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The Application of Tooth Contact Analysis in the Shaper Modification for Face-gear

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Abstract

To get ideal position of contact area for face-gear drives, we researched beginningly the rack-cutter modification, setted up equation of tooth surface of parabolic rack-cutter. According to the machining coordinate systems of shaper and the gear geometry and applied theory. The surface equation of shaper was established by using the equation of rack-cutter tooth surface and matrix for coordinate transform; The gear teeth surface equation of face-gear was got base on machining coordinate systems and the surface equation of shaper. Comprehensively considered the meshing relation among shaper、pinion and face-gear, the coordinate systems of meshing analysis were founded; The equations of meshing contact points for face-gear drives were established; Recurring to the technology of computer simulation, the effects between the face-gear meshing contact path and shaper modification were researched through the computational examples. So, The position of contact area for face-gear drives is controlled.
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Keywords: face-gear; equation of tooth surface; parabolic rack-cutter; modification; computer simulation ;contact path

1. Introduction

Face-gear transmission is a new aviation power transmission, with the advantages of small size, light weight, high load capacity, low noise, high reliability, long life and so on [1]. It is known that face-gear tooth surface parametes were determined by the cutter tooth surface parameters from the literature [2].Therefore the changes of cutter-

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surface parameters have an important impact on meshing performance of face-gear drives, starting from the tool rack, this paper studies on the impact between the face-gear machining cutter surface changes and the face-gear tooth surface equation, meshing contact trace. And the reasonable tool surface parameters were determined. The results were provided a theoretical basis for cutter modification.

2. The basic equation of face-gear tooth surface

2.1. Face-gear cutter tooth surface equation

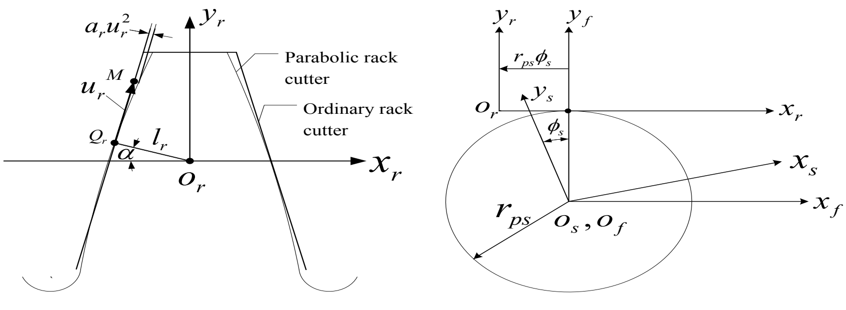
Face-gear cutter is machined by the tool rack, rack cutter tooth surface coordinate system $S_r(o_r, x_r, y_r, z_r)$ was shown in Figure 1 (a)[3], α is rack pressure angle, M is a point on the tool rack surface. Q_r is the perpendicular foot that is marked a upright line to rack tool-surface through the origin o_r. u_r is the rack tool-surface parameter, $u_r = |MQ_r|$, a_r is the parabolic rack-surface coefficient. $l_r = \frac{\pi m}{4}\cos\alpha$. The tooth surface equation of the parabolic surface rack cutter is：

$$\vec{r}_r(a_r, u_r, \theta_r) = \begin{bmatrix} u_r \sin\alpha - l_r \cos\alpha + a_r u_r^2 \cos\alpha \\ u_r \cos\alpha + l_r \sin\alpha - a_r u_r^2 \sin\alpha \\ \theta_r \\ 1 \end{bmatrix} \tag{1}$$

$$\vec{n}_r(a_r, u_r) = \frac{1}{\sqrt{1+4a_r^2 u_r^2}} \begin{bmatrix} \cos\alpha + 2a_r u_r \sin\alpha \\ -\sin\alpha + 2a_r u_r \cos\alpha \\ 0 \end{bmatrix} \tag{2}$$

Among them, θ_r is the surface parameters on the direction z_r .if $a_r = 0$,the parabolic rack surface equation changes into becomes ordinary rack surface equation.

The coordinate system of rack cutter machining involute gear tool is shown in Figure 1 (b), the coordinate system $S_f(o_f, x_f, y_f, z_f)$ is the fixed coordinate system of involute gear cutters, the coordinate system $S_f(o_f, x_f, y_f, z_f)$ is moved coordinate system which fixed linked to the gear cutter, ϕ_s is the gear cutter corner, r_{ps} is pitch radius of gear cutting tools.



(a) (b)

Fig.1 The machining coordinate system of gear cutter

The coordinate transformation matrix M_{sr} from the coordinate system S_r to the coordinate system S_s is

$$M_{sr}=\begin{bmatrix}\cos\varphi_r & \sin\varphi_r & 0 & r_{ps}(\sin\varphi_r-\varphi_r\cos\varphi_r)\\ -\sin\varphi_r & \cos\varphi_r & 0 & r_{ps}(\cos\varphi_r+\varphi_r\sin\varphi_r)\\ 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\end{bmatrix} \tag{3}$$

The gear cutter tooth surface equation is:

$$\vec{r}_s(a_r,u_r,\theta_r,\varphi_r)=M_{sr}\vec{r}_r(a_r,u_r,\theta_r) \tag{4}$$

$$\vec{n}_s(a_r,u_r,\varphi_r)=L_{sr}\vec{n}_r(a_r,u_r) \tag{5}$$

Here, L_{sr} is the first three-order principal minors of matrix M_{sr}.
According to the principle of meshing gears, It is got:

$$f_{sr}(u_r,\varphi_r)=\frac{2a_r^2u_r^3+(1+2a_rl_r)u_r}{r_{ps}(\sin\alpha-2a_ru_r\cos\alpha)}-\varphi_r=0 \tag{6}$$

The he gear cutter tooth surface equation .was setted up by taking formula (1), (6) into (4) .

2.2. Face-gear tooth surface equation

Processing face-gear can use the following four coordinate systems [4]: The coordinate systems $S_s(x_s,y_s,z_s)$ and $S_2(x_2,y_2,z_2)$ are fixed coordinate systems which linked to the initial position of cutter s and gear 2, respectively. φ_s and φ_2 express the cutter s and face-gear 2 rotational angle ,respectively. γ is the angle between the axis z_s and z_2 . In this article, taking $\gamma = 90$ °. As is shown in Figure 2.

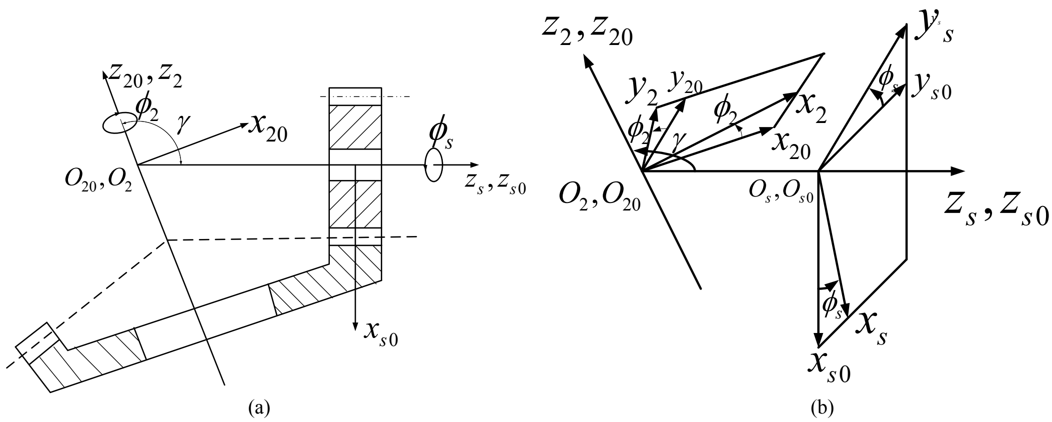


Fig.2 Orthogonal face-gear machining coordinate system

Face-gear tooth surface equations are derived according to the tool surface tooth surface equation and space surface meshing theory. The coordinate transformation matrix from the tool coordinate system to the face-gear coordinate is as follows according to Figure 1:

$$M_{2s}=\begin{bmatrix}\cos\phi_2\cos\phi_s & -\cos\phi_2\sin\phi_s & -\sin\phi_2 & 0\\ -\sin\phi_2\cos\phi_s & \sin\phi_2\sin\phi_s & -\cos\phi_2 & 0\\ \sin\phi_s & \cos\phi_s & 0 & 0\\ 0 & 0 & 0 & 1\end{bmatrix} \quad (7)$$

The face-gear tooth surface equation is:

$$\begin{cases}\vec{r}_2(a_r,u_r,\theta_r,\phi_s)=M_{2s}(\phi_s)\vec{r}_s(a_r,u_r,\theta_r)\\ f(u_r,\theta_r,a_r,\phi_r,\phi_s)=0\end{cases} \quad (8)$$

Where: $\phi_2=m_{2s}\phi_s\,,m_{2s}=\dfrac{N_s}{N_2}$, N_2 is the tooth number of face-gear.

The normal vector of face-gear tooth surface is:

$$\vec{n}_2(\phi_s,u_r,a_r)=L_{2s}\vec{n}_s(u_r,a_r) \quad (9)$$

Here, L_{2s} is the first three-order principal minors of matrix M_{2s} .

According to the principle of space surface meshing, that is got:

$$\begin{aligned}&f(u_r,\theta_r,a_r,\phi_r,\phi_s)=r_{ps}\cos\alpha+2a_ru_rr_{ps}\sin\alpha\\ &-\theta_rm_{2s}(\cos(\alpha+\phi_r-\phi_s)+2a_ru_r\sin(\alpha+\phi_r-\phi_s))=0\end{aligned} \quad (10)$$

Face-gear tooth surface equation can set up by taking (4), (7), (10) into (8).

3. The basic equations of face-gear meshing analyze

3.1. Establish the coordinate system of face-gear meshing analysis

The five coordinate systems can express face-gear meshing analysis as followed: Fixed coordinate systems $S_{10}(x_{10},y_{10},z_{10})$, $S_{s0}(x_{s0},y_{s0},z_{s0})$ and $S_{20}(x_{20},y_{20},z_{20})$ are rigidly connected to the frame of pinion, shaper and face-gear, and two movable coordinate systems $S_1(x_1,y_1,z_1)$ and $S_2(x_2,y_2,z_2)$ are rigidly connected to the pinion and the face-gear.

Coordinate origin O_{s0} and O_{10} are decided by B and $B\cot\gamma$ .B represents the distance between the axes of the shaper and the pinion, and $B=\dfrac{r_{ps}-r_{p1}}{\cos\alpha}$, in which r_{p1} is the pitch radii of the pinion . γ is an angle formed by the axes of the pinion and the face-gear. In the case of orthogonal face-gear drives, the angle $\gamma=90°$. ϕ_1',ϕ_2' are the pinion and face-gear motion parameters.(Fig. 3)

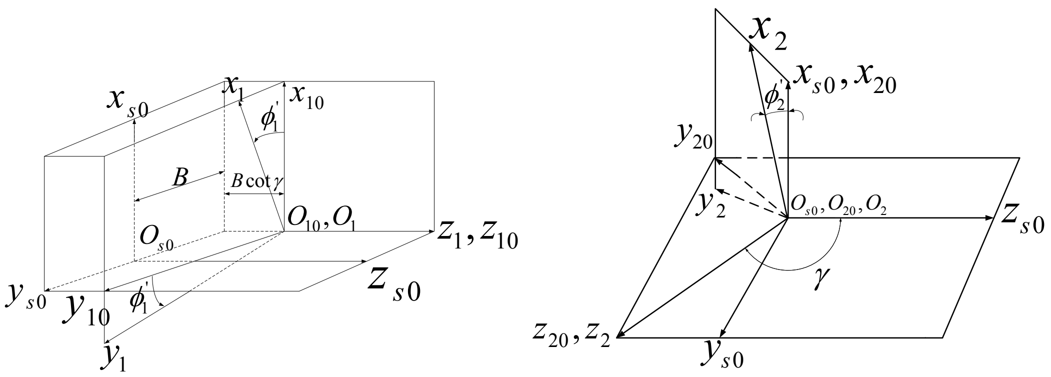


Fig.3 Face-gear transmission coordinates

3.2. Face-gear meshing contact point equation

The pinion tooth surface equation $\vec{r}_1(a_r, u_r, \theta_r)$ and normal vector $\vec{n}_1(u_r, a_r)$ are expressed by changing the subscript "s" into "1" of equation (4), (5).

The coordinate transformation matrix M_{101} from Coordinate system $S_{10}(x_{10}, y_{10}, z_{10})$ to the coordinate system $S_1(x_1, y_1, z_1)$ is:

$$M_{101} = \begin{bmatrix} \cos\phi_1' & -\sin\phi_1' & 0 & 0 \\ \sin\phi_1' & \cos\phi_1' & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (11)$$

The pinion tooth surface equation in the coordinate system $S_{10}(x_{10}, y_{10}, z_{10})$ is:

$$\vec{r}_{101}(u_r, \theta_r, a_r, \phi_1') = M_{101}(\phi_1')\vec{r}_1(u_r, \theta_r, a_r) \quad (12)$$

$$\vec{n}_{101}(u_r, a_r, \phi_1') = M_{101}(\phi_1')\vec{n}_1(u_r, a_r) \quad (13)$$

M_{102} is the coordinate transformation matrix from the coordinate system $S_2(x_2, y_2, z_2)$ to the coordinate system $S_{10}(x_{10}, y_{10}, z_{10})$, then, face-gear tooth surface equation in the coordinate system $S_{10}(x_{10}, y_{10}, z_{10})$ is:

$$\vec{r}_{102}(a_r, \phi_2', u_r, \theta_r, \phi_s) = M_{102}(\phi_2')\vec{r}_2(a_r, u_r, \theta_r, \phi_s) \quad (14)$$

$$\vec{n}_{102}(\phi_2', \phi_s, u_r, a_r) = L_{102}(\phi_2')\vec{n}_2(\phi_s, u_r, a_r) \quad (15)$$

Here, L_{102} is the first three-order principal minors of matrix M_{102} .

Pinion and face-gear have the same coordinates and normal vectors in contact points [5], so it can get:

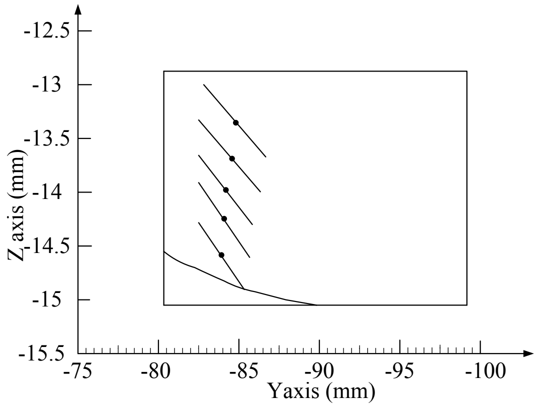
$$\begin{cases} \vec{r}_{102}(\phi_2^{'}, u_r, \theta_r, \phi_s, a_r) = \vec{r}_{101}(u_r, \theta_r, \phi_1^{'}, a_r) \\ \vec{n}_{102}(\phi_2^{'}, \phi_s, u_r, a_r) = \vec{n}_{101}(u_r, \phi_1^{'}, a_r) \end{cases} \tag{16}$$

Contact point trajectory can be obtained by solving equations (16).

4. Face-gear cutter modification calculation example

Taking $N_2 = 160$、$\alpha = 20°$、$\gamma = 90°$, $N_s = 26$, $N_1 = 24$, modulus m = 1.0583mm, researching on the effects between different amounts and contact area of face-gear.

(1) The meshing area is shown in Figure 4 in the condition of tool rack modification amount $\Delta M = 0$.



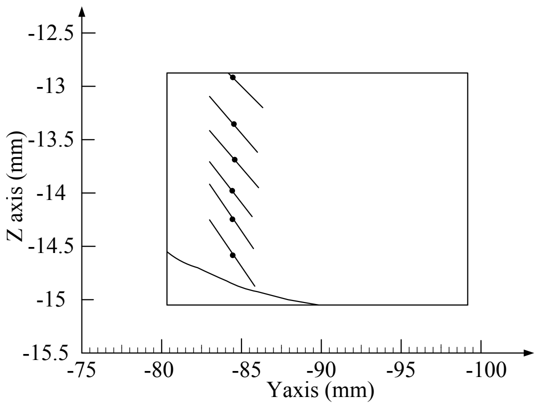


Fig. 4 contact trace of no modification amounts

Fig. 5 Contact trace of being modification amounts

Figure 4 shows that face-gear meshing track is approximately distributed on the plane of Y = 83.8 ~ 84.1mm

(2) When using the parabolic surface of the tool rack, Taking the amount of modification of gear cutting tools $\Delta M = 0.01$ mm, the contact area calculated is shown in Figure 5.

When the cutter top modification amount is 0.01mm, face-gear contact track is distributed on the plane of Y = 84.65 ~ 84.68mm, compared to no modification amount , the contact track is moving 0.5 ~ 0.8mm along direction of the Y shift, the position of the transmission contact track is changed.

Conclusions

Modification cutter of face-gear has been studied based on contact analysis. Firstly, according to rack cutter surface equation and the coordinate system of rack processing gear, the cutter tooth surface equation was established by using the gear meshing principle. According to gear transmission principle, the face-gear meshing transmission coordinates were founded. The meshing analysis equations were established. Recurring to computer analysis, the effects were analyzed between cutter modification and drive contact trace. The results provide a method for getting rational contact path by means of modification cutter.

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