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EFFECT OF SCROLL WRAPS ON PERFORMANCES OF SCROLL COMPRESSOR

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ABSTRACT

A number of geometrical curves have been used to form the wraps of scroll compressor. When the suction pressure, pressure ratio, scroll wrap height and thick, and the suction volume are constant, the effects of involute curves of circle, square, and line segment on performances of scroll compressor, such as geometrical parameters, leakage wire length, and various of gas forces acting on the orbiting scroll are analyzed in this paper. These effects of scroll wraps on performances of scroll compressor vary as the suction volume changes. The research results in this paper should be considered in scroll compressor design.

INTRODUCTION

Scroll wraps are the important basis on scroll compressor design. The performances of scroll compressor are in close relationship with scroll wraps.

Scroll compressor's geometric theory of involute wraps of circle, line segment, and square have been derived1,2. On the basis of these theories, the prototype scroll compressor for air conditioner was developed and tested. To reduce housing diameter, scroll compressor with offset wraps or revised inner curves is devised and designed3. The effects of involute curves of circle, square, and line segment on performances of scroll compressor, such as geometrical parameters, leakage wire length, and various of gas forces acting on orbiting scroll are analyzed and calculated in this paper.

GEOMETRICAL THEORY

The calculating relations of the compression chamber volume composed of involute wraps of circle, square, and line segment have been derived1,2,4. Where only the relation of compression end volume is given.

Line segment involute wrap

\[ V_d = \pi h (l - t) \cdot \left[ 5l - t + \frac{180 - \theta^*}{180} (7l - t) + \frac{\theta^*}{180} (3l - t) \right] \]  \(1\)

where \( h \) is the wrap height, \( t \) is the wrap thick, \( \theta^* \) is the crank angle corresponding to the compression end. i.e. the discharge angle.

Circle involute wrap

\[ V_c = \pi P (P - 2t) \cdot \left( 3 - \frac{\theta^*}{\pi} \right) \cdot h \]  \(2\)

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where \( P \) is wrap pitch, \( \theta_v^* \) is discharge angle.

**Square involute wrap**

\[
V_{\infty} = \frac{\theta_v^*}{180} \pi h \left[ (4a - t)^2 - 4a^2 \right] + \frac{\pi}{2} \sum_{j=1}^{3} \left[ (4 + j)a - t \right]^2 \]

\[
- (2 + j)^2 a^2 + \frac{90 - \theta_v^*}{180} \pi h \left[ (8a - t)^2 - 36a^2 \right]
\]  

\[(3)\]

where \( a \) is the side length of square, \( \theta_v^* \) is the crank angle at compression end.

To compare the effects of three kinds of involute wraps on the geometric parameters of scroll compressor, the follow parameter are supposed to be constant.

- wrap height \( h = 40 \text{mm} \)
- wrap thick \( t = 3.5 \text{mm} \)
- volume ratio \( \varepsilon = 3 \)

If the compression end volume is also a constant, the characteristic parameter circle radius, line segment length, and square side length expressing the involute wraps of circle, line segment, and square can be derived from equations \((1)\) \(\sim\) \((3)\). The other parameters can be also calculated. The calculation results are shown in table 1.

Table 1 shows that if the suction volume, compression ratio, wrap height and thick are supposed to be constant, the compression chamber number or scroll turns of circle involute wrap is least, while that of line segment is most. Whether circle, line segment or square, as the suction volume increases, the characteristic parameters and compression chamber number get greater, while suction end angle get less. As for involute wrap of circle, discharge angle decreases as the suction volume increases.

<table>
<thead>
<tr>
<th>Type of involute wrap</th>
<th>Characteristic parameter (mm)</th>
<th>Compression chamber number (N)</th>
<th>Suction end angle ( \theta_v ) (deg)</th>
<th>Discharge angle ( \theta^* ) (deg)</th>
<th>Suction volume ( V_{\infty} ) (cm(^3))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Segment</td>
<td>6.91</td>
<td>4.004</td>
<td>358.5</td>
<td>90</td>
<td>80</td>
</tr>
<tr>
<td>Circle</td>
<td>2.459</td>
<td>2.937</td>
<td>22.7</td>
<td>247.5</td>
<td>80</td>
</tr>
<tr>
<td>Square</td>
<td>3.591</td>
<td>3.758</td>
<td>87</td>
<td>90</td>
<td>80</td>
</tr>
<tr>
<td>Segment</td>
<td>8.137</td>
<td>4.035</td>
<td>347.5</td>
<td>90</td>
<td>130</td>
</tr>
<tr>
<td>Circle</td>
<td>2.898</td>
<td>3.035</td>
<td>236</td>
<td>236</td>
<td>130</td>
</tr>
<tr>
<td>Square</td>
<td>4.238</td>
<td>3.79</td>
<td>74</td>
<td>90</td>
<td>130</td>
</tr>
<tr>
<td>Segment</td>
<td>9.15</td>
<td>4.058</td>
<td>339</td>
<td>90</td>
<td>180</td>
</tr>
<tr>
<td>Circle</td>
<td>3.2546</td>
<td>3.104</td>
<td>322.5</td>
<td>227.5</td>
<td>180</td>
</tr>
<tr>
<td>Square</td>
<td>4.774</td>
<td>3.817</td>
<td>66</td>
<td>90</td>
<td>180</td>
</tr>
</tbody>
</table>

**OTHER PARAMETERS AFFECTING SCROLL COMPRESSOR PERFORMANCES AND HOUSING DIAMETER**

Crank eccentric distance, i.e. the distance between orbiting scroll center and fixed scroll center, and the terminal point coordinate value of involute wrap have direct effect on the structure parameters of scroll compressor. Leakage wire length of axial clearance mainly influences the volumetric efficiency.

The crank eccentric distance is given as follows:
\[ r = P/2 - t \]  \hspace{1cm} (4)

where \( P \) is the wrap pitch. Circle involute wrap \( P = 2\pi a \), \( a \) is the radius of generating circle. Line segment involute wrap \( P = 2l \), \( l \) is the line segment length. Square involute wrap \( P = 4a \), \( a \) is the square side length.

The leakage wire length of radial clearance is the scroll wrap height, that of axial clearance is given as follows:

**Involute wrap of line segment**

\[ L_a = \pi(l - \frac{t}{2}) + \pi \sum_{i=2}^{N} \left[ (2i - 1)l - \frac{t}{2} \right] + \pi \sum_{i=1}^{N} (2il - \frac{t}{2}) \]  \hspace{1cm} (5)

where \( N \) is the compression chamber number, \( l \) is line segment length.

**Involute wrap of circle**

\[ L_c = \sum_{i=1}^{N} 2\pi a (2i\pi - \theta) \]  \hspace{1cm} (6)

where \( a \) is the radius of generating circle.

**Involute wrap of square**

\[ L_s = \frac{\pi}{4} \sum_{i=1}^{N} \left( (4i - 1)a - \frac{t}{2} \right) + \left( (4i - 2)a - \frac{t}{2} \right) \]
\[ + \left( (4i - 3)a - \frac{t}{2} \right) + (4ia - \frac{t}{2}) \]  \hspace{1cm} (7)

where \( a \) is the square side length.

If \( h = 40\text{mm}, \ t = 3.5\text{mm}, \text{ and } \epsilon = 3 \) are chosen, the structure parameters can be derived. The calculating results are shown in table 2.

**Table 2 The main structure parameters of scroll compressor**

<table>
<thead>
<tr>
<th>Type of involute wrap</th>
<th>( r ) (mm)</th>
<th>( \Delta ) (mm)</th>
<th>Leakage wire length (mm)</th>
<th>Suction volume ( V_{cc} ) (cm(^3))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Segment</td>
<td>3.41</td>
<td>57.73</td>
<td>576.69</td>
<td>80</td>
</tr>
<tr>
<td>Circle</td>
<td>4.226</td>
<td>49.18</td>
<td>490.59</td>
<td>80</td>
</tr>
<tr>
<td>Square</td>
<td>4.3</td>
<td>55.79</td>
<td>634.71</td>
<td>80</td>
</tr>
<tr>
<td>Segment</td>
<td>4.637</td>
<td>69.26</td>
<td>724.86</td>
<td>80</td>
</tr>
<tr>
<td>Circle</td>
<td>5.6</td>
<td>57.46</td>
<td>568.18</td>
<td>80</td>
</tr>
<tr>
<td>Square</td>
<td>4.976</td>
<td>66.30</td>
<td>772.15</td>
<td>80</td>
</tr>
<tr>
<td>Segment</td>
<td>5.65</td>
<td>78.06</td>
<td>849.71</td>
<td>80</td>
</tr>
<tr>
<td>Circle</td>
<td>6.725</td>
<td>65.96</td>
<td>666.72</td>
<td>80</td>
</tr>
<tr>
<td>Square</td>
<td>6.048</td>
<td>75.11</td>
<td>885.15</td>
<td>80</td>
</tr>
</tbody>
</table>

Table 2 shows that if the scroll wrap height and thickness, the compression ratio, and the suction volume are the same, the crank eccentric distance \( r \) of line segment involute wrap is least, while the distance from line segment center to involute wrap terminal point is greatest. The distance from circle center to circle involute wrap terminal point is least. This distance directly influences the housing diameter. Comparing the circle involute wrap with the line segment and square involute wraps, it is found that the scroll compressor using circle involute wrap will have the most compact shape and the least leakage wire length of axial clearance.

Leakage wire length of axial clearance increases as the suction volume extends.
(Figure 1), the increasing tendency of line segment involute wrap being similar to that of square involute wrap, while the increasing rate of circle involute wrap being least. The distance from wrap terminal point to characteristic shape center will increase when suction volume gets larger (Figure 2), the increasing rate of circle involute wrap being least.

\[ t = 3.5 \text{mm} \]
\[ h = 40 \text{mm} \]
\[ \varepsilon = 3 \]

\[ \Delta \]
\[ \text{mm} \]

**EFFECT OF INVOLUTE WRAP TYPE ON GAS FORCES**

Orbiting scroll is assembled between fixed scroll and frame, and can move in axial direction. When scroll compressor operates, the orbiting scroll will be pushed by axial gas force and separates the fixed scroll, arising in compression efficiency to decrease. The axial gas force can be calculated using follow relation:

\[
F_a = \begin{cases} 
  p_s A_i (\rho_i - 1) + p_s \sum_{i=1}^{N} A_i (\rho_i - 1) & \theta \leq \theta < \theta^* \\
  p_s A_i (\rho_i - 1) + p_s \sum_{i=1}^{N} A_i (\rho_i - 1) & \theta^* \leq \theta \leq 2\pi
\end{cases}
\]

where \( p_s \) is suction pressure, \( A_i \) is the acting area of gas force in the \( i \) compression chamber, \( \rho_i \) is the pressure ratio of \( p_s \) and the gas pressure \( p_i \) in \( i \) chamble, \( \theta^* \) is the discharge angle, \( F_a \) is the axial gas force acting on orbiting scroll.

Radial gas force is the gas force acting on orbiting scroll in radial direction. The calculating relation is given by

**Line segment involute wrap**

\[
F_r = \sum_{i=1}^{N} F_{ri} = h \cdot l \cdot p_s (\rho_i - 1) \cdot \sin\theta
\]

where \( F_{ri} \) is the radial gas force acting on the orbiting scroll in compression chamber \( i \), \( l \) is line segment length, \( \rho_i \) is the ratio of discharge pressure and suction pressure.

**Circle involute wrap**

\[
F_r = 2\pi \cdot a \cdot p_s \cdot (\rho_i - 1)
\]

where \( a \) is the radius of generating circle.
Square involute wrap

\[
F_r = \begin{cases} \\
\sqrt{2}a h_p \times (\rho_l - 1) \cdot \cos(135 - \theta) & 0 \leq \theta \leq 90^\circ \\
\sqrt{2}a h_p \times (\rho_l - 1) \cdot \cos(\theta - 45) & 90^\circ \leq \theta \leq 180^\circ \\
\sqrt{2}a h_p \times (\rho_l - 1) \cdot \cos(135 - \theta) & 180^\circ \leq \theta \leq 270^\circ \\
\sqrt{2}a h_p \times (\rho_l - 1) \cdot \cos(\theta - 225) & 270^\circ \leq \theta \leq 360^\circ 
\end{cases}
\]

(11)

where \(a\) is the square side length.

Gas resistance moment has direct effect on operating properties of motor and input power of scroll compressor. Gas resistance moment is expressed by

\[
M_r = r \cdot \sum_{i=1}^{N} F_{ri}
\]

(12)

where \(r\) is crank eccentric distance, \(F_{ri}\) is the tangential force acting on orbiting scroll in compression chamber \(i\).

If the basic parameters of three kinds of involute wraps are those in Table 1 and Table 2, when \(p_a = 0.63\) MPa and gas adiabatic index \(k = 1.2\), the axial and radial gas forces and gas resistance moment acting on orbiting scroll can be calculated using equations (8) – (12).

Figure 3 Axial gas forces acting on orbiting scroll \(\alpha s\). crank angle

Figure 4 Radial gas forces acting on orbiting scroll \(\alpha s\). crank angle
In figure 3, figure 4, and figure 5, (a) express the case that suction volume $V_{cc}$ is equal to 80cm$^3$, and (b) express the case that suction volume $V_{cc}$ is equal to 130cm$^3$. Figure 3 shows that if operating conditions are same, the axial gas force acting on orbiting scroll of circle involute wrap is least but its fluctuation is greatest. As suction volume enlarges, axial gas forces of three types of involute wraps will increase, while increment of the fluctuation of circle involute wrap is greatest. Figure 4 shows that radial gas force acting on orbiting scroll using circle involute wrap bears no relation to the crank angle. Figure 5 shows that the fluctuation and its increment of gas resistance moment using circle involute wrap is greater than that of line segment and square involute wraps.

**CONCLUSIONS**

(1) If wrap height and thick, suction volume, and compression ratio of scroll compressor are supposed to be constant, the compression chamber number comprising circle involute wrap will be least, and the distance from wrap terminal point to the geometry center of characteristic shape and the leakage wire length of circle involute wrap are shortest.

(2) As operating conditions are same, the fluctuation of axial and radial gas forces and gas resistance moment acting on orbiting scroll being formed of square involute wrap are least, while those of circle involute wrap are greatest.

(3) Whether it is formed of line segment, circle or square involute wrap, the gas forces and moment acting on orbiting scroll of scroll compressor will increase as the suction volume extends.

**SYMBOLS**

**Nomenclature**

- $a$  
  Radius of generating circle  
  or square side length
- $A$  
  Acting area of axial gas force
- $F_a$  
  Axial gas force
- $F_r$  
  Radial gas force
- $h$  
  Scroll wrap height
- $k$  
  Gas adiabatic index
- $l$  
  Line segment length
- $L$  
  Leakage wire length
- $M_r$  
  Gas resistance moment

---

**Figure 5** Gas resistance moment acting on orbiting scroll $V.S.$ crank angle
\( N \) Compressor chamber number
\( p \) Scroll wrap pitch
\( p_s \) Suction pressure
\( r \) Crank eccentric distance
\( t \) Scroll wrap thick
\( V_r \) Gas volume at compression end
\( V_s \) Suction volume

Greek letters
\( \varepsilon \) Volume ratio
\( \theta \) Crank angle
\( \theta_s \) Suction end angle

\( \theta^* \) Discharge angle
\( \rho \) Pressure ratio
\( \Delta \) Distance from the geometry center of characteristic shape to the involute wrap terminal point

Subscripts
\( i = 1,2 \) first and second
\( a \) axial direction
\( c \) Circle
\( l \) Line segment
\( s \) Square

REFERENCES