Construction and Analysis of Variable Wall Thickness Profile of Double Scroll Teeth of Scroll Compressor

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Abstract. Based on the changing trend of the geometric parameters of the scroll profile of the involute of circle with variable radii, a new type of double scroll teeth profile of scroll compressor composed of involute of circle with variable radii is constructed. The construction process of the baseline is discussed, and the baseline equations are deduced. According to the principle of normal equidistance, the geometric model of variable wall thickness double scroll teeth is established, and the suction volume, tooth thickness, and scroll area of double scroll teeth are compared with those of the double scroll teeth composed of ordinary involute of circle. The results show that: compared with ordinary double scroll teeth with constant thickness, the scroll diameter when two scrolls mesh is reduced and the revolutions of orbiting scroll required in the working process are reduced and it is easy to select better scroll profile through adjusting the changing coefficient of the base circle radius k , which provides a reference for scroll machinery using environment-friendly working fluids.

1 Introduction

Scroll machinery is another new type of positive displacement compressor after reciprocating compressors, rotor compressors, and screw compressors. It is widely used in refrigeration systems and low-temperature waste heat power generation due to its simple structure, low noise, high efficiency, and light weight. In the system [1]. Especially at present, due to environmental problems and the ozone layer hole, environment-friendly working fluids have received extensive attention worldwide. However, refrigerants with low ODP and GWP values, such as CO₂, require sufficient working pressure in refrigeration and air-conditioning systems [2-3], and the construction of the scroll profile is the key factor in determining it. In this paper, therefore, a kind of profile of variable wall thickness double scroll teeth profile is constructed to provide a reference for it.

At present, domestic and foreign scholars have done relatively little research on the double scroll teeth profile, most of which are involute of circle with the same wall thickness from start to the end. Wang Jun et al. used involute of circle with variable radii and algebraic spirals to construct double scroll teeth with gradually changing wall thickness that can achieve correct meshing, and gave profile equations [4]. Wang Jun et al. have been studied the working process of the compressor in detail [5]. Li Chao et al. analyzed the dynamic characteristics of the double scroll teeth compressor [6]. Li et al. studied the meshing characteristics and geometric theory of the involute of circle with variable radii, and obtained its conjugate meshing profile equation, and compared it with

the involute of circle [7]. Peng Bin et al. proposed a combination curve of variable wall thickness scroll expander with involute of circle, high-order curve, and involute of circle, and deduced the expression of working chamber volume [8]. Wang Jun et al. established a general geometric model suitable for multiple scrolls with arbitrary teeth [9], Sun et al. used the finite element method to obtain the rough and finishing scroll entities and obtained the feed speed and excitation frequency fitting curve [10]. Liu proposed a combination of involute of circle, involute of circle with variable radii and involute of circle [11].

Although the above studies described the gradual changing wall thickness and variable wall thickness, most of the double scroll teeth adopt ordinary involute of circle to establish the model. This paper analyzes the changing trend of geometric parameters of the profile and constructs a double scroll teeth profile composed of involute of circle with variable radii.

2 Geometrical model of involute of circle with variable radii

2.1 The geometric theory of profile

The ordinary involute of circle has a constant base circle radius, on the contrary, base circle radius and polar diameter of this new type of profile are functions of the spread angle of the involute. The equations of base circle radius and polar diameter are as follows:

$$R(\varphi) = R_0 + k\varphi \quad (1)$$

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$$\rho(\varphi) = \int_0^{\varphi} R(\varphi) d\varphi = R_0\varphi + \frac{k}{2}\varphi^2 \quad (2)$$

2.2 General equation of involute

$$\begin{cases} X_0 = (R_0 + k\varphi) \cdot \cos(\varphi) + (R_0\varphi + \frac{k}{2}\varphi^2) \cdot \sin(\varphi) \\ Y_0 = (R_0 + k\varphi) \cdot \sin(\varphi) - (R_0\varphi + \frac{k}{2}\varphi^2) \cdot \cos(\varphi) \end{cases} \quad (3)$$

Where, R_0 is the initial base circle radius, k is the changing coefficient of the base circle radius, φ is the spread angle of involute.

The generated profiles with different value of k are shown in Fig.1.

Fig 1. Schematic diagram of profiles with different value of k

2.3 The changing trend of wall thickness and pitch with different value of k

Fig 2. Schematic diagram of changing trends of wall thickness and pitch

It can be seen from the Fig.2. that when $k < 0$, the tooth thickness and pitch decrease with the decrease of k ; when $k > 0$, the tooth thickness and pitch increase with the increase of k ; the smaller the k , the smaller the corresponding overall wall thickness, the larger the k , the larger the corresponding overall wall thickness; and it can be clearly seen that when k is near the involute spread angle $\varphi = 0^\circ$, the tooth thickness increases with the decrease of k . From the above analysis, it is necessary to try to construct double scroll teeth constructed from this kind of profile.

3 Conditions for the mutual substitution of the involutes of circle with variable radii with different initial base circle radii

Select two involutes S_1 and S_2 with different initial base circle radii R_1 and R_2 , the equations are as follows:

$$\begin{cases} X_1 = (R_1 + k\varphi) \cdot \cos(\varphi) + (R_1\varphi + \frac{k}{2}\varphi^2) \cdot \sin(\varphi) \\ Y_1 = (R_1 + k\varphi) \cdot \sin(\varphi) - (R_1\varphi + \frac{k}{2}\varphi^2) \cdot \cos(\varphi) \end{cases} \quad (4)$$

$$\varphi \in [\varphi_1, \varphi_1 + 2n_1\pi]$$

$$\begin{cases} X_2 = (R_2 + k'\varphi') \cdot \cos(\varphi') + (R_2\varphi' + \frac{k'}{2}\varphi'^2) \cdot \sin(\varphi') \\ Y_2 = (R_2 + k'\varphi') \cdot \sin(\varphi') - (R_2\varphi' + \frac{k'}{2}\varphi'^2) \cdot \cos(\varphi') \end{cases} \quad (5)$$

$$\varphi' \in [\varphi_2, \varphi_2 + 2n_2\pi]$$

Where, φ, φ' is the spread angle of involute, φ_1, φ_2 is

the arbitrary value of angle of S_1 and S_2 , n_1, n_2 is the positive integer and $n_1 > n_2$.

3.1 The replacement process of baselines

The processes of curve S_1 is replaced by S_2 are composed of rotation and translation. As shown in Fig.3. The initial positions of S_1 and S_2 are shown in (1); the position of curve S_2 after rotating $\varphi_1 - \varphi_2$ around the origin of the coordinates is shown in the (2); and curve S_2 is marked as $S_{C'D'}$; the two points A and B coincide with the two points C and D through translation as shown in (3), then the curve S_2 is marked as $S_{C'D'}$, the replacement process ends.

Fig 3. Schematic diagram of replacement process of S_1 and S_2

3.2 replacement conditions

Since the type of profile of involute of circle can maintain the same slope of the tangent at contact points during the rotation process, the replacement process can be completed only when the distance $L_{AB} = L_{CD}$ is satisfied. As shown in Fig.3., the curve segment S_{CD} on the baseline with the initial base circle radius of R_1 can be replaced by the curve segment S_{AB} on the baseline with the initial base circle radius of R_2 . The following equation must be satisfied:

$$\sqrt{[X_2(\varphi_2 + 2n_2\pi) - X_2(\varphi_2)]^2 + [Y_2(\varphi_2 + 2n_2\pi) - Y_2(\varphi_2)]^2} = \sqrt{[X_1(\varphi_1 + 2n_1\pi) - X_1(\varphi_1)]^2 + [Y_1(\varphi_1 + 2n_1\pi) - Y_1(\varphi_1)]^2} \quad (6)$$

The above equation can be solved to get

$$\frac{n_1^2}{n_2^2} = \frac{k^2 + [R_2 + k(\varphi_2 + n_2\pi)]^2}{k^2 + [R_1 + k(\varphi_1 + n_1\pi)]^2} \quad (7)$$

4 The establishment of variable wall thickness double scroll teeth

4.1 Basic theory of double scroll teeth

For a compressor composed of a single scroll tooth, the two scrolls are installed with a phase difference of 180° . For double scroll teeth, two scroll teeth are symmetrically distributed around the origin on both orbiting and fixed scrolls, and these two scroll plates are installed with a phase difference of 90° . Therefore, the whole eight profiles can be calculated and drew through operations of isometry solid, rotation and mirroring in *SOLIDWORKS* when the baseline equation of orbiting or fixed scroll is given.

4.2 The baseline equations of variable wall thickness double scroll teeth

The first segment S_1 of baseline

$$\begin{cases} X = (R_1 + k\varphi) \cos(\varphi) + (R_1\varphi + \frac{k}{2}\varphi^2) \sin(\varphi) \\ Y = (R_1 + k\varphi) \sin(\varphi) - (R_1\varphi + \frac{k}{2}\varphi^2) \cos(\varphi) \end{cases} \quad (8)$$

$$\varphi \in [0, \varphi_1]$$

The second segment $S_{C'D'}$ of baseline

$$\begin{cases} X = [R_2 + k(\varphi - \theta)] \cos(\varphi) \\ \quad + [R_2(\varphi - \theta) + \frac{k}{2}(\varphi - \theta)^2] \sin(\varphi) - [X_2'(\varphi_1) - X_1(\varphi_1)] \\ Y = [R_2 + k(\varphi - \theta)] \sin(\varphi) \\ \quad - [R_2(\varphi - \theta) + \frac{k}{2}(\varphi - \theta)^2] \cos(\varphi) - [Y_2'(\varphi_1) - Y_1(\varphi_1)] \end{cases} \quad (9)$$

$$\begin{aligned} [X_2'(\varphi_1) - X_1(\varphi_1)] &= [(R_2 - R_1) - k\theta] \cos(\varphi_1) \\ &+ \left\{ (R_2 - R_1)\varphi_1 - [R_2 + \frac{k}{2}(2\varphi_1 - \theta)]\theta \right\} \sin(\varphi_1) \end{aligned} \quad (10)$$

$$[Y_2'(\varphi_1) - Y_1(\varphi_1)] = [(R_2 - R_1) - k\theta] \sin(\varphi_1) + \left\{ (R_2 - R_1)\varphi_1 + \left[R_2 + \frac{k}{2}(2\varphi_1 - \theta) \right] \theta \right\} \cos(\varphi_1) \quad (11)$$

$$\theta = \varphi_1 - \varphi_2$$

$$\varphi \in [\varphi_1, \varphi_1 + 2n_1\pi]$$

The third segment S_1 of baseline

$$\begin{cases} X = (R_1 + k\varphi) \cos(\varphi) + (R_1\varphi + \frac{k}{2}\varphi^2) \sin(\varphi) \\ Y = (R_1 + k\varphi) \sin(\varphi) - (R_1\varphi + \frac{k}{2}\varphi^2) \cos(\varphi) \end{cases} \quad (12)$$

$$\varphi \in [\varphi_1 + 2n_1\pi, \varphi_e]$$

Where, φ_e is the ended involute angle.

The above baseline is rotated by π around the origin of the coordinate to obtain another baseline segment of the scroll. The baseline of scroll is shown in Fig.4.

Fig.4. Schematic diagram of baseline of the scroll

4.3 Comparison of geometric parameters of two double scroll teeth models

According to the principle of normal equidistance, the initial base circle radii are chosen as $R=R_1=10\text{mm}$, the number of turns n_1, n_2 are taken as 2 and 1, φ_1, φ_2 are taken as 2π and 1.2π , the ended involute angle and orbiting radius are taken as $\varphi_e=8\pi$ and $R_{or}=6\text{mm}$ respectively, take $k=0, k=-0.05$ to generate the inner profiles of orbiting scroll and outer profiles of fixed scroll of ordinary double scroll teeth and the new type of double scroll teeth, which are installed with a phase difference of 0.5π between the orbiting and fixed scrolls. As the research focus of this paper is on the profile itself, the correction of the teeth head has little influence on indexes such as suction volume, wall thickness and so on, the teeth head part is not modified. The two models are shown in Fig.5.:

Fig.5. Comparison of two types of double scroll teeth

Because the double scroll teeth compressor has 4 suction chambers, the suction process is completed when the spindle rotates 0.5π . The volume of each suction chamber is the same. In order to simplify calculation, the projected area of one suction chamber is used for comparison. Through measurement, the projected areas of one suction chamber of $k=0$ and $k=-0.05$ are 7710.73mm^2 and 7253.92mm^2 respectively; the diameters of these two double scroll teeth during meshing are: 495.72mm and 464.88mm ; the areas of fixed scroll are 28023.32mm^2 and 28221.4mm^2 ; the minimum tooth thicknesses of teeth are 4.85mm and 3.85mm , respectively. When the diameters of the two scroll teeth are the same value, the suction chamber projected area of $k=-0.05$ is 0.4% larger than that of the double scroll teeth of $k=0$, which can be almost ignored. However, with the gradual value decrease of k , the change will become greater and greater. Analyzing above data, it can be concluded that the plate diameter of the new type of double scroll teeth is reduced by 6.3% ; there is little difference in suction volume between them. However, the revolutions required for the orbiting scroll to complete the entire working process are reduced. It can be seen from Figure 4, the wall thickness of $k=-0.05$ in the middle compression chamber is significantly larger than that of $k=0$, which is more suitable for environment-friendly working fluids that require high temperature and pressure operating conditions.

5 Conclusions

(1) The geometric model of involute of circle with

variable radii is discussed, and the changing trend of its wall thickness and pitch is deduced. From which, variable wall thickness double scroll teeth composed of this profile is proposed.

(2) The conditions for the mutual substitution of profiles with different initial base circle radii are calculated, and the baseline equation of this new type profile of double scroll teeth is deduced, and the geometrical models of $k=0$ and $k=-0.05$ are established, through comparative analysis, it is concluded that the new profile can reduce the plate diameter and shorten the time that working fluid staying in the working chamber. According to actual working temperature and pressure, the appropriate scroll can be designed by adjusting the changing coefficient of the base circle radius k , which provides a certain reference for scroll machinery using environment-friendly working fluids.

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