Quantitative measurement of Φ630 mm $F/1.34$ parabolic surfaces with Ronchi grating test method

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The Ronchi grating is applied to measure the large-aperture aspheric surfaces in a quantitative way on the basis of self-made software which includes Ronchi null grating design, collection of Ronchi graph, and data processing. The measured concave parabolic mirror has a diameter of 630 mm and an F number of 1.34. The measurement result is approximately the same as that of the ZYGO interferometer. This analysis software and test method establish a good foundation for the quantitative measurement of the big error about the large-aperture aspheric surfaces of the next generation telescope.

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The diameter of optical surfaces is becoming larger and larger, and the next generation of giant telescope is under programming with the diameter of the optical surface being several tens of meters. To fabricate those large aspheric optical surfaces, corresponding testing methods are required. For the large error that will come out when the optical surface is being ground or at the beginning of polishing, both the traditional interferometer and the sub-aperture interferometry[1,2] are unfit any more while the Ronchi grating test can work[3]. As one of the simplest and most powerful methods to evaluate and measure the aberrations of an optical surface or system, Ronchi test has been used widely and applied to the testing of optical surfaces since it was contrived[4−6]. In China, Wu *et al.* used it to test the optical surface[7], and later Zhou gave some theoretical research about the calculation on the grating to test the aspheric surfaces[8]. However, there is little report about the measurement of parabolic surfaces in a quantitative way in spite of the fact that it is very useful for the large-aperture optical surfaces[9].

In this letter, we introduce a whole testing system for the application of Ronchi grating test to the optical aspheric surfaces in a quantitative way. This system is based on the self-made software which includes Ronchi null grating design, collection of Ronchi graph, data processing, and so on. The experimental result is almost the same as the outcome of the ZYGO interferometer.

As shown in Fig. 1, a light source is placed at the center of the curvature of the surface to be tested, and the Ronchi grating is placed near the center of curvature between the light source and the surface. The image of the grating is superimposed on the grating itself, producing a kind of moiré pattern named Ronchigram that is grasped by the camera also at the center of the curvature. Then, the Ronchigram is transformed to the computer and changed into a matrix of gray scale by the special software. The computer will calculate the aberration according to the difference between the Ronchigram

transformed from the charge-coupled device (CCD) and the standard one. The standard Ronchigram is generated as follows.

The parabolic surface we test is just polished. Its diameter is 630 mm, the radius of the center is 1638 mm, and the F number is 1.34. The Ronchi grating is shown in Fig. 2. The diameter of the grating is 12 mm and the width of the line is 0.5 mm. The whole process of the measure can be divided into three steps as follows. First of all, the Ronchi grating should be produced. The null Ronchi grating should be a thin flake of glass. It always needs several null Ronchi gratings with different frequencies to satisfy the different error existing during the manufacturing. Usually, the bigger the error of the surface is, the lower the frequency of the grating is. The relationship between them has been introduced in previous papers[2]. To make sure that the shade of the Ronchi grating is full of the aperture

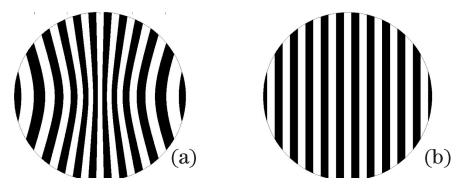Fig. 1. System of Ronchi test experiment.

Fig. 2. Ronchi grating. (a) Null grating; (b) standard grating.

of the mirror, it is advisable to add a circle as a sign outside the Ronchi grating. The grating is at the right place when the shade of the circle is of a same to the mirror under testing. Secondly, the light source should be properly selected. It should be small enough to be considered as a point while enough power should be delivered. Because the surface of the mirror is very rough and the reflection is low, the CCD cannot offer the reflection image of the grating if the light power is low. A special light source made by ourselves was used in this experiment. The power of the solid laser was almost 1 W. The light from the laser was focused into one side of the fiber, then came out from the other side which was a spherical surface to get a big F number. The third step is the experiment. We set the grating and the source at the right place, which means that the shade outside the grating is just full of the diameter of the optical surface under testing. Sometimes, in order to make sure that the camera can catch the Ronchigrams clearly, a spectroscope is used between the source and the Ronchi grating. Once the camera catches the perfect Ronchigrams, it will transform the photos to the computer.

The software for data processing has the following functions. Firstly, it can calculate the Ronchi grating and draw the null one so that the compensatory grating can be made out. At the same time, it generates an ideal Ronchigram saved in the computer. This can be the standard one if the grating is made very accurately or the error of the fabrication of grating is much smaller than that of the optical surface. Secondly, it can collect the photos transformed from the camera and save them as a matrix of gray scale. The most important function is the surface analysis. It can calculate the aberrations of the mirror according to the difference between the reflection Ronchigrams and the standard ones. The flow chart of data processing is shown in Fig. 3.

In order to improve the feasibility, four Ronchigrams of different positions were taken in the experiment. The average result of them will be compared with the result of the interferometer. If θ is the angle between the direction of the grating lines and the y axis in Fig. 2, Fig. 4 shows the detected Ronchigrams when the θ values are respectively 0°, 90°, 180°, and 270°. The Ronchigrams are curving because we used the standard Ronchi grating. A microscope lens was used to enlarge the images to about ten times in size so that they could be displayed clearly.
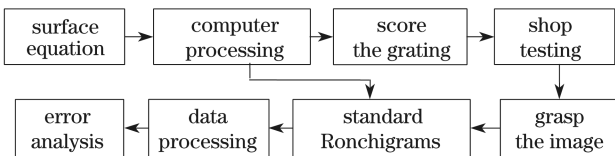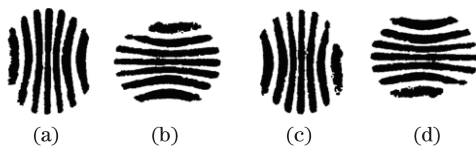
At first, they were filtrated and analyzed as the contour lines formed by the dots of the same height, just as shown in Fig. 5. Then they were further analyzed by the test software. The planar curves of the surface profile were then generated, as shown in Fig. 6 where the peak-to-valley (P-V) value of the surface can be calculated. At last, the wave front maps of the surface were rebuilt, just like those in Fig. 7.

This mirror was also tested by a ZYGO interferometer, and the result is shown in Fig. 8. The P-V value is about 0.882 wavelengths (WL) and the root-mean-square
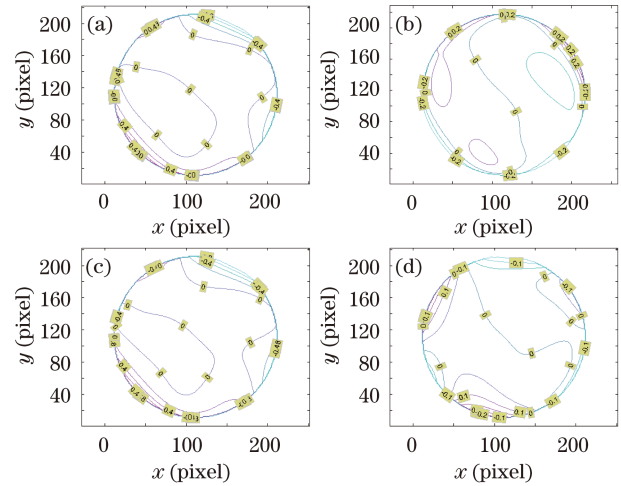

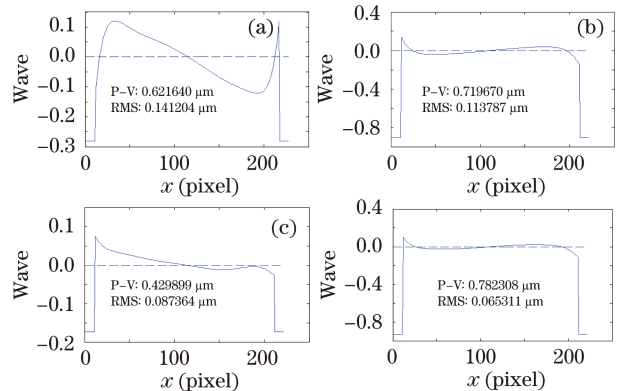Fig. 5. Contour lines of the Ronchigram test.

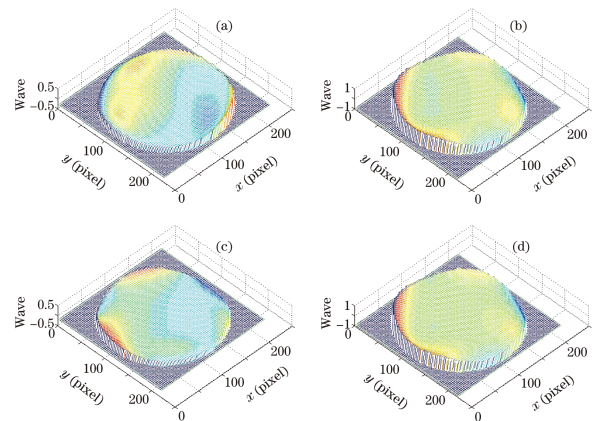Fig. 6. Planar curves of the Ronchigrams. λ=0.6328 μm.
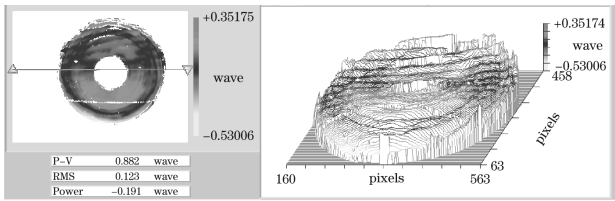

Fig. 3. Flow chart of Ronchi test.

Fig. 4. Ronchigrams taken by the CCD camera.

Fig. 7. Rebuilt maps of wave front.

Fig. 8. Result obtained with ZYGO interferometer.

Table 1. Results of Ronchi Grating Test

	(a)	(b)	(c)	(d)	Average
P-V (WL)	0.983	1.138	0.680	1.236	1.009
RMS (WL)	0.223	0.179	0.137	0.103	0.161

(RMS) value is about 0.123 WL. As shown in Table 1, the average P-V value for the four Ronchigrams is about 1.009 WL and the average RMS value is about 0.161 WL. The difference between the P-V values is about 1/8 WL. The error of the RMS values is less than 1/25 WL. There would be some error in the grating flat. What is more, there is a hole in the middle of the parabolic surface while it is not disposed by the software.

This system of Ronchi grating test is very simple. It realizes the testing for the parabolic surface in a quantitative way. The analysis software and test method have established a good foundation for the quantitative measurement of the big error of large-aperture aspheric surfaces for the next generation telescope with the Ronchi grating method[10]. An assistant method is also given for the new testing methods, such as the computer-generated hologram (CGH)[11]. the infrared interferometry[12,13], and other methods[14−16], to test the surfaces.

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