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J. Lee
Samsung Electronics Co. Ltd.

S. Kim
Samsung Electronics Co. Ltd.

S. Lee
Samsung Electronics Co. Ltd.

Y. Park
Samsung Electronics Co. Ltd.

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INVESTIGATION OF AXIAL COMPLIANCE MECHANISM IN SCROLL COMPRESSOR

Joonhyun Lee, Seonkyo Kim, Seungkap Lee, Yoonser Park
Living System R & D Center
Thermo Fluid Engineering Group
Samsung Electronics Co., Korea

ABSTRACT

In this study we analyzed the effects of the volume of biasing chamber, the diameter of bleed hole, the pressure of biasing chamber, and the stiffness of spring supporting fixed scroll to bearing housing. This paper suggests an optimum method with experimental and theoretical approaches about the mechanism of axial compliance. As a result, the optimum dimensions has been found which increases the efficiency by 15% over that of previous scroll compressor.

INTRODUCTION

Recently, scroll compressors are gaining more popularity over rotary compressors for its higher efficiency, lower noise level & vibrations, compact size, and light weight etc. The mechanism of axial compliance is important to ensure an efficient scroll compressor. It has been found that the tilting motion of fixed scroll significantly reduces the compressor's performance. For this reason, we have to measure the motion of fixed scroll and the biasing pressure of biasing chamber. To prevent the tilting motion and improve the efficiency of the compressor, the optimum mechanism of axial compliance needs to be identified.

ANALYSIS

1. The Dynamic characteristics of Fixed Scroll

Four forces are considered in the present study to analyze the dynamic characteristics of the fixed scroll. In this case, the fixed scroll is subjected to axial gas force, spring force, forces by discharge pressure and back pressure, and overturning moment. The axial clearance of the fixed scroll is determined by the equilibrium of four forces. The resultant thrust force is caused by the force differences between the downward and the upward force which are exerted on the fixed scroll. The downward force is theoretically greater than the upward force, so the fixed scroll is considered to be contacted with the orbiting scroll.

(1) Back Pressure Force

The back force caused by the biasing pressure is calculated from the polar position of bleed hole and the cross sectional area of the biasing chamber. The biasing pressure is measured using the pressure gage and compared with theoretical value which is calculated from the equation:

$$P_s = \frac{P_r (2 \alpha_{max} - 3 \pi - \theta)'}{4\pi (\gamma - 1)} [2(\gamma - 1)\theta(2\lambda - 3\pi)^{\gamma - \gamma} + (2\lambda - 3\pi)^{1 - \gamma} - (2\lambda + \pi - 2\theta)^{1 - \gamma}]$$

where $P_r$ is the suction pressure, $\alpha_{max}$ is the maximum wrap angle, $\theta$ is the angle of the wrap thickness, $\lambda$ is the angle of bleed hole, $\gamma$ is the adiabatic index.

(2) Discharge Pressure Force
The discharge force caused by the discharge pressure is computed by the discharge gas pressure and the area of the fixed scroll which is exposed to the discharge chamber. The discharge force is calculated from the equation:

\[ F_d = \frac{\pi d^4}{4} \times P_d \]

where \( d \) is the area of the fixed scroll exposed to the discharge chamber.

3) Axial gas force

The axial force is caused by the pressure distribution over the compression chambers between the fixed and orbiting scroll. The axial force is calculated from the equation:

\[ F_a = P_n \left\{ \sum_{i=1}^{n} A_i P_n + (\pi R_n^2 - A_i) \right\} \]

where \( A_i \) is the area of the \( i \)th compression chamber, \( P_n \) is the pressure of the \( i \)th compression chamber, and \( R_n \) is the suction chamber radius.

4) Spring Force

The force caused by the displacement of the spring is computed by the following equation:

\[ F_s = N \times K \times \delta \]

where \( N \) is the number of the spring, \( \delta \) is the displacement of spring, and \( K \) is the stiffness.

The overturning moment is exerted on the fixed scroll, which causes the tilting of the fixed scroll. The tilting motion is a main cause of the reduction of a compression efficiency and the increase of noise level. The resultant thrust force, the biasing pressure and the springs need to be designed properly to retain stable motion. This can be achieved by the following conditions.

\[ M_o < F_t \times R \]

\[ F_t = F_b + F_d - F_a - F_s \]

where \( M_o \) is the overturning moment caused by gas force, \( R \) is the maximum radius of the thrust bearing, \( F_t \) is the resultant thrust force, \( F_b \) is the back pressure force, \( F_d \) is the discharge gas force, \( F_s \) is the spring force, and \( F_a \) is the axial gas force.

If we choose the minimum resultant thrust force and the back force in order to prevent the fixed scroll from overturning when the spring is attached to the half position of scroll wrap's height and the radius of the thrust bearing is given, we can design the biasing pressure from the above conditions where the cross sectional area of biasing chamber is given.

**EXPERIMENT**

In order to verify the optimum resultant thrust force, the pressure of the biasing chamber and the behavior of the fixed scroll, the following experiments are performed. The experimental apparatus is shown schematically in Fig. 1. Table 1 is the specification of the scroll compressor. The pump of the compressor has been assembled by the bolted case.

A piezoresistive pressure transducer has been attached at the biasing chamber, where the piezoresistive pressure transducer measures both static and dynamic pressure. The three gap sensors have also been attached at three points of top-flange to measure the axial behavior of the fixed scroll. The gap sensor using this experiment is a kind of sensor utilizing eddy current. These experiments have been performed with varying the volume of a biasing chamber, the diameter of a bleed hole, the polar position of a bleed hole and the stiffness of a spring. The relationship between the pressure of biasing chamber and the axial behavior of the fixed scroll has been analyzed.

**RESULTS**

1. Experimental Results
Under varying the volume of the biasing chamber, the diameter of the bleed hole, the polar position of the bleed hole and the stiffness of the spring, the axial behavior of the fixed scroll and the biasing pressure has been measured.

1) The effect of volume of the biasing chamber

As the volume of biasing chamber increases from 14.31 cc to 51.23 cc, the fluctuation of the biasing pressure and the average pressure decreases as shown in Fig. 2. The average pressure of biasing chamber continuously decreases until the volume of biasing chamber reaches a certain volume (displacement volume) after which almost no change occurs as shown Fig. 2.

Also as the volume of biasing chamber increases from 14.31 cc to 51.23 cc, the clearance between the fixed scroll and orbiting scroll increases as shown in Fig. 3. Fig. 3 shows that the magnitude of the axial motion of the fixed scroll decreases with increasing volume of the biasing chamber. Especially for case of the volume of 38.08 cc, the axial clearance between fixed scroll and orbiting scroll are nearly same as that of 51.23 cc.

2) The effect of diameter of the bleed hole

As the diameter of bleed hole increases from 1.0 mm to 2.0 mm, the fluctuation of biasing pressure increases as shown in Fig. 4. Also the pressure of biasing chamber increases with increasing diameter of the bleed hole.

As the diameter of bleed hole decreases from 2.0 mm to 1.0 mm, the magnitude of axial behavior of fixed scroll increases as shown in Fig. 5. Larger diameter of bleed hole causes larger axial motion of the fixed scroll. The compression efficiency, therefore, is deteriorated because of the increase the axial clearance between the fixed and orbiting scroll.

3) The effect of position of the bleed hole

As the position of the bleed hole gets closer to the center of the scroll wrap, the pressure of the biasing chamber increases due to the increased pressure of the compression chamber which is connected via bleed hole (Ø 1.5 mm). When the bleed hole is located toward the center of the scroll wrap, the fluctuation of the biasing pressure increases as shown in Fig. 6.

Also as the pressure of the biasing chamber increases, the magnitude of axial motion of fixed scroll decreases as shown in Fig. 7, and vice versa.

4) The effect of stiffness of spring

Increasing the stiffness of spring from 5 kgf/mm to 29.5 kgf/mm, causes increase in magnitude of the axial motion of the fixed scroll as shown in Fig. 8, and vice versa.

5) The relationship between the pressure of biasing chamber and axial behavior of fixed scroll

It can be found that the motion of the fixed scroll is not only limited to the axial motion but also a tilting motion can be generated as shown in Fig. 9. This is caused by the overturning moment exerted on the fixed scroll. Because the tilting motion increases the radial and axial clearance between the fixed and the orbiting scroll, and decreases the compression efficiency, a systematic study to minimize the tilting motion of the fixed scroll is required in order to produce an efficient scroll compressor.

DISCUSSION

A new mechanism of axial compliance using slidable pins and several springs makes the tilting motion negligible, and, therefore, improves the efficiency by 15% over that of a conventional scroll compressor without slidable pin & spring mechanism. In order to minimize the friction loss at the thrust bearing and prevent the fixed scroll from tilting motion, the optimum resultant thrust force is considered to be about 200 ~ 250 N.

CONCLUSION

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In this paper the dynamic characteristics of a fixed scroll have been analyzed, experiments to measure the pressure in the biasing chamber and the behavior of the fixed scroll have been performed and a new axial compliance mechanism of a scroll compressor has been developed. The following conclusions are obtained.

1. The static and dynamic pressure in the biasing chamber are increased with decreasing of the volume of the biasing chamber.

2. The motion of the fixed scroll becomes stable with decreasing the diameter of the bleed hole.

3. The static and dynamic pressure in the biasing chamber are increased when the polar position of bleed hole is located toward the center area of the scroll wrap.

4. The motion of the fixed scroll becomes unstable with increasing stiffness of spring supporting the fixed scroll to the bearing housing, and increasing of distance of the attached point from the center of scroll wrap's height.

5. The fixed scroll is tilted in the normal operation, this tilting motion causes the deterioration of the compressor efficiency in a scroll compressor.

REFERENCES

(1) Tojo, K et al., 1986, "Computer Modeling of Scroll Compressor with Self Adjusting Back-Pressure Mechanism", Proc. of International Compressor Engineering Conference at Purdue, pp. 872-885


Table 1 Specification of the scroll compressor

<table>
<thead>
<tr>
<th>SCROLL COMPRESSOR</th>
<th>Capacity</th>
<th>Displacement</th>
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<tr>
<td>(Variable speed)</td>
<td>28,000 Btu/h</td>
<td>38.08 cc/rev</td>
</tr>
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(a) The cross sectional view

(b) The position of the gap sensor

Fig. 1 The simplified schematic of the experimental setup
Fig. 2 Variation of the biasing pressure with the volume of the biasing chamber

Fig. 4 Variation of the biasing pressure with the diameter of the bleed hole

Fig. 3 Variation of the motion of the fixed scroll with the volume of the biasing chamber

Fig. 5 Variation of the motion of the fixed scroll with the diameter of the bleed hole
Fig. 6 Variation of the biasing pressure with the position of the bleed hole

Fig. 7 Variation of the motion of the fixed scroll with the position of the bleed hole

Fig. 8 Variation of the motion of the fixed scroll with the stiffness of the spring

Fig. 9 Tilting motion of the fixed scroll