Methods and Approaches for the Modeling of Spiral Bevel Gear

Hongbin Yang, Rongda Yao
Mechanic and Electronic Engineering, Henan University of Science and Technology, Henan Luoyang, 471003, China

KeyWords：Accurate Modeling, Spiral Bevel Gear, Digitized Manufacturing, Tooth Contact Analysis（TCA）, Simulation Machining.

Abstract. Accurate modeling of spiral bevel gear laid the foundation of the key technology namely Tooth Contact Analysis（TCA）and correction of the deviation of tooth-surface in its digitized manufacturing. It summarized the related outcomes and divided modeling approaches of the tooth-surface of spiral bevel gear into three categories, modeling by the tooth-surface of discrete points and suturing curves and simulation machining, and generalized their vital idea and step. What is more, according to the analysis of some problems and their inadequacies and advanced ways and ideas in the modeling, it proposed three development direction for modeling technology of spiral bevel gear in the future, these development direction were high in accuracy and high efficiency and high flexibility, so as to provide some methods for faster and more accurate design of spiral bevel gear and its machining.

1 Introduction

Spiral bevel gear is a mechanical transmission parts used in the crossing or cross shaft. It plays a key role in the field of automobile, helicopters, machine tools machinery as to its high degree of overlap and carrying capacity, smooth transmission, low noise. The manufacturing precision and quality directly affects the mechanical power transmission efficiency, noise, motion accuracy and lifetime performance because of its complex structure of the tooth surface. Its design and manufacturing technology has been the hotspot in research of gear. Recently researches on the spiral bevel have become increasingly deep in the field of gear design and been working to digitized and diversified.

In this paper, the research achievements of modeling at home and abroad are analyzed from three aspects. In addition，based on the related research，analyzing and summarizing the problems exist in the modeling and sum up the related solutions to these problems. In order to create a condition that contribute to design, analysis and machining accurately and efficiently, the trends of tooth surface modeling are discussed from three directions.

2 Basic ideas of modeling of spiral bevel

2.1 Meshing theory about spiral bevel.

The recent study on the modeling of tooth surface, either modeling by equations or by cutting processing is based on the meshing theory about spiral bevel. It is also named principle of conjugated curved surfaces, which mainly consider the contact transmission between two motional curved surfaces. As shown in Figure 1,Two motional curved surfaces Σ_1 and Σ_2 are contact transmission and in tangency at the point M, their common tangent plane is T. Additionally the point O_1 and O_2 are their respective origin of the coordinate system fixedly connected. The vector of the point M on the surfaces Σ_1 is described with r1, and its unit normal vector is n1. Likewise, the vector of the point M on the surfaces Σ_2 is described with r2, and unit normal vector is n2. The m becomes the vector from the point O_1 to the point O_2. Then conjugate curved surfaces should be satisfied with the equations as follows:

$$\begin{cases} r_2 = r_1 + m \\ n_1 = n_2 \end{cases} \quad (1)$$

Above equations can be transformed by the relative differential method, as following equation:

$$v_{12} \cdot n = 0 \quad (2)$$

Where, v_{12} is relative speed between the surfaces Σ_1 and Σ_2 . Formula (1) represents basic equations, and formula (2) represents meshing equation.

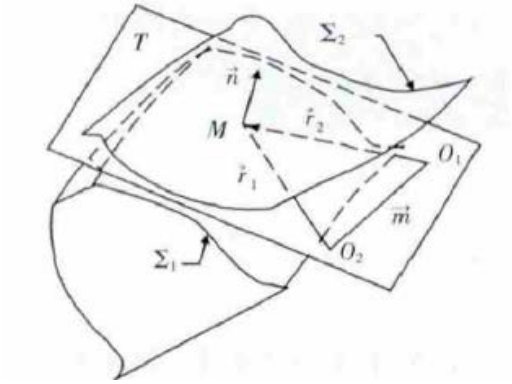

Fig.1: Gears Meshing Theory

2.2 Basic idea of modeling.

Modeling of spiral bevel is based on the meshing theory and machining approaches, by means of relative analysis software and drawing software. The basic idea is taking advantage of the 3D mapping and data analysis software, it can complete general modeling process from point to surface, from the point to the line and then surface, from line to surface, or direct cutting simulation. Researchers have provided us some bold attempts and innovations about the key step in the modeling process, including extracting the tooth surface data points, the point-to-line fitting, structuring from line to surface, and the application of virtual machining, finally all kinds of effective modeling methods were obtained.

3 Methods of modeling of spiral bevel

In the early days, according to the tooth meshing theory Professor Faydor L.Litvin had finished the design of tool shapes and motion conversion, then deduced the equations of tooth surface where the gear was enveloped and generated by tool paths Furthermore, the famous Korean scholar Suh had got rid of the traditional principle and methods, and made creative application of the spherical involutes curve theory in modeling of spiral bevel, which put up with a new pathway of parametric modeling[1,2].

In China, the spiral bevel plays an irreplaceable position in the field of industry, and the government had been increasing investment and research on spiral bevel Combining with the recent research literature about the spiral bevel, this paper summarized the modeling of spiral bevel from three aspects[3].

3.1 The point-to-surface modeling by discrete points.

It is the traditional method that base on the generated equation of gear tooth surface[1,4]. Firstly, the software (such as Matlab) is applied to solve the equations of tooth surface, which obtains information about discrete points equably distribute on the gear tooth surface.Then, it is necessary to import the data of these discrete points into relevant 3D modeling software(Pro /E, CATIA, Solid Works, etc). Finally, the model will be received by constructing surfaces with above points directly, or building the boundary curves of tooth with these points and then suturing the curves. The key part of this approach is to acquire data information of discrete points on the tooth face by following ways:

i) By the analysis software: coordinate information about data points on tooth surface is solved through the software with data analysis and processing functions, such as Matlab or TMSL function library under the DENQNF subroutine.

ii) By measuring: some equipment: such as Three Coordinates Measuring Instrument with tooth surfaces of machining parts could measure and collect the data information directly.

iii) By simulation machining: firstly, simulation should be completed according to the practical machining，then calculate parameters data of points by programming.

iv) By intersecting faces: as shown in Figure 2, the surface cone, back one, root cone and former cone are all intersected with the tooth surface, and then they form four intersecting lines. Data was achieved by collecting points on the four boundary lines of tooth surface.

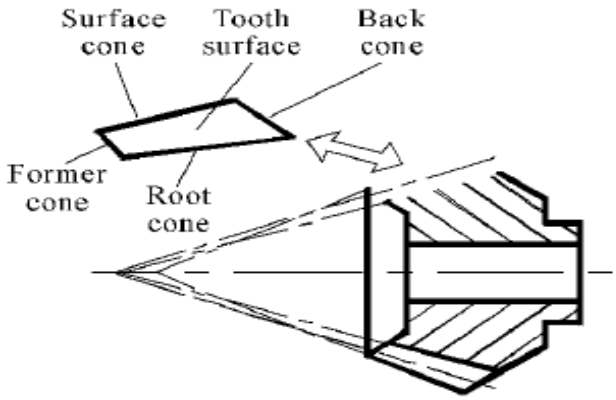

Fig.2: Collect the Points by the Intersecting Surfaces

3.2 The line-to-surface modeling by suturing curves.

At first, mathematical equations of the curve profile should be calculated according to the relevant theory. Then equations are imported into the 3D software, which may draw out the basic shape of the tooth surface. At last, by using of optimization method such as NURBS to improve accuracy, it can export the accurate model after the reconstruction of tooth surface. Among the procedure, the core is to solve the equation expression on the tooth curve and derivate the equations of tooth surface.

Generally speaking, there are two solutions from different theoretical sources. The one base on the meshing theory that figure out the basic tooth profile curves which are exported by the software such as Matlab CAXA and so on, and the other is derivate the expression with the application of spherical involute curve. The former is complex and cumbersome. And the latter is fast and simple, easily parameterized. In the latter solution，the involute curve was used to solve the equations of tooth surface of spiral bevel.

3.3 Modeling by the simulation machining based on virtual reality technology.

It is a great practical significance that gets the model through virtual manufacturing technology. For the machine and the processing method some researchers choose the traditional mechanical machine tools, they prefer the Format and the Generated for the gear, the Tilt and the Modified Roll for the pinion[5]. Another choose Gleason Corporation Free-From-type spiral bevel gear milling machine by the equivalent conversion, the traditional methods are transformed to the NC machining method with six axes five linkages.

In actual machining, there are two important steps, one is the equivalent conversion between the traditional and the Free-From-type spiral bevel gear milling machine, anther is adjustment of the position and orientation of the cutter and gear blank.

i) Equivalent conversion: in order to achieve equivalent processing between the CNC machine tool and the traditional, the following two equations must be satisfied.

$$L_{pt}^{(G)}(\delta,\gamma,\theta) = L_{pt}^{(c)}(\mu,\phi,\psi) \qquad (3)$$

$$\left(\overrightarrow{O_pP_t}\right)_p^{(G)} = \left(\overrightarrow{O_pP_t}\right)_p^{(c)} \qquad (4)$$

where ($^{O_t}P_t$)is the vector from the cutting tools to the tooth blank; $^{L_{pt}}$ is transformation matrix from the cutting tools to the gear blank; CNC bevel cutting machine is represented by the C; the mechanical machine tool is represented by the G; P and t are the coordinate systems fixed with the

gear blank and the cutting tool respectively; (δ, γ, θ) and (μ, ϕ, ψ) are the rotation angles of the three main axes. Getting the motion parameters of the CNC cutting machine through above two simultaneous equations, the equivalent conversion can be achieved.

ii) Adjustment of the position and orientation: the relative position must be consistent with the actual processing position all the time, the adjustment of the initial point is particularly important. The main solution is making the motion parameters from above equivalent conversion controlled by the programming. For a sentence, do secondary development in the software (CATIA, UG, Solid Works, etc) to write a real-time control program. Additionally, in some simulation machining software (VERICUT, etc), it can be controlled directly by NC program[6].

When it comes to the method of actual machining，some researchers adopt the general CNC machine milling. It is so different from the special machine tool processing that provides pathway for the machining, especially for big modulus gear (Gleason gear system maximum machining diameter for Φ2590 mm). Therefore, the simulation basing on the universal milling machining also gradually becomes a kind of gear modeling method. The simulation process is variety due to the choice of the simulation software platform，but it includes some parts as follows:

i) Setting the related configurations

Including choose the simulation software platform(such as Pro/E, UG, CATIA, etc) machine tool, the fixture, the cutter and NC simulation system. Generally speaking, to choose the five axes linkage machine tool, the choices of cutter and fixture according to the manufacturing procedure and the NC simulation system should meet the processing object.

ii) Creating the work-piece blank

It is consist with the material and size, or achieved by drawing operations.

iii) Setting processing parameters

Including parameters of the cutting tool, cutting feed speed, the feed, spindle rotating speed, the amount of backing should be set on the base of specific circumstances of actual processing.

iv) The pre-processing

It contains compiling machining craft procedure, generating tool path, the simulation and the calculation of tool path in the CAM software.

v) The post-processing

It means transform the tool path into the movement track, and completes NC machining by generating NC code.

The vital step in simulation of milling machining is to comply with the machining craft procedure, during the simulation of spiral bevel milling. Firstly, turning processing for the gear blank, secondly, the milling of tooth slots and surfaces. thirdly, grinding the gear tooth surfaces, in order to improve the quality of gear tooth surface processing, at length, making inspection, modification and adjustment to the gear contact area. The main processing technology is the milling parts that can be divided into three processes: rough machining of tooth slots, vice-finishing, and then finishing of tooth surfaces.

4 Approaches for the modeling of spiral bevel

At present, the vital technology in digitized manufacturing are tooth contact analysis (TCA) and correction of the deviation of tooth surface, which were mastered by the Gleason Corporation and never announced. The key technologies are based on the model of spiral bevel. Therefore, based on the results of the present, this paper provides three directions for the modeling techniques of the spiral bevel in the future.

4.1 The precision of the modeling.

Taking advantage of high-speed dry, the cutting precision can reach the level of 4 or 5 in foreign country. However, there is a big gap between our nation and abroad and some problems exist in the modeling process:

i)interpolation accuracy in the collecting of discrete points.

ii)the derivation and processing of the transitional surfaces.

ii)optimization and reconstruction of the tooth surface after simulation processing.

iv)measurement and correction of deviation of tooth surface.

Especially, the transitional surface is a serious problem, but often paid little attention or not mentioned due to the complex modeling. However, it is the integral part of the actual machining tooth surface. As shown in Figure 3, a complete tooth profile consists of at least four segments: the segment ab is tooth top; the segment bc is working tooth profile; the segment de is tooth root; and the connection segment between working tooth profile and tooth root is transition curve cd. Transitional surface is posed by the transition curves, and enveloped with tooth top of the cutting tools or the rounded package of tooth top according to the tool shape.

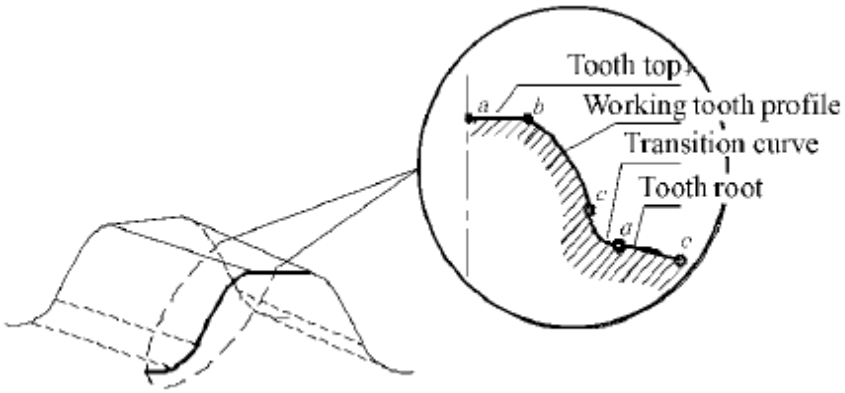

Fig.3: The Basic Components of the Tooth Profile Curve

Subsequently, more and more researchers pay attention to solve these problems, They gradually increase the accuracy of modeling by using of many optimized approaches, such as software data analysis, derivation of the equation of transition curve, reconstruction of tooth surfaces with utilizing functions of curves and surfaces in the NURBS or Bezier. For example, the deviation can be calculated in the reconstruction of tooth surfaces by the NURBS after suturing curves, and controlled within 10^{-8}-10^{-14} mm at the main curvature of gear tooth surface[7]. It has been reached a high accuracy but accuracy problems of spiral bevel still need to be improved.

4.2 The efficiency of the Modeling.

Within a variety of modeling methods researchers have proposed, there are many factors lead to the poor efficiency:

i) Theory is too hard to grasp

Merely derivation of the tooth surface equations need to familiar with a lot of meshing principle and the knowledge of the coordinate transformation and gear cutting machining.

ii) Large amount of data processing

In the acquisition process of the discrete points, it has to use some optimized algorithm for solving nonlinear equations and write complex procedures to analyze the related data.

iii) Cumbersome process and repeated operation

Firstly, a complicated calculation is necessary. Then 3D software trivial operation should proceed. Finally, continue to verify the actual data and do the correction and processing in order to meet the accuracy requirements.

Needless to say, how to get a fast and accurate modeling will become an important topic. The digitized design based on machining simulation technology with the multi-axis linkages CNC machine tool will become a more important research direction. The spherical involute-based fast parametric modeling will also become a new hot spot[8]. Independent development of system software will become the main trend of the research to replace the complicated calculations.

4.3 The flexibility of the modeling.

In the past, modeling by discrete points, due to the complexity of calculation and derivation of longitudinal process, cause data stability and unrepeatable, There have been some problems about integrity and consistency of modeling platform due to the limitation of software function. Modeling

problem of big modulus gear beyond the normal tooth system specifications has not been considered. Along with the further research, the modeling method and field are continuously widened. At the same time, with the development of cloud manufacturing technology, collaborative design for spiral bevel based on the advantages and characteristics of the network resources will become a new bright spot. A variety of information resources in design field will be integrated to achieve seamless data sharing between computer network and user database, and complete flexible collaborative design and manufacturing[10].

The modeling technology will become digitalized, and gradually forms a flexible and multivariate system that can be controlled. Among them, development and application of multi-function data processing software, digitized and initiative design of tooth surface[8,9], CNC programming and multi-axis CNC system development basing on the actual needs, secondary development basing on simulation processing platform, design of spiral bevel with high contact ratio and other methods, will become flexible. The field of molding becomes wider，and the methods of molding become more perfect and powerful. In addition, using universal NC milling processing will promote the modeling more diversified. Using the theory of spherical involute to achieve faster and more accurate modeling of tooth surface make the modeling methods more colorful[11].

5 Conclusion

In this paper，the modeling methods of spiral bevel is summarized from three aspects. Moreover, the existing problems in the process of modeling were analyzed and the related solutions to these problems were summed up. Modeling technology by simulation process based on virtual reality has become the mainstream of the research of modeling, and will be constantly deepen and developed. Enough precision, efficiency, flexibility of molding will promote the manufacture technology of spiral bevel high precision, high efficiency and high flexibility. Comprehensive use of all kinds of related technologies in its field independent research and development of system software, making the parametric modeling technology transform to digital will be the crucial link to improve the level of digital manufacture.

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