Research on Computer Aided Design and Machining of Equipment Globoidal Cam

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Abstract. The Globoidal Indexing Cam Mechanism (Globoidal Indexing Cam Mechanism) is composed of a space cam with a ridge and a turntable with rollers equally divided radially. In this paper, a program for reversing the law of motion of the globular indexing cam mechanism is developed, which realizes the computer-aided design and computer-aided processing of the globular indexing cam, and expounds the method of solving the motion law of the driven disc with the idea of reverse design, using UG twice the development tool UG/Open API realizes the parametric modeling of the globular indexing cam, and introduces the process of using the UG software to process the globular indexing cam surface.

Keywords: Globoidal Indexing Cam, Reverse Engineering, CAD/CAM

1. Introduction
The arcuate indexing cam mechanism is an indexing mechanism used to transmit intermittent movement between two vertical interlaced shafts. Compared with other indexing mechanisms, it has notable features such as simple and compact mechanism, stable movement, accurate indexing, simple and reliable positioning. It is widely used in thousands of various automatic machinery, especially in imported machines[1-2]. Globoidal Indexing Cam Mechanism (Globoidal Indexing Cam Mechanism) is composed of a space cam with a ridge and a turntable with rollers equally divided in the radial direction. It is a new type of indexing mechanism, which not only has the characteristics of simple structure, reliable work, and high indexing accuracy, but also has a rich and flexible cam curve to choose from to meet the requirements of various complex motion control, so in intermittent indexing The field has a wide range of application prospects. In addition to being applied to multi-station automatic machinery, it is also applied to machining center tool change manipulators and robots. There is a huge market demand in the domestic and foreign markets[3].

There are two kinds of reverse solving methods for the globular indexing cam mechanism. One is surface copying, which is traditionally called profiling, which requires three-dimensional scanning equipment to obtain point data on all surfaces and use reverse design software for modeling[4]. This method cannot deal with the defects of the cam surface and the error of the measuring point, and is not suitable for the precision mechanism of the thousand-radius indexing cam mechanism; the other method is to analyze and process the measuring point data of the cam profile. Obtain the movement law of the driven plate in the reverse direction, and then use the conventional forward design method to design and process the arcuate indexing cam mechanism[5-6].
This article first processes the data points according to the cam profile surface data points and applies the program to find the motion law of the driven disk. Secondly, the positive conventional design method is used to determine the coordinate values of other dimensions and cam profile surfaces, and then use UG. The function of surface modeling and secondary development realizes the three-dimensional parametric modeling of the globular indexing cam, and uses the CAM module of UG to process the cam with five axes. The reverse CAD module of this article is embedded in UG, and the reverse CAD/CAM operation of the arc indexing cam mechanism can be performed on the UG operation interface.

2. Reverse calculation of the motion law of the arc surface indexing cam mechanism

The coordinate system \( s_0 \left( o_0 - x_0, y_0, z_0 \right) \) connected with the driven plate frame; the dynamic coordinate system \( s_i \left( o_i - x_i, y_i, z_i \right) \) connected with the driven plate; the fixed coordinate system \( s_{p} \left( o_p - x_p, y_p, z_p \right) \) connected with the cam frame; the dynamic coordinate system \( s_k \left( o_k - x_k, y_k, z_k \right) \) connected with the cam; when the direction of \( z_2 \) is selected, Look at the arrow of \( z_2 \), \( \omega_2 \) is counterclockwise. Measurement coordinate system \( s_e \left( o_e - x_e, y_e, z_e \right) \).

This article adopts the method of taking points with equal radius to measure. As shown in Figure 1, in the measurement, a cylindrical surface with a radius of gyration of a small thousand arc surface indexing cam is selected to cut the arc surface indexing cam, and the intersection line of the cylindrical surface and the arc surface indexing cam surface is carried out one by one. Point measurement, the coordinate value \( \left( x_e, y_e, z_e \right) \) of the convex profile surface at the radial radius \( R \) is measured under the measurement coordinate system \( s_e \left( o_e - x_e, y_e, z_e \right) \).

The processing of the measurement data is based on the measurement radius \( R \), and the distance from the measurement point to the camshaft center line is compared with the measurement radius \( R \). When all the points are compared, the difference between the two is large and the measurement point with the given tolerance is deleted. The remaining measurement points are displayed in the "Output" text box.

![Figure 1. Schematic diagram of measurement](image)

Convert the processed measuring point coordinate \( \left( x_e, y_e, z_e \right) \) to coordinate \( \left( x_2, y_2, z_2 \right) \) in the cam coordinate system \( s_k \). The projection of the point \( b \) on the roller that meshes with the measuring point of the cam profile surface on the roller center line is \( a \), the coordinate value of the point in the coordinate system \( s_k \) is converted to the cam coordinate system \( s_k \). The coordinates \( \left( x_2', y_2', z_2' \right) \). The distance between measuring point \( \left( x_2, y_2, z_2 \right) \) and point \( \left( x_2', y_2', z_2' \right) \) is the radius of the roller. The equation is as follows:

The coordinates of the intersection point between the measuring point and the axis of the roller in the coordinate system \( s_k \) are:
\[ x'_1 = \sqrt{(C - R)^2 + Z_1^2 - \rho_0^2} \]
\[ y'_1 = 0 \]
\[ z'_1 = 0 \]

Where \( C \) is the center distance, \( \rho_0 \) is the roller radius.

Through coordinate transformation, the coordinates in the cam coordinate system \( s_2 \) can be obtained as:

\[
\begin{pmatrix}
    x'_2 \\
    y'_2 \\
    z'_2
\end{pmatrix} =
\begin{bmatrix}
    \cos \phi_2 \cos \phi_1 & -\sin \phi_2 \cos \phi_1 & \sin \phi_1 & -a \cos \phi_1 \\
    -\cos \phi_2 \sin \phi_1 & \sin \phi_2 \sin \phi_1 & \cos \phi_1 & a \sin \phi_2 \\
    -\sin \phi_1 & -\cos \phi_1 & 0 & 0
\end{bmatrix}
\begin{pmatrix}
    x'_1 \\
    y'_1 \\
    z'_1
\end{pmatrix}
\]

(2)

The distance between measuring point \((x_2, y_2, z_2)\) and point \((x'_2, y'_2, z'_2)\) is the radius of the roller, and its equation is as follows:

\[ \rho'_0 = \sqrt{(x_2 - x'_2)^2 + (y_2 - y'_2)^2 + (z_2 - z'_2)^2} \]

(3)

The following objective functions can be established:

\[ f(\overline{\tau}) = \rho'_0 - \rho_0 \]

(4)

Where: \( \rho_0 \) is the actual roller radius. The variables contained in the above objective function are the cam rotation angle \( \phi_2 \) and the driven disc rotation angle \( \phi_1 \). This article uses the penalty function method and uses Visual C++ language to compile an optimization program, and obtain the corresponding relationship between the rotation angle of the driven disk and the cam rotation angle \( \phi_1 = f(\phi_2) \).

Due to processing errors and measurement errors, the \( \phi_1 = f(\phi_2) \) relationship obtained through optimization is not very accurate. The \( \phi_1 = f(\phi_2) \) obtained by optimization should be compared with the general motion law of the cam mechanism to get the accurate motion law. This article uses Visual C++ language to compile a motion law fitting program.

3. Three-dimensional parametric design of arc surface indexing cam

The coordinates of a point on the center line of the driven plate roller in the coordinate system \( s_1 (a_1 - x_1, y_1, z_1) \) are:

\[
\begin{pmatrix}
    x_1 = r \cos \phi_1 \\
    y_1 = r \sin \phi_1 \\
    z_1 = 0
\end{pmatrix}
\]

(5)

Where: \( r \) is the distance from a point on the center line of the roller to point \( O_0 \), and \( \phi_1 \) is the corner of the driven disc.

After coordinate transformation, the coordinate equation of a point on the center line of the roller in the coordinate system \( s_2 (a_2 - x_2, y_2, z_2) \) is obtained, which is:

\[
\begin{pmatrix}
    x_2 = r \cos \phi_1 \cos \phi_2 - C \cos \phi_2 \\
    y_2 = -r \cos \phi_1 \sin \phi_2 + C \sin \phi_2 \\
    z_2 = pr \sin \phi_1
\end{pmatrix}
\]

(6)

In the formula: \( \phi_2 \) is the cam angle, \( C \) is the center distance, when the cam's indexing period profile is left-handed, take \( p=+1 \), and when right-handed, take \( p=-1 \).

3.1. Three-dimensional modeling

According to the formula of the law of motion, the corresponding relationship between \( \phi_1 \) and \( \phi_2 \) is
known. When \( r \) takes a certain value, \( \phi \) takes a series of values, and substituting it into equation (2) can get a spiral track coordinate of a point on the roller centerline rotating around the cam axis. In the same way, the spiral track of another point on the center line of the roller can also be obtained. Thus, a ruled surface with the roller center line as the generatrix and the spiral track line as the guide line can be established.

On the basis of the ruled surface, the thickened sheet tool is used to thicken the ruled surface by one roller radius on the left and right sides, and the entity is directly established from the surface. The thickened sheet is related to the original surface. When the original surface is edited and modified, the thickened sheet is automatically updated. Finally, using the obtained slices or entities to make worms and perform Boolean operations, an accurate cam entity model can be obtained. In order to facilitate interactive operation and improve the utilization efficiency of the model, this article uses UG's secondary development language UG/Open API to associate the cam model expression with the visualization dialog box, and modify the model expression by modifying the parameters in the dialog box. Finally achieve the purpose of modifying the model. Machining of cam profile surface based on UG.

3.2. Processing method
At present, there are many machining methods of cambered camber surface, but from a theoretical point of view, single-sided machining is in a superior state. Single-side machining means that the radius of the tool is small, and only one side of the indexing cam is processed each time. During processing, the contact of the cutting edge of the tool with the convex contour surface on the equidistant surface of the convex contour surface at the center of the tool should conform to the contact between the roller and the convex contour surface. When driven by Qianyanhe, the contact line between the cam surface and the roller surface is a curve along the length of the roller. Therefore, line processing cannot be realized in single-sided processing, so point processing can only be used, and only one point is processed at any time. Each time a curve is processed, the curve family formed by multiple processing is used to approach the ideal. In order to ensure that the curve family is processed, the length of the tool holder must be changed once after processing a curve. The length of the tool holder is increased by a certain step length during successive processing to realize the machining of the cam surface. It is worth noting that the length of the tool holder is fixed in actual processing, and the three-dimensional linear motion of the center of the tool holder is used to achieve the expected change of the length of the tool holder. In single-sided machining, a ball end mill can be used for point cutting. However, this processing method not only has low processing efficiency, but also has poor surface consistency, severe surface hardening, and increased tool wear. This paper adopts the non-developable ruled surface processing method currently being researched and used in our country, that is, the side milling processing method as the single-sided processing method of the cambered cam profile surface. Side milling is the side edge processing using non-spherical milling cutters, mostly cylindrical milling cutters or conical milling cutters. In the side milling process, the double-point offset method is used as the calculation method of the tool position in the side milling process, that is, the two points close to the cam profile surface and the roller line are used as the two points of the ruled surface to construct the tool. The position of the axis is followed by the rotation of the cam and the feed of the tool to process the entire cam profile.

The cam working surface is composed of five parts (refer to Figure 2). The curve is divided into a starting section ab, a rest section bc, an index section cf, a rest section fg, and an end section gh. Usually the cam is symmetrical, so the indexing angle \( \alpha \) of the starting section is equal to the indexing angle \( \beta \) of the ending section. From each cam angle \( \theta_2 \), the angular displacement \( \theta_1 \) and angular velocity \( \omega_1 \) corresponding to the driven turntable are calculated according to the selected mechanism motion law. The relationship between \( \theta_1 \) and \( \theta_2 \) is shown in Figure 1. The figure shows the angular displacement curve of the driven plate in a cam rotation period. In the non-stop section, the curve motion law corresponds to the motion law of the indexing section—improving the sinusoidal acceleration motion law.
The more difficult thing to deal with in the machining of arc-face indexing cams is to follow the machining according to the surface distortion of the cam, while avoiding the over-cutting caused by the falling of thousands of tools. Therefore, in the processing, the working arc is divided into two parts according to the radial projection relationship, and the part that needs to be twisted by the tool shaft is processed together with the working bottom surface, and the part that needs to be twisted by the tool is separately driven by the ruled surface.

![Figure 2. Relationship between $\theta_1$ and $\theta_2$](image)

Using UG's CAM module, the tool position data and NC program code are generated and output to the file according to the basic parameters and motion laws of the arc indexing cam, and the appropriate NC program code is transmitted to the CNC machining center control system through the data transmission software. It can directly carry out the CNC machining of the globular indexing cam.

4. Conclusion
This paper realizes the CAD and computer-aided machining of the globular indexing cam mechanism through the movement reverse program of the globular indexing cam. At the same time, the parametric modeling of the globular indexing cam is realized by using the UG secondary development tool UG/Open API. The process of machining the cam profile surface of the camber indexing is realized, and the CAD integration problem of machining camber indexing cams with variable diameter tools can be solved.

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