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GEOMETRICAL ANALYSIS OF SCROLL COMPRESSOR
FOR HIGH PRESSURE RATIO

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ABSTRACT
The applied range of scroll compressor has been enlarged continuously because of its high efficiency, low noise, small size, and so on. There are some methods for single scroll compressor to perform the high pressure ratio, such as adopting discharge valve, increasing the roll angle of scroll wrap, etc. The present article mainly discusses two other ways for one compressor to reach the high pressure ratio. One way is to change the height of scroll wrap, the other is to alter the position and shape of discharge port. The models used to calculate the working pocket volume and the discharge port flow area are set up. This study lays the theoretical basis for designing the high pressure ratio scroll compressor.

INTRODUCTION
The scroll compressor has been put into commercial use since the early 1980's, more attention has been paid towards the scroll fluid machinery because of its advantages, such as high efficiency, low noise, high reliability and so on. The applied range of scroll fluid machinery has been enlarged continuously. The scroll compressor was first produced in the early stage [1], then the scroll vacuum pump was developed [2], the scroll oil pump was also manufactured [3]. The structure patterns of the scroll fluid machinery are more and more consequently. The built-in compression ratio of the scroll compressor is low at present, as a result, its applied range is restricted to a certain extent. The main reason is that the final roll angle of the involute spiral is too great when the built-in compression ratio is high. The greater the final roll angle, the greater the area of the radial leakage passage, this not only cuts down the compressor efficiency, but also causes the difficulty in producing an accurate profile. This article briefly discusses two ways to enhance the built-in compression ratio of the scroll compressor. One way is to change the height of scroll wrap, this means to adopt the step profile, the other is to alter the position and shape of the discharge port.
WORKING CHAMBER

The essential profile of the scroll is still the circle involute, some modifications are made in the central part, the wrap height in the central part is lower than the outside part's. The fixed scroll is shown in Fig. 1, the orbiting scroll is shown in Fig. 2.

The operating principle of the scroll compressor with the step profile is shown in Fig. 3. The symmetric crescent shaped chambers are moved towards the center as the crankshaft rotation. At first they are separated, then they open onto each other, after that they are separated again, at last they are merged together and discharged through a single port.

The volume of this type compressor is calculated on the basis of the normal type's. The pocket sealed by the inner curve of the orbiting scroll and the outer curve of the fixed scroll is regarded as the chamber I, the symmetric pocket is regarded as the chamber II. The chamber I and II are treated as the normal scroll compressor's in the range of the equal wrap height.

Suction process

When the crank angle $\theta$ varies from $0$ to $2\pi$, the volume of the outermost crescent shaped chambers increases with the crank angle, at last the volume decreases slightly. The working chambers change from the open pockets into the sealed ones, the suction process is finished. The suction volume is given as follows according to the reference (4):

$$V_s(\theta) = h_o(\theta_2 - \theta - \pi) - 2(\psi_s - \pi + \alpha) \sin\theta - (\pi/2 - \alpha) \sin(2\theta) + 2(1 - \cos\theta)$$

where $a$ is the radius of basic circle, $\alpha$ is the half involute thickness angle, $r$ is the radius of orbit, $\psi_s$ is the maximum roll angle of the scroll wrap.

Compression process

When the crank angle $\theta$ varies from $2\pi$ to $(2N\pi + \theta^*_d)$, the compression process is finished, where $N$ is the number of scrolls (multiply of 0.5), $\theta^*_d$ is the crank angle at the discharge starting position. The volumes of chamber I and II are calculated respectively when the crank angle is in the range $(2N\pi + \alpha_o)$ to $(2N\pi + \theta^*_d)$, where $\alpha_o$ is the angle at which the variation of the wrap height occurs, $\theta^*_d$ is the crank angle at which the chamber I and II are merged together to form the central one.

When the wrap heights of chamber I and II are identical, and equal to $h$, the volumes of chamber I and II are given as:

$$V_{MI}(\theta) = V_{MII}(\theta) = V_h(\theta) = 2\pi a^2(\pi - 2\alpha) h[(2N - 1)\pi - \theta]$$

When the wrap height of chamber I is $h_o$, its volume is given as: $V_{boI}(\theta) = S_{boI}(\theta) \cdot h_o$; when the wrap height of chamber II is $h_o$, its volume is given as: $V_{boII}(\theta) = S_{boII}(\theta) \cdot h_o$, where $S_{boI}$ and $S_{boII}$ are the axonometric projection areas of chamber I and II.

(1) When $2\pi \leq \theta < (2.5\pi + \alpha_o)$, the volume of compression chambers is given as:
\[ V_c(\theta) = V_m(\theta) + V_{MI}(\theta) = 4\pi a^2(\pi - 2\alpha)h \left( (2N - 1)\pi - \theta \right) \]

(2) When \((2.5\pi + \alpha_0) \leq \theta < (3.5\pi + \alpha_0)\), the volume of chamber I is given as:

\[ V_I(\theta) = V_h(\theta) - V_A(\theta) + V_B(\theta) \]

Where \(V_A(\theta)\) is the volume which is reduced owing to the change of the wrap height, \(V_B(\theta)\) is the volume which is increased owing to the tangency of two half circles, one of the half circles is in the wrap of the fixed scroll, the other is in the groove of the orbiting scroll. The volume of chamber II \(V_{II}(\theta)\) is equal to \(V_h(\theta)\).

(3) When \((3.5\pi + \alpha_0) \leq \theta < (4.5\pi + \alpha_0)\):

\[ V_I(\theta) = V_h(\theta) - V_A(\theta) + V_B(\theta) \]
\[ V_{II}(\theta) = V_{boll}(\theta) + V_D(\theta) \]

Where \(V_D(\theta)\) is the volume which is increased owing to the change of wrap height.

(4) When \((4.5\pi + \alpha_0) \leq \theta < (5.5\pi + \alpha_0)\)

\[ V_I(\theta) = V_{boll}(\theta) \]
\[ V_{II}(\theta) = V_{boll}(\theta) + V_B(\theta) + V_D(\theta) \]

(5) When \((5.5\pi + \alpha_0) \leq \theta < (2(N-1)\pi + \theta^*)\)

\[ V_I(\theta) = V_{boll}(\theta) \]
\[ V_{II}(\theta) = V_{boll}(\theta) \]

(6) When \((2(N-1)\pi + \theta^*) \leq \theta < (2N\pi + \theta^*_o)\)

\[ V_c(\theta) = S_o \cdot h_o \]

Where \(S_o\) is the axonometric projection area of the central chamber.

**Discharge process**

The crank angle range of the discharge process is from \((2N\pi + \theta^*_o)\) to \((2N\pi + \theta^*)\), the central chamber is connected with the discharge port through a discharge slot. The volume of the working chamber is given as:

\[ V_c(\theta) = S_o \cdot h_o \]

The volume of working chambers in the whole process \((0 \sim (2N\pi + \theta^*))\) is calculated on the basis of the above analyses, the results are shown in Fig. 4, the volumes of chamber I and II \((V_I, V_{II})\) are also drew in the same figure. The axonometric projection area of the central chamber is shown in Fig. 5.

**DISCHARGE PORT**

In order to increase the built-in compression ratio in the central chamber, the method to control the discharge port connection is taken. There is a discharge slot in the end plate of the orbiting scroll as shown in Fig. 2. The discharge port is located in the wrap of the fixed scroll as shown in Fig. 1. The discharge process is shown in Fig. 6. The points A1, B1, C1, D1, E1, F1, G1, H1 are on the edge of the slot, U, V, W are the centers of the arcs, S is
the center of the discharge port. The points 1, 2 are the points of intersection between the slot and the port.

(1) When the circle S and the arc C1D1E1 intersect at points 1, 2, if \( y_2 > y_1, x_1 \leq x_1, \) the flow area \( S_d \) of the discharge port is as follows:

\[
S_d = \int_{x_1}^{x_2} [f_{C1D1E1}(x) - f_s(x)] dx
\]

if \( y_2 < y_1, \) the circle S and the arc C1D1E1 intersect at point 1, the circle S and the arc A1B1C1 intersect at point 2, if \( y_1 > y_2, x_1 \leq x_1, y_2 \geq y_B, \) then

\[
S_d = \int_{x_1}^{x_2} f_{C1D1E1}(x) dx + \int_{x_1}^{x_2} f_{A1B1C1}(x) dx - \int_{x_1}^{x_2} f_s(x) dx
\]

if \( y_1 > y_2, x_1 > x_1, y_2 \geq y_B, \) then

\[
S_d = \int_{x_1}^{x_2} f_s(x) dx + \int_{x_1}^{x_2} f_{C1D1E1}(x) dx + \int_{x_1}^{x_2} f_{A1B1C1}(x) dx - \int_{x_1}^{x_2} f_s(x) dx
\]

(2) When the circle S and the arc A1B1C1 intersect at points 1, 2, \( y_1 < y_1, \) if \( y_2 > y_1, \) then

\[
S_d = \int_{x_1}^{x_2} f_s(x) dx + \int_{x_1}^{x_2} f_{C1D1E1}(x) dx + \int_{x_1}^{x_2} f_{A1B1C1}(x) dx - \int_{x_1}^{x_2} f_s(x) dx
\]

(3) When \( y_2 = y_1, S_d = \pi R_d^2, \) where \( R_d \) is the radius of the discharge port.

(4) When the circle S and the arc E1F1G1 intersect at points 1, 2,

1. if \( x_1 > x_E, x_2 > x_G, \) then

\[
S_d = \pi R_d^2 - \left[ \int_{x_1}^{x_2} f_s(x) dx + \int_{x_1}^{x_2} f_{E1F1G1}(x) dx - \int_{x_1}^{x_2} f_s(x) dx - \int_{x_1}^{x_2} f_{E1F1G1}(x) dx \right]
\]

2. if \( x_1 > x_E, x_2 < x_G, \) then

\[
S_d = \pi R_d^2 - \left[ \int_{x_1}^{x_2} f_s(x) dx + \int_{x_1}^{x_2} f_{E1F1G1}(x) dx + \int_{x_1}^{x_2} f_{E1F1G1}(x) dx - \int_{x_1}^{x_2} f_s(x) dx - \int_{x_1}^{x_2} f_{E1F1G1}(x) dx \right]
\]

3. if \( x_1 < x_E, x_2 < x_G, \) then

\[
S_d = \pi R_d^2 - \left[ \int_{x_1}^{x_2} f_s(x) dx + \int_{x_1}^{x_2} f_{C1D1E1}(x) dx + \int_{x_1}^{x_2} f_{E1F1G1}(x) dx - \int_{x_1}^{x_2} f_s(x) dx - \int_{x_1}^{x_2} f_{E1F1G1}(x) dx \right]
\]

Where the subscripts of \( f(x) \) express the circle or arc.

The flow area of the discharge port is shown in Fig. 7.

**CONCLUSION**

The model used to calculate the working chamber volume is developed on the basis of
the analysis of the step profile, the discharge port is designed properly so as to increase the built-in compression ratio in the central chamber, the model used to calculate the flow area of the discharge port is also set up. This study lays the theoretical basis for designing the high pressure ratio scroll compressor.

REFERENCES


Fig. 1 Fixed scroll  Fig. 2 Orbiting scroll  Fig. 3 Principle of operation
Fig. 4  Volume of working chambers

Fig. 5  Central chamber area

Fig. 6  Discharge process

Fig. 7  Port flow area