Journal of Southeast University (English Edition) Vol. 22, No. 1, pp. 78 – 81 Mar. 2006 ISSN 1003—7985

WEDM oriented micro gear design and mesh simulation

An Luling Wang Wei Zhou Laishui Zhu Rupeng

(College of Mechanical and Electrical Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China)

Abstract: For the design of gears manufactured with wire electrical discharge machining (WEDM) technology, determination of the primary gear parameters is discussed considering the characteristics of the machining method. Some constraint conditions on gear parameters are abnegated, which makes micro gear design more flexible. Based on gear mesh theory, the algorithm of generating gear tooth profiles is studied, which includes involute and non-involute curve segments. The phenomena of tooth profile interferences during gear mesh are analyzed, and a gear mesh simulation algorithm is designed. Based on ACIS, the WEDM oriented software for the design and mesh simulation of micro gears is developed, by which the modeling, mesh simulation and interference check can be implemented. An experiment is carried out to design and manufacture a pair of micro involute gears, and the proposed method is proved feasible.

Key words: wire electrical discharge machining; micro gear; tooth profile; modeling; mesh simulation

Micro gears play important roles in micro mechanical systems. The design and manufacture of micro gears attract much attention from researchers and engineers. The traditional gear machining methods have been proved unfeasible to manufacture such small size gears, since it is extremely difficult to produce such tiny machine tools and cutters. On the other hand, micro wire electrical discharge machining (WEDM) is proved to be a practical solution in the manufacture of micro machine parts[1 – 5].

As far as WEDM programming software is concerned, there have been systems that include gear-modeling functions. However, all of them can only deal with the tooth profile generation of a single gear, not a pair of gears in mesh. In addition, the rationality of gear parameters is not taken into consideration. Therefore, it is difficult to eliminate interference between the teeth profiles of two gears and obtain correct design results.

In this paper, the design method of micro gears is studied. Determination of the primary gear parameters is discussed considering the characteristics of the WEDM method. Some constraint conditions on gear parameters are abnegated to make micro gear design more flexible. Criteria are introduced to make gear design meet the requirements for right mesh and continuous transmission. Furthermore, the mesh interference phenomena are analyzed and an interference check method is given. A software prototype is developed to aid the design and manufacture of micro gear drives. Finally, a practical example is given to demonstrate the feasibility of the proposed method.

1 WEDM Oriented Design of Micro Involute Gear Drive

Involute gears are generally manufactured on specialized gear machine tools and with special gear cutters, such as gear planer and hobber, in which the gear-shaped cutter (planning cutter and hobbing cutter) forms the teeth of the gear by its “meshing” with the workpiece, i. e. with generating motion. To decrease the number of cutters, some of the gear parameters have been standardized, e. g. module, pressure angle, addendum coefficient, clearance coefficient, etc. On the other hand, to meet the specific requirements for gear drive, such as installation with a non-standardized center distance, increase in load capacity, and improvement in drive properties, a profile shifted gear drive is adopted, which leads to complicated calculations.

The gear design for WEDM can be reconsidered, especially the constraints on gear parameters can be eliminated, and calculation for a profile shifted gear is no longer needed. For a micro gear drive, load capacity is one of the important indices considered. Relevant research shows that the pressure angle has a remarkable influence on load capacity and other drive properties. In addition, in machining micro gears, the characteristics and machining parameters of WEDM should also be regarded.

Based on the above analysis, aiming at WEDM a new design method for micro gear drives is proposed, in which the pressure angle is regarded as a variable parameter. Meanwhile, the addendum coefficient and

Received 2005-04-27.
Foundation item: The Teaching and Research Award Program for Outstanding Young Teachers in Higher Education Institutions of MOE, P. R. China.
Biography: An Luling (1962—), male, doctor, associate professor, anllme@ nuaa. edu. cn.

clearance coefficient are determined correspondingly.

The interference which possibly occurs for external gear pairs includes fillet curve interference and involute interference. In addition, for internal gear drive, especially in the case of a small tooth number difference between the two gears, the possible interferences are as follows: ① Profile overlap interference; ② Radial interference; ③ Addendum collision interference opposite the pitch point.

2 Micro Gear Modeling Based on Gear Mesh

As shown in Fig. 1, the gear profile is composed of four segments, i. e. arc *AB* on the addendum circle, involute segment *BC*, fillet *CD*, and arc *DE* on the dedendum circle. *AB* and *DE* can be easily determined. *BC* and *CD* can be obtained by the gear mesh theory.

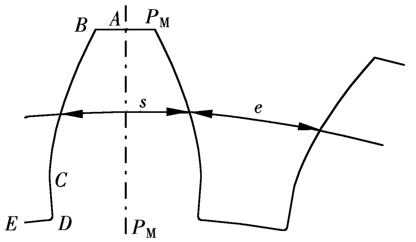

Fig. 1 Composition of gear tooth profile

According to the gear mesh theory[6], the involute profile *BC* of the gear is the function of center distance, pressure angle and base circle radius, and it is generated by the involute profile of the cutter.

As shown in Fig. 2, point *A*, i. e. the intersection of the involute segment with the addendum circle, makes the fillet *CD* in generating motion.

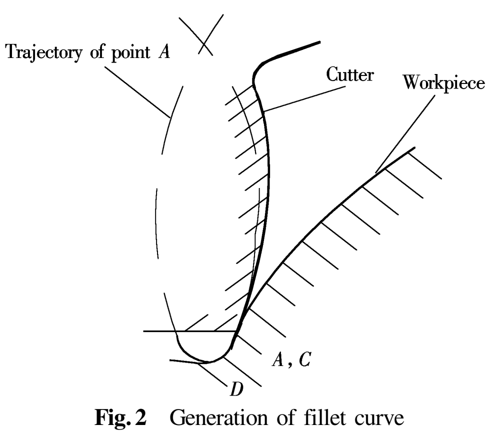

Fig. 2 Generation of fillet curve

The detailed expressions of arcs *BC* and *CD* are not included in this paper. Refer to Ref. [6].

The modeling procedure of the whole gear profile is as follows (see Fig. 1):

① Make reference circle and base circle;

② Draw involute segment curve *BC* and fillet curve *CD*;

③ Calculate tooth thickness and space interval on reference circle according to the tooth number, i. e. *s* and *e* respectively (see Fig. 1), to determine mirror plane P_M and point *E*;

④ Mirror *A-B-C-D-E* profile to generate a complete tooth *T*;

⑤ Copy $Z-1$ teeth by rotation *T* around the center of the gear. *Z* is the tooth number of gear;

⑥ Do interference check and continuous transmission verification.

As the basic parameters of the gear are concerned, pressure angle α, addendum coefficient h^*, and clearance coefficient c^* can be optionally determined in the design method proposed in this paper. Conventionally these parameters are determined by design standards. For example, $h^*=1$, $c^*=0.25$ and $\alpha=20°$. Elimination of the constraints on determining these parameters may cause some problems, and it should be done with care. The problems include unreasonable geometric shapes, e. g. minus crest width, great disparity in the strength of two meshing gears, too small contact ratio (<1), etc. The authors suggest selecting these parameters around standard values.

The software module is developed on the basis of the ACIS geometric modeling kernel.

The parameter definition dialog is shown in Fig. 3. After the users input the parameters one by one, the interference will be checked and the continuous transmission be verified automatically. Alteration of any parameter will trigger off recalculation to guarantee the validity of gear drive.

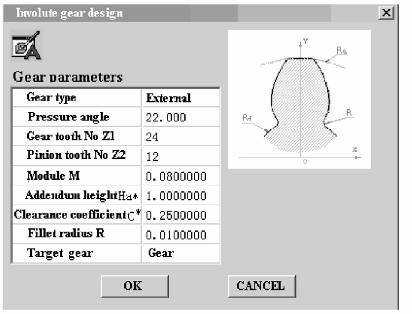

Fig. 3 Software interface of involute gear design

3 Simulation of Gear Mesh Process

In order to avoid interference, the simulation software module for gear mesh is developed by the authors. The simulation algorithm is described as follows.

Suppose that the pinion (smaller gear) rotates clockwise and the gear rotates counter-clockwise. For a very small rotation angle increment of the pinion, the corresponding rotation angle increment of the gear can be determined in terms of transmission ratio.

Because the involute interference phenomenon has been eliminated during gear design, it is not necessary to check this kind of interference. The other two kinds of interferences needed to be checked are

① Interference between the involute or fillet of the pinion and the addendum arc of the gear;

② Interference between the involute or fillet of the gear and the addendum arc of the pinion.

As shown in Fig. 4, regardless of interference types, once interference occurs when pinion and gear rotate with a determined transmission ratio, the region overlap of the two gears will appear. The authors propose an interference check algorithm through a Boolean operation of solid, which is based on ACIS's data environment of integrating wireframe, surface and solid[7]. The algorithm is described as follows:

① Set the original locations for pinion and gear;

② Cover faces onto the wireframe of two gears to form two gear solid models with zero thickness;

③ Rotate pinion and gear by very small increments of angle, say 0. 1°, with determined directions and transmission ratios;

④ Make a Boolean intersection operation between the zero-thickness solid models of pinion and gear, which is implemented with ACIS API. If the result is null, there is no interference; otherwise interference takes place;

⑤ Calculate interference amount.

Fig. 5 shows the interface of gear mesh simulation software.

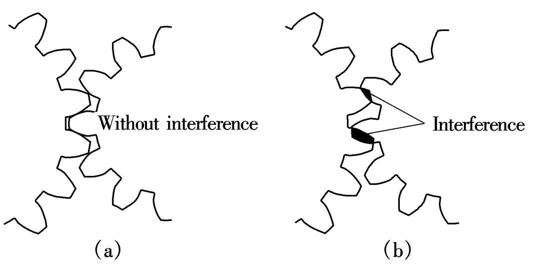

Fig. 4 Simulation of gear mesh. (a) Without interference; (b) Interference

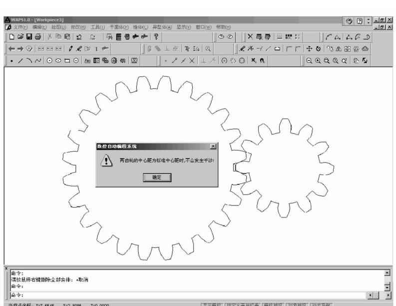

Fig. 5 Simulation interface

4 Experiment

In this paper, an experiment is carried out, in which a pair of micro gears is designed with the software developed by the authors and is fabricated with the WEDM technology. The module of the tested gears is $m = 0.25$ mm, and the tooth numbers are 12 (the external gear, i. e. the pinion) and 18 (the internal gear), respectively. The addendum coefficient is taken $h^* = 0.8$, and the clearance coefficient is taken $c^* = 0.25$, which are determined by experience and checked in the software. Through calculation, the pressure angle is taken $\alpha = 25°$. Through inputting the above parameters into the software, the continuous transmission condition is verified and the interference is checked with simulation automatically. After that, the wire path for WEDM is generated with the CAM module developed by the authors.

The parts are machined on Charmilles ROBOFIL2030F WEDM machine tool, and the wire diameter is 0. 1 mm. The machined gears are shown in Fig. 6.

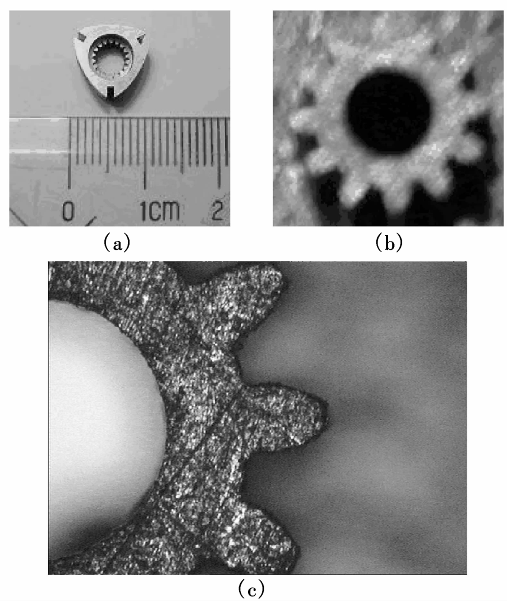

Fig. 6 Gears machined with WEDM. (a) Internal gear; (b) External gear (pinion); (c) Enlarged photo of the pinion

After installation and test operation in a micro prototype machine, the gear drive is proved feasible.

5 Conclusion

Micro gear design is a special problem for WEDM. In this paper, based on the gear mesh theory, the complete tooth profiles of the gear are generated, which include involute and non-involute profile segments. This method avoids theoretical modeling error. Furthermore, aiming at WEDM characteristics, the new determination method of gear parameters is proposed. These parameters include pressure angle, addendum coefficient, and clearance coefficient, etc. Through gear modeling and simulation of the mesh process, interferences can be avoided. The work in this paper is a helpful attempt to improve micro gear design and manufacture. Further research will be carried out mainly in two aspects. One is to establish new criteria of gear parameter determination. And the other is to study new types of tooth profiles suitable for micro gears and the WEDM machining method.

References

[1] Di Shichun, Yu Bin, Zhao Wansheng, et al. Research status and trends of micro-WEDM [J]. *Aviation Precision Manufacturing Technology*, 2004, **40**(1): 12 - 15. (in Chinese)

[2] Yu Bin. Research on control system and machining technology for micro WEDM [D]. Harbin: Department of Mechanical Engineering and Automation, Harbin Institute of Technology, 2004. (in Chinese)

[3] Klocke F, Lung D, Thomaidis D, et al. Using ultra thin electrodes to produce micro-parts with wire-EDM [J]. *Journal of Materials Processing Technology*, 2004, **149**(1 - 3): 579 - 584.

[4] Masuzawa T. State of the art of micromachining [J]. *Annuals of CIRP*, 2000, **49**(2): 473 - 488.

[5] Ho K H, Newman S T, Rahimifard S, et al. State of the art in wire electrical discharge machining (WEDM) [J]. *International Journal of Machine Tools and Manufacture*, 2004, **44**(12, 13): 1247 - 1259.

[6] Wu Xutang. *Gear mesh theory* [M]. Beijing: China Machine Press, 1982. (in Chinese)

[7] Qian Xiaofeng, An Luling, Chen Chen. A new algorithm for set operation of 2D drawings [J]. *Journal of Nanjing University of Aeronautics and Astronautics*, 2001, **33**(1): 37 - 40. (in Chinese)

面向线切割的微小齿轮设计与啮合仿真

安鲁陵　汪　炜　周来水　朱如鹏

(南京航空航天大学机电学院,南京 210016)

摘要:针对线切割加工的特点,讨论了微小齿轮的设计和主要参数的确定,舍弃了普通齿轮设计方法中对参数的一些限制条件,使微小齿轮的设计更加灵活. 基于齿轮啮合理论,研究了渐开线微小齿轮轮廓的生成算法. 分析了齿轮啮合中的齿廓干涉现象,设计了齿轮啮合过程仿真算法. 基于ACIS 几何平台,开发了面向线切割的微小齿轮设计和啮合仿真软件,实现了微小齿轮的造型,并可进行啮合过程仿真和干涉检验. 最后通过一对微小齿轮的设计制造实验,验证了该方法的可行性.

关键词:线切割;微小齿轮;齿廓;造型;啮合仿真

中图分类号:TP391.7;TH13