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Development of Testing Fixture for Space Borne Optical Component Measurement

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Abstract*: *This paper presents the process of design and development of testing fixture for measuring linear and angular errors in semi-finished optical components that are used in space born telescopes.. The telescopes used in earth observation satellites have reflective optical systems or refractive optical systems. Reflective optical systems consist of large size mirrors and refractive systems consist of multi element lens assemblies. Refractive telescope consists of multiple lens elements which have to be fabricated and positioned accurately to get the required image quality. Fabrication of lens elements is a critical process and various parameters have to be measured and controlled accurately during the course of their fabrication. Tilt and decenter of the lens surfaces are two such critical parameters that have to be controlled within few microns. A testing fixture is developed to measure these errors to an accuracy of 20 microns in the lens elements during their fabrication with minimum measurement time.

Index Terms*: *Angular & linear error, high accuracy, measurement, semi-finished space borne optical component.

I. INTRODUCTION

The space borne optical telescopes consists of optical elements which are used for imaging application. These optical elements have to be fabricated to a very high degree of accuracy to get high quality images. The refractive type of telescope consists of multi element lens assembly wherein each lens element is fabricated to a very high degree of accuracy and positioned with respect to other lens elements with an accuracy of few microns. Two main errors that can creep in lens elements during fabrication are tilt and de-center. These two parameters have to be controlled and maintained within 5 microns in the finishing stage. Hence the element has to be fabricated within 20 microns in semi-finished stage. During fabrication, the element undergoes stage by stage measurements to control the dimensional accuracies. Hence, there is a need for testing fixture which helps in measurement of different type of lens elements with good repeatability & precision with minimal handling to avoid risk of damaging the component.

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II. PROBLEM IDENTIFICATION

An optical lens is defined by the radius of curvature of its two surfaces and its diameter and center thickness. The nature of the surfaces can be plane, convex or concave. Accordingly, we have different types of lenses viz., Plano-Plano, Plano-Concave, Plano-convex, Biconcave, Bi-convex and Meniscus. The performance of the telescope system is affected by the linear and angular errors present in the lens elements. These errors are introduced into lens elements during the stages of curve generation and grinding the surfaces. Once these errors are introduced, it is difficult to correct in subsequent polishing process as there is not much removal there. Hence, the curve generation and grinding process has to be controlled to minimize these errors before polishing itself. With the existing test set up, we are able to measure lens with flat surface on one side and curvature on other side. However it cannot accommodate the lens elements with curvature on both sides for measurement. Hence, there is a need to design an attachment that can be used to measure the errors in lens elements with curvature on both sides. Lens holding mechanism should be simple and there should be minimal handling of the lens elements during testing, as they are made of glass material which is highly fragile. The mechanism should allow measurement of lens with all types of profiles viz., flat, convex and concave. It should give errors in the lens elements within an accuracy of 5 microns.

III. DETAILS OF OPTICAL ELEMENT

The optical lens transmits light and these light rays either converge or diverge depending upon the nature of surface. All the rays coming from object are transmitted through lens elements and finally get focused on the imaging plane to create images. The geometrical details of the elements is show in the “Fig.1”

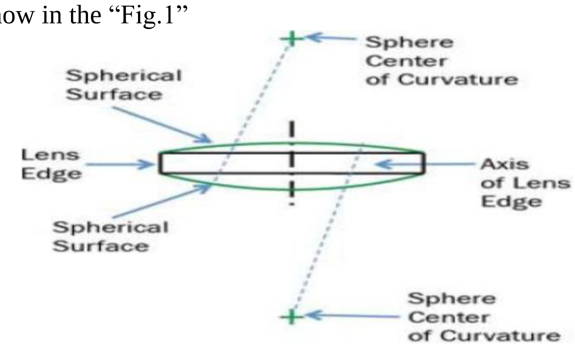

Fig.1 Details of Lens [1]

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IV. ANGULAR AND LINEAR ERROR

The optical axis of lens is defined as the line which is joining the center of curvature of both the surfaces in the lens element. Axis defined by the outer cylindrical surface of lens is called its mechanical axis. In a perfect lens element, both the axes should be collinear. Due to fabrication errors the optical axis does not exactly coincide with mechanical axis the both are at certain angle to each other. This is called angular error, or, wedge in the lens element as given in the Fig.2. The angular error can be calculated by equation (1).

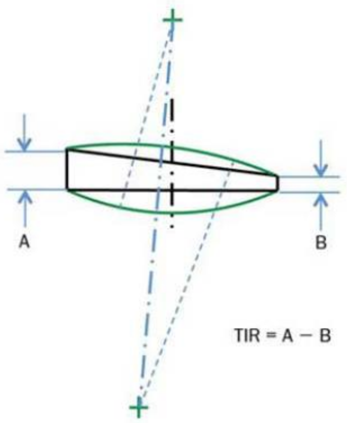

Fig.2 Angular Error [1]

Angular Error:

$\tan\theta$ = (Total Indicator reading) / d (1)

Where θ = Wedge angle in degree

Edge thickness variation (TIR) =A-B

A= maximum value measured on surface.

B= minimum value measured on surface.

d = diameter of the job

Decenter is the distance between mechanical and optical axis of the lens element after adjusting it to make its mechanical axis and optical axis parallel to each other. This is generally named as edge run out (ERO) [2]. The following "Fig.3" clearly shows the linear errors.

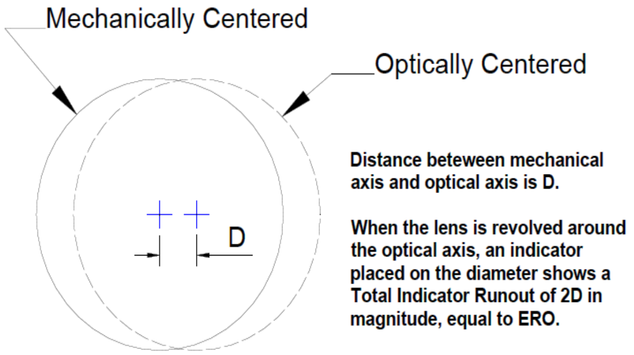

Fig.3 Linear Error [2]

The presence of above errors viz., wedge and decenter in the fabricated lens leads to poor performance of the optical system like defocusing, astigmatism and wave front aberrations [3].

V. PROTOTYPE DEVELOPMENT

The product development process starts with problem identification and ends with development of prototype model. The prototype is tested and validated to check whether the design meets our requirement. Upon successful validation, physical model is developed to solve the problem identified. The following "Fig.4" shows the steps in the development of prototype model.

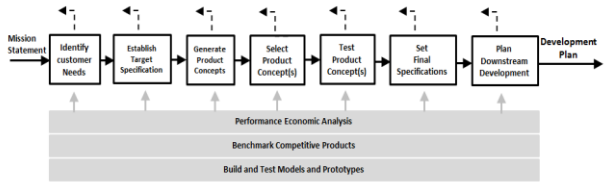

Fig.4 Product development process [5]

The customer needs are identified and defined clearly. Design inputs are collected and the design goals are set. Targets are set based upon the requirements of customer. Based on the above, a concept is generated to give the solution in the form of proto type model. The conceptual three-dimensional model is given below in "Fig.5".

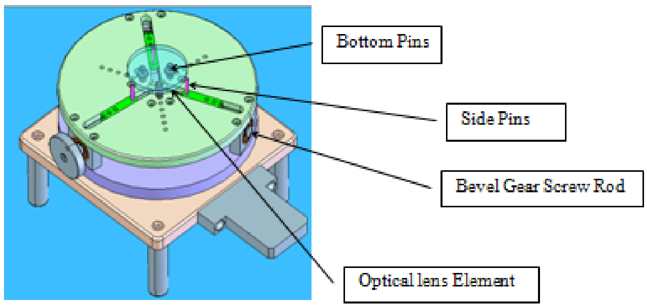

Fig.5 Conceptual Model

VI. TESTING FIXTURE

Measuring fixtures used for identify the tolerance deviation from the specified tolerances. For inspection the primary requirement is the relationship between the referenced datum to the measuring fixture and the dial for inspecting the component [4].The prototype of the testing fixture is mainly designed and developed for measuring angular and linear errors in the lens elements during the course of their fabrication (in semi-finished form). This fixture shall Measure and control the errors, to give a good quality component. Suit for lens elements with different type of profiles viz., plane, convex and concave profiles. Eliminate the requirement for manual holding of the optical component during the measurement.

6.1. Important Parts of the Fixture

There are mainly three important parts for function of the fixture. They are bottom pins, side pins and bevel gear mechanism.

6.1.1 Bottom pins:

The total number of the bottom pins is three out of which the height of two pins is adjustable and third one has fixed height and is used as reference pin. These three pins act as three point support on the bottom of lens elements.

6.1.2 Side pins:

There are three side pins mounted on the movable slider block which moves back and forth from the table origin based on the diameter of the lens to be measured. These pins provide line contact on periphery of lens at 120 deg apart.

6.1.2 Bevel gear mechanism:

The gear mechanism plays a main role in self-aligning the lens to the table origin. There are three bevel screw rods of size M16 x1.5 mm pitch with three nuts of same size, 120 degree apart which engages with one bevel gear to move the slider blocks.

6.2 Working Principle

The movable side holding pins are taken to the extreme outer position. The bottom pins are positioned at an appropriate distance based on the diameter of lens. Bottom pin are leveled within 20 microns using a master flat having a parallelism of 5 microns. Lens to be measured will be placed on the bottom pins. Side holding pins are moved in radially to hold the lens on its periphery. Holding should be just enough to avoid rotation of lens in the fixture. Using dial gauge of 2 micron least count, angular and linear errors on the lens is measured.

VII. VALIDATION OF RESULTS

The fixture is tested and validated based on the qualified semi-finished lens samples refer "Table". The different types of the lenses are pretested with the existing measuring devices by only angular errors refer "Fig.6"and the same components are tested on the developed fixture with angular error and linear errors refer "Fig.7".

Fig.6 Semi finished lens testing on existing device

Fig.7 Semi finished lens testing on developed Prototype fixture

Table for Fixture Validation

Lens profile nature	Angular Error Measurement by existing Granite base measuring device (Microns)	Angular Error Measurement by developed Prototype Testing Fixture (Microns)	Angular Error Measurement Deviation (ΔA) (Microns)	Linear Error Measurement by developed Prototype Testing Fixture (Microns)
Plano-Plano	18	16	-2	22
Plano-Concave	20	20	0	26
Plano-Convex	18	22	4	20
Meniscus	20	24	4	26
Biconcave	18	24	6	22
Biconvex	16	24	8	22
Average	18.33	**21.16**	2.8	**23**
Uncertainty errors				
Repeatability error	6<microns			
Instrumental error	2			
Job setting error	1			

Error percentage calculated by the equation (2)

$$\text{Error \%} = \frac{\text{Measured value} - \text{Actual value}}{\text{Actual value}} \quad (2)$$

$$\text{Angular Error \%} = \frac{21.16 - 18.33}{18.33} = 15\%$$

Linear Error = 23

Total error Budget is included uncertainties errors for qualifying the testing fixture for implementation in the measuring processes.

VIII. CONCLUSION

The device in current use is able to measure only angular error and requires additional attachments such as bell cup or matching element for measurement of lenses with different type of profiles. The developed prototype eliminates additional attachments and suits to all type of profiles. The prototype meets the measuring capability requirements of less than 30 microns for both angular and linear error of semi-finished optical components used for space borne telescopes.

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Since repeatability less than 6 microns, further improvements can be incorporated in the machining tolerances by achieving minimum deviation and to improve the measurement accuracies and reputability. This method eliminates the manual holding and provides automatic self-aligning feature with tilt correction facility.

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