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STUDY ON COMPRESSOR PERFORMANCE WITH THE ORIFICE SHAPE OF A COMPRESSOR SUCTION VALVE

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ABSTRACT

Household refrigerators consume a lot of power. This power consumption causes not only environmental problems but also energy reduction problems. Therefore, this paper was aimed to optimize the performance of the compressor which consumes the most power in the refrigerator. For this, the performance of the refrigerator according to the suction orifice shape was examined using the 3D rigid valve model. As a result, increasing the number of suction orifices increases the cooling capacity by up to 1.3% and increases the EER by 0.13.

Keywords: refrigerator compressor, suction orifice, cooling capacity, compressor work, EER

INTRODUCTION

The energy consumption efficiency of the refrigeration cycle is important because about 6% of the total power consumption at home is caused by the refrigerator. The ratio of household refrigerators to household power consumption is 14.2% in Japan, 14% in the United States and 21% in Korea [1]. This is because Korea is using the second refrigerator Kimchi refrigerator.

Over the past decade, much research has been done to reduce the energy consumption of refrigerators. Aprea *et al*. [2] reduced the energy consumption of the refrigeration cycle by 9% using the mixed refrigerant HFO134z. In addition, Lloyd *et al*. [3, 4] studied the changes in refrigerator energy consumption according to room temperature to reduce energy consumption. In addition, a method for effectively removing frost during defrosting process was proposed.

Compressors account for 80% of the power consumption of the refrigerator. Therefore, it is important to increase the compressor efficiency to effectively reduce the energy consumption of the refrigerator. Ozsipahi *et al.* [5] studied the lubrication system to improve the efficiency of reciprocating compressors. In addition, Abdalla *et al*. [6, 7] studied a linear compressor with less energy consumption and friction loss and less vibration noise than reciprocating compressors. Recently, studies on oil-free linear compressors that do not use oil have been continued [8, 9].

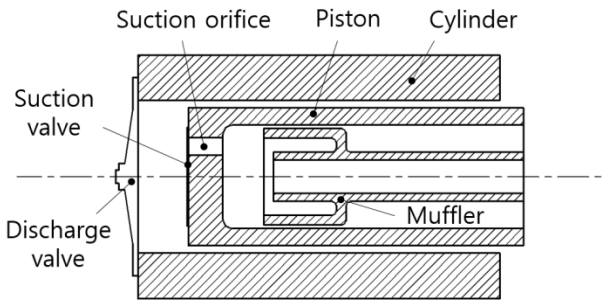


Figure-1. Schematic of a linear compressor.

Figure-1 is a schematic view of a linear compressor. The refrigerant passes through the muffler and suction port and through the suction valve to the compression chamber.

The refrigerant is compressed from the compression chamber to a high temperature and a high pressure, and is discharged to the discharge chamber through the discharge valve. Therefore, the valve used in the compressor is an important factor for determining the compressor efficiency. Woo *et al.* [10] conducted a study on reliability when the suction reed valve of a compressor was subjected to repetitive pressure loading. The failure rate and durability of the reciprocating compressor were confirmed through this study. Hwang *et al.* [11] compared and analyzed the discharge valve behavior of the linear compressor using FSI model and rigid body model. Park *et al.* [12] performed the compressor cycle analysis considering the valve behavior of the linear compressor. As a result, much research has been conducted on valves for improving compressor efficiency. However, the research on the optimization of the suction system of the linear compressor is still insufficient.

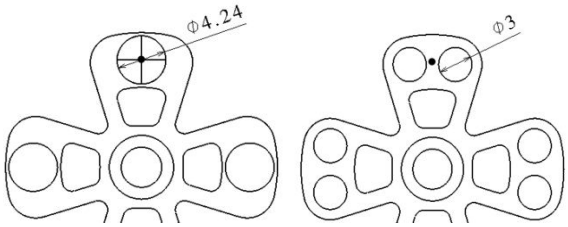
Therefore, in this paper, the total orifice area is kept constant and the number of orifices is changed. Through this, the valve head, compressor work, cooling capacity and EER change were investigated and the shape of the suction orifice was optimized.

NUMERICAL ANALYSIS METHODS

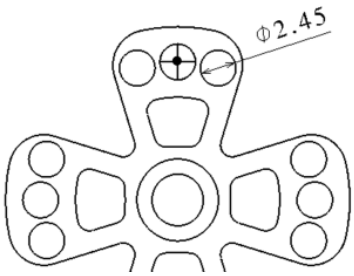
Stiffness of suction valve

Figure-2 shows the shape of the suction valve according to the number of suction orifices. In all three cases, the total orifice area is equal to 14.1 mm^2. Figure-3 shows the restraint condition for the structural analysis of the suction valve. Each suction orifice was subjected to a pressure of 0 to 5 kPa. The fixed position of the screw is given as a fixed boundary condition, and the strain of the valve is shown in Figure-3 reference points. The material of the suction valve is Sandvik 20C [13].

The stiffness of the suction valve was determined using the deformation amount of the suction valve and the



(a) Case 1(one orifice) (b) Case 2 (two orifices)



(c) Case 3 (three orifices)

Figure-2. Schematic of suction valves.

vibration equation of Equation (1). In addition, the natural frequency (f) of the suction valve is obtained by modal analysis, and the effective mass (m_e) and damping coefficient of the suction valve are obtained using equation

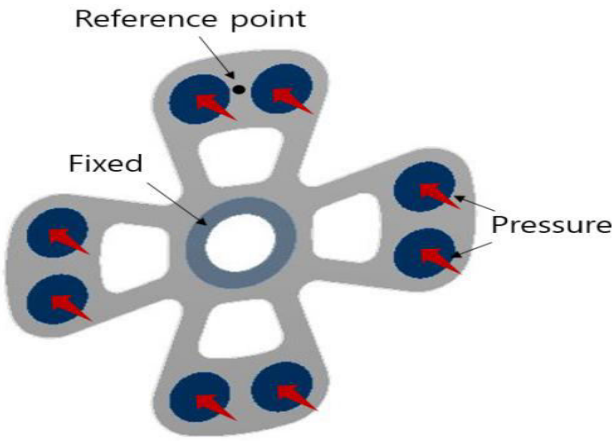


Figure-3. Constraints for the structure analysis of the suction valve.

$$F = m_e\ddot{x} + c\dot{x} + kx \tag{1}$$

$$m_e = \frac{k}{(2\pi f)^2} \tag{2}$$

$$c = \zeta\sqrt{m_e k} \tag{3}$$

Table-1. Valve stiffness, effective mass and damping coefficient of the suction valve according to the number of suction orifices.

Model	Stiffness	Effective mass	Damping coefficient
Case 1	118.5 N/m	1.945E-05 kg	0.9601E-02
Case 2	125.0 N/m	2.052E-05 kg	1.0131E-02
Case 3	126.5 N/m	2.076E-05 kg	1.0249E-02

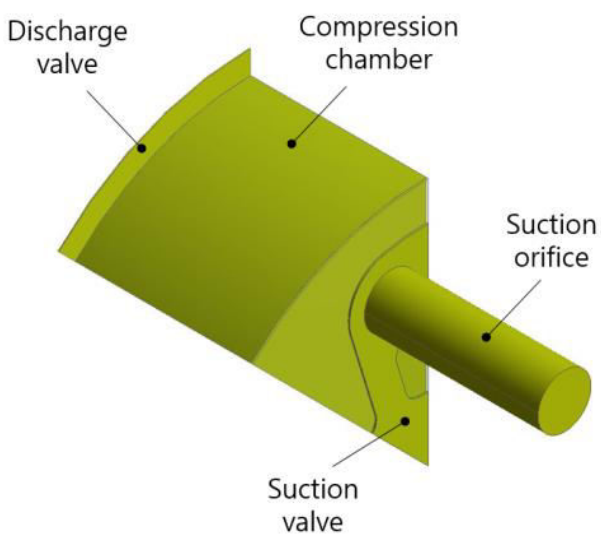


Figure-4. 3D rigid valve model (1/8).

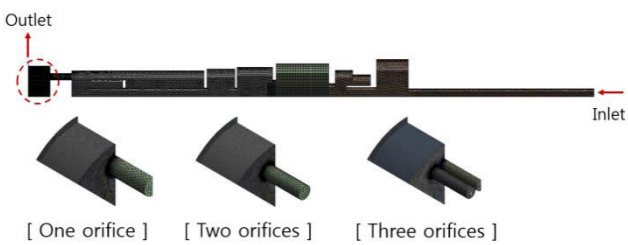


Figure-5. Mesh system for 3D rigid vale models.

(2) and equation (3). At this time, the natural frequency is 392.8 Hz and the damping ratio (ζ) is 1.

Table-1 shows the stiffness, effective mass and damping coefficient for each model. The stiffness of case 1 decreased 5.2% compared to case 2, and the stiffness of case 3 increased by 1.2% compared to case 2. The effective mass and damping coefficient changes according to the model are also similar to the stiffness variation.

3D rigid valve model

Figure-4 represents a part of the 3D rigid valve model. In order to shorten the analysis time, the whole 1/8 model was used for the analysis. The 3D rigid valve model consists of a suction orifice, a suction valve, a compression chamber, and a discharge valve. The height of the fluid gap was 0.06 mm for the discharge valve and 0.1 mm for the suction valve. For the rigid body model, the analysis time was about 5 hours per cycle.

Figure-5 shows the lattice system of the 3D valve model according to the suction orifice shape. At this time, the mesh number is about 180, 000. The CFD analysis of the 3D valve model was performed using Fluent [14]. The suction valve and the discharge valve each used a rigid body model. Piston behavior is described using UDF (User Defined Function).

RESULTS AND DISCUSSIONS

Variation of valve lift according to stiffness

Figure-6 shows the variation of suction valve deformation when the pressure of 0 ~ 5kPa is given to the suction orifice. The valve deformation is linearly proportional to the force and the slope of this straight line represents the stiffness of the suction valve. The stiffness

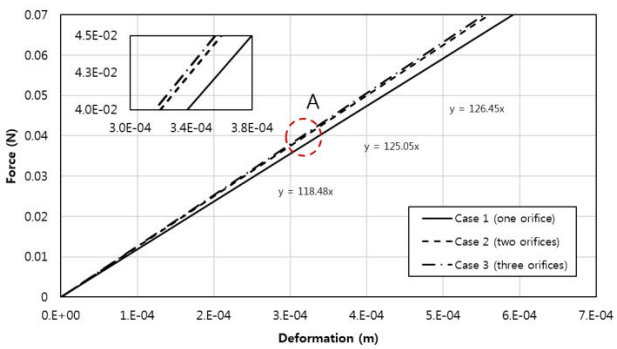


Figure-6. Valve stiffness with model.

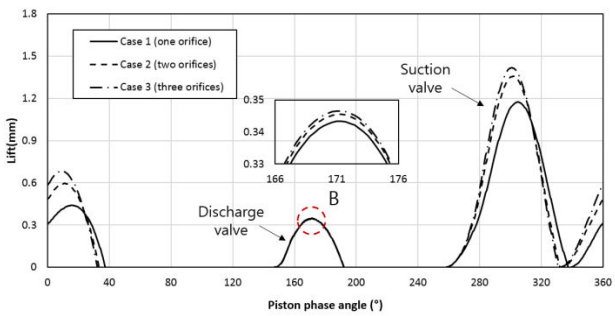


Figure-7. Variation of valve lift with model.

of case 1 was the lowest and the difference of stiffness between case 2 and case 3 was insignificant.

Figure-7 shows the change in the valve lift according to the piston phase angle. First, the suctionvalv-

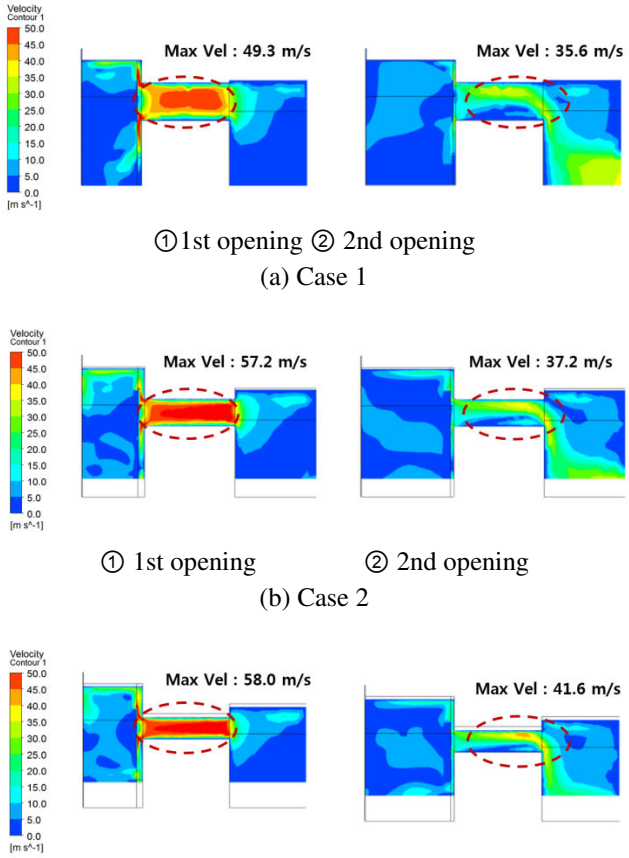


Figure-8. Velocity contours with the number of suction orifices.

e opens twice for one cycle, which is related to the natural frequency of the suction valve. In the case of suction valves, valve lift increases as the number of orifices increases. However, the difference between case 2 and case 3 is not relatively large. The discharge valve is opened once per cycle. In addition, the valve lift difference shows little change depending on the model. However, it can be seen that when the variation of the head valve of the discharge valve is enlarged, it is small, but the head increases as the number of orifices increases. This is due to the fact that as the number of orifices increases, the stiffness also increases.

Figure-8 shows the refrigerant velocity contours at the first valve opening and the second valve opening. The orifice velocity of case 3 during the first valve opening showed the highest velocity of 58m/s. Also, during the second valve opening, the highest velocity of 41.6m/s was observed for case 3.

Cooling capacity, compressor work and energy efficiency ratio

Figure-9 represents the mass flow rate of the suction valve according to the piston phase angle. The higher the number of Suction orifices, the sooner the peak mass flow rate is reached. This is due to the fact that the timing of the maximum lift of the suction valve is

advanced. As the mass flow rate reaches its peak, the total mass flow rate also increases.

Figure-10 shows the P-V diagram according to the number of suction orifices. Depending on the number of orifices, compression days do not change significantly. However, it can be seen that the suction pressure increases slightly when the number of suction orifices increases in the suction process.

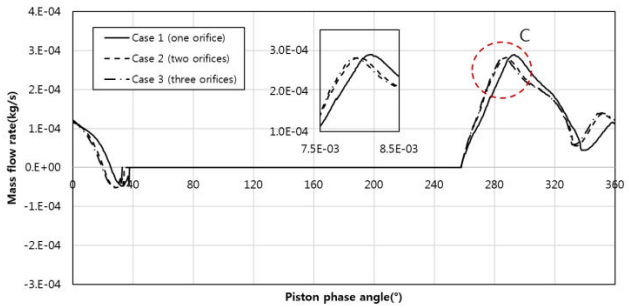


Figure-9. Variation of mass flow rate with piston phase angle for 3 models.

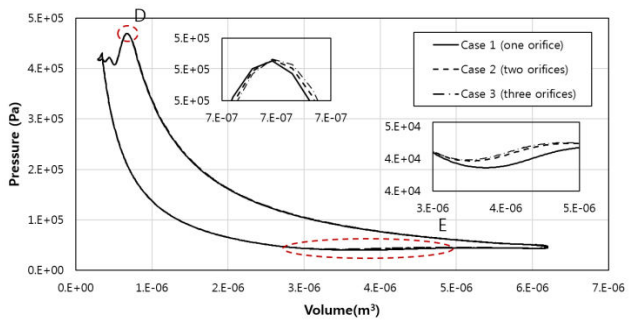
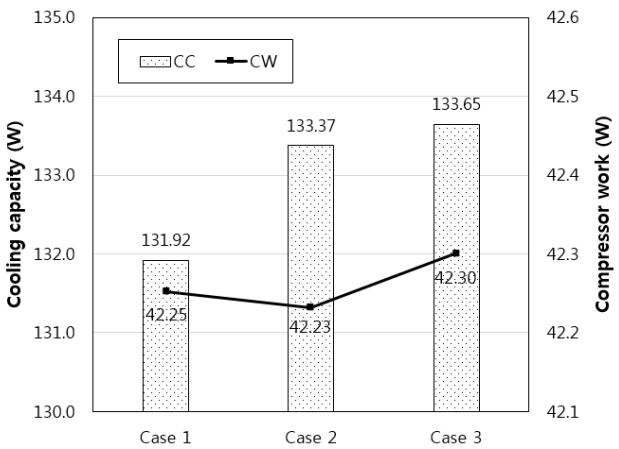
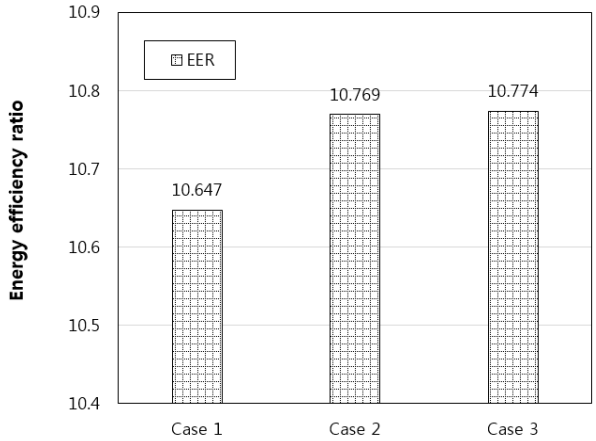


Figure-10. Pressure - Volume diagrams for 3 models.



(a) Cooling capacity and compressor work



(b) Energy efficiency ratio

Figure-11. CC, CW, EER for 3 models.

Figure-11 shows the cooling capacity (CC) and compressor work (CW), and energy efficiency ratio (EER) according to the number of suction orifices. Cooling capacity is the largest in case 3, but little difference from case 2. In case 1, the least cooling capacity is due to the minimum valve lift. Case 3 has the largest compression, but the actual difference is small for all three models. This is because there is little difference in the PV diagram. Therefore, there is almost no change in compression days, and case 3 is the highest in cooling capacity, so EER is also the highest in case 3. Case 3 is about 1.2% higher than EER of case 1.

CONCLUSIONS

In this paper, the performance of the compressor according to the number of orifices is investigated through CFD while maintaining the total area of the suction orifices constant. The conclusions of this study are as follows.

a) As the number of suction orifices increases, the deformation at the reference point decreases. However, the valve stiffness, the damping coefficient and the valve effective mass increase with increasing suction orifice number.
b) As the number of orifices increases, the valve lift increases which enhances the refrigerant mass flow rate into the compression chamber.
c) The cooling capacity of case 3 increased by 1.73W compared to case 1, but the change in compressor work was insignificant. Thus, EER of case 3 is improved by 0.13 compared to case 1.

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REFERENCES

[1] S. Y. Choi, U. M. Han, H. H. Cho, H. S. Lee. 2018. Review: Recent advances in household refrigerator cycle technologies. Applied Thermal Engineering. 132: 560-574.

[2] C. Aprea, A. Greco, A. Maiorino, C. Masselli.2018. The drop-in of HFC134a with HFO1234ze in a household refrigerator. International Journal of Thermal Sciences. 127: 117-125.

[3] H. Lloyd, A. Lu, F. Bob. 2018. Impact of room temperature on energy consumption of household refrigerators: Lessons from analysis of field and laboratory data. Applied Energy. 211: 346-357.

[4] H. Lloyd, A. Lu, F. Bob. 2018. Energy impacts of defrosting in household refrigerators: Lesson from field and laboratory measurements. International Journal of Refrigeration. 86: 480-494.

[5] M. Ozsipahi, S. Cadirci, H. Gunes, K. Sarioglu, H. Kerpicci. 2014. A numerical study on the lubrication system for a hermetic reciprocating compressor used in household refrigerators. International Journal of Refrigeration. 48: 210-220.

[6] I. I. Abdalla, T. Ibrahim and N. M. Nor. 2013. Linear permanent magnet motor for reciprocating compressor applications. International Power Engineering and Optimization Conference. 29-34.

[7] I. Abdalla, T. Ibrahim, N. M. Nor. 2016. Development and optimization of a moving-magnet tubular linear permanent magnet motor for use in a reciprocating compressor of household refrigerators. Electrical Power and Energy Systems. 77: 263-270.

[8] I. Jomde, A. Anderson, V. Bhojwani, S. Kedia, N. Jangale, K. Kolas, P. Khedkar. 2018. Modeling and measurement of a moving coil oil-free linear compressor performance for refrigeration application using R134a. International Journal of Refrigeration. 88: 182-194.

[9] K. Liang. 2018. Analysis of oil-free linear compressor operated at high pressure ratios for household refrigeration. Energy. 151: 324-331.

[10] S. W. Woo, D. L. O'Neal, M. Pecht. 2010. Reliability design of a reciprocating compressor suction reed valve in a common refrigerator subjected to repetitive pressure loads. Engineering Failure Analysis. 17: 979-991.

[11] I. S. Hwang, S. J. Park, W. S. Oh, Y. L. Lee. 2017. Linear compressor discharge valve behavior using a rigid body valve model and a FSI valve model. International Journal of Refrigeration. 82: 509-519.

[12] S. J. Park, I. S. Hwang, W. S. Oh and Y. L. Lee. 2017. A study on cycle performance variation of a linear compressor considering valve behavior. Journal of Mechanical Science and Technology. 31(9): 4481-4488.

[13] Y. S. Lee and S. K. Son. 2018. Study on fatigue strength of a suction flapper valve used in a high efficient reciprocating compressor. International compressor engineering conference at Purdue.

[14] Ansys Fluent 15, Ansys Inc. 2014.