Testing Method of Off-axis Parabolic Cylinder Mirror for FIMS

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ABSTRACT

Far-ultraviolet IMaging Spectrograph (FIMS) is a far ultraviolet diffuse imaging spectrometer which will be launched in 2002 as the main payload of KAISTSAT-4. We have designed the optics for observing diffuse emission sources by employing an off-axis parabolic cylinder mirror in front of a slit which guides lights to a diffraction grating. The reflective diffraction grating is an ellipse of rotation providing angular resolution. We describe our plan to measure the off-axis parabolic mirror and our initial experiments to establish the measurement technique. To assist manufacture of the off-axis parabolic cylinder, a cylindrical wavefront generated using computer generated hologram(CGH) will be used during the polishing to check errors in surface profile using the Fizeau interferometer.

Keywords: manufacturing, parabolic cylinder mirror, computer generated hologram, far ultraviolet, spectrograph

1. INTRODUCTION

Space observation in far ultraviolet region provide important information about various physical processes occurring in the interstellar media. FIMS (Far-ultraviolet IMaging Spectrograph) is a diffuse far ultraviolet(long wavelength band: 900–1150Å, short wavelength band: 1335–1750Å) imaging spectrometer, designed to trace the balance and flow of energy through Galactic plasma. To obtain a large grasp factor within the small payload size allowed within a micro satellite, a parabolic cylinder mirror is used. Manufacturing and testing of the off-axis parabolic cylinder mirror is a critical issue in development of the FIMS system. We have explored interferometric testing of the off-axis parabolic mirror figure.

We describe preliminary testing experiments of an standard on-axis cylinder mirror using a CGH null or an optical fiber as a reference surface. We also describe the optical setup that will allow testing of the off-axis parabolic cylinder mirror so that we may use fringe analysis during the polishing to meet the optical specifications. Our result shows that the procedure of using CGH null is applicable to manufacturing the off-axis parabolic cylinder mirror.

2. FIMS OPTICAL SYSTEM

Instead of using an on-axis mirror system as a telescope, off-axis parabolic cylinder mirror is proposed as a candidate and revealed suitable for obtaining image as well as spectrum. The schematic diagram of the FIMS optical system is represented in figure 1. As shown in the figure, parabolic cylinder mirror focuses a collimated beam along one axis. The elliptical grating focuses along the other axis while dispersing light to spectrum. The optical system is able to obtain angular image in along-slit-direction and to scan the sky across along-slit-direction.

Based on the conceptual design, we optimized the optical parameters to satisfy our scientific requirements. The optical performance of FIMS was considered geometrically and radiometrically. The geometric performance was analyzed by investigating the point spread function and resolution. The calculation was done both using commercial ray-trace code and by solving equations of wavefront aberration. The results are compared and found to be essentially the same. Through an optimizing process, we established the specifications of the optical system and estimated the tolerance limit of manufacturing. We estimated that angular resolution varies within $5' \sim 10'$ while spectral resolution

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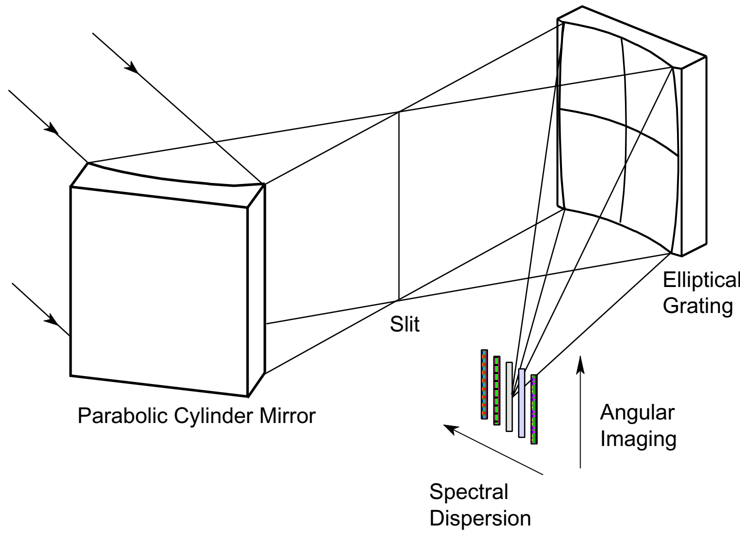

Figure 1. Schematic diagram which represents operation principle of FIMS

varies within $2 \sim 5$Å, according to the wavelength and field angle. The resulting specifications are listed in table 1. The off-axis parabolic cylinder mirror has a focal length of 125 mm and f/# of 2.2.

Radiometric performance was characterized by effective grasp which relates the intensity of emission sources and detected signal. The value was derived by multiplying geometric area, reflectivity of the optical components, quantum efficiency of the MCP, and solid angle where the detector sees. Based on the effective grasp value of $\sim 1.0 \times 10^{-4}\mathrm{cm}^2\mathrm{sr}$, we have estimated the detection possibility of the diffuse emission and compared with the previous observations. It is revealed that one-year survey can discriminate how the galactic emission sources are distributed.

The mechanical design of the system is depicted in figure 2. At the focal plane, an MCP is employed as a detector and slit assembly divide grating room from imaging part. Right in front of the slit, a shutter assembly adjust the effective area to observe bright sources such as aurora and geo-coronal emissions.

3. INTERFEROMETRIC TEST OF A CYLINDRICAL SURFACE

There are several methods to interferometrically test cylindrical optics. A simple way is to use a plane reflection at the focal line. In this case, the light does not return along the same path. Consequently, the fringe pattern contains information only about errors that are symmetrical about the center plane. The interpretation is less than straightforward. An alternative plan is to use an optical fiber as a reference surface(Geary[1] , 1995) instead of using a mirror at the focal line. We performed a preliminary experiment on a standard on-axis cylinder mirror using an Al-coated optical fiber, but found the setup so sensitive to the position and tilt of the optical fiber that we failed to obtain a stable interference pattern. We found it difficult to obtain the tension required to keep the optical fiber straight.

Recently, testing aspheric surfaces(Arnold et al.[2] , 1995) with commercially available CGH's has become common. We used a CGH cylinder null 'H45F1.5C'(Diffraction International[3]) to experiment with testing a standard on-axis cylindrical mirror. The CGH diffracts a collimated beam from a Feazeu type interferometer to a f/1.5 cylindrical beam with quality of $\sim \lambda/10$.

3.1. Manufacturing process of parabolic cylinder mirror

The mirror profile can be described by simple 1 dimensional quadratic function, $y = ax^2$, where the coefficient a is determined by the focal length. Since we use a 90° off-axis configuration, the coordinate system is rotated by 45°. Because the parabolic cylinder is not symmetric about the optical axis, it is impossible to shape the substrate using turning-based machines such as diamond turning method. Instead, we will use a computer controlled CNC machine

Table 1. FIMS optical specifications

Instrument Parameters	Short Wavelength Band	Long Wavelength Band
Band Pass	900–1150 Å	1335–1750 Å
Field of View	[a] $4° \times 5'$	$8° \times 5'$
Mirror Figure	Off-axis Parabolic Cylinder	Off-axis Parabolic Cylinder
Mirror Focal Length	125±2 mm (F/2.2)	125±2 mm (F/2.2)
Off-axis angle θ	90±1.5°	90±1.5°
Mirror Substrate Size	50 × 93.35 × 17.5 mm	50 × 93.35 × 17.5 mm
Mirror Figure Quality	0.8 λ(P-V) per cm 633 nm	0.8 λ(P-V) per cm 633 nm
Surface Roughness	25 Å	25 Å
Slit Height	2.75 cm	2.75 cm
Slit Width	150 μm	150 μm
Grating Figure	Ellipse of Rotation	Ellipse of Rotation
Detector Size	2.5×2.5 cm^2	2.5×2.5 cm^2
Detector Pixels	512×512	512×512
Mirror Coating	B_4C	MgF_2
Grating Coating	B_4C	MgF_2
Photocathode	KBr	CsI + Grid
Fixed Filter	MgF_2	CaF_2
Effective Grasp	0.6×10^{-4} cm^{2}sr	1.25×10^{-4} cm^{2}sr

[a] $4° \times 5'$ for background observation

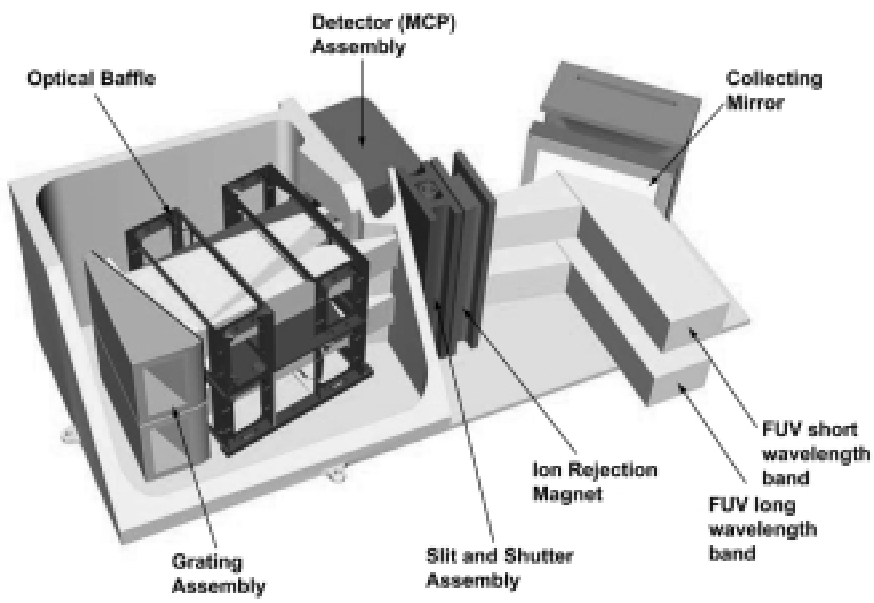

Figure 2. Three dimensional schematic diagram which represents the mechanical design of the FIMS system

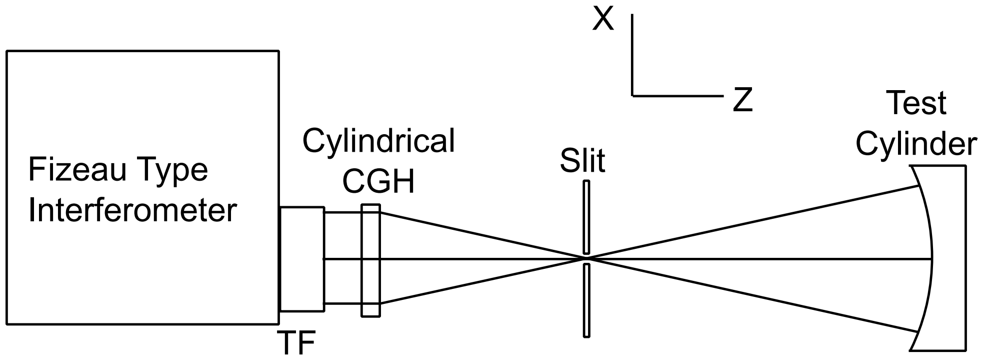

Figure 3. The optical setup for measuring the standard on-axis parabolic mirror using the cylindrical CGH

in the process of substrate shaping and grinding. The precision of the grinding process is under 4μm. The profile error will be measured by a contact-type 3 dimensional measurement system. After measuring the profile at 10 by 10 points throughout the substrate, grinding by hand will be iterated until the error decreases to under $\sim$ 1μm. For errors less than 1 μm, interferometric testing will substitute for contact-type measurement to further guide the polishing process.

3.2. Test of usual cylinder mirror Using CGH

Our CGH null diffracts a collimated laser beam to generate a cylindrical reference beam of f/1.5. Because of the nature of diffraction patterns, the CGH generates beams of other orders. The CGH is designed to use order +1 or -1. One is corresponding to converging beam and the other corresponding to diverging beam. A schematic diagram which represents the method of using the CGH in testing cylinder surface is shown in figure 3. A slit at the CGH focal line blocks the diverging beam from the CGH.

At the align mode of a Fizeau-Type interferometer, a cylindrical CGH causes 3 bright spots to appear on the screen. The spot at one side corresponds to the converging beam that can be identified by observing interference pattern after locating a reflection flat at the position of the slit. As shown in figure 4, the converging beam(figure 4(a)) and the diverging beam(figure 4(b)) form different interference patterns. After tilting the CGH mount to place the converging beam at the center, we performed a measurements a 125 mm radius, the same as focal length of FIMS mirror, as depicted in figure 3.

Interference patterns of the test cylindrical mirror are shown in figure 5. Figure 5(a) is the interference pattern when the mirror is adjusted to minimize fringes. Considering the geometry of the test setup, one fringe correspond to $\lambda/2$ on the test surface. This measurement of the surface profile shows the test mirror has about 1 λ P-V error in profile. From the best focal position, the interference pattern is monitored while defocusing and tilting the test mirror. Figure 5(b) shows the change of the pattern as the mirror is translated along the z-axis(optical axis): the fringes in the left and right sides increases. The pattern of (c) and (d) are the changes of the pattern when the mirror is tilted about the x and y axis respectively. In case of tilting about the x axis, fringes appear as horizontal lines and number of fringes increases. Fringes appear as vertical lines if the mirror is tilted about the y axis.

3.3. Using a CGH for off-axis parabolic cylinder mirror testing

Parabolic surfaces are optically useful in that collimated beam normally incident on the surface converges to a perfect focus regardless of the position where the lights are reflected. The collecting mirror in FIMS optical system utilizes the characteristics of the parabolic surface and uses 90° off-axis parabolic surface, so its testing setup must be different from the case of a usual cylinder surface.

The test can executed in two steps as depicted in figure 6. The first step is to adjust reflection flat which should be aligned 90° tilted from a reference beam to fix at proper position and angle. The procedure is represented in figure 6(a). To adjust the reference mirror, we employ a cube beam-splitter which has all the reference surfaces necessary to adjust the reference mirror in proper position using align mode of the interferometer. And then, the surface error

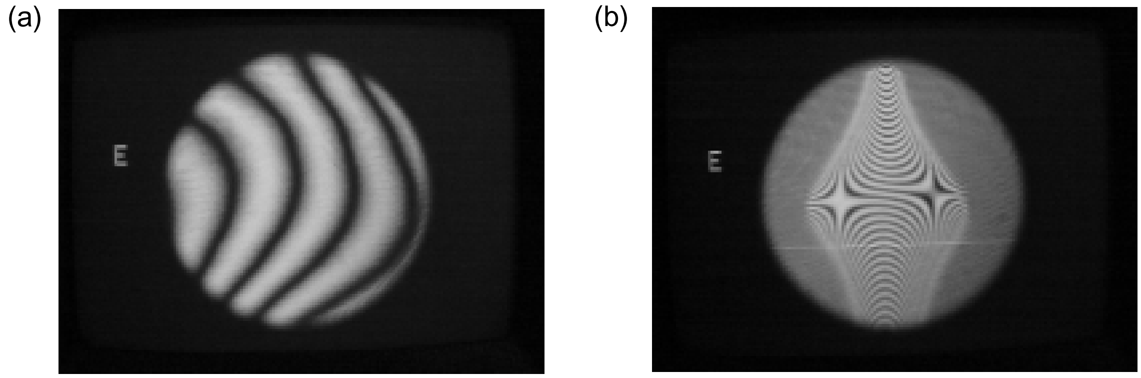

Figure 4. Interference pattern when a flat mirror is located at the focal line of the CGH. The converging beam(a) and the diverging beam(b) generate different interference patters

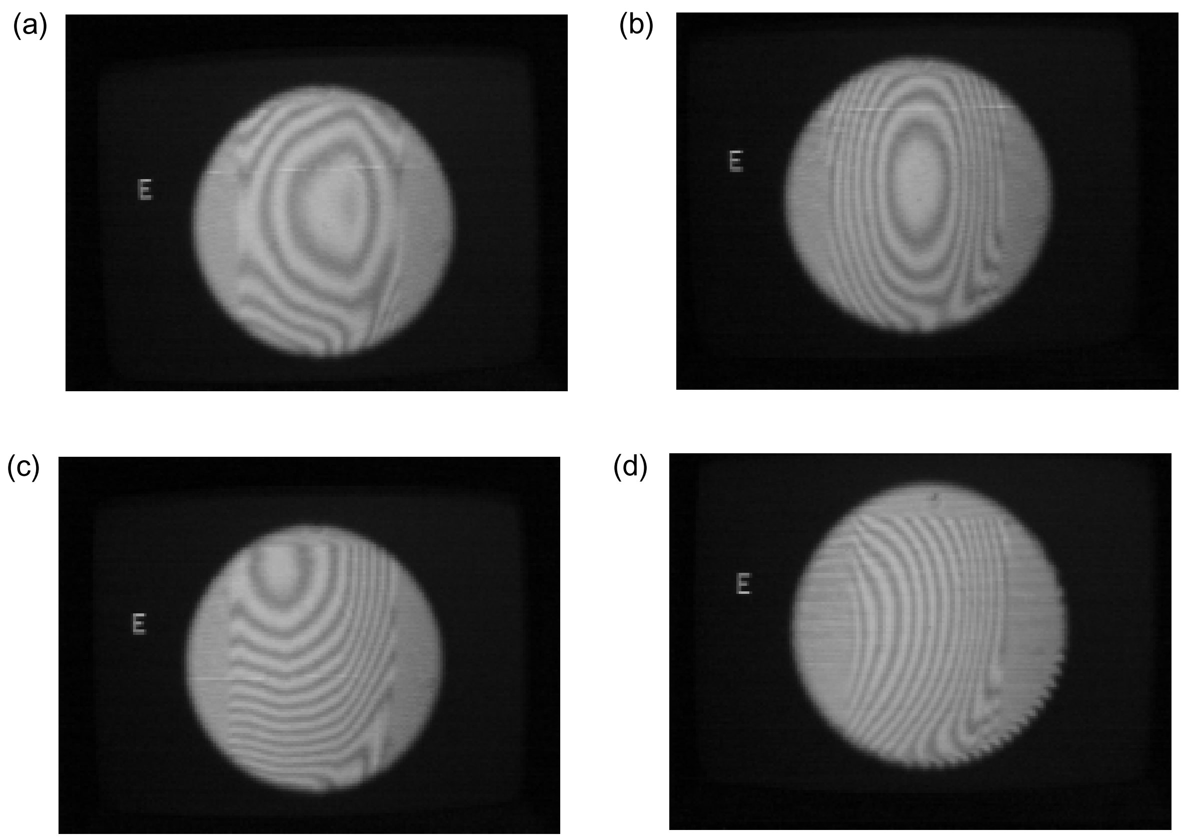

Figure 5. Interference patterns of the standard on-axis cylindrical mirror. (a) is the interference pattern when the mirror is adjusted to minimize fringes. (b) is the change of the pattern as the mirror is translated along the z-axis(optical axis). The pattern of (c) and (d) are the changes of the pattern when the mirror is tilted about the x and y axis respectively.

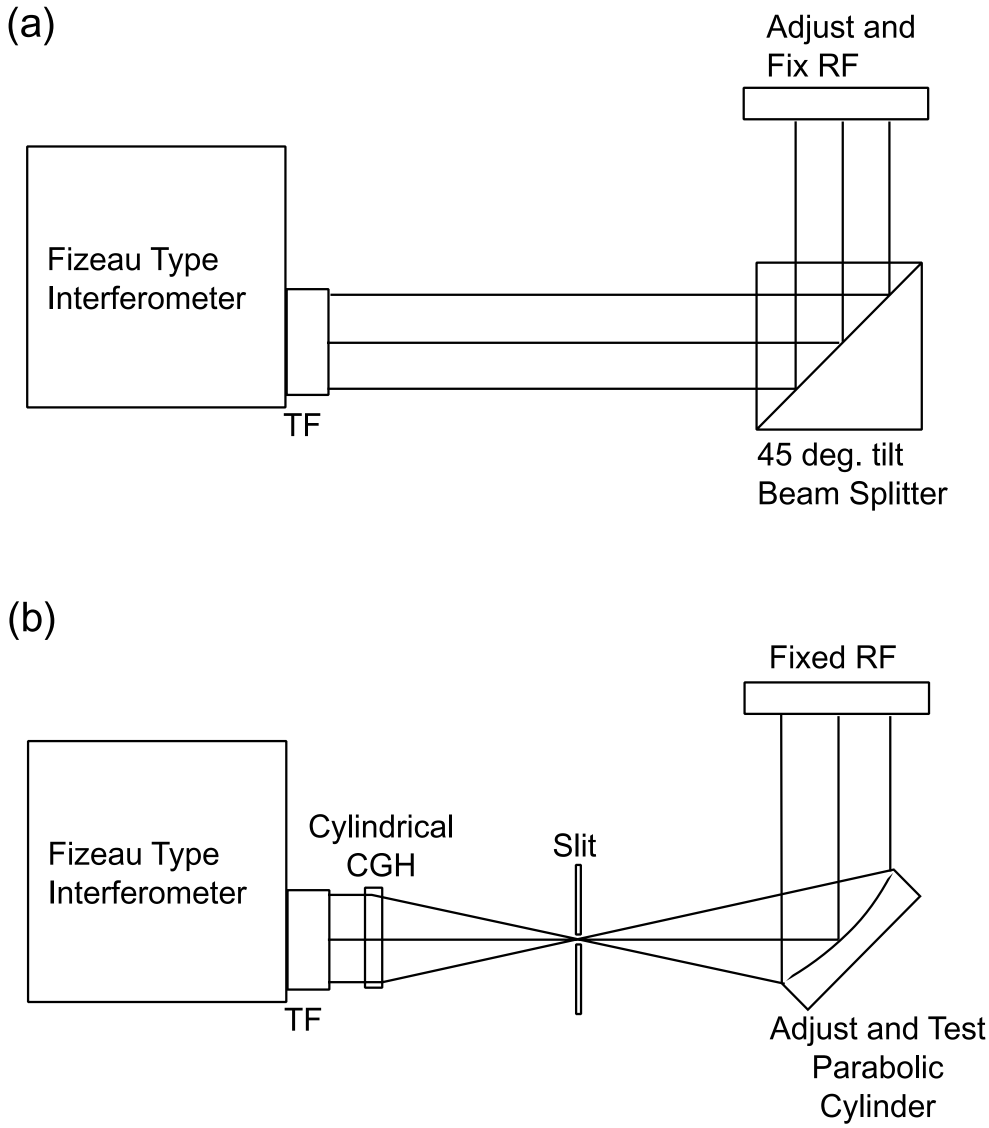

Figure 6. Procedure of testing an off-axis parabolic cylinder mirror using a beam-splitter to reduce the degree of freedom which utilize the angle of the reflected beam from a beam-splitter is 90°. (a) shows the preliminary procedure to fix the reference flat mirror in a proper position using the beam-spliter. (b) is the optical setup where the off-axis parabolic cylinder mirror is adjusted to make a fringe pattern. The setup is not tolerant to the error in the off-axis angle.

is measured adjusting the test parabolic cylinder mirror as represented in figure 6(b). The setup will not be tolerant to the error in the off-axis angle.

An alternative way is testing an off-axis parabolic cylinder mirror using a retro-reflector. This method has a tolerance in off-axis angle of the mirror. Figure 7(a) shows the preliminary procedure to fix the off-axis parabolic cylinder mirror in a proper position using the retro-reflector. Figure 7(b) is the optical setup where the reference mirror is adjusted to make a fringe pattern.

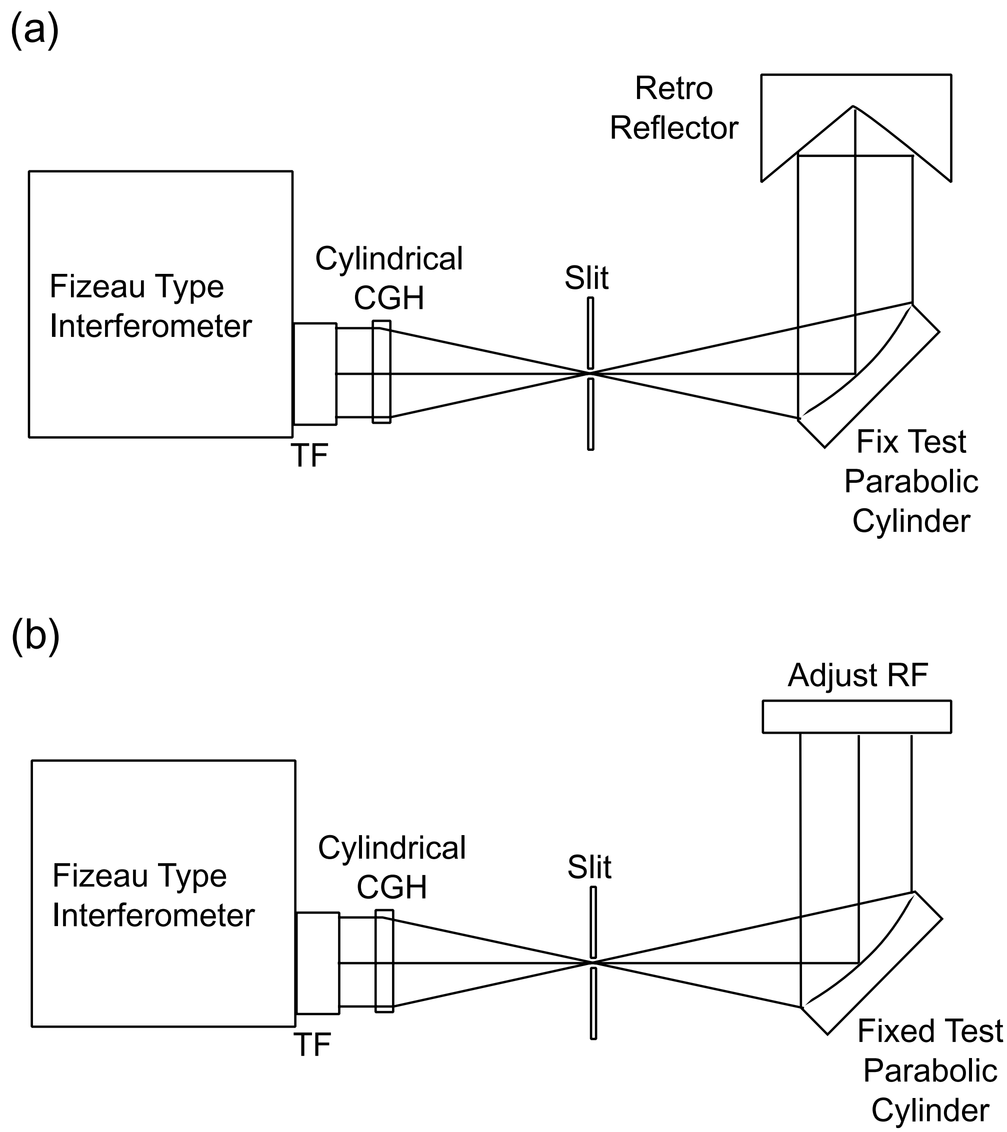

Figure 7. Procedure of testing an off-axis parabolic cylinder mirror using a retro-reflector to reduce the degree of freedom which has a tolerance in off-axis angle of the mirror. (a) shows the preliminary procedure to fix the off-axis parabolic cylinder mirror in a proper position using the retro-reflector. (b) is the optical setup where the reference mirror is adjusted to make a fringe pattern.

4. SUMMARY

We have introduced the design procedure and specifications for FIMS which is a far ultraviolet diffuse imaging spectrometer. Manufacturing and testing of an off-axis parabolic cylinder mirror for FIMS is a critical issue in development of the system. We have studied methods of testing cylindrical optics and found a valuable method of using a CGH null which generates a cylindrical wavefront.

We have performed surface measurement on a standard on-axis cylinder mirror using the CGH null. Finally, we have proposed methods of testing an off-axis parabolic cylinder mirror and expect that the setup will assist the polishing process. We have ground the off-axis parabolic surface using a precision CNC machine and check the error of the surface profile is equal to or less than $1 \sim 2$ μm throughout the substrate.

ACKNOWLEDGMENTS

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