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Methods to extend surface error map in dwell time algorithm

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Abstract
In deterministic optical figuring processes, such as CCOS, MRF and IBF, a key step is to determine the dwell time used to control the figuring process, and a lot of dwell time algorithms have been applied. However, for a successful deterministic optical figuring process, besides of the dwell time algorithm, the extension method of the surface error map is also important. As different extension methods will result in different dwell times and residual error maps, in this study, extension methods are discussed and a smoothly fall extension method has been proposed. Study shows that this new extension method is able to result in smallest residual error and relatively short dwell time.

Keywords: Deterministic optical figuring process, optical fabrication, ion beam figuring, dwell time, edge extension, surface error.

1. Introduction

In deterministic optical figuring processes, such as computer controlled optical surfacing (CCOS)[1,2], magnetorheological finishing (MRF)[3,4] and ion beam figuring (IBF)[5,6], a key step is to determine the dwell time used to control the figuring process, and a lot of dwell time algorithms have been applied[7-9]. However, for a successful deterministic optical figuring process, besides of the dwell time algorithm, the extension method of the surface error map is also important. At present, there are three main edge extension methods: flat extension [10], Gaussian extension [11], and smooth extension [12]. Generally, smooth extension results in a smaller residual errors, while flatten extension and Gaussian extension result in larger residual errors. Gaussian extension will result in small dwell time due to its fall edge.

Although smooth extension results in small residual error, it will cause larger dwell time for rise edge. To obtain small residual errors and relatively small dwell time, the extension edge should be smoothly fall down. Actually, Gaussian extension is a fall extension, and it really gets the smallest dwell time. However, it falls so fast that causes a larger residual error. Therefore, a new smoothly fall extension should be investigated, and it should fall slowly than Gaussian.

2. Smoothly fall extension

In the Gaussian extension method, the extension edge falls rapidly in Gaussian shape (which is also the shape of the tool removal profile). It theoretically requires the dwell time suddenly reduce to zero beyond the physical edge and this is the root cause of problems. Therefore, we consider making the dwell time to extend horizontally. Thus the removal is slowly fall (illustrated in figure 1). We think this fall profile is more suitable to edge extension. This new fall edge profile is

$$m(x) = \frac{1}{B}\int_{-(d/2-x)}^{d/2} p(u)du \, , \qquad (1)$$

where, *B* is a constant used to normalize $m(x)$, *d* is the width or diameter of the tool removal profile $p(x)$. We can easily get $m(0)=1$, and $m(d/2)=0.5$.

By combining this extension profile with the normal smooth extension method, i.e. to product the normal smooth profile with the profile $m(x)$, we thereby construct a new extension method, smoothly fall extension.

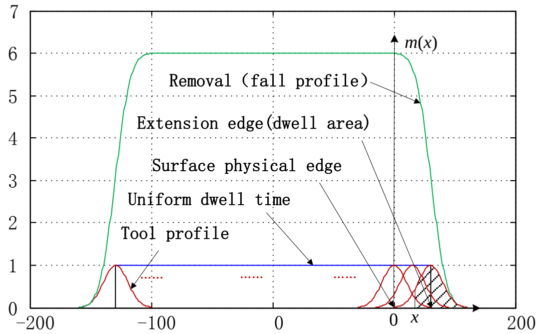


Figure 1. Illustration to get smoothly fall extension profile

Now, we have 4 edge extension methods: flat extension, Gaussian extension, smooth extension, and smoothly fall extension. Let's use an example to show their differences. The original error is 200mm long. Suppose the tool removal profile is a Gaussian function with 60mm width, then the error profile should be extended to 260mm long. Figure 2 shows the extended profiles of different extension methods.

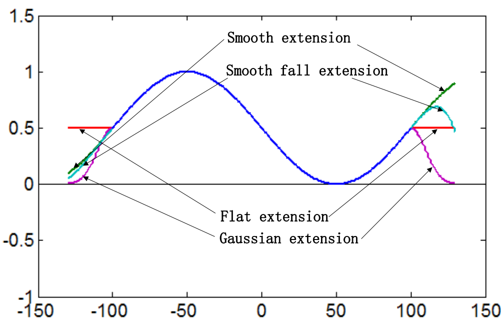


Figure 2. Extension profiles of different extension methods.

3. Comparison demonstration

Figure 3 is a physical surface error map with aperture 150mm. Figure 4 is an IBF tool removal profile which is used in this study.

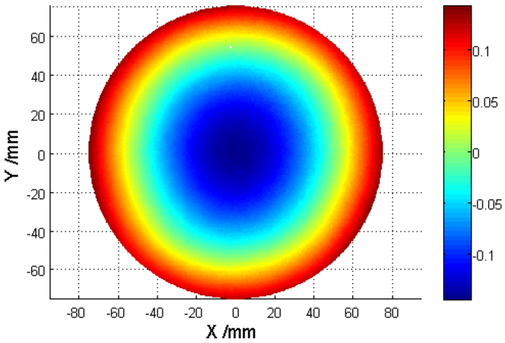


Figure 3. Original surface error map.

First, we use the 4 extension methods mentioned above to extend the error map. The corresponding results are shown in figure 5(a)-(d). Then, we use IBFCAM software [12] to calculate corresponding dwell times and residual errors. The corresponding results are shown in figure 5(e)-(h) and figure 5(i)-(l) respectively.

The results show that the smooth extension and the smoothly fall extension result in almost same and smallest residual errors, 0.78nm RMS and 0.76nm RMS, respectively. Furthermore, the smoothly fall extension only consume a relatively shorter dwell time, 129.5min, than that of smooth extension, 142min.

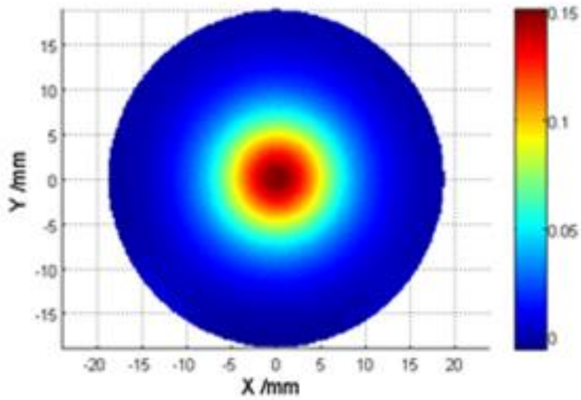
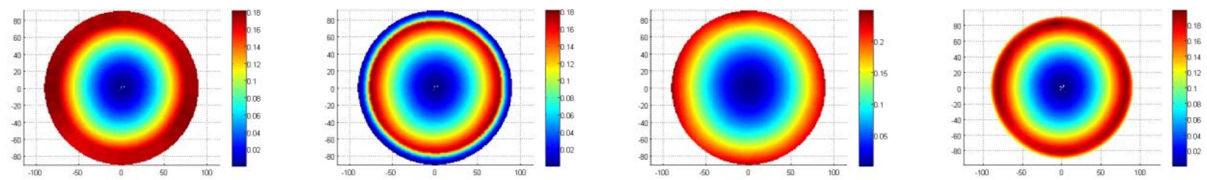
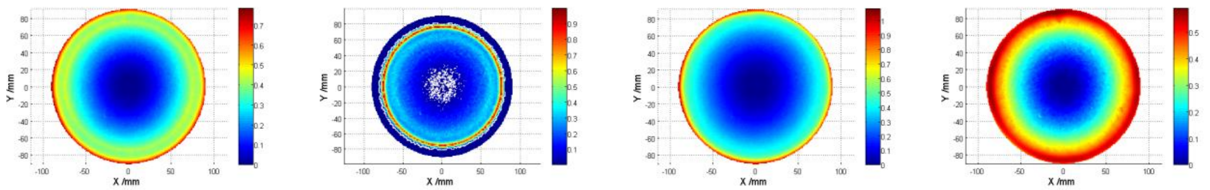


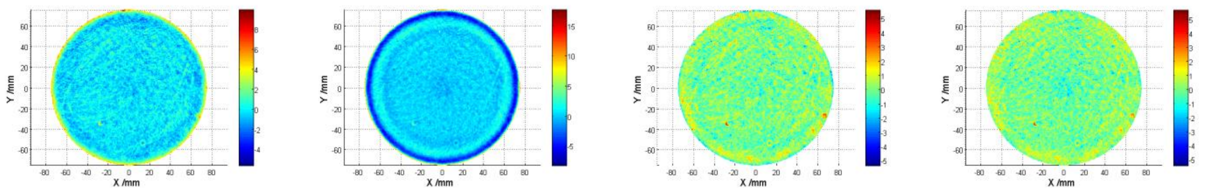
Figure 4. IBF tool removal profile.



(a) Flat extension. (b) Gaussian extension. (c) Smooth extension. (d) Smoothly fall extension.



(e) Dwell time: 129.6min (f) Dwell time: 86.5min (g) Dwell time: 142min (h) Dwell time: 129.5min



(i) Residual error: 1.24nm rms (j) Residual error:1.99nm rms (k) Residual error:0.78nm rms (l) Residual error:0.76nm rms

Figure 5. Results of all the 4 edge extension methods.

4. Conclusion

A new edge extension method, smoothly fall extension, has been proposed. Compared to other present extension methods, it will result in smallest residual error and relatively shorter dwell time.

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