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Jang Moo Lee
Seoul National University

Byoung Cheol Kim
Daewoo Electronic Co. Ltd.

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A STUDY ON THE CAVITY RESONANCE OF A COMPRESSOR

Jang Moo Lee , Professor in Dept. of Mechanical
Design & Production Engineering
in Seoul National University
Byoung Cheol Kim , Jaehoon Song
Engineer
Daewoo Electronic Co. Ltd.
604, Yong Hyun-Dong,
Nam-Gu, Incheon,
KOREA

ABSTRACT

The cavity resonance problem of compressors has been studied for years by many researchers. But only the analytical solution for the simple shape, for example, annular cylinder, or Finite Element Analysis for simple modeling has been considered. This paper approaches the cavity resonance problem by FEM and experiment. FEM was used both for the simple modeling and fine modeling to the real compressor cavity in ADINAT program. The result of the simple modeling and fine modeling was compared and the convergence to the actual state was checked.

For the verification of the result from the FEM, cavity resonance experiment was carried out. Comparison and analysis of the results from two approaches are shown in this paper.

The fact that cavity resonance problem has an effect on the noise spectrum under operation and that the natural frequency of a compressor can be changed continuously with temperature was investigated in this paper.

INTRODUCTION

Household electronic goods, including the refrigerator, are required to be made more silent. Fig.1 shows noise sources interconnected paths through which the sound energy can reach the shell and its possible countermeasures. As can be seen from the Fig.1, there are many noise sources and complicated paths. Thus, reducing the compressor noise has been an important but difficult problem. This report offers some basic information of noise characteristics of compressor focused on the cavity resonance. Cavity resonance affects broad ranges of noise spectrum. But the influence of cavity resonance on low frequency - up to 500 Hz - is so evident, and this study investigate this phenomenon theoritically and experimentally.

ANALYSIS AND EXPERIMENT OF CAVITY RESONANCE

When a certain volume of fluid or gas is surrounded by a wall that has an arbitrary shape, there exist natural frequencies causing resonance of that volume. For example, if the length of one dimensional pipe coincides with a multiple of a certain wavelength, the pipe resonates. In the same way, we can solve for the cavity resonance frequency of rectangular parallelpiped volume with its side lengths l_x , l_y , l_z as follows.

$$f_n = \frac{c}{2}\sqrt{\left(\frac{n_x}{l_x}\right)^2 + \left(\frac{n_y}{l_y}\right)^2 + \left(\frac{n_z}{l_z}\right)^2}$$

$c = \sqrt{\gamma RT}$: speed of sound

$n_x , n_y , n_z = 0, 1, 2, \cdots$

In general, the natural frequency of cavity is the function of volume, shape, pressure and temperature. In the noise problem of compressor, if the cavity frequency coincides with the driving frequency, the compressor will generate loud noise.

1) Modelling of Compressor Cavity and its Results

Under the assumption of homogeneity, isotropic conditions and medium, small oscillation, if one ignore the effects of viscosity and thermal conductivity, one can get the linearized wave equations for the propagation of sound in fluids from the state equation, linearized conductivity equation, and linearized force equation as follows.

$$\nabla^2 p = \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2}$$

In case of solid boundary, the boundary equation is as follows.

$$\frac{\partial p}{\partial n} = 0$$

where ∇^2 is Laplacian, c the speed of sound of fluid, and $\partial p/\partial n$ the pressure gradient of normal direction to boundary surface.

From the above two equations, one can solve the general three dimensional cavity problem. By using the separation of variables, we can get the following Helmholtz's equation can be obtained.

$$\nabla^2 p + \left(\frac{\omega}{c}\right)^2 p = 0$$

In order to solve this equation in case of arbitrary 3-dimensional shape, the FEM(Finite Element Method) can be used. The matrix equation of node pressure is as follows.

$$([K_a] + i\omega[D_a] - \omega^2[M_a])\{p\} = \{0\}$$

where $[K_a]$, $[D_a]$, $[M_a]$ are the acoustics stiffness, damping, and mass matrix respectively.

Using the analogy of wave equation and heat transfer equation, the authors made use of ADINAT program, usually used for solving the heat transfer problem, in order to analyze the cavity problem.

Fig.2 shows the inside of reciprocating compressor. For the analysis of this complex shape of cavity, FEM was performed both for the simple modeling and fine modeling. The simple modeling idealized the compressor as two equivalent cylinders while the fine modelling took into account the asymmetric geometry of the compressor.

Fig.3 shows the simplified modeling of cavity and its results - the first six models and natural frequencies - are presented in Fig.4. This one half of the cavity having 67 nodes and 28 elements is modeled by symmetric property. The results of this simplified modeling was found to be incorrect as will be shown in the latter section.

To revise the simple model and its results, the cavity was modelled finely and its shape is shown in Fig.5. To avoid confusion of the drawing, the partitioned state of the cavity modeling is presented in Fig.6 and it shows cylinder and muffler side, frame side, and motor side respectively. It is composed of 516 nodes and 160 elements and the results are shown in Fig.7. As shown in the results, one can find that all the nodal surfaces are not actually a horizontal or vertical surface as shown in the result of simple modeling. It is distorted because the fine modeling is calculated with complex inner shape (mechanical part). It was also found that the first and second modes of simple model are changed to the second and first modes of fine model respectively. The reason for this result is this : in the simple model the inner boundary of cavity - mechanical and motor part - is considered to be a cylinder, in other words, it is linearized in vertical direction. So the effective length of this direction is shortened. And the natural frequency of (0 0 1) mode is calculated higher than real natural frequency of that mode.

2) Experiments and its Results

a) Cavity resonance experiment

For the comparison with the results of Finite Element Method, experiments were carried out. Fig.8 shows the experimental set up for cavity resonance. 1/2 inch microphones were mounted on one inside and the other outside of compressor. The authors swept the frequency of sound using the function generator, and FFT divides the sound pressure of microphone B by that of microphone A. By repeating this execution at many other points of compressor (41 points), the natural frequency and mode shape were obtained. The arrangement of this experiment is shown in Fig.9 and the results are shown in Fig.10.

The real compressor is filled with Freon gas. Since it is hard to perform this experiment surrounded by Freon gas, the air was used. The natural frequency was converted considering the ratio of sound speed of Freon and air (Freon : 161m/sec, air : 340m/sec).

It was found that the results agree with the results of FEM agree with that of experiments on the whole. Table.1 shows the comparison of the results of FEM with that of experiment. According to this comparison, the 1, 8, 9, 10th frequency of FEM are higher than horizontal modal surface, this modes have horizontal nodal surface, (so the sound pressure oscillates vertically). In FEM all the boundaries are assumed to be solid boundaries, but in the actual state, the lower boundary is oil surface that is more flexible than other boundaries, i.e., the compressor case which is made of steel.

Therefore, the frequencies of modes that have horizontal nodal surface was calculated higher in FEM. Also, considering that in general natural frequency by FEM is calculated higher than real natural frequency, the results of this research is considered to be reasonable.

b) The change of compressor natural frequency

After turning on the refrigerator, the temperature of compressor will increase. When the temperature reaches at $70^{o}C$, the first acoustics natural frequency of the compressor is 472.5Hz as shown in Fig.11 (horizontal impact and pick up). This frequency coincides with the harmonics of driving frequency of compressor - 58.75Hz - so this becomes one major factor of noise problem.

On the other hand, the natural frequency decreases with time lapse as shown in Fig.12. This phenomenon implies that 470Hz is not the natural frequency of structure but the cavity resonance frequency. The cavity resonance frequency is proportional to the speed of sound which is proportional to the square root of temperature. So, the cavity frequency is calculated 420Hz at room temperature, and this was verified by the impulse test as shown in Fig.12.

The results of the same natural frequency measurement with vertical impulse and vertical pick-up are shown in Fig.13. It decreases from 385Hz to 360Hz.

This horizontal and vertical mode are (1 1 0) and (0 0 1) mode in the preceding section respectively. Fig.14 and Table.2 shows that the vibration pick-up point in the compressor and acceleration magnitude under operation. The result of this testing also shows the (1 1 0) mode and (0 0 1) mode.

Fig.15 is the vibration and sound spectra from the compressor right after turning one refrigerator at room temperature every 4 minutes. The accelleration is picked at the vertical side of the compressor and the sound is measured at the 20cm back of the refrigerator. These spectra show the transition of peak from 420Hz to 470Hz with time increasing. This measurement states that the natural frequency changes with temperature of compressor as mentioned previously.

c) Proposal for countermeasure of cavity resonance

As discribed in the preceding section, the compressor under investigation is not so good for noise problem, and thus it is necessary to improve this situation. To change the cavity resonance frequency, the temperature, pressure or shape of the compressor should be changed. But the temperature or pressure change has delicate influence on the capacity and performance of the compressor, so the shape of the cavity is to be changed.

First, the authors performed cavity resonance experiment with blockade, which made of paper and clay, between the mechanical part and the shell as shown in Fig.16. Fig.17 (a) and (b) show the spectrum change with one blockade and two respectively.

Second, the authors stuck clay to the inside of top case ($60cm^3$ volume), and performed the same experiment. It shows the change of spectrum from 995Hz to 980Hz as shown in Fig.18. This change is equivalent to 7Hz in Freon atmosphere. It was also found that the spectrum change when the clay was added to the stator part.

These countermeasures may be able to present some proposal for improvement of cavity resonance , but more research is required to reduce the noise of compressor significantly and practically.

CONCLUSION

In this paper, some information about noise characteristics of refrigerator compressor concentrated on cavity resonance are offered. The cavity between mechanical part and shell structure is analyzed by the use of FEM. It was found that simple modeling is convenient but fine modeling (which takes into account the asymmetric geometry) should sometimes be carried out as in this case. Cavity resonance experiment was performed for the compressor to compare the experimental results with that of the FEM. More studies are needed to analyze this complex boundary condition and vibration-sound coupled condition. The fact that the natural frequencies of the noise spectrum can be changed by cavity resonance is presented by numerical analysis and experiments in this paper.

REFERENCES

1. Takashi Matsuzaka, "Analysis of Cavity Resonance in 5HP Hermetic Reciprocating Compressor with Elliptical Shell.", Proc. 1983 Purdue Comp. Tech. Conf.

2. Kiyoshi Sano, "Analysis of Hermetic Rolling Piston Type Compressor Noise, and Countermeasures.",
3. Tim Sisson, and Fran Simpson, "Analysis and Control of Hermetic Compressor Sound Power Levels.", Journal of Sound and Vibration, 1983
4. K. Tojo, S. Machioa, and S. Saegusa, "Noise Reduction of Refrigeration Compressor.", Proc. 1980 Purdue Comp. Tech. Conf.
5. J. E. Manning, and G. Maidanik, "Radiation Properties of Cylindrical Shells.", Journal of Acoust. Soc. Am. 36, 1964

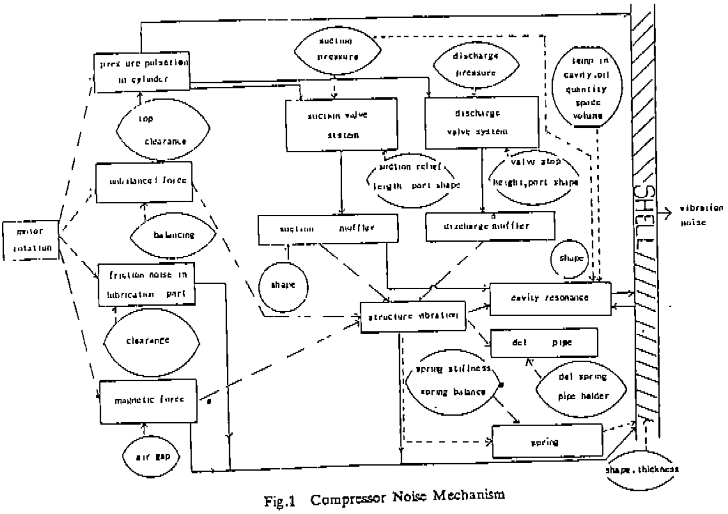


Fig.1 Compressor Noise Mechanism

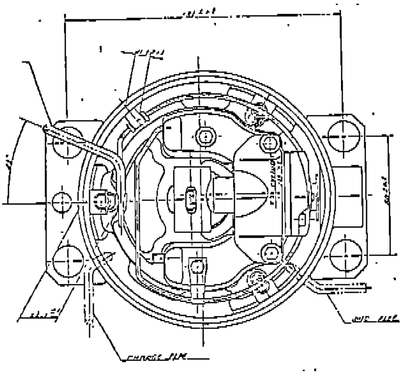


Fig.2 Reciprocating Compressor

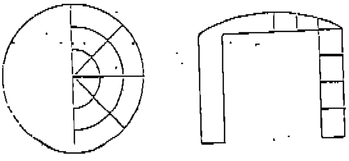


Fig.3 Simplified Cavity Modeling

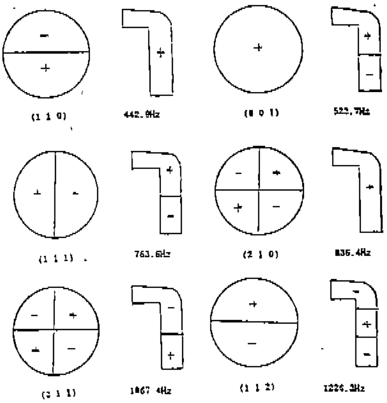


Fig.4 Natural Frequeny and Mode Shape (Simple Model)

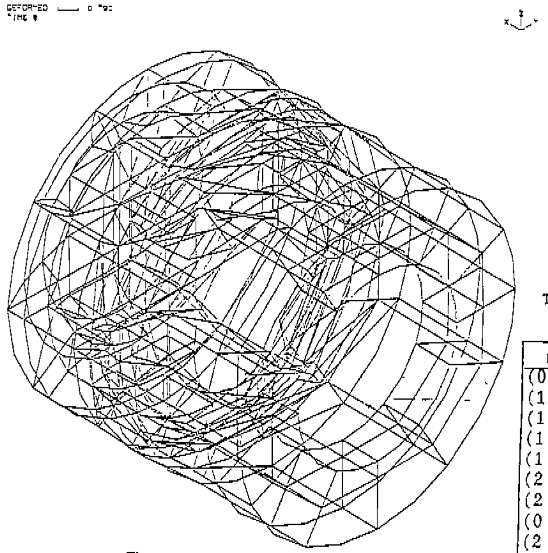


Fig.5 Compressor Cavity Modeling

Table 1 Natural Frequency Comparison of FEM and Experiment

mode	ADINAT	Experiment
(0 0 1)	403	385
(1 1 0)	449	447
(1 1 0)	472	468
(1 1 1)	703	700
(1 1 1)	734	723
(2 1 0)	835	835
(2 1 0)	885	895
(0 0 2)	911	794
(2 1 1)	1059	954
(2 1 1)	1064	977

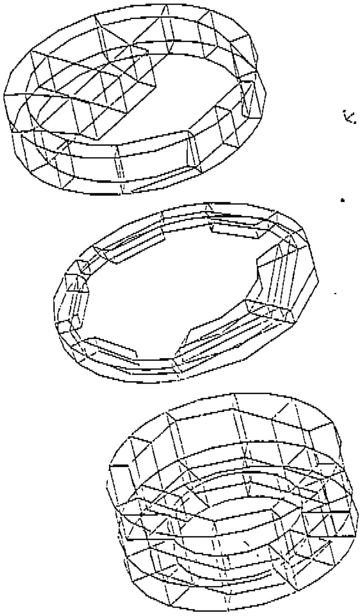
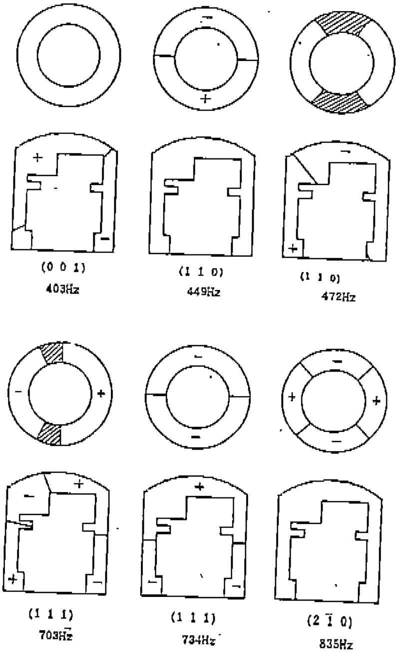


Fig.6 Compressor Cavity Modeling



(0 0 1) 403Hz

(1 1 0) 449Hz

(1 1 0) 472Hz

(1 1 1) 703Hz

(1 1 1) 734Hz

(2 $\bar{1}$ 0) 835Hz

Fig.7 Natural Frequencies and Mode Shapes (FEM)

Table 2 Acceleration Magnitude During Operation

Circumferential			Axial		
position	352.5Hz	470Hz	position	352.5Hz	470Hz
1	-47.7	-45.9	1	-44.3	-41.9
2	-46.6	-36.9	2	-48.0	-36.9
3	-48.0	-34.9	3	-64.0	-38.6
4	-51.5	-33.5	4	-57.5	-37.3
5	-58.1	-34.5	5	-56.7	-38.5
6	-58.0	-38.1	6	-64.8	-38.4
7	-52.5	-42.7	7	-54.7	-38.6
8	-49.5	-64.1	8	-42.6	-48.5
			9	-41.9	-58.0
			10	-41.1	-55.3

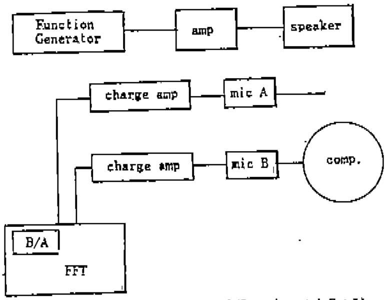


Fig.8 Schematic Diagram of Experimental Set-Up for Cavity Resonance

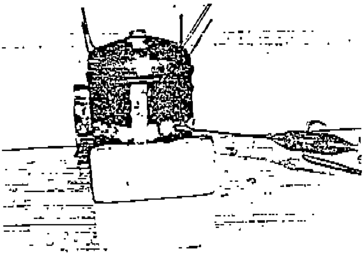


Fig.9 Cavity Resonance Experimental Set-Up

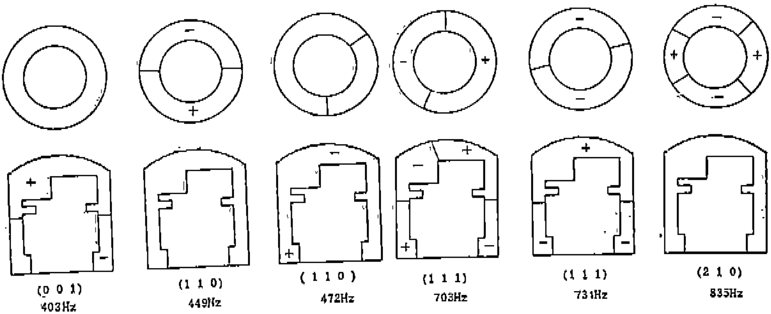


Fig.10 Natural Frequencies and Mode Shapes (Experiment)

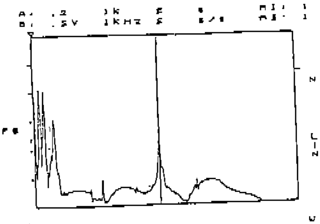


Fig.11 Frequency Spectrum of Acceleration of Compressor

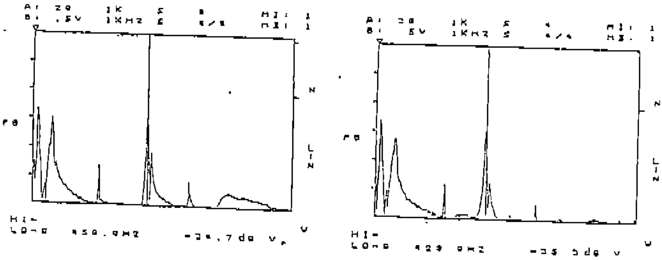


Fig.12 Natural Frequency Change with Time Lapse (Horizontal)

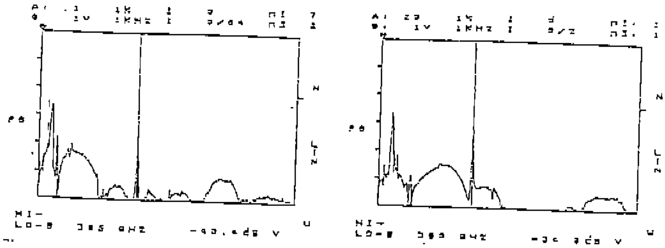


Fig.13 Natural Frequency Change with Time Lapse (Vertical)

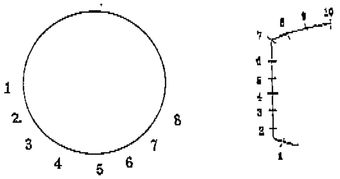


Fig.14 Vibration Pick-Up Point

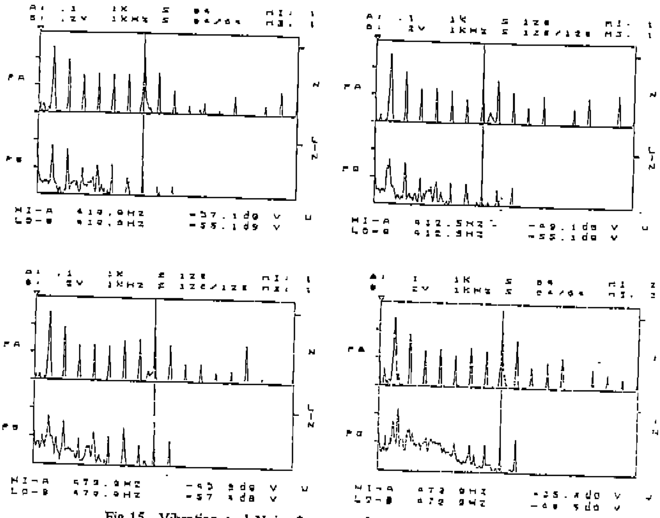


Fig.15 Vibration and Noise Spectrum Change with Time Lapse

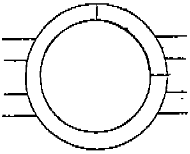


Fig.16 Blockade of Compressor Cavity

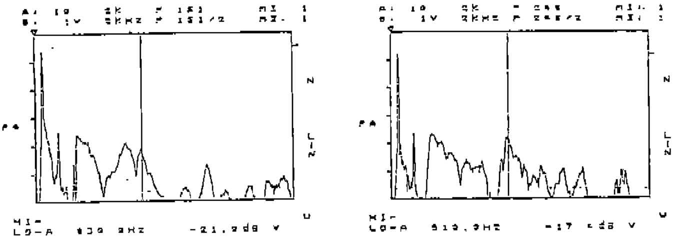


Fig.17 Cavity Resonance Spectrum with Blockade

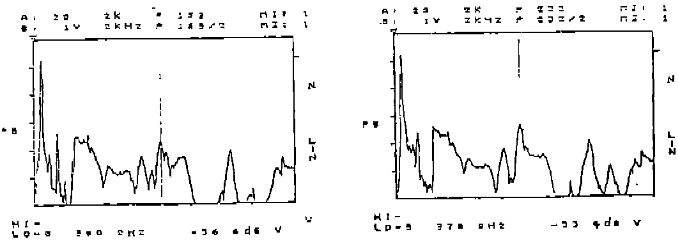


Fig.18 Cavity Resonance Spectrum with Modified Case