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Modeling and Simulation of Chinese SONG telescope

Liang Gao[1,2,3,a], Guomin Wang[1,2,b]

[1]National Astronomical Observatories / Nanjing Institute of Astronomical Optics & Technology, Chinese Academy of Sciences, Nanjing 210042, China;

[2]Key Laboratory of Astronomical Optics & Technology, Nanjing Institute of Astronomical Optics & Technology, Chinese Academy of Sciences, Nanjing 210042, China;

[3]University of Chinese Academy of Sciences, Beijing 100049, China

[a]lgao@niaot.ac.cn, [b]gmwang@niaot.ac.cn

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Abstract: Telescope structure is used to support and position the optical mirrors in the right place during the period of telescope observation, so it will have such capability to withstand a certain load. In order to ensure SONG telescope has such capability, FEM analysis and calculation are finished in this paper. With the help of ANSYS, firstly the finite element model of SONG telescope is built. Then using this model, the analysis and calculation of static and dynamic are performed, including the deformation under the gravity load with the tube in different directions, eigenfrequency calculation of the whole system and the responses under the seismic acceleration spectra. The results show that the max. offsets and max. relative tilt angles between primary mirror and secondary mirror are very little under the gravity load. The first natural frequency is 20.083Hz, larger than the design requirement 8Hz. The results of seismic load analysis show that the deformation in the telescope structure is 0.42mm and the stress is 33.8MPa, less than the allowable stress of the structure material. The above analyses verified that the structure design of SONG telescope is reliable and acceptable.

Introduction

SONG (Stellar Oscillations Network Group) is a Danish initiative to design and build a global network of eight 1-m class telescopes. The scientific goals of SONG is to study the internal structure and evolution of stars at a level of detail similar to that achieved for the Sun under similar observing conditions, using an advanced technique called asteroseis-mology, which enables astronomers to “look inside the stars” and to search for and characterize planets with masses comparable to the Earth in orbit around other stars.

At the beginning of telescope-make, simulation is a very important work to estimate the performance of the telescope preliminary design. The system-level finite element models of almost all telescopes abroad were built. The responses under all kinds of loads have been analysed and proved, lots of results and experiences have been obtained[1]. Firstly the whole finite element model is built in which the primary mirror(MA) and secondary mirror(MB) are substituted by mass elements, so that the relative offsets and tilt angles can be worked out. Then the first six natural frequencies and modal shapes are extracted. With the trend of more and more earthquake around the world, we simulate the effect of seven magnitude earthquake applied on the telescope. The simulation results show that the preliminary design can meet the system requirements.

Modeling of SONG telescope

Brief Introduction of the Structure of SONG telescope. Chinese SONG telescope is an alt-azimuth telescope whose primary mirror diameter is 1m, focal ratio is f/37. Fig. 1 shows the whole telescope mount, including azimuth axis system, altitude axis system, center block, up/down truss, MA system and MB system.

Finite Element Model of SONG. The model is properly simplified on the premise that the accuracy of analyses is influenced lighted in order to make the model not too complex. Nearly all the structures of SONG telescope are shell shapes, so the SHELL63 element is used to simulated the rack; In the process of analyses, the surface shapes of MA and MB are not researched, what are paid attention to is the relative position of MA and MB, so MA and MB are simulated by MASS21 element[1]. The up truss and down truss are simulated by PIPE16 element whose shape is the same with them. Fig. 2 shows the whole finite element model when the tube is vertical. In this model, the azimuth axis in the direction from bottom to top is the positive of Z-axis; The altitude axis in the direction from left to right is the positive direction of X-axis. The whole model contains 44319 nodes, 87770 SHELL63 elements, 136 PIPE16 elements and 2 MASS21 elements[2].

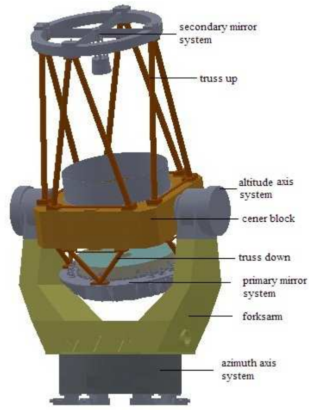


Fig.1 SONG telescope mount

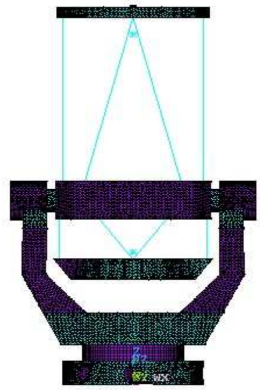


Fig. 2 Finite element model of SONG

Static analysis of SONG telescope

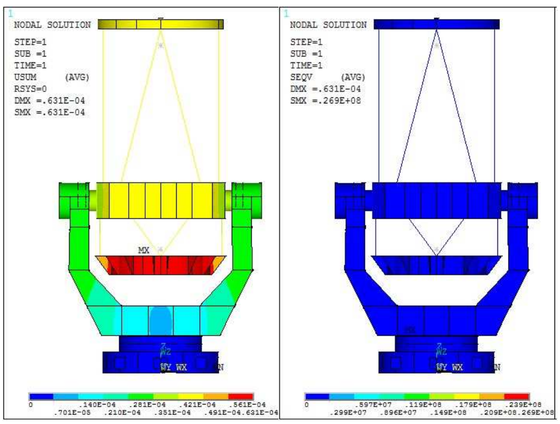
Stress and deformation. When a telescope is at work, the gravity could make the optical support structure deformed so that it could produce all kinds of aberrations. Gravity can produce different effect when the angle of pitch varies. In this paper, deformations and stresses under gravity load are analyzed when the tube is in the following three cases, which are the tube is vertical, the tube is 45° pointing from zenith and the tube is horizontal. The relative offsets and tilt angles between MA and MB are mainly paid attention to.

The boundary conditions of the static analysis are

Constraint all the nodes of the eight basement location columns on all six degrees of freedom;

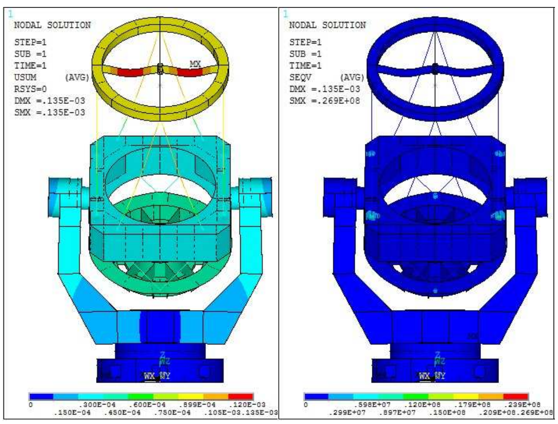
Apply 1g gravity acceleration on the whole finite element model.

There would be deformations and stresses in the telescope structure when under gravity load, Fig.3~Fig. 5 show the deformations and stresses in the above three cases.



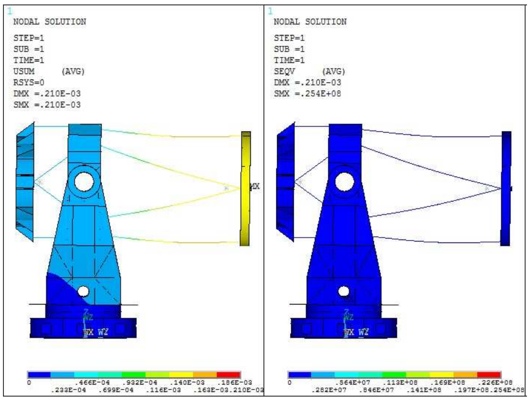
(a) (b)

Fig.3 Deformation(a) and stress(b) when tube is vertical



(a) (b)

Fig.4 Deformation(a) and stress(b) when tube is 45° from zenith



(a) (b)

Fig.5 Deformation(a) and stress(b) when the tube is horizontal

Fig. 3 shows that when the tube is vertical the maximum deformation is 0.06mm, which happens in the primary mirror-cell, the maximum stress is 26.9MPa. Fig. 4 shows that when the tube is 45° from zenith the maximum deformation is 0.14mm, which happens in the outer ring of the top ring, the maximum stress is 26.9MPa. Fig. 5 shows that when the tube is horizontal the maximum deformation is 0.21mm, which happens in the vanes of the top ring and the maximum stress is 25.4MPa. When the tube is 45° from zenith and the tube is horizontal, the maximum stress happens in the joint of the trusses and the center block. The above stresses are all much smaller than allowable stress of the material of the telescope. What could be seen from above results is preload should be applied in the vanes of the top ring so that the deformation would be smaller.

Relative offsets and tilt angles of MA and MB. When the tube is vertical, relative displacement will be produced along the optical axis of the optical system, this could make MA and MB out of focus. When the tube is 45°and horizontal, MA and MB will get down under the gravity load, the changing of the relative position will lead MA and MB tilt to the optical axis and out of focus. Table 1 lists the maximum relative offsets and tilt angles of MA and MB of the three cases (MB minus MA). This can provide some references to adjusting the tilt and out of focus of MA and MB when the tube is from 0°~180° from zenith.

Table 1 Maximum relative offsets and tilt angles of MA and MB for three positions

	UX[mm]	UY[mm]	UZ[mm]	RX[″]	RY[″]	RZ[″]
Vertical	4.76e-5	1.73e-5	1.39e-2	---	---	---
45°	6.88e-5	4.45e-2	-3.06e-2	-5.88e-2	-4.37e-4	-4.61e-4
Horizontal	6.51e-5	-2e-5	-7.32e-2	-8.14e-2	1.55e-4	-6.27e-4

What can be seen from Table 1 is under the gravity, either the relative offsets or the relative tilt angles are very little in the three cases, they are much smaller than the adjusting range of the six degrees of freedom mechanism which supports the MB system.

Dynamic analyses of SONG telescope

Modal analysis. Modal analysis is the basis of dynamic analysis, natural frequencies and mode shapes could be calculated from modal analysis to predict the responses under dynamic load.
Typical modal analysis is to solve the basic classical eigen value of the basic equation:

$$[k]\{\varphi_i\} = \omega_i^2[M]\{\varphi_i\} \tag{1}$$

In the above equation, $[k]$ is stiffness matrix; $\{\varphi_i\}$ is the i th modal shape; ω_i is the i th modal natural frequency; $[M]$ is the mass matrix[3].

Table 2 is the natural frequencies and mode shapes of the first six modals, what could be seen from Table 2 is the value of the first natural frequency is 20.083Hz, greater than the design requirement which is 8Hz.

Table 2 The first six natural frequencies and vibration models of SONG telescope

	1	2	3	4	5	6
Frequency[Hz]	20.083	22.106	51.960	54.294	55.624	64.668
Model shape	System Vibration by X	System Vibration by Y	Truss Vibration by Y	Tube Vibration by X	System Rotating by Z	Truss Vibration by X

Analysis of responses under seismic load. The rack and high accuracy optical components of a telescope must have a certain earthquake resistant behaviour within their working life time, they must meet the requirements that after suffering the earthquake they can continue to work after maintenance and debugging. In order to ensure that the telescope is not destroyed, seismic analysis must be done before designing the telescope.

The SONG telescope will be installed on Delingha observatory, Qinghai province, west side of China. According to the site characteristics, the eigenperiod of Delingha, Qinghai observatory, Tg=0.4 and $\beta_{\max} = 2.25$, $\beta_{\min}$ equals 20% of $\beta_{\max}$ in general, so $\beta_{\min} = 0.45$. The earthquake dynamic factor β can be defined by the following equation:

$$\beta(T) = \begin{cases} 1.0 + 12.5T & T = 0 \sim 0.1s \\ 2.25 & T = 0.1 \sim 0.2s \\ 2.25 * (0.2/T)^{0.9} & T = 0.2 \sim 1.1958s \\ 0.45 & T = 1.1958 \sim 3.0s \end{cases} \tag{2}$$

The above equation is correct when the damping ratio ξ=0.05, in general the damp ratio of a telescope ξ=0.01[4], so β need to be corrected, the equation is:

$$\beta(T,\xi) = \beta(T,0.05) / \lambda(T,\xi)\,. \tag{3}$$

In Eq. 3 $\lambda(T,\xi) = \sqrt[3]{16.6\xi + 0.16}(0.8/T)^{\alpha}$, $\alpha = (0.05-\xi)/(0.156+3.38\xi) = 0.21$ (4)

According to the requirement of the telescope and aseismatic design, the earthquake resistance of Delingha is 7 magnitude, seismic coefficient k is 0.125 and important factor is 1.3. So the acceleration response spectrum of SONG telescope can be calculated from the following equation:

$$Sa = 1.3 \cdot k \cdot \beta \cdot g\,. \tag{5}$$

Apply earthquake acceleration response spectra to the basement location column in three directions , two horizontal directions X and Y, a vertical direction Z(acceleration of the vertical direction is about 65% of that of the horizontal direction), so we can calculate the response of the telescope under the seismic acceleration spectrum. Table 3 list the deformation and stress of the telescope under seismic load.

Table 3 Responses of seismic acceleration spectra

	Maximum deformation of the telescope[mm]	Maximum stress of the telescope[MPa]	Maximum displacement of MA[mm]	Maximum displacement of MB[mm]
response	0.42	33.8	0.11	0.37

Conclusions

Firstly the element model was built, and static and dynamic analyses were done with Finite Element Method. In static simulation, the deformation and stress, relative displacements and rotations were worked out; In dynamic simulation, the first six frequencies, modal shapes and the responses under seismic acceleration spectrum were worked out. The conclusion is under these loads, the deformations and stresses of SONG telescope were very little, the telescope cannot be damage and could work normally. The above simulations verify that the design of Chinese SONG telescope is reasonable. It is more and more important to analyze the responses of telescopes under various loads with FEM, the paper can provided a certain of reference value to the design and analysis of telescopes.

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