

THE SPATIAL SHAPE REPRESENTATION AND 3D MODELING OF SPECIAL-SHAPE SPRING

Xiangchen Ku^{1,2}, Runxiao Wang¹, Jishun Li², Dongbo Wang¹

¹*School of Mechatronics Engineering, Northwestern Polytechnical University, Xi'an, China; Email: kuxch@sohu.com.* ²*School of Mechatronics Engineering, Henan University of Science and Technology, Luoyang, China.*

Abstract: The solid modeling of special-shape spring is important to improve production efficiency of spring coiler. However, how to describe and represent its spatial shape is difficult because there is various special-shape spring with complex spatial shape. Consequently, the 3D modeling and visualization of special-shape spring is not easy to implement. The paper presents a solution to this problem. First, we extract four kinds of elementary shape feature and define their data structure respectively using feature technology. The special-shape spring may regarded as the combination of different elementary shape features. The dynamic linked lists are employed to record the position relation between them. Then, this article studies the 3D modeling methods of special-shape spring based on OpenGL. The emphasis is the discretization of the spring solid surface. Last, the high reality solid modeling is created with C++ Builder.

Key words: special-shape spring; shape feature; representation; 3D modeling.

1. INTRODUCTION

Spring is one kind of basic mechanical parts used widely. The shapes of spring is quite different¹, thus it formed various special-shape spring with complex spatial shape. Along with the development of computer technology, the solid modeling technology is playing more and more important role in the product design and manufacture process. Currently there are some papers have discussed the solid modeling for compression spring with simple shape^{2,3}. But all these 3D modeling of spring in these papers depends on some commercial 3D modeling software. Although these software can create solid

This project is supported by the Doctoral Programme Foundation of Education Ministry of China under the grant No.20050699033.

Please use the following format when citing this chapter:

Ku, Xiangchen, Wang, Runxiao, Li, Jishun, Wang, Dongbo, 2006, in International Federation for Information Processing (IFIP), Volume 207, Knowledge Enterprise: Intelligent Strategies In Product Design, Manufacturing, and Management, eds. K. Wang, Kovacs G., Wozny M., Fang M., (Boston: Springer), pp. 171-176.

modeling satisfactorily, but there are still some limitations in the application of these software, such as expensive cost, inconvenient operation and high specialization. Therefore, these software is unsuitable for the design and manufacture of special-shape spring.

In fact, it is a difficult task to express the spatial shape information of special-shape spring with uniform format especially for it's complex coil end. Consequently, there is no related papers which have discussed the solid modeling of special-shape spring at present. So the effective representation of special-shape is indispensable to its solid modeling. In this paper, a solution to the solid modeling of special-shape spring is proposed and implemented by feature-based technology. Firstly, four kinds of elementary shape feature are extracted in terms of spring shape feature. The spatial shape of the special-shape spring is described with these elementary shape features. Then using OpenGL and C++ Builder, the solid modeling for special-shape spring is researched.

2. REPRESENTATION OF SPATIAL SHAPE OF SPECIAL-SHAPE SPRING

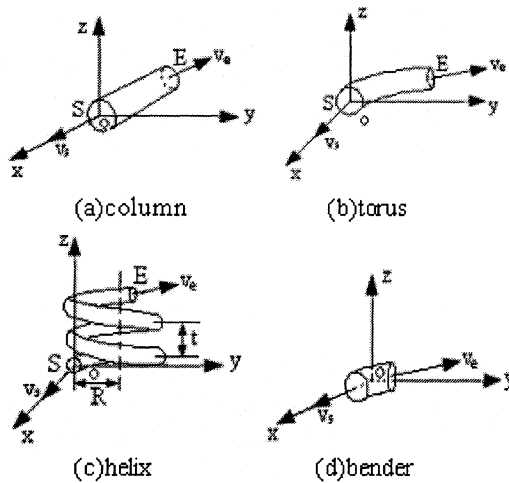


Figure 1. Definition of elementary shape feature

The shape feature is a basic unit to form mechanism parts. Therefore, the special-shape spring may regarded as the combination of different shape feature⁴. There are four kinds of elementary shapes abstracted from the special-shape spring, including helix, torus, bender and column. Figure 1 shows the definition and expression of these four elementary shape features.

The elementary shape feature is not only the abstraction of the shape but also the representation of the spring coiling, because each of these features correspond one coiling method. Each of these elementary shape features is defined by two vertexes and direction vector. The vertex is the connection points between two different elementary shape feature. The end vertex of the previous elementary shape feature is the start vertex of next one. By using this kind of connection relations, different elementary shape features can be assembled one by one and whole spring spatial shape information can be generated finally.

In order to describe and manage the spring shape information, the data structure of elementary shape feature is defined as follows:

```
①struct FeatureBase //data structure of elementary shape feature
{
enum {line,circle,spring,bender} type; //type of elementary shape feature
VERTEX *start_point; //start vertex
VECTOR *start_vector; // direction vector of start vertex
VERTEX *end_point; // end vertex
VECTOR *end_vector; //direction vector of end vertex
VERTEX *start_position;//global coordinates of start vertex
VERTEX *end_position; //global coordinates of end vertex
HELIX *helixbody; // shape parameter of helix
float angle_plane;//the angle between the two planes which the
//elementary shape feature is located
struct FeatureBase *next; //pointer of next elementary shape feature
};
②struct VERTEX //data structre of vertex position
{
float x,y,z; //coordinates of vertex
};
③struct VECTOR //data structure of vector
{
float nx,ny,nz; //coordinates of vector
};
④struct HELIX //data structre of helix
{
char direction; //direction of rotation
float num; //number of coil
float bot_radius; //bottom radius of helix
float top_radius; //top radius of helix
float start_pitch; //start pitch of helix
float end_pitch; //end pitch of helix
```

};

3. THE 3D MODELING OF SPECIAL-SHAPE SPRING

OpenGL used simple geometry unit to generate complex solid. Therefore, it is need to disperse the spring solid surface into a series of slices colored by OpenGL in the modeling of spring. One spring coil can be divided into small segment of n , then every small segment is dispersed as equal points. The triangle planes which OpenGL can filled and colored are constructed using these equality points. Many these triangle planes are put together according to the sequence and high reality solid modeling can be obtained finally.

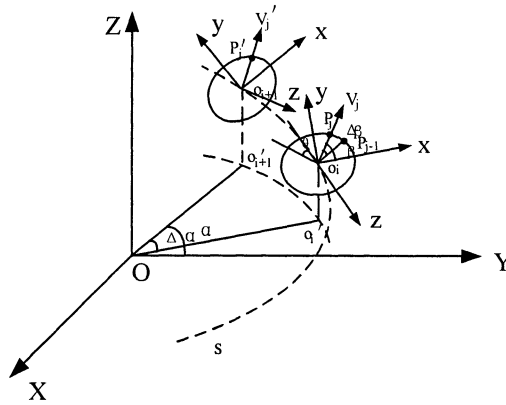


Figure 2. Discretization of spring solid surface

As shown in Fig. 2, in a global coordinate system $OXYZ$, s is a part of k th coil centric line of a right screw spring which spiral angle is θ . o_i and o_{i+1} is section center respectively, and their projection in the XOY plane is o'_i and o'_{i+1} . The part between o_i and o_{i+1} called i th segment when one coil is divided with step length of $\Delta\alpha$. Taking o_i as origin and establishing local coordinate system, x axis is parallel to Oo'_i and z axis is parallel to normal vector of section. The o_i global coordinate is: $x_i = R \cos \alpha$, $y_i = R \sin \alpha$, $z_i = (i/n + k)h$ (where, R is radius of spring, h is pitch, $\alpha = i * \Delta\alpha$, $i=0,1,2,\dots$).

In *xoy* plane, the circumference of section circle is divided into a series of points with step length $\Delta\beta$ started from point $(d/2, 0)$ (where, d is diameter of wire). The relationship between the global coordinates (X, Y, Z) and local coordinates (x, y, z) of the points in the circumference is as follows:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} \cos Xx & \cos Xy & \cos Xz \\ \cos Yx & \cos Yy & \cos Yz \\ \cos Zx & \cos Zy & \cos Zz \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix} + \begin{pmatrix} x_0 \\ y_0 \\ z_0 \end{pmatrix} \quad (1)$$

In the Eq.(1), (x_0, y_0, z_0) is the global coordinates of the origin, and the coefficient matrix is composed by direction cosine between the two coordinate system, the rest may be deduced by analogy.

As shown in Fig. 2, supposing P_j is j th point in the circumference, it's local coordinates is $((d/2)\cos\beta, (d/2)\sin\beta, 0)$ (where, $\beta = j * \Delta\beta$). Using the Eq. (1), the global coordinates of this point (P_{jx}, P_{jy}, P_{jz}) may be obtain as:

$$\begin{aligned} P_{jx} &= -(R + (d/2)\cos\beta)\sin\alpha + (d/2)\sin\beta\sin\theta\cos\alpha \\ P_{jy} &= (R + (d/2)\cos\beta)\cos\alpha + (d/2)\sin\beta\sin\theta\sin\alpha \\ P_{jz} &= (d/2)\sin\beta\cos\theta + (i/n + k)h \end{aligned}$$

In order to obtain high sense of reality, it is necessary to calculate the normal vector of the disperse points. Because these points are located in the circumference of section circle, therefore the normal vector of the point equates the vector from the centre of a circle to this point. If the local unit normal vector of point P_j is $(\cos\beta, \sin\beta, 0)$, then the global unit normal vector $V_j(V_{jx}, V_{jy}, V_{jz})$ is:

$$\begin{aligned} V_{jx} &= \sin\beta\cos\alpha\sin\theta - \cos\beta\sin\alpha \\ V_{jy} &= \cos\beta\cos\alpha + \sin\beta\sin\alpha\sin\theta \\ V_{jz} &= \sin\beta\cos\theta \end{aligned}$$

Using the similar method, point P'_j and vector V'_j in another section circumference which correspond to the point P_j and vector V_j can be calculated. When these corresponding points is obtained, the helix curved surfaces are created using the continual small pieces of triangle surface, then the high reality solid modeling can generated by adding the illumination and material quality. The column and torus which compose special-shape spring also can be divided into small pieces of triangle surface. As a result, the solid modeling of whole spring is created.

4. IMPLEMENTATION AND EXAMPLES

After obtaining the shape parameter, the paper creates the solid modeling of special-shape spring using OpenGL under the C++ Builder 6.0 environment. Fig. 3 shows a solid modeling of spring.

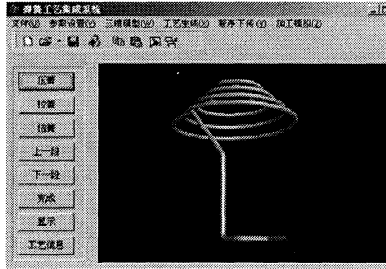


Figure 3. Solid modeling of special-shape spring

5. CONCLUSIONS

The advanced manufacture technology not only requires the blueprint, but also needs 3D model to describe products. This paper studies spatial shape representation and solid modeling of special-shape spring. The characteristics and contributions of the research includes (1) extracting four kinds of spring shape features and defining their data structure, (2) providing the complete shape information of spring with dynamic linked list which records the assemble process of different elementary shape features, (3) creating the solid modeling of spring, and (4) the system provides a sound foundation for the visual design and CNC coiling of special-shape spring.

6. REFERENCES

1. Michael Johnston, (2001), An engineer's guide to spring design, *Wire industry*, vol.68, pp.35-38.
2. Giuseppe Boschiero, (1999), Reducing setup times for critical compression springs, *Wire industry*, vol.66, pp 673-676.
3. YU Zhi-kun, WU Yan-ping, (2003), Study of Modeling Methods on Three Dimensional Spring Model, *Journal of Kunming University of Science and Technology*, vol.28, pp.46-48.
4. Ting-Kuo Peng, AMY J.C.Trappey, (1996), CAD-integrated engineering-data-management system for spring design, *Robotics and computer-integrated manufacturing*, vol.12, pp.271-281.