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Development of a Miniature Twin Rotary Compressor

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ABSTRACT

In this paper, we will introduce the miniature compressor which is designed for various applications. Twin rotary compressor structure was adapted to reduced in size and minimize vibration. The weight of the miniature rotary compressor is about 20% that of the reciprocating compressor which has equivalent cooling capacity. To minimize the noise and vibration, the muffler and the cylinder are optimized and torque control algorithm is used for the compressor controller. For a variety of applications, developed compressor is designed for both HBP and LBP condition. Considering the mass-productivity and reliability, IPM type motor is designed.

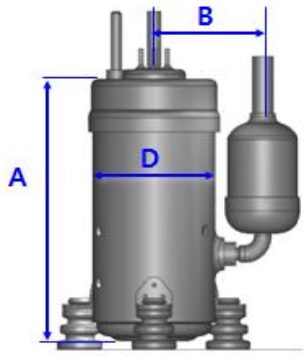
1. INTRODUCTION

In recent times, there are increasing demands for small home appliances to satisfy the trends like personalization and increasing of single-person households. We developed mini rotary compressor, for such small and compact HVAC home appliances.

Twin rotary compressor structure has been adapted to reduce in size to minimize vibration. Developed mini compressor has weight and volume about 20% compared to reciprocating compressor which has same capacity. Table 1 shows the main dimensions and characteristics of developed mini compressor. Because the mini compressor is likely to be used close to user, we made much effort on reducing the noise and vibration of the mini compressor.

In this paper, the design concept of mini rotary compressor including mechanical structure, motor and controller will be briefly introduced.

Table 1 : Detail specification of mini rotary compressor

Specifications	Characteristics	Feature
Refrigerant	R134a	
Oil Type	POE	
Motor Type	BLDC 220V, DC24V, DC12V*	
Speed Range	1,200 ~ 4,800 rpm	
Weight	1.2kg	
Height (A)	115.2mm	
Body Diameter (D)	Φ54.8mm	
Accumulator Distance (B)	48.4mm	

***Under development**

2. DEVLOPMENT OF MINI ROTARY COMPRESSOR

Figure 1 shows the EER trend of compressor with respect to compression volume. As the compression volume gets smaller, the efficiency of the compressor trends to deteriorate because it's dead volume and leakage effects. For miniature compressor design, it is important to prevent deformation of parts. Design for minimizing deformation of compressor components, motor design for miniature rotary compressor and bearing reliability analysis will be described next paragraph.

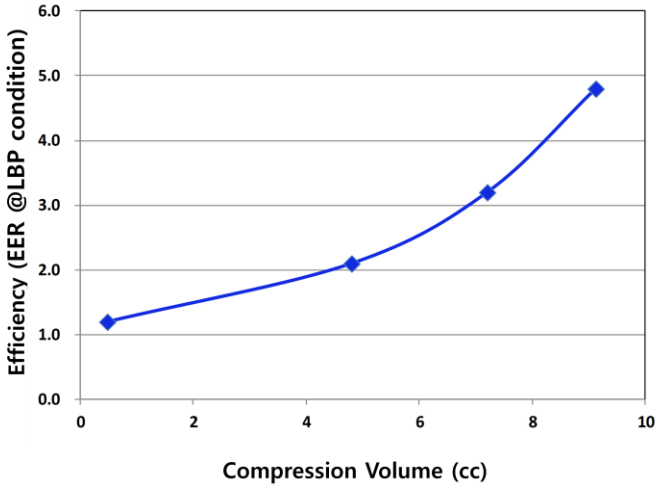
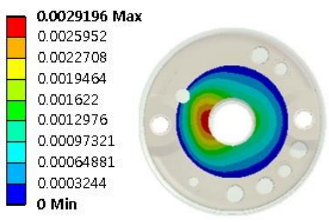
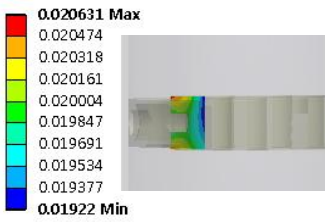
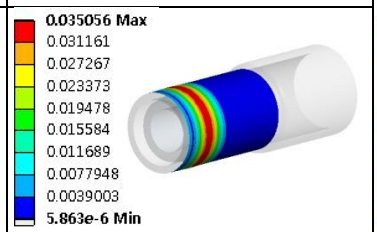
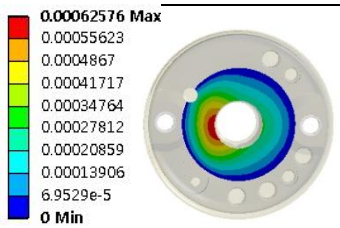
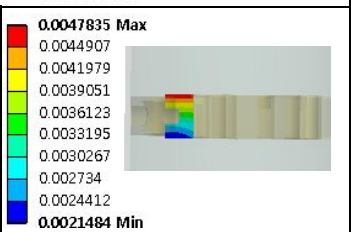


Figure 1 : Volume effect for compressor efficiency

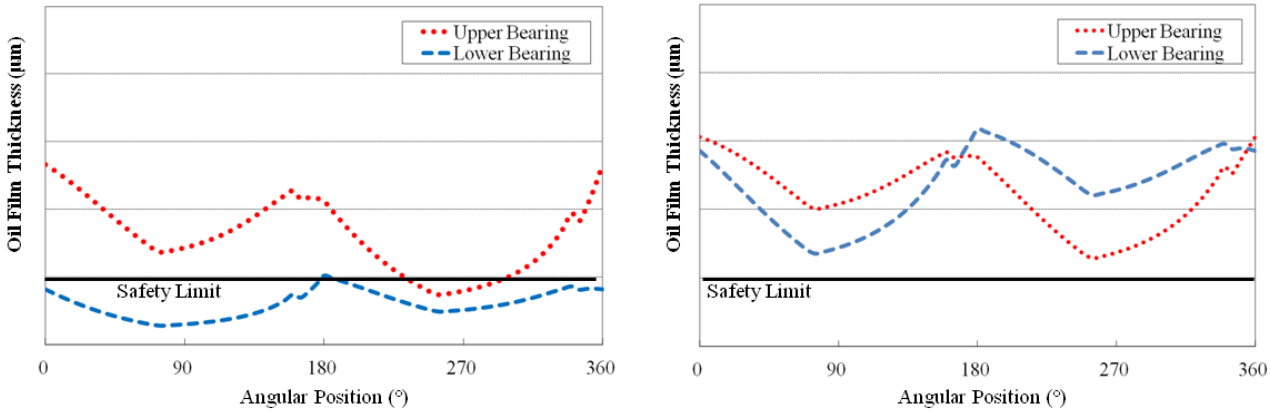
2.1 Design of mini rotary compressor mechanical structure

Preventing deformation of mechanical structure components is important for mini compressor design. Deformation of compressor components more seriously influence to efficiency and reliability especially for mini compressor. Therefore deformation analysis was carried out to minimize the deformation occurred by clamping and assembly process. First, upper and lower bearing deformation analysis were performed to estimate its deformation margin. We experimentally verified clamping force and measured the clearance with gap sensor.

Table 2 : Deformation analysis result

	Suction Tube Pressed-in Deformation	Muffler Fastening Deformation	Cylinder Vane Slot Pressed–in Deformation
Initial Model			
Improved Model			
Result	**37.5% improved**	**68.9 % improved**	**75.0% improved**

For a variety of application, developed compressor is designed for both HBP(High Back Pressure) and LBP(Low Back Pressure) condition. Figure 2 shows the minimum oil film thickness of mini compressor. Through bearing load analysis, we calculated minimum oil film thickness, and designed oil film thickness level to meet design guide. As shown in Figure 2, oil film thickness of early proto type compressor was subminimum, so bearings were re-designed to secure the minimum thickness. After re-designing of bearing part, we could satisfy safety limit of oil film thickness.



(a) Early Proto Type (b) Final Design

Figure 2 : Oil thickness optimization

2.2 Design of controller for mini rotary compressor

The IPM motor commutation time is determined by rotor position, so sensing position of rotor is necessary. However, sensing the position of rotor in high temperature and high pressure refrigerant conditions in compressor is very difficult. Therefore, sensor-less control is generally applicable for compressor control. Sensor-less control determines commutation time from stator winding voltage in driving condition. The sine wave control is applied to systems to reduce motor iron lose and torque ripple by 120 degree of angle commutation.

3. NOISE REDUCTION DESIGN OF MINI ROTARY COMPRESSOR

Noise and vibration characteristic for mini rotary compressor is very important consideration point for customers. Almost application that contains mini compressor is installed inside house and working close to users. To reduce noise and vibration many efforts have been applied to mini rotary compressor. Following methods are used for reducing noise and vibration. Twin type rotary mechanism, improving structure stiffness, flow pass optimization, motor design optimization, torque control and high damping materials are used for low noise and vibration technology.

3.1 Low vibration structure of compressor

Low vibration and noise characteristics were essential to mini rotary compressor, so we developed the mini compressor with twin rotary structure. Mini rotary compressor is twin type compressor. Twin rotary compressors have two cylinders performing compressing function. In twin rotary compressor, upper and lower cylinders are assembled vertically. Thus it has very complicated structure to manufacture and assembly especially for small size compressor. However twin rotary compressors have low vibration characteristic because upper and lower cylinders structurally cancel their vibration each other.

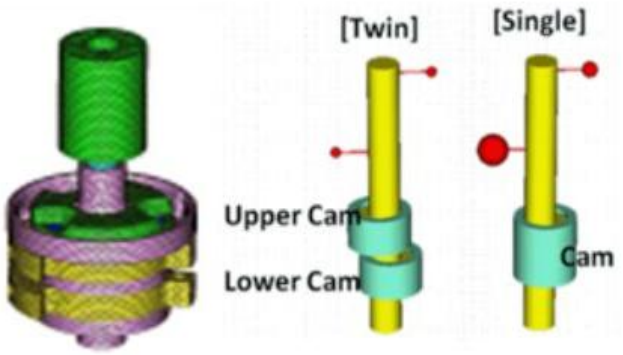


Figure 3 : Structure of twin type mini rotary compressor

As described in Figure 4, compressive load of upper and lower cylinder is reduced. Consequently, vibration is more greatly reduced than single rotary compressor.

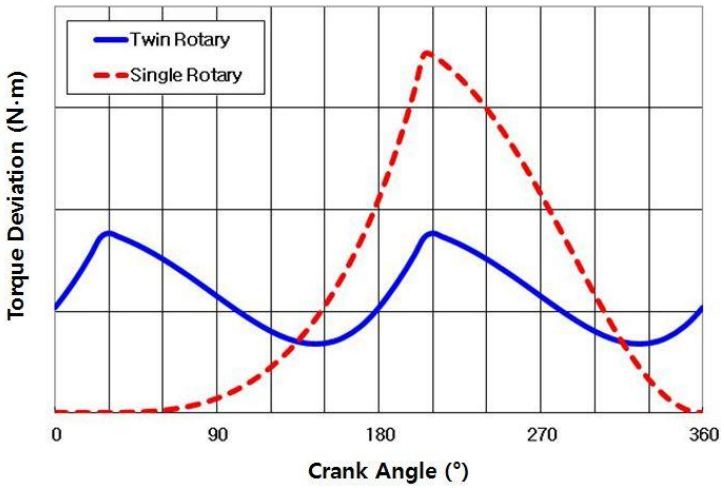


Figure 4 : Torque deviation of twin and single rotary compressor

Figure 5 shows comparison in developed mini twin rotary compressor and conventional single rotary compressor. Result shows that vibration can be significantly reduced in twin rotary compressor by structure characteristic. Especially the vibration is reduced nearly 90% at low speed condition which is main operating condition of mini compressor.

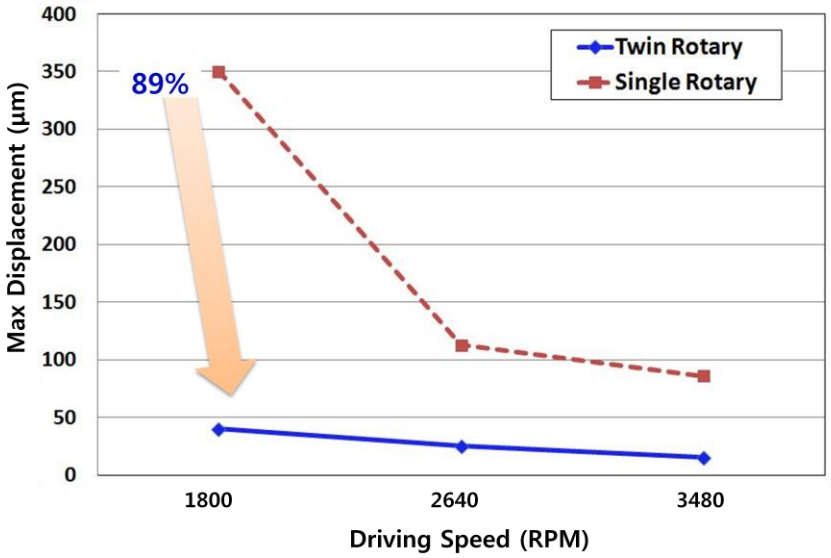
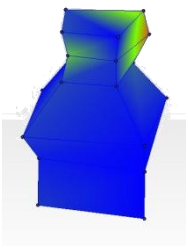
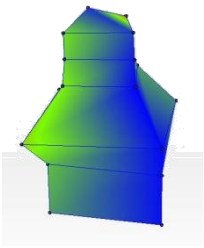
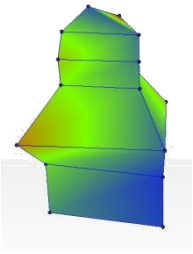


Figure 5 : Vibration comparison of two types of mini rotary compressor

3.2 Mechanical structure stability improvement

For estimating mechanical structure maximum vibration points, we did impact hammer test to find mode shape that represents structure's vibration characteristics. As shown in Table 3, Resonance mode shapes are found at compressing unit of early proto type. To reduce radiation noise by structure vibrating, we re-designed structure welding system at maximum displacement point of mode shape. As a result, noise and vibration of mini rotary compressor were extremely improved by optimize welding system.

Table 3 : Mode shape of mechanical structure

Product	**Mode Shape**		
Type	**1st Mode**	**2nd Mode**	**3rd Mode**
Characteristic			

3.3 Flow Pass Design

The refrigerant flow generates air-borne noise in hermetic type compressors and muffler design is effective method for reducing the air-borne noise. By acoustical CAE, we designed optimum muffler inside passage and position of discharge hole for reducing flow noise. Figure.6 shows acoustic resonance at each mode. By setting hole's position at the nodal line prevents flow noise by phase interference.

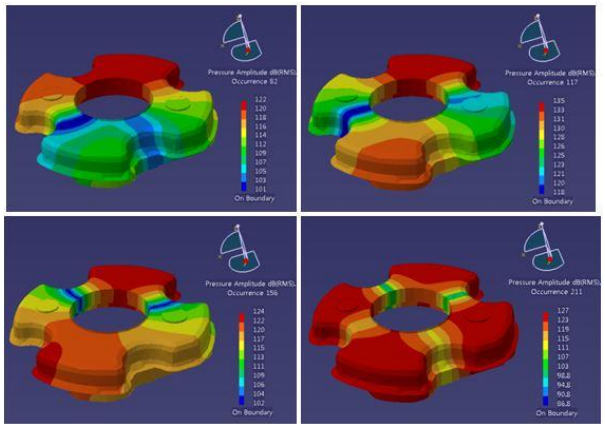


Figure 6 : Acoustical Mode shape of Muffler

3.4 Design of low noise mini rotary compressor motor

Important design points of mini rotary compressor motor are high efficiency and low noise vibration. Initially, we considered all type of motor such as SPM (Surface Permanent Magnet) and IPM (Interior Permanent Magnet). Firstly, we evaluated SPM type motor for proto type. However we developed mini rotary compressor with IPM type motor for reliability and mass production. For large output of mini rotary compressor motor, we conducted optimum design of core shape and stator winding. To prevent scattering of the permanent magnet, we determined rotor shape as IPM type for assuring mechanical strength, also. For matching torque requirement of mini compressor, we carried out optimum designing of rotor shape and stator winding.

As mentioned before low noise and vibration are very important for mini rotary compressor. The motor of mini rotary compressor is pressed fit in compressor shell. The directly contact structure between motor and shell have weakness at noise and vibration. Therefore, we designed motor shape for reducing noise and vibration. For reducing motor noise, we analyzed noise characteristic using electro-magnetic source and radial force analyzing of motor. In order to eliminate the noise source, stator and rotor shape were optimized and mechanical strength was reinforced.

3.5 Torque Controller

The noise and vibration of compressor is influenced by matching characteristics of controller and compressor mechanical structure. In this paper, we developed the torque control algorithm using sinusoidal controller to make low noise and vibration.

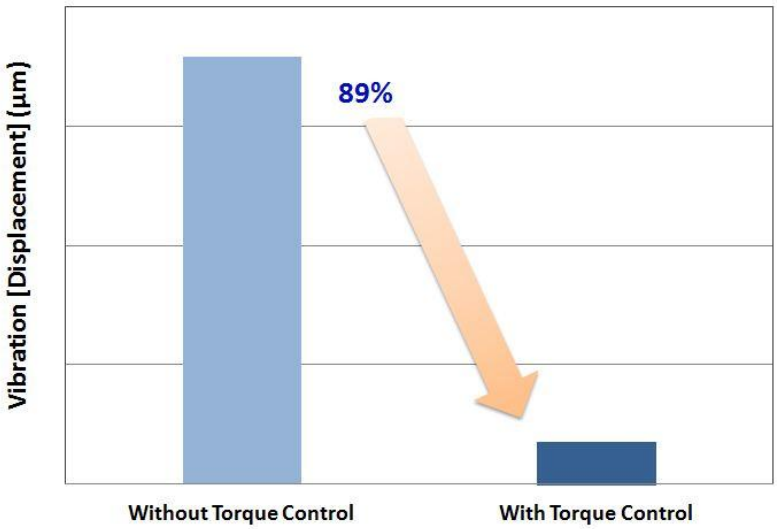


Figure 7 : Result of Torque control

Figure 7 shows vibration test result. When torque control is applied to compressor, controller senses compressor load and applies optimized motor torque. Thus compressor's noise and vibration largely decreased. The vibration of compressor before the applying torque control was large. However it was reduced about 88% when torque control is applied. In structurally, reciprocating compressor is supported by spring which makes vibration damping. Mini compressor realized similar vibration level of reciprocating compressor with twin rotary structure and torque control vibration.

3.6 Grommet Design

The grommet supports compressor and reduces the vibration of compressor by damping. The mini rotary compressor had lower vibration level, but expected vibration level was similar with reciprocating compressor's one. In case of reciprocating compressor, its mechanical structure of compressing is supported by isolation spring. Therefore its vibration level is much lower than that of rotary compressor. To realize low vibration level of the mini rotary compressor, we developed grommet in chemically and mechanically. First, we designed grommet shape to damp compressors vibration and prevent grommet's large deformation. And then, we changed chemical components, too. In this paper, we will show two types of grommet test result.

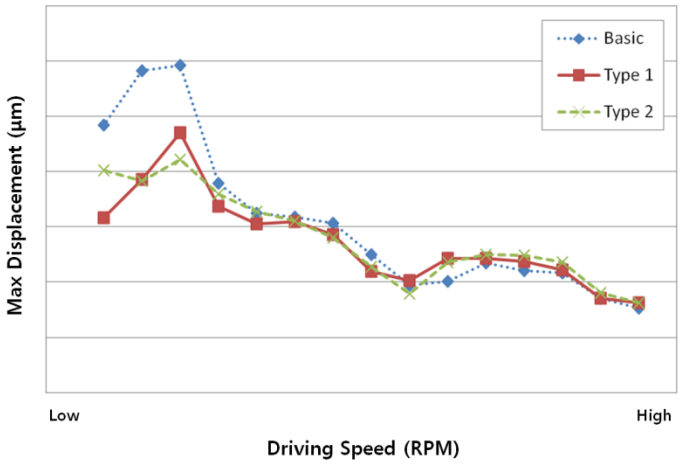


Figure 8 : Grommet performance comparison

Figure 8 shows grommet design test result. From the result, Type1 grommet has better vibration performance than basic grommet. Especially it has great performance in low rotation speed condition. Therefore we chose the type1 grommet for low vibration compressors.

6. CONCLUSIONS

In this paper, we introduce the recently developed 2.4cc mini rotary compressor. The developed mini rotary compressor has 1/4 size to same capacity reciprocating compressor. For miniaturizing rotary compressor, we carried out mechanical structure and motor analysis. From the analysis, we set its final design for securing reliability and efficiency. Moreover, we tried to reduce vibration and noise level. Because rotary compressor components were pressed fit in shell, thus its noise and vibration directly transferred to outside of compressors. For improving the noise and vibration of the mini compressor, we applied various low noise and vibration items. First, the twin rotary structure was applied because of its low vibration characteristics. And the welding system is optimized for improving structure stability. The motor and controller were optimized, also. The motor shape was designed in terms of electro-magnetic, and torque control is applied for reducing vibration when structures take large load. High damping material is used for reducing vibration and transfer to application. Figure 9 shows performance, noise and vibration result of mini rotary compressor development. By applying low noise and vibration improvement items,

we achieved low noise and vibration level. Noise level was improved about 15% and vibration was improved over 90%. Performance of our mini compressor is about 25% higher than conventional compressor with same displacement. Noise level is about 13dB lower and vibration level is 90% lower than other small size single rotary type compressors.

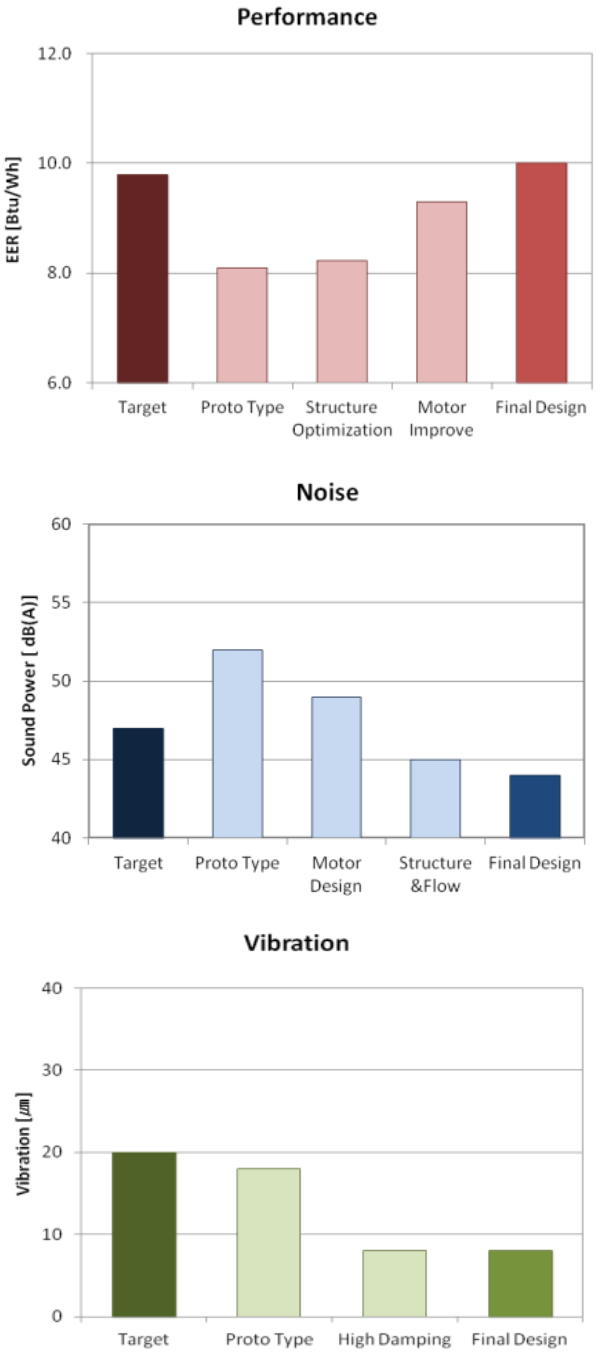


Figure 9 : Performance, noise and vibration

We hope that developed miniature compressor will be applied to a variety of applications such as cold water purifier, dehumidifier, small refrigerator, spot cooler and small dryer etc.

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