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Study on the Lapping Processes Based on Multi-elastic Unit Plate

[1]Xu Yue-zeng, [2]Yong Dai and [1]Jiang Fan
[1]Zhejian Gtongji Vocational College of Science And Technology, Hangzhou, 311231, China
[2]Zhejiang University of Technology, Hangzhou, 310032, China

Abstract: In order to reduce cutting depth differences caused by free abrasive grain size range and enhance accuracy with efficiency, a new efficient and high precision nondestructive processes method that based on multi-elastic unit plate was mentioned. Meantime, mechanism of this plate was studied and cutting depths model of single abrasive used to simulate the processes of lapping was established. Experiment processes and simulation results of lapping between multi-elastic unit plate and traditional eternity plate were compared. It was found that lapping processes based on multi-elastic unit plate can ensure the working efficiency and highly improve machining accuracy. It was verified that cutting depths model of multi-elastic unit plate and simulation results can be applied to choose the parameters of lapping processes based on multi-elastic unit plate.

Key words: Abrasive finishing, multi-elastic unit plate, material removal rate, working accuracy, simulation

INTRODUCTION

With development of modern technology, more and more new techniques are applied to the high precision lapping processes. The machining efficiency is enhanced, as well as machining equality and precision (Hua and Li, 2004; Yang and Tian, 2003).

In aspects of plate material selection, surface modification and plate model design, some innovations and optimizations are pioneered by both domestic and foreign scholars to realize surface processes of high precision nondestructive. Deshpande *et al.* (2008) researched lapping effects between different materials of grinding abrasive. Zeng Z.G. who works in Chinese Academy of Sciences Institute of Optoelectronics Institute of Optoelectronics (Zeng *et al.*, 2002) design and optimize the construction of live lapping plate based on finite element analysis. National Key Lab. of Sciences and Artificial Crystal R&D center have developed ultra precision plane grinding machine, which is modified by turning machining. Yuan *et al.* (2006), who work in Zhejiang University of Technology, research on online modification method of lapping plate surface based on correction ring. A continuous correction plate flatness can be obtained by rotating the correction ring. All those researches play a great role on the development of grinding technology.

In process of ultra precision machining, there is a contradiction between prevention of surface scratch and crack and improvement of lapping efficiency. In order to coordinate contradiction, a grinding method with multi-elastic unit plate is mentioned in this study. Multi-elastic unit plate consists of a plurality of elastic units with force limiting function. In normal situation, the machining effect of elastic unit plate is the same as traditional entirety plate. However, when some abnormal large abrasive appear and grinding positive pressure exceeds the limit, elastic unit will sink down, so as to avoid generation of deep scratches.

FORCE LIMITING MECHANISM OF MULTI-ELASTIC UNIT PLATE

Structure of multi-elastic unit plate: Characteristic of lapping machining is that some free abrasive exist between lapping plate and workpiece. In process of ultra precision plane machining, one of key to ensure machining quality is to ensure abrasive grain size and concentration distribution evenly. In process of grinding machining, if the dispersion of abrasive grain size is large, which means abrasive grains are not in the same size or some abnormal large impurities are mixed in abrasive, lapping pressure will be focused on large free abrasive grains and cutting depth will too deep to ensure surface accuracy.

In order to solve the uneven stress of different sizes of abrasive grains, a kind of lapping plate with elastic units is mentioned. The structure is shown in Fig. 1. Multi-elastic unit plate consists of plurality of elastic units which contain cell body and force application elements. Force application elements support the cell body and can be adjusted by changing spring stiffness or magnetic field intensity.

Corresponding Author: Xu Yue-Zeng, Zhejian Tongji Vocational College of Science And Technology, Hangzhou, 311231, China

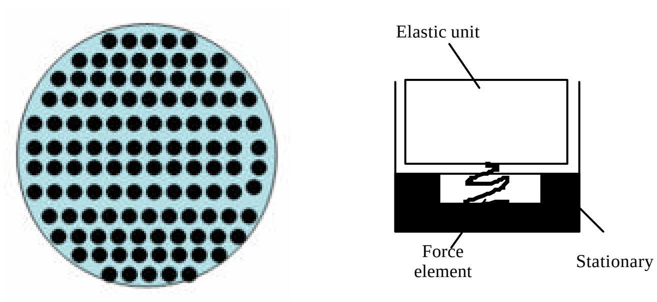

Fig. 1: Multi-elastic unit abrasive plate and elastic unit

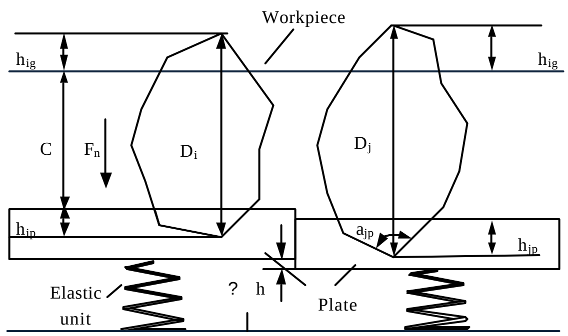

Fig. 2: Mechanical model of single brasive

In normal machining process, workpiece is contacted with several elastic units. When pressure of each unit is less than its stress, the machining effect of elastic unit plate is the same as the entirety plate. However, when abnormal large abrasive appear on the workpiece surface, pressure of elastic units will increase. If the pressure exceeds the limit stress of elastic units, the units will sink down to avoid appearing excessive scratches.

Construction of cutting depth model: Support force of elastic units is provided by the pure elastic elements. When some abnormal large abrasive grains are mixed in machining, the pressure of abrasive contacted with workpiece is limited. The relationship between single abrasive and workpiece is shown in Fig. 2.

In Fig. 2, diameter of large abrasive grains is defined as D_j; load between workpiece and grinding is defined as F; force limiting element is supposed as pure elastic elements with elastic coefficient K. if the elastic unit afford pressure and sink down Δh, according to Fig. 2, the formula between pressure F and cutting depth is as follow:

$$F_n = k \times \Delta h + \frac{\pi}{2} \times h_j^2 \times \sigma_{s1} \times \tan^2 \alpha_{jp} \quad (1)$$

While:

$$h_{jp} = \sqrt{\frac{\sigma_{s1}}{\sigma_{s2}}} \times h_{jg} \quad (2)$$

Because:

$$h_{ip} + h_{ig} + C + \Delta h = D \quad (3)$$

Therefore, the model of elastic unit cutting depth is as follow:

$$h_{jg} = \frac{D - C - \Delta h}{1 + \sqrt{\sigma_{s1} / \sigma_{s2}}} \quad (4)$$

α_{ip} is indentation apex angle of abrasive, σ_{s1} is the yield strength of abrasive, σ_{s2} is the yield strength of elastic unit plate, h_{ip} is embedded depth of abrasive, D is diameter of abrasive grains group except large grains, C is distance between workpiece and lapping plate.

In equation, the cutting depth is related with diameter of abrasive, yield strength of abrasive, stiffness of elastic unit and indentation apex angle. In the normal machining situation, there are no abnormal large abrasive between elastic unit and workpiece. Δh is 0. The pressure of abrasive grains group is approximately equal, which is determined by the external force. When some large abrasive appeared on the surface of workpiece, $\Delta h>0$. The pressure applied by external force will be eliminated by elastic units. Therefore, abnormal large abrasive will afford less pressure than other normal abrasive. As pressure of large abrasive grains directly influents depths of scratches, reduction of pressure of large abrasive grains can help reduction of appearance of deeply scratches.

Grain size sensitivity: When workpiece and grinding machines are selected, cutting depth of abrasive grain groups in grinding machines is mainly determined by the depth which grains embed in the workpiece. Its value is determined by machining load and time. When workpiece is machined by grinding machining, diameter of grains is uneven. It makes pressure of grain and depth of scratches different.

Surface roughness and material removal rate is considered as the evaluation indexes of grinding accuracy are not enough. Those evaluation indexes will become meaningless at all, if some deep depth scratches are produced in workpiece. Surface roughness and material removal rate is considered as the evaluation indexes of grinding accuracy are not enough. Those evaluation indexes will become meaningless at all, if some deep depth scratches are produced in workpiece. it is necessary to carry out analysis and evaluation for grinding system ability to avoid deep scratch. An important parameter for evaluation is Grain Size Sensitivity (GSS). GSS shows relative changes degree of scratch depth caused by changes of grains diameter. It can be described as follow:

$$GSS = \frac{h_{ig} - h_{jg}}{D_i - D_j} \tag{5}$$

h_{jg} is depth of large grain embedded in workpiece; h_{ig} is average depth of grain groups embedded in workpiece: D_j is diameter of large grain; D_I is average diameter of grain groups. A certain relationship is found between depth of scratches and indentation depth difference of grain groups. When the difference depth of grain groups is increased, quantity and depth of scratch relatively increase too and vice versa. If grinding machining has low GSS value, it will be prone to developing scratches.

NUMBERICAL SIMULATION OF GRINDING PROCESS

Modeling and numerical simulation: Grinding refers to the mutual action of mechanical friction by abrasive grain, liquid and workpiece, which removes extreme thin layer material from workpiece, meanwhile high geometric accuracy and well surface roughness can be ensured. If grinding parameter is unreasonably set, required grinding accuracy and depth will not be obtained. Numerical simulation of elastic unit plate based on Lab View should be carried out to improve efficiency of selection of appropriate parameters.

Cutting depth in process of grinding is mainly determined by machining load and time. When multi-elastic unit plate is applied, difference of cutting depth is related with difference of grain diametersand numbers of elastic unit. Because of properties of workpiece material, three technique schemes are designed and numerical simulation of machining process is carried out shown in Fig. 3.

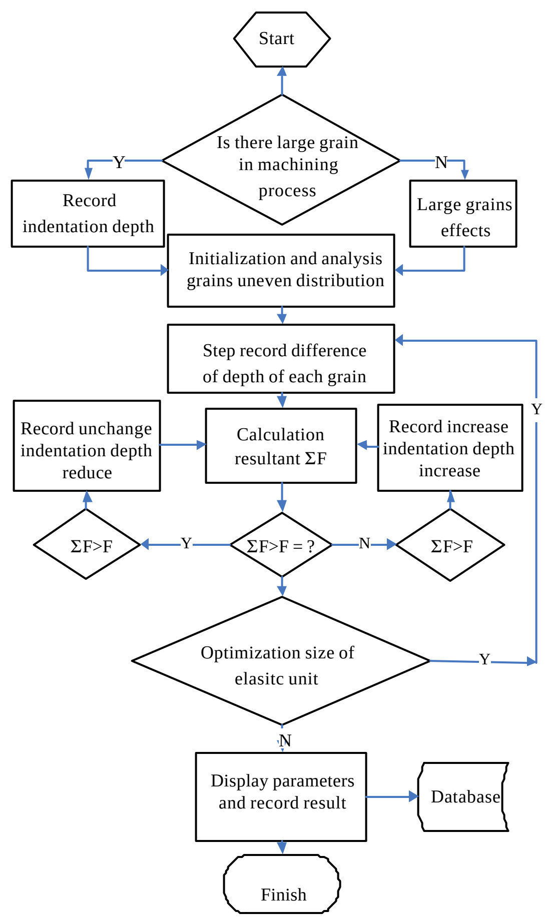

Fig. 3: Conception of simulation process

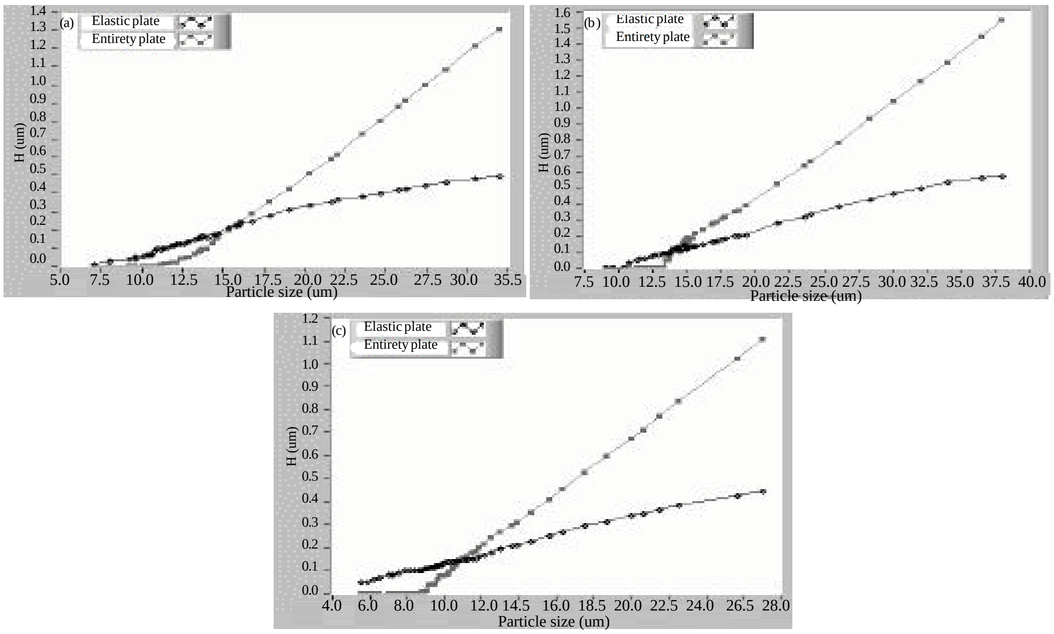

Fig. 4(a-c): Simulation results comparison of different types of abrasive grain

Parameters are shown in Table 1

Result analysis: According to parameters described in Table 1, it is carried out numerical simulation of grinding process. In simulation, evaluation reference is adopted for average of grain indentation depths and sample length is adopted for length of workpiece. Required data is shown in Fig. 4.

According to data in Fig.4, different grinding plates and parameters are used. The grinding depths are shown in Table 2.

It can be recognized that grinding plate with multi-elastic units is better than traditional entirety plate in the same load condition. Value of maximum cutting depth and GSS are lower than traditional entirety plate. Compared with traditional entirety plate, the grinding plate with multi-elastic unit can limit scratches caused by large grain efficiently.

It is calculated that values of GSS and roughness (R_a) in different parameters are shown in Table 3.

Compared with three groups of data, it can be result that accuracy of plate with multi-elastic unit is higher than traditional entirety plate in the same load. Compared with group 1 and group 2, with numbers of elastic unit increased, accuracy of cutting is increased in the same load. Compared with group 2 and group 3, change of accuracy can be ignored with grain indentation depth increased, when plate with multi-elastic unit is used.

Table 1: Simulation parameters of elastic unit plate

No.	Grain size	Unit number	Elastic stiffness/(N/mm)	load/N
1	800	10	0.1	3
2	1 000	30	0.5	5
3	1 200	50	1.0	10

Table 2: Simulation results of the cutting depth

	Entirety plate		Elastic unit plate	
No.	Max depth	Average depth	Max depth	Average depth
1	1.57	0.26	0.62	0.19
2	1.32	0.23	0.55	0.18
3	1.12	0.21	0.51	0.17

Table 3: Simulation results of machining

	Entirety plate		Elastic unit plate	
No.	GSS	Ra/μm	GSS	Ra/μm
1	0.083	0.264	0.0275	0.187
2	0.069	0.221	0.0235	0.174
3	0.057	0.205	0.0214	0.162

EXPERIMENT OF MULTI-ELASTIC UNIT PLATE

Experiment design: In order to verify the advantage of machining with multi-elastic unit plate and the feasibility of numerical simulation, experiment was carried out.

Experiment was performed on Nanopoli-100 precision polishing machine with 30rpm rotation speed. Its control precision is ±0.5° and loading is realized by weight. Two kind of grinding plate were used, there are plate with multi-elastic unit and cast iron plate. Numbers of elastic unit are 30, its stiffness is 0.5N mm^{-1}. type of sample is

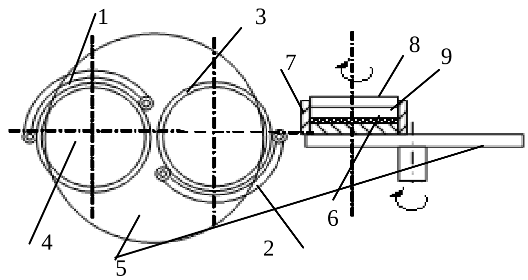

Fig. 5: Elastic unit lapping experiment system 1-Correcting ring separator 2-Correcting ring 3-Friction wheel 4-Loading holes 5-Elastic-unit plate 6-Workpiece 7-Binder 8-Weight load 9-Substrate

Fig. 6: Removal rates in different load

SMS440C, size number of grain is 1000. The system of experiment is shown in Fig. 5.

Comparison analysis of machining efficiency and surface roughness: Experiments were carried out by using elastic-unit plate and entirety plate to analyze machining efficiency and surface roughness.

Comparison of machining efficiency is carried out by experiment of material removal rate. Two kinds of plates for grinding at the same processing load and speed, the material removal rates are shown in Fig. 6. in the graphic, machining efficiency of entirety plate is slightly larger than the multi-elastic unit plate, meanwhile, the processing efficiency of two machining methods were increased with the increase of load.

Surface roughness of workpiece obtained by elastic unit plate is less than entirety plate and reduced along with time; value of GSS is only one third for entirety plate, GSS of entirety plate is increased with machining time, while the GSS of multi-elastic unit plate basically unchanged (Table 4).

Table 4: Roughness comparison with two plates

	Entirety plate		Elastic unit plate	
time/min	Ra/μm	GSS	Ra/μm	GSS
10	0.874	0.058	0.743	0.022
20	0.852	0.061	0.794	0.021
30	0.753	0.063	0.650	0.022
40	0.652	0.064	0.600	0.022
50	0.542	0.065	0.492	0.023
60	0.520	0.068	0.470	0.022

Table 5: Removal rates comparison

	Material remove rate/|Mm	
Load/KPa	Measured	Simulated
5	0.09	0.15
10	0.14	0.25
20	0.21	0.34

Table 6: Roughness comparison

	Surface roughness Ra/μm		GSS	
Load/KPa	Measured	Simulated	Measured	Simulated
5	0.25	0.18	0.021	0.021
10	0.31	0.25	0.022	0.022
20	0.35	0.27	0.024	0.023

Material removal rate of multi-elastic unit plate is slightly less than entirety plate's and surface roughness of multi-elastic unit plate is better than entirety plate's. Because of limit stiffness of elastic unit, grains groups are forced more uniform.

Experimental validation of the numerical simulation: From the results of comparison experiment, the advantage of multi-elastic unit plate is appearance. Machining efficiency is basically unchanged, while precision is higher than entirety plate. For different workpiece machining, best grinding parameters is the key to ensure the processing efficiency and quality. These parameters selection and combination will be a time-consuming work. Numerical simulation is one of the ways to improve the efficiency of optimum process parameters. It is necessary to verify the cutting depth model and numerical simulation method.

Validation experiment of numerical simulation is carried by 3 groups of experiments with different load. Results and data are shown in Table 5 and Table 6.

The results show that numerical simulation of grinding machining and single grain cutting depth model of elastic unit plate based on Lab View can obtain the values, which are more similar to the actual results of grinding. It shows that selection method of grinding machining parameters based on multi-elastic unit plate is feasible.

CONCLUSION

Through the research and experiments, the following conclusions can be obtained:

- Under same conditions, machining efficiency of multi-elastic unit plate is slight lower than entirety plate's and increases with the growth of load; surface accuracy of multi-elastic unit plate is higher than entirety plate's and increases with the growth of load and the grain size sensitivity is almost not changed. The method of grinding machining with multi-elastic unit is consideration of efficiency and accuracy
- Under same conditions, simulation values of machining efficiency of elastic unit plate is slight higher than the measured values; simulation results of surface roughness is slight less than measured values. grain size sensitivity is almost equal. Results show that using grain cutting depth model to simulate the grinding machining process can be used to grinding machining parameter selection
- Research results show that using multi-elastic unit plate grinding technology can ensure the machining efficiency. Machining precision can be greatly improved. Its prospect of engineering application is great

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