The active support system of LAMOST reflecting Schmidt plate

Xiangqun Cui*, Yeping Li, Xiaoyu Ni, Dehua Yang , Zhengqiu Yao,
Guoping Li and Yuefei Wang

National Astronomical Observatories / NIAOT, CAS, P. R. China

ABSTRACT

The reflecting Schmidt plate M_A of LAMOST is with 5.7m x 4.4m reflecting area and consists of 24 segmented hexagonal sub-mirrors. Each sub-mirror is 25mm in thickness and 1.1m in diagonal. To correct the spherical aberration of the primary mirror, during observation, the aspherical shape of M_A should be changed in every 1.5 minutes. To achieve the good image during observation, the active support system of M_A will not only create the correct off-axis aspherical shape on each sub-mirror, but also maintain the co-focus for all 24 sub-mirrors. This paper presents the studying design with finite element analysis and experiments on the active support system of M_A, including its axial and lateral supports, force actuators, optimization of the stiffness of the force actuator, sub-mirror cell, the mirror support structure etc. There are 30 force actuators and three position actuators, which support each sub-mirror and connected by sub-mirror cell. Total 24 sub-mirror cells located on the top of the M_A main support structure. All force actuators work as both active and passive supports for each sub-mirror. It showed that the support system is complex but should work properly within the optical requirement.

Key words: Astronomical Telescope, Active optics, Mirror support system, Mirror cell

1. INTRODUCTION

Large Sky Area Multi-object Fiber Spectroscopic Telescope (LAMOST) is composed of two large mirrors: 5.7m x 4.4m reflecting Schmidt plate (M_A), and 6.7m x 6m primary mirror (M_B) [1, 2]. To reduce the cost and lower the risk in manufacturing, transportation and coating process, both mirrors are segmented. M_A is a very critical part in LAMOST. It consists of 24 hexagonal plano sub-mirrors (see Fig.1), and each sub-mirror is 1.1m in diagonal and 25 mm in thickness. To eliminate the spherical aberration of the primary mirror, the Schmidt corrector is required, which is with an aspherical surface. And due to the tracking process during the observation, its aspherical surface is variable. The variable aspherical surface can be realized by deformable mirror active optics. It not only needs active optics to control the surface shape and co-focus of sub-mirrors of M_A, but also it takes the task of tracking the objects, and relaying the star light to the primary mirror of M_B in the direction of fixed optical axis.

Comparing with those existed segmented mirrors of larger telescopes in the world with LAMOST M_A, the characteristic and difficulty of the support system of M_A is both deformable mirror active optics and segmented mirror active optics applied on one mirror been used. To avoid the interference between the active deformable axial support system and three active displacement actuators for co-focus on each sub-mirror, we used a double support system. From the point of view of the whole support system of M_A, it is support a 5.7m x 4.4m reflecting mirror. But in real case, it is a parallel support system for 24 thin hexagonal sub-mirrors. There are 39 axial support points (Fig. 2), including 3 axial fixed points and 30 force actuators (3 of them in the center area carrying 3 whiffletrees), which support each sub-mirror and connected by sub-mirror cell. Total 24 sub-mirror cells located on the top of the M_A main support structure. There are 3 displacement actuators adjust the tip-tilt of each sub-mirror cell actively. All force actuators work as both axial active and passive supports for each sub-mirror. So the whole M_A support system is composed of 24 sub-mirror cells, 720 force actuators, 72 displacement actuators, passive supports of sub-mirrors and sub-mirror cells.

* xcui@nairc.ac.cn ; phone 86 25 5471761; fax 86 25 5405562; http://www.nairc.ac.cn; Nanjing Institute of Astronomical Optics and Technology/ National Astronomical Observatories, Chinese Academy of Sciences, 188 Bancang St., Nanjing 210042, P. R. China

This paper presents the studying design with finite element analysis and experiments on the active support system of M_A, including its axial and lateral supports, force actuators, optimization of the stiffness of the force actuator, sub-mirror cell, the prototype of the support system in outdoor experiment, the mirror support structure etc. An outdoor experiment for testing the support system and the active control of the aspherical surface shape of the sub-mirror is under going, Even the final active support system of M_A has not come out before the final results obtained from the outdoor experiment and modification, it showed that the support system should work very close to the optical requirement.

2. SUPPORT SYSTEM OF SUB-MIRROR

For the segmented mirror like in HET[3] and Keck[4], a whiffletree support structure is used for its passive support system, and a spring diaphragm at the center blind hole is used to support the sub-mirror in lateral direction. There are 3 displacement actuators connect the whiffletree to the main support structure, and can correct the tip-tilt and piston of the sub-mirror for co-focus (and co-phase for Keck). The difference between LAMOST and those telescopes are: (a) the surface shape of the sub-mirror has to be actively controlled during the observation; (b) the sub-mirror is relatively thin with a thickness of 25 mm.

2.1. Axial Support System

For axial supports, to fit the special condition of LAMOST , we have been thinking about to take a combined active and passive support system by active lever and counterweight actuators[5, 6], or by force actuators composed of ball-screw and spring which is designed for JNLT[7] (now called SUBARU). Because there is no enough space in the sub-mirror cell, we chose the actuator with screw and spring. Comparing with the lever and counterweight actuator (lever actuator), the actuator with screw and spring (elastic actuator) is not a complete floating support system, or say it is not a complete astatic system. It may transfer a part of the deformation of the sub-mirror cell to the mirror surface. To resolve this problem, a stiff enough sub-mirror cell is been required, and the stiffness of the actuator has been optimized. The optimization for the actuator stiffness is a compromise between the wind load and the deformation of the sub-mirror surface due to gravity deflection of the sub-mirror cell. Therefore, this analysis includes influences of wind load, gravity deformation of the sub-mirror cell. When calculation with conditions like that: (a) a wind load with wind speed less than 2m/s, and in distributed in Gaussian on the sub-mirror surface; (b) the stiffness of the actuator is 13.5N/mm; (c) including the gravity deformation of whole system; (d) when M_A is point on 82.3° altitude angle; the results of the optimization for the stiffness of the actuator showed the surface deformation of the sub-mirror is PTV 117nm and RMS 20.7nm.

This axial support system is a combination of the passive and the active axial support systems. To keep the surface accuracy of the sub-mirror, while the altitude angle of M_A changes, the gravity deformation has to be actively corrected. This is a shortage to use elastic actuator comparing with the lever actuator. The dynamical range of the actuator includes active forces for both gravity deformation and spherical aberration correction. Also other errors should be corrected by active optics, such as thermal deformation of the sub-mirror and residual surface error of the optical polishing. Plus gravity load, the support force of each actuator is about ± 100N. To fit the image quality, the requirement for force accuracy of each actuator is less than 50mN.

There are three axial fixed supports which are distributed in 120° symmetry, to define the position of the sub-mirror in three degrees of freedom (an axial displacement in z, rotations around x and y). Two types of axial fixed supports are studied for LAMOST. One is using three-spring diaphragms, which is stiff in axial and tangential directions but flexible in radial direction. This type of fixed points has been tested in the outdoor experiment system. Another type of fixed support is three ball pivot joints (see Fig.3), which define three degrees of freedom together with the center lateral support system. The second type of fixed support system is going to be tested soon. Which one will be used in support system of M_A sub-mirror will be decided after all results coming out from experiments. In Fig. 3 we can see one of 30 axial actuators and two of three axial fixed supports. To avoid the interference on axial force actuators from the displacement actuators while the sub-mirror is actively controlled in tip-tilt mode, the support system of each sub-mirror is treated as a normal support system of the monolithic mirror. That is to say, three displacement actuators are not combined with three fixed supports of the sub-mirror. They are located bellow the sub-mirror cell and connect the sub-mirror cell and main support structure. Three displacement actuators will actively adjust the tip-tilt and piston of the sub-mirror together with whole support system and sub-mirror cell.

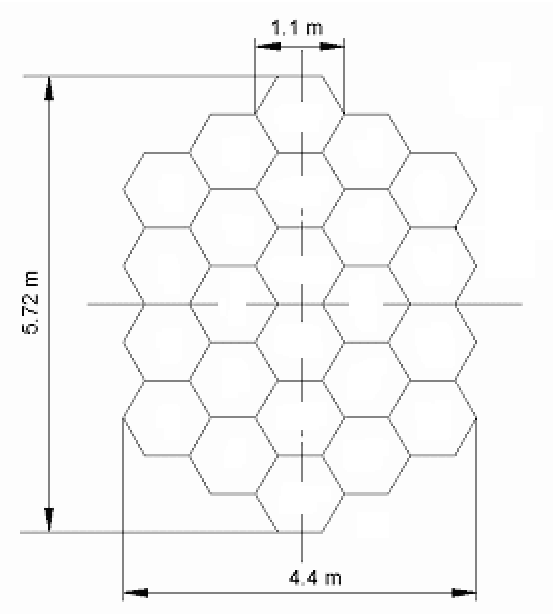

Fig. 1 Reflecting Schmidt plate M_A

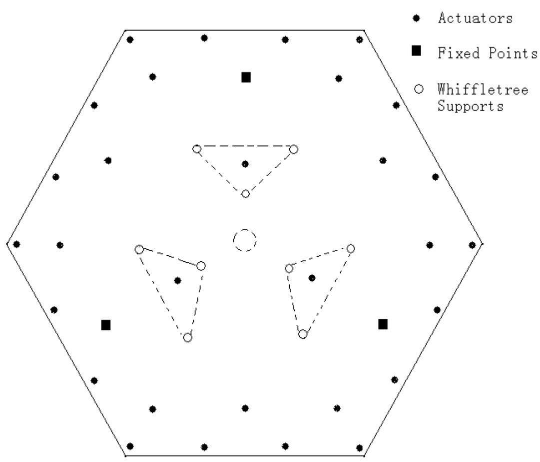

Fig. 2 Support points of each sub-mirror of M_A

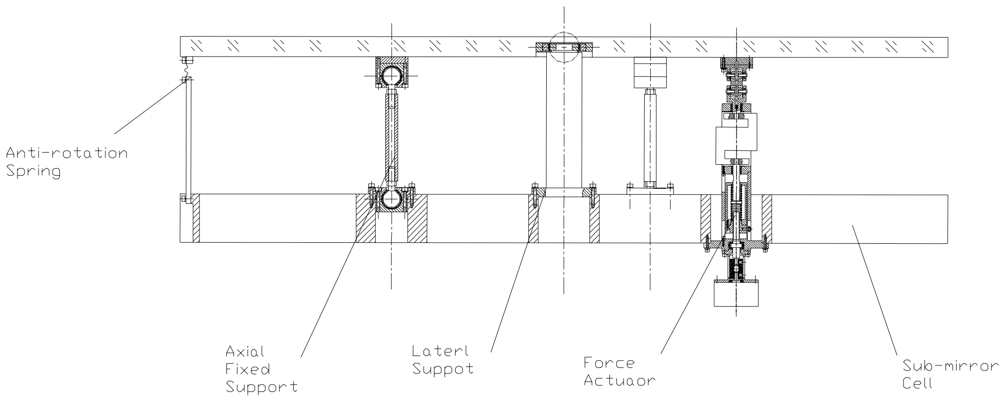

Fig.3 Support system of Sub-mirror (only one actuator displayed)

2.2 Lateral Support System

There are two lateral support systems have been considered. One is similar as described in reference paper 7. It is a kind of local lateral support system, combined with axial actuator and located at the same place. Using this type of lateral support system is because of the difficulty to put the lateral supports at the out edge of each sub-mirror, and to save the space in the sub-mirror cell. The problem is difficult to drill a blind hole at each support place to put the lateral support point at the center plane of the gravity of the sub-mirror because of the very thin (25mm) sub-mirror . Aditionally, the active support system has to correct the moment, which created on the sub-mirror by the lateral support system. This kind of lateral support system has been tested in the full- scale outdoor experiment for active optics and all relative parts of LAMOST. It showed that this additional active correction made more difficulty on the active optical control, and it increased the active force range of the actuator. For this reason, a second lateral support system, which is a center lateral support like Keck and HET used for their sub-mirrors, has been considered. But the difficulty of this type of lateral support system used in LAMOST M_A sub-mirror is the mirror blank is too thin. It is obvious that the blind hole in the sub-mirror center could not be drilled deeper, and also could not with large size in diameter. The problem is the space for the lateral support mechanism is too tight, and not easy to use the spring diaphragm for the lateral support. As a compromise, a center lateral support system with a ball bearing has been considered.

2.3. Distribution of Axial Support Points[2, 8, 9]

As we described in reference papers 2, 8, 9, The number and distribution of axial support points should not only satisfy the surface accuracy of the sub-mirror under the gravity load, but also could carry out the accurate active correction for eliminate the 3rd order spherical aberration, which is a variable off-axis aspherical shape on each sub-mirror. To reduce the complexity and lower the cost of the active support system, it is better to reduce the number of the axial support points. Considering about above reasons, and to take a center lateral support, an axial support system with 39 points has been optimized again. Excluding 3 fixed points, there are only 30 actuators needed for each sub-mirror (see Fig.2). The surface accuracy of the sub-mirror due to maximum gravity deformation is PTV 81.1nm and RMS 14.2nm.

3. FORCE ACTUATOR

The requirements for force actuators used in LAMOST are listed below:

- Axial load capacity ±100N (pull and push) with an accuracy 0.05N;
- Small dimension, can install in sub-mirror cell;
- Good thermal property, easy for ventilation;
- Easy for assembly, disassembly, and maintenance;
- With good linearity, easy for control;
- Axial stiffness is 13.5N/mm.

There are two types force actuators have been designed and tested. One is shown in Fig.4, and another one is in Fig.6. Both types of force actuator are elastic actuator with spring and screw.

The type 1 consists a step motor which rotates a precision ball screw and drives a nut, that presses the elastic element, connects through a load cell to the back of sub-mirror. The control system consists of step motor, load cell and computer, which control the force with accuracy less than 0.05N. In the laboratory test, the actuator failure rate is low. A key element in the force actuator is the load cell. After measuring non-repeatability, linearity, long-term drift, we have selected load cells with type number SM-100N supplied by Interface Co. The second key element is the elastic element. After comparing and testing, a combined spring is designed for the force actuator, which can bear pull and push force, with linearity error (both push and pull directions tested in lab.): PTV=41mN, RMS=7.97mN (Fig.5).

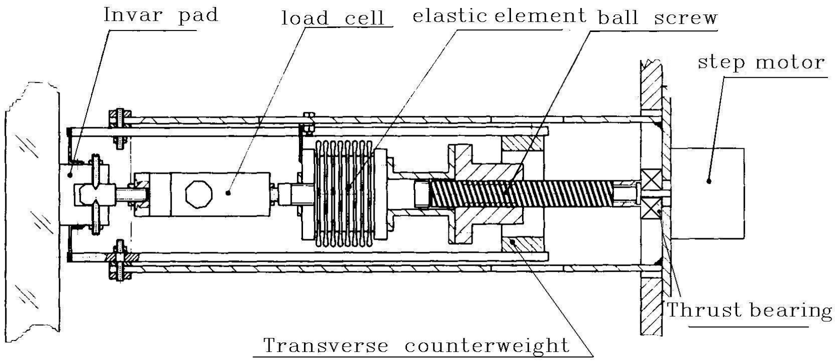

Fig.4 Actuator type 1

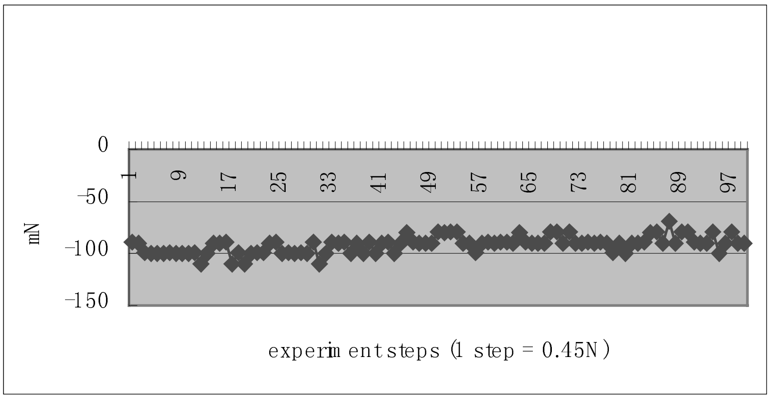

Fig.5 The linearity error of the actuator type 1

To improve the performance of the actuator, reduce the size and cut down the cost, in force actuator type 2, a lead screw is used to instead of ball screw, and an elastic coupling added between motor shaft and screw. This type of force actuator should have got the same performance as the type 1, but with lower cost. A preliminary test in laboratory has been done and the preliminary result about its linearity error are PTV=2.241N, RMS=0.169N (Fig. 7). The large linearity error may be caused by friction of the lead screw. Now some efforts are still put forwarded on this type of actuator.

Both types of actuator can response in few seconds. When final results come out from the outdoor experiment for active optics, one can see which type of force actuator could be adopted.

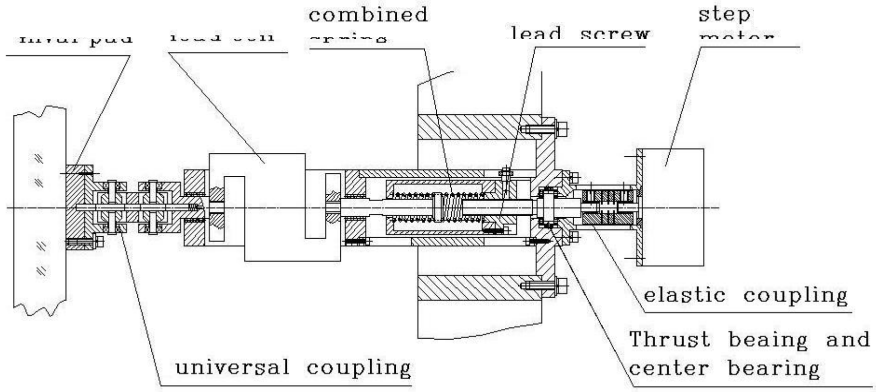

Fig.6 Actuator type 2

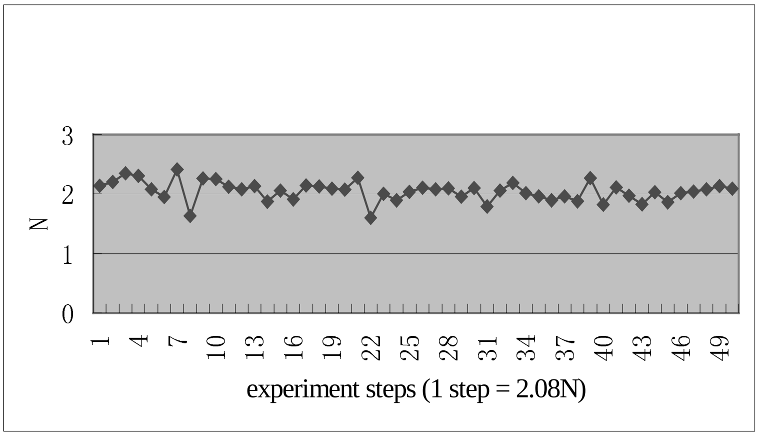

Fig.7 Preliminary results for linearity error of actuator type 2

4. SUB-MIRROR CELL

The sub-mirror cell is also a very important part in the active support system of M_A. There is a mirror cell for each sub-mirror, and connects the sub-mirror and its support system to the main support structure (M_A cell). Relatively, each sub-mirror cell with the sub-mirror and its support system is supported kinematical like that for a monolithic mirror blank. Especially for active control of the sub-mirror in tip-tilt and position, to avoid the conflict with force actuators, three displacement actuators support and move the sub-mirror cell related to the top of the main support structure.

The requirements for the sub-mirror cell are stiff enough for the surface shape of the sub-mirror under full load (gravity, wind etc.), easy for access of the maintenance and properly light. By finite element method, an optimization has been done. Fig.8 and Fig.9 are finite element models of the optimized sub-mirror cell. The detail design for the sub-mirror cell and kinematic connection with main support structure, including the mounting mechanism of displacement actuators are in process.

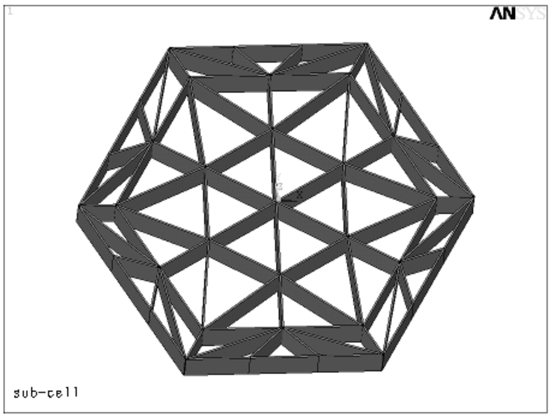

Fig.8 Finite element model of sub-mirror cell

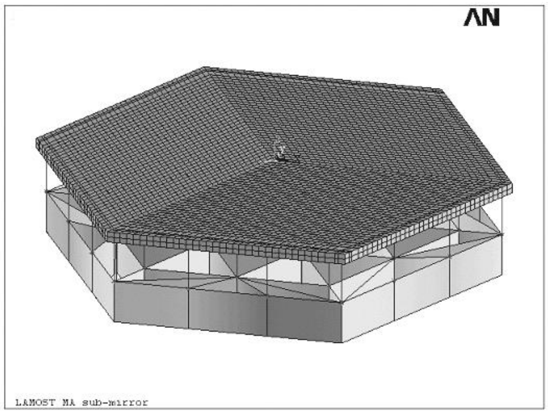

Fig.9 Finite element model of sub-mirror with sub-mirror cell

5. MAIN SUPPORT STRUCTURE

Each sub-mirror system includes a sub-mirror, 30 axial supports, a lateral support, a sub-mirror cell, three displacement actuators and relevant components. As the layout seen in Fig.3, each sub-mirror system weighs approximate 150 kg and is defined by the three positioners which are connected to the top joints of the M_A main support structure, which named as M_A cell.

The design scheme of M_A cell has to be conforming to the drive mode and the support mode of itself. Inherently, LAMOST has no central section as traditional telescopes. The structure of M_A cell is to be supported only by two journals on both sides and friction drive on both sides is adopted for elevation axis. Thus, based on the configuration, an unloading method was before introduced to improve the support performance. It was using two rollers to elastically support the cell against the arc on its truss bottom[10]. Afterwards, the auxiliary unloading system was cancelled, and consequently, the design of M_A cell has been revised and resulted in a three-layered space truss, as shown in Fig.10. Analogous mirror cells have been investigated [4, 11]. The M_A cell finally shapes in a half ellipse with its three layers shrinking gradually down[12]. The elevation axis, indicated with axis X in Fig.10, is in the surface plane of M_A.

Each positioner of the sub-mirrors (totally 72 for M_A) is settled on a joint of top layer of the cell. On both sides of this layer will connect elevation journal plates, and on the edge ring, there stands a guardrail truss for securing the mirrors and for handling mirror covers.

The middle layer is a plane truss patterned as the projection of the sub-mirrors, while the bottom of the cell is a concaved layer of truss (looks seemingly three layers viewed from side) whose projection are exactly congruent equilateral triangles.

Optimized with finite element software, the M_A cell weighs 2640 kg with journals and deflects 0.25 mm when pointing to zenith. Its lowest natural frequency is up to 27.2 Hz.

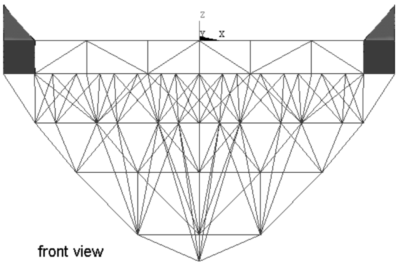

Fig.10a Front view

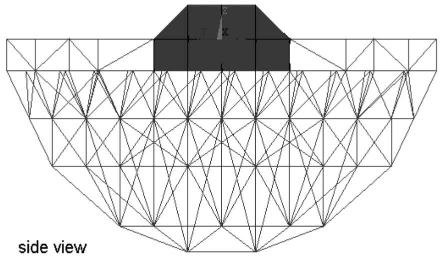

Fig.10b Side view

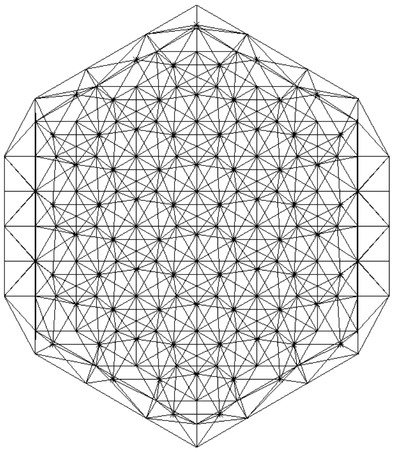

Fig.10c Top view

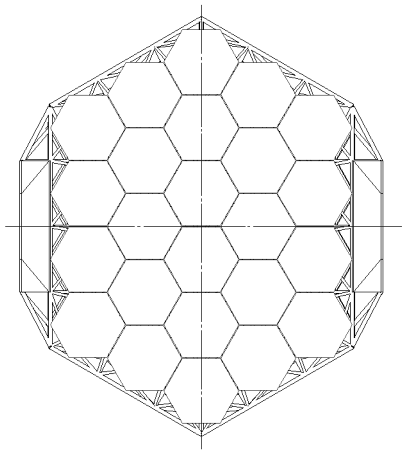

Fig.10d with sub-mirrors

Fig. 10 Finite element model of main support structure

6. CONCLUSIONS AND EXPECTATION

The active support system of LAMOST M_A is a very special and complex support system. The studies and preliminary design including some experiments have shown that this active segmented and deformable thin mirror should work properly and satisfy the accuracy of the optical image quality of the telescope. But in detail design, there are still many works have to be done carefully. Especially with the outdoor experiment system for deformable mirror active optics, every part in the sub-mirror system will have been tested and optimized. There is a new active support system will be soon install on the experiment system, and the results should come out around the end of this year. The advantage to use the segmented mirror is easy to make full-scale unit prototype and test it for the final whole system. For the segmented mirror active optics, an experiment has been done in laboratory[13], but the new displacement sensors and actuators are going to be tested as soon as possible.

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