Error spectrum full range convergence technique for laser optics element

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Abstract: In the application of laser optics, it requires well surface roughness and profile to reduce the laser energy losing. Such as ultra-smooth processing technology is generally used for processing optical components to meet the surface quality requirements. However, traditional elevation parameters PV(Peak-Valley)/RMS(Root Mean Square) are not enough to meet the optics demand. Error Spectrum distribution is an important technical index to be concerned in the field of ultra-high power laser. Different spectral errors cause different laser energy losing. So it is necessary to explore the error full-spectral convergence processing technology. In this paper, basing on the discussion of error spectrum Evaluation methods, the full spectral range converges technology is introduced to meet the demands of high power laser.

•1. Introduction

Precision optical components have extremely high processing accuracy and play an increasingly important role in high-tech projects such as aerospace[1]. Whether it is possible to master the processing technology of precision optical components has become an important indicator of the level of national manufacturing. Traditional optical element processing methods rely on skilled workers' repeated, continuous, and stable work to manufacture a piece of optical element that meets the requirements. This method has the disadvantages of being time-consuming and unstable. The quality assurance and process control are offline, and the quality of the optical element is difficult to guarantee. Due to manual processing, there is not much attention paid to the error spectrum .

With the application and promotion of deterministic polishing technology, the dependence of high-precision optical components on skilled workers has been effectively solved. However deterministic polishing technology has its own certain technical defects. Deterministic polishing technology main principle is based on the Preston's equation. It achieves deterministic polishing removed by changing the pressure of the polishing disc, the relative speed, the dwell time and the corresponding process parameters. It could be effectively converge processing errors to meet the optical requirements by using deterministic polishing technology which base on the quantitative analysis. Small polishing tool is usually used to polish optical components in deterministic polishing techniques. In this case, the profile of optical element processed by deterministic polishing usually could be suitable, which contains more small-scale manufacturing errors—mid-high spatial frequency error.

The optics for laser system not only require low surface roughness, but also impose higher requirements on surface error spectrum. Different error spectrum on optical element could case different performance of optical systems[2-6]. Such as the low-spatial frequency error of the optical surface distorts the image of the imaging system and contains various aberrations; the mid-spatial frequency error of the optical surface causes small angles of light scattering, which affect the contrast of the image; high-spatial frequency of the optical surface reduces the reflectivity of the optical surface for large-angle scattering. In this paper, the evaluation methods for assessing the error spectrum are discussed, then the way to control the error spectrum for laser optics are introduced.

2.Evaluation method for error spectrum

2.1 Power Spectral Density(PSD)

Traditionally, PV, RMS and Zernike Polynomial are used to express the detection results of optical components. These parameters lack a description of the error spectrum, which cannot wholly reflect the system's requirements of optical components. PSD character curve (7-9) is proposed to evaluate optical surface errors using the during the development of NIF by the Lawrence Livermore laboratory in the United States. Error spectrum analysis is basing on the data dealled with Fast Fourier Transform from the optical surface error, to determine the distribution of different spectrum. The benchmark for its evaluation method is to formulate a PSD characteristic curve for the optical surface.

Characteristic curve equation shows as follow:

$$PSD = A \cdot f^{-B}, 1/(1000 \cdot D) < f < 1/(1000 \cdot C)$$

where A is constant, in μm. B is Frequency power exponent, which should be >0. C and D are the minimum and maximum space periods (sampling length), in mm.

The evaluation method based on the PSD characteristic curve is to calculate the PSD curve of the surface error of the optical element, then compare it with the characteristic curve. When the PSD curve of the surface error is below the characteristic curve, the optical surface is qualified. Otherwise, it is considered unqualified

Because PSD evaluation method is based on the Fast Fourier transform, the PSD curve, as statistical evaluation, cannot express the location of different error spectrums on the optical surface. This evaluation method cannot directly guide the actual correction processing.

2.1Surface Residuals

Surface residual evaluation method is a kind of assessment way basing on wavefront aberration, which divides surface error into zernike aberration and Mid- spatial frequency error. The way to get optical surface residual as follow: a. Based on the relationship between the residual height with the phase, the surface residual could be calculated of each point by using phase shift technology. The true error of optical component surface could be obtained by fitting. b. Then the Zernike polynomial fitting is used to obtain the true surface error, which mainly is considered to be the low-spatial frequency error. c. Then the true wavefront data and the Zernike polynomial error data are used to obtain the residual error. Because the residual error has removed the low-spatial frequency error of the Zernike polynomial fitting, the residual error mainly reflects the mid-high spatial frequency error.

This method can truly reflect the correspondence between the error spectrum with the surface of the actual optical element. However, the evaluation method is obtained after fitting the Zernike polynomial, the true residual is subject to the fitting accuracy.

In summary, different evaluation methods have different advantages and disadvantages. Therefore, in the actual processing of optical components, different evaluation methods need to be formulated according to the error distribution requirements of actual parts.

•3 Error spectrum control method

•*3.1Process parameter control*

Processing parameters of deterministic polishing could be involved three categories: removal function, dwell function, and tool path. Removal function is closely related to the process technique. The shape of the removal function corresponding to the different processing technique is shown in Fig 1.The shape of the removal function is closely related to the parameters: pressure, relative speed, and movement mode. Taking the CCOS (Computer Control Optical Surfacing) as an example, different speed ratios and eccentricity have different effects on the removal function[10]. In literature[1] show that when the removal function approximates a Gaussian shape, deterministic polishing can be convergent to get requirement after several polishing loop.

The removal amount of deterministic polishing could be got with the convolution between the dwell time and the removal function. All deterministic processing principles follow the Preston's removal theory. By removing the determined position material, the optical element converges to the corresponding surface shape accuracy requirements. The only difference is that the dwell time calculation algorithm is different. At present, the calculation of dwell time can be divided into matrix calculation method, iterative method, deconvolution method etc. Different algorithms bring different efficiency and accuracy.

The tool path is another important factor that affects the error spectrum distribution. Common tool path include concentric circles, spiral lines, grid lines, etc. These tool path show a specific spatial frequency. Therefore, the selection of tool path is particularly important when processing some high-precision optical components. As shown in the figure 3 below, there is a peak from the PSD curve, and its peak frequency is analyzed. Its spatial frequency is consistent with the feed step, and it shows obvious spectrum characteristics.

Therefore, in order to avoid the processing error spectrum caused by the processing tool path, some scholars have studied different tool path for precision polishing[12]. The results show that short-range tool path such as pseudo-random path and Hilbert tool path could improve error spectrum on imaging quality compared to long-range tool path.

With the development of deterministic polishing technology, a large number of deterministic polishing technologies have been formed, such as Computer Control Optical Surfacing (CCOS)[13,14], Stressed–Lap Polishing,(SLP)[15,16], Bonnet Polishing, (BP) [17,18], Ion Beam Finishing (IBF)[19, 20], Magneto-Rheological Finishing (MRF)[21], etc. For these different process technique, the removal function, processing efficiency, and removal effect are quite different. Therefore, to select suitable processes for manufracturing optical element surface is basing on analysis of different process technique and error spectrum requirement. Through process technique combination optimization, the differences among them are fully utilized to eliminate low, medium, high frequency error, so as to achieve the convergence of surface shape and full error spectrum convergence.

Taking the MRF technology for example, its removal function shape is shown in Figure 1. Because of its stable removal function, it has been widely used in optical machining. The advantage of MRF is suitable for low spectrum converges and its removal of medium-high frequency errors is weak. Therefore, in the high precision optical machining, for its disadvantage, only using MRF polishing technique couldn't meet the requirement. In most cases, CCOS is used to eliminate the high-frequency errors after MRF processing.

In literature 4, it shows a different process technique combination sample, which use CCOS, IBF, and MRF to control the processing accuracy of optical components, and finally the low frequency, medium-frequency, and high frequency errors meet the requirements. The main reason is that different processing methods have different removal functions, which leads to their different ability to control error spectrums.

In addition to the combination of different process technique, different removal functions with the same process technique can also be used to achieve the convergence of the profile error and error spectrum.

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3.2Combination of different process technique

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3.3Error spectrum quantitative correction

Because of the PSD curve is only used as an evaluation index, it can't guide the surface correction of the actual optical element. PSD characteristic curve is the way to evaluate whether the optical element is qualified. When the PSD curve of the optical element exceeds its characteristic curve, the way of analysis the unqualified spectrum is shown as follows to get quantitative correction [11] :

a) Obtaining the surface shape error data of the optical element using measuring equipment;

b) Sampling the error data and calculating the corresponding PSD curve;

c)Comparing the obtained PSD curve with the PSD characteristic curve and finding the unqualified spectrum;

d)with the wavelet analysis of unqualified spectrum from step c) by using the wavelet toolbox and finding the distribution area on the optical element;

e) Select the appropriate process and processing parameters to eliminate the errors.

The above process only performs correction processing for the 1-D PSD curve, and the surface of the actual optical element is a complex surface usually. It need to extend the error spectrum quantitative analysis in 2-D surface.

The data process of 2-D surface is consistent with the 1-D PSD error spectrum quantitative correction processing. The difference are the selection of unqualified error frequency and wavelet transform method. In 2-D surface error data treatment, the wavelet transform should be 2-D and need choose suitable scaling function.

4 Conclusion

In this paper, two main evaluation methods of error spectrum are analyzed for high-power laser optical components. And the advantages and disadvantages of two evaluation methods are also analyzed. then three kinds of control way of error spectrum are introduced. Finally, 1-D PSD is taken as an example to explain error spectrum quantitative correction technology. With wavelet analysis, the relationship between processing error and error spectrum could be established. In this way, the full error spectrum of optical element could be improved to meet the requirement.

5 References

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