Pilot Study for Ion Beam Figuring Process

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ABSTRACT

The ion beam figuring is a kind of advanced technology of mirror processing. It has the advantages of high processing precision, high speed and no damage to the mirror surface. The ion beam figuring machine is established by using a one meter diameter vacuum coating plant in this research project. Mechanical scanning device, ion source and workpiece make up of the machine. Water, electricity and gas will be imported to the vacuum chamber. The computer software, extracting the error function between the ion beam processing function and mirror surface function by using the data of interferometer measuring, will calculate the dwell-time function in the course of processing. The computer will control the whole process based on the dwell-time function. The experiment processing indicates that PV will reach 1/14λ and RMS will reach 1/70λ by once ion beam figuring.

Keywords: Precision Optical Processing, Ion Beam Figuring, Ion Beam Figuring Processing, Study for Ion Beam Figuring Process

1. INTRODUCTION

As the development of astronomy and the advance in technology, the diameter of astronomical telescope increases and requirements of its performance are getting higher and higher. International modern large telescope has been able to achieve 80% of the light energy concentrated in less than 0.2". In contrast, the level of domestic processing is still very low. It is very hard to concentrate 80% of the light energy in less than 0.6".

In order to guarantee the high-precision processing needs of astronomical telescope, developed country has successfully developed the ion beam figuring machine which can process the mirror of large-diameter telescope in around 1990 based on realizing ion beam figuring technics for small-diameter telescope in the early 1980s. For example, the ion beam figuring facility developed by the Eastman Kodak company can process mirror up to 2.5m diameter.

The mirror will be accurately figured ultimately by using ion beam figuring[1]. The large mirror principal of the Eastman Kodak company introduces to the visiting Chinese that when they grind a large-diameter aspherical mirror, they just carry out preliminary polishing and then carry out ultimate polishing by using ion beam figuring technics. This greatly reduces the difficulty, improves the work efficiency and guarantees the quality specially.

1.1 The working principle of ion beam figuring

The principle of ion beam figuring is completely different from the conventional mechanical polishing. It is that gas molecules are ionized by ion source in a vacuum chamber and then ion-directional flow is formed by accelerating of high voltage electric field. The surface atoms will be removed one by one with appropriate energy ion bombardment of the workpiece surface[3,4].

The unique traits of ion beam figuring processing determined by its principle:

1. High processing precision. The basic unit, which is removed from the surface of workpiece by ion beam, is atom. The processing parameters which will affect the polishing speed, such as ion energy and ion density, can be controlled accurately and the stability is fine. Point by point figuring is being used when processing, so the crossed influence is small. Its processing precision can reach RMS 1/50λ ~ 1/100λ[2,3].
2. There is no mechanical fore to the mirror during ion beam figuring processing,. It does not cause surface cracking and deformation and there is no metamorphic layer.
3. Processing precision is unacted on the influence of environmental temperature field.

5th International Symposium on Advanced Optical Manufacturing and Testing Technologies: Advanced Optical Manufacturing Technologies, edited by Li Yang, Yoshiharu Namba, David D. Walker, Shengyi Li, Proc. of SPIE Vol. 7655, 76550N · © 2010 SPIE · CCC code: 0277-786X/10/$18 · doi: 10.1117/12.864885

4. The exterior roughness is fine and the processed surface is very clean. The organic and inorganic contamination which attach the surface in the previous process will be removed completely. It will allow the coated reflective film to improve adhesion, the granularity to decrease and the reflectivity to improve.
5. The effect of ion beam processing the heartland of mirror is same with ion beam processing the edge part of mirror. It is different from that the influence (edge effect), which is caused by partial vacantness of small grinder during CNC polishing (CCP) processing, must be eliminated by special amendment[5,6,7].
In summary, ion beam figuring processing is a kind of processing method which has no stress on the atomic scale and non-contact. It has the incomparable superiority compared with the conventional process. In addition, it is significative that this process which must use a high level of computer control technology will make polishing process no longer depend on operator's skill and experience.

1.2 The controlling principle of ion beam figuring process

The controlling principle of ion beam figuring process is same with CCP technology. The mirror will be figured by controlling the dwell-time of the ion beam in different locations on the surface. The theory is based on well-known Preston equation[5,6]:

$$\frac{dh(x,y)}{dt} = KP(x,y)V(x,y) \quad , \tag{1.1}$$

As to the ion beam figuring process, where P is the working function of ion beam. V is the relative velocity of ion beam with the workpiece. K is a kind of coefficient which is related to the structure of experimental device and the trait of workpiece material. $P(x,y)$ can be accurately determined by experiment. K will be determined by experiment according to the combination of specific materials and specific process parameters. In this way, the computer software will adjust its speed when the ion beam is being scanning the mirror according to the error distribution of mirror surface so that ion beam will have different dwell-time at different points. This will achieve accurately figuring.

1.3 Research work in progress and experiment results

We reconstruct an old coating machine. Mechanical scanning device designed by ourselves, which is installed in the vacuum chamber, is driven by external motors. The power lines, cooling pipes, gas lines needed by ion source are imported to the vacuum chamber. The ion source is installed on the rail of the vacuum chamber. The required water, electricity and gas connect to the ion source through pipelines. This will guarantee natural work when ion source is moving. At the same time, the vacuum degree is not affected. Operation of this equipment over the years indicates that the situation of using is satisfying.
For solving the problem of ion source working parameter stability, the power of ion source is reconstructed. It makes the stability of beam energy and beam current respectively achieve the requirement.
According to the correlative data, a mathematical model is established and computer controlling software is developed. Combining the working function of ion beam, the computer calculates the dwell-time for how long the ion beam will dwell at every point in the process of scanning after the error distribution of mirror is measured by interferometer. This will finish scanning under its control.
The software interface is very friendly. In addition to the basic functions, the software also can demonstrate three-dimensional animation and vividly display the processing process. The software will also direct the beam spot location on the mirror with two-dimensional animation in real time. The ion beam velocity and coordinate will be displayed by digit. The changes in velocity will be displayed by curve.
After repeated experiments, we have obtained relatively good results under the existing test equipment and measurement conditions. Many experimental data indicate that the mirror accuracy can achieve 0.07λ(1/14λ) PV and 0.013λ(1/75λ) RMS per ion beam figuring. Figure 1 and Figure 2 show the measured fore-and-aft data of a sample.
Glass-ceramic, quartz glass and K9 glass are mainly used for samples in the experiment. Because the etching rate of ion beam to diverse materials is different, the working function of each kind of material should be measured by a number of experiment.
The temperature coefficient of K9 glass is too large, so the data will not achieve stable point easily when measuring. The other two kinds of glass have a small problem in this area.

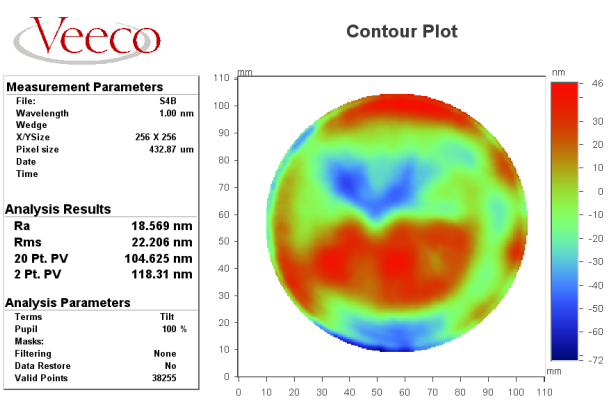

Figure 1: Before figuring PV 1/6λ RMS 1/28λ.

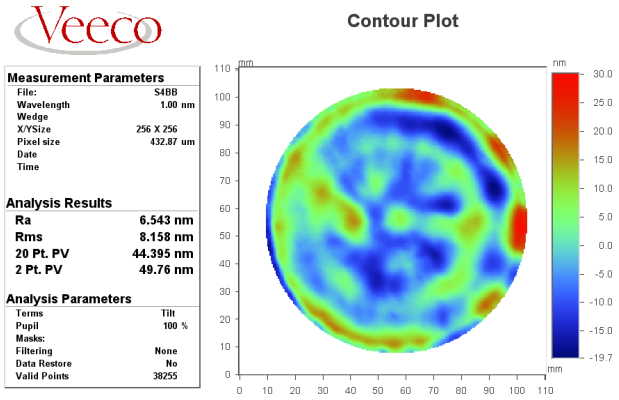

Figure 2: After figuring PV 1/14λ RMS 1/77λ

2. RESULTS

In the course of the study in this project, two new ideas which have some signification in technology we think are produced.

2.1 A simple method of convolution operation

The relationship of mirror error function $Z(x,y)$, ion beam working function $R(x,y)$ and dwell-time function $D(x,y)$ is convolution in the mathematical model of computer:

$$Z(x,y) = R(x,y) ** D(x,y) = \iint R(x,y)D(x,y)dxdy \quad , \tag{2.1}$$

We find that the operation of $D(x,y)$ in equation (2.1) can be simplified a kind of unfettered matrix accumulation operation. Practice shows that compared with matrix operation now, this method has the following advantages:

1. The smaller calculation and the faster speed, low demand on the computer, particularly fitting operating the bigger matrix;
2. Calculations and processing method is identical. The concept is clear and it is flexible and convenient to use.

2.2 Using the method of coating to amend the large concave mirror

According to the principle of ion beam figuring, we think that by appropriate coating tools such as magnetron sputtering sources, coating materials(eg SiO2) can be used to fill the concave of mirror. It also can achieve the effect of amending mirror. Accordingly, the same mechanical scanning will be adopted in a 2.4m magnetron sputtering coating plant. The uniform coating or coating amendment of mirror figure up to 1.6m mirror in diameter will be achieved by computer-controlled 160mm in diameter sputtering source. In addition, as long as high-precision measurement is solved, the effect of using the method to process large-diameter aspherical mirror should also be good.

From the practice of ion beam figuring processing, it is not difficult that processing accuracy will be improved to a very high level sequentially. The mirror can be processed multiple times to gradually increase the mirror accuracy. The precondition is that the mirror figure accuracy measured by interferometer should be guaranteed before processing. There are more than one such statement in literature: The accuracy achievable is limited only by the accuracy of the test data for virtually any optical form[8].

The amendment to optical error in the optical path of interferometer, which is included the figure of processed sample, has been observed. This is significant for the manufacture of astronomical telescopes. The error of main mirror will be amended by specially processing the secondary mirror. It will greatly improve the image quality of telescope. The working mode of IBF's point by point figuring has the unique advantage in this aspect.

3. CONCLUSIONS

Through this study, we have seized the design method and manufacture technology of ion beam figuring used for large-diameter mirror. The next step, a large equipment, which is used for processing more than one-meter diameter mirror with high precision, will be developed. There are some new ideas in the structure of equipment. The internal structure will be simple and the utilization rate of the vacuum space is high. At the same time, the positioning accuracy of scanning system and high reliability of operation will be guaranteed.

4. ACKNOWLEDGEMENT

The pilot study we have finished is supported by National Natural Science Foundation of China. The foundation number is 10373081. Figure 3 shows a new ion beam figuring machine. And this project is also supported by National Natural Science Foundation of China. The foundation number is 10827302.

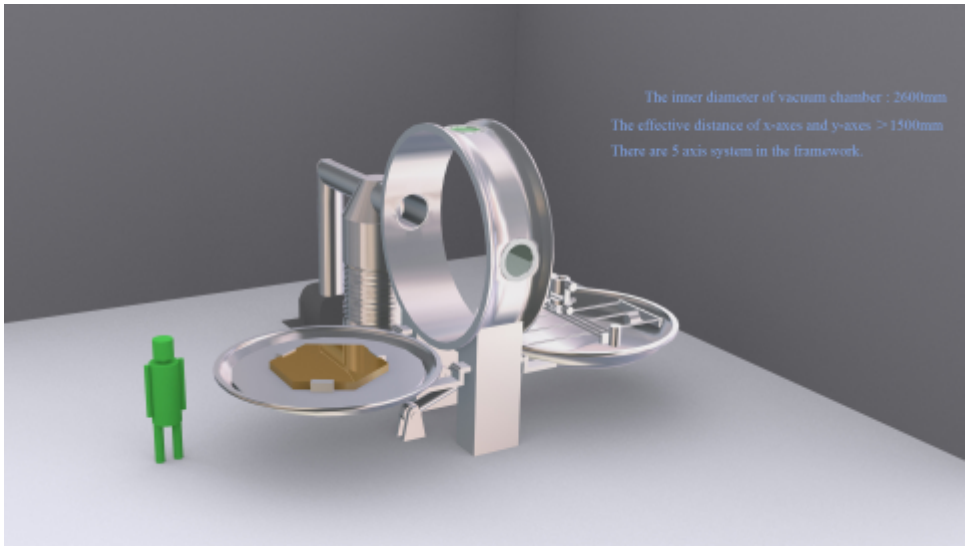

Figure 3: The blueprint of new ion beam figuring machine

REFERENCES

1. Peter Wizinowich et al., *The optical quality of the W.M.Keck Telescope*, Proc of SPIE, 1994, vol 2199, pp.94-104.
2. J.S.Zafran et al., *Ion polish of optical surface*, OPTICAL ENGINEERING, 1982, vol 21 No.6, pp.1022.
3. FANG Yudian et al., *Electron beam and ion beam processing, Machinery Industry Press*, 1989, pp.186-229.
4. CHENG Shuying et al. , *RIBE-5 Reactive ion beam etching machine*, Vacuum, 1993, vol 1, pp.11-19.
5. YANG Shijie, *The application of computer in processing astronomical telescope mirror*, The publication of Purple Mountain Observatory, 1987, vol 4, pp.385.
6. CAO Tianning, *Computer-controlled polishing parabolic shape*, Chinese Journal of Scientific Instrument, 1993,vol 4, pp.402.
7. ZHANG Xuejun, YU Jingchi et al. , *Theoretical method for Edge Figuring In Computer Controlled polishing of Optical Surface*, Proc of SPIE,1994, vol 1994, pp. 239.
8. R.N.Wilson, *Reflecting Telescope Optics II*, 1999, pp.33-37.