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Rotary Compressor Noise Analysis Using Mechanisms and Electromagnetics Coupled Approach

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ABSTRACT

This research is conducted to investigate noise source and design low noise compressors. For improving energy efficiency, there is expansion usage of high performance variable speed brushless DC motor for rotary compressor. However brushless DC motor makes more vibration of compressor than constant speed motor compressor in high speed operating condition. Therefore it is necessary to reduce noise and vibration for improving air conditioner quality. In this study, compressor's noise and vibration are simulated using structural and electromagnetics coupled methods. From the rotor motion simulation result, precession motion of rotor is applied for simulating actual motor movement.

1. INTRODUCTION

Recently home appliance companies make an effort to improve energy efficiency of their product, air conditioning system and refrigerator. Compressor is most energy consuming part of appliances. Rotary compressors in air-conditioner have been considered for energy efficiency enhancement and noise reduction. For reducing energy consumption of compressor, Kageyama, K.et al(2002) studied about brushless DC(BLDC) motor type compressors. BLDC type compressor can drive with optimized speed depending on cycle conditions like setting temperature, environment temperature, etc. However increased power of motor makes compressor vibration more than constant speed type compressor.

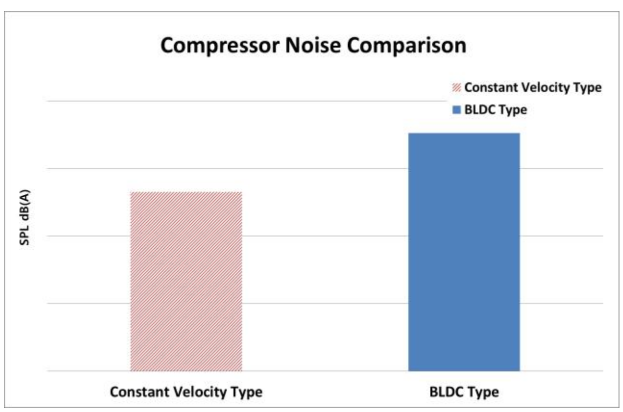


Figure 1: Compressor noise comparison constant speed type and BLDC type motor

Sungtae woo. et al(2008) studied about improving compressor's noise and vibration. Noise sources of compressor are electromagnetic noise, structure-born noise and air-born noise. J Lee and U Yoon Lee (2012) showed optimized flow path designs of accumulator to reduce air-born noise. For reducing structure-born and electromagnetic noise, structural improvement is needed. The goal of study is conducting structural simulation, and designing low noise and vibration compressor. In this study, structural and electromagnetics coupled simulation is carried out for increasing simulation accuracy. Motor force is set as noise and vibration source because motor directly excites compressor parts on operating condition. Electromagnetics simulation results are mapped to stator teeth, and then structural analysis is performed. From result, acoustic field analysis is carried out. Finally simulation result is analyzed with noise measurement test.

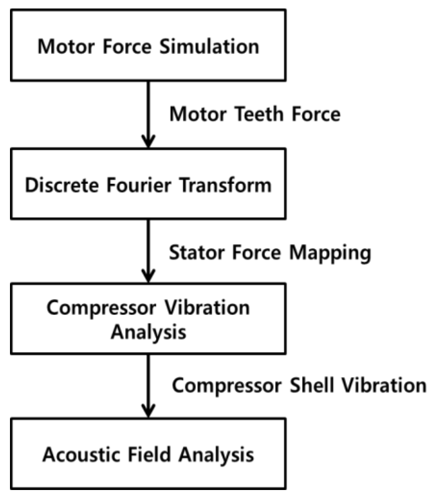


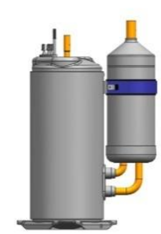
Figure 2: Compressor noise analysis flow

2. COMPRESSOR SIMULATION

2.1 Simulation Model

For simulation, compressor model is selected. Twin rotary compressor is applied for simulation. Motor is 6poles, 9slots and compressor cooling capacity is 20000BTU/hr.

Table 1: Compressor specification

Specifications	Value	Feature
Refrigerant	R410a	
Motor	Brushless DC Motor, 6 Pole 9Slot	
Magnet	Neodymium	
Type	Twin Rotary	
Cooling Capacity	20000 Btu/hr	

2.2 Motor simulation

In this paper motor force is main noise and vibration source of rotary compressor. In rotary compressor, stator is usually assembled to case by press fit, and motor vibration directly transferred to other parts of compressor.

Motor behavior is analyzed prior to compressor structural simulation. In rotary compressor, rotor is supported overhanging. Due to structure, rotor's whirling motion can be shown when compressor is operating. Then forces on stator tooth are not same because of air gap imbalance in real whirling motion. Force imbalance between teeth makes vibration on compressor. However, it is difficult to realize whirling motion with air gap imbalance. For realizing similar motor behavior, centrifugal, eccentric, and precession motor motion simulations are conducted. Motor force simulation is carried out using ANSYS Maxwell Software. Maxwell software is commercial program and used to simulate low frequency electromagnetic field.

2.2.1 Centrifugal Motion

Centrifugal motion means rotor is rotating ideally without revolving and every stator tooth has same size of air gap. All forces on stator teeth are same by air gap size. Simulation result shows motor pole's effect only. Figure 4 shows 348Hz is highest force. 348Hz is multiplying of 58 rps driving speed and motor poles number. In the other frequencies, except multiple of operating speed and motor poles number, there are no significant forces.

Figure 3: Centrifugal motion

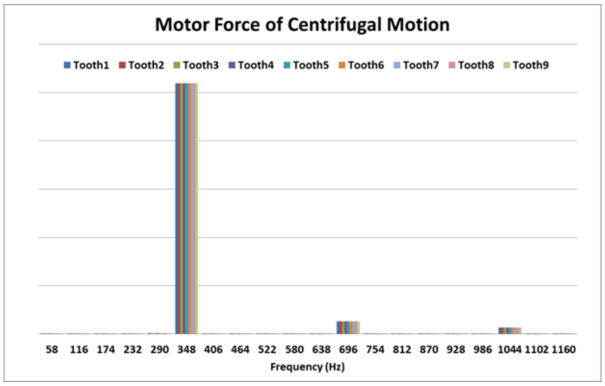


Figure 4: 58 rps centrifugal motion force result

2.2.2 Eccentric Motion

Eccentric motion center of rotating is moving to one side. In eccentric motion, one of air gap is very smaller than the others. Then rotor does not revolve along stator. For simulation, the minimum air gap value refers to assembly specification. In eccentric motion simulation, result represents air gap imbalance, but cannot shows whirling motion of rotor.

Figure 5: Eccentric motion

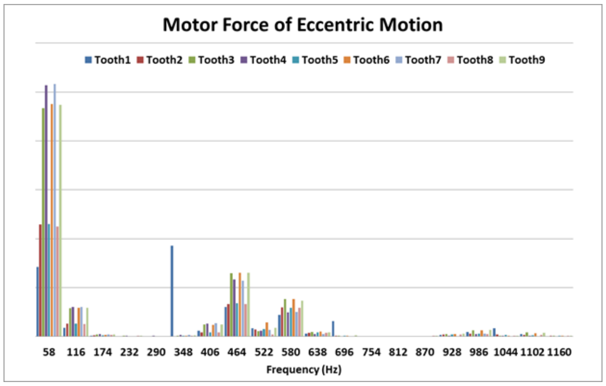


Figure 6 : 58 rps eccentric motion force result

2.2.3 Precession Motion

In rotary compressor, precession motion always appears in case parts and assembly tolerance. When rotor is rotating and revolving around stator. Rotating speed and rotating speed are same. Revolving radius is subtracting the minimum air gap value from the stator inner radius. In the precession motion simulation, all air gaps are same and rotor whirling motion can be shown.

Figure 7: Precession motion

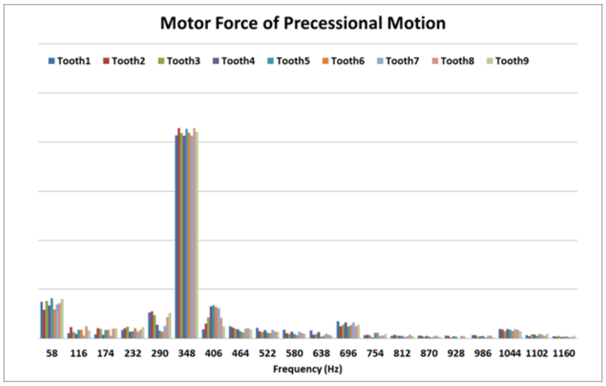


Figure 8: 58 rps precession motion force simulation result

2.2.4 Result Analysis

Centrifugal motion simulation result shows only motor poles multiple components. In this case, frequencies except motor poles multiple components cannot be used for structural analysis. In eccentric motion simulation, result shows that tooth forces have a big difference by air gap difference. But result cannot represent motor poles number at all. Precession motion simulation result shows compressor vibration characteristics well. Stator forces are uniformly distributed at each tooth, and result shows compressor operating speed and motor poles number also. Therefore, precession motion result is applied to structural simulation.

2.3 Structure Simulation

2.3.1 Force setting

From motor simulation results, stator forces are divided into Fx, Fy and transferred as tangential and radial force on stator teeth. For vibration analysis, discrete fourier transform is applied. Transformed tangential force and radial force are mapped teeth1 to teeth9, and these forces are used for exciting force of compressor vibration.

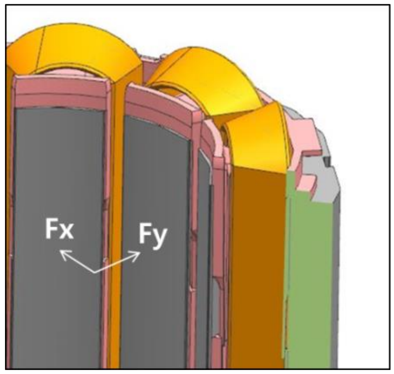
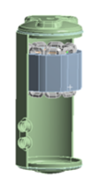
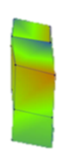
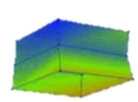
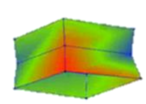
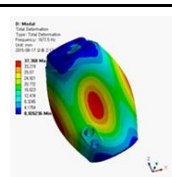
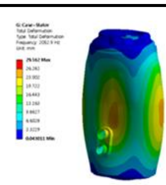
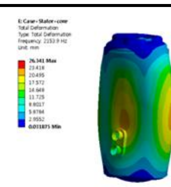


Figure 9: Teeth force setting

2.3.2 Modal Analysis

Prior to structural simulations, modal parameters are examined with modal test. From modal test results, natural frequency, damping ratio, and modal shape can be detected. Experiment modal analysis (EMA) is impacts object using hammer and detects modal parameters. In this research, EMA is applied for verifying modal value of compressor parts. There are difference between modal test and simulation result. For correlating modal test and simulation result, elastic modulus and density of simplified parts are slightly adjusted.

Table 2: Mode shape of FRF test and simulation

	Shall + Bottom Cap	**Shall + Stator**	**Shall + Stator +Core**
Model			
Test			
Simulation			

2.4 Acoustic Simulation

In this paper, semi spherical acoustic field is applied reflecting experiment environment. ANSYS Workbench is used for acoustic simulation. It is assumed that vibration on compressor surface excites surrounding air. Noise signals are measured using 4 microphone settings which are set every 90dregrees at 900mm from compressor surface.

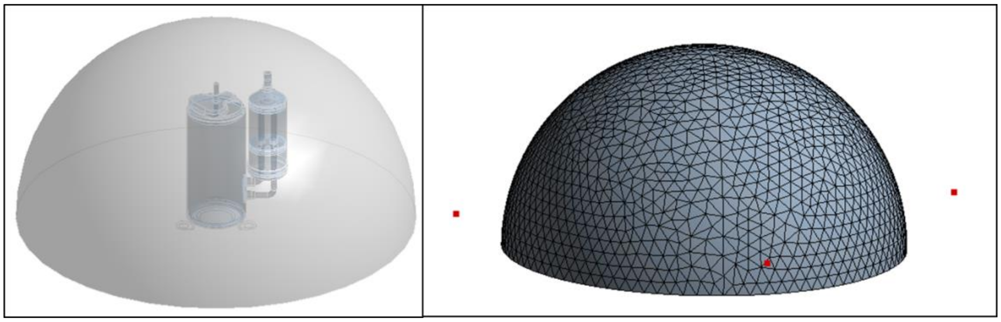


Figure 10: Acoustic field and microphones setup. Red points indicate microphone.

3.RESULTS

3.1 Results analysis

For analysis simulation, the results of the compressor noise are expressed through the sound pressure level. Between 4 microphones, the maximum value of noise is used for comparing frequency behavior. First, 58 rps operating speed of compressor condition is simulated. From simulation, overall value of simulation is 49.5dB(A) and, measurement is 56.1dB(A). Its overall frequency range is 0~2KHz. Results show that overall values are roughly similar, and peak level have similar trend, too. Additionally other operating speeds are applied to simulation for verifying compressor simulation accuracy. Operating frequency is 72 rps, 86 rps and 94 rps for comparing with measurement results. Simulation results are shown in table 3, and maximum error is 11.9%. Results show higher simulation accuracy than without coupling simulation of structural and electromagnetic.

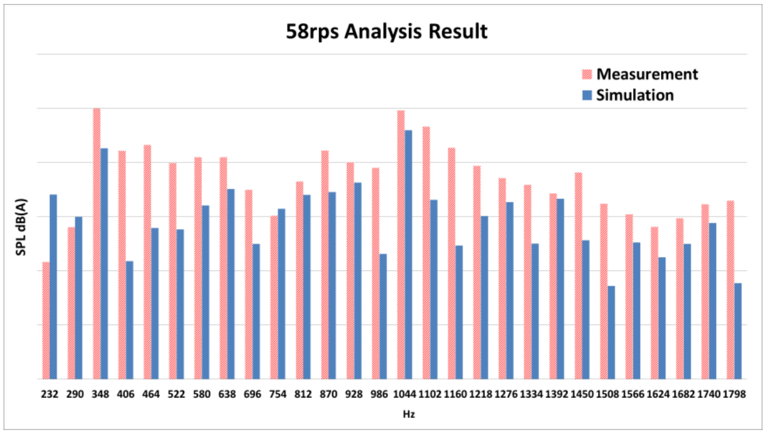


Figure 11: 58 rps analysis result

Table 3: Comparison of overall noise

Operating Frequency	Overall dB(A) (0~2KHz)		
	Measurement	**Simulation**	**Error (%)**
58 rps	56.2	49.5	11.9
72 rps	56.5	52.7	6.7
86 rps	58.9	54.5	7.5
94 rps	59.7	54.9	8.0

4. CONCLUSIONS

The purpose of study is noise analysis of compressor using coupled structural and electromagnetics simulation. From research, simulation results are very similar with measurements, and simulation can be assumed that it has high accuracy by comparison with independent acoustic simulations without motor electromagnetic coupling. In terms of motor simulation, the real motion of rotor is assumed as combination of eccentric motion and precession motion. However, due to limitation of simulation, only precession motion motor simulation has been conducted for getting more accuracy result.

The compressor air-born noise can be observed at accumulator, muffler and other cavities can make sharp changing in flow energy. Moreover there is refrigerant oil effect, also. Such a refrigerant flow is air-born noise source of compressor. The reason why this study does not conduct flow simulation have a lot of time cost in 3D flow analysis. In future research, the study of coupled simulation with flow noise will be conducted for better analysis accuracy.

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