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Research on Simulation Algorithm of Spiral Bevel Gear's Virtual Manufacturing

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Abstract: ***Now the manufacturing of spiral bevel gears is going in digital virtual manufacturing direction, and virtual machining is a key link in digital manufacturing. Based on the spiral bevel gears meshing theory, the simulation algorithm is researched. Equation of Cutter and blank is established. Solving the gear tooth boundary points in the machine tool coordinate system, which is the key arithmetic of the tooth modeling? With Delphi and OpenGL interaction techniques, the simulation environment is set up, including machining parameters and displaying interface, triangular patches to build the models for cutter, blank and the gears. The cutting process simulation is realized in real-time by analyzing of the NC codes, which can be independent of the existing commercial software.***

Keywords: spiral bevel gear, molding method milling, meshing theory, algorithm.

1. Introduction

In the field of machinery, gear transmission because of its high efficiency, compact structure, reliable operation, long service life, stable transmission ratio, etc is widely used aviation, navigation and coal mining machinery and other fields [1] - [2].

Along with the continuous development of science and technology, the structure of the gear, the design level and design method are also in unceasing development, the characteristics of gear, such as performance requirements more and more is also high. Spiral bevel gear, as the representative of mechanical transmission, its manufacturing level to a certain extent, reflects the development level of industry in our country, In the late 1980s Virtual Manufacturing technology have been proposed, the use of computer simulation technology and virtual reality technology, the digital processing of the product. Virtual manufacturing technology in machining spiral bevel gears can play on the performance of the prediction, assessment. It can also effectively shorten the production cycle, saving manufacturing costs. The technique after ten years of continuous development has not only achieved a very substantial result, but had a revolutionary impact on the manufacturing sector. Spiral bevel gears are still indispensable parts of drive systems of various machinery and equipment, in the event that there is a need for power transmission between intersecting axes. Accurate tooth surface and good surface quality are critical to achieve the low-noise bevel gear drives. Because of a relatively complex geometry, continuous efforts are made to streamline the design and manufacturing process [3]-[4].

Vector rotation formula is the foundation of the coordinate transformation, the coordinate transformation is a bridge model to solve the boundary point, because the gear billet coordinate system and tool coordinate points belong to different coordinate system, so in solving boundary point coordinates, need based on the coordinate transformation matrix, the gear billet and cutting tool equation through coordinate transformation, the machine tool coordinate system conversion to the same coordinate system, then simultaneous solution.

The modeling design of the spiral bevel gear is still relevant topic of research. Simulation process according to the spiral bevel gear cutting with virtual reality technology are equivalent conversion based on machine cutter and machine tool motion parameters at the actual

Status and program control between the cutter and gear blank using Delphi.

In spiral bevel gears virtual simulation algorithm, getting the gear blank and tool intersection algorithm is the key point can be obtained through the intersection of the solid model tooth. Intersection by simultaneous equations obtained gear blanks and tools. In the paper, forming method based on processing of bigger wheels, and therefore before the establishment of the equation and simulation processing needs research and processing principles meshing theory of spiral bevel gears. It is important to establish the correct coordinate system, solving the intersection coordinates and simulation process. Currently, most simulation software relies on expensive commercial software. In this research paper focuses the use of a high degree of visual Delphi and OpenGL interactive graphics technology and spiral bevel gears virtual simulation algorithm and exploitation of system implementation [5].

Belong to the space of spiral bevel gears of gear tooth bevel gear, also known as the bevel gear used to pass the intersection between axis of motion and power. According to the curves (arc, accurate involute, extended epicycloid) and use (parallel shaft driving, the parallel axis), etc. the existing system of spiral bevel gear is mainly Gleason gear tooth and MrLikang system [6]. The system of spiral bevel gear is based on the Gleason gear.

2. Gear Billet Parameterized Modeling Process

According to the principle of forming processing large wheel teeth, first of all, on the surface of the wheel under the work piece coordinate system to establish the mathematical equation, the mathematical relationship of each place according to the parameter data to establish, save the generation, the mathematical model for building large wheel to prepare data structure of the solid models. On the basis of the parameters of the big wheel (shown in table 1), a structure model of the gear blank, as shown in Fig.1, the structure of the gear blank parts name shown below (shown in table 2) .

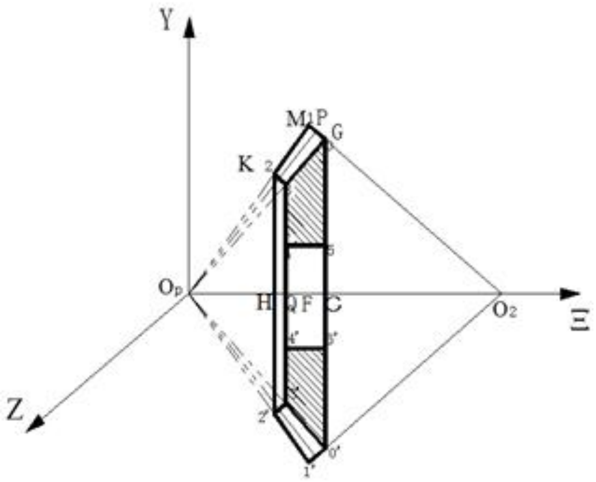


Figure 1: 3D dimensional modeling

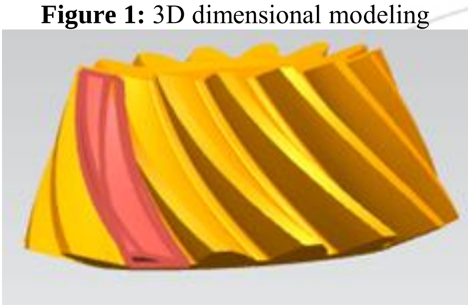


Figure 2: Gear blanks structural model

Main relations between each part are as follows:

$$PF = O_pF * \sin \quad (1)$$

$$O_pF = \sqrt{AP^2 - P} \quad (2)$$

$$CG = PF - (O_pc - O_pF) * \tan\left(\frac{\pi}{2} - \right. \quad (3)$$

$$O_pk = A_m - \quad (4)$$

$$KH = AK * \sin \quad (5)$$

Table 1: Wheel Parameter

Bevel gear	parameter
tooth number (z)	29
face width of a tooth	56mm
Height of addendum	7.52mm
Tooth dedendum	12.01mm
Outer end diameter	309.59mm
pitch angle	50.23□
face angle	53.10□
Root angle	46.52□
helix angle	35□
The average pressure Angle	22.3□
Big end modulus m	10.3448

Table 2: The given parameters tooth billet

name	name
QC	Thickness of the wheel
O_pP	Outer cone distance
KM	face width
JQ	Before half cone diameter
QC	Mounting Hole Dia
O_pF	Pitch cone vertex to round crown
O_pH	Pitch cone vertex to the front wheel distance of the crown
O_pc	Pitch cone vertex distance to the bottom of the gear
a_g	Root cone axis and Angle
a_j	Section of the cone axis and Angle
a_m	Surface of cone Angle with axis

0-5 is the boundary of the set under the Delphi modeling ring order, 0 as the back cone tip end round; 1 is the back cone big end round; 2 for the former big end cone round; 3 for the Former cone small end round; 4 for the former cone small round; 5 for the back cone small round. CG, O_pF, KH, JQ is the radius of the ring 0 to 4 respectively R1, R2, R3 and R4, before the cone circle the diameter of the cone round before 4 and 5 for the installation hole diameter corresponds to the radius of the ring 4 and 5 R5, R6. Will type (1) ~ (5) to establish the mathematical relationship of converting parameter model by means of parametric modeling, to prepare for the gear billet entity modeling.

3. The Establishment of the Cutter Parametric Model

Bevel gear machining tool used is a disc cutter, there is double-sided disc cutter, one side of the points, In order to improve efficiency in production rate, usually sided machining spiral bevel gear cutter, and two sides can be processed at the same time the gullet. Disc cutters have straight edges and curved edges of points, When processing, Curved blade cutter tooth surface shape can be corrected, But when manufacturing more difficult. Currently Gleason straight teeth straight-line edge cutter processing The structure of the milling cutter is shown in figure 3. In the actual processing used in the dish, Work out of convex and concave of spiral bevel gears respectively.

$$R_0 = R + \frac{W}{2} \quad (6)$$

$$R_1 = R_2 = K + B \quad (7)$$

$$R_3 = R_4 + \frac{d}{2} \quad (8)$$

$$R_5 = R_6 = K \quad (9)$$

$$R_7 = R - \frac{d}{2} \quad (10)$$

Gear blanks with the same principle of parametric modeling formula (6) - (10) to establish the mathematical relationship of the tool through parametric modeling.

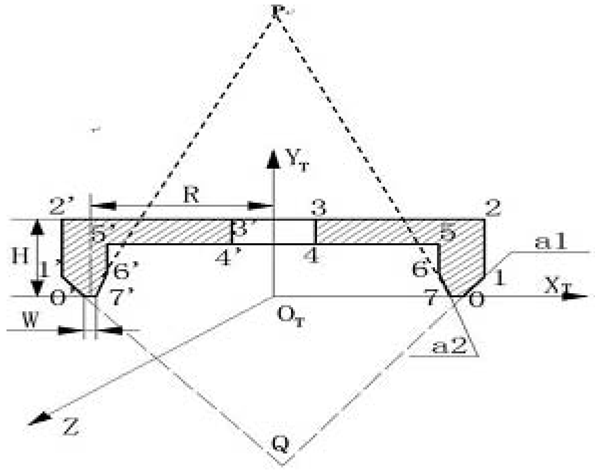


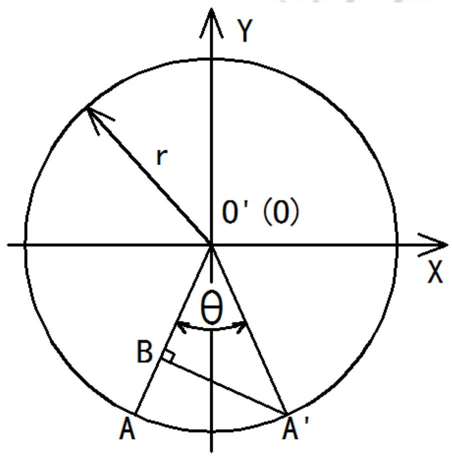
Figure 3: cutter plate structure

Where R_0, R_1, R_2, R_3, R_4, R_5, R_6 and R_7, are the radius of the ring 0 to 7 respectively.

4. Gear Billet Entity Modeling

After established the parameters of gear blank, the structure, and then establish entity model of gear blank, gear billet entities have in the back cone, cone before, vertical surface, tooth ring, cone surface and bottom ring, namely 0 to 7 ring data points. Entity model is set up to consider not only life like but also algorithm is concise, take discrete points based on the ring, constructing depots, data structure, using the grey discrete points to establish solid model. Refer to figure 1 coordinates, 0 to 7 ring radius and the coordinates of the points in the ring.

After the solid model of gear blank and cutting tool, the next step is to solve the tooth surface, to solve the tooth surface is the key point is to solve the intersection of cutter and gear blank, the intersection of cutter and gear blank by simultaneous equations of cutter and gear blank Because the cutter and gear blank points belong to different coordinate system, need through the coordinate transformation matrix to convert them into the same coordinate system to solve.



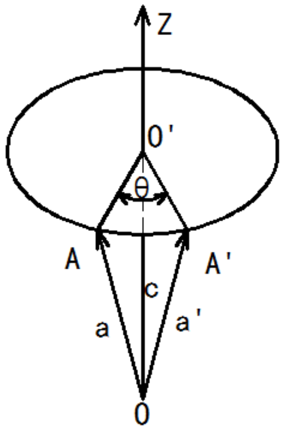


Figure 4: Vector rotation

$\vec{a}=\overrightarrow{OA}, \vec{a'}=\overrightarrow{OA'}, \angle AO'A'=\theta, \vec{c}=\frac{\overrightarrow{OO'}}{|\overrightarrow{OO'}|}$

By the vector addition rules

$$\overrightarrow{OA'}=\overrightarrow{OO'}+\overrightarrow{O'B}+\overrightarrow{BA'} \quad (11)$$

$|\overrightarrow{OO'}|=ac$, $\overrightarrow{OO'}=(ac)\vec{c}$;

The direction of $\overrightarrow{BA'}$ is vertical with the flat formed by $\vec{a}$ and $\vec{c}$, so $\vec{c_1}=\frac{\vec{c}\times\vec{a}}{|\vec{c}\times\vec{a}|}$.

Because $|\vec{c}\times\vec{a}|=r$, so $\overrightarrow{BA'}=\sin\theta(\vec{c}\times\vec{a})$;

The direction of $\overrightarrow{O'B}$ is vertical with the flat formed by $\vec{c_1}$ and $\vec{c}$, so $\vec{c_2}=\frac{(\vec{c}\times\vec{a})\times\vec{c}}{|(\vec{c}\times\vec{a})\times\vec{c}|}$, so $\overrightarrow{O'B}=\cos\theta(\vec{c}\times\vec{a})\times\vec{c}$.

Get the vector rotation formula:

$$\vec{a'}=(ac)\vec{c}+\sin\theta(\vec{c}\times\vec{a})+\cos\theta(\vec{c}\times\vec{a})\times\vec{c} \quad (12)$$

If $\vec{c}=\vec{I}$, $\vec{a}=(x,y,z)$

So $\vec{a'}$ around the axis $\vec{I}$, Rotating formula: $\vec{a'}=x\vec{I}+(y\cos\theta-z\sin\theta)\vec{J}$

$$+(y\sin\theta+z\cos\theta)\vec{K} \quad (13)$$

Written in matrix form:

$$\begin{bmatrix}x'\\y'\\z'\end{bmatrix}^T=\begin{bmatrix}x\\y\\z\end{bmatrix}^T\begin{bmatrix}1&0&0\\0&\cos\theta&\sin\theta\\0&-\sin\theta&\cos\theta\end{bmatrix} \quad (14)$$

If $\vec{c}=\vec{J}$, $\vec{a}=(x,y,z)$

So $\vec{a'}$ around the axis $\vec{J}$, rotating formula:

$$\begin{bmatrix}x'\\y'\\z'\end{bmatrix}^T=\begin{bmatrix}x\\y\\z\end{bmatrix}^T\begin{bmatrix}\cos\theta&0&-\sin\theta\\0&1&0\\\sin\theta&0&\cos\theta\end{bmatrix} \quad (15)$$

If $\vec{c}=\vec{K}$, $\vec{a}=(x,y,z)$

So $\vec{a'}$ around the axis $\vec{K}$, rotating formula:

$$\begin{bmatrix}x'\\y'\\z'\end{bmatrix}^T=\begin{bmatrix}x\\y\\z\end{bmatrix}^T\begin{bmatrix}\cos\theta&\sin\theta&0\\-\sin\theta&1&0\\0&0&1\end{bmatrix} \quad (16)$$

Hypothesis X= $[x,y,z,1]^T$, It is O-XYZ Coordinates X Point homogeneous coordinates, so

$X'=XT$ (17)

Where, T is called transition matrix.

$$T=\begin{bmatrix} a_x & b_x & c_x & d_x \\ a_y & b_y & c_y & d_y \\ a_z & b_z & c_z & d_z \\ 0 & 0 & 0 & 0 \end{bmatrix} \quad (18)$$

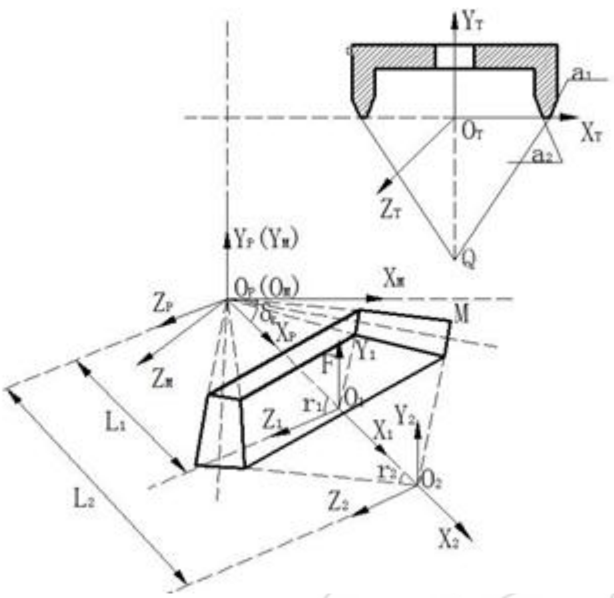


Figure 5: Teeth Coordinate System

In the machine tool system gear billet In the machine tool coordinate system (O_M - X_M, Y_M, Z_M) under the back cone.

In the work piece coordinate system (O_p - X_p, Y_p, Z_p back taper equation is:

$$x_p - q = -\sqrt{z_p{}^2 + y_p{}^2} \cdot \cot\beta_1 \quad (19)$$

$q=|\overrightarrow{O_p O_2}|= {}^{O_p P}/_{\cos\alpha_j}, \beta_1=90^{\circ} - \alpha_j.$

Then OP-XPYPZP workpiece coordinate system Machine coordinate system matrix relationship with the machine tool coordinate system (O_M - X_M, Y_M, Z_M).

$$[x_p \quad y_p \quad z_p]^T = T[x_M \quad y_M \quad z_M] \quad (20)$$

$$\begin{bmatrix} x_p \\ y_p \\ z_p \\ 1 \end{bmatrix} = \begin{bmatrix} \cos\alpha_g & 0 & \sin\alpha_g & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\alpha_g & 0 & \cos\alpha_g & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_M \\ y_M \\ z_M \\ 1 \end{bmatrix} \quad (21)$$

Coordinate conversion relations as follows:

$$\begin{cases} x_p = z_M \sin\alpha_g + x_M \cos\alpha_g \\ y_p = y_M \\ z_p = z_M \cos\alpha_g - x_M \sin\alpha_g \end{cases} \quad (22)$$

Equation (22) in to (19), the back taper equation under (O_M - X_M, Y_M, Z_M) machine tool coordinate system:

$$z_M \sin\alpha_g + x_M \cos\alpha_g - q = -\sqrt{(z_M \cos\alpha_g - x_M \sin\alpha_g)^2 + y_M{}^2} \cdot \cot\beta_1 \quad (23)$$

In the workpiece coordinate system (O_p - X_p, Y_p, Z_p) face cone equation is:

$$x_p = -\sqrt{z_p{}^2 + y_p{}^2} \cdot \cot\alpha_m \quad (24)$$

Equation (22) in to (24), the face cone equation under (O_M - X_M, Y_M, Z_M) machine tool coordinate system:

$$z_M \sin\alpha_g + x_M \cos\alpha_g = -\sqrt{(z_M \cos\alpha_g - x_M \sin\alpha_g)^2 + y_M{}^2} \cdot \cot\alpha_m \quad (25)$$

V: Position of vertical wheel
H: Position of Horizontal wheel
So get face equation of outer tool：

$$z_M + \left(R - \frac{W}{2}\right)\cot a_1 = \sqrt{(x_M - H)^2 + (y_M - V)^2} \cdot \cot a_1 \quad (26)$$

$$z_M \sin\alpha_g + x_M \cos\alpha_g - q = -\sqrt{(z_M \cos\alpha_g - x_M \sin\alpha_g)^2 + y_M{}^2} \cdot \cot\beta_1 \quad (23)$$

$$z_M \sin\alpha_g + x_M \cos\alpha_g = -\sqrt{(z_M \cos\alpha_g - x_M \sin\alpha_g)^2 + y_M{}^2} \cdot \cot\alpha_m \quad (25)$$

$$z_M + \left(R - \frac{W}{2}\right)\cot a_1 = \sqrt{(x_M - H)^2 + (y_M - V)^2} \cdot \cot a_1 \quad (26)$$

Back cone face, face cone , outer face from (23), (25),(26) were obtained.

5. Simulation Realized by the Delphi and OpenGL

Based on the virtual simulation system, Delphi is as a development platform, OpenGL as a standard graphics library implementation spiral bevel gears. OpenGL is as a professional 3D program interface, In the process of program execution speed slow. Visualization, to a certain extent determines the quality of the simulation system, at the same time Delphi also has a large visual component library (VCL), more than one hundred components. These advantages provide great convenience for programmers. under Delphi by adopting the idea of parametric modeling, first under the Delphi by adding a series of controls, including gear billet model, cutting tool and machine tool adjustment parameters, etc. Then establishes the size of the mathematical relation between these parameters and save the generated model, establish interactive dialog. It is shown in Fig.6.

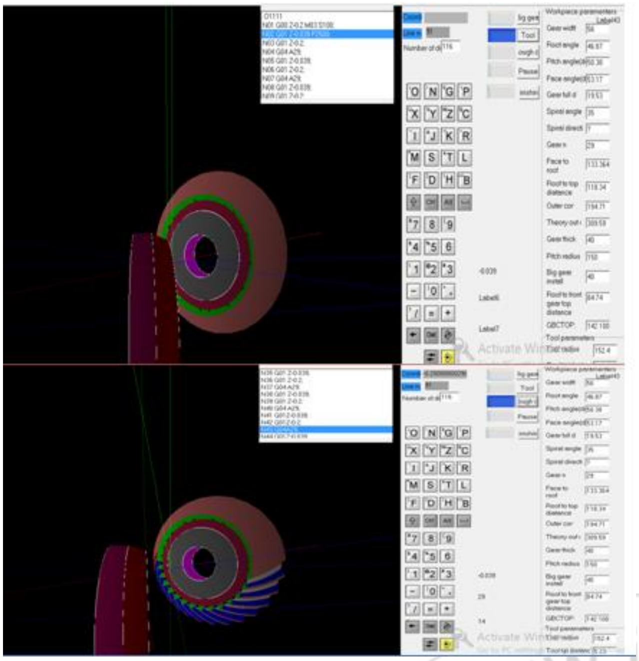


Figure 6: Cutting Simulation Processes

6. Summary

This article mainly aims at simulation of the forming processing bigger wheel. The simulation algorithm of spiral bevel gear is researched with Delphi development environment combining OpenGL interaction techniques.

In accordance with the principles and working methods meshing spiral bevel gear, according to the cutter processing features, simplified tool model is established.

On the principle of gear cutting forming method of the bigger wheel, parameterized modeling is established too.

The solving of the tooth boundary points are key arithmetic of the tooth modeling.

The cutting process simulation of the spiral bevel gear is realized in real-time by analyzing of the NC codes, inputting of big wheel parameters into the simulation system in this thesis.

Virtual simulation algorithm of spiral bevel gears is a key link in digital manufacturing, mainly in order to verify the accuracy of machine tool adjustment parameters and tooth contact analysis.

7. Appreciation

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