Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Procedia CIRP 27 (2015) 137 – 142
www.elsevier.com/locate/procedia

13th CIRP conference on Computer Aided Tolerancing

Influence of Tool Assembly Error on Machined Surface in Peripheral Milling Process

Weixin HU, Jiayan Guan, Bo Li, Yanlong Cao*, Jiangxin Yang
Zhejiang University, Yuquan *Campus*, Hangzhou 310000, China

* Corresponding author. Tel.: +86-571-87953198; fax: +86-571-87951145.*E-mail address:* sdcaoyl@zju.edu.cn

Abstract

Simulation and prediction of the machining process and the machined results of milling process is an important link in the control of milling quality. It is important on improving the machined surface quality, improving processing efficiency, and reducing processing errors. In the milling process, the assembly error of the cutting tool has great importance that should not be ignored for the forming of milled surface. Aiming at the problem of machining error in milling process caused by tool assembly error, this article investigated the milling process of peripheral milling, and researched the surface topography caused by the tool assembly error. Then the author established a simulation model to forecast the processing error caused by peripheral milling cutter assembly error. The model calculates the location of the tooth tipoff the milling tool by analyzing the knife tooth trajectory variation caused by the tool assembly error. Then discrete tracks of the teeth, to obtain the final processed surface by calculating the minimum value of all the teeth traces at discrete points. Through this model, we can get different surface morphology formed by different tool assembly errors to explore how the tool assembly error influences the processing quality. The study shows that when the cutter assembly errors exist, each tooth tip trajectory changes, making the surface topography phenomena that surface rises and falls, and cutting grooves' size shrinks and expands. Cutting groove depth will change in the direction of the tool axis direction. The surface roughness will increase when the cutter assembly error increases, but the roughness does not change after increasing to a threshold value.

Peer-review under responsibility of the organizing committee of 13th CIRP conference on Computer Aided Tolerancing
*Keywords:*Peripheral Milling;Toolerror;Toothtrack;Surface topography; Roughness

1. Introduction

Machining error reduces the accuracy of the workpieces and affects the performance of the workpieces. Machining error can also reduce the service life of workpieces. With the development of industry, requirements on manufacturing precision continue to increase. Research of Mechanism of processing error and its control strategies in peripheral milling process has drew the attention of many researchers.

Zhang Xiang et al. [1] established a micro-ball-end cutting force model by taking into account the scale effects. They simplified the tool as a stepped cantilever, and then combined the applying of the principle of virtual displacement with the deformation of the machine-workpiece system to get the amount of deformation under the milling cutter force. Then they coupled the deformation to the cutting edge of the track. They established a surface milling process physical model combining spindle runout, the minimum chip thickness, and the deformation of the machine - workpiece system.

QU Wei-gang and YANG Mao-kui[2]present a theoretical model by which the machining error in ball end milling of curved surfaces can be predicted. On the basis of the theoretical model, the machining errors resulting from force induced tool deflections are calculated at various parts of the machined surface.

WAN Min and ZHAGN Wei-hong[3] proposed a Finite Element numerical simulation procedure to study the cutting force changes and surface errors in the thin-walled Peripheral milling process.

ZHAO Fei et al.[4] use dageometric model to study the assembly error of the NC machine tool, and proposed the

Peer-review under responsibility of the organizing committee of 13th CIRP conference on Computer Aided Tolerancing
doi:10.1016/j.procir.2015.04.056

intergraded expression of assembly error character, which contains periodic and cumulative components. Using the simulation analysis, they studied the signal characteristics of the assembly error in NC machine built-in sensor, and the motion precision of the feed system

Zhen-Qiang Yao et al.[5] proposed a cylindrical surface milling method to calibrate the cutting force coefficients with the characteristics of low cutting depth and varying lead angleIn order to avoid chatter risk of the traditional calibration test with an entire-ball-immersed cutting depth. They also presented a dual-cubic-polynomial function to describe the non-uniform cutting force coefficients of the ball part cutting edge and the nonlinear chip size effect on cutting force.

A.C. Okaforand Yalcin M. Ertekin [6]use rigid body kinematics, homogeneous coordinate transformation and small angle approximation of the errors to model each slide of the three axes vertical machining center. They developed an expression for the volumetric errors in the multi-axis machine tool by synthesizing the machine's parametric errors such as linear positioning errors, roll, pitch and yaw etc..

Miguel Arizmendi et al.[7]established a transformation equation of actual milling and milling motion considering tool assembly error. Using space coordinate transformation, they developed a model of milling process considering cutter assembly error. They used the model to study the influence of tool eccentricity on the surface morphology including milling groove width and special milling groove texture position. Then, they studied ways to get tool assembly error by milling groove width and special milling groove texture position.

In this article, a Peripheral Milling surface topography prediction model is established based on tool assembly error in order to improve the accuracy of prediction of machining error in milling. The model is used to analyze the influence of different tool assembly error on machining surface.

2. The influence of tool setting errors on trajectory of teeth tips

2.1. The influence of tool offset on tooth tip trajectory

In the research, a tool coordinate axis is established. The Z axis is the cutting tool rotary axis, the coordinate originis. The intersection of top surface and the Z tool axis, and the XY axis are in the same direction with milling machine. If the tool offset error is d. The status of the tool can be shown in fig.1.

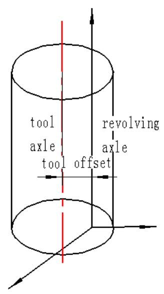

Fig.1. Tool offset

The offset angle is the angle between the line from the first knife tooth tip to the tool axis and the line from the tool axle to the revolving axle. Concerning tool offset error d and offset angle a, the practical tooth tip trajectory can be got as shown in fig.2. The picture shows that the practical tooth tip trajectory is larger than ideal tooth tip trajectory and when the larger offset angle become larger, the practical tooth tip trajectory will shrink.

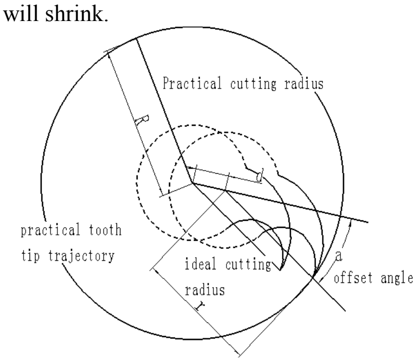

Fig.2. Practical tooth tip trajectory

Expanse the surface of the milling cutter, the relationship between the milling cutter's helix angle β, lag angle $\emptyset$ and height z can be shown in fig.3.

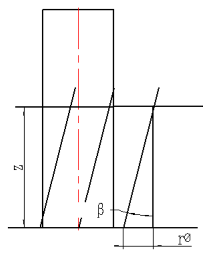

Fig.3. Lag angle$\emptyset$

2.2. The influence of tool offset and declination on tooth tip trajectory

The influence of tool declination on tooth tip trajectory is decided by two parameters. The first parameter is the declination angle, which is the angle between tool axle and its revolving axle.

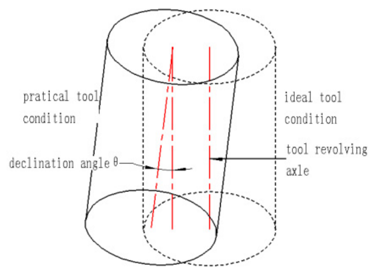

Fig.4. Tool offset and declination

Another parameter is the angle ε that cutter axis and rotary axis are relative to the cutter deflection angle as shown in fig.5. Plane 1 is decided by tool revolving axle and tool offset, plane 2 is decided by tool axle and is parallel to revolving axle.

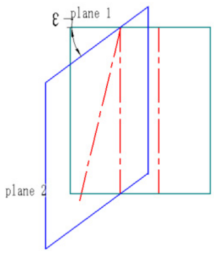

Fig.5. Angle ε

The influence of declination angle on the z axle is small enough to be ignored. In the XY plane, the tool declination influences the practical tooth tip trajectory and the practical tool offset angle as shown in fig.6.

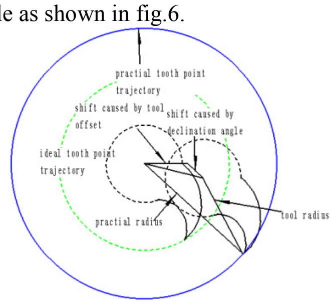

Fig.6. Tool tip trajectory influenced by tool offset and declination

When the feed rate is v, and the rate of turning is ω, the teeth tips of the milling cutter turn around the revolving axle, and the revolving axle is moved at equal speed. The practical tooth trajectory becomes trochoidal.

$$x = R_{r,i,z}\cos(\omega \times t + \sigma_i - \emptyset) + v \times t \quad (1)$$

$$y = R_{r,i,z}\sin(\omega \times t + \sigma_i - \emptyset) \quad (2)$$

The coordinate position of any tooth tip at any time at any height can be got as shown in equation (3), (4), (5) and (6).

$$x_{i,z,t} = \sqrt{d_z^2 + r^2 - 2d_z r\cos a_n} \times \cos(\gamma_{i,z,t}) + v \times t \quad (3)$$

$$y_{i,z,t} = \sqrt{d_z^2 + r^2 - 2d_z \cos a_n} \times \sin(\gamma_{i,z,t}) \quad (4)$$

$$a_n = [a - \Delta a + \frac{z \times \tan\beta}{r} + 2\pi(i-1)/n] \quad (5)$$

$$\gamma_{i,z,t} = \omega \times t - \frac{z \times \tan\beta}{r} + \sigma_1 + 2\pi(i-1)/n \quad (6)$$

3. Simulation of the machined surface

3.1. tool assembly error's influence on surface topography

To illustrate the influence of tool setting error, a particular case is considered. By considering the cutting conditions listed in Table 1 and simulating each tooth tip trajectory at different heights through the procedure described in Section 2, the milled surface topography can be obtained.

Table 1. cutting condition

Cutting condition	
Tool radius	5mm
Tool length	45mm
Number of teeth	4
Machining time	0.1s
helix angle	30°
Tool rotating speed	100r/s
Feed rate	0.2m/s
Offset angle	0
First tooth locating angle	180°

Fig.7 shows that four teeth tip trajectories form the machined line at the bottom of them. Fig.8 and fig.9 show that every tooth tip creates its grove in the exactly same shape. The width of the grove is a quarter feed. We can get the machine surface by getting all the machined line at each height.

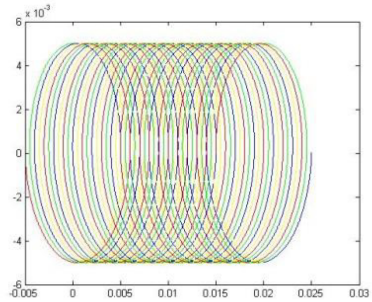

Fig.7. Four teeth tip trajectories with no offset error

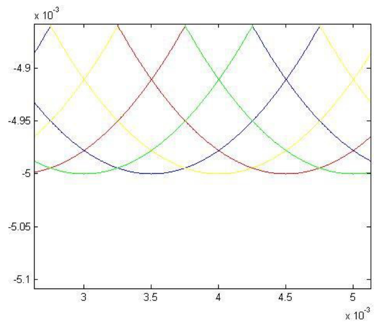

Fig.8. Enlarged view

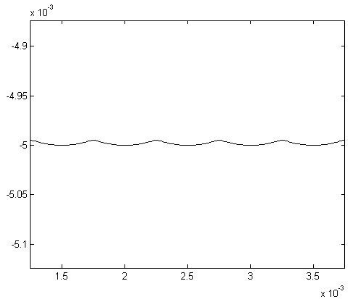

Fig.9. Machined line

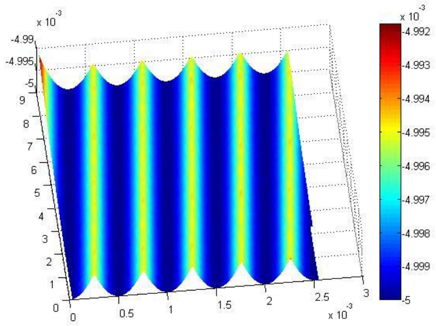

Fig.10. Machined surface

Section 2 shows that when the offset error changes the practical tooth tip trajectories also changes. Fig.11 shows the difference between the four trajectories when the offset is5μm.

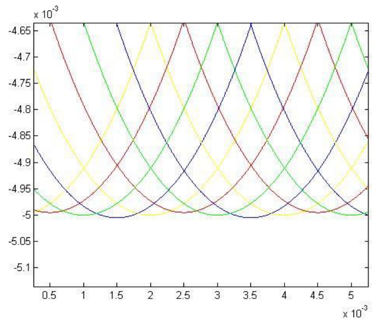

Fig.11. Four teeth tip trajectories with 5μm offset

Fig.12 shows that each groove created by tooth tip has different width and different depth in one feed. as a consequence, the machined surface has undulation periodicity.

Because of the helix angle, the practical cutting radius of each tooth changes with height, which cause the practical teeth tips' trajectories changes. The depth of grooves changes with trajectories. Fig.12 shows the height's influence on practical cutting radius and the depth of grooves clearly.

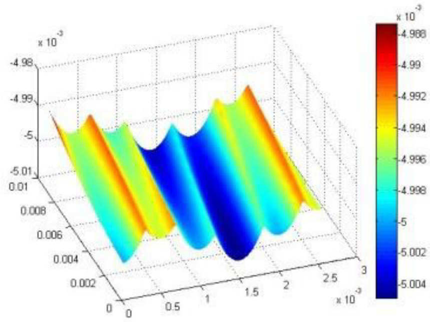

Fig.12. machined surface with 5μm offset

When the offset increase to50μm, the tooth tip trajectory which has the biggest practical cutting radius almost cover all the other trajectories. The machined line only show three grove in a feed and two of them shrink deeply. It can be predicted that the machined line will have only one groove in a feed when the offset continue to increase.

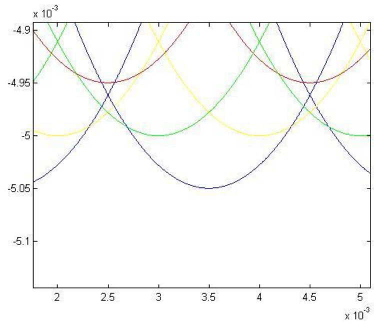

Fig.13. Tooth tip trajectory with 50μm offset

Fig.14 not only shows that ant the height 0, the tooth tip trajectory which has the biggest practical cutting radius almost cover all the other trajectories, but also shows that the surface topography changes with height because of the change of cutting radius. The increase of height shrinks the biggest cutting radius and enlarges the smallest cutting radius.

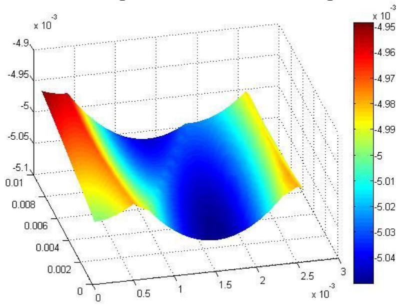

Fig.14. Machined surface with 50μm offset

3.2. .3.2 tool assembly error's influence on surface roughness

We can see from the previous sections that the surface topography changes with tool setting error. So, we can predict that tool setting error may cause surface roughness to change.

In order to get the offset error's influence on surface roughness, we set the declination angle to be 0, calculate different surface roughness at the lowest height with different offsets. Fig.15 shows that when the offset increases from 0 to 65μm, the Ra of the surface increases from 1μm to 23μm. Then, the Ra remains the same when the offset keep increasing. By studying the surface topography, we found that the final machined line is formed only by one tooth when the offset is larger than 65μm . So, the surface topography remains the same when the offset reaches a threshold value.

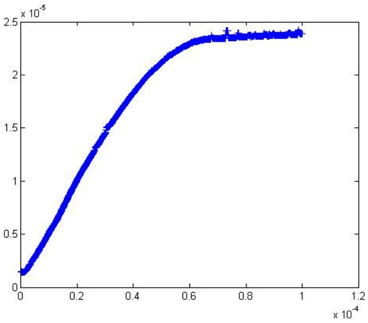

Fig.15. Relationship between offset and surface roughness

In order to get the offset error's influence on surface roughness, we set the offset and angle ε to be 0, and calculate different surface roughness at the lowest height with different declination angles. Fig.16 shows that when the declination angle increase from 0 to 0.015rad, the Ra of the surface increase from 1μm to 23μm. Then, the Ra remains the same when the offset keep increases. The reason is also that the final machined line is formed only by one tooth when the offset is larger than 0.015rad. the influences of declination angle and offset on surface are similar because they all change the surface topography by changing practical cutting radius.

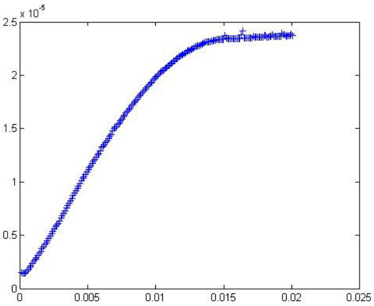

Fig.16. Relationship between declination angle and surface roughness

To get the angle εinfluence on surface roughness, we set the offset to be 5μm, the declination angle to be 0.015rad, calculate different surface roughness at the lowest height with different angleε. Fig.17 shows that when the angle increases from 0 to π, the Ra of the surface decreases, when the angle increases from π to 2π, the Ra of the surface increases.

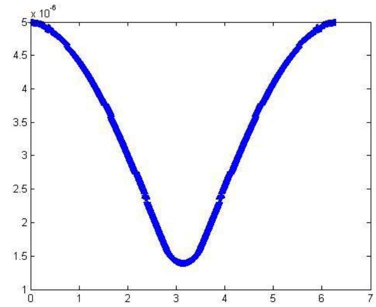

Fig.17. Relationship between angle ε and surface roughness

Angle ε influences the practical tool offset and the practical tool offset angle together with declination angle. The practical tool offset and the practical tool offset angle influence the cutting radius. Fig.17 and fig.18 show that the corresponding relationship between cutting radius and surface roughness.

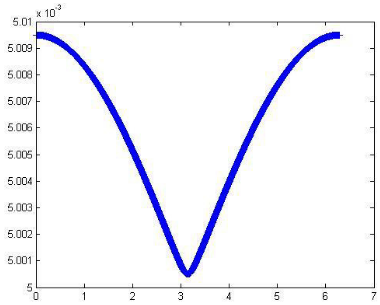

Fig.18. Relationship between angle ε and cutting radius

4. conclusion

In this article we studied the milling process of peripheral milling with tool assembly error. A model for the prediction of the topography of surfaces machined by peripheral milling accounting for tool setting error is proposed. With this model, the effects of tool setting error, surface topography and roughness can be evaluated quantitatively and the following conclusions can be drawn:

(1) When the cutter assembly errors exist, each tooth tip trajectory changes, making the surface to pography phenomena that surface rises and falls, and cutting grooves' size change.

(2) Practical tool radius changes with height, which cause the surface topography to change. Cutting groove depth will also change in the direction of the tool axis direction.

(3) When the tool offset error reaches a threshold value, the surface topography will not change with offset error.

(4) Surface topography is influenced not only by magnitude of the tool assembly errors, but also by the direction of the errors.

Acknowledgements

This research was supported by the National Nature Science Foundation of China (No.51275464), the National Basic Research Program of China (973 Program, No.2011CB706505), and the Fundamental Research Funds for the Central Universities of China.

References

[1] Zhang Xiang, Han Zhenyu, Fu Hongya, Sun Yazhou, 2010, Modeling and Simulation of Machined Surface Error in Micro-Ball-End Milling, Journal of Computer-Aided Design & Computer Graphics, p. 2177.

[2] QU Wei- gang, YANG Mao- kui, 2008, A Prediction model of Machining Error in NC Machining, Computer Simulation, p.281

[3] Wan Min , Zhang Weihong, 2008, Overviews of Technique Research Progress of Form Error Prediction and Error Compensation in Milling Process, ACTA AERONAU TICA ET ASTRONAU TICA SINICA, p. 1340

[4] ZHAO Fei, MEI Xue-song, JIANG Ge-dong, TAO Tao, SHI Jian-qiang, 2013, Modeling and Characters Analysis of Assembly Error of Numerical Control Machine Tool, JOURNAL OF SHANGHAI JIAO TONG UNIVERSITY, P.703

[5] Zhen-Qiang Yao, Xin-Guang Liang, Lei Luo, Jun Hu, 2013, A chatter free calibration method for determining cutter runout and cutting force coefficients in ball-end milling, Journal of Materials Processing Technology, p.1575

[6] A.C. Okafor, Yalcin M. Ertekin, 2000, Derivation of machine tool error models and error compensation procedure for three axes vertical machining center using rigid body kinematics, International Journal of Machine Tools & Manufacture, p.1199

[7] Miguel Arizmendi, Justino Fernandez, Alain Gil, Fernando Veiga, 2010, International Journal of Machine Tools & Manufacture, p.51