MODELING AND SIMULATION OF FINE GRINDING/FINISHING PROCESSES

Fengfeng (Jeff) Xi

Department of Aerospace Engineering, Ryerson University, Toronto, Ontario, Canada, M5B 2K3

Introduction

Fine grinding/finishing processes are used to achieve high surface quality with form accuracy and surface roughness in nano scale. Their applications include figuring and polishing of optics lens [1], finishing of aircraft jet engine fuel nozzles [2], and surface grinding of silicon wafers [3]. Though there is a great deal of experimental studies, little research has been accomplished on the analytical modeling of fine grinding/finishing processes.

In this paper, a method previously developed by the author [4] for regular grinding processes is expanded to model fine grinding/finishing processes. Unlike traditional grinding modeling methods, the presented method takes into consideration the random distribution of the abrasive grain heights of the grinding/finishing tool. With the simulated tool topography, the grinding/finishing process analysis is then carried out based on respective grinding kinematics or contact mechanics.

In cylindrical grinding such as that for fuel nozzle finishing, a numerical search method has been developed to solve the profile of the ground surface according to the grain protrusion heights. In surface grinding such as that for wafer grinding, a graphical method has been developed to solve the profile of the ground surface by applying a spiral motion to the tool topography while forwarding it along the feed direction. In precession finishing such as that for optics figuring, a contact modeling method has been developed to solve the profile of the finished surface with consideration of tool compliance. At the end, Monte Carlo methods are applied for simulation to account for the stochastic characteristics of the simulated ground/finished surface.

Abrasive Tool Modeling

Since the topography of the ground surface can be considered as an imprint of the grinding tool, the first step of the analysis is to generate the topography of the grinding/finishing tool using a Gaussian function. It has been shown in [4] that the mean value and the standard deviation of the abrasive grain heights can be estimated using the empirical equations based on the grit number of the abrasive tool. For fine grinding/finishing, the grit numbers are over 1000. Figure 1 shows the simulated tool topography with grit number of 2000.

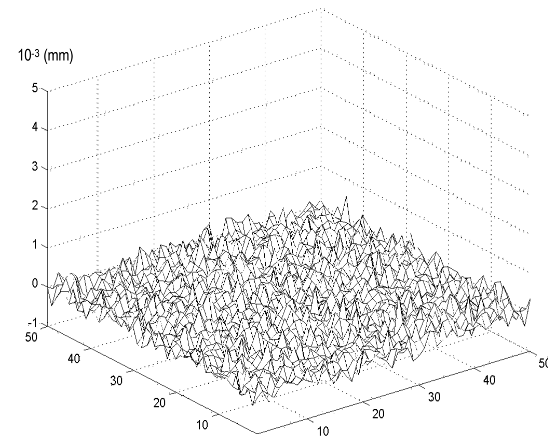

Fig. 1 Simulated tool topography

Cylindrical Grinding Modeling

In this case, Figure 1 represents the topography around the circumference of the grinding wheel. A search method is developed [4] to determine the profile of the ground surface. By sorting out the data set, the grains can be re-arranged according to their protrusion heights. The search process starts with determining the cutting paths of the first two most protruded grains and their intersection point, and then continues on to next grains in decreasing height till no intersection point can be found. Figure 2 shows the computed profile of the ground surface using the tool shown in Figure 1.

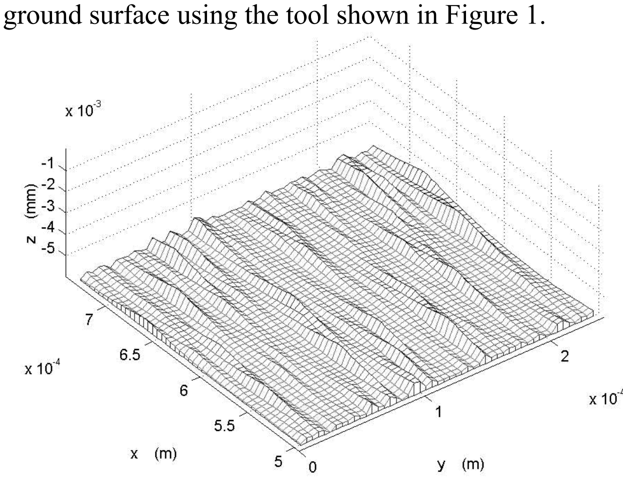

Fig. 2 Simulated ground surface

Surface Grinding Modeling

In this case, Figure 1 represents the topography of the side face of the grinding wheel. Since the tool is spinning while feeding relative to the work as shown in Figure 3, the tool profile is subject to a series of repetitive spiral motion. The ground surface is resulted from the overlapping of the spiral cutting paths. A graphical method [5] is developed to determine the profile of the ground surface by utilizing the geometric computing functions built in commercial CAD packages. Figure 4 shows the simulated profile of the ground surface using the graphical method.

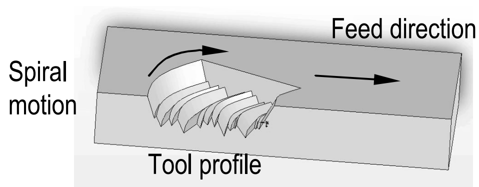

Fig. 3 Surface grinding graphical model

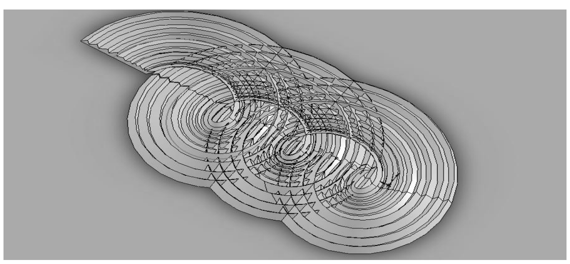

Fig. 4 Simulated ground surface

Precession Finishing Modeling

In this case, Figure 1 represents the topography of a ball-end finishing tool with a spherical surface. Since the velocity at the contact point by the ball-end is zero, the tool is tilted by an angle away from the normal of the work surface, leading to what is called precession finishing [1]. Furthermore, unlike the previous two cases, the finishing tool has compliance either passive or active. For this reason, a contact modeling method is developed to determine the profile of the finished surface with consideration of tool compliance.

There are two levels of contact modeling, macro and micro. As shown in Figure 5, the former is concerned with the determination of the contact area between the finishing tool and the work and this analysis is carried out using the Hertz theory. The latter is concerned with the determination of the micro cutting depths and this analysis is performed using indentation theory. Figure 6 shows the simulated profile of the finished surface.

Conclusions

In this paper, it is shown that the topography of a grinding/finishing tool can be modeled based on the grit number. With the simulated tool topography, the profiles of the work surface ground or finished by a fine grinding/fishing process can be determined using respective grinding kinematics or contact mechanics. The presented methods are effective because the computed values are on the same order of magnitude as those of measurement. To account for the stochastic characteristics of the simulated ground/finished surface, Monte Carlo methods are applied for simulation.

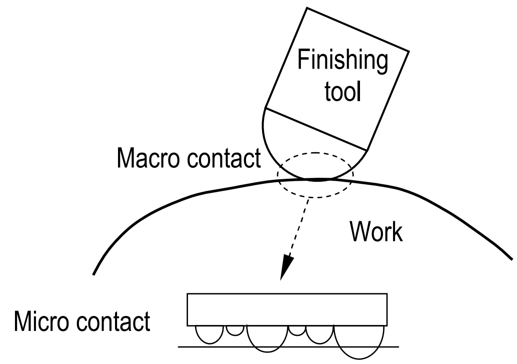

Fig. 5 Two levels of contact modeling

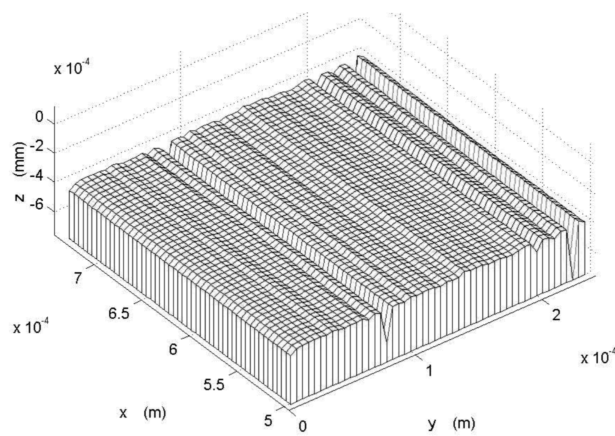

Fig. 6 Simulated finished surface

References

1. Walker, D., Brooks, D., King, A., Freeman, R., Morton, Roger, and McCavana, G., The 'Precessions' tooling for polishing and figuring flat, spherical and aspheric surfaces, *Optics Express,* 11/8 (2003) 959- 964.
2. Takao, M., Akihiko, K., Masahiro, I., Koichi, D., Hishida, H., and Takashi, N., Development of a finishing robot for jet engine parts, *K.H.I. Technical Review*, 143 (2000) 62-67.
3. Pei, Z.J., and Strasbaugh, A., Fine grinding of silicon wafers, *International Journal of Machine Tools and Manufacturer,* 41/5 (2001) 659-672.
4. Zhou, X. and Xi, F., Modeling and predicting surface roughness of the grinding process, *International Journal of Machine Tools & Manufacture*, 42 (2002) 969-977.
5. Li, M., *Three-dimensional modeling of ground surfaces*, Master's Thesis, (2007), Ryerson University.