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INVESTIGATION OF CHECK VALVE BEHAVIOR IN A SCROLL COMPRESSOR FOR NOISE

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ABSTRACT

In scroll compressors equipped with check valve which prevents the reverse rotation of scroll, check valve make a noise, so called shut down noise in case of power off. But check valve has two types of noise . One is shut down noise and the other is valve moving noise which generated by the movement of valve. Additionally valve movement noise is depends on the pressure ratio. For this reason, it is necessary to analyze the pattern of the flow which due to the geometry and valve movement in order to reduce the noise under operation.
This paper attempts to solve above two problems using CFD and visualization, and presents the results.

1. INTRODUCTION

The role of check valve in a scroll compressor is to control the reverse rotation of scroll counteraction of discharge pressure in case of power off. If power is shut off without check valve in a scroll compressor, reverse rotation will be continued during 8-12 seconds with accompanying very severe noise. This reverse rotation is due to the pressure difference between suction port and discharge port. Therefore reverse rotation continued until pressure balanced between two ports. If reverse rotation is permitted, damage to the compressor will be produced in the reason of insufficient lubrication, especially at scroll and old ham ring part. in case of power off, if severe damage were not occur, compressor will be produced unwanted loud noise. In this reason, check valve must be equipped with scroll compressor to prevent the reverse rotation. And check valve should be located in the flow line as close to the discharge port as possible.

There are several kinds of check valve in scroll compressor such as reed valve, free floating valve, cylinder valve, ball type valve, etc.. The characteristics of these valves are differ with each other and choices are depend upon the various condition, for example, reliability, productivity, cost, sensitivity of pressure, color of noise and main usage of scroll, etc.. This paper handles the free floating valve only, because of simplicity and productivity. The merits of this type of check valve are sensitivity of pressure pulsation and noise problem comparing other types. But it is very cheaper than any other one.

Discharge pressure pulsation are caused by compression mechanism of scroll. It makes some trouble at the check valve such as valve moving noise. Generally valve moving noise depends on the pressure ratio, which is the ratio of discharge pressure and suction pressure in compressor. To avoid the effect of fluctuation of pressure, check valve should be located at external of compressor or make some distance from discharge port and check valve will be considered. But the distance between check valve and discharge port makes some cavity of flow and then cavity makes shut down noise. So it is necessary to increase the pressure ratio which is the starting point of valve movement noise. In actual system, large pulsation is normally caused by over- or under-

compression condition, which will not happen at normal operation of compressor. Valve moving noise is severe in high pressure ratio and it accompanies with vibration. In this case, Large pulsation can cause the excitation of valve to the valve resulting in increase the noise and vibration.

This paper covers with check valve movement and environment condition and presents the process of control the shut down and valve movement through various analyses.

2. ANALYTICAL AND EXPERIMENTAL RESULTS

There are several papers that handle with theoretical investigation of free floating valve in a scroll compressor. Most of the analyses are consist with one degree of system and there are lots of assumptions in calculation. Therefore, these papers cannot overcome the assumption of analytical method of one degree of system such as damping and spring components. Especially, free floating type valve has a heavy correlation between valve characteristics and the gas pulsation. For this reason, the possibility of pressure pulsation and two kinds of valve noise problem will be analyzed and compared with experiments in this paper.

Shut Down : Fig.1 shows the pressure of discharge port of fixed scroll without check valve in case of power off .

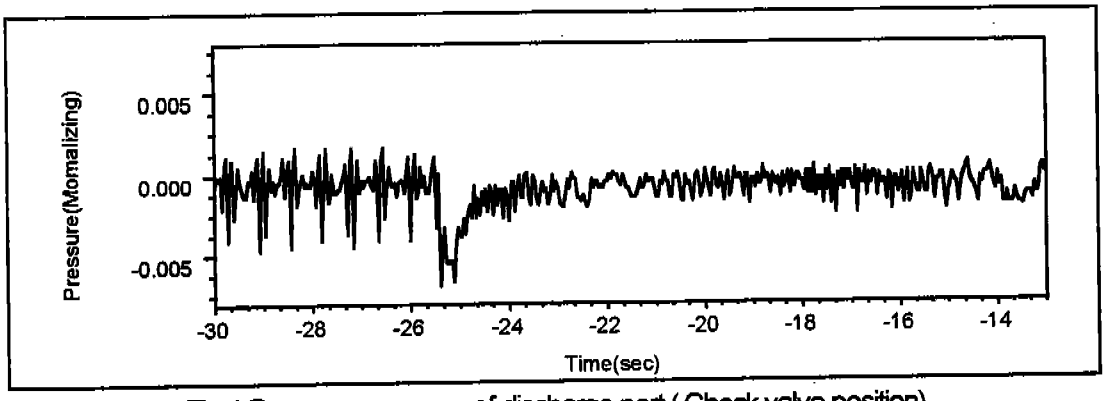


Fig.1 Pressure response of discharge port (Check valve position)

According to Fig.1, reverse rotation occurs for 12 second. But during first 0.31 seconds(called dead time), there is no reverse rotation. Next, 11 seconds have reverse rotation and then eventually the rotation is stopped. With closer view of pressure curve during dead time, the shapes curves are rippled with period of 0.0167 seconds. Where, it is possible to calculated the time to rotate of rotor having rotational inertia moment of scroll compressor using below equation(1) and (2).

$$T_c \cdot \varpi_0 = W_{input}\eta_m \qquad (1)$$

$$\ddot{\theta} = -T_c / I_R \qquad (2)$$

where, T_c is Torque, ϖ_o is angular velocity, W_{input} is input power, η_m is efficiency, $\ddot{\theta}$ is angular acceleration and I_r is rotational moment of inertia. Using equation (1) and (2), it can be deduced the rotational angle due to the inertia effect and then it can be calculate the revolution number.

Comp	*Input(Watt)*	*Efficiency*	ϖ_o (rad/sec)	T (Nm)	I_r (Nms^2)
2.5 Hp	2224	0.85	364	5.2	0.0017
3.0 Hp	2550	0.85	364	5.2	0.0018

Table.1 input data

Calculation was carried out based on Table.1 data. From this calculation, it is possible to get a revolution due to the inertia of rotational moment. In case of 2.5 Hp compressor, number of revolution until to stop is 3.48 and 3.5 Hp compressor has 3.22 . It means that the dead time is a kind of struggle time between inertial force of rotational and pressure difference as mentioned above. The force of pressure difference is bigger than the inertia force. If the compressor is controlled by inverter system, there is no problem because the inverter control the pressure difference and revolution and revolution, to put the inertia effect over the pressure difference effect. But fixed revolution compressor still has this problem. During dead time, pressure fluctuation is still going on with time step 0.0167 seconds. This time interval is equivalent to normal revolution interval. It needs to control the time control of valve closing time to avoid the shut down noise. This is the exact way of control to overcome the shut down noise. Among the dead time, only first 3 fluctuation is higher than the reverse rotation pressure which sustain the 0.048 sec, therefore this 0.048 second is critical time to control the shut down noise.

CFD program provides with transient time response against pulse input. With modified the geometry of discharge port of fixed scroll and space of valve chamber, and find the rapid decrease pressure curve can be obtained.

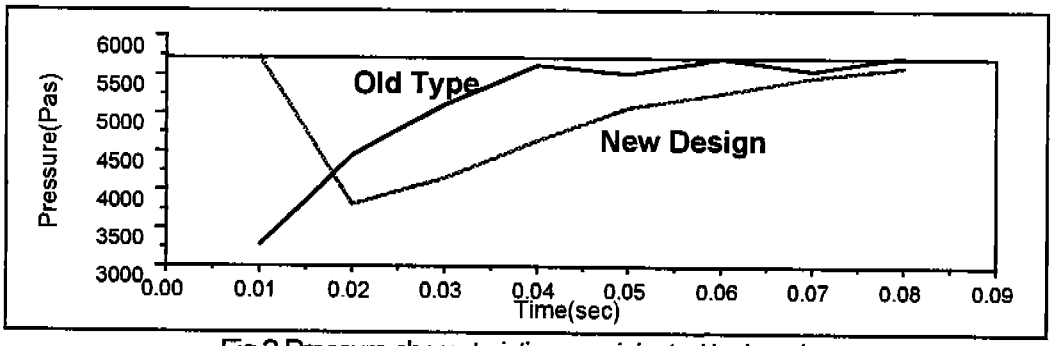


Fig.2 Pressure characteristic curve injected by impulse

Fig.2 shows the difference pressure characteristic curve between new design structure and old one and new one reveals a rapid decrease pattern. Using this changes of flow and geometry changes, a good result was obtained as following Fig.3. Left of Fig.3 is old model which produced shut down noise, right is improved model which is controlled shut down noise. X axis means the time and y axis mean the non-dimensional noise level in this figure.

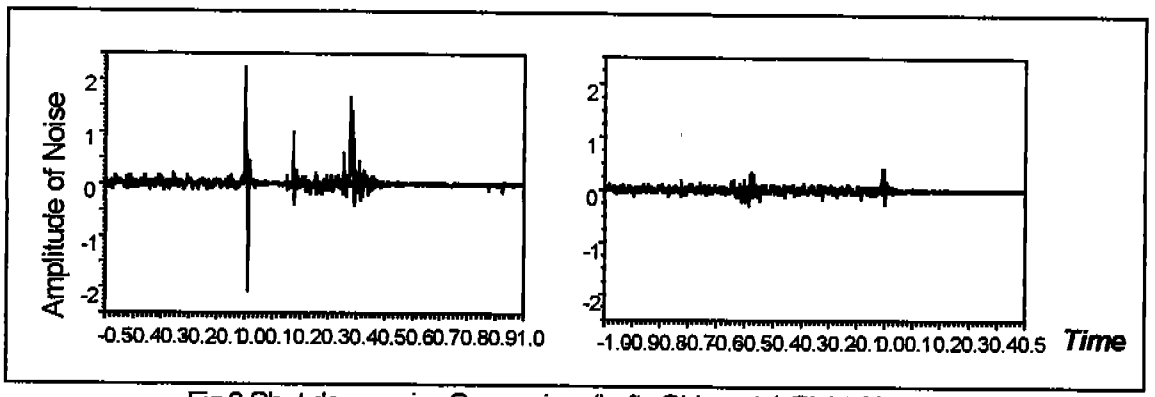


Fig.3 Shut down noise Comparison(Left : Old model, Right :New model)

Valve moving noise : Valve is very sensitive with the pressure fluctuation. So ,if a certain level of external excitation forces injected to the valve, valve is no longer stationary component and produced the noise and vibration which contacting the valve stopper. This noise and vibration is based on the instability of valve which

affected by pressure fluctuation. Pressure pulsation is not severe at low pressure ratio between suction port and discharge port. But high pressure ratio produce the severe pressure pulsation. In this reason, valve moving noise is highly related to the pressure ratio. In the normal condition of air-conditioner, it needs only about 5.5 pressure ratio for cooling system. Valve moving noise is not a performance problem but only noise problem. Fig.4 shows the characteristic of valve moving noise. X-axis means the time and y-axis means noise level. Left side of Fig.4 is the stationary noise without valve movement, and right side shows the valve moving noise. At that time, noise increased about 3-5 dB(A) or so. But as mentioned above, performance has no problem, therefore it is only product quality problem.

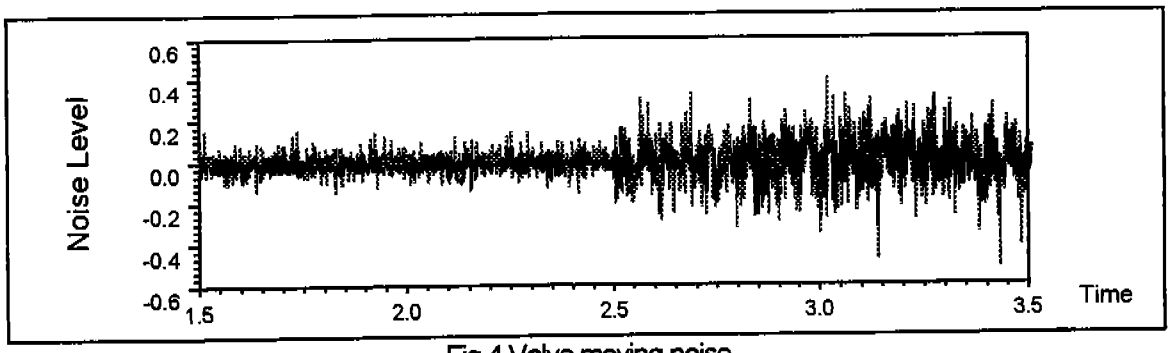


Fig.4 Valve moving noise

In order to increase the valve moving start pressure ratio, it is necessary to know the valve movement and pressure pulsation. Fig.5 shows pressure pulsation at the position of check valve. Y axis means dynamic pressure. Near the discharge port of fixed scroll is highly correlated with pressure pulsation and noise. From this aspect, it can be considered that contacting noise between valve and stopper is due to the pressure pulsation.

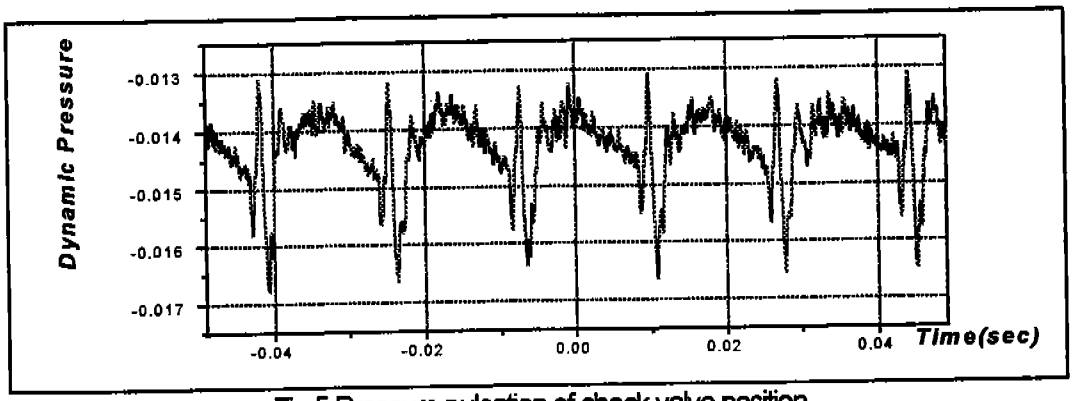


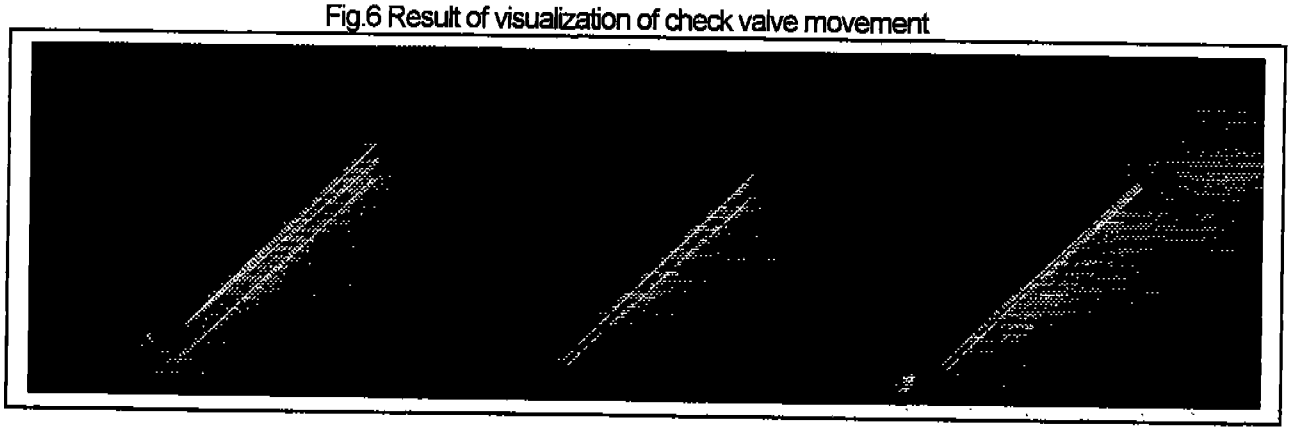
Fig.5 Pressure pulsation of check valve position

The difficulties of moving valve noise control is geometry restriction which will not affect shut down noise. Under this condition to Increase pressure ratio of valve moving point , it is need to investigate the movement of valve itself and valve environment al condition of valve, such as, which force is more effected to move the valve comparing any other components ?, or how to increase the contacting force between valve and stopper ?. To meet these needs, two methods are adopted, one is visualization and the other is CFD analysis. Visualization is mainly focused on the valve vibration at a certain pressure condition whilst CFD is focused to fine the valve environment analysis.

Visualization of valve motion : The motion of check valve was analyzed using PIV visualization method. PIV(Particle Imaging Velocimetry) is very helpful to know the vibration mode and movement because using AOM(Acoustic Optic Modulator) which makes a laser light sheet to fairy high sampling frequency . For this

experiment, PIV system was consist of 5 watt class of Argon laser, AOM, fiber optics, camera and bragg cell , and test compressor equipped with two small windows to endure the high pressure. One side of window was made for laser light illumination, the other was for the camera.

Fig.6 Result of visualization of check valve movement



Through the visualization, check valve shows two major motions. One is rotating mode and the other is up and down mode. Left side picture of Fig.6 shows the back hinged mode , and middle picture shows front hinged mode and right side picture shows up and down mode. Originally, one frame(1/30 second) have 4 images of picture and each picture have 2500 micro seconds interval. The time duration for illumination is 25 micro second every picture. From this information, it is possible to know the velocity of valve and mode of motion. Speed of up and down motion shows maximum 1.8 meter per second and rotation velocity shows maximum 194 radian per second.

According to the many papers which cover with valve problem, they use only one degree of freedom system and they considered normal force of valve surface. But, considering the visualization results, it is not sufficient analysis. Because valve has rotating and up-down mode. This motion of check valve present the excitation force. It means that rotating mode came from rotational excitation force and also up-down mode came from normal excitation force of valve surface.

CFD(Computational Fluid Dynamics) : It is very difficult to estimate the force of excitation. But using CFD analysis of valve environment, minimum information about excitation forced will be obtained.

The CFD program used here was Fluent. All analysis in this paper used a steady state assumption with stationary boundaries. Though Fluent has some limited capability for modeling moving boundaries, the motion of check valve was not to practical. Nonetheless, estimation of excitation forces using steady assumptions with stationary boundaries would also expected to verify the component of excitation force. It was decided to concentrate on one point in discharge process. The point were selected at the maximum flow rate which is expected through the discharge port of fixed scroll. Three dimensional volume grids were built above mentioned point during the cycle time.

The results of CFD analysis represent existence of two external excitation force. One is the normal excitation force of valve surface(called as vertical excitation force). This excitation force originated by fixed scroll discharge port and directly affected pressure pulsation. The role of this component is very important under operation. It is true that this force produce the contacting force between valve and stopper. Pressure ratio of valve movement is low if this excitation force is weak. The other excitation force is rotational force originated by check valve space. Rotational excitation force is as strong as vertical excitation force. Rotational excitation force depends on the volume of valve space and volume rate of discharge.

Solving of valve movement : Valve moving noise is depends on the pressure ratio. Also, pressure ratio is depends on the pressure pulsation and two excitation forces. Geometry changes analysis using CFD was concentrated to increasing the vertical excitation force. Next, with combined analysis according to the shapes of valve and valve stopper, it is possible to reduce the rotational excitation force. The major key parameters are :

1. Width relationship between valve and stopper
2. Radial distance of valve cavity
3. Size of valve cavity
4. Volume reduction ratio

Optimizing with above parameters, it is available to increase the pressure ratio up to 10.5 without shut down noise.

3.SUMMARY

Check valve and stopper was modified to reduce shut down and valve moving noise. All the process of this research is based on the visualization and pressure measurement. Through the whole step, free floating type valve analysis recommend to do the 2-degree of freedom analysis include vertical excitation and rotational excitation force. Finally, all the parameter was chosen by the concept of 2-degree of freedom. These data and simulation results will be helpful to develop the a new check valve.

Reference

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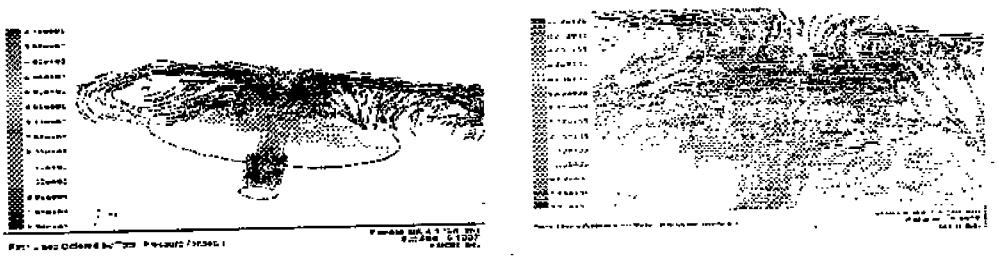

Fig.7 CFD results of valve chamber