Research on mirror lateral support of large astronomical telescope

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ABSTRACT

Mirror support system of astronomical telescope is composed of axial support and lateral support. In traditional telescope, because the contribution of lateral support to surface distortion is less than axial support, there are usually few lateral support methods such as lever counterweight, hydrostatic pressure and steel strap in the past. With increase of diameter to thickness ratio and use of strongly concave mirrors, lateral support is becoming more complicated and important than before. At the same time, application of segmented mirror make it impossible to support periphery of mirror, so, some new schemes have been designed to meet requirement of large segmented-mirror telescope. This paper introduces some classic and recent methods of lateral support for large telescope and gives some results of finite element analysis.

Keywords: Astronomical telescope, mirror lateral support, finite element analysis

1. INTRODUCTION

The mirror of large astronomical telescope is susceptible to deformation due to gravity. Release of gravitational effects have to be considered in the case of mirrors fabricated, tested and mounted on the telescope. Traditionally, the mirror support system includes the axial support and lateral support. Although the deformation of mirror is usually more sensitive to axial support, the lateral support is a crucial factor to maintain good mirror figure when telescope is used to observe the celestial objects.

2. THE RELATION OF MIRROR FIGURE AND LATERAL SUPPORT

When the telescope point at the horizontal-axis the largest deformation of mirror that caused by lateral support occurs. The gravity and support force of mirror is perpendicular with the normal direction of mirror (figure 1). In this case, the main influence factor of mirror figure is the deformation along Z-axis. Because of the co-operation of gravity and support force, the mirror occurs poissons effect and the strain ε_Z can be calculated according to the below equation:

$$\varepsilon_Z = -\frac{v}{E}\left(\sigma_X + \sigma_Y\right)$$

In this equation, σ_X and σ_Y is the stress along X and Y direction, v is poissons ratio and E is elastic module of mirror material, especially σ_X is determined completely by the lateral support. Mercury tube mount, as a typical lateral support, causes the stress along the X direction as the $\sigma_X = -K(1-\cos\theta)\sin\theta$. In here K is constant and θ is polar angle of lateral support force.

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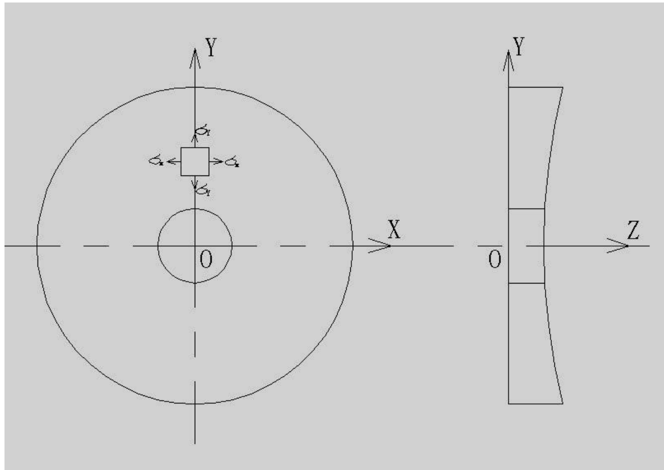

Figure 1. Stress distributing of mirror with lateral support

3. CLASSICAL LATERAL SUPPORT

3.1 Mercury tube mount

The mercury tube mount is usually used for lateral support of large mirror (figure 2). This type of force field results closely when is floated against an annular mercury-filled tube located between the mirror and a rigid cylindrical mirror cell. The width B of the tube is chosen so that the mirror can be floated. If G is weight of mirror and R is radius of mirror, ρ is density of mercury, then B can be selected according to below equation: $B = \frac{G}{\pi R^2 \rho}$

A the same time, the axial location of the tube center should coincide with the plane through the center of gravity of the mirror in order to avoid creating an overall moment.

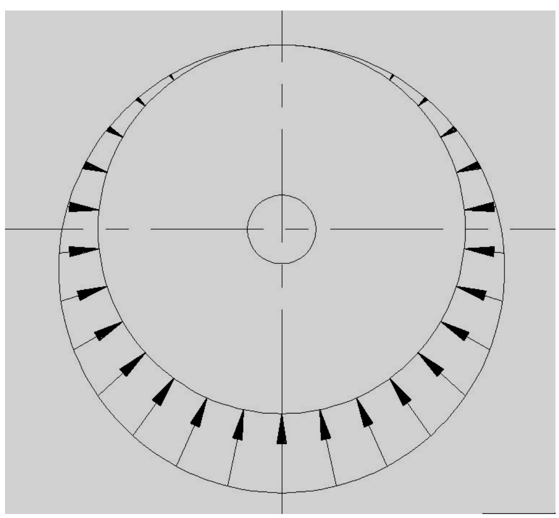

Figure 2. Compressive force scheme with mercury tube lateral support

3.2 Steel strap mount

The steel strap lateral support offers not only high performance but also simplicity so it is quite popular for commercial and custom applications. The strap supports the lower half of the mirror's rim by applying a continuum of compressive forces directed through the mirror center of gravity (Figure 3). If it can be assumed that there are no any friction along circumferential direction, the normal compressive forces Q is equal at any place, Q can be calculated according to below equation (G is weight of mirror and R is radius of mirror): $Q = \frac{G}{2R}$

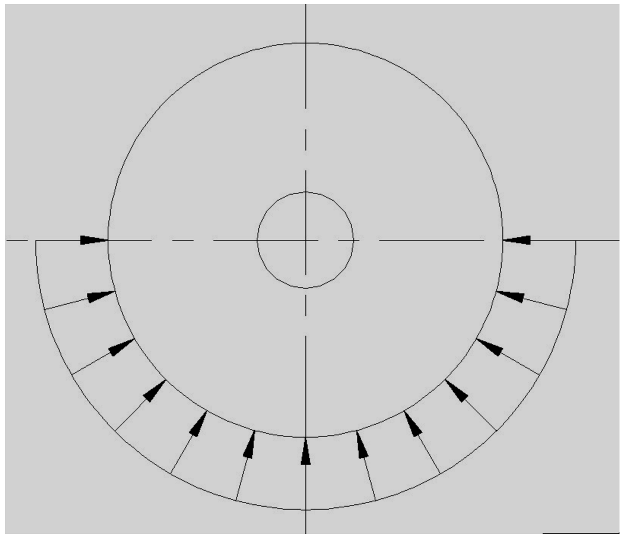

Figure 3. Compressive force scheme with steel strap lateral support

3.3 Lever counterweight mount

The above two methods is usually used during mirror fabrication and test. When mirror is mounted to the telescope, the lever counterweight is most popular support ways in past. Even the mirror with diameter 4m also can be supported very well. Ideally, the edge forces exerted by lever counterweight can push up in the lower half of the mirror and pull up on the upper half. The forces should also act in the plane containing the center of gravity of the mirror so that overturning moments are avoided. The most important advantage of lever counterweight is that each support force of floating point can change automatically with variation of direction of gravity, so electric control system is unnecessary. The figure 4 show a push-pull forces scheme, a series of counterweighted radial levers arranged so as to exert parallel push-pull forces on the mirror's edge, the forces are equal in magnitude, support equal-weight vertical slices of the mirror and act in a plane through the mirror's center of gravity.

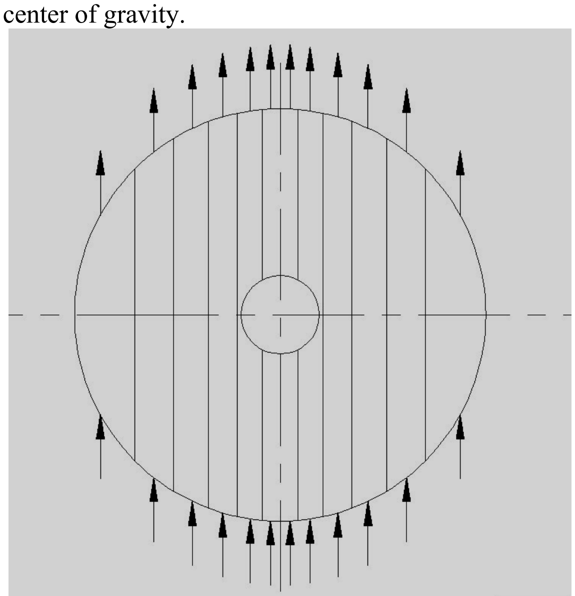

Figure 4. Push-pull forces scheme with lever counterweight lateral support

4. RECENT LATERAL SUPPORT METHODS

With the development of segmented mirror technology, more and more large telescopes use many sub mirrors to replace a monolithic large mirror. Because the gap between one sub-mirror and adjacent one usually is only several millimeters, it is impossible to support periphery of sub mirror, some new schemes have been designed to meet requirement of large segmented-mirror telescope.

Compare with monolithic mirror, the sub mirror is small and light so a single lateral support located at the center of gravity can be used, provided that it only acts radially in order to form a kinematic mount in combination with the axial supports. A successful lateral support has been used on the Keck telescope mirror segments (Figure 5). A diaphragm supports whole lateral weight of mirror, at the same time, gives the mirror freedom to move in the axial direction to avoid interfering with the axial-support system.

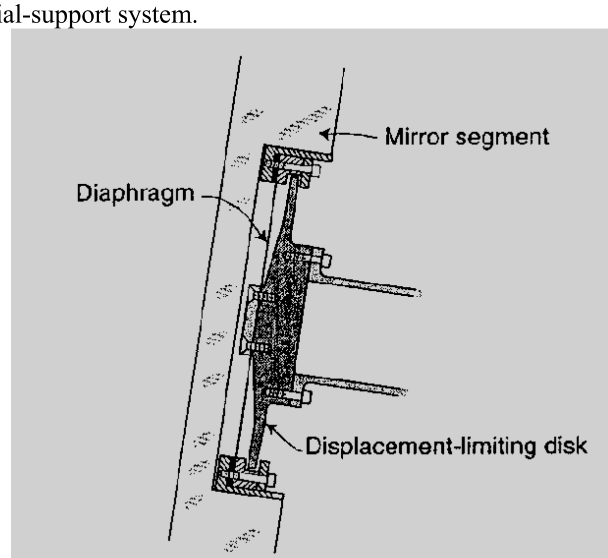

Figure 5. Center hole lateral support of Keck telescope

To avoid boring holes or pockets at the back of the sub mirrors, The GSMT have put forward a new lateral support scheme called “bi-pod” (Figure 6). Through a set of push-pull mechanism, which is directly attached to the back of the segment, the lateral gravity and moment can be compensated.

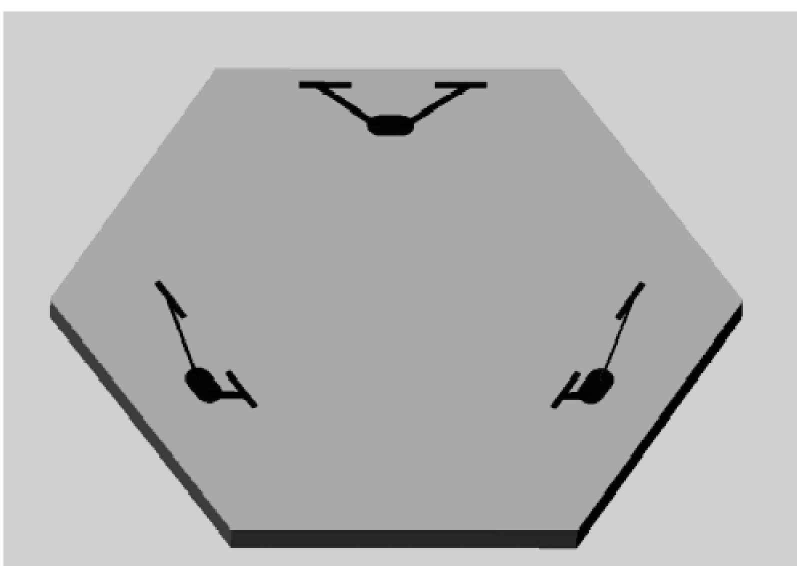

Figure 6. “Bi-pod” lateral support of GSMT

The lateral support of sub mirror of primary mirror of LAMOST project also used center hole support design (Figure 7). Through six invar pads that are bonded at the center hole of mirror, whole lateral weight of mirror are supported by a set of ingenious device.

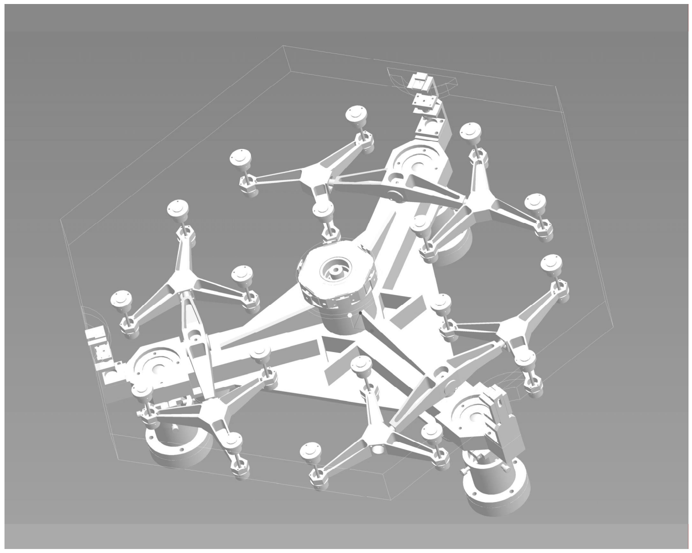

Figure 7. sub-cell of LAMOST primary mirror

The results of finite element analysis and prototype test have shown good performance of this sub cell (Figure 8,9). The RMS of mirror figure is about 5nm. At the same time, with a prototype of sub cell, many tests have been done. After rotating mutual position of the sub-mirror and sub-cell along normal of sub-mirror and re-assembling, a knife edge is used to test the mirror figure and the mirror figure has no obvious change. It implies the sub-cell has qualitative good performance. On the other hand, aiding star test method, some pictures of spot of image also were taken, cause of the influence of airflow, the sharp spot of image can't be snatched. A typical spot of image is shown in Figure 9. The diameter of spot of image is about 2 arc seconds.

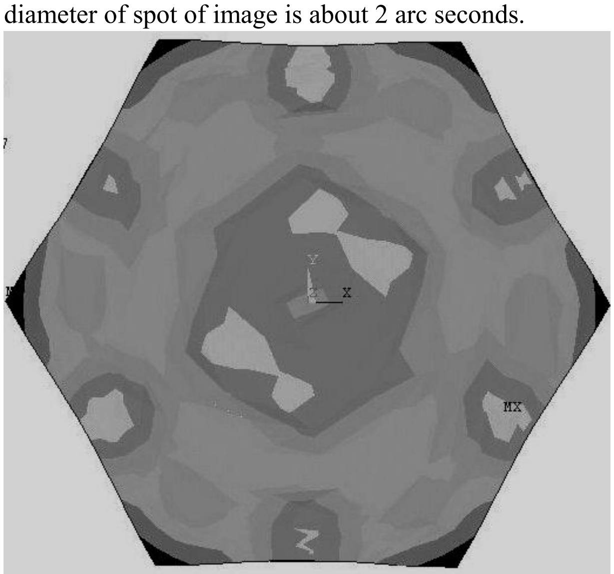

Figure 8. The normal deformation contour

Figure 9. Spot of image from prototype

5. CONCLUSION

Mirror support theory and practice have been extensively studied and are well reported in the classical literature. But with the development of large telescope, some new challenges have emerged and the lateral support of mirror is becoming more and more important in large telescope. To acquire high accurate mirror figure, it is crucial to select a proper supporting method and design a refined device.

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