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Study of Novel Rotary Cylinder Compressor

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ABSTRACT

A positive displacement Rotary Compressor is introduced: RCC (Rotary Cylinder Compressor). For implementing suction and exhaust process, the compressor's cylinder and shaft revolve around their own axes while the piston reciprocates relative to the cylinder and shaft respectively. Compared with Rotary Compressor, the RCC has the advantages of high volumetric efficiency and small torque ripple.

1. INTRODUCTION

Rotary Compressor has the advantages of simple structure, easy production, small size, light weight, few wearing part, and high reliability (Sekigami *et al*, 1987, Sekigami *et al*, 1987). It has been widely used in the field of air conditioning.

However, there are some defects of the Rotary Compressors (Matsuzaka *et al*, 1982, Lee *et al*, 1988). The sealings about roller-cylinder and slider-roller are linear, which results in worse sealing effect and larger leakage than face sealing. The Rotary Compressor has the clearance volume, which results in finite pressure ratio. The slider bears large bending moment and belongs to the cantilever support structure, which results in wear easily. In order to reduce the vibration caused by eccentricity of the shaft, balance structure needs to be set up. These shortcomings limit further improvement of the performance of Rotary Compressor.

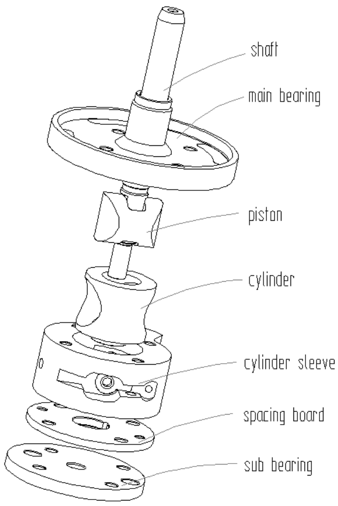
For the current defects of Rotary Compressor, GREE(R) has proposed a new type of compressor: Rotary Rotary Cylinder Compressor. This article mainly introduces the structure and operation principle of Rotary Cylinder Compressor, and makes a qualitative analysis of volumetric efficiency and mechanical efficiency.

2. STRUCTURE OF ROTARY CYLINDER COMPRESSOR

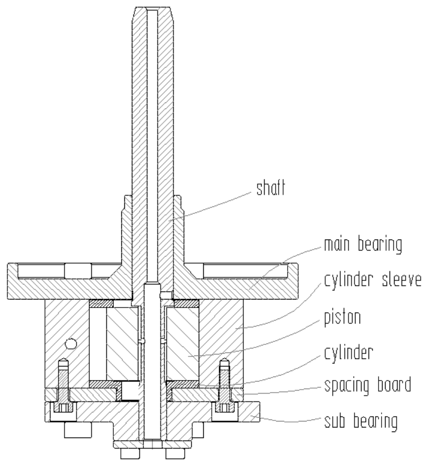
The Rotary Cylinder Compressor body mainly contains seven parts: main bearing, shaft, cylinder, piston, cylinder sleeve, spacing board, and sub bearing as shown in Figure 1.

The center of shaft is different from the center of cylinder. The distance between two different axes e is the eccentricity of compressor. The piston stroke L is twice the eccentric amount $L=2\cdot e$. The compressor displacement formula is as follows.

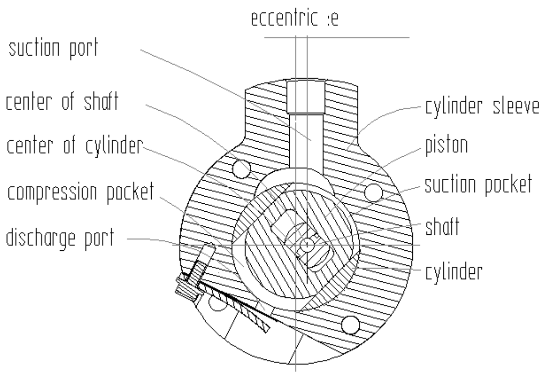
$$V = 2 \cdot L \cdot S = 4e \cdot S \quad (1)$$



(a) Structure decomposition diagram



(b) Side sectional view of pump body



(c) Cross sectional view of pump body

Figure 1: Schematic diagram of pump body of Rotary Cylinder Compressor

3. OPERATION PRINCIPLE OF ROTARY CYLINDER COMPRESSOR

3.1 Suction and exhaust process

During operation of the compressor, motor drives the shaft to rotate, shaft drives the piston to rotate, and piston drives the cylinder to rotate. The cylinder and shaft rotate around their respective axes. The piston reciprocates relative to shaft and cylinder simultaneously. Two different reciprocating motions are perpendicular to each other. As the cylinder always rotates, the compressor is named Rotary Cylinder Compressor (RCC).

The piston reciprocates relative to cylinder so that the volume of cavity formed by piston, cylinder and cylinder sleeve changes periodically. The cylinder performs a circular motion relative to the cylinder sleeve so that former volume cavity periodically links with suction port and discharge port. Under the joint action of the above two relative movements, RCC completes the suction, compression and exhaust processes, as shown in Figure 2.

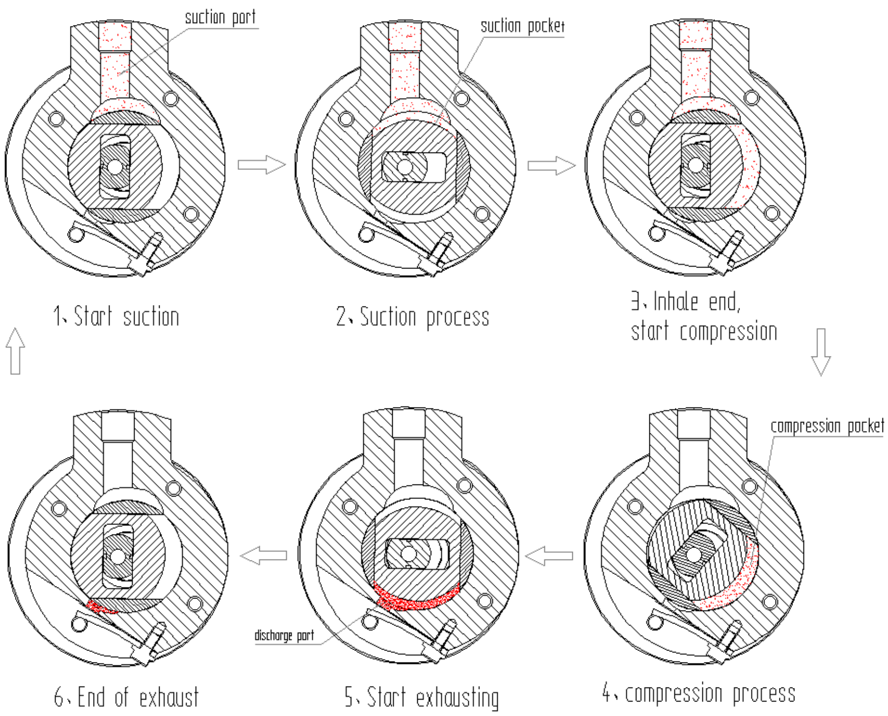


Figure 2: Schematic diagram of suction and exhaust process

3.2 Torque characteristics

The relationships about chamber volume, pressure with rotation are as follows.

$$V_\theta = e \cdot S \cdot (1-\cos\theta) \tag{2}$$

$$P_\theta \cdot V_\theta^n = P_s \cdot V_s^n \tag{3}$$

$$P_\theta = \begin{cases} P_s & 0 \le \theta < \pi \\ P_s\left(\dfrac{2}{1-\cos\theta}\right)^n & P_s\left(\dfrac{2}{1-\cos\theta}\right)^n \le P_d \ \& \ \pi \le \theta < 2\pi \\ P_d & P_s\left(\dfrac{2}{1-\cos\theta}\right)^n > P_d \ \& \ \pi \le \theta < 2\pi \end{cases} \tag{4}$$

According to the above formulas, the relationship between torque and angle can be obtained:

$$T = F_\Delta \cdot e' = P_\Delta \cdot S \cdot e' = \left[\left(P_{\theta+\pi} - P_\theta\right) \cdot S\right] \cdot e \cdot \sin\theta \quad 0 \le \theta < \pi \tag{5}$$

RCC has the structural feature of a single-cylinder with double-compression chamber: the suction, compression and exhaust processes are completed within 2π. Suction process completes within the first π while compression and exhaust processes complete within the last π. Two volume chambers are independent of each other. And there is a phase difference of π among two volume chambers. The former features make the torque cycle π.

Figure 3 shows the variation of torque with rotation angle of RCC and single-cylinder rotary cylinder at the same displacement. From the figure, torque cycle of RCC is π while the Rotary Compressor's is 2π. With the same displacement, the average moment of two kinds of compressors is equal. But the maximum torque of RCC is 12% smaller than that of the single-cylinder Rotary Compressor. In general, the smaller the torque fluctuation is, the more stable the operation is. In other words, RCC runs more smoothly than Rotary Compressor in the same displacement condition.

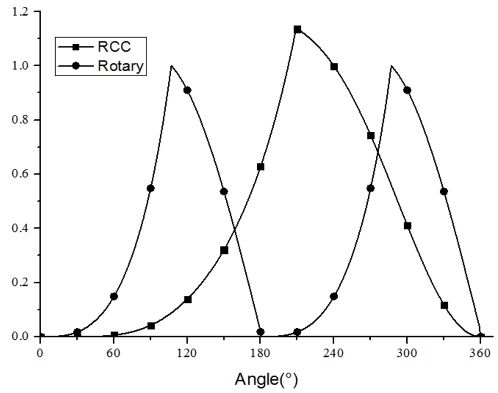


Figure 3: Comparison of torque curves

4. EFFICIENCY ANALYSIS

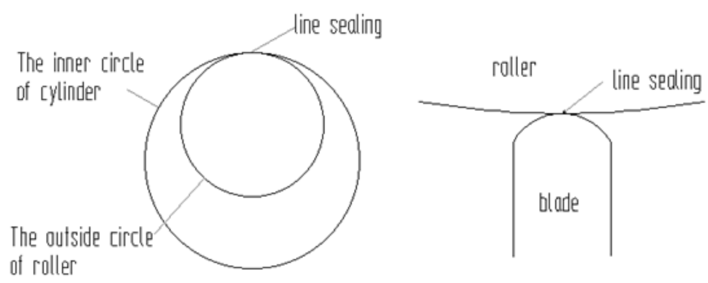
4.1 Volumetric efficiency

4.1.1 Leaking channel and sealing

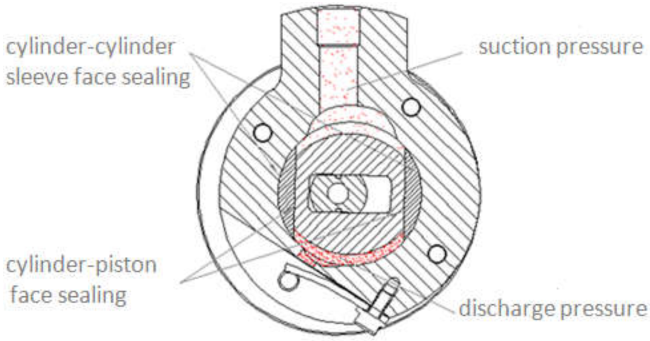
RCC has two leaking channels: cylinder-cylinder-sleeve, cylinder-piston. Both leaking passages are face sealings. The Rotary Compressor has five leaking channels: roller-cylinder, roller-slide, roller-main-bearing, roller-sub-bearing, slide-slide-slot. The first two are linear sealings. Because the effect of linear sealing is less than face sealing, the leakage of these two leaking channels is relatively large in the total leakage. RCC is superior to the Rotary Compressor in terms of the sealing effect or the number of leaking channels.

Table 1: Sealing comparison of RCC and Rotary Compressor

Rotary Compressor		**RCC**	
Distribution	Sealing	Distribution	Sealing
slider/roller	linear sealing	cylinder/ cylinder sleeve	face sealing
roller/cylinder	linear sealing	cylinder/piston	face sealing
roller/main bearing	face sealing	/	/
slider/slider slot	face sealing	/	/
roller/sub bearing	face sealing	/	/



（a）Schematic diagram of linear sealing of Rotary Compressor



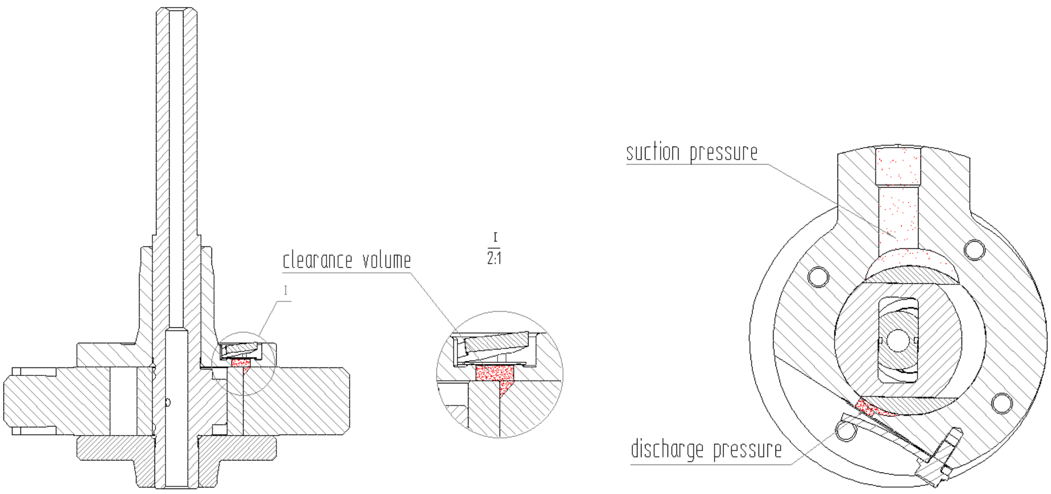
（b）Schematic diagram of face sealing of RCC

Figure 4: Comparison of seal forms

4.1.2 Clearance volume

After the exhaust process, there is still some space where high-pressure gas exists. This part of the space is clearance volume. During operation of the compressor, high-pressure gas in the clearance volume expands to the suction chamber. This part of the gas will be used by next compression cycle. The above process will reduce the actual suction volume of compressor and volume efficiency. As the volume of cavity is changing, this part of the gas is recompressed. Repeated compression process will increase the indicator work of compressor.

The clearance volume of Rotary Compressor mainly comes from the vent hole and the exhaust oblique incision. Suction chamber of RCC is separated from the compression chamber. Suction and exhaust processes are independent of each other. At the end of the exhaust process, the high pressure gas of exhaust port is closed in the vent hole, but it can't enter suction chamber. Of course, there's no more expansion. From this point of view, RCC has no clearance volume as shown in Figure 5.



(a) Rotary Compressor (b) RCC

Figure 5: Comparison of the clearance volume

In summary, RCC has less leaking channels and no clearance volume compared to Rotary Compressor. All these features are beneficial to increase cooling capacity and reduce indicated power of compressor. Finally, the performance of RCC is excellent.

4.2 Mechanical efficiency

In addition to volumetric efficiency, mechanical efficiency also greatly influences the efficiency of compressor's pump body. Under a certain working condition, Table 2 shows the mechanical power consumption of RCC and Rotary Compressor at 30 Hz. Figure 6 shows the variation of the mechanical power consumption with the compressor frequency under the former conditions. Below 40 Hz, the power dissipation of RCC is less than the Rotary Compressor. The lower the frequency is, the greater the advantage is. At 15 Hz, it is only 48.79% of the Rotary Compressor. But over 40 Hz, the trend of power consumption with frequency is opposite. At this time, RCC is larger than the Rotary Compressor. The higher the frequency is, the greater the difference is.

Table 2: Compressor operating parameters

Refrigerant	R410A
Condensation Temperature(℃)	40
Evaporation Temperature(℃)	20
Swept Volume(cc)	9.6

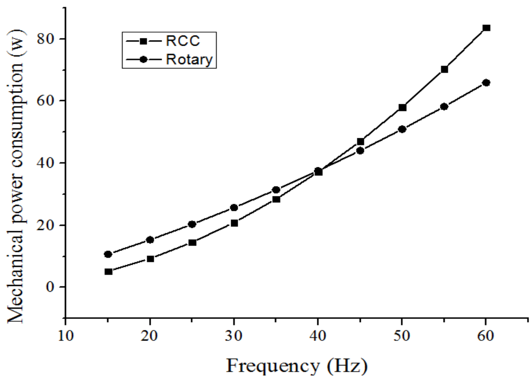


Figure 6: Mechanical power consumption with frequency

As shown in Table 2, the pump body of Rotary Compressor has total eleven friction pairs. Eight of them are rotating friction pairs, and the rests are reciprocating friction pairs. However the pump body of RCC has total nine friction pairs as shown in Figure 7. Seven of them are rotating friction pairs, and the rests are the reciprocating friction pairs. From the contrast results, the number of friction pairs of RCC is less than Rotary Compressor's.

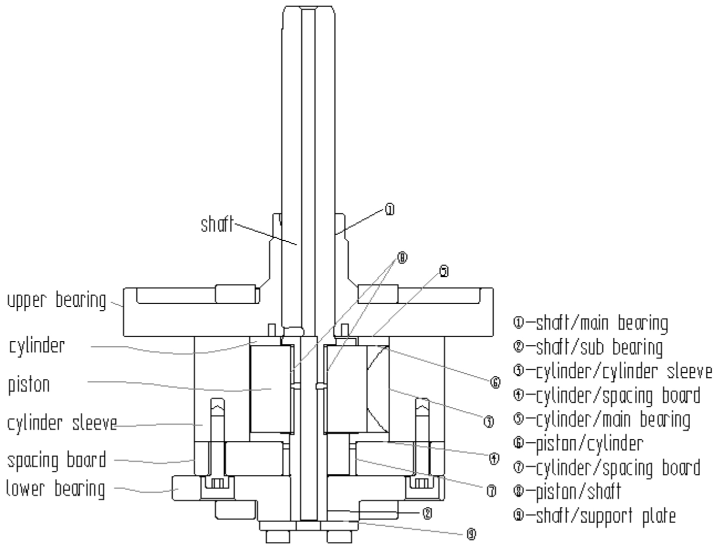


Figure 7: Distribution of friction pair of pump body of RCC

Table 3: Analysis of Movement Characteristics of RCC and Rotary Compressor

Movement Characteristic	RCC	Rotary Compressor
rotating movement	cylinder/cylinder sleeve	shaft/roller
	cylinder/spacing board	shaft/main bearing
	shaft/main bearing	shaft/sub bearing
	cylinder/spacing board	thrust face
	shaft/sub bearing	roller/slider
	cylinder bearing	roller/sub bearing
	thrust face	roller/main bearing
	/	roller/cylinder
reciprocating movement	shaft/piston	slider/slider slot
	piston/cylinder	slider/sub bearing
	/	slider/main bearing

5. CONCLUSION AND NEXT STEPS

This paper introduces a new structure of compressor (RCC), which has the characteristics of high volume efficiency, smooth operation, high mechanical efficiency at low and medium frequency. Follow-up work will focus on reducing power consumption at high frequency.

RCC is essentially a piston compressor. However, there is no suction valve plate, which means that the suction resistance is less than piston compressor (Miu et al, 1987). RCC is simpler and the operation is more stable as a result of no crank linkage mechanism. All these indicate that RCC has a wide range of application prospects.

NOMENCLATURE

V	compressor displacement	cc
L	piston stroke	mm
e	eccentricity of compressor	mm
S	cross section area of piston	mm^2
P_θ	pressure of compression pocket	MPa
P_s	suction pressure	MPa
P_d	discharge pressure	MPa
V_θ	chamber volume	cc
V_s	max chamber volume	cc
T	torque of RCC	N ·mm
F_Δ	resultant force of the piston top	N
e'	arm of force	mm

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