The pre research of the deploy technology for the large aperture space astronomical telescope

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ABSTRACT

The spherical primary mirror (Mb) of the Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) is segmented and composed of 37 hexagonal sub-mirrors, and segmented active optics method is successfully developed in it. LAMOST project has passed through the project acceptance in 2009. The success of LAMOST makes deployable primary mirror possible. The deployable large aperture space astronomical telescope is one of the most development potential space observation spacecrafts in the future. This paper is targeted at the reflecting Schmidt telescope LAMOST, which has a 6.67X6.05m primary mirror. The feasibility of the deployable structure of the large reflecting space telescope's primary mirror has been mainly researched. The analysis of the design scheme for the deployable primary mirror has been carried out, and according to the feature and the design of LAMOST, a subdivision type deployment scheme has been given; The locating principle of the both side wings and the locking device after deployment has been analyzed; In addition the problems in the process of deployment is also preliminary discussed. This paper is targeted at the reflecting Schmidt telescope LAMOST, which has a 6.67X6.05 primary mirror. The feasibility of the deployable structure of the large reflecting telescope's primary mirror has been mainly researched. The analysis of the design scheme for the deployable primary mirror has been carried out, and according to the feature and the design of LAMOST, a subdivision type deployment scheme has been given; The locating principle of the both side wings and the locking device after deployment has been analyzed; In addition the problems in the process of deployment have been preliminary discussed.

Keywords: LAMOST, space telescope, feasibility, deployable primary mirror, scheme

1. INTRODUCTION

Along with the development of astronomical technology, astronomers hope to observe the events of the early universe, the much farther objects and more detail of the objects, which requires the development of the larger aperture, higher resolution ground and space astronomical telescope.

Due to the thick atmosphere, some restrictions have been put on the ground-based telescopes. The atmosphere affects the observation in two aspects, at first because the atmospheric disturbance effects, the point light source after becomes a fuzzy spots after the light passes through the atmosphere, which greatly reduces the resolution of the telescope, and makes the large ground telescopes barely to achieve the diffraction limit; Secondly, the ozone in the atmosphere strongly absorbs the UV light and the water vapor absorbs most infrared radiation, so the band of the ground telescopes have greatly curtailed. In addition, the atmospheric dispersion effect also has an impact on the observation of the ground base telescope.

The space telescopes have clear advantages compared with ground-based telescopes. Because the space telescopes can completely get rid of the influence of the Earth's atmosphere, they can get higher resolution and much more the observation band. Hubble Space Telescope (Figure 1) is the largest space astronomical optical telescopes, which is a cooperative project of the U.S. NASA and European Space Agency. Its primary mirror aperture is 2.4 m, and the tube diameter is 4.27 m, the entire length of the telescope is 12.8m and weigh is about 11.6 tons, which is mainly used for the visible and near infrared observations. Hubble Telescope has made noteworthy achievements at the age of the universe, star formation, black holes and other aspects. Because the Hubble Space Telescope is about to retire, the United States is developing a new generation of space telescopes, James - Webb Space Telescope (Figure 2) to replace the Hubble telescope..

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Figure 1. Hubble Space Telescope

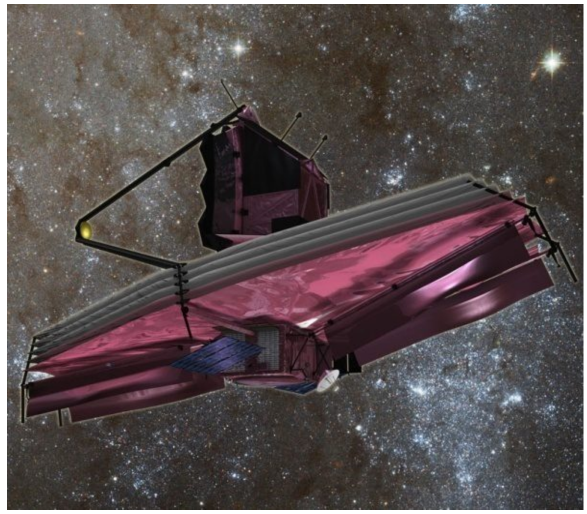

Figure 2. JWST space telescope

The research on the space telescope has just start in China, the current research project is the Space Solar Telescope (SST), which is a one meter optical telescope and is mainly used to observe the sun. In addition, there is no large-aperture space telescope plan. The development of large-diameter deployable space telescopes has great significance to China's astronomy and space technology. To make China's astronomy and astronomical instruments to fully walk in the international front, we should take advantage of the successful development of the segmented mirror and thin mirror (a deformable mirror) active optical technology, ultra-thin mirror the development of new technologies such advantages as soon as possible to carry out pre-study programs and key technology of large diameter space telescope.

2. THE STRUCTURE OF THE PRIMARY MIRROR (MB) OF LAMOST

The spherical primary mirror MB (Figure 3) of LAMOST (Figure 4) consists of 37 hexagonal sub-mirrors. The diagonal size of each sub-mirror is 1.1 m, the thickness is 75 mm, and the weight is 150 kg. The width of the spherical primary mirror is 6.05 m and the height is 6.67 m. The floating support structure (whiffletree) has been used on the MB sub-mirror, In order to easily adjust the sub-mirror's position and orientation, the axial and radial position of the sub-mirror have been separated, two positioning mechanism is arranged in the back of the sub-mirror, so the sub-mirror room space is relatively compact. Before the start of the observation, the attitude of the sub-mirror has to be adjusted using the segmented active optical methods to get the optical index meet the observational requirements. In the observation process, the state of the primary mirror remains intact.

Figure 3. The primary mirror (MB) of LAMOST

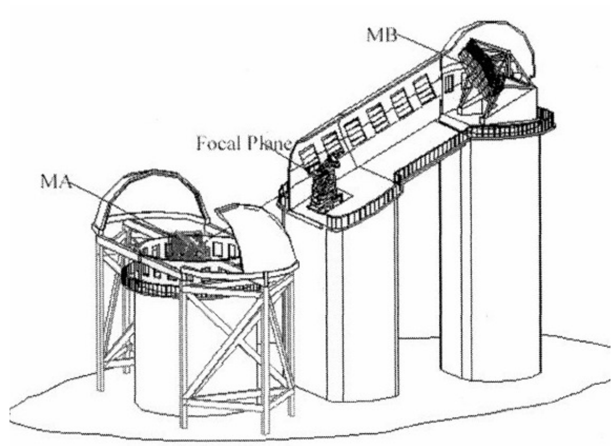

Figure 4. LAMOST.

There are three displacement actuators behind each MB sub-mirror, the sub-mirror just generate translation driven by the contact of the displacement actuators, so the attitude modification of the sub-mirror can be controlled by a computer. At the edge of each sub-mirror there are two capacitive displacement sensors, the capacitance will change when two adjacent sub-mirror's relative displacement has been changed, and this relative displacement can be measured thanks to the capacitance sensor. Assuming one of the sub-mirrors could not be move, the remaining 36 sub-mirrors have 105 displacement actuators and 168 displacement sensors, the displacement of each displacement sensor is a linear function of the other 6 sensors of the two adjacent sub-mirrors. Using the A / D converter the displacement of the sub-mirror can be got, which then be transferred to the closed-loop control system as a feedback signal. The adjustment range of the displacement actuator is ± 1mm and the accuracy is less than 50nm.

Thanks to the structural characteristics of LAMOST, there are several advantages in the primary mirror split program. The mechanical precision has been reduced in the progress of the deployment, leading the deployment of the primary mirror can come to true.

3. THE ANALYSIS OF THE SCHEME OF THE PRIMARY MIRROR'S SPLIT AND FOLD

The research of the launch vehicle of China starts in 1956. Since the self-developed medium-range rocket had a successful test flight in June 1964, the Long March series rockets have been successfully launched for hundreds of times, and China already has the ability to undertake international launch jobs, and occupies a place in the international launch market. At present the diameter of the core level of the Long March rockets in the service is 3.35 m, with a maximum thrust of about 2961 tons. The Long March V rocket in the research has a 5m core level diameter, and the maximum thrust is estimated to be 8220 tons.

Due to the launch vehicle's carrying capacity, on one hand the lightweight primary mirror design has to be used to reduce the launch weight, on the other hand for it is impossible to directly launch a 6m telescope at present, the aperture of the telescope's primary mirror has to be limited. In order to adapt the launch requirements it is necessary to decompose the primary mirror into several small size of the sub-mirror, to reduce the size of primary mirror, it will be folded before the launch; launch vehicle will be sent to the telescope into the booking orbit, then the sub-mirror will expand and fixed, to make it into a full primary mirror after the telescope has been sent to the orbit. The 6 meter class space telescope could be launched by this way. Therefore, the fold-able primary mirror design is an important method of large-aperture space telescope at present stage.

There are two methods to expand the primary mirror, which are petal style and the stack style.

The petal style scheme is similar to the expanding of the petals, in general the primary mirror can be divided into two parts, the central sub-mirror section and the surrounding sub-mirror section. The central part is fixed and the surrounding parts links to it through several hinge parts. Before launch the surrounding parts would rotate a certain angle along the hinge according to the pre-designed scheme by some mechanical parts, which make the surrounding sub-mirror stay at back or front of central sub-mirror to reduce the primary mirror.

In the stack style scheme the primary mirror is composed of 7 hexagonal sub-mirrors, the 6 surrounding mirrors arrange along the 6 lines of the central mirror to form a segmented mirror. Before the launch the 6 surrounding mirror would be lifted to the top of the central mirror according to some pre-designed scheme. The aperture of the folded primary mirror is equivalent to the aperture of the central sub-mirror. The sub-mirror could be expanded and fixed according to the fold reverse order after the launch.

Compared to the petal style the launch diameter in the stack style scheme is relatively small, but the mechanical structure is more complex. In addition considering the large space telescope the size of the each sub-mirror in the stack style scheme is larger than in the petal style. For example, if a 6.4m primary mirror is split into 7 sub-mirrors, each hexagonal sub-mirror's diagonal diameter is about 2.4m, thus the manufacturing costs and difficulty are greatly increased.

Though the hinge is also used in the petal style scheme, the mechanical structure is relatively simple, and the number of the hinges is less. Thereby the requirements for machinery and electronic control are greatly reduced and the folding progress in the ground and the unfolding progress in the space will be much easier and reliable.

In the petal style scheme the Ball Aerospace scheme is a typical one, in which scheme the primary mirror is composed of several hexagonal sub mirrors, and the mirror is separated into 3 parts, known as the middle part and the left and right flank part. Before launch, both sides of the wing parts respectively rotate about 90 degrees along the emission direction as the axis backwards, and placed at the both sides of the primary truss. The advantage of this scheme is that the fixed part of the primary mirror is relatively large, however the launch diameter is reduced significantly, both sides of the symmetric wing part of the structure is relatively simple, at the same time the folding and unfolding trajectory is simplex, so by this method the success rate could be greatly increased and the risk of the launch could be greatly reduced.

The width of LAMOST primary mirror (Figure 5) is 6.05m, which greatly exceeds the diameter of the launch vehicles in China, even by the Long March 5 whose core diameter is 5m it is impossible to launch the telescope. So in order to launch this level telescope it is necessary to find a method to split and fold the primary mirror.:

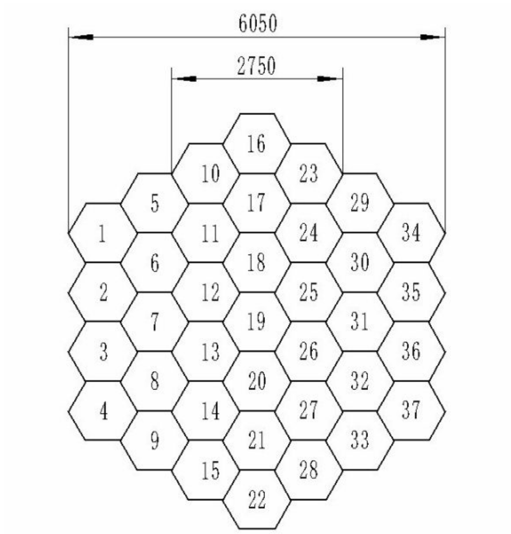

Figure 5. The segmented primary mirror of LAMOST

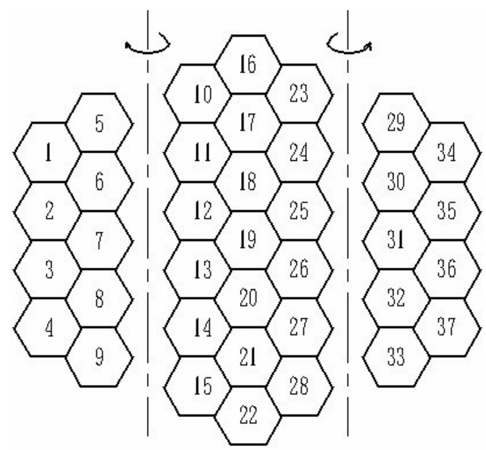

Figure 6. The split schematic of the mirror

The primary mirror of LAMOST could be divided into 7 columns, which are symmetrical, if the 1st and the 2nd column in the left and the 6th and 7th column in the right could be regarded as the two wings, and the 3rd, 4th and 5th columns as fixed central part, the largest width of the mirror could be reduced to 2.75m. The left and the right wing parts can respectively rotate along the axis as the figure 6 and they could be folded and fixed just in the left and right side of the truss of the central parts. When the telescope's primary mirror was sent to the launch vehicle the optical axis of the primary mirror would keep horizontal, at the same time the secondary mirror and its truss would need to fold too. By this way the launch size of the primary mirror could be reduced to 3m to 3.5m level, so the launch size limit for the telescope could be broken, and the large telescope could be sent to the space by the existing rockets, even it could be realized to launch a 6.5m class large space telescope.

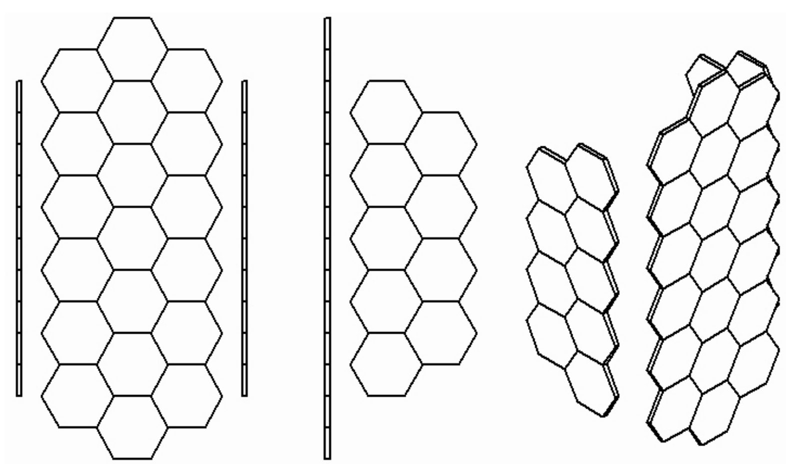

Figure 7. The effect after the folding of the primary mirror

It could be seen that from the folding renderings, the folded primary mirror's size is about half of the unfold one (about 3m), so the launch size is greatly reduced, and after the mirror is folded, the driven mechanism and the terminal instruments could be placed in the room, which is between the two wings and the back of the primary mirror. Because the size of whole primary mirror room can be reduced to the half of the width of mirror, it is ensured that the telescope could meet the size and load of the launch vehicle's requirements.

4. THE FOLD DRIVING AND LOCATING DEVICE OF THE WINGS

Space Telescope mirror room and support truss are the main carrying body of a telescope, which play important roles of the support of the primary mirror and the connection of the payloads and subsystems. To ensure the quality of optical imaging, the stiffness, strength and stability of the mirror room and support truss require strictly, which have to endure not only the gravity of every parts but also the load of launch movement to prevent the parts' permanent deformation during the launch progress. When the system is designed we have to be careful to avoid the telescope's inherent frequency meeting the launch vehicle's vibration frequency. At the same time the position accuracy and the stability of the wings has to be ensured when the segment mirror is deployed in the space. Therefore, it is particularly important to study the primary mirror's positioning and locking mechanism after the deployment

As we all know the spatial position of the object that has not been located is uncertain, that is the degrees of freedom (DOF). In the Cartesian coordinate system an ideal rigid body only has 6 DOFs. As shown in the figure 8 the object could not only move along axis Ox, Oy, Oz, called translational DOF dx, dy, dz, also could rotate along the three axes, that is called rotational DOF, rx, ry, rz.

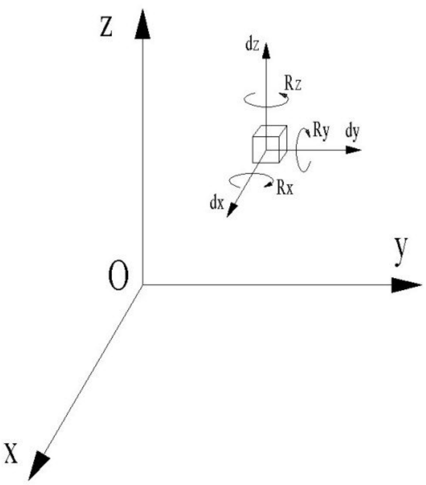

Figure 8. The Cartesian coordinate system

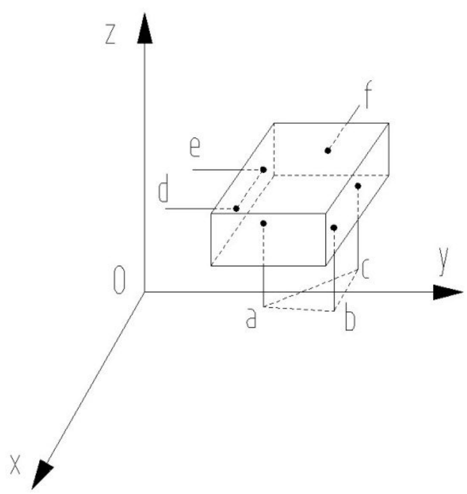

Figure 9. The supporting point

If the position of a free rigid body could be defined in space, it's necessary to set 6 constraints to respectively constrain the 6 DOFs of the rigid body. In the position analysis of the rigid body one point is used to position the rigid body, but at least 6 constraints are used to restrain the body's all 6 DOFs. As it's shown in Figure9, the point a, b, and c are respectively used to restrain the body's 3 DOFs, Rx, Ry, dz; the support points d and e are used to restrain the DOFs, dy and Rz; and the point f is used to restrain the last DOF, dx, so the rigid body's all 6 DOFs could be restrained. Most of the large mechanical equipment uses this method to position.

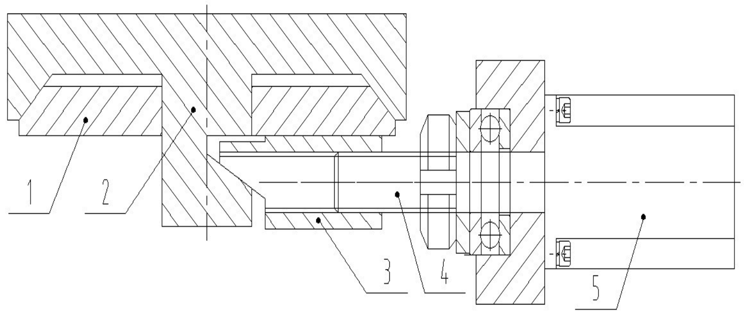

Figure 10. The locating and fixing mechanism

It is required very high repeat positioning accuracy in the wing fixing progress, the self-supporting structure (Figure 10) is commonly used for flat position. The advantage of this structure is no need to set the adjusting mechanism, the structure itself can automatic guide, and the repeat positioning accuracy could be very high. As it is shown in the Figure, object 1 and 2 is a spherical pair, when the wing of the primary mirror was driven by a stepping motor to a predetermined position along a hinge, the spherical pair automatic combined, and then the motor drives the wedge-shaped latch by the T-screw (4) until the preload was applied to the spherical pairs, to achieve the purpose of locking.

The folding drive structure includes a pair of hinge mechanisms, and drive mechanism. The hinge in the pre-launch and launch process could bear part of the weight of the wing of the primary mirror. When the telescope has reached the preset orbit the wing of the primary mirror would be totally fixed by the locking mechanism, and the hinge will no longer supply the supporting force for the wing. In order to not affect repeat positioning accuracy of the structures, the hinge and the locating and locking mechanism could not interfere with each other, so it is required that a suitable gap has to be designed for the hinge mechanism, so that the hinge would not interfere the position accuracy when the wings rotate to the default position to preload by the hinge structure.

5. BRIEFLY DISCUSSES ABOUT THE DEPLOYMENT PROCESS

Before the telescope is launched, the wings of primary mirror are folded and fixed on both sides of the truss, and the fixed structure can bear part of the primary mirror's weight in the pre-launch and launch process, when the launch is complete, the structure can automatically release. The wing fixture can use explosive devices, which is already a mature technology and generally used in space launch. But the distribution points of the explosive devices should be paid attention to, and the primary mirror should appropriate suitable protection to ensure its safety.

To ensure the primary mirror to successfully deploy the deploy device and the locking mechanism should be backed up design, and could not interfere with each other.

In order to adapt to the space environment, the deploying and the locking mechanism should use a good thermal stability, resistance to low temperature and high strength alloys.

To reduce the launch weight, the high-strength lightweight materials should be used, and the structure has to be optimized in the design. The lightweight design will be used under the premise of ensuring the mechanical properties.:

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