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Study on Profile Generation of Conjugate Plate Cams for a Roller Gear Cam Mechanism

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ABSTRACT

A roller gear cam mechanism is presented. It consists of two or more plate cams with particular teeth, called Conjugate Cam Tooth (CCT) and a turret with axially located rollers. A practical and available configuration has been found out by synthesizing its parameters. The profile equations of the conjugate cam are derived by using a relative velocity method. A program for the design automation of shape of the conjugate cam and the motion simulation of this kind of mechanism has been developed using the derived formulae with C++ language. Finally, an example is given.

Keywords : Conjugate Cam, Plate Cam, Roller Gear, Roller Gear Cam Mechanism, Modeling and Simulation, CAD

1. Introduction

A roller gear cam mechanism is an intermittent-rotation mechanism. Due to the advantages of high loading capacity, low noise, low vibration, and high reliability in comparison with some traditional intermittent-rotation mechanisms, it can be widely applied in automatic tool changers of CNC machines for changing two parallel cutters, automatic feed apparatus for intermittently feeding a sheet or rod material in a predetermined length to a working machine such as presses, machines such as a turret lathe for successive machining processes, and in various automated manufacturing devices.

There are different types of the roller gear cam mechanism. H. S. Yan and H. H. Chen[1] introduced the design procedures of a roller gear cam mechanism where a globoidal cam with ribs and a turret with radially located rollers are arranged such that their axes are disposed at skew to each other. In this paper another type of a roller gear cam mechanism is presented where two or more plate cams with particular teeth, called Conjugate Cam Tooth (CCT) and a turret with axially located rollers are arranged such that their axes are parallel each other. The teeth and rollers are in linear conjugate contact. Figure 1 shows such a design with eight rollers. When the cam rotates at a constant angular velocity about the input axis, the rollers roll along the surface of the tooth and drive the turret following a given displacement curve. Since the axes of the cam and follower are parallel, the backlash can be reduced to zero by shortening their central distance and this mechanism can be designed as external set or internal set like general spur gears.

For this new cam mechanism, the parameter synthesis and the geometry of conjugate surfaces are of

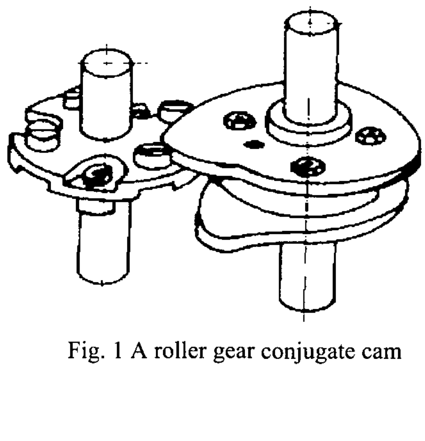


Fig. 1 A roller gear conjugate cam

major concern in designing and manufacturing the double cams. Our purpose here is first to synthesis the roller gear cam mechanism to find available and practical configurations, and second to generalize the surface geometry of double cams meshing turret rollers based on a relative velocity method[2].

2. Model and Parameters

Fig. 2 shows a general model of the roller gear cam mechanism. It has two pieces of a plate cam and a rotating roller follower with equally distributed rollers in a circle. The profile ABC forms a special tooth, the Conjugate Cam Tooth (CCT), which makes the follower rotate in given motion functions. The profile CD and E_1A_1, called Conjugate Arc Teeth (CAT), meshes two rollers to keep the follower still when the cam rotates, which are on the different cams. One conjugate cam tooth meshing with two non-adjacent rollers makes the follower rotate one angle, and then another conjugate arc teeth keeps the follower still or another CCT turns it one angle more. Suppose that the rotating follower has N rollers of radius R_r, equally distributed in a circle of radius R, then the indexing angle of the follower is

$$\phi_m = \frac{2\pi}{N} \tag{1}$$

The tooth CCT consists of two segments of curve on a cam, AB and BC, which are defined as a forward working curve and a backward working one, and their corresponding angular range is α_1 and α_2 which are same to each cam tooth for the given specifications of this mechanism.

Since three rollers involved with the cam change their positions when a turret is in motion, the corresponding position angles ϕ_1, ϕ_2 and ϕ_3 are necessary. In the initial of rotation, they are

$$\begin{cases} \phi_1 = \phi_{10} \\ \phi_2 = \phi_{20} \\ \phi_3 = \phi_{30} \end{cases} \tag{2}$$

The positions of the rollers with respect to the cam axis are expressed by the position angles, θ_1, θ_2 and θ_3. When the follower rotates through an indexing angle ϕ_m they will change from an initial position to an ending position, that is, θ_1 changes from θ_{10} to θ_{11}; θ_2 from θ_{20} to θ_{21}; and θ_3 from θ_{30} to θ_{31}.

The tooth CAT consists of two arc segments of the same central angle β_j and the phase angle α_0 on different cams. Their radii are expressed by R_{b1} and R_{b2}, respectively. The parameters of the CAT but the central angle are dependent on the basic parameters, N, R, R_r and d, and the position angle of rollers ϕ_{10}.

Since a rotating cam involves three rollers of the roller gear, three segments of curve on the cam meshing them must be considered. Both of the forward working curve and the backward one are designed according to the requirement of conjugate cams, and other, D_1E_1, allows the roller 2 to rotate without interference.

For the forward profile of CCT, we have

$$\begin{cases} R\sin\phi_{10} = (R_{b1} + R_r)\sin\theta_{10} \\ d = R\cos\phi_{10} + (R_{b1} + R_r)\cos\theta_{10} \end{cases} \tag{3}$$

Solving for R_{b1} and θ_{10}, we obtain

$$R_{b1} = \sqrt{(R\sin\phi_{10})^2 + (d - R\cos\phi_{10})^2} - R_r \tag{4}$$

$$\theta_{10} = \tan^{-1}\left(\frac{R\sin\phi_{10}}{d - R\cos\phi_{10}}\right) \tag{5}$$

For the segment CD and C_1D_1 of the CAT, the radius R_{b2} and an initial position angle θ_{20} are, respectively

$$R_{b2} = \sqrt{(R\sin\phi_{20})^2 + (d - R\cos\phi_{20})^2} - R_r \tag{6}$$

$$\theta_{20} = \tan^{-1}\left(\frac{R\sin\phi_{20}}{d - R\cos\phi_{20}}\right) \tag{7}$$

where $\phi_{20} = \phi_m - \phi_{10}$ (8)

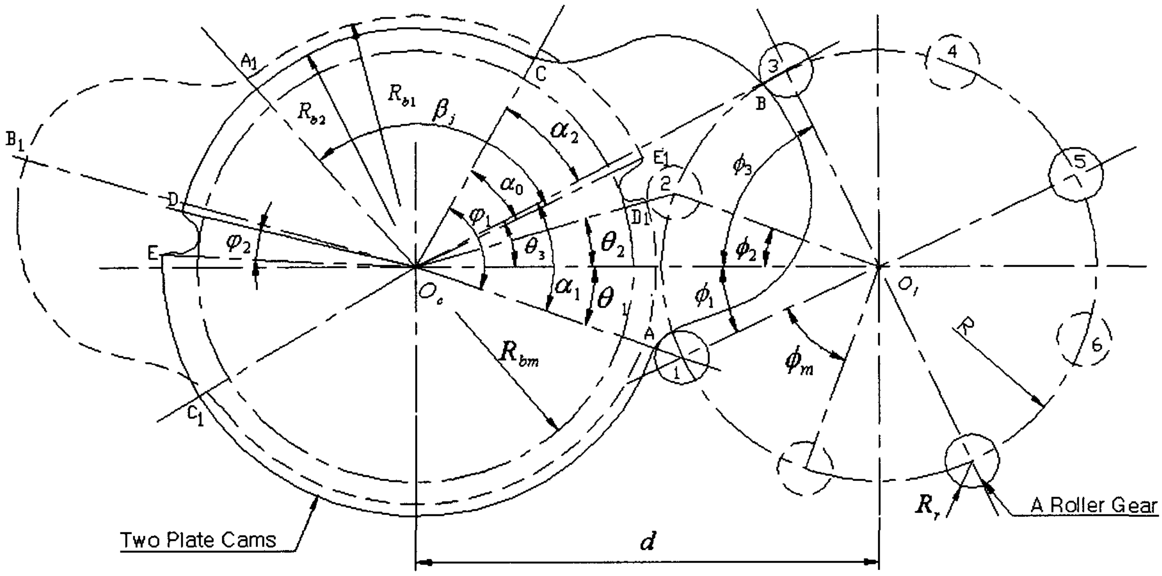


Fig. 2 Model of a roller gear cam mechanism

and for the backward profile of CCT, we find

$$R_{b3} = \sqrt{\begin{matrix}(R\sin\phi_{30})^2 \\ +(d - R\cos\phi_{30})^2\end{matrix}} - R_r \quad (9)$$

$$\theta_{30} = \tan^{-1}\left(\frac{R\sin\phi_{30}}{d - R\cos\phi_{30}}\right) \quad (10)$$

where $\phi_{30} = 2\phi_m - \phi_{10}$ (11)

The phase angle α_0 between the two pieces of arc for the CAT is given by

$$\alpha_0 = \theta_{10} + \theta_{20} \quad (12)$$

The angle range of the forward working curve and the backward working curve of the CCT are found as

$$\alpha_1 = \theta_{10} + \theta_{30} \quad (13)$$

$$\alpha_2 = \theta_{11} + \theta_{20} \quad (14)$$

The angle range φ_1 of the CCT and the free segment DE or D_1E_1 are expressed by

$$\varphi_1 = \theta_{10} + \theta_{30} + \alpha_2 \quad (15)$$

$$\varphi_2 = \theta_{10} + \theta_{30} + \alpha_2 - \alpha_0 - \theta_{20} \quad (16)$$

when the follower rotates through an indexing angle ϕ_m, the cam has a maximum radius R_{m1} and ending position angle θ_{11} for the forward profile, that is

$$R_{m1} = \sqrt{(R\sin\phi_{11})^2 + (d - R\cos\phi_{11})^2} - R_r \quad (17)$$

$$\theta_{11} = \tan^{-1}\left(\frac{R\sin\phi_{11}}{d - R\cos\phi_{11}}\right) \quad (18)$$

where $\phi_{11} = \phi_m + \phi_{10}$ (19)

and a minimum radius R_{m3}, an ending position angle θ_{31} in the backward profile,

$$R_{m3} = \sqrt{(R\sin\phi_{31})^2 + (d - R\cos\phi_{31})^2} - R_r \quad (20)$$

$$\theta_{31} = \tan^{-1}\left(\frac{R\sin\phi_{31}}{d - R\cos\phi_{31}}\right) \tag{21}$$

where $\phi_{31} = \phi_m - \phi_{10}$ (22)

Obviously, $R_{m3} = R_{b2}$ (23)

In rise motion, the rotational angle range of the cam while the CCT works is found as

$$\theta_c = \alpha_1 - \theta_{10} + \theta_{11} \tag{24}$$

and in dwell motion, the rotational angle range of the cam while the CAT works as

$$\theta_H = \beta_j - \alpha_0 \tag{25}$$

In order to have continuity between the forward curve and the backward curve, let

$$R_{m1} = R_{b3} \tag{26}$$

and then we have

$$\cos\phi_{11} = \cos\phi_{30} \tag{27}$$

$$\phi_{11} = \phi_{30} \tag{28}$$

Substituting Eqn.(10) and (19) into Eqn.(28), we find

$$\phi_{10} = \phi_m / 2 \tag{29}$$

Since $\phi_{10} = \frac{1}{2}\phi_m$, from Eqn.(4) to (24), a set of reasonable and practical parameters of the roller gear mechanism are obtained as

$$\phi_{10} = \phi_{20} \tag{30}$$

$$R_{b1} = R_{b2} \tag{31}$$

$$\theta_{10} = \theta_{20} \tag{32}$$

$$\alpha_0 = 2\theta_{10} \tag{33}$$

$$\alpha_1 = \alpha_2 \tag{34}$$

$$\theta_c = 2\cdot\theta_{30} \tag{35}$$

$$\varphi_1 = 2(\theta_{10} + \theta_{30}) \tag{36}$$

$$\varphi_2 = 2(\theta_{30} - \theta_{10}) \tag{37}$$

The condition without interference for the roller 2 is

$$\varphi_2 \cdot R_b > 2R_r \tag{38}$$

3. Generation of the profile of the CCT

Fig. 3 is a schematic diagram for generation of the profile of the CCT where one follower roller is in contact with a conjugate cam tooth. The axis of the follower with equally distributed rollers is parallel to that of the cam, and the distance between them is denoted by d. The turret will make revolution counterclockwise about its axis when the cam rotates clockwise.

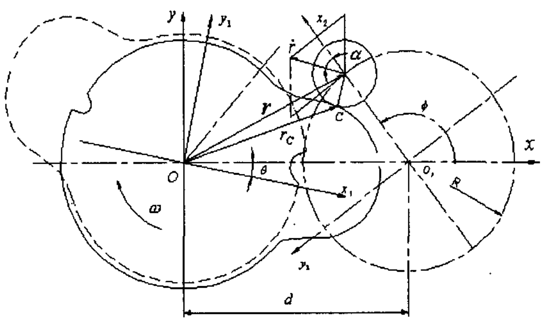


Fig. 3 Generation of the Profile of the CCT

To express the motion of each part in a cam-follower, three coordinate systems are set. The first is called a Cam Coordinate System (CCS) x_1-o-y_1 with an origin fixed at the axis of cams to describe the cam shape. The second is a FRame Coordinate System (FRCS) x-o-y with an origin also located on the cam axis and its x axis passes through the pivot of the follower in order to describe the position and motion of the follower with respect to the cam. In initial position where the rotational angularθ is 0, the coordinate axis o-x coincides with the axis o-x_1. The third is called Follower Coordinate System (FOCS) x_2-o_f-y_2 with an original at the center of rotational follower. In reality, the CCS and FOCS are movable, and the FRCS is stationary; while in a reverse model, only CCS is still. The following is the derivation of profile of the CCT using relative velocity method based on the reverse model.

Since the angular displacements of the rollers, 1 and 3, are same for any rotation of the follower, we have

$$\begin{cases} \phi_1 = \phi_{10} + s(\theta) \\ \phi_3 = \phi_{30} - s(\theta) \end{cases} \tag{39}$$

where $s(\theta)$ is the motion function of a follower.

As shown in Fig. 3, the displacement vector and velocity vector of the roller center in the CCS are respectively

$$\mathbf{r} = d \cdot e^{j\theta} + R \cdot e^{j(\theta+\phi)} \tag{40}$$

$$\dot{\mathbf{r}} = \dot{\theta} d\, j e^{j\theta} + R(\dot{\theta} + \dot{\phi}) j e^{j(\theta+\phi)} \tag{41}$$

where $\phi = \pi + \phi_1$ for the roller 1;
and $\phi = \pi - \phi_3$ for the roller 3;
and $\dot{\phi} = v\dot{\theta}$ (42)
where $v = ds/d\theta$;
and $\dot{\theta}$ is angular velocity of the cam

The velocity components in the FOCS can be expressed by

$$\begin{cases} \dot{r}_{x2} = \dot{\theta} d \sin\phi \\ \dot{r}_{y2} = \dot{\theta} d \cos\phi + R\dot{\theta}(1+v) \end{cases} \tag{43}$$

and then the direction angle of the velocity can be defined as

$$\begin{aligned} \alpha &= \tan^{-1}\left(\frac{\dot{r}_{y2}}{\dot{r}_{x2}}\right) \\ &= \tan^{-1}\left(\frac{d\cos\phi + R + Rv}{d\sin\phi}\right) \end{aligned} \tag{44}$$

we note that α is equal to the pressure angle of the cam.

Since the contact point C is located on the circumstance of the roller and its velocity versus the cam is parallel to the relative velocity of roller centers, the position of the point C on the roller is found as

$$\begin{aligned} \mathbf{r}_C &= d \cdot e^{j\theta} + R \cdot e^{j(\theta+\phi)} \\ &\quad + R_r e^{j(\theta+\phi\pm(\frac{\pi}{2}+\alpha))} \end{aligned} \tag{45}$$

In the eq.(45), the lower in the "sign ±" is used for the roller 1 and the upper the upper for the roller 3.

Finally, the profile of the cam in the components in the CCS, is expressed by

$$\begin{cases} C_{x1} = d\cos\theta + R\cos(\theta+\phi) \\ \quad + R_r \cos(\theta + \phi \pm (\frac{\pi}{2} + \alpha)) \\ C_{y1} = d\sin\theta + R\sin(\theta+\phi) \\ \quad + R_r \sin(\theta + \phi \pm (\frac{\pi}{2} + \alpha)) \end{cases} \tag{46}$$

4. Examples

To examine the equations derived for the new roller gear cam mechanism and use them to generate exact cam shape, a CAD program for design of the cam and simulation of the cam mechanism is developed using C++. Here one of motion pattern of the follower is given when the cam makes a full revolution, that is, Rotation-Rotation-Dwell. After inputs of parameter of the conjugate cam with rotating followers, shown in Table 1, and the outputs, the displacement curve of the follower in Fig. 4 and pressure angle in Fig. 5 and the cam shapes in Fig. 6, are automatically shown.

Table 1 Input parameters

Design Parameters	Values
Rotation of Cam	CW
Number of Rollers [N]	8
Radius of Roller [Rr]	15 mm
Radius of Follower [R]	100 mm
Center Distance [d]	200mm
Motion Curve	Poly.3-4-5

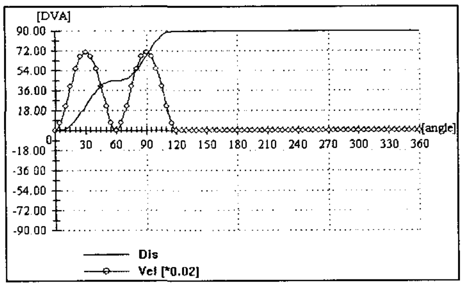
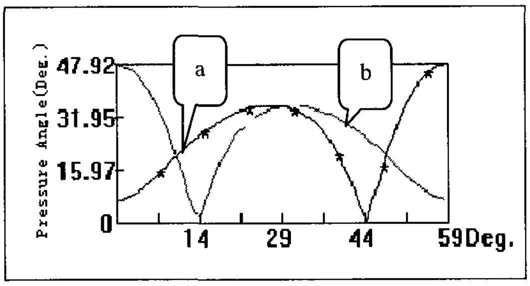


Fig. 4 Displacement, Velocity and Acceleration Curves of the Turret for the Designed Roller Gear Cam Mechanism



(a) On forward profile (b) On backward profile

Fig. 5 Pressure Angle Curve of the CCT

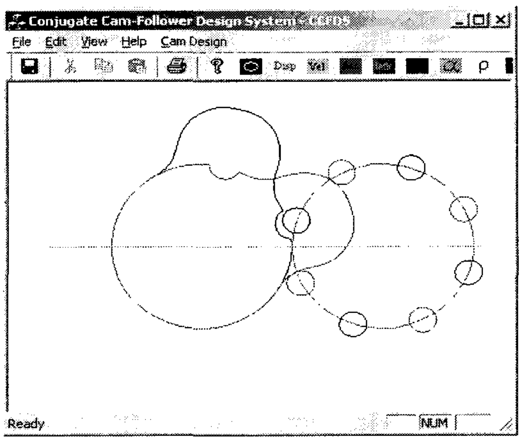


Fig. 6 The Designed CCT Shapes for the Roller Gear Plate Cam Mechanism

5. Conclusions

Roller gear conjugate mechanism is used a index drive unit and several machine automatic equipments. In this paper, a roller gear conjugate cam mechanism is presented and its parameters is defined in this paper. The expressions of configuration constraints and the CCT profile for this kind of mechanism are derived, and after choosing reasonable parameter the roller gear cams with same CCT are invented.

A computer program is developed based on the derived formulae for simulating the motion of the roller gear cam mechanisms. A typical example shows that the synthesized parameters and the derived formula for this new mechanism are correct.

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