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OPTICAL TELESCOPE REFOCUSSING MECHANISM CONCEPT DESIGN ON REMOTE SENSING SATELLITE

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I. ABSTRACT

The optical telescope system in remote sensing satellite must be precisely aligned to obtain high quality images during its mission life. In practical, because the telescope mirrors could be misaligned due to launch loads, thermal distortion on supporting structures or hygroscopic distortion effect in some composite materials, the optical telescope system is often equipped with refocussing mechanism to re-align the optical elements while optical element positions are out of range during image acquisition. This paper is to introduce satellite Refocussing mechanism function model design development process and the engineering models. The design concept of the refocussing mechanism can be applied on either cassegrain type telescope or korsch type telescope, and the refocussing mechanism is located at the rear of the secondary mirror in this paper. The purpose to put the refocussing mechanism on the secondary mirror is due to its higher sensitivity on MTF degradation than other optical elements.

There are two types of refocussing mechanism model to be introduced: linear type model and rotation type model. For the linear refocussing mechanism function model, the model is composed of ceramic piezoelectric linear step motor, optical rule as well as controller. The secondary mirror is designed to be precisely moved in telescope despace direction through refocussing mechanism. For the rotation refocussing mechanism function model, the model is assembled with two ceramic piezoelectric rotational motors around two orthogonal directions in order to adjust the secondary mirror attitude in tilt angle and yaw angle. From the validation test results, the linear type refocussing mechanism function model can be operated to adjust the secondary mirror position with minimum 500 nm resolution with close loop control. For the rotation type model, the attitude angle of the secondary mirror can be adjusted with the minimum 6 sec of arc resolution and 5^{o}/sec of angle velocity.

II. INTRODUCTION

In order to obtain higher quality imagines from the telescope installed in remote sensing satellite, the usage of refocussing mechanism is always needed to adjust the misaligned focus center due to launch loads, gravity release, thermal deformation in orbit, or hygroscopic distortion effects for some materials. Although all works can be made to align the optical focus center on ground, those above impacts could still lead to optical elements misalignment while on orbit. These misalignment will make modulus transfer function (MTF) much degradation and should be recalibrated on orbit by refocussing mechanism.

The general refocussing mechanisms applied in remote sensing satellite can be divided into three categories according to driving type: (1) Direct transmission refocussing mechanism which can directly drive optical element by driver motor. (2) Indirect transmission refocussing mechanism which will drive the optical element through gear box. (3) Thermal refocussing mechanism which makes use of thermal deformation property of supporting structure material to calibrate optical elements. For the first type, the driving motor will use step motor to directly drive the optical elements step by step. The constitution elements of this refocussing mechanism is simple and the displacement can be directly read out for control purpose. Besides, the occupied volumn is small and total mass is light which are benefit for the mechanical design. As for the second type, the driving motor output must be transformed to displacement through gear box and the backlash tolerance could be cumulated to large amount of alignment error. Furthermore, there will occupy much space to accommodate this mechanism and could affect the light path design. The third type has been used in many remote sensing satellites. This refocusing device is always designed as one part of the telescope supporting structures and will be then deformed to adjust the focus center while heating or cooling the supporting structure. The mechanical configuration of this type is the simplest one but the response time is slower. Besides, one challenge needed to be resolved for thermal refocussing mechanism design is to isolate thermal effect to other structure parts while heating.

The direct transmission refocussing mechanism will be introduced in this paper, and the ceramic piezoelectric material made step motor is selected as the driving motor either in linear mechanism or tilt mechanism [1]. The following sections will describe the development process of direct transmission refocussing mechanism from design concept to function model.

III. FUNCTION DESCRIPTION AND DESIGN CONSIDERATIONS

Once the refocussing mechanism design concept being decided, two important issues need to be considered on its mounting location. One is telescope MTF degradation sensitivity and the other is the mounting feasibility.

For MTF degradation study, different MTF degradation sensitivity comparison on one general cassigrain typed telescope (shown in Fig. 1.) is made for different optical misalignment [2]: secondary mirror (M2) despace, M2 decenter, M2 tilt and imagine sensor defocus (these misalignment descriptions are illustrated in Fig. 2.). From the results (shown in Table 1.), the MTF degradation of M2 despace misalignment or M2 tilt misalignment is larger than that on imagine sensor despace misalignment or M2 decenter misalignment.

For mounting feasibility consideration, there are three possible locations for direct transmission refocussing mechanism. The first one is between the primary mirror (M1) and its supporting bracket. The second location is behind M2. Besides, the refocussing mechanism can also be installed on the imagine sensor mounting structure. Among three mounting locations, it is seldom to adjust the M1 attitude because of its moving uniformity. As for the location on imagine sensor mounting structure, the mounting space is limited to its complicated harness arrangement. Therefore, after combining MTF degradation and mounting feasibility considerations, the location behind the M2 (shown in Fig. 3.) is adopted for this paper. This design can generate varied M2 displacement in x, y, z direction separately according to the control signals, so that M2 attitude can be changed to achieve fine tuning purpose.

Therefore, in this study, the refocussing mechanism will directly drive M2 to move along Z_{op} direction for despace control, to rotate around X_{op} direction or to rotate around Y_{op} direction for tilt control. According to these design requirements, two kinds of refocussing mechanism are separately designed: one for despace refocussing mechanism and the other for tilt refocussing mechanism. For the despace refocussing mechanism, the design purpose is to reach 25mm displacement with 0.5μm resolution in M2 Z_{op} direction. As for the tilt refocussing mechanism, it is designed to drive M2 in $\pm 3^{o}$ angle with 6 sec of arc of resolution. These design requirements are defined only for the refocussing mechanism function model and will be better while applied on flight telescope model.

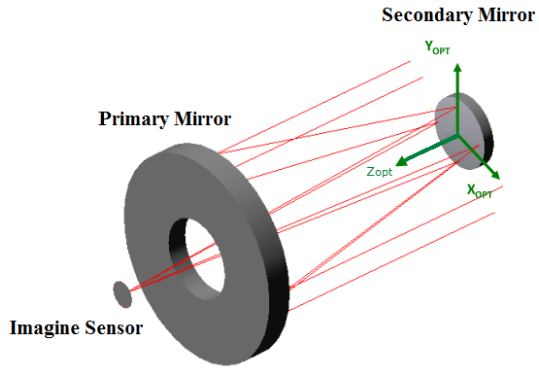


Fig. 1. Cassegrain Telescope Configuration

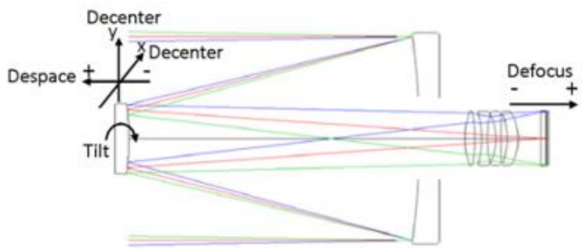


Fig. 2. The Misalignment Illustration on M2 Despace, Decenter, Tilt and Imagine Sensor Defocus

Table 1. The MTF Degradation Comparison Result for General Cassigraim Telescope [2]

Component	Variable Parameter	Data	MTF Degradation
CMOS	Defocus	±50 μm	<7%
M2	Despace	±2 μm	~3.2%
	Decenter	30 μm	~2.6%
	Tilt	0.015°	~5.3%

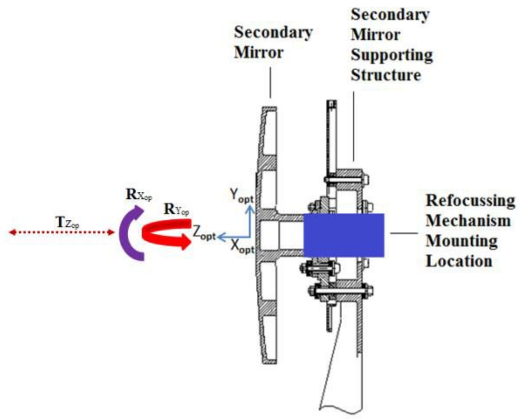
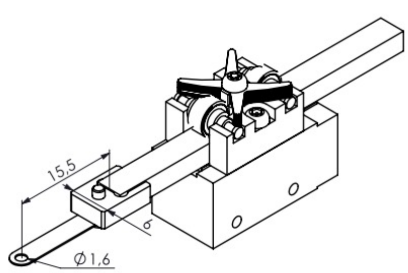


Fig. 3. The M2 Refocusing Mechanism Mounting Location Schematic Plot

IV. DESIGN CONCEPT

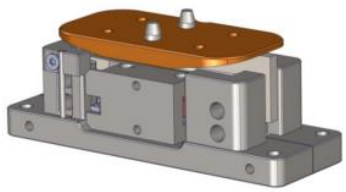
In this paper, the piezoelectric ceramic made step motor is used for the driving motor both for despace refocussing mechanism and tilt refocussing mechanism. There are many mechanical advantages for piezoelectric ceramic made step motor, such as light weight and tiny volume, Therefore, the piezoelectric ceramic driving motors developed by PiezoMotor® Inc. are used for study.

After several studies, model #LL1011A step motor of Piezo LEGS® Linear 6N [3] series is selected as the driving motor of the linear refocussing mechanism. The mechanical configuration and its technical specifications of this motor are shown in Fig. 4. As for tilt refocussing mechanism, model #LC2010 step motor of Piezo LEGS® Caliper 20N [3] is used for the driving motor. The mechanical configuration and its technical specifications are shown in Fig. 5.



Technical Specification			
Type	**LL1011A- stainless steel**	**Unit**	**Note**
Maximum Stroke	80 (L−20.8)	mm	100.8 mm rod, no mechanical adapter
Speed Range [a]	0-15	mm/s	recommended, no load
Step Length [b]	4	μm	one wfm-step
	0.0005 [c]	μm	one microstep [c]
Resolution	< 1	nm	driver dependent
Recommended Operating Range	0-3	N	for best microstepping performance and life time
Stall Force	6.5	N	
Holding Force	7	N	
Maximum Voltage	48	V	
Power Consumption [d]	5	mW/Hz	=0.5 W at 100 Hz wfm-step frequency
Mechanical Size	22 x 19 x 10.8	mm	see drawing for details
Material in Motor Housing	Stainless Steel		
Weight	23	gram	approximate
Operating Temp.	−20 to +70	ºC	

Fig. 4. The Linear Driving Motor Configuration and its Technical Specifications (adapted from PiezoMotor® Product Catalogue 2014/2015) [3]



Technical Specification	
Type	**LC2010 for gonio stage**
Stroke	±10° [a]
Minimum Radius	86 mm
Speed Range [b]	0-7 °/s [a]
Step Angle/Length [c]	30 µrad [a]
	0.004 µrad [a d]
Resolution	< 10 nrad [a]
Recommended Operating Range	0-10 N
Stall Force	20 N
Holding Force	22 N
Maximum Voltage	48 V
Power Consumption [e]	10 mW/Hz
Connector	2 x soldered cable with JST 05SR-3S
Mechanical Size	60 x 20.7 x 20.4 mm
Material in Motor Housing	Stainless Steel, Aluminum
Weight	110 grams
Operating Temp.	0 to +50 °C

Fig. 5. The Rotation Driving Motor Configuration and its Technical Specifications (adapted from PiezoMotor® Product Catalogue 2014/2015) [3]

To drive step motor, the PiezoMotor® Microstep driver PMD101 [3] is used to generate waveform step signature. Besides, the closed loop control function needs to be embedded in the refocussing mechanism to make precise adjustment. Therefore, the optical ruler as well as its detector are mounted between step motor and its supporting structure to detect the exact displacement. Once the controller receive the displacement signal from optical ruler detector, the feedback signal can be calculated and send back from the controller to the PMD101 driver to precisely control the moving steps. The control block diagram is shown in Fig. 6.

For linear refocussing mechanism, the focus center will not be skewed during refocussing calibration because the focus line between M2 and M1 is always in line. However, for tilt refocussing mechanism, M2 surface center can be skewed if M2 is not put in proper position. Therefore, to maintain M2 surface center fixed during tilt refocussing calibration, the rotation center of the curve path shall be coincided with M2 surface center, illustrated in Fig. 7. In this case, there is 75mm distance from M2 dummy surface center to the mounting surface in order to fix M2 surface center.

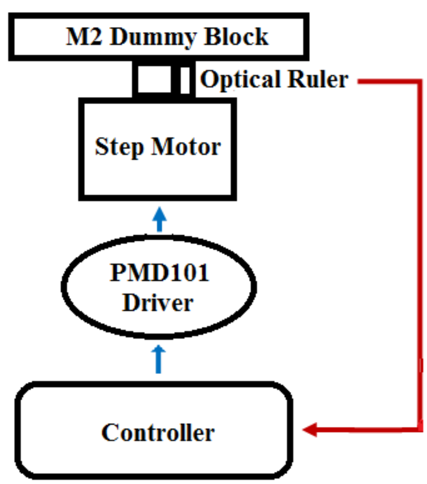


Fig. 6. The Control Block Diagram of Refocusing Mechanism Engineering Model

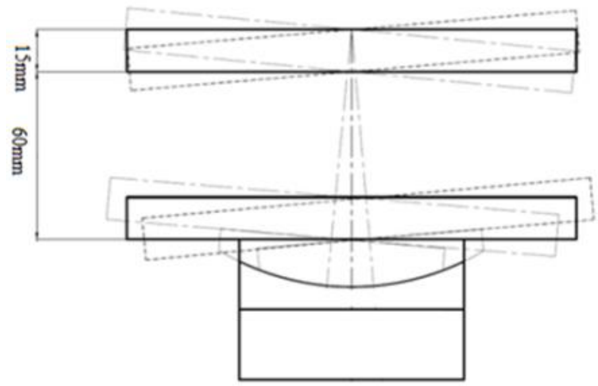


Fig. 7. M2 Mounting Consideration in Tilt Refocussing Mechanism

V. EXPERIMENT FUNCTION MODEL

After confirming the techanical specifications of all devices, the detailed design is then developed. Due to future application, M2 mass is designed to be 1.0kg although the actual mass of M2 can be largely reduced. For linear refocussing mechanism, it is designed to use two parallel linear guides to support M2 dummy block. The step motor is then placed in the center region of these two linear guides. Besides, the step motor driver bar is connected at the center of the M2 dummy block in order to provide balanced driving force. The optical ruler is mounted on the side of the linear guide to detect the moving direction and its distance. The assembled function model is then supported by the mounting fixture which can be fixed in the experiment table. For PMD101 driver and the controller, they are placed on the other locations and connected with the signal lines as well as power lines. The linear refocussing mechanism function model design plot is shown in Fig. 8 and the experiment function model (as shown in Fig.9) is completed on 2014 [4].

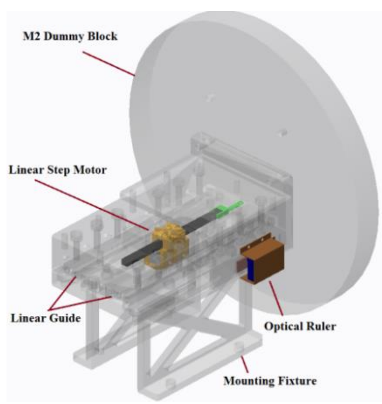


Fig. 8. The Design Plot of Linear Type Refocusing Mechanism Function Model

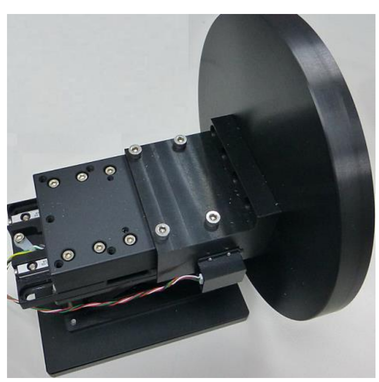


Fig. 9. The Linear Refocusing Mechanism Function Model

For tilt refocussing mechanism, there designed two orthogonal rotation step motors which are stacked together, one for tilt direction and the other for yaw direction. To avoid the skewed phenomenon during tilt adjustment, there design one 75mm extension bracket to connect M2 dummy block and mounting plane. Besides, two sets of curve guide are also designed two different moving path, and to support the M2 dummy block as well as extension bracket. To precisely control the rotation angle, the position angle will be detected by optical ruler separately for each direction. The design plot of tilt refocussing mechanism function model is shown in Fig. 10. The function model is completed on 2015, shown in Fig.11.

VI. CONCLUSION

In order to maintain high quality images, it is necessary to calibrate mirror misalignment caused by launch loads, thermal deformation or hygroscopic deformation in some materials. In this paper, the ceramic piezoelectric made step motors are used as driving motor for M2 refocussing mechanism because of its light weight, simple constitution and fine resolution characteristics. From the measurement results, all the design purposes are met for both linear and tilt refocussing mechanisms. However, there are much effort needed to be paid while mounting in flight model.

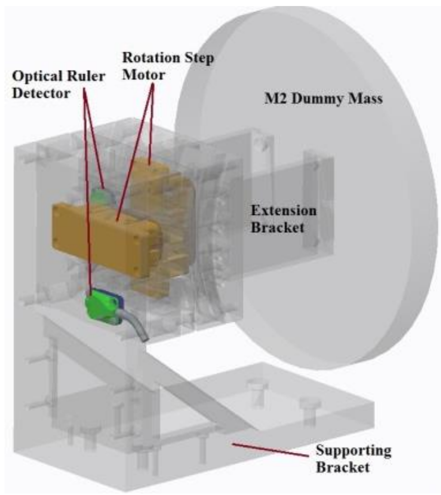


Fig. 10. The Design Plot of Tilt Type Refocusing Mechanism Function Model

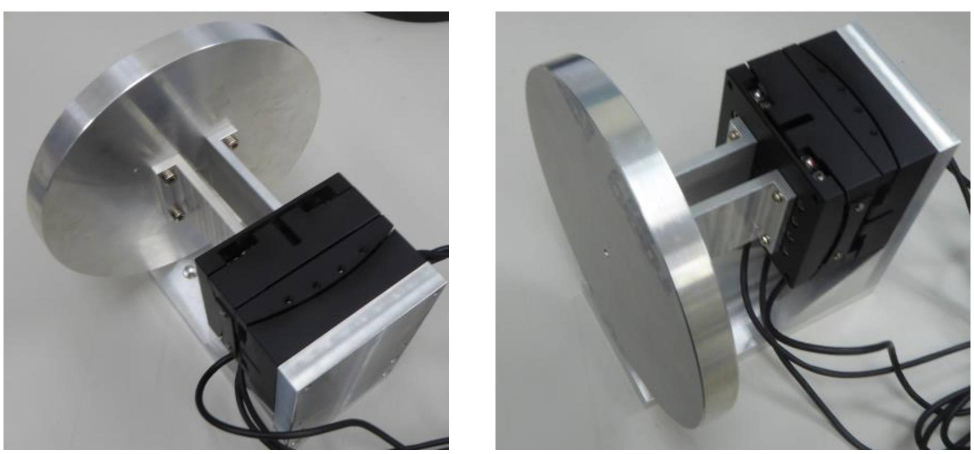


Fig. 11. The Tilt Refocusing Mechanism Function Model

The challenge tasks to develope flight refocussing mechanism model are: (1).The suitable hold-down and released devices to lock the refocussing mechanism during launch process and to release that on orbit. In order to verify this function, many dynamic verifications need to be performed to make sure that mechanism can be survived from the severe launch environments. (2). The mechanism mass shall be reduced to avoid much impact on telescope stiffness. Therefore, the supporting structures connected to M2 needs to be detailed design and the composite material can be considered. (3). To achieve space qualified standard, many space qualification tests shall be passed, such as thermal vacuum test, thermal cycling test, EMI/EMC test, etc. Finally, outgassing standard shall also be met for all devices.

To sum up, two kinds of refocussing mechanism function model have been successfully completed, and the next generation function model is under development for higher resolution telescope usage in the future.

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