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Hexapod for Space Telescopes: A Review

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Abstract- *Space borne telescopes are subjected to orbital loads like temperature excursion, absence of gravity, moisture desorbption of metering structure etc, which leads to misalignment of optical system and loss of the optical performance. Future space based large telescope will be made from number of smaller mirrors, which are aligned together to create a larger segmented mirror. Due to orbital loads misalignment will occur in these smaller mirrors supported by large structures and intern this willintroduce aberrations in imaging. Hence, there is a need of some technique which measures the onboard optical misalignment and corrects it. Wavefront sensing and reconstruction is a technique, which measures the wavefront and the aberration presents in a wavefront. This technique can be used in space based telescopes to sense the optical misalignment by measuring an error in wavefront. It provides necessary feedback to the hexapod to restore optical performance by realignment. Hexapod is a device which provides 6 DOF of the moving plate (platform) relative to the fixed plate (base), all the six actuators are actuated with computed thermal field.*

Keywords *– Hexapod, Space telescope, Thermal actuator, Refocusing mechanism, Stewart platform*

I. INTRODUCTION

As the capability of space-based observatories has grown and their data products shared, whole new fields of science and industry have emerged around interpreting, organizing and extending the information they generate to greater and more prolific purposes. Electro-optic modules (EOM's) are used for remote sensing application. An EOMconsists of the optical elements, related electronics and the mechanical structure housingboth of them[1]. The mechanical structure has to be very much stable and precise during it'sthroughout operational life in orbit as it supports the optical elements. An optical elementincludes Primary mirror, Secondary mirror and Lens assembly.

In the astronomical world the Stewart platforms are sometimes used to control the motion of the secondary mirrors in telescopes equipped with active optics systems and besides from active optics, a deep interest for the Stewart platform is demonstrated in hexapod[5]. Hexapod is a device which is used in particular applications like refocusing mechanisms for space telescopes, flight simulator by generating general motion in space etc. It has six legs which are aligned in special arrangement to have 6 Degree of Freedom (DOF). Basically hexapod is consist of top plate and bottom plate connected by six actuators with the help of joints. Especially for space telescope we must have to consider space environment while choosing any parts and materials of any parts.

It has been found thatthermal actuation provides greater displacement at lowvoltages when compared to other mechanisms. This thermally driven refocusing mechanism has ability to re correct the misalignment between primary mirror and secondary mirror with few microns.

II. Literature survey in brief

Scope of the Refocusing Mechanism (RFM) is to correct long term variations due to thermal optical properties degradation, moisture release and launch induced deformations. The RFM is required to correct steady displacements, with an accuracy of 100 nanometers and a total stroke of ±15 micrometers, with tight stability and tilt requirements [1]. The choice of two cylinders instead of a single one has several advantages, but also adds some complexity to the design. The main advantage is capability to keep a nominal "zero position" with a minimum amount of electrical power. When the external environment of the mechanism is rapidly changing, the mechanism can be designed so that the dynamic response of the two cylinders is as similar as possible, so that the perturbation is cancelled by design [1]. According to speed of mechanism (cooling), single actuation is strongly dependent on the environmental conditions while double actuation is mostly driven by the heating power, this fenomanon is clearly shwn in figure 1.

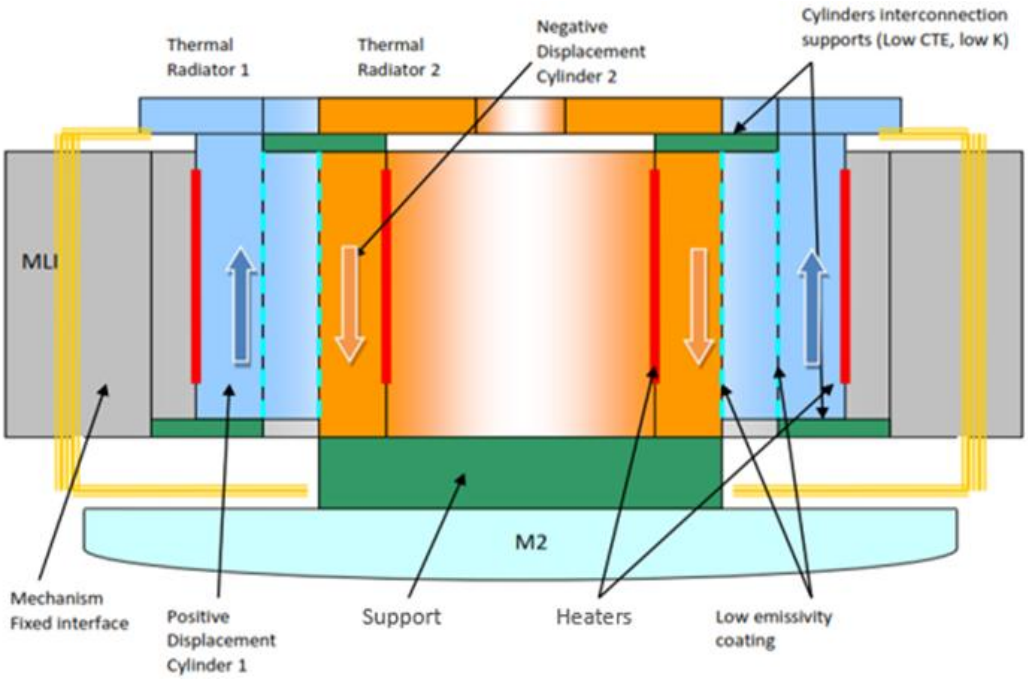

Figure 1 Double-actuation thermally actuated mechanism[1]

NASA's current mission the James web space telescope (JWST) uses a deployable 6.5m segmented primary mirror. Modal Image Optimization (MIO) method is used for optimizing the surface of an active mirror. In this method images produced at focal plane were used for the alignment of the segments. Mirror fabrication and polishing costs are reduced by eliminating much of the total mirror area. Furthermore, silicon carbide (SiC) is a material used for mirror because of its light weight that also reduces the costs of launch [2]. Due to Zerodur mirrors bend under radiation a full SiC (Silicone Carbide) telescope is preferred to alternate Zerodur mirror [3]. In pleides high resolution earth observation satellite secondary mirror is not spherical in design as well this mirror is supported by thermal refocusing device because of the high axial magnification of secondary mirror (M2), the front cavity needs a very accurate control of the distance between primary and secondary mirror within a few microns. The M2 sub-system is accurately pre-aligned in front of the primary mirror using laser tracker and three dimensional measurements [4].

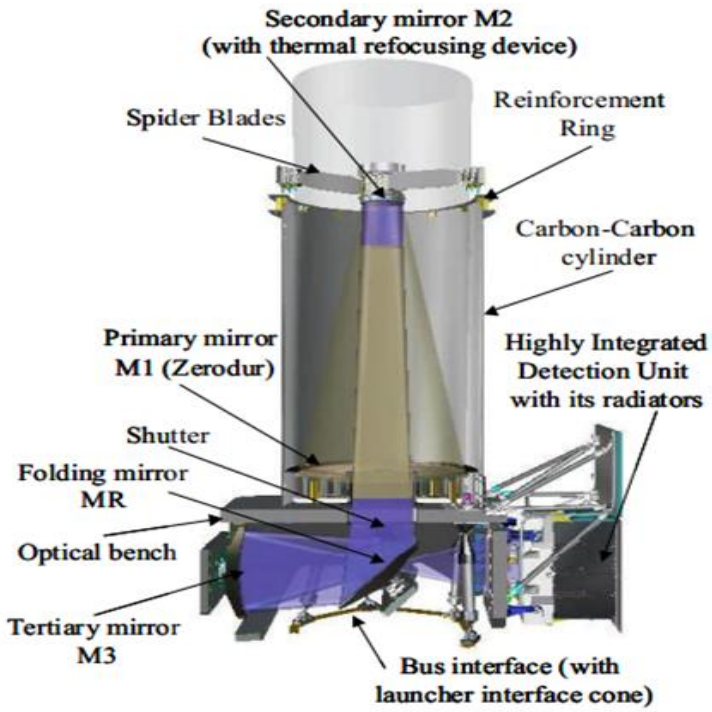

Figure 2 High resolution pleides hr camera[4]

Stewart platforms have been used in a wide range of engineering applications; for example, in aeronautic and automotive test benches, in ankle re-education systems, in milling machines, heart surgery, etc. In the astronomical world the Stewart platforms are sometimes used to control the motion of the secondary mirrors in telescopes equipped with active optics systems. Here only translation is considered and tilt is not calculated because tilt is just pointing error which just moves the image in the focal plane and can be actively compensated by the auto guiding system [5].

In order to optimize image sharpness during the satellite lifetime, the instrument includes an innovative thermal refocusing device which avoids the need for a complex mechanism. In this satellite images of the stars were used to fit thermal model to most of wave front error (WFE) [6]. In JWST 18 segmental primary mirror is used all this segments were positioned with the help of seven actuators. Here six actuators are used in strut and one actuator at the center used for giving curvature to the segment as well as to the primary mirror. In secondary mirror also six actuator (Hexapod) were used. All this actuator is specially designed for nano positioning consisting 24 step stepper motor and this motor is attached to the 60:1 gear head and a resolver to make gear motor assembly. Finally, with the help of hexapod flexure the nanometer order actuation is possible [8]. The length of every leg of hexapod is controlled by a motor and is continuously read back by six absolute digital encoders [12].

III. Outcomes

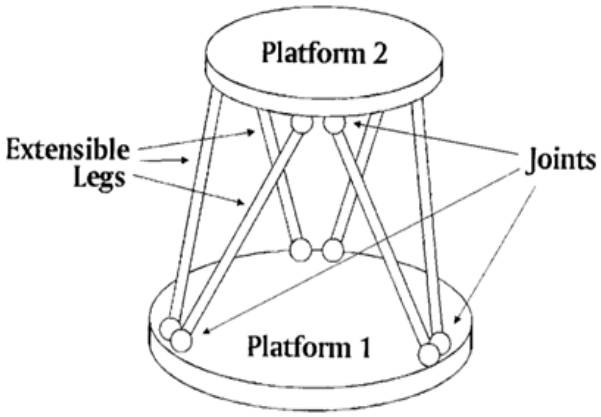

Figure 3General Schematic of Hexapod System

From literature it is clear that hexapod (shown in figure 1) is important mechanism for space applications, pieazoactuator based hexapod is widely used, but thermal actuator based hexapod is more reliable option. A different position in space borne telescopes such as primary and secondary mirrors where hexapod may be used with different types of actuators are as shown in below table 1:

Table 1 Hexapod mechanism used by different agencies worldwide.

Satellite	Subsystem	Actuator
Pleiades (1A and 1B)	Secondary mirror with thermal actuator	Thermal actuator
JWST (NASA)	Hexapod for Secondary mirror + wave front sensor	Tiny mechanical motor with harmonic drive
JWST (NASA)	Hexapod for Primary mirror segments	Tiny mechanical motor with harmonic drive
Terrestrial planet finder (NASA)	Hexapod for Secondary mirror, Laser based metrology Deformable mirror	Piezo electric actuator
GAIA	Five DOF + Wave front sensor	Permanent magnet stepper motor
Deployable Satellite	Hexapod for SM	Piezo electric actuator

IV. Material Selection

Depending on material properties the material selected for different components of thermal actuator based hexapod are as listed in table 2.

Table 2 : Material selected for different components [17]

HexapodComponents	Material
Cylinders of thermal actuator	Aluminium alloy
Thermal isolators	CFRP
Joints	Titanium alloy
Base plate and top plate	INVAR

V. Mathematical calculation for actuator

The design of thermal actuator is like that if we increase the temperature of outer cylinder it will increase the length of actuator and if we increase the temperature of inner cylinder it will reduce the length of actuator. The main criteria for thermal actuator is the length of actuator and range of actuation. The temperature of the cylinder can be controlled with an accuracy of 0.25°C p2p (i.e. ±0.125°C) [16].

The total length can be calculated as:

$$\Delta L = L \times CTE \times \Delta T$$

$$\delta L = L \times CTE \times \delta T \leq 0.1 \text{ micron} \Rightarrow L = \frac{\delta L}{CTE \times \delta T} \approx 35 \text{ mm}$$

In other case if the requirement is to obtain the stroke of ±15 microns than the required change in temperature will be:

$$\Delta T = \frac{\pm \Delta L}{L \times CTE} \geq \frac{\pm \Delta L}{\frac{\delta L}{CTE \times \delta T} \times CTE} = \delta T \times \frac{\pm \Delta L}{\delta L} = \pm 19^{\circ}C$$

A strategy of double-cylinder actuation is preferred, because its required minimum amount of power for neutral position,as each actuator is driven in the range of 0-20°C, rather than having a single cylinder actuated over 40°C peak to peak range [1].

VI. Conclusion

As per discussion, thermal actuator based hexapod is more reliable than other hexapods. Dual direction actuation of thermal actuator is preferred for quick response in desired direction. For 40mm length of thermal actuator, controlled stroke of ±15 microns is possible with controlled temperature of ±19˚C of actuator cylinders. For auto and precise controlling all six actuators must be actuated according to computed thermal field. Thermovacuum test is necessary to check performance of hexapod in space environment.

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