

Study of One-Side Machining Theories and Designs Based on Globoidal Indexing Cam Mechanism of Tapered Rollers

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Abstract. This paper studies the globoidal indexing cam mechanism of tapered rollers and deduces the contour equation of the globoidal indexing cam of tapered rollers using the spatial meshing theory and rotation matrix. The paper focuses on the processing difficulties and a solution of a cutting tool controlling mathematical model whose viability has been verified with MATLAB simulation.

Introduction

The globoidal indexing cam mechanism is used between two vertically staggered shafts for indexing or stepping transmission. For its high-speed, high-precision, heavy-load and reliable features, this mechanism is gradually replacing mechanisms like scored pulley, ratchet wheel and intermittent gear, and it has become one of the major developing directions of the indexing and stepping transmission mechanisms. [1] There are a variety of studies at home and abroad on matters such as the parametric design, machining simulation and finite element analysis of the globoidal indexing cam mechanism of cylindrical rollers. [2-4] But this mechanism rises the pressure when the meshing depth is increased and creates uneven abrasions hence reduces the cams' lifespan. On the other hand, the tapered roller-globoidal indexing cams have decreasing roller radiuses with the meshing depth increasing, so the changing of pressure angles is smoother and the abrasions between rollers and cams is lighter. [5] This tapered roller-globoidal indexing cam mechanism has attracted a wide attention since it was announced, but the mechanism has a complex working contour surface, which makes it very difficult for manufacturing and restricts its spreading and applying.

The one-side machining is a key solution to the problems above: on one hand it overcomes the disadvantage when using the traditional generating cutting method to process the globoidal indexing cams - it does the milling to the grooves while processing the cams, when the limb milling is being done on one side, the conventional milling is being simultaneously done on the other side. Contrast with the point-by-point processing, this method has better efficiency and provides a higher surface quality. These advantages have made it an ideal method to process the globoidal indexing cams. To study a cutting tool controlling method for the globoidal indexing cam mechanism of tapered rollers using one-side machining is a field well worth exploring.

One-side Machining Theories

When the tool size is smaller than the roller size for some reason, cam roller and the ideal contact line are different space curves (Fig.1) of the conical surface from the tool and the cam actual contact line, the two line do not overlap, and it is impossible to make them completely coincidence, However, the process can take a certain approach to MN and PQ away recently. Which also minimize the profile error, take the following specific methods can realize the result:

Tool in the original position of the centre roller moving along the radius distance ΔR such method fixed direction and make error regular, and control process is simple, this is one-side machining theory.

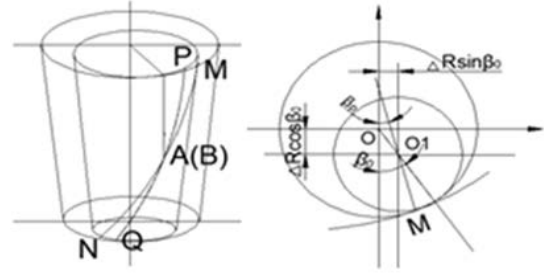


Fig.1: tool position of one-side machining.

Theoretical Working Contour Equation of Globoidal Indexing Cam

The coordinate of globoidal index cam as shown in Fig.2

σ - $oxyz$: Coordinate system fixed with frame

σ - $o_1x_1y_1z_1$: Coordinate system fixed with cam

σ - $o_2x_2y_2z_2$: Coordinate system fixed with follower wheel

φ_1, φ_2 : Angle of cam and follower wheel

h_0 : the distance of the rotation centre to the inner end of the roller

h : distance from the roller end to any roller section

R_f : maximum radius of the roller

β : contact angle

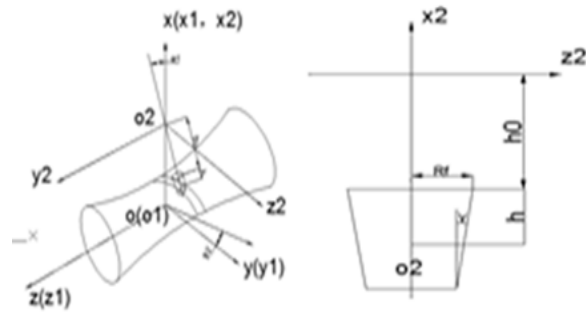


Fig.2: coordinate of globoidal index cam.

Based on the Space engagement theory and rotation matrix, the theoretical working contour equation of globoidal indexing cam can be concluded as:

$$\begin{pmatrix} x_0 \\ y_0 \\ z_0 \end{pmatrix} = \begin{pmatrix} [a - \cos \varphi_2 (h + h_0) - (R_f - h \tan \gamma) \sin \varphi_2 \cos \beta] \cos \varphi_1 - (R_f - h \tan \gamma) \sin \varphi_1 \sin \beta \\ [a - \cos \varphi_2 (h + h_0) - (R_f - h \tan \gamma) \sin \varphi_2 \cos \beta] \sin \varphi_1 + (R_f - h \tan \gamma) \cos \varphi_1 \sin \beta \\ - \sin \varphi_2 (h + h_0) + (R_f - h \tan \gamma) \cos \varphi_2 \cos \beta \end{pmatrix} \quad (1)$$

$$\beta = \arctan \frac{h + h_0 - (R_f - h \tan \gamma) \tan \gamma}{a - \cos \varphi_2 [h + h_0 - (R_f - h \tan \gamma) \tan \gamma]} \frac{d\varphi_2}{d\varphi_1} \quad (2)$$

Among them: β correspond to the contact Angle, there is two values β and $\beta + \pi$ correspond to the cam two profiles.

Actual Work Contour Equation of Globoidal Indexing Cam

Refer to Fig.2, based on one-side machining theories, the actual contact angle β_0 as follows:

$$\beta_0 = \beta\left(\frac{H}{2}\right) = \arctan \frac{\frac{H}{2} + h_0 - (R_f - \frac{H}{2} \tan \gamma) \tan \gamma}{a - \cos \varphi_2 \left[\frac{H}{2} + h_0 - (R_f - \frac{H}{2} \tan \gamma) \tan \gamma\right]} \frac{d\varphi_2}{d\varphi_1} \quad (3)$$

In any section $(h+h_0)$, the vector of point M (engagement point of tool and cam) as follows:

$$\vec{r}_{m2} = \begin{pmatrix} -(h + h_0) \\ \Delta R \cos \beta_0 + (R_f - h \tan \gamma) \cos \beta_p \\ \Delta R \sin \beta_0 + (R_f - h \tan \gamma) \sin \beta_p \end{pmatrix} \quad (4)$$

Transformation matrix from $\sigma\text{-}o2x2y2z2$ to $\sigma\text{-}oxyz$:

$$M_{02} = \begin{pmatrix} \cos \varphi_2 & -\sin \varphi_2 & 0 \\ 0 & 0 & 1 \\ \sin \varphi_2 & \cos \varphi_2 & 0 \end{pmatrix} \quad (5)$$

So, in the fixed coordinate system $\sigma\text{-}oxyz$ the vector of point M:

$$\vec{r}_2 = \begin{pmatrix} -\cos \varphi_2(h + h_0) - (\Delta R \cos \beta_0 + (R_f - h \tan \gamma) \cos \beta_p) \sin \varphi_2 \\ \Delta R \sin \beta_0 + (R_f - h \tan \gamma) \sin \beta_p \\ -\sin \varphi_2(h + h_0) + (\Delta R \cos \beta_0 + (R_f - h \tan \gamma) \cos \beta_p) \cos \varphi_2 \end{pmatrix} \quad (6)$$

So, $\vec{r}_1 = a_0 i + \vec{r}_2$

$$\vec{r}_1 = \begin{pmatrix} a_0 - \cos \varphi_2(h + h_0) - (\Delta R \cos \beta_0 + (R_f - h \tan \gamma) \cos \beta_p) \sin \varphi_2 \\ \Delta R \sin \beta_0 + (R_f - h \tan \gamma) \sin \beta_p \\ -\sin \varphi_2(h + h_0) + (\Delta R \cos \beta_0 + (R_f - h \tan \gamma) \cos \beta_p) \cos \varphi_2 \end{pmatrix} \quad (7)$$

The relative speed of meshing point M,

$$\vec{v}_{12} = \vec{v}_1 - \vec{v}_2 = \omega_1 k r_1 - \omega_2 j r_2 \quad (8)$$

In $\sigma\text{-}o2x2y2z2$, the normal vector which though the point M:

$$\vec{n}_{m2} = \begin{pmatrix} -\tan \gamma (R_f - h \tan \gamma) \\ (R_f - h \tan \gamma) \cos \beta_p \\ (R_f - h \tan \gamma) \sin \beta_p \end{pmatrix} \quad (9)$$

So, $\vec{n}_m = M_{02} \cdot \vec{n}_{m2}$

$$\vec{n}_m = \begin{pmatrix} (R_f - h \tan \gamma) (-\cos \varphi_2 \tan \gamma - \sin \varphi_2 \cos \beta_p) \\ (R_f - h \tan \gamma) \sin \beta_p \\ (R_f - h \tan \gamma) (-\sin \varphi_2 \tan \gamma + \cos \varphi_2 \cos \beta_p) \end{pmatrix} \quad (10)$$

According to mesh condition, equation can be deduced as follow: $\vec{v}_{12} \cdot \vec{n}_m = 0$

By simplified calculation,

$$\tan \beta_p = \frac{1}{\cos \beta_p} \left(\frac{\frac{w_2}{w_1} (-\tan \gamma \Delta R \cos \beta_0) - \cos \varphi_2 \tan \gamma \Delta R \sin \beta_0}{\cos \varphi_2 \tan \gamma (R_f - h \tan \gamma) + [a_0 - \cos \varphi_2 (h + h_0) - \sin \varphi_2 \Delta R \cos \beta_0]} \right) + \left(\frac{\frac{w_2}{w_1} [h + h_0 - \tan \gamma (R_f - h \tan \gamma)] - \sin \varphi_2 \Delta R \sin \beta_0}{\cos \varphi_2 \tan \gamma (R_f - h \tan \gamma) + [a_0 - \cos \varphi_2 (h + h_0) - \sin \varphi_2 \Delta R \cos \beta_0]} \right) \quad (11)$$

In expression,

$$A = \left(\frac{\frac{w_2}{w_1} (-\tan \gamma \Delta R \cos \beta_0) - \cos \varphi_2 \tan \gamma \Delta R \sin \beta_0}{\cos \varphi_2 \tan \gamma (R_f - h \tan \gamma) + [a_0 - \cos \varphi_2 (h + h_0) - \sin \varphi_2 \Delta R \cos \beta_0]} \right)$$

$$B = \left(\frac{\frac{w_2}{w_1} [h + h_0 - \tan \gamma (R_f - h \tan \gamma)] - \sin \varphi_2 \Delta R \sin \beta_0}{\cos \varphi_2 \tan \gamma (R_f - h \tan \gamma) + [a_0 - \cos \varphi_2 (h + h_0) - \sin \varphi_2 \Delta R \cos \beta_0]} \right)$$

So,

$$\beta_p = \frac{A}{\arcsin \sqrt{1 + B^2}} + \arctan B \quad (12)$$

The actual cam contour equation of globoidal indexing cam can be concluded as:

$$\begin{pmatrix} x_m \\ y_m \\ z_m \end{pmatrix} = \begin{pmatrix} \{a_0 - \cos \varphi_2 (h + h_0) - [(R_f - h \tan \gamma) \cos \beta_p + \Delta R \cos \beta_0] \sin \varphi_2\} \cos \varphi_1 \\ - [(R_f - h \tan \gamma) \sin \beta_p + \Delta R \sin \beta_0] \sin \varphi_1 \\ \{a_0 - \cos \varphi_2 (h + h_0) - [(R_f - h \tan \gamma) \cos \beta_p + \Delta R \cos \beta_0] \sin \varphi_2\} \sin \varphi_1 \\ + [(R_f - h \tan \gamma) \sin \beta_p + \Delta R \sin \beta_0] \cos \varphi_1 \\ - \sin \varphi_2 (h + h_0) + [(R_f - h \tan \gamma) \cos \beta_p + \Delta R \cos \beta_0] \cos \varphi_2 \end{pmatrix} \quad (13)$$

Among them: β_p correspond to the contact Angle, there is two values β_p and $\beta_p + \pi$ correspond to the cam two profiles.

Calculation Example

Now processing a globoidal indexing cam mechanism of tapered rollers and simulate the result by using MATLAB, the parameters as follows:

Centre distance	Tool radius	Maximum radius of roller	Coning angle
160mm	15mm	20mm	8°
The distance from any section of the roller to its end	The mashing height of tool	The distance of rotation centre to the inner end of the roller	
20mm	10mm	70mm	

Select the sine motion, the angle of cam from 0° to 120°, the mashing height of roller from 0 to 20mm. The measuring principle according to the reference [6]. The results of simulate is shown as Fig.3.

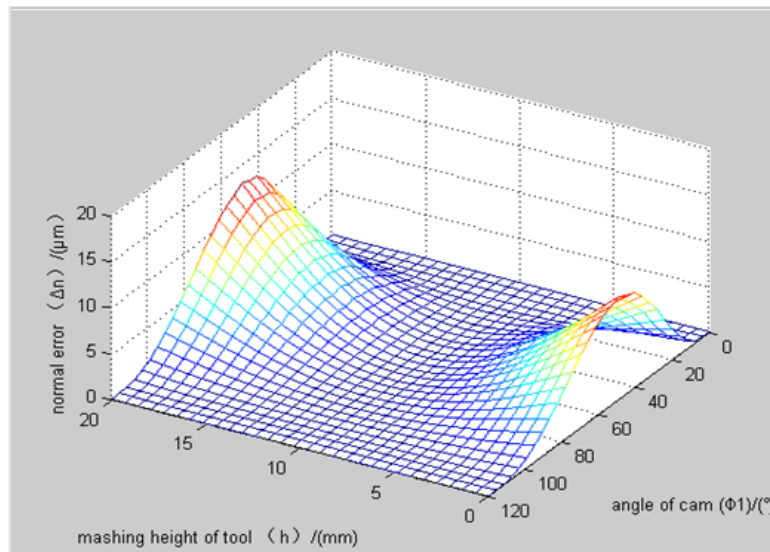


Fig.3: error distribution map of one-side machining theories.

At the contact point of the roller, the normal error $\Delta n_{1/2}=0$. The results accord with the conclusion upon the analyzing of One-Side Machining Principle. On both sides of point A, Machining error increased regularly. Maximum machining error $\Delta n_{max} =0.013\text{mm}$. The result indicates that the normal error is within tolerance.

Conclusion

This paper is based on current processing method of globoidal indexing cams and focuses on the application of the one-side machining theories in the tapered roller-globoidal indexing cam mechanism. Using spatial meshing theory and rotation matrix, the contour equation of the tapered roller-globoidal indexing cams is derived and verified with simulation. The simulation results indicates that the normal error is within tolerance, and the increased thickness below point A actually helps the mechanism to endure the abrasions created when the pressure angle is increased and provides remission for the deformation in the heat treatments. The contour surface normal error model of the tapered roller-globoidal indexing cams can be used to make assessments of the contour surface of globoidal cams processed. The practice of choosing a variation range of the cutting tool radius according to the maximum allowable error of the cams' contour surface will improve the service life of the cutting tools and has a favourable economical efficiency and application value.

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