TMT tertiary mirror dynamical model measurement and modification

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Abstract: To measure the dynamic performance of the thirty meter telescope tertary mirror, the model based on the accerleration signal was established for parameters calculation and identification. First and foremost, under the TMT requirement, the procedure to obtian the dynamic property of the system by acceleration signal was presented. Then, by the output to the unknown excitation, the free response can be reached. After that, the polynomials fitting was used to process the transfer function obtained from the previous step to identify the model parameters. This method was then applied to a four-meter scale system, the first two orders of strcture were correspondingly 88 Hz and 107 Hz. What is more, the mode shape is also calculated and the parameters in the modle are modified by it. The work of this artile is expected to be helpful for the accomplishent of the thirty meter telescope.

Key words: TMT M3; dynamical model; transfer function; random decrement technique
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TMT 三镜动力学模型辨识与标校

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摘 要: 为了更好地对于30 m 望远镜三镜(TMT M3)的动力学进行度量与检测,基于加速度信号建立了系统模态信息的计算与评价方法。首先, 分析了如何利用加速度计对于 TMT 三镜系统进行检测。之后,利用系统对于未知载荷的响应,基于随机减量法获得了系统的自由响应;之后,根据多项式拟合的方法,对于获得的传递函数进行处理。根据之前所提出的方法,对于 4 m 级系统,获得了其系统前两阶模态为 88 Hz 以及 107 Hz,并获得了对应振型。所做的工作对于 TMT 三镜的完成有着很好的指导作用。

关键词: TMT 三镜; 动力学模型; 传递函数; 随机减量

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0 Introductions

The thirty meter telescope is a Ritchey-Chrétien system, composed by first mirror with 492 hexagonally-shaped hyperboloid co-phased segments, and 3.594 m by 2.576 m elliptical flat tertiary mirror. The tertiary mirror will point to the instrument on the both sides of the elevation axis, during the telescope tracing. The work condition is very complicated, so the analysis and estimate process is very challenging. The tertiary mirror is developed by the Changchun Institute of Optics, Fine Mechanics and Physics, CAS, (CIOMP) in Changchun, China[1-5].

Admittedly, the finite element analysis technique has developed very well. The deviation between the actual structure and design model still exists. It can be made sure that the geometry size of the structure is exactly the same as the one in the design model, neither dose the material property. What is the most important, when the structure is under machining, the stress is left in the material, it makes the natural frequency rise due to the preload. Consequently, to match the gap between finite element model and testing result, some parameters should be modified[6-10].

In the construction procedure of large telescope, the identification step is always involved, such as SOFIA air based telescope to the environment oscillation and the GMT (Giant Magellan Telescope) ground telescope to the wind load. But for the powerful adjustment phase in the telescope(such as the active damping system in the SOFIA telescope and the active optical system in the GMT), in the TMT (Thirty Meter Telescope), the tertiary mirror is very limited in weight and space. Almost, all the performance is based on the previous design and analysis, so the model modification is very important[11-14].

In this paper the dynamic calibration testing method will be discussed. Then the measurement is processed to a four meter scale system, the data set will be analyzed.

1 Definition

The system of the tertiary mirror is shown in Fig.1. The coordinate helps us to describe the location in the tertiary mirror system. We concern the motion of the image most, so the performance of the mirror should be noted.

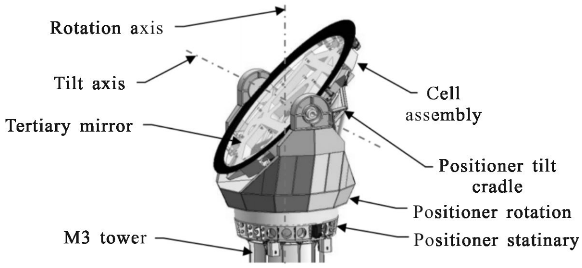


Fig.1 Sketch of the TMT M3

For the accelerometer, it is widely used in the oscillation testing. It is convenient to allocate in the large system with wax, as shown in Fig.2. It should also be paid attention that the mass of the acceleration will sometimes influence the dynamical property of the structure. So, if the structural is not heavy enough, it is better not to move the sensors between different times of testing. If the accelerometers are not enough, it is better to put some mass to replace the accelerometers when they are removed.

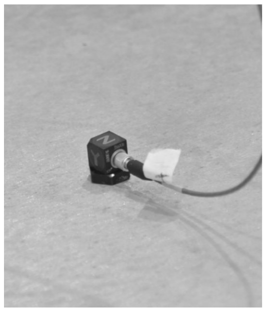


Fig.2 Accelerometer for the TMT M3

1.1 Collection of data

Firstly, we consider the data collection. The dynamic testing is concerned about the acceleration in certain direction.

In a large sense, three points on a rigid body can decide the location of the object. However, when the signal to noise ratio is not that good, some more testing points should be involved to assist the identification. There are four accelerometers on the mirror. The sensitive axis is along the normal line of the mirror. It is enough to tell the rigid body motion and some low order ones of warping modes.

1.2 Random decrement technique and free response

According to system in such large size, the traditional method, namely, directly measuring the transfer function, may not work very well.

For one thing, with the increase of the scale of the telescope, the transfer function will be harder to be reached. So, the common method to deal with this is measuring the response of the system according to some unknown excitation, and abstracts the free response of the system. Then the transfer function can be obtained.

Random decrement technique is a popular method to obtain free response for identifies the parameters. The identification is mainly for the non-physics parameters.

The description of the random decrement technique is shown in Eq.(1):

$$\delta(\tau)=\frac{1}{W}\sum_{k=1}^{W}x(t_k+\tau) \tag{1}$$

The expression of the linear system is as follows:

$$[M]\{\ddot{x}\}+[C]\{\dot{x}\}+[K]\{x\}=\{f(t)\}$$

The linear operator is noted as: L_{ij}. The formula can be rewritten as:

$$[L]\{x\}=\{f(t)\}$$

We consider some time delay of the response, and average the W responds up to the unknown excitation. For the linear system, the different operator can change its location:

$$\frac{1}{W}\sum_{k}^{W}[L_{ij}]\{x_j(t_k+\tau)\}=\frac{1}{W}\sum_{k}^{W}\{f_j(t_k+\tau)\}$$

Suppose the excitation is random, so the average of the excitation is zero.

$$\frac{1}{W}\sum_{k}^{W}\{f_j(t_k+\tau)\}=\{0\}$$

Now we know, the Eq.(1) is the free response of the system. Then, we use the Fourier transfer to obtain the transfer function:

The transfer function of a linear system is as follow:

$$H(s)=\sum_{k=1}^{N}\left(\frac{A_k}{s-s_k}+\frac{A_k^*}{s-s_k^*}\right)=\sum_{k=1}^{2N}\frac{A_k}{s-s_k}$$

It can be transferred to the other form:

$$H(s)=\frac{a_0+a_1s+\cdots+a_{2N}s^{2N}}{b_0+b_1s+\cdots+b_{2N}s^{2N}}=\frac{C(s)}{D(s)}$$

For the frequency domain:

$$H(j\omega)=\frac{C(j\omega)}{D(j\omega)}$$

The residual error is:

$$e_i=\sum_{k=0}^{2N}a_k(j\omega_i)^k-\widetilde{H}_i[\sum_{k=0}^{2N-1}b_k(j\omega_i)^k+(j\omega_i)^{2N}] \tag{2}$$

We can use the least square estimation to obtain the parameters that we want.

2 Properties

As shown in Fig.1, the mirror is located in a cell which contains many trusses. If the testing is to be processed previously, the structure under testing shall has some similarity. The 4-meter aluminum mirror is shown in Fig.3, which is passively supported by the whiffle tree, and the mirror is about 2.35 ton.

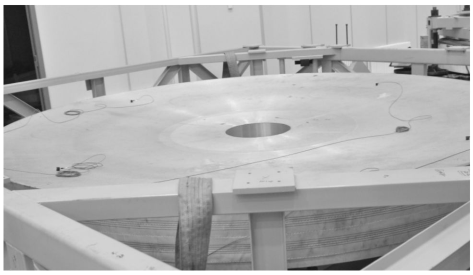


Fig.3 Allocation of the accelerometers on the mirror

The allocation of the accelerometers has been discussed in the previous section. There are in total four sensors put on the mirror. Two are along the tilt axis, namely, the short axis of the tertiary mirror, in Fig.1, and the other two are on the long axis.

The excitation is applied to the tertiary mirror which is always from the positioner assembling. So the excitation in the testing is applied on the location almost beside the tilt axis head.

The excitation is applied by random hitting. The random decrement technique is used to obtain the free response, as shown in Fig.5. Fig.4(a)-(d) are correspondingly the free respond of the four testing points. What is can be seen from the figure is that the signal in Fig.4(c) is not damping very well. There may be some other structure interacting with the mirror.

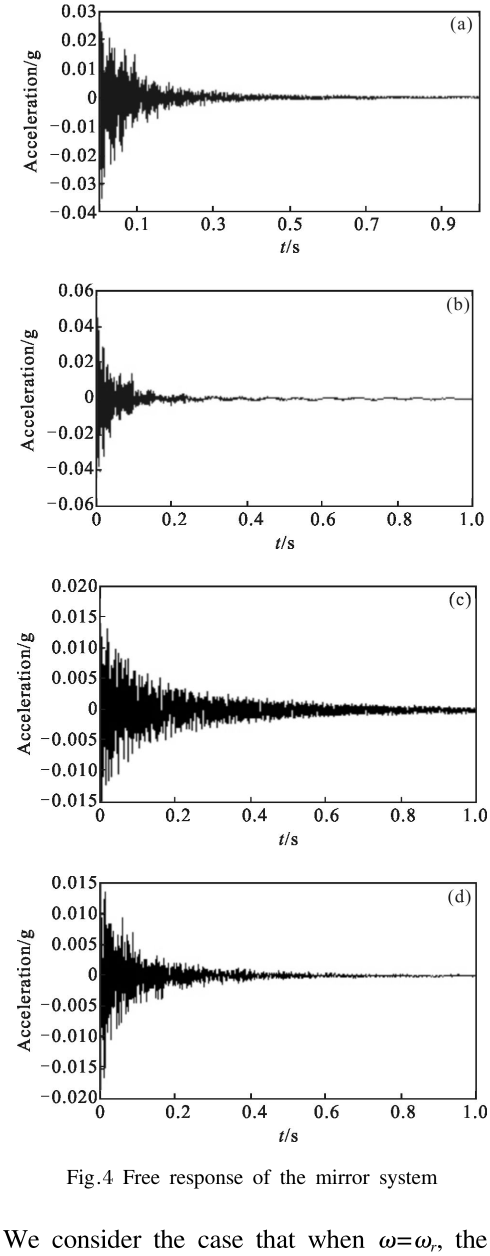


Fig.4 Free response of the mirror system

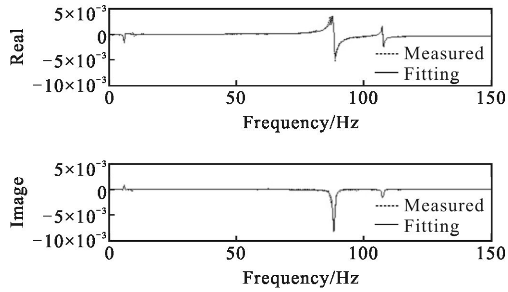
We consider the case that when $\omega=\omega_r$, the image part of the transfer function can be rewritten as

$$H_{lp}^{I}=\frac{-1}{K_{er}2\xi_r}=\frac{-\phi_{lr}\phi_{pr}}{K_r2\xi_r}$$

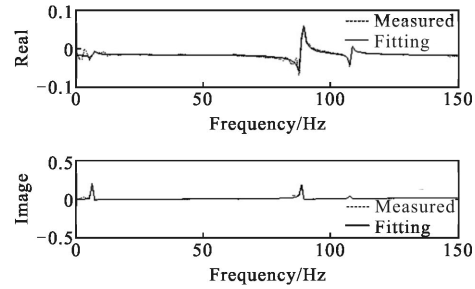
The conclusion can be drawn that the image part of the transfer function is in proportion to the element in the mode shape vector:

$$\{\phi_{lp}\}=-K_r2\xi_r\{H_{lp}^{I}(\omega_r)\} \tag{3}$$

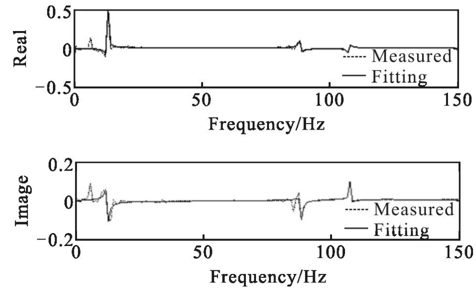
As a consequence, the fitted transfer function and the measured transfer function is shown in Fig.5(a)-(d).



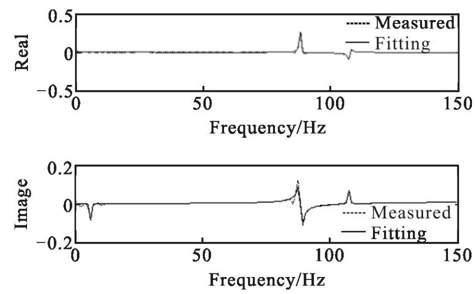
(a) 88.110(0. 45%damping)107.264 (0.19%damping)



(b)88.068(0.43%damping)107.251(0.16%damping)



(c) 88.124(0.37%damping)107.251(0.16%damping)



(d) 88.028(0.58%damping)106.396(0.28%damping)

Fig.5 Real and image part of the transfer function of the mirror system

Firstly, the disturbance at the very low frequency range is noise. The resonance peaks whose according frequencies are not the same for every response function, may be the noise component. Furthermore, the real and image parts of the frequency response function performed as it should be at the resonance frequencies.

And then, from the four transfer function, different frequency and damping ratio will be obtained.

The peak located around the 107 Hz, is powering. It is the rigid body model. Meanwhile, the peak around 88 Hz is the self-mode called astigmatism.

From the Fq.(3), we can obtain the model shapes of the dynamic system. Actually, the mode shape vector is the most important parameters in this test, because the frequency and damping information can be reached only by one test point (even though with lower accuracy). The extra testing points are to assist the calculation of the elements in the mode shape vector. On the other hand, the mode shape can also help to identify the fake model as is described in the previous part.

The mode shape calculated is as follow:

$$\vec{\phi}_1=(0.173\,5 \quad -0.097\,15 \quad 0.097\,85 \quad -0.096\,98)$$

$$\vec{\phi}_2=(0.043\,29 \quad 0.098\,04 \quad 0.070\,82 \quad 0.024\,72)$$

The mode shape is shown in Fig.6. The first order is astigmatic and the second order shape is power. By the natural frequency and mode shape the finite element model can be modified, by the assumption:

Fig.6 Mode shape of the transfer function of the mirror system

We can use the power as an example: The ideal normalized mode shape is:

$$\vec{\varphi}_2^{\,0}=(1 \ 1 \ 1 \ 1)$$

The practical model is:

$$\vec{\varphi}_2=(1.751 \quad 3.966 \quad 2.849 \quad 1)$$

Considering that:

$$\begin{cases}[\Phi]^{\mathrm{T}}[M][\Phi]=[I]\\ [\Phi]^{\mathrm{T}}[K][\Phi]=[\omega^2]\end{cases}$$

$$\begin{cases}[\Phi_0]^{\mathrm{T}}[M][\Phi_0]=[I]\\ [\Phi_0]^{\mathrm{T}}[K][\Phi_0]=[\omega^2]\end{cases}$$

Where:

$$[\Phi_0]^{\mathrm{T}}=\frac{\vec{\varphi}_2^{\,0}}{\sqrt{m_0}}=\frac{(1 \ 1 \ 1 \ 1)}{\sqrt{m_0}}$$

$$[\Phi]^{\mathrm{T}}=\frac{\vec{\varphi}_2}{\sqrt{m_0}}=\frac{(1.751 \quad 3.966 \quad 2.849 \quad 1)}{\sqrt{m_0}}$$

The residual error can be expressed as follow:

$$e_1=[\Phi]^{\mathrm{T}}\begin{bmatrix}k_1&0&0&0\\0&k_2&0&0\\0&0&k_3&0\\0&0&0&k_4\end{bmatrix}[\Phi]-[\Phi_0]^{\mathrm{T}}\begin{bmatrix}k_0&0&0&0\\0&k_0&0&0\\0&0&k_0&0\\0&0&0&k_0\end{bmatrix}[\Phi_0]$$

we suppose the mass and frequency are known, the original data is:

$$m_0=2.35\ \mathrm{t},\ \omega=107\ \mathrm{Hz}$$

So

$$k_0=2.66\times10^8\ \mathrm{N/m},\ \begin{bmatrix}k_1&0&0&0\\0&k_2&0&0\\0&0&k_3&0\\0&0&0&k_4\end{bmatrix}=\begin{bmatrix}1.06\times10^8\ \mathrm{N/m}&0&0&0\\0&5.96\times10^8\ \mathrm{N/m}&0&0\\0&0&3.09\times10^8\ \mathrm{N/m}&0\\0&0&0&3.20\times10^7\ \mathrm{N/m}\end{bmatrix}$$

And this is the modification in the stiffness. For the finite element model, some spring unit can be attached to the nodes of the mirror linking with the nodes on the support structure. Thus, the model is more close to the actual one.

3 Conclusions

The tertiary mirror is supplied by the Changchun

Institute of Optics, Fine Mechanics and Physics, CAS, (CIOMP) in Changchun, China. For the manufacture, fabricate, supporting and alignment are very challenging, there is a 1/4 scale prototype under construction.

The prototype is constructed to help them understand the procedure of building large telescope. The model modify is one of the most important task under consideration. A more precise model (FEA model) can be used to obtain the seismic and wind load response.

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