

## 3D Parametric Modeling Of Logarithmic Spiral Bevel Gear Based on Pro/toolkit

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### Abstract

As a new type of bevel gear, logarithmic spiral bevel gear has the feature that the spiral Angle is equal everywhere, which makes its transmission more stable, bearing capacity larger and service life longer when meshing with each other. In this paper, based on Pro/E(Pro/Engineer) and the formation principle of logarithmic spiral bevel gears, spherical involute and log-helix are tooth profile and tooth row curves of the bevel gears, an accurate three-dimensional model of log-helical bevel gears is established. A three-dimensional parametric modeling system of spiral bevel gears was developed based on the feature of shape structure on logarithmic spiral bevel gears and the call of functions in Pro/E.

### Keywords

Logarithmic spiral bevel gear; 3D parameterized modeling; 2nd development.

### 1. Introduction

As a new type of spiral bevel gear, logarithmic spiral bevel gear has the characteristic of equal spiral angle everywhere, which guarantees more stable, high load, low noise and longer service life in the process of meshing logarithmic spiral bevel gear. The logarithmic spiral bevel gear is based on the free-form surface numerical control spiral bevel gear milling machine to establish the tooth surface module, which is expressed by the function of the rotation angle of the workpiece gear. Using the spiral bevel gear manufacturing idea, the researcher studied the machining principle of a new spiral bevel gear, which laid a theoretical foundation for a new spiral bevel gear - logarithmic spiral bevel gear machining technology. It has the characteristics of being everywhere, and has been favored by more and more researchers. The 3D modeling of logarithmic spiral bevel gear affects the accuracy and accuracy of gear manufacturing. Therefore, the accurate 3D modeling of logarithmic spiral bevel gear has become the first part of the study [1-3]. Nowadays, there are three methods to design three-dimensional model of logarithmic spiral bevel gear by computer aided geometry: the first method, B-spline (NURBS) surface method. B-spline surface method is a three-dimensional software, the use of matrix operations on the gear surface sampling points, the sample points connected to the surface, that is, the formation of gear surface [4]. The second method, parametric modeling method, establishes the relationship between geometric parameters (such as top circle, root circle, base circle) and the basic parameters (modulus, tooth number) logarithmic spiral bevel gear with internal program. The parameterized solid model can be acquired automatically by rotating and mixing scanning after inputting basic parameters. The third method, tooth cutting method, according to the formation mechanism of the tooth side of the gear, establishes the helix with constant helix angle, establishes the profile of the inner and outer cross section of the tooth with the precise involute curve, and transits to the circular arc[5].

According to the forming mechanism of gear tooth side, the precise spherical involute is firstly established as the profile of the internal and external cross section of the gear; secondly, the logarithmic helix with constant helical angle is established; then the logarithmic helix is used

as the sweeping lead to make the spherical involute as the internal and external profile curve, and the sweeping is used to form the single tooth of the gear, and then the single tooth root is excessive. The fillet is optimized, and finally the precise 3D model of logarithmic spiral bevel gear is formed through the array. According to this method, this paper uses the secondary development interface Protoolkit of Pro/E and C language to analyze the three-dimensional parameterized feature description of logarithmic spiral bevel gears in Pro/E. By means of computer expression, processing and operation, the method, steps and precise modeling process of 3D parametric development are given. The 3D parametric design system of logarithmic spiral bevel gear is completed, which greatly improves the design efficiency[6].

## 2. Parameters of Logarithmic Spiral Bevel Gear

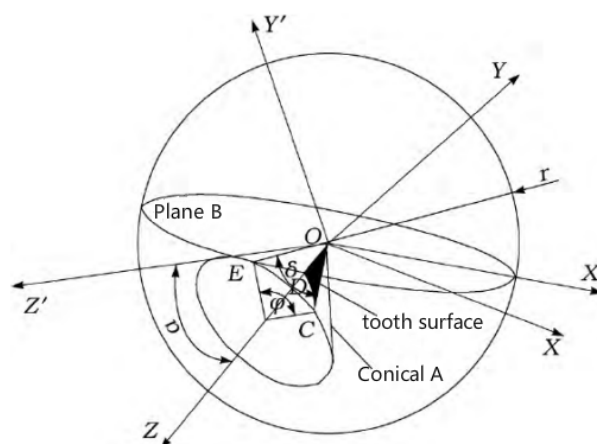
### 2.1. Name of Each Element of the Cone Surface, Cone Angle and Tooth of the Bevel Gear

The bevel gear consists of: face cone, root cone, back cone, front cone and joint cone. Gear bevel Angle is composed of face Angle, root Angle, back Angle and pitch Angle. The basic elements of gear teeth include tooth size end, tooth tip, tooth root, helix Angle and tooth surface pitch [7].

### 2.2. Tooth Surface Curve of Logarithmic Spiral Bevel Gears

#### 2.2.1. Tooth Profile Curve

The profile curve of spiral bevel gear is approximately replaced by plane involute. Although the three-dimensional model is simple, the error is large and the accuracy is not guaranteed. The tooth surface of logarithmic spiral bevel gear is actually a part of the sphere, that is, the profile curve of the gear tooth is the involute of the sphere. The formation process is shown in Figure 1: the cone (base cone) M of plane N and conical gear is tangent to the line segment OA. When N rolls over an Angle on conical M, the line segment OA turns an Angle and takes up the position of OC. At this point, point A draws an involute AC in space. In space, the segment OA draws an involute cone surface, which is the tooth profile surface of the straight bevel gear. Since the length of the cone bus OA is constant when the plane N rolls along the cone M, the involute drawn by point A is on the sphere, which is called the spherical involute.



**Fig 1.** Forming principle of spherical involute

Firstly, a dynamic coordinate system (Oxyz) is established, where the y axis is perpendicular to the plane N and the x and z axes are located in the plane N. A coordinate system (OXYZ) is established, wherein the Z axis coincides with the Central Line of the cone and the X axis is located in the plane N. Then the equation expression of point C in the moving coordinate system can be obtained. According to the position relation in Figure 4, the transformation formula of

the operational coordinate system (Oxyz) and the fixed coordinate system (Oxyz) can be obtained. Finally, the equation of point C in the moving coordinate system is transformed into the equation in the fixed coordinate system (OXYZ) through the transformation formula, namely the equation of the spherical involute:

$$\begin{cases} x = r(\sin\varphi\sin\delta + \cos\varphi\cos\delta\cos\alpha) \\ y = r(\sin\varphi\cos\delta\sin\alpha - \cos\varphi\sin\delta) \\ z = r\cos\delta\cos\alpha \end{cases} \quad (1)$$

R is the radius of the base circle;  $\varphi$  is the Angle of OA rotation of conical bus;  $\delta$  is the Angle between OA and OB on plane N;  $\alpha$  is the half Angle of the cone M.

### 2.2.2. Tooth Curve

The tooth curve of log-spiral bevel gear is the logarithmic spiral line[8]., which is different from the general spiral bevel gear tooth curve. The main difference is that the spiral Angle formed by the tooth curve of log-spiral bevel gear is the same everywhere and does not change with the change of motion. The spiral Angle of general spiral bevel gear tooth curve and the mother cone is always changing. The constant change of helix Angle will seriously affect the efficiency, bearing capacity and service life of gear meshing transmission. Therefore, the spiral Angle formed by logarithmic spiral bevel gears is the same everywhere, which has been favored by researchers. Formation principle of spiral bevel gear tooth profile curve is shown in Figure 2: on the cone, cone bus along the cone axis angular velocity of the same uniform circular motion, and the cone on the bus any move points along its bus as uniform linear motion, the fixed point on the conical surface of trajectory is defined as a conical helix, the spiral bevel gear tooth profile curve.

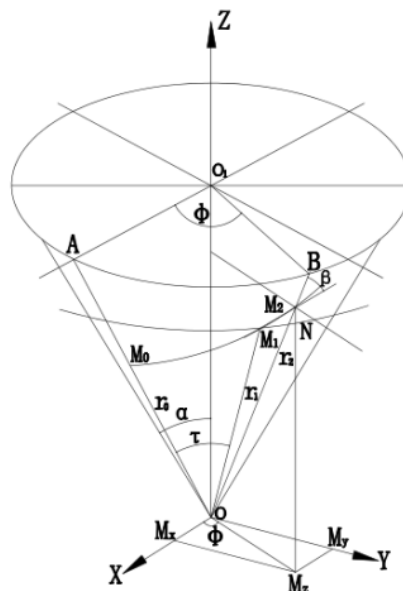


Fig 2. Formation of spiral bevel gear tooth curve

M0 is defined as the starting point of spiral bevel gear, and the height from M0 to cone vertex is  $r_0$ .  $M(x, y, z)$  is any point on the helix,  $M(x, y, z)$  is an Angle of  $M(x, y, z)$  relative to the initial point M0, and the distance between  $M(x, y, z)$  and the cone vertex is  $r$ , and the helix Angle is negative. Its vector equation is:

$$r(\varphi) = be^{m\varphi}(\sin\alpha\cos\varphi i + \sin\alpha\cos\varphi j + \cos\alpha k) \quad (2)$$

$m = \sin\alpha\cot\beta$ ;  $a$ : Half of a cone Angle;  $\beta$ : Spiral Angle (The Angle formed by the tooth curve and the parent cone);  $\varphi$ : The Angle at which any point in a cone rotates relative to the starting point;  $b=r_0$ ; The  $\varphi$  is a variable,  $\alpha$ ,  $\beta$ ,  $b$  is a constant. The parametric equation of the tooth profile curve of conical spiral bevel gear is:

$$\begin{cases} x(\varphi) = OMx = be^{m\varphi}\sin\alpha\cos\varphi \\ y(\varphi) = OMy = be^{m\varphi}\sin\alpha\cos\varphi \\ z(\varphi) = OMz = be^{m\varphi}\cos\varphi \end{cases} \quad (3)$$

### 3. Modeling of Logarithmic Spiral Bevel Gears

#### 3.1. The Formation of Involute Tooth Profile

Based on in the face of logarithmic helical gear tooth profile curve, the analysis of the tooth profile curve in Pro/E, according to the gear basic parameters: the number of teeth and pitch cone Angle, heel modulus, dividing line diameter, tooth Angle, shaft Angle, spiral Angle, Angle, the cone Angle of root, the addendum circle diameter, etc, in turn draw gear, small end addendum circle, dividing circle, circle, root circle; Then choose the reference coordinate system of large and small ends for reference, and choose cartesian coordinate system according to the "curve options" menu manager in Pro/E. Input the involute equation of large and small ends successively in the curve equation window to complete the involute tooth profile curve of large and small ends. Finally, according to the design specification of gear tooth profile, the excessive arc of tooth root [9] is calculated, and the generated involute tooth profile of large and small ends is shown in Figure 2.

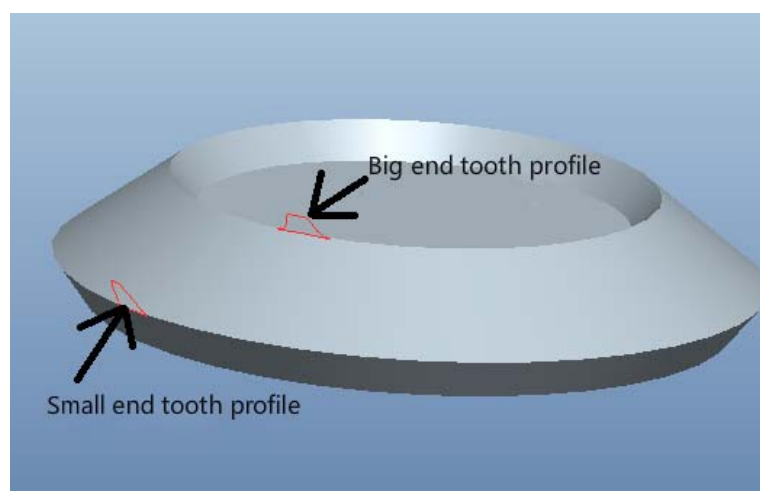
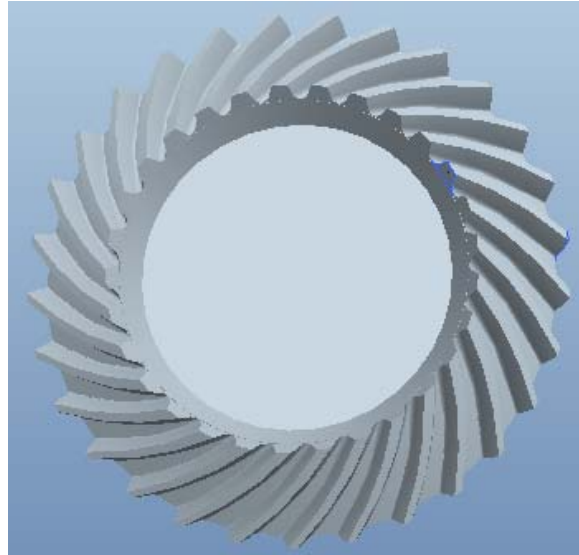


Fig 3. Big and small end tooth profiles

#### 3.2. The Formation of Logarithmic Spiral Bevel Gears

Using the method of generating tooth profile curve in section 3.1 and taking the coordinate system of cone vertex as the reference, input the log-spiral bevel gear tooth profile curve equation in the curve equation to generate the circular cone logarithmic helix. In Pro/E, rotate the part of the root circle of large and small ends around the conical axis to form a solid root circle. The mixed scanning features were selected for generation, the large and small tooth profile was selected for scanning section, and the circular cone logarithmic helix was selected

for scanning path. The single tooth entity of gear is generated by scanning feature. With the function of array, take the axis of cone as the axis of array, select single tooth entity for circular array. The number of arrays is the tooth number  $Z$  of gears, and the Angle is  $360/Z$ . The three-dimensional shape of log-spiral bevel gears after completion is shown in Figure 4.



**Fig 4.** Logarithmic spiral bevel gear

#### **4. Pro/E and C Language Secondary Development Interface Protoolkit**

The three-dimensional modeling process of the above logarithmic spiral bevel gears is in Pro/E, using its own operating commands to complete the shaping of spiral bevel gears. However, in practical application, if each gear is designed and produced by the above method, the following problems will exist:

The design process is tedious. Due to the complexity of the structure of the gear itself and the correlation between the dimensions and dimensions, there are a lot of parameters corresponding to it and the corresponding relations are also complex. If the corresponding relationship between parameters in the r&d design is established and handled by the method of creating relationships in Pro/E, the r&d cycle is long and the design efficiency is low.

(2) The designer of the gear design with Pro/E software must be familiar with the geometry information and design methods of the 3d model of the gear and want to get a precise design model. Because the precise mathematical description and representation of the tooth profile, tooth profile line and tooth profile surface of the whole gear are very important, each item must be designed strictly according to the standard requirements of the gear, otherwise it will affect the gear meshing transmission. Moreover, in the subsequent simulation, manufacturing or finite element division, it is necessary to be very familiar with the relevant parameters such as the position of arbitrary points and curvature on the surface of tooth profile, so that these features can be processed.

Based on the above considerations, the interface Protoolkit of Pro/E and C language is used for secondary development, and the three-dimensional parametric design system of logarithmic spiral gear can be established to meet the requirements. Protoolkit is the most efficient and functional interface in Pro/E and C. After being familiar with the application of this method, the rich classes and functions defined by it can be used to quickly find the features of any point position, vector and curvature of the object in Pro/E, so as to meet various needs of users [10].

#### 4.1. Characteristics of the Object(ProFeature)

The most basic feature of Pro/E, like other three-dimensional software, is: modeling of feature objects and parameterized control objects. For all 3d part models, they are composed of recombination of the basic features of the part [11]. The basic features of the part include reference, stretch, mirror image, rotation, rounding Angle, curved surface and so on. Each type of feature corresponds to an element tree, where the type of feature, reference information of feature, sketch section of feature, size information of feature and other attributes are defined. The type of feature must be defined before using the corresponding feature. In Pro/E and C language secondary development interface Protoolkit, the feature is defined as follows:

```
typedef struct feat_by_name_find //Define structure types
{
    FeatByName *feats;
    int num_feats;
} FeatByNameFind;
static ProError status; //Define static state
ProValueAlloc(&value); //Add element values
ProElementValueSet(element, value); //Sets the set values for the elements tree
...
err = ProFeatureRedefine(NULL, feature, created_elemtree, opts, 1, &errs); //Complete feature building
```

#### 4.2. Truncated Surface Object(ProSection)

The truncated surface object is a two-dimensional model [12], and the three-dimensional part features are all constructed by the superposition of the truncated surface. Before generating three-dimensional parts, a truncated surface must be determined, which can be realized through stretching, scanning and rotation. For log-spiral bevel gear, its truncated surface is the profile surface of bevel gear.

Creating a circular section:

```
ProError ProUtilCreateCircleSection (ProSection section, Parameter *params) //Truncated surface object, Define circular section parameters
{
    Pro2dCircleddef circle;
    Pro2dEntdef* ent;
    Pro2dLinedef* line;
    Pro2dPnt point;
    int brk=0;
    int circle_id, circle_diam, side_id, bot_id;
    ProSectionPointType pnt_types[2]; //The type of break point ProError err;
    ProWSecerror errors;
    Do {...}
};
```

#### 4.3. 3D irregular Shape Feature Object(ProSketched)

The convex feature formed by stretching and rotating is defined as three-dimensional irregular shape feature, which can be composed of one or more cross section shapes. For log-spiral bevel gear, its three-dimensional irregular shape feature can be viewed as: the tooth profile curve of the large and small end face of the gear is scanned along the log-helix.

3D irregular shape feature object:

```
ProError ProUtilCreateSketchedFeature(GearParam *g_ptr, FeatureDef *feat_def, ProFeature
*feature)
{ static ElemTreeData sketch[]={1, PRO_E_SKETCHER, {PRO_VALUE_TYPE_POINTER}}
};
```

Create the entity:

```
circle.type = PRO_2D_CIRCLE; //Connect the x-coordinate of the circle to the side datum plane
err = ProSectionEntityFromProjection(section, params[1].r, &side_id); //Project the
reference geometry onto the sketch plane and create the known entity in the nodal circle.
```

```
err = ProSectionEntityGet (section, side_id, &ent); // Retrieving user entities
```

```
line = (Pro2dLinedef*) ent;
```

```
circle.center[0] = line->end1 [0];
```

```
err = ProSectionEntityFromProjection(section, params[2].r, &bot_id);
```

```
err = ProSectionEntityGet (section, bot_id, &ent);
```

```
line = (Pro2dLinedef*) ent;
```

```
circle.center[1] = line->end1 [1];
```

```
circle.radius = params[0].d/2;
```

```
...
```

Create a gear:

```
ProError ProUtilCreateToothSection (ProSection section, Parameter *params) //Basic gear
parameters
```

```
{
```

```
Pro2dLinedef line;
```

```
Pro2dPnt point, p1, p2, p3;
```

```
Pro2dCircledf *p_circle, add_circle, ded_circle, t_circle;
```

```
Pro2dArcdef arc;
```

```
int dims[2], brk=0, ring_gear, z, arc1_id, arc2_id, d_id;
```

```
int circle_id, ded_id;
```

```
ProSectionPointType pnt_types [2];
```

```
ProError err;
```

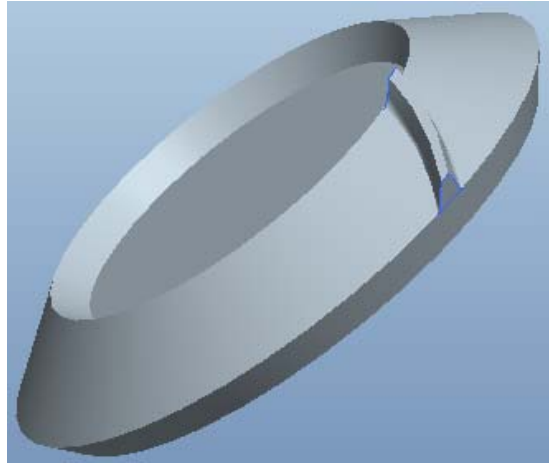
```
ProWSecerror errors;
```

```
double d, r, angle, r_base, r_t, m, an ;
```

```
Do {...}
```

The above is the correlation function used in the three-dimensional parametric modeling of log-spiral bevel gear. According to the above description, model Protoolkit parameterized control of the secondary development interface using Pro/E and C language, and the results are shown in Figure 5.





**Fig 5.** Single tooth of logarithmic spiral bevel gear

#### 4.4. The array Object

In Pro/E and C language secondary development interface Protoolkit, when the object feature has the same type feature, it can be used to generate the same feature by the array object array. For log-spiral bevel gears, the 3d irregular single teeth generated by 4.3 are generated along the axis of the bevel gears to generate log-spiral bevel gears through the array object.

```
int ProUserCreateTeeth(GearParam *g_ptr)
{ static FeatByName tooth_datum[] = {"DTM_TOOTH_1"},
};
  Static ElemTreeData tree [] = {...};
  int n_dims, ret, *p_dim_ids, *p_feat_ids, *p_tooth_ids, i, n_feats;
  int n_tooth_feats;
  PRODIMENSION dim;
  ProFeature feature, feat_plane, feat_tooth;
  ProLayerItem layer_item;
  ProLayer layer;
  ProCharName str;
  ProName w_str;
  ProElement elem_tree;
  ProModelitem modelitem;
  ProError err;
  If (!g_ptr->tooth_created)
  Return (-1);
```

The above is the function used in the three-dimensional parameterized modeling in Pro/E and C language secondary development interface Protoolkit. For the precise modeling of the three-dimensional parameterized modeling of the entire logarithmic spiral bevel gear, the steps to generate the three-dimensional model are as follows:

Step 1. Allocate memory for feature objects;

Step 2. Add parameter values: tooth number, pitch Angle, big-end modulus, dividing circle diameter, spiral Angle, tooth row Angle, face Angle, root Angle, etc;

Step 3. Use parameter functions to generate large and small end tooth profile truncation surface objects and tooth shape curve objects;

Step 4. Take large and small tooth profiles as cross-sections and scan along the tooth curve to form a single tooth feature;

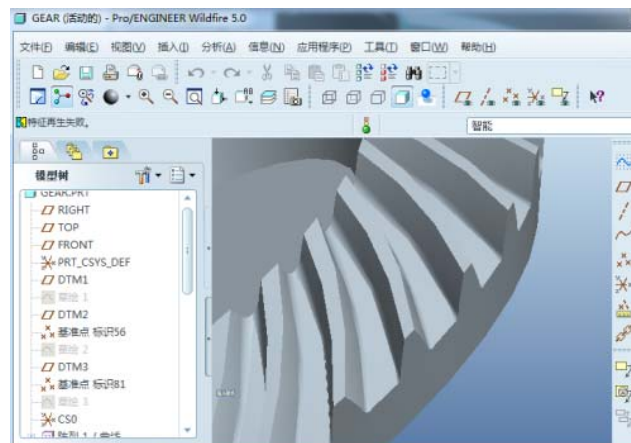


Step 5. The creation of the three-dimensional model is completed with the circular array.

The above is to operate under Pro/E 5.0, and develop a three-dimensional parameterized precision modeling system of logarithmic spiral bevel gears with Protoolkit under VS2008. Figure 6 shows the logarithmic spiral bevel gear obtained by this method. The basic parameters of the gear are shown in table 1.

**Table 1.** Dimension table of logarithmic spiral bevel gears

The parameter name	Parameter	The parameter value
Number of teeth	$z$	29
Pitch cone Angle	$\delta$	$64.98^\circ$
Big end modulus	$m_s$	3.62
Pitch diameter	$d$	105mm
Tooth line Angle	$a$	$20^\circ$
Shaft Angle	$\Sigma$	$90^\circ$
Spiral Angle	$\beta$	$39.52^\circ$
Surface of cone Angle	$\delta_a$	$68.49^\circ$
Root cone Angle	$\Phi_f$	$60.32^\circ$
Tip circle diameter	$d_a$	108mm

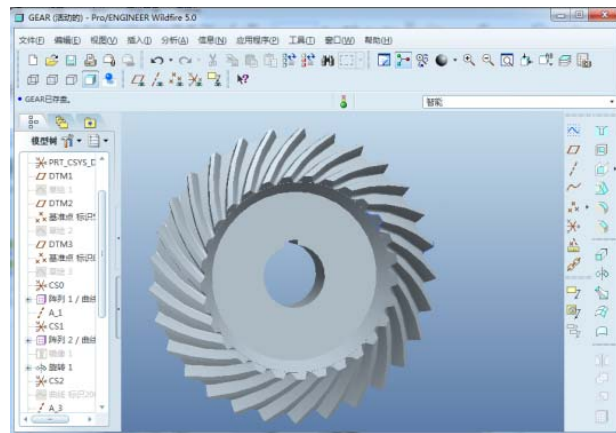


**Fig 6.** Logarithmic spiral bevel gear

## 5. Results and Discussion

Based on the application of Pro/E and C language secondary development interface Protoolkit, 3d modeling of logarithmic spiral bevel gears was successfully completed, and the system operation results are shown in Fig. 7. Compared with the traditional and cumbersome method of manual three-dimensional modeling, this parametric design simplifies the design process, shortens the research and development cycle, improves the efficiency, and reduces the risk of manual command manual modification error. Compared with the research reports on three-dimensional parametric modeling of spiral bevel gears published by gao xiaojuan and zhang fusheng, etc. 1. In terms of programming, most of the reports are rather rough. 2. In the aspect of program editing, the steps were optimized and the process was shortened; 3, the advantages of Pro/E 3 d parametric characteristics is not only parts arbitrary parameter modeling for subsequent optimization, simulation, manufacturing and dealing with freedom, can meet a variety of application requirements of users, and rich API functions and advantages of Pro/E secondary development characteristics of the generated 3 d model object for free operating and processing, greatly improve the modeling precision and efficiency. Despite the successful operation of the design program, the design related gears are short of actual machining process

validation. According to different processing conditions and actual production requirements, the parametric model of the above log-spiral bevel gears needs to be optimized and the design scheme adjusted to meet various production needs.



**Fig 7.** System operating results

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