An Exact Reverse Design Approach for Disk Cam Mechanisms

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Abstract *In the view of the difficult problem of receiving the original design of the cam and its follower motion specification, an exact new reverse design method for disk cams is provided. The essential difference between the proposed method and other existing approaches is its ability to make the cam profile smooth while still exactly satisfying boundary condition of follower displacement, velocity and acceleration. It takes computer movement simulation technology as the main instrument. Firstly, in order to reverse the follower motion specifications accurately, an new method is proposed in the paper, first of all, smooth disposal is processed to the cam profile which is formed by the equalized measurement data, and then the cam profile is processed into a series of discrete data. Secondly, this paper does research on motion specification of disk cam follower through establishing mathematical modeling and analysis treatment, finally it works out the expression of follower motion specifications. In addition, the way of distinguish the real motion specification of cam mechanism is put forward. Thirdly, the simulation modeling is established and the follower motion specifications which is the accurate gauge of the reversed disk cam is also achieved. An example shows that the proposed method can be a powerful tool of cam profile smoothing, which verifies the method can realize exact reverse design for disk cam mechanisms rapidly. The approach is not only suitable for own program but also for CAD/CAE software, and it can be used for the spatial cam reverse design as well.*

Keywords *Reverse Design Motion Simulation Motion Specification Cam Mechanism*

1. Introduction

A cam is a mechanical device for transmitting mechanical work to another component (the follower) according to the transmission, direction and control function. A planar cam mechanism is the common type to transform rotary motion of the cam into translating or oscillating motion of the follower. Since the motions of a follower depend on the cam profile and the follower type, the exact profile of the cams must be given to obtain the prescribed output of the follower after reasonable choice of a follower type and parameters for the cam follower systems. Therefore, how to achieve process of the introduced products without drawing, and how to test for processed products, which not only play an important rule on import machinery accessories, but also can speed up the digestion and absorption of foreign advanced technology. So as to create and develop our own new products has very important practical significance.

2. Relevant Research

Many scholars make a great deal of reverse investigation on disk cam mechanisms. For example, the reverse design equation of follower motion specification is founded basing on the data which are measured by CMM and the meshing relation of cam and roller. Using cubic spline function, the interpolation functions of actual cam contour is obtained, and then academic contour line equation is worked out, finally the motion specification of follower and the implementation are reversed.

Nowadays, there remain lots of difficulties on reverse design of disk cam mechanisms, such as realize measurement and evaluation reversed disk cam fleetly and precisely. As the Fig. 1 shows, a new approach was introduced. First achieved the cam profile by the measured data and processed smooth disposal, second calculated the follower motion specification via motion simulation， finally the new method of detection and evaluation for the cam profile fitting result using the motion specification of cam mechanism was put forward. This method of reserve design is not only suitable for own program conveniently, but also for existing CAD/CAE software.

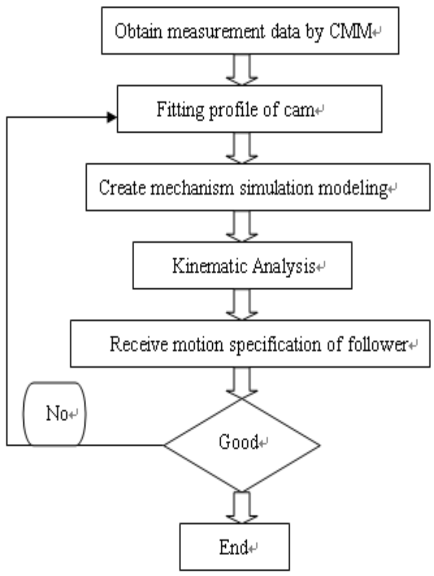


Fig. 1 The flow of cam reverse design

3. Curve fitting and discrete of disk cam contour

The data which were measured by CMM can not be used directly in reverse design of disk cam motion specification. It should process smooth disposal. However, it is complicate to dispose the profile formed by the measured data smooth directly. Thereby, in this paper, it took the method that firstly fitting profile via the measured data and then transforming the smooth curve into discrete points. Nowadays, NURBS curve is widely used for various curves fitting .Because it is convenient to adjust the curve slightly due to the localized Performance of basis function of . Its K-th power curve equation is:

$$\begin{cases} \mathbf{p}(u) = \dfrac{\sum_{i=0}^{n} B_{i,k}(u) W_i \mathbf{V}_i}{\sum_{i=0}^{n} B_{i,k}(u) W_i} = \sum_{i=0}^{n} R_{i,k}(u)\mathbf{V}_i \\ R_{i,k}(u) = \dfrac{B_{i,k}(u) W_i}{\sum_{j=0}^{n} B_{j,k}(u) W_j} \end{cases} , \quad u \in [0,1] \qquad (1)$$

$\mathbf{V}_i$ –control vertex;

W_i - weighted factor;

$B_{i,k}(u)$ - *K-th* power basic function of B-spline.

First the cam contour curve was processed into discrete points after fitted, and then the discrete point-group of cam contour curve can be obtained. (x_i'', y_i'') (i= 1, 2, 3……n).

4. Reverse Design of Motion Specification

As figure 2 shows, $O-xyz$ was basic coordinate system, $O_1-x_1y_1z_1$ was variation coordinate system which was consolidated with cam. $O_2-x_2y_2z_2$ was variation coordinate system firmed with follower. Roller and cam are meshed in points . Basing on conjugate meshing principle, it can be concluded that the normal of cam which get across must get across roller-center point $O_{f,i}$.

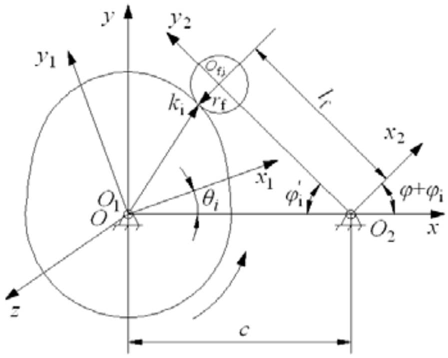


Fig.2 Cam mechanism and its coordinate system

4.1 Calculate the Coordinate of Roller Center Point

When cam rotates counterclockwise, the angle between coordinate system and coordinate system can be described as:

$$\theta_i = \frac{2\pi \cdot i}{n} \tag{2}$$

Suppose the theoretic coordinate of cam contour curve is ( ), the roller center point can be concluded as follow:

$$\begin{bmatrix} x_{f,i} \\ y_{f,i} \\ 1 \end{bmatrix} = \begin{bmatrix} \cos\theta_i & \sin\theta_i & 0 \\ -\sin\theta_i & \cos\theta_i & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_i''' \\ y_i''' \\ 1 \end{bmatrix} = \begin{bmatrix} x_i'''\cos\theta_i + y_i'''\sin\theta_i \\ -\sin\theta_i \sin x''' + y_i'''\cos\theta_i \\ 1 \end{bmatrix} \tag{3}$$

The slope of cam counter curve normal via meshing point can be calculated by formula (4):

$$n_i'' = \frac{x_{i-1}'' - x_{i+1}''}{y_{i+1}'' - y_{i-1}''} \tag{4}$$

Then the expressions of theoretic cam contour point can be worked out.

$$\begin{cases} x_i''' = x_i'' \pm \dfrac{r_f}{\sqrt{(n_i'')^2 + 1}} \\ y_i''' = y_i'' \pm \dfrac{n_i'' \cdot r_f}{\sqrt{(n_i'')^2 + 1}} \end{cases} \tag{5}$$

The coordinate of roller center can be deducted putting formula (5) into formula (3).

4.2 Calculate the Swing Angle of Rocker

In coordinate system $O-xyz$ the original point of $O_2-x_2y_2z_2$ coordinate system is known, the original angle between $O-xyz$ and $O_2-x_2y_2z_2$ coordinate system is φ , hypotheses the angle between rocker and X axis is φ_i'. Then the swing angle of rocker can be described as follow while the cam rotating.

$$\varphi_i = \frac{\pi}{2} - \varphi - \varphi_i' \tag{6}$$

According to the triangle geometric relations:

$$\tan\varphi_i' = \frac{y_{f,i}}{c - x_{f,i}} \tag{7}$$

Then put formula (7) into formula (6)，obtained formula (8):

$$\varphi_i = \frac{\pi}{2} - \varphi - \tan^{-1}\left(\frac{y_{f,i}}{c - x_{f,i}}\right) \tag{8}$$

The swing angle of rocker can be constructed by formula (3), (5) and (8).

4.3 Calculate Velocity and Acceleration of Follower

Using s_i 、v_i and a_i represented discrete actuality displacement, velocity, and accelerate of follower separately, the expressions were constructed as follow:

$$\begin{cases} s_i = \varphi_i \\ v_i = \dfrac{\varphi_{i+1} - \varphi_{i-1}}{\theta_{i+1} - \theta_{i-1}} \\ a_i = \dfrac{v_{i+1} - v_{i-1}}{\theta_{i+1} - \theta_{i-1}} \end{cases} \tag{9}$$

4.4 Calculate Dimensionless Motion Specification of Follower

The actual motion specification curve of follower can be obtained by processing the follower actual motion specifications into dimensionless. Because the follower actuality displacement, velocity, and accelerate are discrete, so they can be dimensionless processed directly. The time , displacement , velocity , and accelerate can be expressed as follow:

$$\begin{cases} T = \dfrac{t}{t_h} \\ S_i = \dfrac{s_i}{h} \\ V_i = \dfrac{v_i t_h}{h} \\ A_i = \dfrac{a_i t_h^2}{h} \end{cases} \tag{10}$$

In the expressions:

T, S_i, V_i, A_i ——dimensionless discrete time, displacement, velocity, and acceleration of follower;

t_h ——intervals of cam lifting or returning time;

h ——position corresponding to of follower.

5. Example of Cam Mechanism Reverse design

A piece of cam which belongs to conjugating cam is shown in Fig.3. For this disk cam mechanism, the distance between A and B is 228mm, the length of pendulum rod is BC=145 mm, and radius of roller circle is 65 mm.

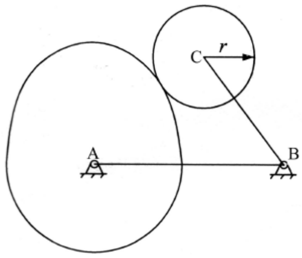
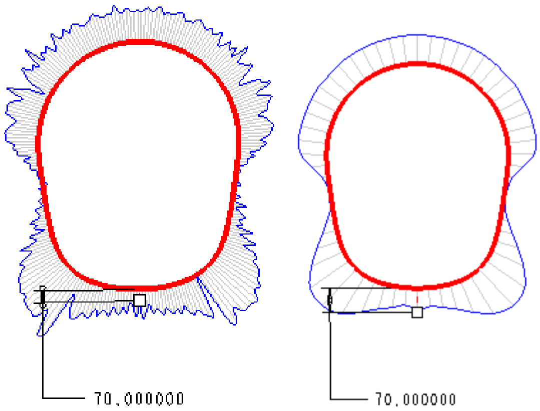


Fig. 3 Disk-cam mechanism with swinging follower

The discrete data is measured by CMM， the diameter of probe-radius is 1mm.

Cam contour curve fitting shown as in Figure 4 was obtained by equalized data. The curvature quality of contour curve directly fitted via compensation data is poor in Fig. (a). However, the curvature of contour curve shown in Fig. (b), which was fitted by points and processed smoothing, is more smooth and high-quality.



(a) Curvature of cam contour curve which is fitted directly(b) Curvature of cam contour curve which is treated smoothly

Fig. 4 Curvature of cam contour curve

According to fitting cam contour curve, the paper built a motion model and simulate motion， shown in Fig. 5. The follower actual motion specification curves were obtained. (Fig.6) Then Compared the motion specification of the follower with the desired curve of design requirements(the expected tract of the actual follower is known)，if the difference is in the scope of permissible error of the track, the reverse cam quality is eligibility, otherwise it need to re-reverse design cam.

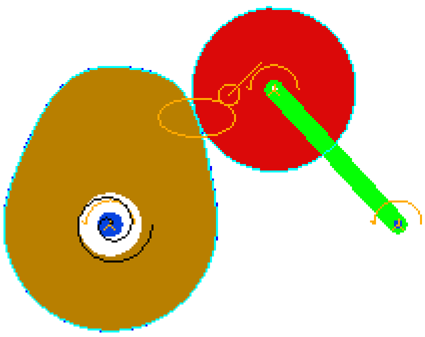
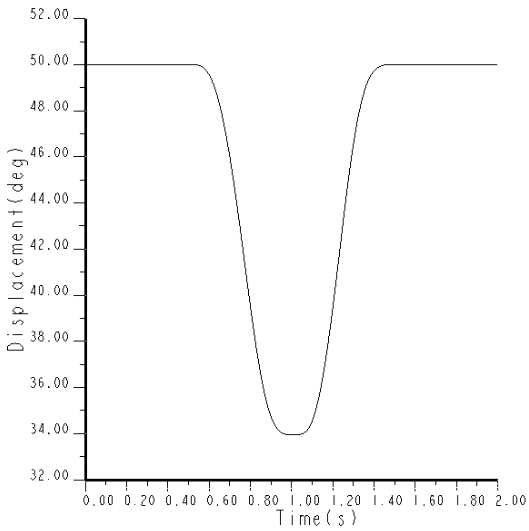
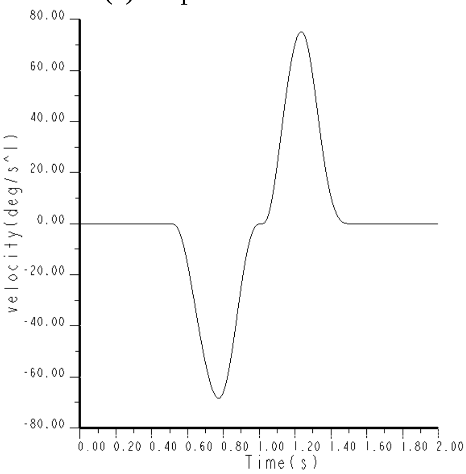


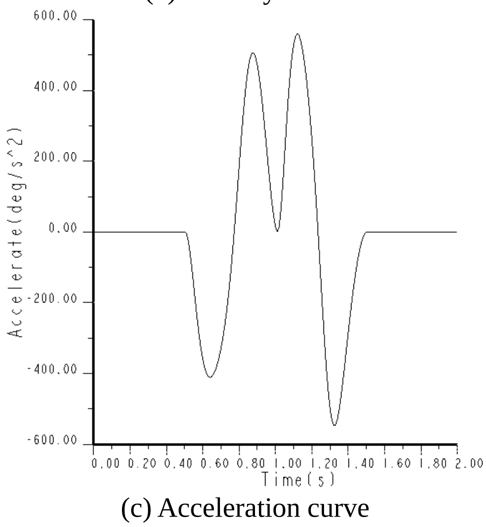
Fig.5 Mechanism simulation modeling



(a) Displacement curve



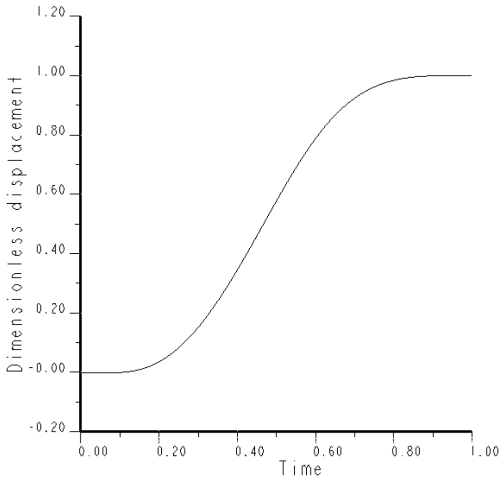
(b) Velocity curve



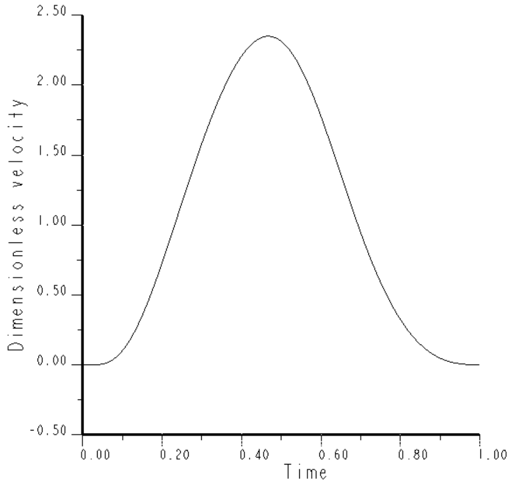
(c) Acceleration curve

Fig. 6 actual motion specification curve

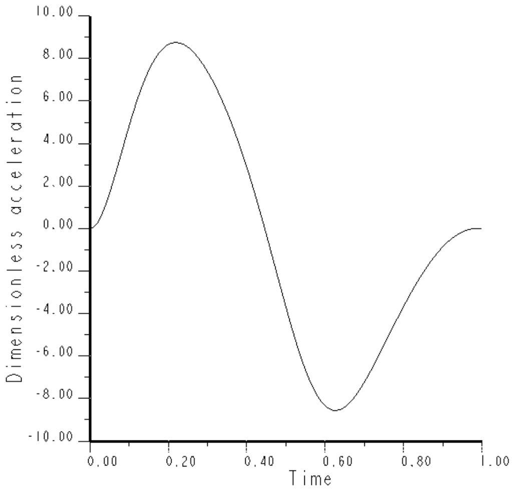
According to the actual motion specification curve, the cam rotates 90°during lifting and returning time separately. Processed actual motion specification curve into dimensionless motion specification, the dimensionless motion specification of lifting and returning curve were constructed in Fig.(7) and Fig.(8).



(a) Lifting dimensionless displacement curve

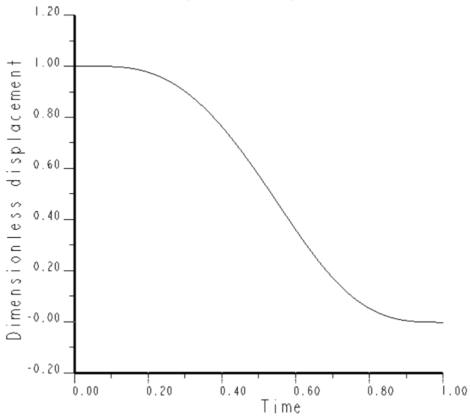


(b) Lifting dimensionless velocity curve

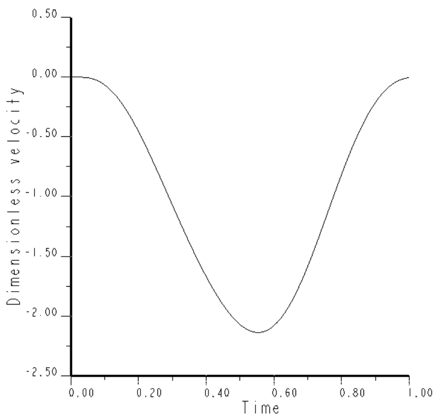


(c) Lifting dimensionless acceleration curve

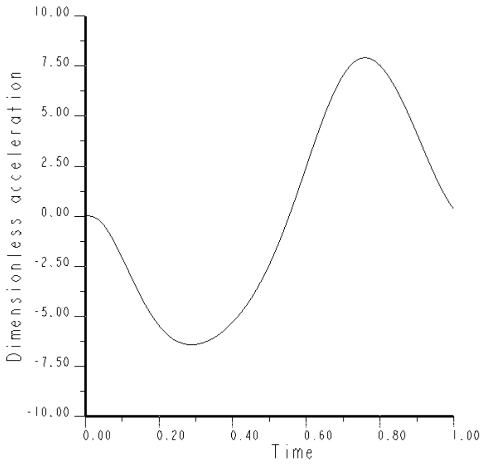
Fig. 7 lifting curve of dimensionless motion specification



(a) Returning dimensionless displacement curve



(b) Returning dimensionless velocity curve



(c) Returning dimensionless acceleration curve

Fig. 8 returning curve of dimensionless motion specification

Basing on lifting motion specification curve, it can be concluded that the lifting motion specification is polynomial motion of 4-5-6-7.

While it can be concluded that the returning motion specification is polynomial motion of 4-6-8-10， basing on returning motion specification curve.

6. **Conclusion**

An exact approach to profile generation of disk cams and evaluation of the reverse designed cam is presented for cam-follower systems. The way of identification the real motion specification of cam mechanism was put forward also. The approach is not only suit for own program but also for CAD/CAE software, and it can be adopt to the reverse design of spatial cam Mechanisms as well.

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