Numerical Simulation of the Fast Steering Mirror

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Abstract. According to the structural characteristic and working properties, the finite element analysis model of the fast steering mirror (FSM) is established. The numerical simulation is conducted for the FSM. The resonance frequency by use of the modal analysis is compared with the measured result. It is concluded that the resonance frequency of the mirror has the least influence on the mirror in the entire steering mirror structure. The theoretical basis is provided for the structural design of the steering mirror.

Keyword: Fast Steering Mirror (FSM), Finite Element, Numerical Simulation, Laser Communication

1. Introduction
The fast steering mirror (FSM) plays import role in adaptive optics. It enables the beam to achieve rapid and small-angle deflection. It can correct tilt error and stabilize high energy laser beam. It is widely used in the fields such as precise tracking of targets in laser communications [1]. This paper uses ANSYS method to analyse the structure of the mirror, and provide a theoretical basis for the structure design of the FSM [2].

2. The Structure of the FSM
The structure of the FSM is shown in figure 1.
1. reflecting mirror 2. specular seat 3. driver 4. support of the fast steering mirror

**Figure 1.** The structure of the FSM

The bandwidth of the FSM is very important. It is about tens of Hz. However, the bandwidth of the deformed mirror is between tens of Hz to several hundreds of Hz [3]. It corresponds with the Greenwood frequency [4]. When correcting static atmospheric turbulence, the bandwidth ratio of the FSM to the deformable mirror is 1:5 to 1:10. When correcting dynamic targets such as airplanes and satellites, the bandwidth ratio is 1:2 or even 1:1. So the FSM must be increased to several hundreds of Hz [5]. This paper adopts ANSYS method to analyse the overall structure of the FSM, providing a theoretical basis for the structure design of the FSM.

### 3. Dynamic Equation and Solving Method of FSM

#### 3.1. Dynamic Equation

The element dynamics equation in the global coordinate system is as follow [6][7]:

\[
\begin{bmatrix}
    m_g
\end{bmatrix}\{\ddot{\delta}\} + \begin{bmatrix}
    c_g
\end{bmatrix}\{\dot{\delta}\} + \begin{bmatrix}
    k_g
\end{bmatrix}\{\delta\} = \{F_g\}
\]

(1)

Where \[m_g\] is the mass matrix, \[c_g\] is the damping matrix and \[k_g\] is the stiffness matrix. \[T\] is the conversion matrix from the local coordinate system to the global coordinate system [7], we get:

\[
\begin{align*}
    [m_g] &= [T]^T [m_i] [T] \\
    [c_g] &= [T]^T [c_i] [T] \\
    [k_g] &= [T]^T [k_i] [T]
\end{align*}
\]

(2)

Because the displacements of all elements on the common node are equal, the dynamic equations of the elements are assembled, and the dynamic equation of the overall structure in the global coordinate system is obtained as:

\[
\begin{bmatrix}
    M
\end{bmatrix}\{\ddot{\delta}\} + \begin{bmatrix}
    C
\end{bmatrix}\{\dot{\delta}\} + \begin{bmatrix}
    K
\end{bmatrix}\{\delta\} = \{F\}
\]

(3)

which:

\[
\begin{align*}
    [M] &= \sum [m_g] \\
    [C] &= \sum [c_g] \\
    [K] &= \sum [k_g]
\end{align*}
\]

(4)

Where \[M\] is the mass matrix of the overall structure, \[C\] is the damping matrix and \[K\] is the stiffness matrix of the overall structure.

In general case, the damping effect may not be considered when solving the resonance frequency and vibration mode of the mechanical structure. Without external load, the structural dynamic equation is:

\[
\begin{bmatrix}
    M
\end{bmatrix}\{\ddot{\phi}\} + \begin{bmatrix}
    K
\end{bmatrix}\{\phi\} = \{0\}
\]

(5)

The result is as follow:

\[
\begin{bmatrix}
    K
\end{bmatrix} - \lambda [M]\{\phi\} = \{0\}
\]

(6)

It can be concluded from the above formula that the natural frequency and mode shape of the structure only depend on the distribution of mass and stiffness, so these two parameters can be used to characterize the inherent dynamic characteristics of the structure[8].

#### 3.2. Modeling
The FSM is mainly composed of reflecting mirror, specular seat, mirror base, piezoelectric driver, support and other components [9] [10]. The material of the mirror is quartz crystal. The material of the driver is piezoelectric ceramics. The material of the support is Plain low carbon steel Q235. To perform the finite element analysis, the finite element model must be established which is composed of nodes, elements and basically consistent with the geometric shape of the mechanical structure system. The FSM is simplified [11]. The model diagram of the FSM is shown in figure 2. The geometric structure of the mirror is a cylindrical surface with a diameter of 200mm and a mirror thickness of 20mm. The finite element mesh model is shown in figure 3.

![Figure 2. The finite element model of mirror](image1)

![Figure 3. The finite element model of FSM](image2)

4. Simulation and Analysis
After modal analysis, the calculated first five resonance frequencies of the FSM are 4718, 5190.3, 5892.5, 6814.3 and 8023.9. The curve is shown in figure 4.
Figure 4. The Resonance frequency curve of the FSM

The natural frequencies of the first two orders have the greatest influence on the mirror, the influence of the first two resonance frequencies on the mirror is specially studied. The corresponding vibration models are shown in figure 5 and 6.

Figure 5. The mirror model of the first order resonance frequency

Figure 6. The mirror model of the second order resonance frequency

5. Conclusion
After measuring, it is concluded that the fifth order resonance frequency of the FSM is no more than 1900Hz at most. The modal analysis result shows that the lowest resonance frequency is about 4747Hz, which exceeds the lowest resonance frequency of the tilting mirror. The resonance frequency has the
least influence on the FSM in the overall structure. The simulation provides the first hand materials for the structural design of the fast steering mirror.

6. References

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