euspen's 17th International Conference & Exhibition, Hannover, DE,2017
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Modeling surface generation in ultra-precision grinding based on the surface topography of grinding wheel

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Abstract
This paper presents a new modeling method for analyzing the surface generation based on modeling surface topography of the grinding wheel. Since the high spindle speed of grinding wheel as compared with that of the workpiece, the same area of workpiece surface is ground many times by different protrusion points on the grinding wheel. It is difficult to model all the grinding trajectories of each abrasive grain not only because of the difficulty to obtain all accurate kinematic equations but also due to a huge amount of calculations. The model presented in this paper firstly filters the protrusion points on the grinding wheel which primarily determine the surface generation of the workpiece. Hence, the kinematic trajectory model is built by considering the spindle speed of both the grinding wheel and the workpiece. It is found that the simulation efficiency improves greatly due to the method of filtering grinding points. As a whole, this paper presents an effective way to model the surface generation in ultra-precision grinding.

Type the keywords Ultra-precision grinding, modelling and simulation, grinding wheel, surface generation, abrasives

1. Introduction

Ultra-precision grinding is applied in many areas such as aerospace, biomedical because of its advantages its ability to machine hard-to-machine materials, etc. Due to the fact that grinding is a complex process, it imposes a formidable challenge to study the mechanism of surface generation of the grinding process. At present，a geometric model has been built up according to the kinematic of the interaction of the workpiece and the grinding wheel so as to simulate the surface generation. Chen proposed a grinding model considering spindle vibration and focused on silicon carbide material [1]. However, complicated models need large calculations to solve the mixed trajectories of various grains on the grinding wheel. Because the surface generation of surface topography of workpiece was mainly formed by the most protruded grinding grains, it is a feasible way to firstly filter majority of grinding grains so as to reduce the calculation.

This paper presents an idea to filter grinding grains. Firstly, the mechanism of ultra-precision spindle grinding is proposed, and then the grinding wheel surface topography is simulated, based on the grinding wheel simulation results, the most protruded grains on the grinding wheel are chosen to model the surface generation of workpiece. Lastly, comparison between simulation results and experimental results are made.

2. Modelling surface generation

In ultra-precision grinding process, the machining mechanism is shown in Figure 1. The workpiece is mounted and rotated with the spindle, grinding wheel feeds along X-axis with a higher spindle speed, during the grinding process, and the material of workpiece is removed by the grinding grains.

In grinding process, the geometry of the grinding wheel has direct relationship with the workpiece surface [2]. According to previous research work and the relevant theory [2], a simulated wheel surface topography with the grit number 46 and the structure number 9 is shown in Figure. 2. X-axis means the width of grinding wheel, Y-axis is part of circumferential length of grinding wheel.

The next step is to model the surface topography of workpiece. To illustrate how to build up the workpiece topography model clearly, two extreme cases are analyzed:1) When spindle speed of grinding wheel is zero, the grinding grains keep static relative to the machine tool. In this case, the grinding process can be regards as 'multi points turning', these 'multi points' refers the fixed grinding grains which are cutting the workpiece surface;
2) When spindle speed of workpiece is zero while the feed rate is not zero, the grinding process can be regarded as each grinding wheel grain is carrying on vertical raster milling, however, the cutting topography by less protruded grains are covered by more protruded grains. As a result, the workpiece topography is determined by the most protruded grains on the wheel each unit width.

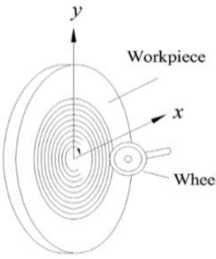

Figure 1. Machining mechanism of precision spindle grinding

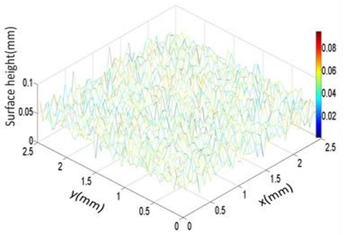

Figure 2. Simulated grinding ultra-wheel topography

In general conditions, spindle grinding process can be regarded as a combination of turning process and raster milling processes, and the real cutting grains are the most protruded grain points on the grinding wheel with unit width. If the number of the most protruded grain points is named as $N_{i(i=1,,,n)}$, for an arbitrary point $A_{(x_A, y_A, z_A)}$ on the workpiece surface, it is feasible to derive the relevant relationships as follows:

$$i_A = floor\left[\frac{(\sqrt{{x_A}^2 + {y_A}^2} - v\cdot\frac{\arctan(\frac{y_A}{x_A})}{2\pi\omega}) - k\cdot\frac{v}{\omega}}{\frac{v}{\omega\cdot n}}\right] \quad \text{Eqn. (1)}$$

$$z_A = D_c - h_{i_A} \quad \text{Eqn. (2)}$$

Where in equation (1), i_A means point A on the workpiece surface was finally machined by i_{th} most protruded grain point on the grinding wheel, v is the feed rate of grinding wheel, ω is spindle speed of workpiece, k is the number of screw pitch between point A and the center of workpiece , n is the number of most protruded grains. Where in equation (2), D_c is depth of cut, h_{i_A} is the protrusion height of i_{th} most protruded grain point, which can be obtained by the simulation data of grinding wheel surface topography.

3. Experimental and Simulation results

According to the above modelling idea, simulation topography of workpiece was conducted. The simulation conditions and results are shown in table1, figure 3 and figure 4a respectively. An experiment was also conducted. The workpiece material is steel which was grinded by Moore Nanotech 450UPL. To verify the model, experimental conditions (table 1) are consistent with that of the simulation. The experimental result was measured by an Electron Microscope TM3000. As shown in figure 4b, i the experiment results show that there is a spiral profile on workpiece surface, the spiral line spacing was 100 µm. As shown in figure 4a, the simulation results also show a 100 µm spiral line spacing which is consistent with the experimental results. The spiral surface topography was caused by the relative displacement between the tool and the workpiece with a frequency to spindle rotational speed ratio f/ω_2, where ω_2 is the spindle speed of workpiece and f is feed rate of grinding wheel.

Table 1. Both experimental and simulated conditions

Number of most protruded grains (*m*)	50
Spindle speed of grinding wheel (ω_1)	4000 rpm
Spindle speed of workpiece (ω_2)	400 rpm
Feed rate of grinding wheel (*f*)	40 mm/min
Depth of cut (D_c)	1 µm

The measured arithmetic roughness (Ra) of the workpiece is 194.4 nm which is measured by a Zygo Nexview™ 3D Optical Surface Profiler, while the simulated value of the Ra of the workpiece is 167.8 nm. The difference between the measured and simulated results is due to the fact that the model is built based on a simulated grinding wheel topography which is different from that from a real grinding wheel whose topography is difficult to be accurately obtained in the current stage. Moreover,, the model is built mainly based on geometrical modelling which does not taking into account of other process and material factors such as spindle vibration, the elastic behaviour of the materials of the grinding wheel and the workpiece, etc.

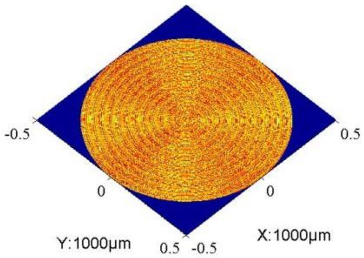

Figure 3 Simulated surface topography of workpiece based on grinding wheel topography

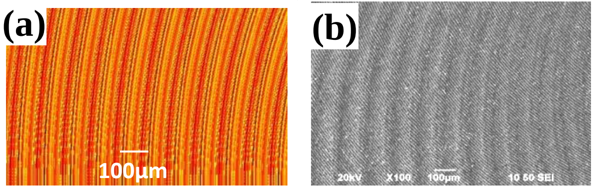

Figure 4. Comparison between simulation results (figure 4a) and experimental results (figure 4b) for surface generation in grinding. The scales of figure (a) and figure(b) are both 1000 µm × 1000 µm.

While more importantly, compared with previous trajectory model[2], the model presented in this paper does not need to calculate the trajectories of each two adjacent grains, as well as the calculation for searching for the surface profile generated by the most protruded grains since it has been filtered and determined by Equation (1) and Equation (2). In brief, the number of calculation steps to obtain the final surface topography of workpiece is significantly reduced in the order of $1/m^2$, where m is the average number of grains on the grinding wheel with unit width.

4. Conclusions

Surface generation in ultra-precision grinding is influenced by its grinding wheel topography, this paper presents a model which reduces the number of calculation steps and improves the simulation efficiency a lot through filtering most grains on the grinding wheel, firstly wheel surface topography model considering the grit number and the structure number is built up, then the kinematic filtered trajectory model is proposed. The result shows that the simulated surface topography of workpiece is similar with the experimental results. To predict more accurate results, this initial simple model needs considering more factors influencing surface generation of workpiece such as workpiece and grinding wheel materials, vibration, etc.

Acknowledgement

This work described in this paper was mainly supported by PhD studentships (project account codes: RU7J and RU3K) from The Hong Kong Polytechnic University.

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