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Developing a Compact Automotive Scroll Compressor

Fengshou Yi
Nanjing Aotecar Refrigeration Compressor Company

Yonggui Qian
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Nanjing Aotecar Refrigeration Compressor Co., Ltd,
No.103 Daming Road, Nanjing, Jiangsu, PR. China, Zip 210012
Tel: 86-25-52193204; Fax 86-25-52600072; E-mail: y1fs@hotmail.com

ABSTRACT

A compact automotive scroll compressor is developed to substitute an original compressor with equivalent suction volume. Comparing with the original compressor, the outer diameter of the compact compressor is reduced 10%, and the length is reduced 8%, and the weight is reduced 28%. The compact compressor is improved twice to increase its durability. The first improvement is to flat the load profile by moving the scroll center to the orbiting bearing center. The second improvement is to change the balls coupling to pins coupling. Eventually the durability of the compact compressor meets the technical standard requirement.

1. INTRODUCTION

Automotive scroll compressor has higher EER (energy and efficient ratio) than other type automotive compressor, such as swash compressor and rotary vane compressor. It is very suitable for the application in small car since the engine for small car is too weak to drive a heavy power consumption compressor. Traditionally, Engineers choose rotary vane compressor for small car application since this type compressor has the minimum volume based on equivalent capacity. Therefore, a compact scroll compressor which has the similar volume as well as the equivalent refrigeration capacity is the most desirable compressor for the HVAC engineers in small car application.

It took two years to design this desirable compressor based on an original compressor. The first year is to fulfill the refrigeration capacity in a limited volume. The second year is to improve the durability of the new compressor.

2. TASK

The object of this project is to downsize a 63.7 cc/r automotive scroll compressor, whose outer housing diameter is Φ106 mm and length is 180 mm, to a compact automotive scroll compressor, whose outer housing diameter is Φ95 mm and length is 165 mm, with a same suction volume. The durability of the new compressor must meet the technical standard requirement. Figure 1 is the crossing section drawing of the original compressor.

3. SOLUTION

3.1 Reducing the outer diameter of the scroll plate

The first step of the downsizing is to reduce the diameter of the fixed scroll and the orbiting scroll. From the suction volume formula (Morishita et al., 1984), the closed suction volume is:

$$V = 2\pi h r_b r_o (2\phi_e - 3\pi) \qquad [1]$$

If the diameter of the scroll plate is reduced, ϕ_e will be reduced, or r_b will be reduced. It is found that r_b reduction will lead to more suction volume loss, so in this case, the author chooses to only reduce ϕ_e. In order to keep the suction volume constant, the involutes height h is increased to offset the reduction of ϕ_e. The required diameter of fixed scroll is Φ86 mm if the diameter of the outer housing is Φ95 mm, and then ϕ_e should be 14.39, reduced 13.6%

than the original compressor. Based on this involutes angle, the height of the scroll wrap should be increased to 38 mm, increased 15% to offset the reduction in involutes angle.

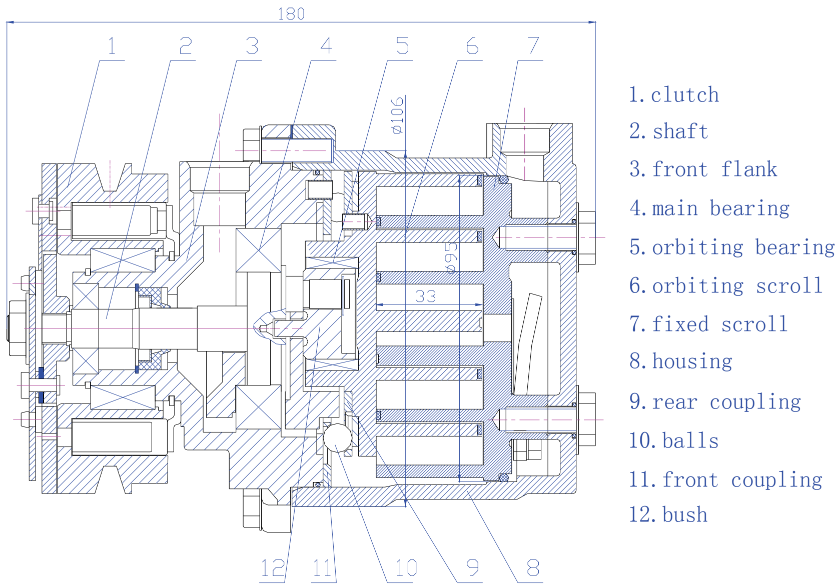

Figure 1: Crossing section drawing of the original compressor

3.2 Reducing the diameter of driving device

The second step of the downsizing is to reduce the diameter of the ball couplings. As for the front coupling, its maximum outer diameter is limited by the inner diameter of the housing, and its minimum inner diameter is limited by the bearing house of the orbiting scroll. Obviously, a small outer diameter of the orbiting bearing helps to get a small inner diameter for the front coupling. But the load ability of the small outer diameter should be equivalent to the original orbiting bearing whose dimension is 283516 (means inner diameter is 28mm; outer diameter is 35mm; length is 16mm， later such express is same). The dimension of the new orbiting bearing that has equivalent load ability is 162416. The outer diameter of this bearing is Φ24mm, and then the minimum inner diameter of the front coupling can be Φ47mm. With the restricting of inner diameter of the housing, the minimum outer diameter of the front coupling can be Φ87mm.

The diameter of the balls in the original compressor is Φ9 mm. It is too big to match the coupling whose outer diameter is Φ87mm, inner diameter is Φ47mm. To match the inner diameter and outer diameter of the coupling, the diameter of the balls is reduced to Φ6.35 mm.

Since the radius compliance device is on the bush, which is inserted in the orbiting scroll, the outer diameter of the bush should be big enough to enclose the compliance device. Unfortunately, if the dimension of the new orbiting bearing is 162416, the outer diameter of the new bush is only 16mm, and then the compliance device has not enough space to locate in. Thus, a new compliance which uses smaller space should be designed to fit the Φ16 bush. The new designed bush is shown in Figure 2. The function of the pin in the original bush is replaced by the convexity in the new bush. The hole located in the original shaft to put the pin into is replaced by the concave in the new shaft, shown in Figure 3.

If the front coupling with outer diameter Φ87 mm is used, the outer diameter of main bearing (a ball bearing), which dimension is 356214, must be reduced since its outer diameter is so big that there is no enough entity in the front flank to support the balls. So the outer diameter of the main bearing must be reduced. A needle bearing whose dimension is 223020 is chosen to supersede the original main bearing. The load ability of the new needle bearing is equivalent to the original main bearing. Thus, a compact design to replace the original compressor is formed. Figure 4 is the crossing section drawing of the new prototype compressor.

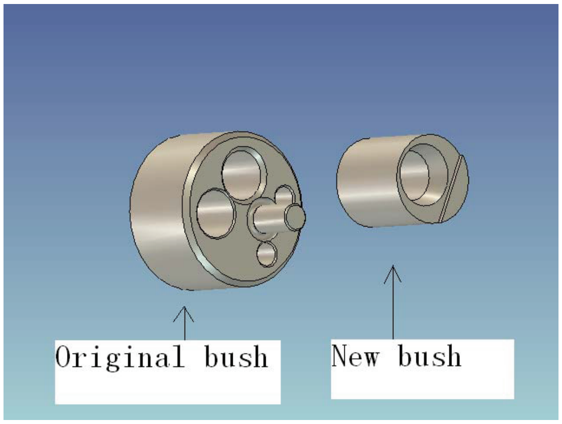

Figure 2: Picture of New bush and original bush

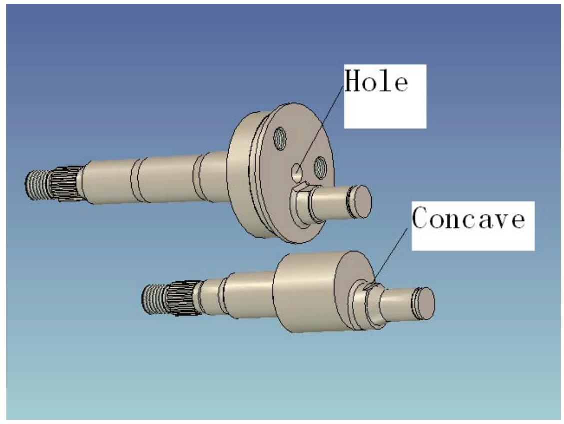

Figure 3: Picture of New shaft and original shaft

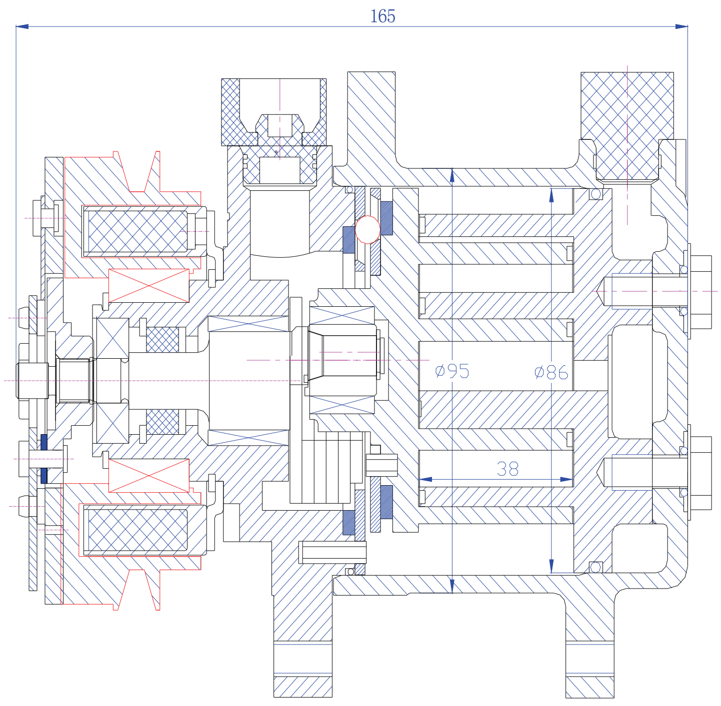

Figure 4: Crossing section drawing of the new prototype compressor

4. EXPERIMENTS

4.1 Performance test for the prototype compressor

The compact design is implemented into a prototype compressor. A performance test is conducted to measure the refrigeration capacity and power consumption. The operating condition is: suction pressure 0.28Mpa; discharge pressure 1.791Mpa; superheat 10℃; subcooling 5℃; revolution 2000rpm. The test result shows the refrigeration capacity decreases 2%, and the power consumption increases 10% comparing with the original compressor. The compressor is also tested in another operating condition. This operating condition is suction pressure 0.30Mpa; discharge pressure 1.5Mpa; superheat 10℃; subcooling 5℃; revolution 2000rpm. The new result shows the refrigeration capacity decreases 1% and the power consumption increases 4% comparing with the original compressor.

4.2 Analyzing the performance test result

According to these test results, it can infer that the tangential leakage (Yi et al., 2003) in the central chamber increases too much due to the height of the scroll increased 15% and leakage area between scrolls wraps, shown in Figure 5 as HI and FG, increases obviously. In order to control the leakage area, the clearance should be reduced. The original clearance is reduced 20% per step, so five compressors with different neck and head clearance are assembled. These five compressors are operated in critical operating condition to get maximum head and neck deforms. The one both without head and neck friction and with minimum clearance is picked up. This method suggests the clearance can be reduced 40%. The tested refrigeration capacity of the clearance reduced compressor is still less 1% than the original compressor and its power consumption is more 3% than the original compressor in the first operating condition.

4.3 Durability test result for the prototype compressor

Two of the clearance reduced compressors are tested in durability test condition. The durability test is composed by two parts. One part is low speed condition, simulating the cars idle, suction pressure 0.38-0.45 Mpa; discharge pressure 2.51-2.86 Mpa; revolution 510-770 rpm; clutch 10 minutes on, 1 minute off. Another part is high speed condition, simulating cars on highway, suction pressure 0.13-0.24 Mpa; discharge pressure 1.27-1.34 Mpa; revolution 4500-5500 rpm; clutch 10 seconds on, 5 seconds off. The technical standard requires that a compressor can experience both conditions for 500 hours without malfunction.

One compressor experienced the high speed condition test for 400 hours, and then the compressor was malfunction. Each part was scrutinized, and it was found several Φ6.35 mm. balls were broken. Another compressor experienced the low speed condition for 450 hours, and then was malfunction, too. It was found that several Φ6.35 mm balls were also broken. Later, bigger diameter balls, whose diameter are Φ6.75 mm, were used, but the condition did not improved, several balls still were broken at approaching life time. If the original Φ9 mm balls still are used, the outer diameter of the compressor housing will resume to the original Φ106 mm, and then the task will failure. Now the key of the task is to find a solution to eliminate the balls broken, or substitute the function of balls without increasing the outer diameter of the housing.

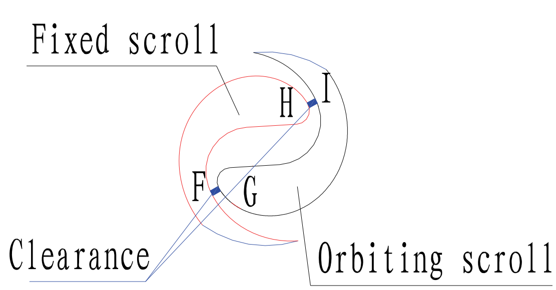

Figure 5: Clearance between scroll neck and head

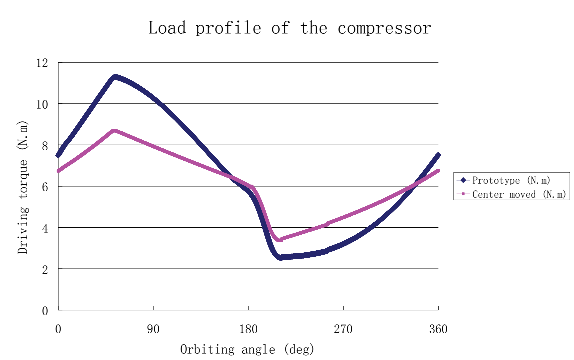

Figure 6: Load profile for the prototype compressor

5. IMPROVEMENT

5.1 Improvement in the compressor load profile

It was found that there is a rule in the broken balls for each failure compressor. The rule is that only three balls are broken and the position is same in each failure compressor. This means the load profile of the compressor is not smooth. It must have a sharp apex in the load profile. The load profile is calculated by the simulation program (Yi et al., 2004). It is shows that there is an apex at the orbiting angle 54° , shown in Figure 6. When the center of the scroll is moved close to the orbiting bearing center from 2.4 mm to 1 mm, the load profile looks flat. A new compressor with scroll center moved 1.4 mm to the orbiting bearing center was tested in the duration operating condition. This compressor experienced the high speed condition for 500 hours, and the low speed operating condition for 250 hours, and then malfunction. The wrong part is still the broken balls. It seems that the prototype compressor cannot meet the standard requirement, unless a new device is applied to replace the balls.

5.2 Reform in the driving device

Eventually, pins are used to replace the function of balls. The pins are directly inserted into the orbiting scroll. The rear coupling is cancelled. The taper holes in the front coupling are transformed into cylinder holes. One side of the front coupling touches the orbiting scroll to function as thrust bearing. In order to brief the machining of the front coupling and reducing its deformation, the cylinder holes in the front coupling are reduced from the original sixteen to four. Its crossing section picture is shown in Figure 7.

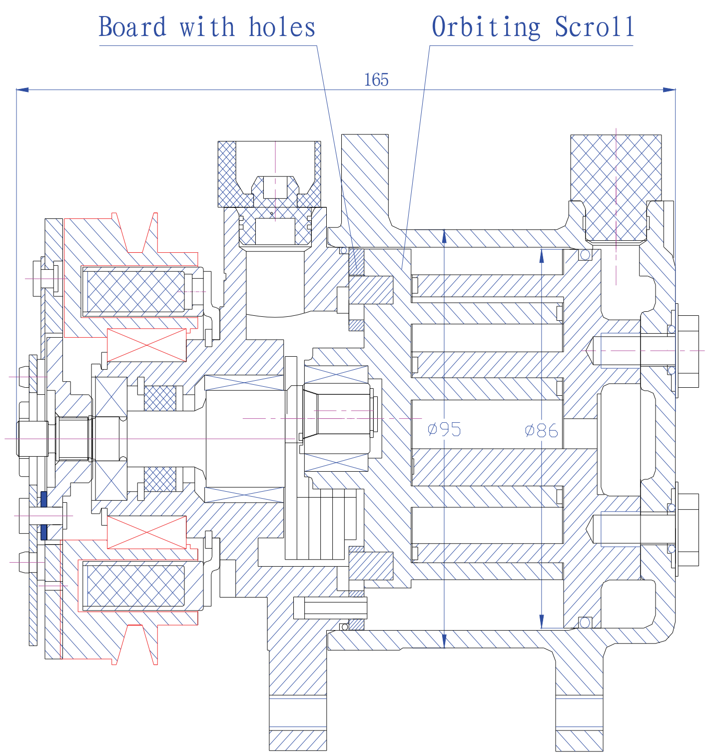

Figure 7: Crossing section drawing of the improved compressor

The improved compressor is tested in the duration operating condition. It experienced for 500 hours in the low speed operating condition and for 500 hours in the high speed condition. After the duration test, the compressor was opened to scrutinize each part. Fortunately, each part keeps well condition.

6. CONCLUSIONS

A task to develop a compact compressor without reducing its suction volume is described in this paper. It shows that the original compressor can be compacted by applying new devices, such as long needle bearing, convexity bush. The compressor life time can be improved by optimizing design, such as changing offset distance between the center of the scroll and the center of the orbiting bearing. The life time can also be prolonged by using new device, such as pins coupling. The test result also shows that the performance is not optimized when the volume of the compressor is minimum. In other word, the downsize compressor cannot be the compressor with the highest EER.

NOMENCLATURE

V	volume of suction chamber	h	height of the scroll involutes
r_b	radius of the basic circle	r_o	orbiting radius
ϕ_e	ending involute angle of scroll		

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