2008

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ABSTRACT

It is well known that the compressor with variable capacities has a higher efficiency than the typical single capacity compressors for the air-conditioner system. Therefore, many compressor makers are trying to develop variable types of capacity-controlling compressors, one of which is a vane locking controlled rotary compressor. This paper investigates the rotary compressor using a vane controlling method to verify a motion of the vane according to a controlling signal, which is triggered by the discharge and suction pressure from a certain location of air control cycle. From this investigation, the vane movements and the pressure of related of it are measured to find out how many times a vane is collided with an opposite object that is roller or cylinder. The results of this test give a solution to minimize the number of collision times, which improves the life reliability and reduces the undesired noise.

1. INTRODUCTION

For the rotary compressor with capacity modulation by a vane control, the first needs to be considered is the unwanted impulsive noise, which is generated by collision between a vane and a rolling piston for full cooling capacity operation and between a vane and a cylinder for part capacity operation when it collides to a rolling piston for full capacity operating modulation. Reducing this impulsive noise is very critical to the life reliability and commerciogenic value. For this paper, only the impulsive noise of full load modulation due to its higher level, which is can be strongly noticed by a bare ear during development of this system, comparing to the level of part load modulation.
The specification of the compressor is described in Table 1, and the modulation method of a vane control compressor is shown in Figure. 1

Table 1: The compressor specification

Capacity	36KBtu/h @Full, 18KBtu/h @Part
Refrigerant	R410A
RPM	60Hz, Single Speed
Capacity control pump	Upper pump

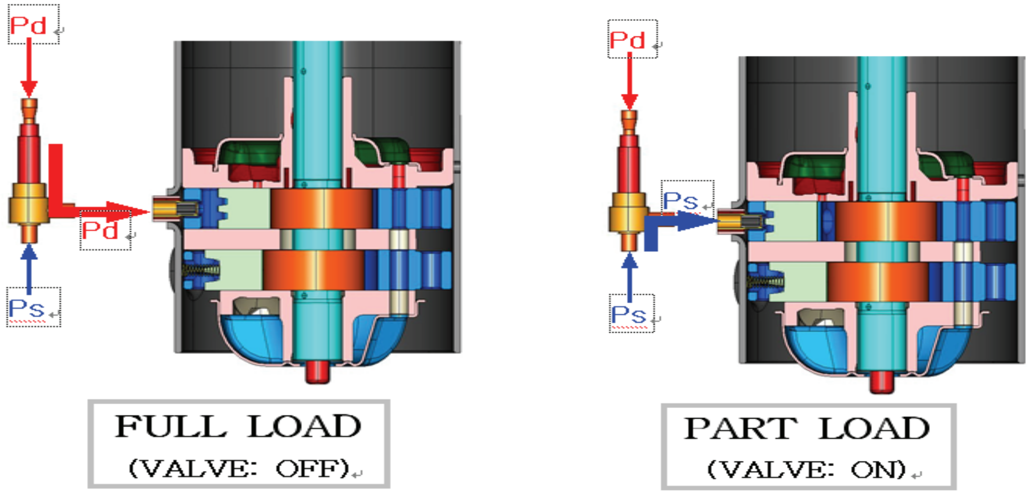

Figure 1: Modulation method by pressure applied to the vane chamber

2. DEFINING AN IMPULSIVE NOISE LEVEL

The capacity modulation by mechanical operation with collision can reduce the life reliability of whole compressor system. When the pressure applied to chamber of the backside of a vane, the collision between a vane and a rolling piston occurs and the moment is described in the figure1, which shows the randomized rotating angular position of the first collision happens. Therefore the level impulsive noises are varied according to at each case that some are acceptable and some are not. To evaluate these noise levels, a new specification should be designed and decide how low level is acceptable for this case. According to the ISO 7779 that is about the measurement of airborne noise emitted by information technology and telecommunications equipment, the impulsive noise is clearly defined. For this standard, the difference in decibels between the time averaged A-weighted impulse sound pressure level, L_{pAI}, and the A-weighted sound pressure level, L_{pA}, should be obtained. The difference ($L_{pAI} - L_{pA}$) is the impulsive parameter, ΔL_I. If $\Delta L_I > 3$ dB the noise is considered to be impulsive. (ECMA-74, 2005) This ISO is considered to be very suitable for the compressor with vane controlled capacity modulation to make a permissible impulsive noise peak level, which is applied to the goal how much modulation noise level to be obtained for the commercialization. Figure 2 describes the difference ($L_{pAI} - L_{pA}$).

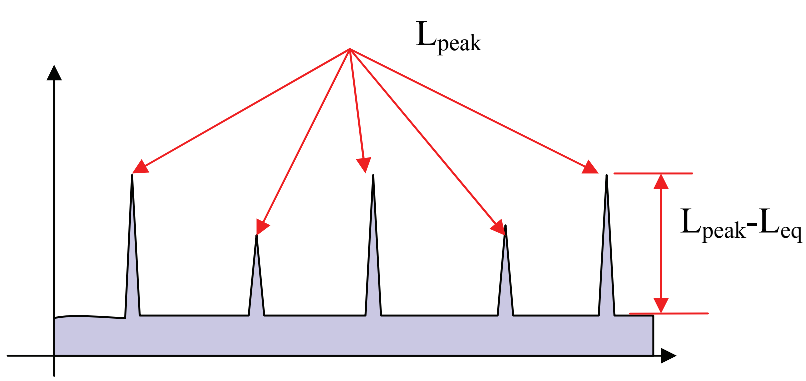

Figure 2: Impulsive noise definition, L_{peak}-L_{eq}

To reduce the difference ($L_{pAI} - L_{pA}$) less than 3dBA, all the possible factors that contribute to the impulsive noise for the full load operating modulation are classified and the mechanical parameters of these are modified to retrieve which factors are applicable to the system.

3. STUDYING POTENTIAL FACTORS

The five potential factors affecting modulation noise that is generated by the collision between roller and vane are listed in the next. Those factors are selected due to their contribution to the vane and roller motion.

- **The mass of Vane**: Supposing that the acceleration of vane is constant when it is loaded to the roller, the heavier it is, the more force it can get. Therefore the lighter vane with reducing thickness than before can be of advantage to reducing impulsive noise
- **Loading moment according to the roller position**: According to the figure 3, if there exists the same vector directional component of vane loading as the rolling piston in certain moment, the impulsive force is possibly lower than the moment when the opposite directional vector component exists that causes a head-on collision. As shown in graph, a vane is loaded randomly, but usually between 180 and 360 degree. Ideally, the impulsive noise can be minimized when the first loading contact encountered as vane is chasing the rolling piston behind of it with same speed right after the rolling piston passing the vane slot which is shown in Figure 4 at near 0 degree. However, managing this condition requires control system for a valve, which applies pressure to a chamber behind the vane, and sensing method to detect the angular position of a rolling piston. Furthermore, the controller and sensor are supposed to be synchronized to be operated at the moment when the vane is loaded to the rolling piston. Due to this reason, designing this system is almost impractical for a compressor. However, if there is a very economic method for this operation possible, that will be the best one for reducing impulsive noise.
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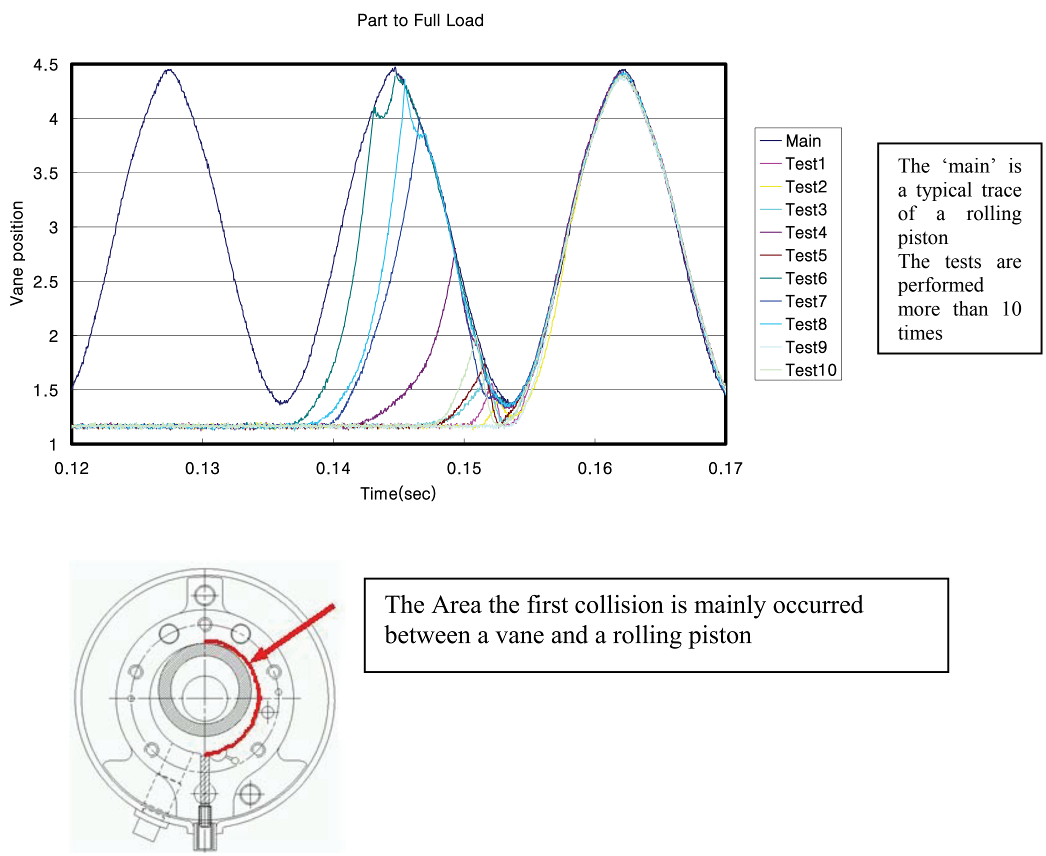

Figure 3: The trace of a vane loading to the rolling piston

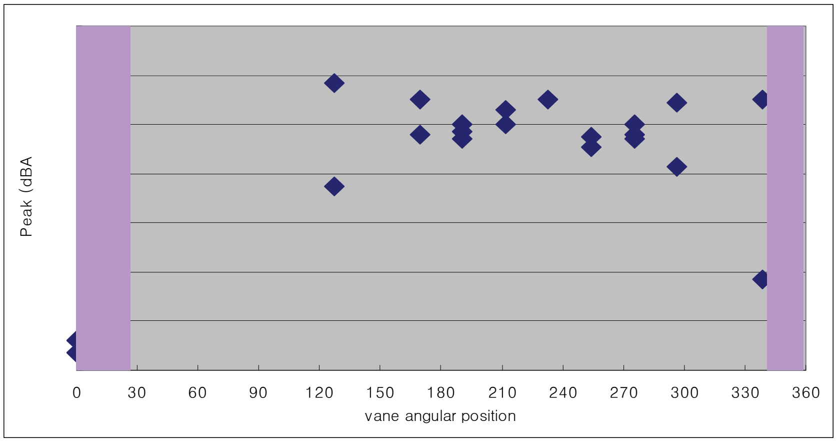

Figure 4: Impulsive noise level measured according to the angular position of rolling position from the vane slot.

- **Vane loading pressure**: Another factor contributing to the vane loading force is the pressure level applied to the chamber behind the vane. The lower the pressure is applied, the lower force is applied to the vane and the acceleration of it to the rolling piston is also lowered, which helps to reduce the impulsive noise level. Therefore, the sub factors affect the pressure level and acceleration of vane are supposed to be considered and those are the force from a magnet and the diameter of pipe, which are explained in the next two factors...
- **Magnet force**: When the vane is unloaded, it is supposed be hidden and settled inside of vane slot. To help the vane fixed at part load operation without any unstable behavior making noise caused by cyclic collision between rolling piston and cylinder, strong magnet is applied inside of vane slot to hold the vane. If magnet is very strong and requires very high pressure to deploy the vane from it to the rolling piston, the higher pressure should be applied to the chamber the vane settled in order to have enough force the vane can just about to move. This condition can lead the vane to have a high acceleration to the rolling piston resulting in high impulsive noise by collision. Therefore, the lower magnetic force the magnet has the lower acceleration the vane can have after the separation from the magnet. Lowering the acceleration of vane loading can reduce the impulsive noise due to the lower force pushing the vane. However, if the magnet force is too low to hold the vane right after the part load operation initiated, the vane can hit the cylinder and rolling piston and make repetitive noise called 'chattering'. In conclusion, the optimized size of magnet should be considered between lowering acceleration of vane for the loading and stable settlement of it for unloading operation. The magnetic force can be calculated by the equation as shown in Figure 5. (Magnet Sales & Manufacturing Inc, 1995)
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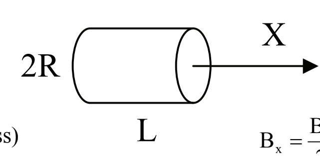
Magnet force

$$F = 0.577B^2A$$

where F : force(pounds), B : flux density(Kilogauss)
A : pole area (square inches)



$$B_x = \frac{B_r}{2}\left(\frac{(L+X)}{\sqrt{R^2+(L+X)^2}} - \frac{X}{\sqrt{R^2+X^2}}\right)$$

Figure 5: Calculation of Magnetic Force

- **Diameter of pipe**: The high discharge pressure is used vane loaded to the rolling piston. If the high pressure supplies to the chamber before vane to move separated from the magnet, all the force from the pressure would be transferred to the vane and the its impulsive noise can make as much. Therefore, if the time that takes the pressure to fill the chamber is delayed, the pressure inside of the chamber can increase slowly and reaches the separable limit for the vane from the magnet. Before the pressure reaches maximum, the vane begin to move to the rolling piston with minimized impulsive noise generating.

4. EXPERIMENTAL EVALUATIONS AND RESULTS

When the 0.8mm of vane thickness is reduced, this leads to 20% of mass reduction, the impulsive noise decreases as much as about 5dBA.
The Figure 6 shows the test result of impulsive noise reduction according to the diameter of the magnet. The magnet has Niobium composition and the magnet force decreases as the diameter reduced p9 to p7, which leads to improvement of impulsive noise reduction as much as 4dBA.
The Figure 6 shows the effect of the diameter of the pipe. To modify the diameter of the pipe, several diameters of wire are inserted to reduce the hydraulic diameter of the pipe to find the optimal size.

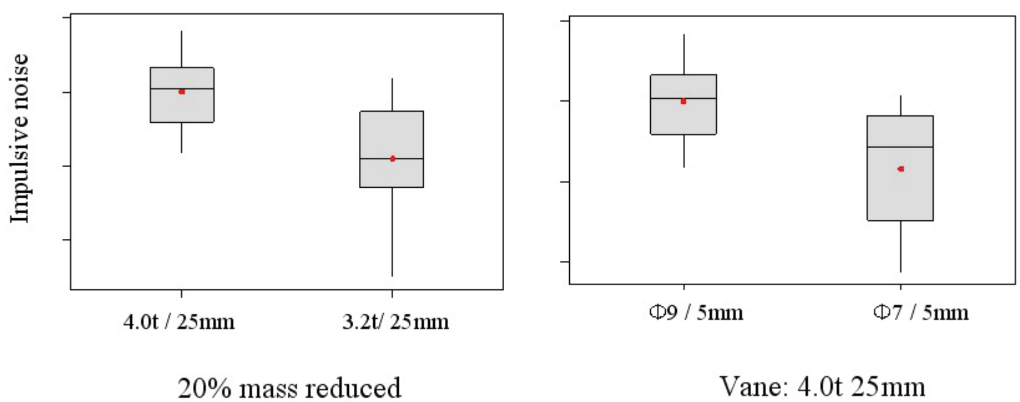


Figure 6: Impulsive noise reduction by modifying the mass of vane and the diameter of magnet

The diameter of the pipe connected to the chamber placed behind of the vane is modified to increase the flow resistance, which delays the time to reach the maximum pressure and vane begins to move with as low pressure as possible. By this modification, the impulsive noise by loading is decreased as much as 6dBA shown in Figure 7 which is one of the experimental results by reducing 7.5% of area of inner circle of the pipe. When the final diameter is decided, that diameter can be applied to the proper location inside or outside of a compressor.

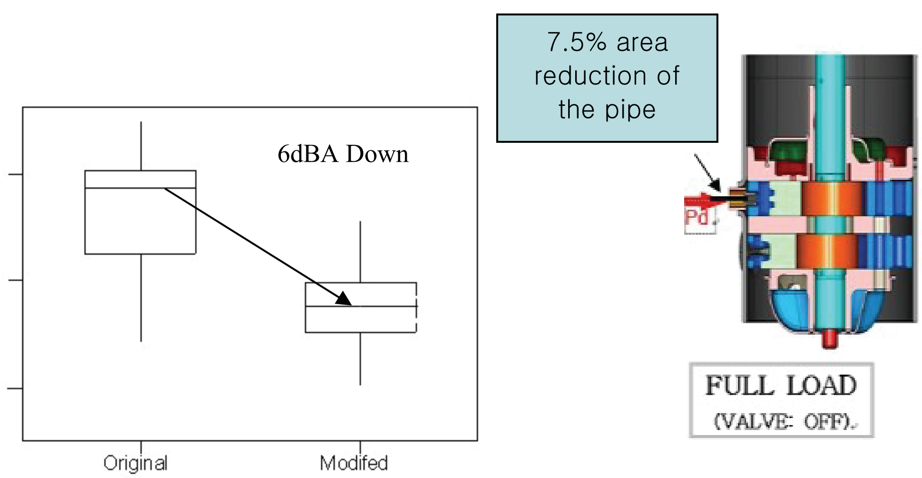


Figure 7: The effect from the diameter of pipe for the impulsive noise

By the experiments performed above, the three factors, which are the mass of a vane, the magnetic force and the diameter of a pipe, are known to be critical and effective in reducing the impulsive noise. From this result, the combinations of these three optimal factors are applied to the compressor developed to have a low capacity modulation noise.
The comparison between the compressors with optimized specification and without it is shown in Table.2.

Table2: Optimized specification of the compressor

Factors	Modification	-
Vane	4t to 3.2t	Mass reduction 20%
Magnet	Φ9mm to Φ7mm	Magnet force reduction 25%
Pressure and Flow rate control	Reduced diameter of Pipe connected to the vane chamber	D=1.3mm wire inserted 35% area reduction
Cylinder vane hole Diameter	D=1mm	-

The compressor with improved modulation noise performance is applied to the air conditioning system, and evaluated under the real use condition of both heating and cooling. The impulsive noise is successfully masked by the noise from the fan of outdoor unit tested, and the difference ($L_{pAI} - L_{pA}$) is less than 2.2dBA that is less than 3dBA expected as a goal. Actually the modulation noise is hardly noticed with an ear.

5. CONCLUSIONS

- For the compressor with capacity modulation by controlling motion of a vane, impulsive noise is evaluated by ISO, which defines impulsive noise by 3dBA limit according to the stable environmental noise
- The mass of a vane, a magnetic force and the pressure of vane chamber located in behind of it are the key factors to be dealt with to reduce impulsive noise.
- By optimization of key factors, the impulsive noise could be controlled within 3dBA difference from the stable operating noise level.
- The air-conditioning system with the compressor optimized has an impulsive noise with less than 3dBA difference according to ($L_{pAI} - L_{pA}$) relationship and it is hardly noticed with an ear.

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