

Introduction of a 2.5m telescope mount

Bozhong Gu*, Guomin Wang , Jiang Xiang

National Astronomical Observatories/Nanjing Institute of Astronomical Optics and Technology,
Chinese Academy of Sciences, Nanjing 210042, P.R.China

ABSTRACT

Telescope is a very important tool for astronomers to survey and study the stellar stars and astronomical phenomena. The performance of a telescope is its capability to track the observing objects and keep the image on the field of view during the observing period. All these functions will be achieved by telescope mount, including mount control system. The mount is to support the mirror cell and keep the mirror cell position stability. Meanwhile, with the help of control system, the mount acts as tracker of the observing objects. So, for a telescope, the mount and its control system play an important role during the telescope operation. This paper introduces the structure design and analysis of the mount system of a 2.5m optical/infrared telescope, such as azimuth axis, elevation axis, M2 positioning system, M3 positioning system, and so on. Especially, an innovative support and escape mechanism of M3 will be proposed and analysed in this paper.

Keywords: astronomy, telescope, telescope mount, structure design

1. INTRODUCTION

The mount of a 2.5m astronomical telescope introduced in this paper is a cooperation project between Nanjing Institute of Astronomical Optics and Technology, CAS (NIAOT, China) and Sagem Défense Sécurité (France). NIAOT is in charge of the telescope mount design and manufacture, including basement, rotating table, fork, center section, truss, top-ring, M2 positioning unit, M3 positioning unit, derotator of C1, N1 and AGU, etc. NIAOT also is in charge of the telescope control system which will cooperate with Nanjing SaiGu T&S Development Co., LTD. The telescope is a Ritchey-Chretien Cassegrain with f/8 focus. The general specifications of mount are given as followings:

- ✓ Alt/az mount;
- ✓ Amplitude of the azimuth rotation: $\pm 270^\circ$ with respect to south;
- ✓ Amplitude of the elevation rotation: 5° to 89.5° in operation, and 0° to 90° in maintenance;
- ✓ Resolution of the rotation: <0.01 arcsec on all axes;
- ✓ Maximum acceleration: $0.3^\circ/\text{sec}^2$ on all axes;
- ✓ Maximum rotation speed: $1^\circ/\text{sec}$ on all axes;
- ✓ Pointing accuracy: $5''$ RMS over the full sky;
- ✓ Pointing accuracy: $3''$ PTV within a cone of 45° angle with respect to zenith;
- ✓ Relative pointing performance is better than $0.7''$ for 1° offset after taking zero on a reference star;
- ✓ Tracking accuracy: $0.25''$ RMS and $0.75''$ PTV over 10 minutes open loop;
- ✓ Tracking accuracy: $0.2''$ RMS over 3 hours in closed loop with AGU;
- ✓ First resonance frequency: 7 Hz;
- ✓ M1 – M2 alignment: max axial displacement $\pm 5 \mu\text{m}$, max tilt $\pm 50 \mu\text{rad}$, max decentering $\pm 40 \mu\text{m}$;

*Bozhong Gu, bzhgu@niaot.ac.cn; phone 0086-025-85482213; fax 0086-025-85405562

- ✓ Blind spot: 1 degree diameter;
- ✓ One Cassegrain focal station C1 and four Nasmyth focal stations. Two main Nasmyth stations are located at the central holes of the altitude axles and two additional are oriented at 90 and 270 degree with respect to the altitude axis.

The whole mount is schematically shown in Fig.1. The main task of structure engineer is to find a cost effective way to meet the above requirements. That is the main goal of this paper to show how to design the mount structure. These parts will be detailed in the following sections.

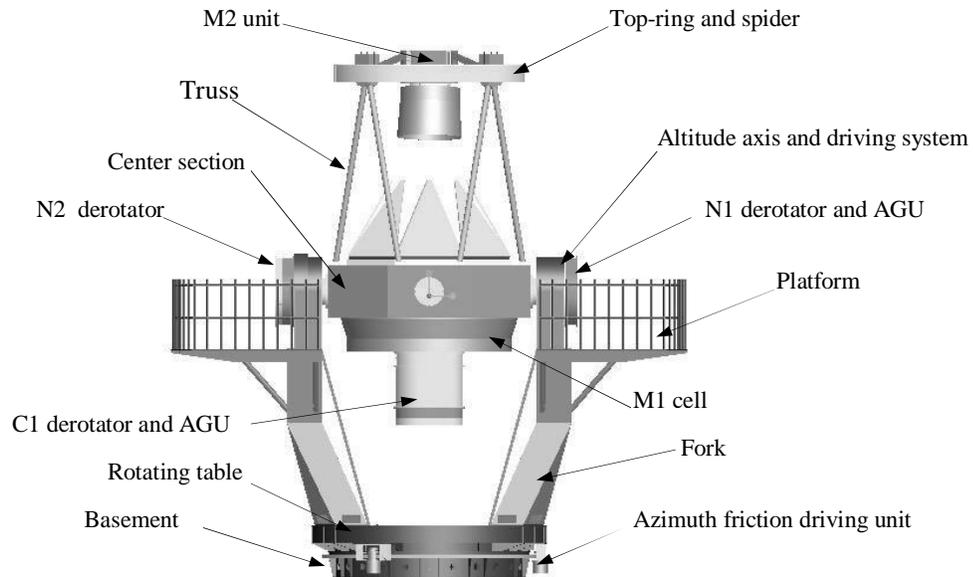


Fig. 1 3-D structure of the 2.5m mount

2. AZIMUTH AXIS STRUCTURE

The azimuth axis is a very important part which defines the radial and vertical position of the telescope. Another role of the azimuth axis is to work together with altitude axis to finish the telescope star tracking. The positioning task is fulfilled by basement and the azimuth tracking task is fulfilled by rotating table with the help of control system. Fig.2 (next page) shows the general structure of azimuth axis in 2-D drawing, mainly consists of basement, rotating table, vertical supporting bearing, radial centering bearing, azimuth driving unit and control feedback device.

2.1 Basement structure

The basement is an in-between part which connects the telescope with the foundation pier and transfers the vertical azimuth bearing loads from the telescope assembly to the supporting pier. In addition, the basement provides the friction drive surface for the azimuth drive and mounting surface for the azimuth encoders, azimuth bearings, and azimuth hydrostatic bearing oil collection system. So, for the basement, the normal requirements are as followings:

- ✓ High stiffness to weight ratio;
- ✓ High hardness to ensure the material having enough safe factor;
- ✓ High stability to keep the right position of telescope;
- ✓ Having the adjustment function to ensure the verticality of the mount;

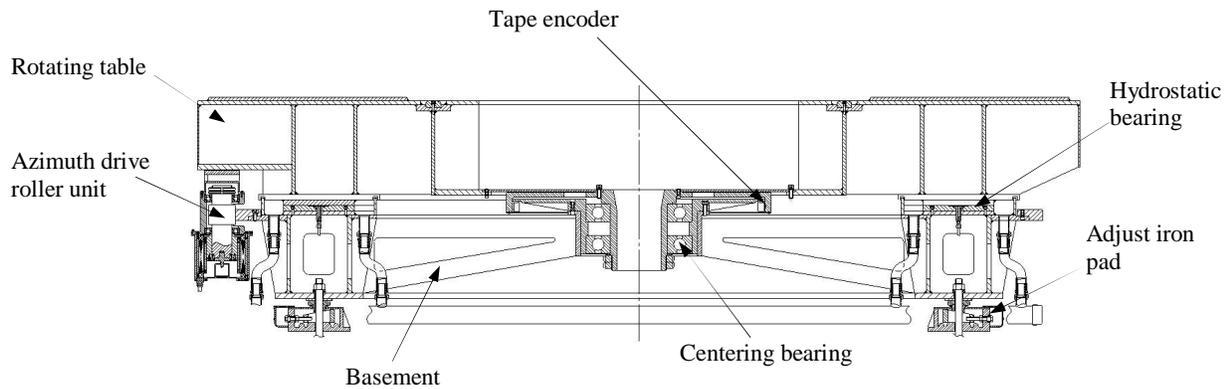


Fig. 2 Azimuth axis structure of 2.5m mount

- ✓ Having the function to centering the mount;
- ✓ Having perfect manufacturable;
- ✓ Easy to transport;
- ✓ Other things such as anti-corrosive;

The structure of 2.5m basement is shown in Fig.2. The envelop dimension is $\phi 3540\text{mm} \times 460\text{mm}$. It is a stiffness optimized plated structure fabricated from a kind of low-carbon steel and is machined from a single piece weldment. The basement will be fully stress relieved prior to final machining operations. The bottom of the basement will be connected to the concrete pier by means of total 12 anchor bolts embedded in the pier concrete in advance. Between the basement and concrete pier, there are corresponding 12 adjusting iron pads whose load capacity is 6 metric tons per unit. With the help of these adjusting pads, the levelness of the top of hydrostatic bearing pads, bolted on the surface of basement, can be adjusted to meet the requirement.

2.2 Azimuth bearing

The azimuth axis bearing system is comprised of radial bearing and axial (vertical) bearing. Rotation axis is defined by a couple of ball bearing with which to centering the rotating table while the telescope tracking the target. Inner ring of the ball bearing is attached to the shaft of the rotating table while the outer ring attached to outward of bearing housing welded to the base box, just as Fig.2 showing. The rotating table shaft is mounted to a flexure plate which will compensate the hydrostatic bearing oil thickness while the rotating table is pumped up or not. The axial preload will be applied to enhance the bearing stiffness and to increase its running accuracy. Inner diameter of the bearing is 260mm.

Externally pressurized, self-alignment hydrostatic oil bearing is used as axial bearing to support the telescope weight which is about 27 metric tons. The primary advantage of hydrostatic bearing is their ability to stiffly carry relatively large loads while allowing smooth, low friction, low stiction, and near zero hysteresis motion. The oil bearing pads are located on the top surface of basement by means of 27 bolts per unit and the oil bearing track is welded on the bottom of rotating table, shown as Fig.3. In this case, the oil inlet and outlet pipes

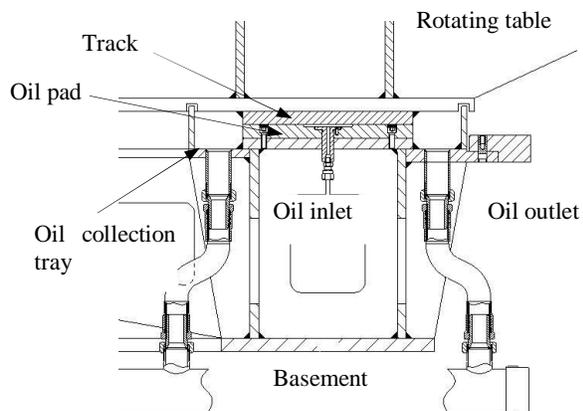


Fig.3 Structure of azimuth hydrostatic oil bearing

are going through the basement. That is to say, the oil pipes do not need to rotate during the rotation of rotating table, which will be helpful for the oil pumping system. The hydraulic pumping system is located in the dome room. Oil exit temperatures at the bearing pads will be maintained 0-0.5 deg below the ambient temperature to minimize the thermal input into the enclosure. Oil viscosities and pressures will be selected to sustain a nominal film thickness of approximately 100~150 microns to provide the required minimum bearing pad stiffness.

2.3 Azimuth drive

Friction drive was adopted as the azimuth drive system. Comparing to other drive systems, such as gear drive system, no backlash, no high-frequency periodic errors and easy manufacture are the main advantages of friction drive. By using relatively small driving roller, the drive motor can directly drive the big wheel, without the necessity of any gear reduction which will introduce motion errors. The main problem of friction drive is the slippage occurring on the contact surface of roller and wheel where the driving stiffness is not as high as the contact gears. Large acceleration and driven load variation are the main factors to introduce the slippage happening. But, for most of astronomical telescopes, also including this 2.5m telescope, the motion acceleration and driven load variation are not too large. What is more, for the 2.5m mount, the diameter of azimuth disc is $\phi 3660\text{mm}$ which can offer a large gear ratio if friction drive is used for the drive system. According to the experiment study results pointed out in the reference paper [3] and the experience gained from LAMOST project, the friction drive can get high drive accuracy in the state of slow rate, small acceleration, and little torque change, cleanness of contact surface and high precision of mounting alignment. Azimuth friction drive structure of 2.5m mount is shown in Fig.4. Fig.5 is the 3-D picture of a roller unit.

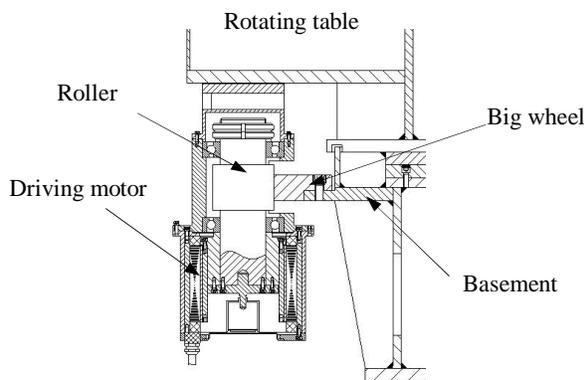


Fig.4 Structure of azimuth friction drive

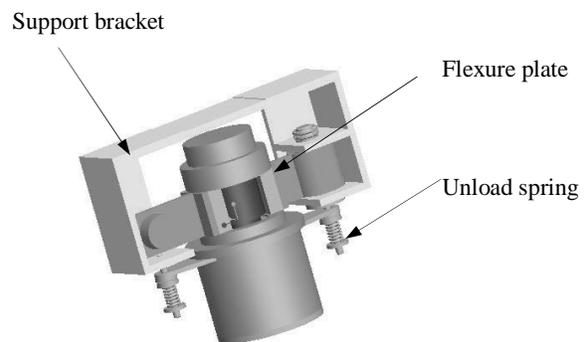


Fig.5 3-D of friction drive roller unit

There are three sets of roller units located around the big wheel (120-degrees apart) to minimize the eccentric caused by preload against the big wheel. The friction rollers are 90mm thick and 120mm in diameter with a small crown. The cylinders are made of an alloy of steel, heat-treated to a Rockwell C hardness of 55, which has minimum yield strength of 540 Mpa. After the heat treatment, the rollers will be finished with a grinder to remove the oxide layer so that the surface roughness Ra will meet the surface requirement, such as 0.8 μm . The contact (Hertzian) stress between the roller and wheel should be kept at an acceptably low level to avoid damaging the rollers while maintaining sufficient friction force to avoid any slippage under normal operation. The diameter of big wheel is 3660mm with 50mm thick which is made of a kind of alloy steel. The friction torque of 2.5m telescope is 52.5Kg.m and the acceleration torque is 308.9Kg.m. So, the total driving torque is 361.4Kg.m. The length of contacting cylinders is 50mm. Assuming a steel-to-steel coefficient of friction of 0.11, so the normal force required to allowing adequate roller traction without slippage is about 6000N, which is applied by a compress spring. The maximum contact stress between roller and big wheel, with Poisson ratio of 0.3, is given as the following equation:

$$\sigma_{j\max} = 0.418 \sqrt{\frac{QE_d k_d}{b}}$$

Where: Q is the normal force applied on the roller, E_d is the equivalent Young's modulus.

$k_d=k_{11}+k_{12}+k_{21}+k_{22}=1/r+0+1/R+0$, r is the diameter of roller; R is the diameter of big wheel.

B is the contact length

Taking in the design parameters, the maximum contact stress is 194 Mpa, less than the limited stress.

The rollers are mounted in the roller housing through angle-contact bearings and the roller housing is supported by two elastic plate made of spring steel, just as Fig.5 shows. The stiffness of the elastic plate in the tangential direction is $1.85 \times 10^4 \text{Kg/mm}$ and 32.5Kg/mm in the normal direction. This allows the roller assembly to be pressed to the wheel surface to compensate for the surface runout of the big wheel. The torque motor is in line with the drive shaft by use of a high stiffness coupler.

Heidenhain tape encoder ERA780C will be used as position feedback device to the control system. The resolution is better than 0.01 arcsec with 4 readings. Tape is mounted on the rotating table and readings are mounted on the basement through a stiffening plate.

3. ALTITUDE AXIS STRUCTURE

The altitude axis is shown in Fig.6 and is comprised of three major components: altitude shaft, altitude bearing and altitude drive system. The Optical Support Structure (OSS) is supported by the altitude axis and the weight of them is transferred from the altitude bearings to the azimuth table through two side yokes.

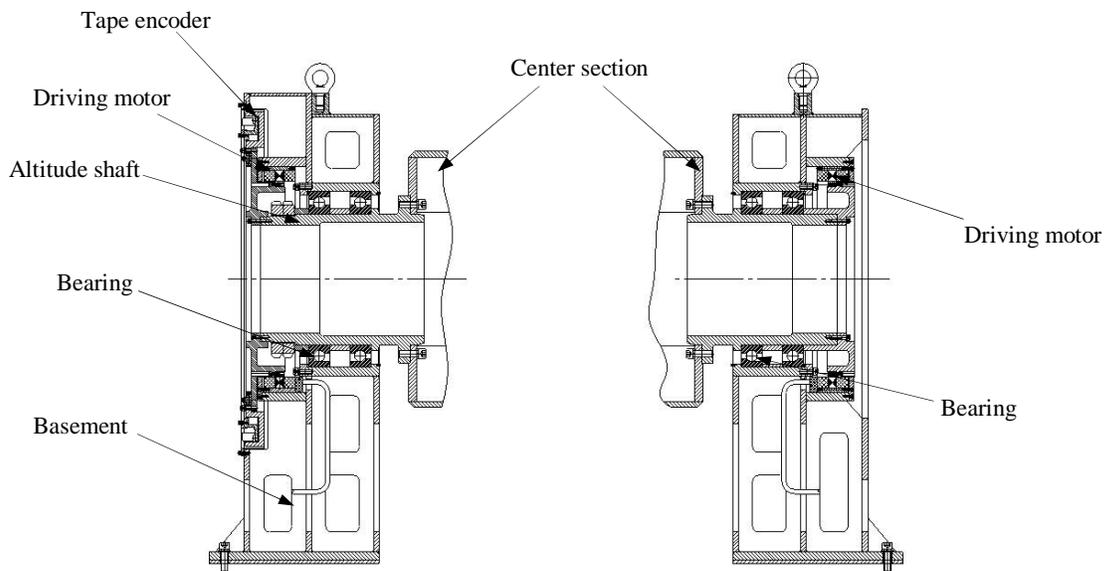


Fig.6 Altitude axis structure

3.1 Altitude shaft

Altitude shafts are important parts, with $\phi 380\text{mm}$ inner hole for light going through to Nasmyth foci, to support the OSS weight through center section and locate the position of the center section. The weight for each altitude shaft to support is 7.1 metric tons. The most important thing for the two side shafts is the identity which will have influence on the orthogonal of azimuth axis and altitude axis. On the other hand, it will introduce error to altitude axis tracking. The parameters of shaft are optimized by FEA to ensure its stiffness.

3.2 Altitude bearing

A kind of angle contact bearing is adopted to support the altitude shafts shown as Fig.6. This kind of bearing can bear the axial and radial load simultaneously, total 4 bearings for altitude axis. Inner diameter of the bearing is 460mm. A certain preload is applied to the bearing to release the backlash and enhance the rotation stiffness. The weight of OSS is about 14 metric tons which will be transmitted to azimuth table through fork. Fork is a steel weldment monocoque structure just as most mid-sized ground-based telescope mounts because it is a relatively mass to efficient structure and lends itself well to carrying loads. Another advantage of monocoque fork is that it will easy installation on site as a single art. The thickness of the weldment steel and the reinforce rib arrangement are optimized by FEA software ANSYS. Structure of the fork is shown as Fig.7.

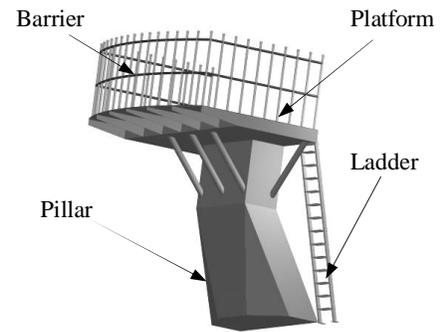


Fig. 7 Structure of fork

3.3 Altitude drive

Just as Fig.6 showing, the direct drive is adopted as the drive system for the altitude axis, rather than friction drive as azimuth drive in order to make the altitude structure compactable, and then to decrease the azimuth rotating table size. Two motors will be used to drive the altitude axis at the two sides. Friction torque of altitude axis is 49.6 Kg.m and acceleration torque is 110.6 Kg.m with $1^\circ /s^2$ acceleration. For the 2.5m telescope, the amplitude of the altitude rotation is from 5 degrees to 89.5 degrees with respect to horizon. Considering the 2.5m aperture, the M1 cell will also suffer the wind force. Wind force is given as the following formula:

$$F_{wind} = 0.5C_D \cdot \sigma_{air} \cdot V^2 \cdot A$$

Where: C_D is the drag coefficient $\equiv 1.0$ for this estimate;

σ_{air} is the air average density, 1 Kg/m^3 at 2100 meters high where the telescope will be mounted;

V is the wind speed, 50 km/hr according to the telescope specifications;

The wind torque around the altitude axis is given in the following Table 1.

Table 1 Wind torque applied on altitude axis

Item	Area Exposed to Wind (m ²)	Wind Force (N)	Area c.g. Distance from Alt. (m)	Wind Torque (Kg.m)
Top-ring	0.936	90.29	3.728	33.66
Vanes	0.56	54	3.854	20.8
M2 box	0.42	40.52	4	16.2
M2 cell (baffle)	0.73	70.42	3.188	22.45
Truss	1.4	135.06	2	27
Mirror cover	2.61	251.78	1.2	30.2
M1 baffle	0.36	34.73	0.65	2.26
M1 baffle spider	0.2	19.3	0.52	1
M1 cell	1.58	152.42	0.766	-11.68
Total Wind Torque Applied on altitude axis				141.89

So, according to the above calculation, the total driving torque is about 302 Kg.m which will be offered by two brushless frameless torque motors. Preliminary the motor will be chosen from Etel motor company for its good performance experienced from LAMOST project. It can be seen from the general drawing Fig.1 that the altitude motors are close to

the optical path. So, more attention must be paid to the motor heat dissipation control in order to ensure this will not degrade the image quality and surround seeing.

Heidenhain tape encoder ERA780C will be used as position feedback device to the control system just as azimuth axis. The resolution is better than 0.01 arcsec with 4 readings and interpolation and counter IK220 card. Tape is mounted on the altitude bearing housing and readings on the altitude shaft through a plate.

4. CENTER SECTION

The structure of center section is shown in Fig. 8, which is a weldment part with common steel plates. High stiffness to weight ratio is its main design requirement which is finished by finite element software. The weight of center section itself is about 4.6 metric tons and it will be supported by altitude bearings through altitude shafts described as above. Primary mirror cell is attached directly under the center section through 18 M24 screws. The weight of the down attached parts is 6.8 metric tons. On top surface of center section, there are 8 fine machined planes, shown as Fig.8, to mount the telescope tube which supports the top-end parts, including secondary mirror, mirror cell, M2 positioning unit, connecting box, etc. The structure of center section is symmetric to altitude axis.

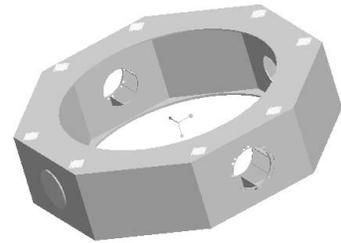


Fig.8 Structure of center section

Besides two $\phi 460\text{mm}$ holes to allow large optical beams through it to N1 and N2 foci, there are two $\phi 350\text{mm}$ holes for two additional student Nasmyth foci located at 90° and 270° orientation starting from the altitude axle hole. These student Nasmyth foci will be used in future and now they are covered with circular plates, as picture shows.

5. M2 POSITIONING SYSTEM

M2 positioning system is used to correct the misalignment of the secondary mirror with respect to the primary mirror, which is mainly due to thermal effect and mechanical distortion induced by telescope elevation changes during the operation. The misalignment includes three factors: defocus (Δz), decenter (Δx , Δy) and tilt ($\Delta \theta_x$, $\Delta \theta_y$), total 5 freedoms. The 2.5m telescope will equipped with a kind of hexapod to correct the main aberrations introduced by mirrors misalignment and distortions. Hexapod is composed of support structure and control system. Support structure consists of six parallel movement suit, mobile plate, fixed plate, and corresponding control system. M2 cell is attached to mobile plate and the fixed plate is attached to center box of top ring. The weight of M2 mirror and its cell is about 250Kg which is the load for hexapod to support. According to the general configuration, the space left for hexapod in optical direction is only 250mm which is a big challenge for hexapod designer. Control system is applied to the structure to introduce the corresponding movements. Real-time capability, precision in positioning and smoothness of the movement are the main characteristics of the hexapod control system. The motion performance is listed in the following Table 2.

Table 2 Specifications of M2 positioning system

Hexapod performance	Centering		Focus		Tilt	
	Ideal requirement	Minimum requirement	Ideal requirement	Minimum requirement	Ideal requirement	Minimum requirement
Range	$\pm 6\text{ mm}$	$\pm 4\text{ mm}$	$\pm 8\text{ mm}$	$\pm 6\text{ mm}$	$\pm 1^\circ$	$\pm 0.5^\circ$
Max speed	0.5 mm/s	0.25 mm/s	0.5 mm/s	0.1 mm/s	6 mrad/sec	2 mrad/sec
Resolution	1 μm	2 μm	1 μm	2 μm	2 μrad	4 μrad
Repeatability	$\pm 4\text{ }\mu\text{m PTV}$	$\pm 10\text{ }\mu\text{m PTV}$	$\pm 2\text{ }\mu\text{m PTV}$	$\pm 4\text{ }\mu\text{m PTV}$	$\pm 5\text{ }\mu\text{rad PTV}$	$\pm 1\text{ }\mu\text{rad PTV}$

6. M3 POSITIONING SYSTEM

For the 2.5m telescope, there are two Nasmyth foci and two student Nasmyth foci and one Cassegrain focus. M3 positioning system is used to transfer the light beam to these foci according to the observing arrangement and to ensure the alignment between optical elements. The requirements for M3 positioning system, according to the telescope general specifications, are as followings:

- ✓ Having the ability to change between Cassegrain focus and Nasmyth foci according to the observing configuration.
- ✓ Once M3 is escaped, light has free access to the 1° Cassegrain field of view.
- ✓ Positioning unit will be within the center section.
- ✓ M3 alignment (initial or after each installation) with the optical axis (M1-M2 axis) on the one hand and with the elevation axis on the other hand will be performed with a tolerance of 0.5mm.
- ✓ With respect to the 2 orthogonal axes, M3 unit shall be adjustable, the adjustable range is $\pm 0.5^\circ$ with a precision of $1''$.
- ✓ The support structure (spider) will be in the shade of the M2 support structure to minimize the light obstruction.
- ✓ Positioning system will ensure M3 mirror locking in 4 orientations for 4 Nasmyth foci, 90° apart.
- ✓ Angular positioning and locking accuracy shall be better than $10''$.
- ✓ Repeatability shall be better than $2''$ RMS, orientation stability will be better than $6''$.
- ✓ Time to go from one Nasmyth position to the other shall be less than 2 minutes.
- ✓ Accuracy of mirror re-installation in the Nasmyth path will be better than $10''$.
- ✓ M3 positioning system escape time shall be less than 2 minutes.
- ✓ Translation adjustment range along Nasmyth axis (N1-N2) is 5mm with the precision of 0.01mm.
- ✓ The M3 positioning system can be removed completely and easily with a crane to provide full access to the Cassegrain focus.
- ✓ The power supply of the M3 position system can be turned off while keeping the last position obtained before the power supply is turned off.
- ✓ The M3 positioning system shall be ease the maintenance.

We proposed a structure, shown as Fig. 9, to meet the above requirements. The structure is composed of three main sub-

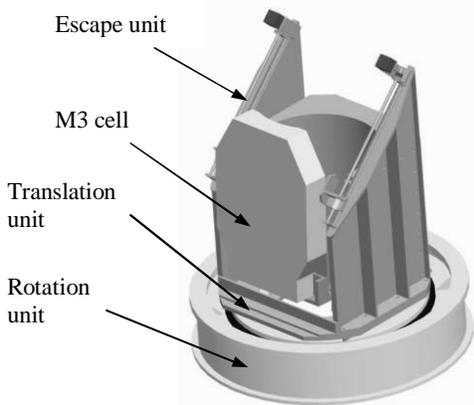


Fig.9 M3 positioning system

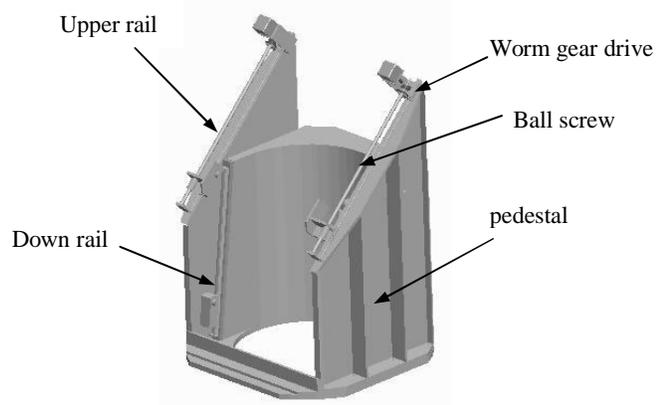


Fig.10 M3 escape unit

parts: escape unit, rotation unit and translation unit. The room left for M3 escape is very small. So, the escape motion consists of two linear movements, just as Fig. 10 shows. M3 cell is supported by a U shape welded supporting structure through 3 bolts . The supporting structure is optimized to ensure high stiffness and to keep M3 cell free from outside stress. The supporting structure is positioned by 4 ball rails through 4 corresponding blocks of rails mounted on a stiffing pedestal, shown as Fig.10. The motion is driven by the combining of worm gear and ball screw. Here, the main reason using worm gear is to prevent free play. Linear encoder is used to feedback the position information to control system. There are switches and hard ends to ensure the safety of the motion. Besides the escape function, the tilt adjustment of the M3 will also be fulfilled by this system.

The motion of translation along Nasmyth axis is driven by slide screw along the ball screw rails. The position is controlled by linear encoder through motion control system. A spring is used to release the backlash of the slide screw.

Rotation system is composed of supporting roller bearing, spur gear drive, driving motor and position feedback tape encoder. Two set of pinions are arranged 180° separate to release the backlash of the system and driven by two servo motors. The diameter of the gear is 900mm with 30 gear ratio.

7. CONCLUSIONS

This paper is only to introduce the structure design of the 2.5m telescope mount. The corresponding FEM analyses and optimization of the structure is also proposed in this Conference (7018-159). The mechanical design shows that the sub-assemblies can meet the requirements from the operation functions. On the other hand, the FEM results show that these structures can meet the stiffness requirement to bear outside load, such as gravity load, wind load and the first eigenfrequency requirement (7 Hz). The 2.5m telescope mount now is in the stage between Preliminary Design Review (PDR) and Critical Design Review (CDR). The parts introduced in this paper are the main sub-assemblies of the mount. Others, such as Derotator and Acquisition and guiding unit are in the design stage because some of the parameters are not determined.

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