The Technique of Aligning the Optical Axis of An Off-axis Parabolic Mirror by Three Rotational Parallel Laser Beams

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ABSTRACT

In this paper we demonstrate a new technique in which we use the three parallel laser beams alignment device and the CCD camera to rapidly and accurately align the optical axis of an off-axis parabolic (OAP) mirror. In this method the optical axis of an OAP mirror is made parallel to the "three incident laser beams" in the plane of incidence, by checking direction of these three reflected laser beams and changing the height and orientation of the OAP mirror. This fast aligning method for finding the optical axis of an OAP mirror can measure the Slant Focal Length deviation to an accuracy of 0.2％ .

Keywords: alignment, off-axis parabolic mirror, Slant Focal Length (SFL)

三束旋轉平行雷射光之離軸拋物面鏡光軸正線技術

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摘 要

在本篇論文，說明一項新的針對離軸拋物面鏡的正線技術，其運用三束平行雷射光及 CCD 照相機，對離軸拋物面鏡進行快速並準確的正線；此方法中，經由驗證反射之雷射光方向以調整離軸拋物面鏡的位置及高度，使離軸拋物面鏡的光軸與入射之三束雷射光相互平行，此快速找尋離軸拋物面鏡光軸的方法，可用來量測傾斜焦距，其精度可達 0.2 ％。

關鍵詞：正線，離軸拋物面鏡，傾斜焦距

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I. INTRODUCTION

The OAP mirrors offer the advantage of an unobstructed aperture and minimize system size, giving access to evaluate the performance of optical system testing. The OAP mirrors shown in Fig.1 are especially suitable for broadband and multiple wavelength applications due to their completely achromatic characteristics. When collimated light is incident parallel to the optical axis, a concave parabolic surface focuses the light into an excellent corrected point on the optical axis. The OAP mirror is a segment cut out of a large parent parabola. As the OAP mirror becomes more complex, precise optical axis alignment becomes more challenging. Mirror manufacture and alignment usually employ a sophisticated and expensive interferometer, such as laser unequal path interferometer, autocollimator by knife edge method, to measure the OAP mirror's characteristics, such as focal length, off-axis distance, and optical axis [1]. Aligning optical axis of OAP mirror not only takes much of time, but also these methods cannot be used in UV and IR region.

Because of the above problems, we establish a new optical technique to align the optical axis of an OAP mirror using the three parallel laser beams and CCD camera. There are some advantages in this method: (1)It is a rapid and simple alignment method. (2) It simplifies the electro-optic system and lowers the cost. (3) The different wavelengths of laser diodes are used to enable getting wider spectral range of optical system alignment. (4)Because the rotation mechanism of the three parallel laser beams arrangement, it adjusts the OAP mirror with more freedoms of orientation. This is a fast method for aligning the optical axis of an OAP mirror and can measure the SFL deviation to accuracy of 0.5%.

II.BASIC PRINCIPLE

The structure of the OAP mirror is shown in Fig.1. The OAP mirror is specified as following. Parent focal length **(PFL)** is the focal length of the parent parabola. It defines the shape of the surface as Z=ZR^2/(4*PFL), where ZR is radial distance from vertex and Z is sagittal depth of the surface. Slant Focal Length **(SFL)** is the distance between OAP mirror's mechanical center and parabola focus. Optical centerline is the line parallel to parent parabola optical axis and coming through the mechanical center of OAP. Before proceeding to measure the SFL and ZR of an OAP mirror, it is necessary to align it correctly.

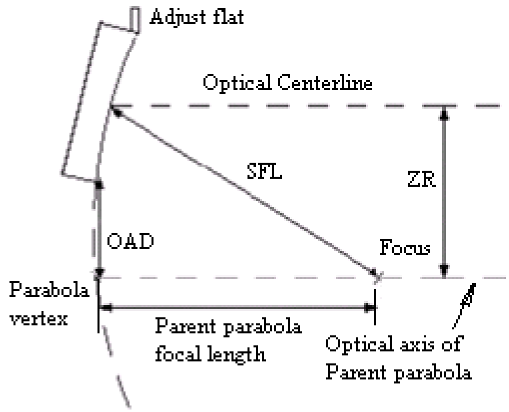

Fig.1 The off-axis parabolic mirror

An OAP mirror is not aligned accurately enough due to the aberrations of the alignment reflected beam, the depth of focus and the size of the focal spot. In an ideal optical system, all rays of light from a point in the object plane would converge to the same point in the image plane, forming a clear image. The influences which cause different rays to converge to different points are called aberrations. However, the parabola is not completely free of aberration; it has both coma and astigmatism. When the stop is put at the center of the curvature of the corresponding spherical mirror, i.e., it has the same focal length as the parabolic mirror in the paraxial region. The stop position is at the placed of twice of the focal length. This can be proved by inserting the necessary parameters to the lens maker equation [2]. It shows

$$\frac{1}{f} = (n-1)(C_1 - C_2) \quad (1)$$

And inserting the mirror's parameters, we have

$$n = -1, c_1 = 0, C_2 = \frac{1}{R}$$
$$R = 2f \quad (2)$$

Thus it meets the Schmidt camera' s condition. Then the coma and astigmatism are minimized and the image is located on a spherical surface of radius f [3][4].

Another factor of optical alignment is depth of focus (DOF). The concept of depth of focus rests on the assumption that for a given optical system, there exists a blur (due to defocusing) of small enough size such that it will not adversely affect the performance of the system. The depth of focus, shown in Fig.2, is the amount by which the image may be shifted longitudinally (δ) with respect to the image plane and which will introduce no
more than the acceptable blur.

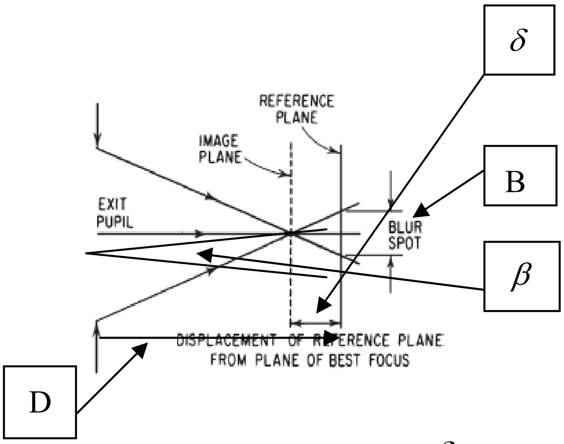

Fig.2 Depth of focus δ

In Fig.3, D is the distance from exit pupil to the reference plane, and B is the diameter of the blur spot or linear blur. Then it shows

$$\beta = \frac{B}{D} \tag{3}$$

where β is called angular blur.

Apparently, if reference plane is sit on the image plane, then $B = 0$, and $\beta = 0$.

Ⅲ.THE OPTICAL ALIGNMENT SYSTEM

We develop a specific technique to align the optical axis of the OAP mirror. This alignment system can be applied to UV~IR regions with the different wavelengths of alignment laser diode. The optical alignment system in Fig.3 is composed of: (1) the OAP mirror, (2) alignment device, (3) rotational mechanism shown in Fig.4, (4) pinhole and (5) optical table and mount. These are described as followings.

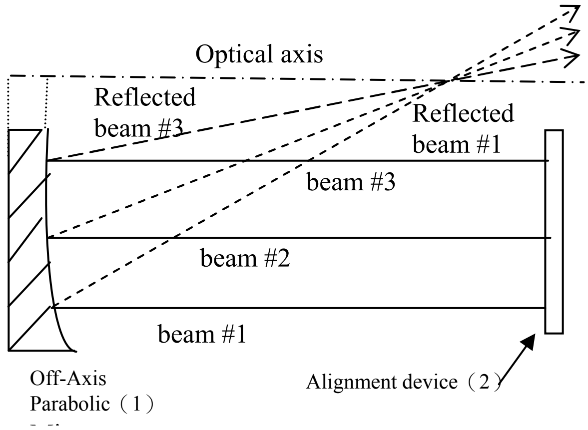

Fig.3 The optical alignment system

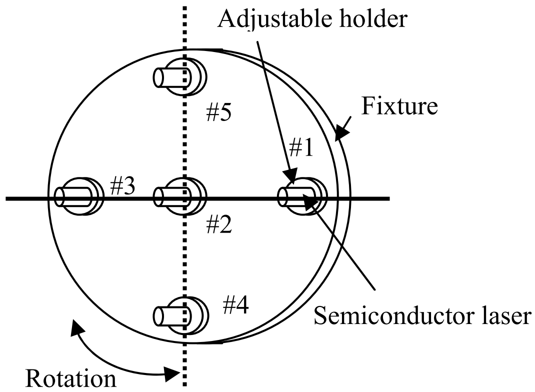

Fig.4 The rotational mechanism

3.1 OAP mirror

The OAP mirror shown in Fig.5 is the main part of the alignment system. The target of the alignment is to adjust the 3-D position of the OAP for various optical testing.

Fig.5 The OAP mirror under test

3.2 Alignment device

The alignment device includes three parallel semiconductor lasers, the rotation mechanism, precise adjustable holder and the fixture shown in Fig.6.

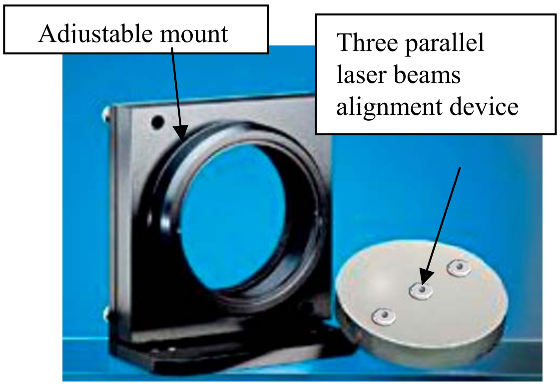

Fig.6 The three laser beam alignment system

The semiconductor laser beams on the fixture are made parallel each other with precise adjustable holder and perpendicular to the surface fixture. An adjustable holder for mounting and orienting the semiconductor laser is set by a removable retaining laser within a mount of ring.

3.3 Rotation mechanism

The rotation mechanism adjusts the initially horizontal laser beams to vertical or any direction as shown in Fig.4. For example, the three laser beams lines horizontally , i.e., ＃1、＃2、and ＃3 from right to left in Fig.4. When it clockwise rotates 90 degree, it shows ＃4、＃2、and ＃5 from down to up in Fig.4. In the rotation mechanism, it can rotate any degree to adjust the OAP mirror orientation we want.

3.4 Pinhole

The pinhole which has a size of 30μm. When the diffraction pattern of concentric circular rings was appeared, the laser beam passes through the pinhole accurately. The diffraction patterns formed by a pinhole consist of a central bright spot surrounded by a series of bright and dark rings. We can describe the pattern in terms of the angle θ, representing the radius angle of each ring. If the aperture diameter is D (mm) and the wavelength is λ (mm), the radius angle θ of the first dark ring is given by $\sin\theta=1.22(\lambda/D)$. With this diffraction technique, the pinhole is used to precise align laser beam parallel to the OAP of the alignment system.

3.5 Optical table and mount

The optical table offers standard damping and high stiffness, making a cost-effective choice for general optical testing. The optical mount is used to hold optical element precisely for the optical alignment process.

Ⅳ.EXPERIMENT AND RESULTS

The conditions and specifications used for the experiment are listed in Table 1.

Table 1.The experiment conditions

Off-axis parabolic mirror	
Slant EFL	457mm
Diameter	24.5mm
ZR	127mm
Max. thickness	56.13mm
Min. thickness	6.35mm
Laser ranger	
Range of measurement	from0.02 up to 60m
Measuring accuracy	+-1mm
Time for a measurement	2.5~10 sec.
Light source	Red laser Diode
Semiconductor laser of alignment device	
Wavelength (λ_p)	635nm
output power	3mW
Beam Divergence	＜2mrad
Operating Current	25mA
Beam diameter	3.3mm
CCD camera	
Resolution	752x582
Spectral range	350~1100nm

Experiment procedures are divided into two parts as followings:

4.1 Pre-Experiment

Pre-Experiment of three semiconductor laser beams fine adjustment:

(1) The fixture of alignment device is vertically (perpendicular) put on the optical table such that laser beam #2 is nearly parallel to the surface of the optical table.

(2) The precise adjustable holder is fine adjusted to make the laser beam #2 parallel to the surface of the optical table. To check the parallelism, we use the pinhole which moves on the optical table from position 1 to position 2

(about 50 cm distance, for SFL=457mm) with a fixed height and has observed the pinhole diffraction pattern that the laser beam passes through the pinhole accurately.

(3) The plane mirror is put on the optical table at 3 meter distance from the alignment device. To adjust the plane mirror, the reflected beam #2 is made parallel to the optical table. To check the plane mirror perpendicular to the optical table, we use a piece of paper to chop reflected beam #2, and we can easily see how well the reflected beam #2 overlap at the output hole of laser beam #2.

(4) Step (2) is repeated until the beam #4, #5, #3 and beam #1 is parallel to the surface of the optical table.

(5) Finally, we use a piece of paper to chop reflected beam#4, #5, #3 and #1, and we can easily see how well the reflected beam #4, #5, #3 and #1 overlap at the output hole of laser beam #4, #5, #3 and #1, respectively.

4.2 Experiment with OAP mirror (refer to #1)

(1) An OAP mirror is adjusted at first so that its optical axis is in the incident plane made by three horizontal parallel incident laser beams.

(2) The OAP mirror is adjusted again so that the three horizontal parallel reflected beams come to a focus at the same point, i.e., the saggital optical plane of OPA is found.

(3) Three vertical parallel incident beams are parallel to optical axis by adjusting the OAP mirror and the three vertical reflected beams also come to a focus at the same point obtained in (1), i.e., the tangential optical plane of OAP is found.

(4) Capture the focus pattern at the reference plane (ref. Fig.2) with the CCD camera. The reference plane is moved from left to right of the image plane to see if it fits Eq.(3).

(5) The SFL of an OAP mirror and the off-axis distance are measured by laser ranger.

We measure focus pattern curve that the focus pattern size versus the position of the reference plane. Focus patterns sizes of reference plane are captured with CCD camera is shown in Fig.7.

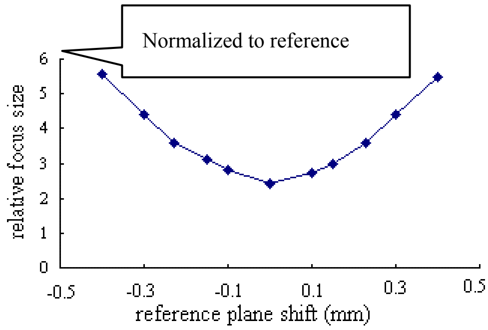

Fig.7 Focus size when reference plane shifted

The eleven focus patterns from left of the image plane to right of it are measured. The 30% of the center of the maximum intensity is defined as the focus pattern of the OAP mirror. The alignment of the OAP is finished when getting relative minimum focus size. This validates the experimental system.

This alignment experiment repeatedly does twenty times. The test results show that the average SLF is 458.6 mm and the standard deviation is 0.755mm or 0.2% shown in Table 2.

Table 2. SLF of OAP mirror

458.1	457.5	458.3	458.3
458.2	458.3	459.4	458.3
458.5	458.5	459.3	459.6
458.6	459.3	459.7	459.2
456.5	458.6	459.1	458.6
Average		458.6 mm	
Standard deviation		0.755 mm	

V. CONCLUSION

We have effectively presented the use of the three parallel laser beams alignment device with CCD camera to align the optical axis of OAP mirror. This system is designed for the optical engineers needing fundamental electro-optical practical techniques to achieve alignment of the off-axis optical systems. The advantages of the off-axis alignment techniques are: (1) it is simple to operate; (2) it simplifies the optical test system and lowers the cost [5], and (3) it is less expensive to maintain the equipments. Above all, it can be summarized in Table.3.

Table 3. The advantages of ThreeRotational Parallel Beams Method”

Method / Item	Traditional Method (Autocollimator)	Three Parallel Beams Method
Cost	High(NT150,000.00)	Low(NT15,000.00)
Profession technician	High	Medium
Adjust time	Long (one day)	Short (half day)
Commercialize	Difficult	Easy
Extendibility	Slow(visible band)	High(UV~IR band)
Alignment area	Depend on exit pupil	Large area

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