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The Special Use of Ghost Image in Null Testing The Large Aperture Aspherical Mirrors

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ABSTRACT

Nowadays, more and more large aperture aspherical mirrors are wildly used in the optical system, many of them with fast ratio and large asphericity. When manufacturing these aspherical mirrors, we can only choose the null testing method, so the null compensators for these surfaces are required. For reduce the residual error and easy to process, the compensator used in the null testing usually accompany by the existence of the ghost image, customarily the ghost image is considered to be useless. In this research we analyze the relationship between the ghost image and the optical axis of the system by study the optical properties of the null testing, find out that adjusting the misalignment of the optical axis not only should eliminate the coma term, but also should rectify the field, the center field also the correct optical axis means that the ghost image should be at the center of the interference image. Then we discuss the auxiliary role of the ghost image in the measurement and adjustment, and apply that to the experiment: null testing a 1.6 meter aspherical mirror by the compensator, which has obvious ghost image in the interferogram, by combined adjusting the compensator and the interferometer during the operation we finally get the optimized method. The result shows that according to the state of the ghost image and with the help of the scientific adjusting method, we can quickly and accurately realize the correction of the optical axis when null testing the aspherical surface by the null compensator, that has important scientific guiding significance for modern manufacturing and testing of the large aperture aspherical mirrors.

Keywords: aspherical mirror, null testing, compensator, ghost image, adjusting

1. INTRODUCTION

With the progress of optical technique, more and more large aperture aspherical mirrors are wildly used in astronomical telescopes(such as the primary mirror of VLT and MMT), space cameras and other optical systems, and how to process these large aperture mirrors scientifically is a key problem at present[1,2]. Scientific processing is inseparable from high precision testing, nowadays, the testing method of aspherical mirrors mainly includes null stigmatic testing and null compensation testing[3].

The null stigmatic testing is tested by a couple of stigmatic points of some aspheric surfaces, the testing is simple, intuitive and high precision, for example, the auto collimate testing of the paraboloid primary mirror by a flat, the Hindle testing of hyperboloid secondary mirror by a spherical standard mirror[4], etc. Generally, this method requires a standard mirror with larger aperture than the mirror been tested, but it is difficult to match the appropriate standard mirror for the aspherical mirror with aperture larger than 1 meter, also the oblate spheroid surface and the high order aspheric surface can not be tested by this method.

The null compensation testing test the aspheric surface by the compensator[5]. The standard wave emitted from the interferometer match the aspheric surface as much as possible after passing through the compensator, it is considered to be consistent of them if the residual error is with in an acceptable quantity through design[6]. This method is almost applicable to all concave aspherical mirrors, and the cost is not high, also, it is not limited by the aperture and the relative aperture of the mirror been tested. Therefore, it is wildly used in the processing and testing of large aperture aspherical mirrors in the world.

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In the null compensation testing, the imaging quality of the compensator is directly related to the final processing and testing. Commonly the compensator design needs to meet two conditions: First, the residual error should as small as possible; Second, avoid the ghost image as much as possible or the ghost image is not in the imaging aperture area[5,7].

2. THE CAUSES AND FUNCTIONS OF GHOST IMAGE

The ghost image is the image reflected on the CCD of the interferometer by one or more surfaces of the compensator lens group. There are many factors that influence the size and position of the ghost image on the interferogram, such as : the distance from the focus of the compensator to the center of a sphere which forming the ghost image, one surface of a lens is tangent to the wave passing through its front elements in a ring[7,8]. When designing the compensator, it is necessary to not only minimize the residual error, but also comprehensively consider the difficulty of the lens processing, it is approved as long as the ghost image is not within the interference aperture of the actual imaging. So the null compensation testing is mostly accompanied by the ghost image.

Normally the ghost image is thought to be useless. However, the null compensation testing have differences with the null stigmatic testing. In null stigmatic testing, complete correction of optical axis can be achieved by adjusting two mirrors to eliminate the coma[3]. But in the null compensation testing, we adjust the compensator to eliminate coma can not guarantee the complete correction of the optical axis, because in this state, it may be the imaging with field. For different compensators, the field will introduce different influence, such as: the middle frequency error astigmatism or the high frequency error asymmetry, that will cause misguiding to the subsequent processing. Figure 1 shows the null compensation testing results of a large aperture aspherical mirror by adjusting the compensator to different fields, the coma aberration is minimized during the adjusting each time and only the high frequency error is retained in the analysis, the lower left is the result of the central field, it can be seen that the results of other fields are superimposed with varying degrees of high frequency asymmetric, for the primary ray does not coincide with the rotational symmetry axis of the aspheric surface.

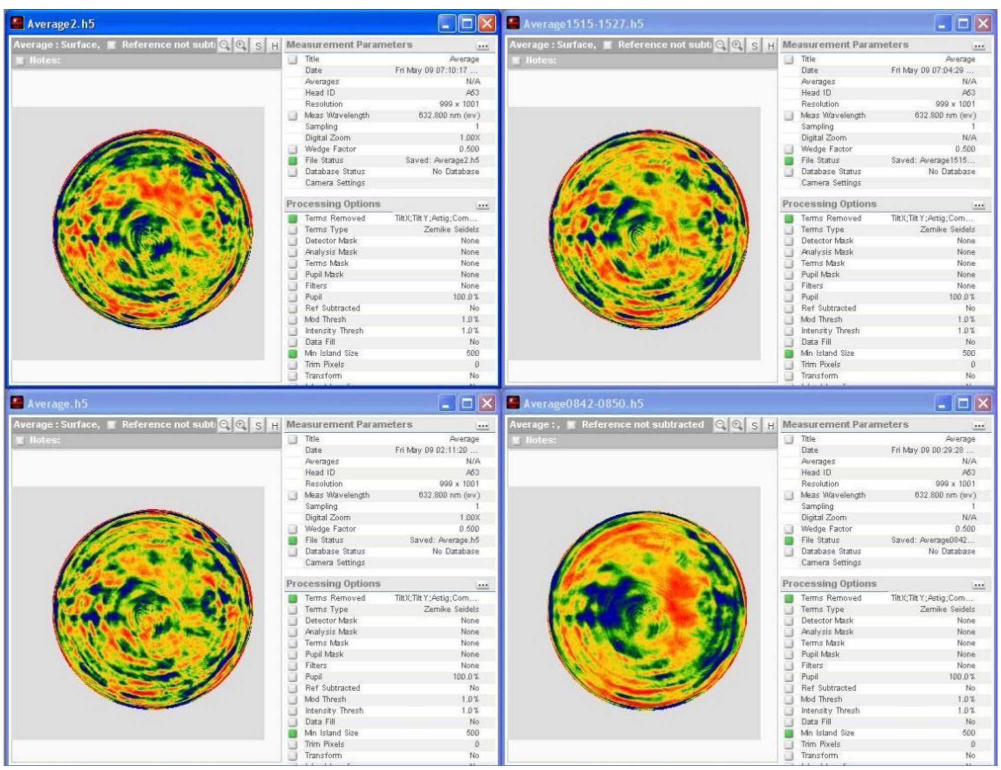


Figure 1. The results of null compensation testing in different fields for the same aspherical mirror.

The optical axis of the compensator is consistent with the rotational symmetry axis of the aspherical mirror in the design stage, also the optical axis of the compensator is consistent with the optical axis of each side of the lens after the centering adjustment. If the primary ray emitted from the interferometer that participate in the imaging is coincide with the rotational symmetry axis of the aspherical mirror, it must coincide with the rotational symmetry axis of each lens of the compensator. This means that the ghost image of the compensator must be in the center of the interferogram when the optical axis is completely consistent. According to this characteristic we can realize the complete correction of the optical axis.

3. ADJUST OPTICAL AXIS QUICKLY AND ACCURATELY BY THE GHOST IMAGE

Different compensators show different shapes and numbers of ghost images on the interferogram. For null compensation testing of the axis symmetric aspheric surface, the correction of the optical axis can be realized by judging the position of the ghost image and adjusting it to the center of the interferogram. Nowadays, the adjustment dimension of support mechanism for online testing and processing of the large aperture aspherical mirror is limited due to its heavy weight, therefore, the optical adjustment is generally realized by moving the compensator and the interferometer.

The perfect optical adjustment not only needs to eliminate the coma, as straighten the interference fringes, but also the field is corrected. The two are complex processes, so the joint adjustment of compensator and interferometer are needed. The bias of the field reflects the degree of the focus deviate from the rotation symmetry axis, the focus needs to move toward to the optical axis, that is, the interferometer and compensator need to move toward to the optical axis. In actual testing, we do not know the deviation direction of the field, so how to scientifically adjust according to the ghost image is a key problem. On the interferogram, the position of ghost image reflects the angle and degree of the field deviation, and its position can be changed by moving either the compensator or interferometer, but only by adjusting the interferometer first to make the ghost image move to the center of the interferogram is the correct direction of the field adjustment.

We have summed up a set of rapid adjusting method based on years of practical experience, that is: First, build the testing light path to coincide the image point and the focus, control the mirror spacing to minimize the spherical aberration; Second, eliminate the coma by moving the adjusting mechanism of the compensator in this state; Third, find out the ghost image on the interferogram, move the interferometer to make the ghost image move 2/3 deviation to the center of the interferogram, and then move the compensator to make the interference fringes obvious, at this time the new coma aberration will be generated, continue adjusting the compensator to eliminate coma; Forth, repeat these steps until the ghost image is in the center of the interferogram and the coma is eliminated, final fine tuning until the ghost image and the interferogram are completely symmetrical.

4. EXPERIMENT

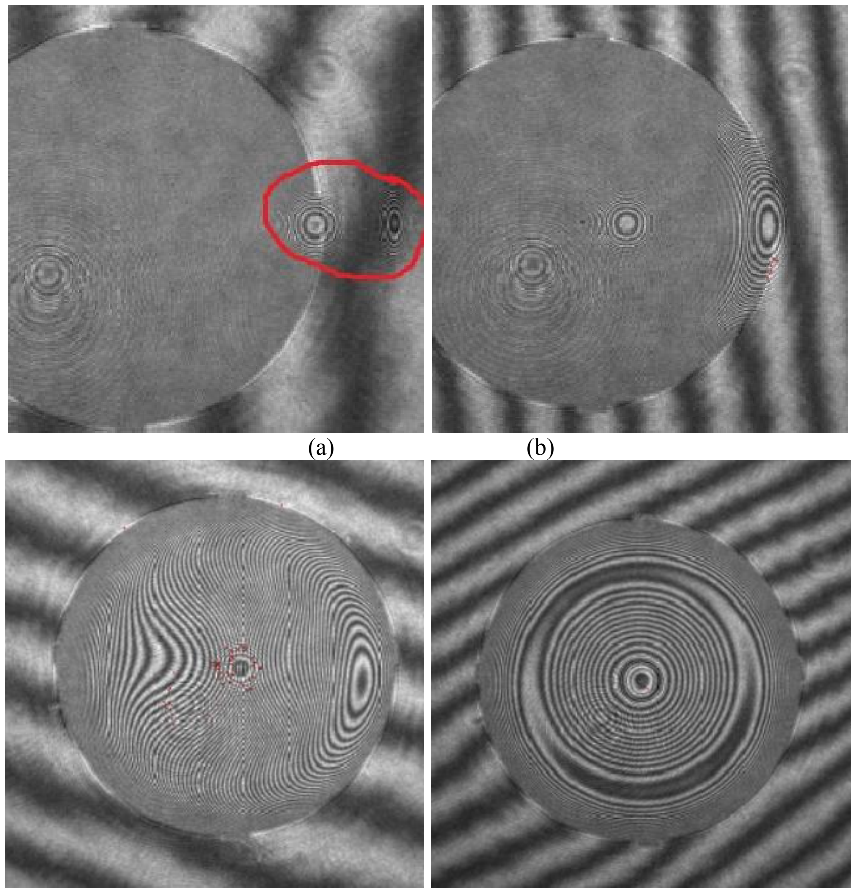
We have applied this method to machining and testing of an aspherical mirror with 1.6 meter diameter, 4 meter vertex radius and a middle hole. The mirror is machined based on the null compensation testing for its large aperture and heavy weight, and the structure of the compensator is the two-piece lens. In order to control the residual error, avoid the ghost image and match the F number of the camera lens, the edge of one lens needs to be as thin as possible. After combined consideration from the perspective of the difficulty of compensator manufacturing and the final imaging quality, the compensator is considered to meet the use condition while the ghost image is not in the effective imaging area, therefore, there are two obvious ghost images in the centre no data area of the interferogram when the axis is in the central field.

First we find out the image point and control the mirror spacing, then adjust the compensator to eliminate coma, there are two separate ghost images on the right of the central hole when the interference fringes are straight, the ghost images are not obvious due to the large field deviation, that are located in the red mark, as the Figure 2(a) shows.

Secondly we move the interferometer to make the ghost images move toward to the central region, and the compensator is adjusted to eliminate coma to make the fringes become straight again. At this point the two ghost images have entered the central no data area, as Figure 2(b) shows.

Continue moving the interferometer and adjusting the compensator to eliminate the coma, the two ghost images are obvious on the interferogram for the optical axis of the compensator is close to the rotational symmetry axis of the aspheric surface, the axis of the surfaces that forming the ghost images also approach the rotational symmetry axis of the aspheric surface, as the Figure 2(c) shows.

Keep adjusting so that both ghost images are in the center of the interferogram, fine tuning until a concentric ring is formed and eliminate the coma, at this time, the primary ray is in the center field. We can see that one of the ghost image is a ring band image, this indicating a ring band of one surface of the lens is tangent to the interference wave passing through its former surfaces, as the Figure 2(d) shows.



(a) (b)

(c) (d)

Figure 2. The schematic diagram of correcting the optical axis based on the ghost image.

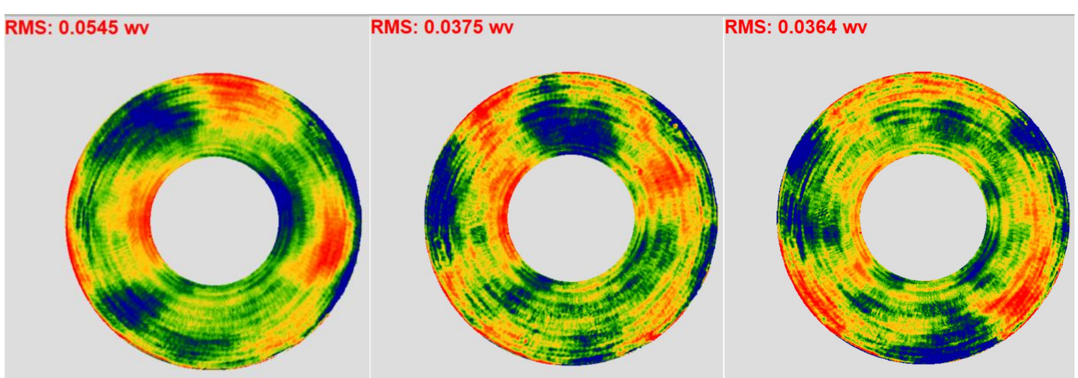


Figure 3. The testing results for the ghost image in valid data area, edge of invalid data area and near center.

The Figure 3 shows the testing results with the ghost image in different locations, respectively corresponding to (a), (b) and (c) states of the Figure 2. The asymmetry aberration is obvious in the testing result when the deviation of the ghost image is large. The asymmetry become attenuation while reducing the deviation of the ghost image. When the ghost image is near the center the asymmetry is almost invisible, it indicate that the deviation of field in a certain range will not affect the testing result. Therefore, in the aspherical mirror processing, the ghost image is generally adjusted to the state as Figure 2(c), the field is considered to be corrected.

5. CONCLUSIONS

By analyzing the imaging characteristics of the null compensation testing, we find the special correspondence between the ghost image and the field. According to reasonable judgment of the state of the ghost image and combined with scientific means of assembly and adjustment, we can achieve the thorough optical axis correction, this research has important scientific guiding significance for processing and testing of the large aperture aspherical mirrors.

Acknowledgments

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