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High-Accuracy Polishing Technique Using Dwell Time Adjustment

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Abstract. Two algorithms for dwell time adjustment are evaluated under the same polishing conditions that involve tool and work distributions. Both methods are based on Preston's hypothesis. The first method is a convolution algorithm based on the Fast Fourier Transform. The second is an iterative method based on a constraint problem, extended from a one-dimensional formulation to address a two-dimensional problem. Both methods are investigated for their computational cost, accuracy, and polishing shapes. The convolution method has high accuracy and high speed. The constraint problem on the other hand is slow even when it requires larger memory and thus is more costly. However, unlike the other case a negative region in the polishing shape is not predicted here. Furthermore, new techniques are devised by combining the two methods.

Key words: Polishing; surface grinding; dwell time; convolution method; fast Fourier transform; constraint problem.

1 Introduction

Recently, the focus on the processing of high-precision optical elements into target shapes has shifted to surface creation technology using polishing heads that can control the amount of material removed [1–6]. This technology is known as corrective polishing method where polishing shape is given by scanning the variable velocity of the polishing head on the work surface of a physical object and by controlling the dwell time of the polishing head. It is known that the accuracy demanded for modern optical elements is extended to the order of nanometer. Moreover, the polishing areas are becoming larger

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and posing new challenges for the polishing techniques especially when it takes longer time to complete the task. Also, the calculating algorithm for the dwell time distribution to determine processing accuracy and cost are becoming increasingly more important.

In one calculation method, the amount of material removed is estimated using a model equation that accounts for the polishing velocity, the switching processes and anti-processes at each point, and the technique for finishing the target shape [7]. However, in this method the amount of material removed in one scan is considered to be uniform but the dwell time distribution cannot be obtained. Hence, a method for calculating the dwell time distribution with a fast Fourier transform (FFT) was proposed by Negishi et al. [8] which is one of the two methods addressed in this paper. The other method evolved from a technique for solving one dimensional algorithm for the dwell time calculation as a constraint problem and was developed by Yang et al. [9].

In this current study, the technique for obtaining the dwell time distribution by the one-dimensional algorithm for constraint problem is extended to address a two-dimensional problem which is more appropriate for actual surfaces. This technique is then compared with the FFT calculation technique, and the characteristics of the two techniques are analyzed later in this paper. Furthermore, new techniques are designed by combining the two methods.

2 Two techniques for solving the dwell time distribution

Polishing removal is based on a convolution model [3] derived from Preston's hypothesis. The unit removal shape is obtained from a polishing experiment with a polishing head driven for a unit time. The model is expressed by an integration of a convolution equation over the grinding area A:

$$h(x,y) = \int_{\mathbf{A}} g(u,v) f(u-x, v-y) du dv, \tag{2.1}$$

where $h(x,y)$ is removal shape, $g(u,v)$ is dwell time distribution, $f(x,y)$ is unit removal shape, and x, y, u, v are variables. Moreover, polishing adjustment progresses by bringing the removal shape close to the error shape, which is defined as the difference between the work shape and the architectonic shape:

$$d(x,y) = h(x,y) + e(x,y), \tag{2.2}$$

where $d(x,y)$ is the error shape, i.e., the target removal shape measured by a shape measurement device and $e(x,y)$ is the residual error shape that cannot be modified. It is necessary to calculate the dwell time distribution g from the target removal shape d and unit removal shape f during polishing adjustment. The concept of convolution is shown in Fig. 2.

We first describe the technique for calculating $d(x,y)$ the dwell time distribution by FFT [9]. During the calculation, the following conditions are to be met for polishing adjustment: