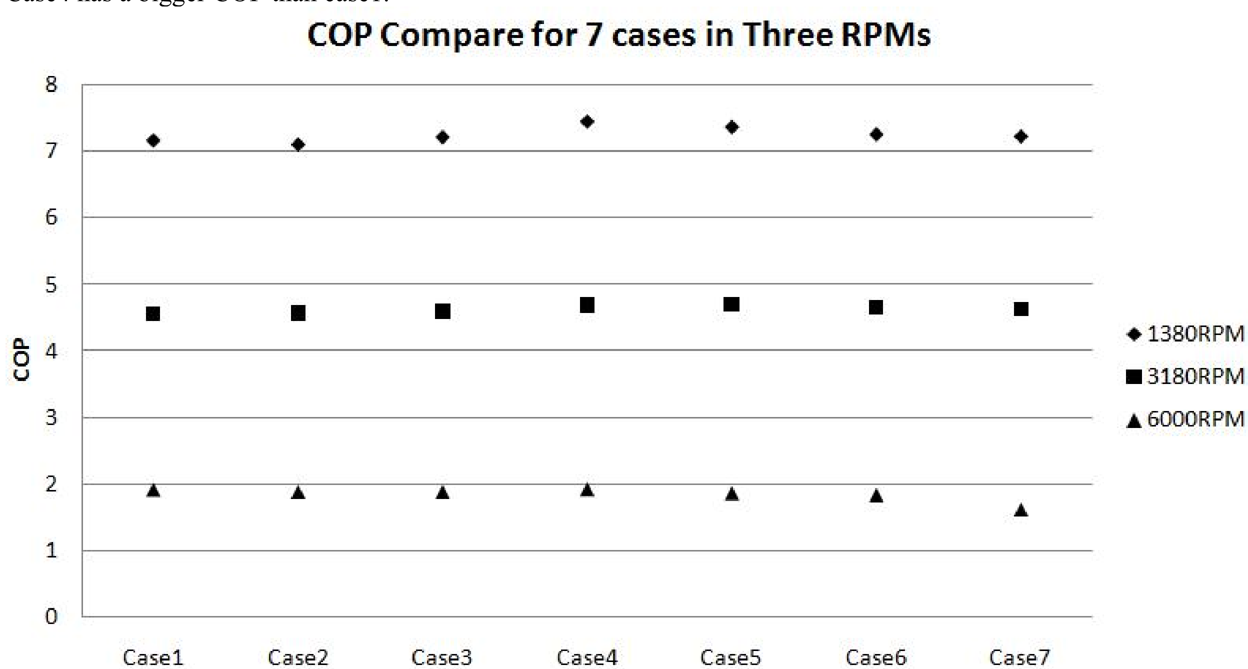


Figure 9: Total cycle performance data for each cases in three operating condition

4. CONCLUSIONS

The flutter noise in compressor valve is analyzed and derived the core parameter: the damping of valve. Using the damping valves will affect the noise and cycle performance.

In this paper, six cases of damping valves containing rigid valves with different height are designed to check the noise and cycle performance in different operating conditions. As analyzed in the paper, case2(0.3mm valve+0.1mm damping+0.3mm valve) has a better comprehensive noise performance while case4(0.3mm valve+0.1mm damping+0.15mm valve) has a better cycle performance.
Next, more combining forms of damping valves will be researched to find more methods to improve the noise.

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