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Mechanism of high parallelism generation in double-sided lapping

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Abstract

Double-sided lapping (DSL) is an ultra-precision process widely used for machining optical components, wafers, and precision physical experiment samples owing to its high efficiency and parallelism. Most previous research focused on flatness, surface roughness, material removal rate, etc. However, as a critical parameter, parallelism was rarely investigated in the DSL process. To explain why two surfaces of the workpiece become parallel by DSL, several workpieces, including a slide which render the model close to the actual process, are taken to calculate the parallelism evolution, and the parallelism convergency mechanism is clarified. The calculation result has indicated that the parallelism was improved from 100.0 µm to 25.6 µm based on the parallelism evolution model. The results of subsequent experiments on thin copper substrates to analyze the parallelism evolution quantitively have demonstrated that, as expected, it matches with theory analysis and parallelism improves from 108.6 µm to 28.2 µm.

Keywords: Double-sided lapping, parallelism, measurement system, theoretical model

1. Introduction

Flat workpieces are indispensable parts in many fields, and the demand for its parallelism increases with the rapid development of the industrial regions [1]. Normally, high parallelism is always obtained through fly cutting or ultra-precision turning [2]. However, the two sides of the workpiece are machined successively in the cutting process, in which only a high total thickness variation (TTV) rather than the parallelism can be achieved. Nevertheless, the parallelism is not only determined by thickness, but also decided by flatness, which is hard to improve on workpieces with weak rigidity attributed to the effect of the residual stress [3]. Thus, a process in which both sides of workpieces can be machined simultaneously is proposed to weaken the effect of residual stress, and the high parallelism, as well as the flatness, is guaranteed by the process [4]. Double-sided lapping as a qualified process, which machined the two sides of the workpiece concurrently, is employed to achieve high parallelism [5].

Double-sided lapping is an ultra-precision machining process, which is always used to achieve high flatness and efficiency [6]. In the process, several rather than one workpiece are machined in the meantime, and the flatness, surface roughness, TTV, etc. are similar after machining. The material removal models were developed accurately by analyzing the contact pressure, relative motion between the workpiece and the lapping plate. Additionally, flatness, surface roughness and material removal rate are primarily investigated on hard and brittle materials such as silicon, sapphire, SiC, etc. [7]. Parallelism, as a crucial index, has undergone experimental investigation during the double-sided lapping process [8]. However, the parallelism evolution after double-sided lapping with floating upper plate has not been analyzed theoretically, and the mechanism of the parallelism convergency has not been clarified.

To solve the problems, a theoretical derivation of parallelism evolution has been built in this paper. The contact pressure, as well as the material removal has been obtained based on the established model. Then, the parallelism evolution of tapered and parallel workpieces was calculated. Five thin copper substrates including a tapered workpiece were employed to verify the established model by double-sided lapping process.

2 Theoretical model

In DSL process, five workpieces are machined concurrently in actual process, in which three workpieces are processed initially from the analysis above, and the other two are machined gradually. The model with five workpieces is spread based on the one with three workpieces to simulate the actual process. The mechanical model of the process is shown in Figure 1.

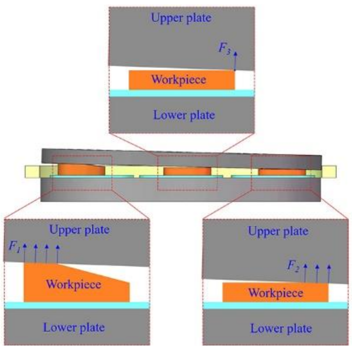


Figure 1. The schematic of workpiece force analysis with five workpieces

The material removal model can be calculated based on the Preston Equation, shown in Eq. (1) and (2).

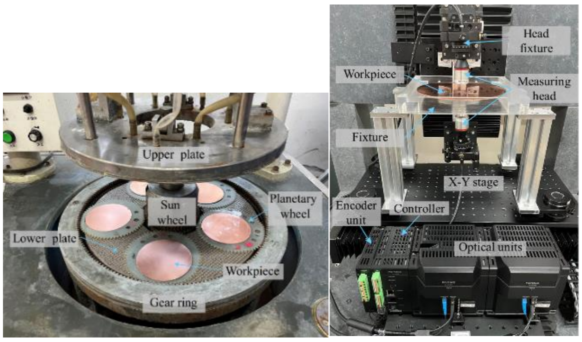
$$\begin{cases} F\cos\theta = F_1 + 2F_2 + 2F_3 \\ F_1L_1 + 2F_3L_1\cos 2\beta = 2F_2L_1\cos\beta \\ F_1 = F(\theta, \beta) \\ P = \dfrac{F_1}{A} = \dfrac{F(\theta, \beta)}{\mathrm{A}} \end{cases} \tag{1}$$

$$MR = k\int_0^{\frac{\pi}{\omega_n}} \frac{F(\theta, \beta)}{\mathrm{A}} \sqrt{\begin{matrix} R^2(\omega_p-\omega_h-\omega_n)^2 + (L_1\cos\theta)^2(\omega_p-\omega_h)^2 \\ +2RL_1(\omega_p-\omega_h-\omega_n)(\omega_p-\omega_h)\cos\omega_n t \end{matrix}}\, dt \tag{2}$$

In which F_1, F_2 and F_3 are the contact pressure on different workpieces respectively. A indicates the contact area between the workpiece and lapping plate. β is the deflection angle of the workpiece. θ is the slope of the upper plate. R is the distance between the point to the center of the workpiece, ω_p is the rotational speed of the lapping plate, ω_h is the revolution speed, ω_n is the rotational speed of the workpiece, and L_1 is the distance between the center of workpiece and the sun wheel.

3. Experiments

Five copper substrates sized Φ 100 mm×2.9 mm, including a tapered one mentioned before with the parallelism of 100 µm fabricated by turning process, have been symmetrically placed in a double-sided lapping machine (YJ-6B5LA by Yujing Machinery Co., Ltd., Hunan, China) as shown in Figure 2 to verify the theoretical model.



(a) (b)

Figure 2. Double-sided lapping setups

Twin fixed-abrasive pads with 15-25 µm diamond particles have been utilized to perform the DSL tests with coolant using deionized water. The parallelism of the workpiece was evaluated each 10 min by the instrument shown in Figure 2(b), and the measurement uncertainty is 0.34 µm (coverage factor k=2).

4. Results and discussion

4.1 Calculation results

The material removal (MR) on the surface has been calculated based on the theoretical model. The parallelism could be directly obtained by the thickness variation as the workpiece in the model has been assumed as an ideal flat. Given the calculation results shown in Figure 3, it would be reasonable to assume that the DSL process would enhance not only the thickness uniformity but also the workpiece's parallelism (had been improved from 100.0 µm to 25.6 µm).

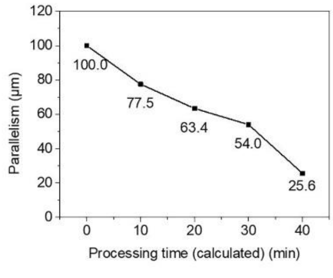


Figure 3. Calculation results of slide workpiece parallelism evolution

4.2 Experimental results

Five workpieces, including a tapered workpiece with a thickness of 2.8 mm~ 2.9 mm, were selected in the double-sided lapping process to verify the theoretical model. During the process, the machined area becomes more extensive and the thickness tends to be uniform. Within 40 min processing, the whole surface was machined, and the parallelism has been improved from 108.6 µm to 28.2 µm finally as shown in Figure 4. Due to the initial surface shape, the pressure distribution is not the same with the calculation, which causes the difference between Figure 3 and Figure 4 at the processing time of 20 min and 30min.

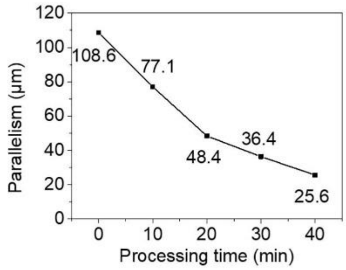


Figure 4. Experimental results of slide workpiece parallelism evolution

5. Conclusions

In this study, a theoretical model is developed to analyze the parallelism evolution, and the mechanism of parallelism convergency in DSL process is investigated. The following main conclusions are presented.

(1) A theoretical model has been established to clarify the mechanism of workpiece becoming parallel. In the modeling, five workpieces including slide one were employed in the calculation. The parallelism evolution has been calculated on slide workpieces, and the parallelism was improved from 100.0 µm to 25.6 µm.

(2) Experiments have been conducted to verify the theoretical model with one slide workpiece and four parallel workpieces. The slide-thin copper substrate becomes parallel after the double-sided lapping process, and the parallelism is modified from 108.6 µm to 28.2 µm, which agreed with the calculation results.

The future work will focus on the double-sided lapping machines improving, with more sensors to make the machines intelligent.

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