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THE GRAPHIC METHOD OF MODIFIED WRAP OF SCROLL COMPRESSOR

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ABSTRACT

After analyzing the interaction between the cutter and the involute in machining processes of scroll wraps and its influence on the discharge angle and the compression ratio, a new method suggested by present authors for modification of the involute wrap of the scroll compressor is presented in this paper. The new method, different from any other method which has ever been published, includes graphical and analytical solution, and the equation of the discharge angle of a pair of modified scroll wraps is also given. This definition of the modified angle as well as its sense is introduced by the author for the first time. After modification by the new method, the discharge angle sometimes may become 2π and the top clearance may turn into zero. Therefore, a higher compression ratio and compressor volumetric efficiency can be achieved.

NOMENCLATURE

- ε Compression ratio of scroll compressor
- N Number of crescent gas pocket generated by a pair of scroll members
- θ Rotational angle of crank shaft
- θ' Discharge angle
- k Adiabatical index of gas
- d Diameter of cutter
- p Scroll pitch
- t Scroll thickness
- a Radius of the base circle of involute
- R_{or} Rotational radius of crank

INTRODUCTION

The scroll compressor is a new type of volumetric compressor with high-efficiency, energy-saving, material-saving and low-noise characteristics. It can be widely used in many industrial fields such as air conditioning, refrigeration, vacuum-pumping and gas compression, and it can be expected to partly replace the other types of mini-compressor in the future. A key and very important problem in the design of such a compressor is the wraps modification of the scroll component. This problem has attracted more and more attention from researchers worldwide and its solution is approaching gradually [1]. In this paper, a new method which includes both graphical and analytical solution for wraps modification is presented, and the result has been applied to the design of a scroll compressor.

1. The Compression Ratio of The Scroll Compressor and Its Influence Factors

Several types of mathematical curves can be adopted as scroll wraps configurations, examples include the involute of a circle, the involute of a line segment, and the Archimedean spiral. Among these, the involute of a circle is widely used in the current design practice. The research work reveals that a scroll compressor, whose scroll wraps are machined according to a single curve model of either the involute of a circle or the Archimedean spiral, is of not only lower volumetric ratio but lower volumetric efficiency as well. Taking the processing of an involute of a circle as an example, a further investigation on this problem can be carried out.

The compression ratio of a scroll compressor can be calculated by the following equation [2]:

$$\varepsilon = [(2N-1)/(3-\theta'/\pi)]^{k} \qquad (1)$$

It is clear from equ.(1) that the compression ratio of a scroll compressor for a special gas is closely related to the number of the crescent compressed volumes N and the discharge angle of the compressor θ'. Beacuse N is not as great as the ring number of a scroll wrap and is normally taken as 2 ~ 4 in the design of a scroll compressor, the other parameter θ' plays a more important role, and this requires more attention and discussion.

The so-called discharge angle θ' is the rotational angle of the main shaft corresponding to the last pair of meshing points of the innermost closed crescent compression volume. According to this definition, when the rotational angle θ becomes greater than the discharge angle θ', the last pair of meshing points of the innermost wraps disconnects, and the two innermost closed crescents then connected with each other and both of these connected to the gas discharge hole, which indicates the end of the compressing process and the commencement of discharge.

The value of the discharge angle primarily depends on the interaction of the cutter in the machining process of the involute wrap. This interaction is illustrated in Fig. 1. If a milling is used, the diameter of the milling cutter is required to satisfy the following condition:

$$d < P - t \qquad (2)$$

When the scroll wraps are milled by using the two-side forming method, the cutter diameter is

$$d = P - t \qquad (3)$$

If a cutter with smaller diameter is not used to replace the operating cutter when a certain point A on the involute is reached, it is impossible to continue the milling process of the involute wrap as the remaining part of the involute will be an arc of a circle with the same radius as that of the cutter.

In fact, it is difficult to replace the cutter frequently in the actual machining process owing to the fact that the processing precision may be largely influenced by such actions. On the other hand, as a cutter with a smaller diameter has less rigidity and thus may produce or aggravate the tremblings, the replacement of the operating cutter by a cutter with smaller diameter may have great effects on the size and surface precision of the machined element.

The meshing state between the two scroll wraps, which are interacted by the cutter in the machining process, is shown in Fig. 2. It is clear from this figure that there is not any contact between the two scroll wraps when $\theta > 300°$, and so the discharge angle θ' is approximately equal to $300°$. Therefore the two scroll elements can not mesh correctly with each other, because the shape of the involute wrap has been changed by the cutter in the machining process.

Wraps modification is an effective method for solving the above mentioned problem. If modified appropriately and neglecting the influence of the size of the gas discharge hole and the thickness of the scroll wrap, the discharge angle of the compressor sometimes may reach $360°$ and the top clearence may turn into zero. This increases not only the compression ratio of the compressor but also its volumetric efficiency.

2. A New Method of Wraps Modification of The Scroll Compressor

Many investigators have been working to develop more effective methods for wrap modification. A new wrap modification method has been developed by the authors in their theoretical study and engineering design of the scroll compressor in recent years. By this method, not only a graphical result can be derived, but an accurate numerical result can be calculated with analytical equations as well.

As shown in Fig. 3, $\odot O_1$ is the generating circle of the involute of a scroll wrap. Through point O_1, the center of $\odot O_1$, draw a straight line with an inclination γ measured from abscissa. Take a line segment O_1B and let its length be equal to the half crank radius of the crank shaft. Through point B, draw an angle β, which satisfies the following equation:

$$\mathrm{ctg}\ \beta + 2\beta = \pi + \gamma \quad (4)$$

As shown in Fig. 3, the straight line AC, a side of angle β, intersects the outer and the inner involute of the wraps at C and A respectively. Now draw the normal bisector of the line segment BC, which intersects the extended line of line segment O_1B at point E; then draw circular arc BC, with E as the circle center and with the length of EB as the circle radius. Similarly draw the normal bisector of the line segment AB, which intersects the extension line of line segment BO_1 at point F; then draw another circular arc AB, with F as the circle center and the length of FB as the circle radius. The circular segment arcs AB and BC are the modified parts of the original involute wraps, the point B is the connecting point between the two circular segments, and A and C are respectively the connecting points of the inner and outer involute of the scroll component with the circular segments AB and CB.

In addition to the graphic method discussed above, we can obtain accurate numeric results from the analytical equation. The radius of the modified circular arcs satisfies the following equations:

$$R = r + R_{or} \qquad (5)$$

$$r = \frac{a}{\sin 2\beta} - \frac{R_{or}}{2} \qquad (6)$$

$$\operatorname{ctg}\beta + 2\beta = \pi + \gamma \qquad (7)$$

Angle γ, termed as a modified angle by the authors, can be chosen by the designer. The value of γ can make the position of point B change. Point B is not only the connection point between circular arcs BC and BA, but also indicates the final position of the innermost contact point between the two scroll wraps in one revolution. Therefore, the discharge angle θ' can be determined by the following equation:

$$\theta' = 2\pi - \gamma \qquad (8)$$

Obviously, when $\gamma = 0$, $\theta' = 2\pi$, as show in Fig. 4. In this case, the two innermost wraps always contact each other in each revolution, and the zero-top clearance appears at the end of the discharge process.

In addition, the value of angle γ can affect the shape and strength of the innermost scroll wraps. The bigger the angle γ is, the greater the strength of scroll wrap will be, as shown in Fig. 5.

The value of angle β is limited by the value of angle γ. The following table and Fig. 6 show the relationship between them.

β	γ	β	γ
0°	23.21827	50°	16.16445
5°	22.15997	55°	15.72030
10°	21.22081	60°	15.30309
15°	20.37816	65°	14.91018
20°	19.61530	70°	14.53928
25°	18.91959	75°	14.18844
30°	18.28117	80°	13.85590
35°	17.69223	85°	13.54015
40°	17.14645	90°	13.23983
45°	16.63862		

The above mentioned modification method, both the graphical and the analytical solution, has been convincingly proved by the authors.

3. The Practical and Experimental Results

On the basis of this modified method, a specially-designed computer code has been developed. By using this computer code, the involute-wraps of scroll compressors with different configuration parameters can be modified. This computer code can not only draw the modified graphical result of a pair of involute wraps but also can give the accurate results required for the machining process. The precision of these results is far beyond that the designing processes requires and the machining processes can reach.

A configuration of the meshing between the two scroll wraps, which is completed by the above computer code corresponding to $\gamma=0$, is illustrated in Fig. 7. The accuracy of engagements between the two scroll wraps is fully demonstrated in this figure, where points A, B, C, D, E and A′, B′, C′, D′, E present the successive varying positions of a pair of meshing points on the two scroll wraps correspording to the rotational angle of the crank shaft at 0°, 90°, 180°, 270° and 360° respectively. The clearance between two the meshing points can be precisely shown by this computer code, which can further prove the precision of the mesh. It is clear from this figure that the gas discharge angle of the two modified scroll wraps has increased from 300° to 360° and the top clearance of the scroll compressor can be regarded as zero.

By applying this wraps modification method to the engineering design of a scroll compressor, the authors have obtainded accurate computational results for the process. The digital milling machine programmed according to these results has performed the processing assignment very well. The connections between the involute wraps and the circular arc wraps are smooth, without any visible disconnections. The test data of a sample compressor have proven that the mesh between the two modified scroll wraps are excellent. The compression ratio of the scroll compressor has overpassed 10 when tested in the air.

CONCLUSION

(1). The involute wrap of the scroll compressor can be modified by the above graphical and analytical method. The accurate computational result of modification for the machining process can be calculated with the analytical equations. After modification by using the above method, the two members, fixed and obiting scroll, mesh with each other perfectly.

(2). For involute wraps of the scroll compressor modified by the above method, the discharge angle: $\theta' = 2\pi - \gamma$. As especially, when $\gamma = 0$ the $\theta' = 2\pi$.

(3). The modified angle γ affects the shape and strength of the modified involute wraps of the scroll components.

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2. Etsuo M., "SCROLL COMPRESSOR ANALYTICAL MODEL", Proc. of the 1984 International Compressor Engineering Conference at Purdue. 1984. pp. 487 ~ 495

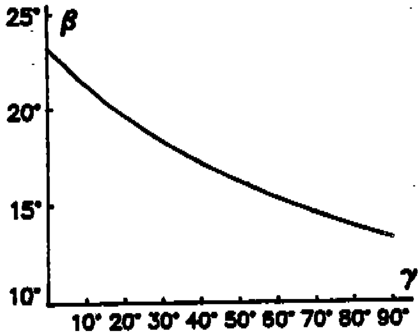

Fig.6 The relationship curve between γ and β

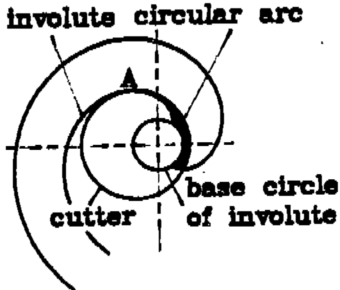

Fig.1 The interaction between the cutter and involute wrap

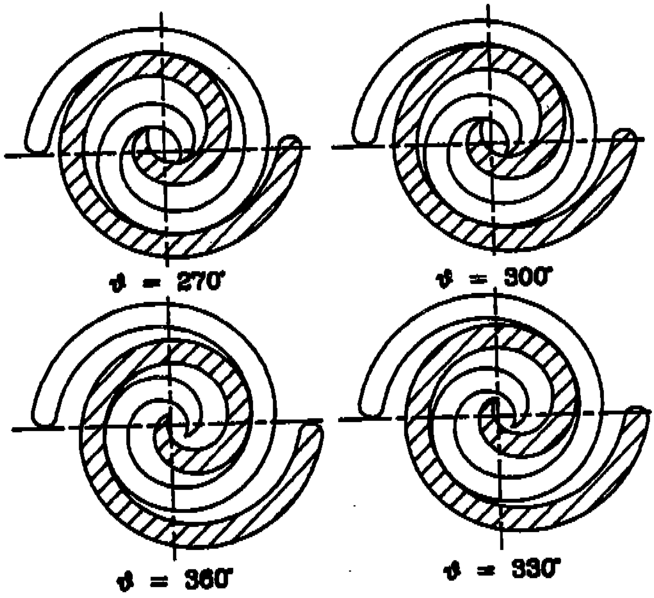

Fig.2 The meshing state of a pair of involute scroll wraps interacted by the cutter

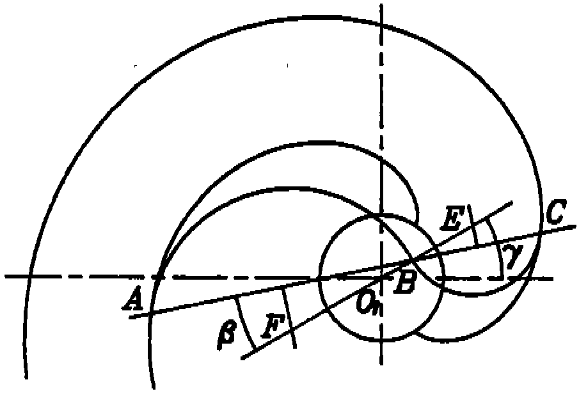

Fig.3 The illustration of the graphical method for modification of the scroll wrap

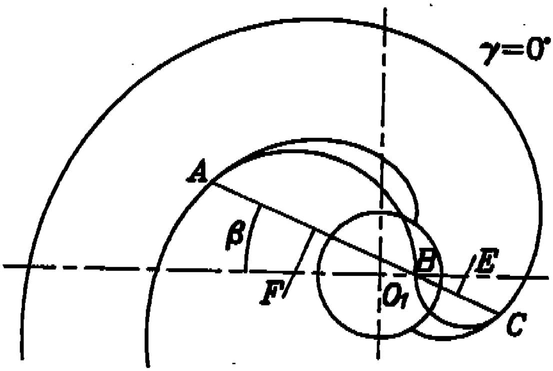

Fig.4 The illustration of the graphical result of modified scroll wrap when $\gamma=0°$

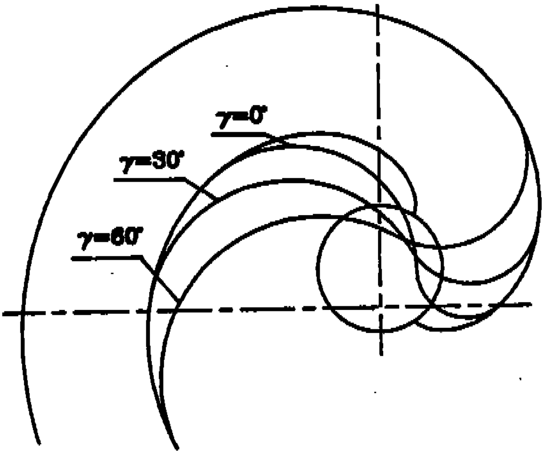

Fig.5 The comparison of the shape with a different modified angle

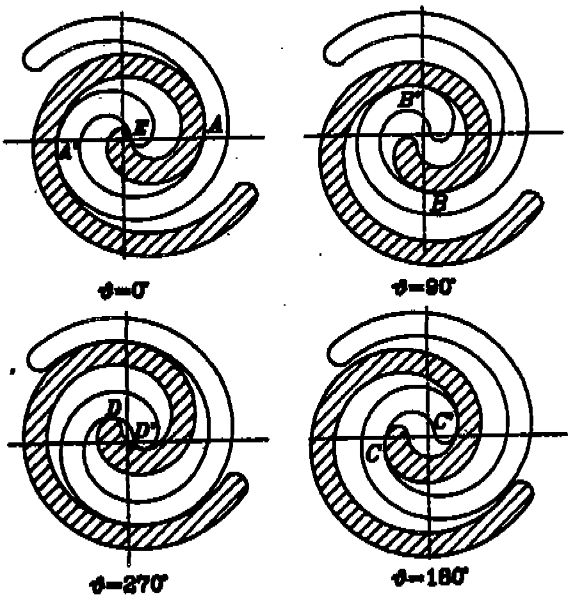

Fig.7 The illustration of the meshing state of a pair of modified wraps when $\gamma=0°$