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Investigation of a novel circular arc claw rotor profile for claw vacuum pumps and its performance analysis

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ABSTRACT

Claw rotor profiles greatly influence the performances and applications of claw vacuum pumps. This paper proposes a novel circular arc claw rotor profile, in which circular arcs are employed instead of cusps; and obtains the changing rules of claw rotor profiles varied with the value of circular arc radius. Numerical simulation of gas flow in the working process of claw vacuum pumps is carried out, and the stress distributions caused by gas pressure of claw rotors are calculated. The comparisons of pressure, temperature and stress distributions between the proposed profile and the reference profile are made. The results show that the proposed profile has better performances, such as small recess volume, big compression ratio and low stress. The proposed profile is therefore more suitable for high load operation conditions, and has a broad application prospect.

1. Introduction

Claw vacuum pumps are rotary positive displacement fluid machineries with built-in compression [1,2], whose main advantages include high reliability, simple construction, structural compactness, oil-free, as well as dry vacuum pump [3]. Claw vacuum pumps are characterized by greater performance if compared to roots vacuum pumps and are more efficient in discharging gas pressure, which is higher than the suction pressure substantially. So claw vacuum pumps are actually used in a wide variety of vacuum pumping application.

Although this kind of machine has been used for many years, there are very few published literatures of studies on it. Allen [4] proposed a claw rotor whose profile includes a pointed tip on both sides that has a clearance particle feature and can prevent accumulation of pollutants. Hsieh [5,6] proposed a profile of claw rotor by means of the theory of gearing and the equation of undercutting, which helped to improve gas sealing and reduce carryover; and Hsieh also presented a simple mathematical model for the geometric design of a claw type rotor, using different parameters to discuss its influences on the gas port and pump performance. Giuffrida [7] presented the working principles of the claw rotor compressor and reported the formulation of volumetric efficiency; and Giuffrida [8] also proposed a rotor profile suitable for the claw-type mechanism, which seems to be preferable compared with a reference profile [7]. Ioffe et al. [9] developed a model based on algebraic and differential equations to describe pressure and temperature time dependence for a multistage claw rotor vacuum pump. The model includes volume variation, gas flow between stages, leakage within and between stages, gas mixing, and heat exchange. Peng et al. [10] developed an analytical study of the rotary tooth compressor, and constructed a mathematical model to simulate the thermodynamic processes within it and predict its performance.

The above mentioned claw rotor profiles contain cusps, which will lead to high stress, big deformation, poor gas sealing, and eventually the reduction of running life of claw vacuum pumps. Aiming at solving the disadvantages caused by cusps of the reference profile [7] for claw rotors, this paper proposes a novel circular arc claw rotor profile, in which circular arcs are employed instead of cusps to improve the performances for claw vacuum pumps. Differences between the proposed profile and the reference profile are compared by employing numerical simulation of the working process and stress calculation of claw rotors. The pressure, temperature fields and stress distributions of these two types of profiles are obtained. The study results show that the proposed profile is better than the reference profile in terms of working process and stress distribution. These results provide a foundation for design and application of the proposed profile, and have important theoretical value for claw vacuum pumps.

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2. Geometry of claw rotor profiles

2.1. Profiles of claw rotors

Claw vacuum pumps contain two same-shaped claw rotors which mesh with each other during working process. The reference profiles [7] for claw vacuum pumps are shown as Fig. 1. It can be seen that two cylinders with left and right rotors are partly overlapping and each of them has a claw and a matching recess. The two rotors rotate in opposite directions around their axes and are synchronized by a pair of gears.

The reference profile contains cusps. Taking the left rotor as an example, it contains six curves: an epitrochoidal arc *ab*, a circular arc *bc*, an epitrochoidal arc *cd*, a circular arc *de*, an epitrochoidal arc *ef* and a circular arc *fa*.

The profiles on the left rotor mesh with the profiles on the right rotor in the working process. That is epitrochoidal arc *ab*, point *b*, circular arc *bc*, point *c*, an epitrochoidal arc *cd*, circular *de*, point *e*, an epitrochoidal arc *ef* and circular arc *fa* on the left claw rotor mesh with point b_2, epitrochoidal arc b_2a_2, circular arc a_2f_2, epitrochoidal arc f_2e_2, point e_2, circular arc e_2d_2, epitrochoidal arc d_2c_2, point c_2, circular arc c_2b_2 on the right claw rotor, respectively. So we can see that points mesh with epitrochoidal arcs of the reference profile in the working process.

In Fig. 1, ω is angular velocity of claw rotors; L is distance between the axes of left and right rotors; R_1 is radius of claw head circular arc; R_2 is radius of pitch circle; R_3 is radius of claw bottom circular arc. The relationship of above parameters is as follows.

$$2R_2 = R_1 + R_3 = L \tag{1}$$

2.2. Equation of claw rotor profiles

In this section, we will derive the equation of the curve which meshes with a point in the working process. For claw vacuum pumps, the left and right rotor rotate in opposite direction with the same angular velocity, so the profiles of the left and right rotors mesh with each other during the working process. We transform the motion of two opposite rotation between left and right rotors into another equivalent motion, which is defined as the left rotor is fixed, the right rotor rotates around its own axis, and also rotates around the axis of the left rotor in the same direction and with the same angular velocity.

As shown in Fig. 2, the circle o on left and the circle o_1 on right represent left and right rotors, respectively. There is a point a_1 on the right rotor meshes with a curve, called Curve 1, on the left rotor. We want to obtain the equation of Curve 1 which meshes with the point a_1. After a very small angle t of rotation, when the equivalent motion is used, the circle o_1 rotates an angle t counterclockwise around its own axis and rotates the same angle t counterclockwise around point o; then the points o_1 and a_1 moves to o_2 and a_2 on the right rotor. At the same time, the point a_2 is still on Curve 1; therefore, the equation of Curve 1 is derived when we obtain the coordinates of the point a_2 varied with t.

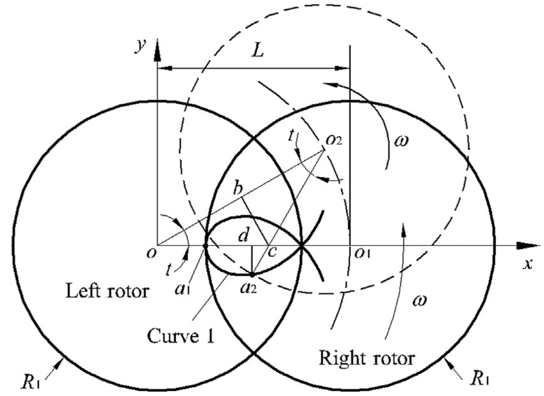

Fig. 2. Generation of an epitrochoidal arc.

In Fig. 2, x and y are spatial coordinates in Cartesian geometry; point c is the intersection between o_2a_2 and x axis. Segment cb is perpendicular to oo_2, b is the pedal point; segment a_2d is perpendicular to x axis, d is the pedal point. So angle $\angle boc = \angle bo_2c = t$, and triangle $\triangle coo_2$ is an isosceles triangle. The x coordinate value of point a_2 is the distance of od; the y coordinate value of point a_2 is $-a_2d$. Therefore, coordinates of point a_2 can be derived, and the equation of Curve 1 which is epitrochoidal arc are as follows.

$$\begin{cases} x\left(t\right) = \dfrac{L - R_1}{\cos t} - \left(R_1 - \dfrac{L - R_1}{2\cos t}\right)\cos 2t \\ y\left(t\right) = \left(R_1 - \dfrac{L - R_1}{\cos t}\right)\sin 2t \end{cases} \tag{2}$$

Where, t is an angular parameter, positive when rotating counterclockwise and negative when rotating clockwise.

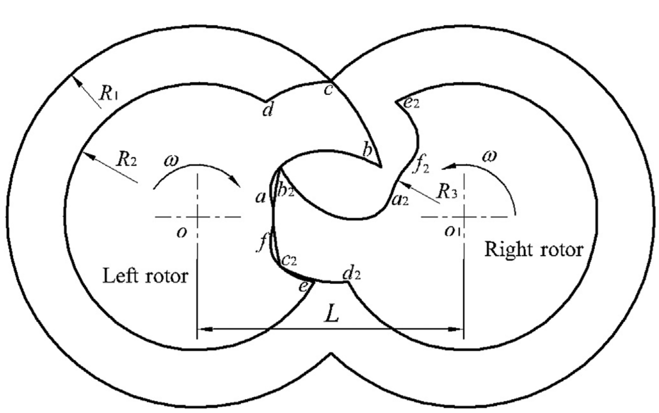

Fig. 1. The reference profile.

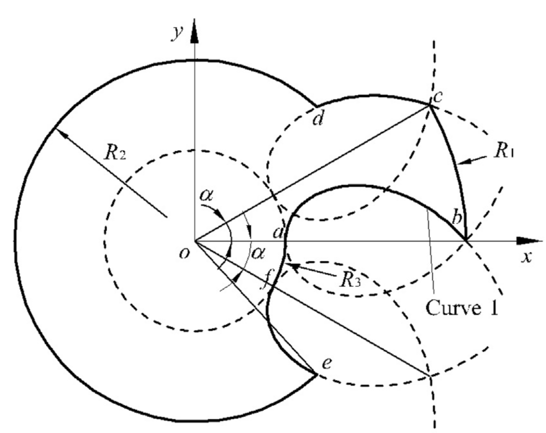

Fig. 3. Generation of claw rotor profile.