Design and Application of Fast Steering Mirror based on GMM

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Abstract

The fast steering mirror introduced in this paper using Giant Magnetostrictive Material (GMM) as the offset-generating component, the FSM was actuated by the elasticity of the GMM, which was controlled by the magnetic field generated by the current in the coil around the GMM. This fast steering mirror was applied in the tilt correction system for atmospheric laser beam propagation, and the tilt introduced by the turbulent current was reduced by 90%, the stability and concentration of the laser facula was enhanced greatly.

Keywords: Fast steering mirror; GMM; Tilt correction; Atmospheric laser beam propagation

1. Introduction

The fast steering mirror was the reflecting mirror to adjust the beam direction between the object and the receiver is widely used in astronomical telescope, laser communication, image stabilization, fine tracking and pointing system. For the FSM has high resonant frequency, fast response time and small dynamic lag, it can also be used to correct the facula tilt created by the turbulent when the laser propagate in the atmosphere in real-time.

The giant magnetostrictive material [1] is a novel functional material developed from 1970s. Its length (or shape) will extend or shorten in magnetic field. Compared with traditional magnetostrictive material, PZT, voice-coil actuator, GMM has big magnetostriction (λ=800x10^{-6}~1600x10^{-6}), high precision, high output power, fast response time, high Coupling Factor. So we choose the GMM as the actuator component for the FSM.

2. Structure and operation principle of FSM

Fig1(a) shown the main structure of the FSM, composed by the base, the flexible bearing axes, two GMM actuators, two elastic springs and the reflecting mirror. The center of the reflecting mirror was fixed by one end of the flexible bearing axes, and the other end of the flexible bearing axes was fixed on the base. Two GMM actuators were fixed on the base by 90^{o}, the knockout pin of the actuator support under the reflecting mirror, and two springs were fixed out of the actuator parallelly, one end was fixed on the base, the other end was fixed under the reflecting mirror. When the actuator extends,

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I=1A，Through the MATLAB simulation program，the result was shown in Fig.2:

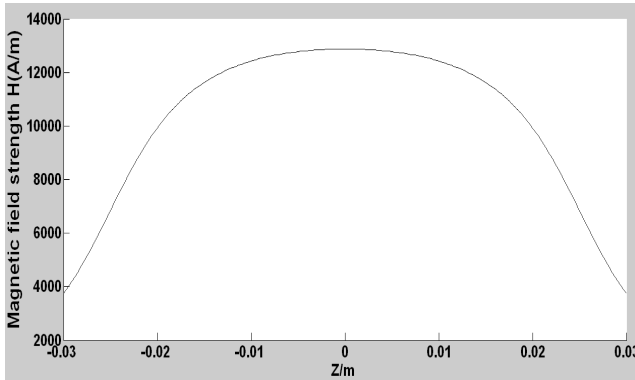


Fig. 2 .the distribution of the magnetic field

From the result we figured out that the magnetic field strength is homogeneous when z=(-0.015~0.015m), so we choose the GMM length=30mm to ensure that the GMM would in homogeneous magnetic field.

3. Resonant frequency of the FSM

The FSM should have enough bandwidth. The FSM was made up of many components, these components composed of many different inertia-elastane system, they have different resonant modes. And the bandwidth of FSM was limited by the lowest resonant frequency. The lowest resonant frequency was decided by the actuator's elastane and the mirror's inertia. Assume the reflecting mirror is a rigid body, based on an elastic system, the self-oscillating angular frequency [4] is:

$$\omega = \left(\frac{C_0}{J}\right)^{1/2} \tag{1}$$

In the equation，the elastic bearing angular stiffness $C_0 = CL^2$，C is the actuator's tension stiffness or compression stiffness：

$$C = E^{'}S/l \tag{2}$$

In the equation, $E^{'}$ is Young's modulus of GMM，S GMM's sectional area，l is GMM's length.

The moment of inertia to the pivot point: $$J = J_0 + m r_0^2 \ , \tag{3}$$

r_0 is the distance from GMM to the bearing axes.

When $r_0 = 0$: $$J = J_0 = \frac{\pi \rho h D^4}{64} \tag{4}$$

Then the angular frequency ω is: $$\omega = \left(\frac{64E^{'}SL^2}{\pi\rho hlD^4} \right)^{1/2} \quad (5)$$

And $l = \frac{\delta}{d_{33}^2 H_0}$, $d_{33}^2 = d\lambda / dH$

In equation (5), H_0 is magnetic field strength; d_{33}^2 is GMM's magnetostriction. Substitute equation (5):

$$\omega = \frac{8}{D^2} \left(\frac{d_{33}^2 E^{'} H_0}{\pi\rho} \right)^{1/2} \left(\frac{SL^2}{\theta h} \right)^{1/2} \quad (6)$$

When $k = \left(\frac{d_{33}^2 E^{'} H_0}{\pi\rho} \right)^{1/2}$

Then (6) can be written as: $$\omega = \frac{8k}{D^2} \left(\frac{SL^2}{\theta h} \right)^{1/2} \quad (7)$$

The equation (7) shown the relationship between ω and the mirror's diameter D ,inclination angle θ, the mirror's thickness and h distance from GMM to the bearing axes . In common, the mirror's thickness $h \approx D/10$, ensure the mirror's stiffness. And we can increase the resonant frequency by enlarge the GMM's sectional area S and L. When these parameters are defined, we can figure out ω. Substitute the FSM's mirror to equation (7), then the lowest resonant frequency is：

$$f = \omega / 2\pi = 203Hz. \quad (8)$$

We also measured the lowest resonant frequency of FSM by experiment. From 0.1~200Hz, input sinusoidal signal to the FSM's driver circuit every 10Hz, then record the biggest inclination angle. The result was shown in Fig.3 :

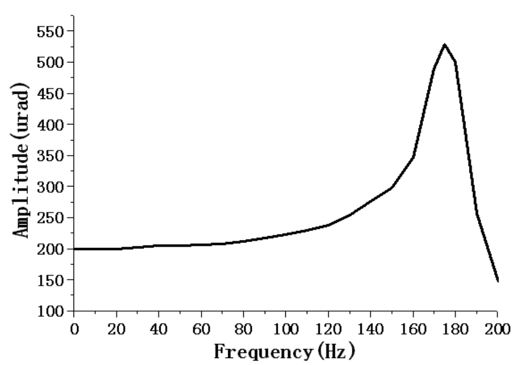


Fig.3 FSM's frequency characteristics

Fig.3 shows the lowest resonant frequency is about 180Hz, smaller than the former theoretical calculation. That's because we approximated the mirror's stiffness, and the FSM's base was assumed stable.

4. The FSM's application in the tilt correction system for atmospheric laser beam propagation

The FSM was applied in the fine tracking loop of the tilt correction system [6] for atmospheric laser beam propagation, the fine tracking loop contained a FSM, one position sensitive detector, single-chip computer tracking-controller and FSM driver. The system could be used to correct the tilt when the laser beam propagate in atmosphere, improve the facula quality. The experiment process was shown in Fig.4, the laser beam that the telescope received was reflected by the FSM to the light splitting mirror, the laser beam was splitted into two beams, one beam entered the imaging system, the other arrived PSD. The PSD collect the position of the facula, transformed into electric signal, after applied and filtered, the single-chip computer began A/D convertion and figured out the offset of the facula, then figured out the value of output voltage to drive the FSM, the FSM was drived to rotate by the FSM driver, then the facula would be always in the center of the imaging system.

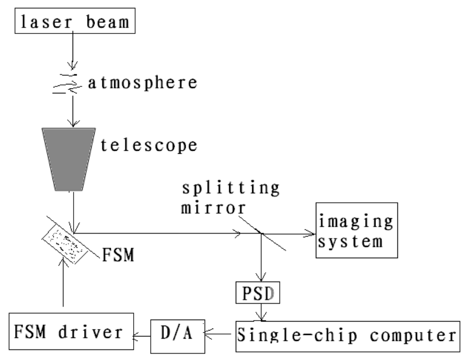
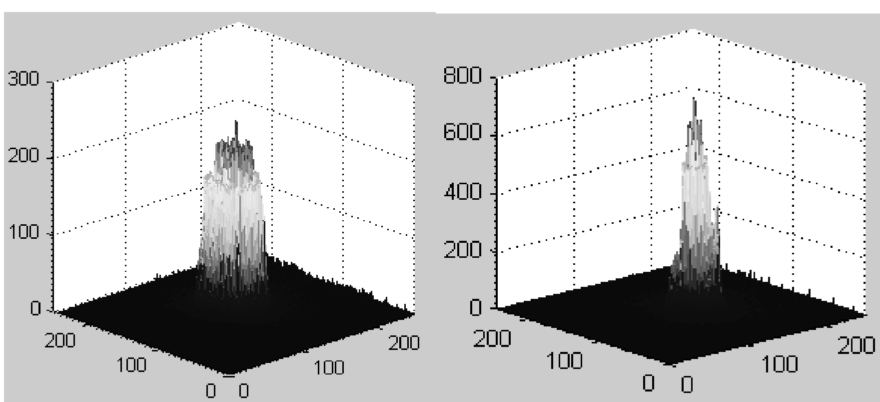


Fig.4 Fine tracking sytem

Fig.5 shown the facula's gray scale image that processed by MATLAB image processing program. When the system in closed loop, the facula concentration improved greatly, the open-loop peak lightness value is 196, the closed-loop peak lightness value increased more than two times, reached 637.



(a) Open loop (b) Closed loop

Fig.5. The facula's gray scale image through MATLAB software

Fig.6 shown the open-loop and closed-loop tilt variance of the laser facula that the telescope received from 1miles away.

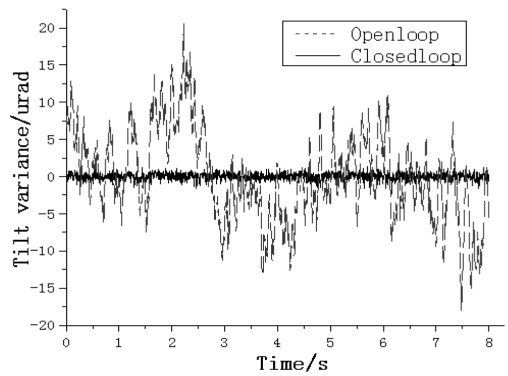


Fig.6 X,Y direction open-loop and closed-loop tilt variance

As shown in Fig.6 , we figured out the open-loop tilt variance is 4.385urad in X direction, 2.778urad in Y direction; the closed-loop remain variance is 0.405urad in X direction, 0.327urad in Y direction. And the telescope's whipping and the system noise introduced some error to the remain variance.

Fig.7shown the power spectrum line [7]. The tilt energy generated by turbulent current is main in low frequency, the tilt energy was reduced by 1~4 orders through the fine tracking system based on FSM. but in higher frequency, the tilt energy was not reduced because of the speed and precision of the system's limit.

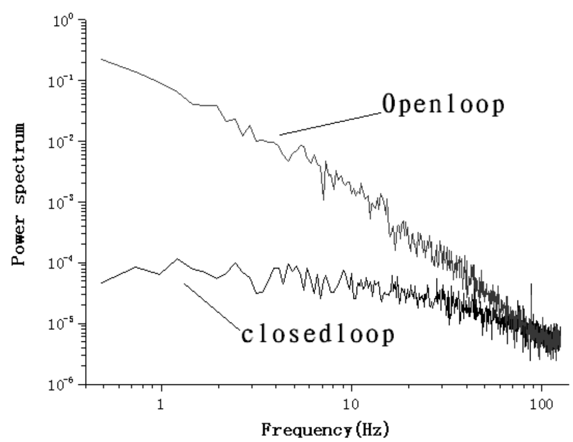


Fig.7. Tilt Power spectrum

5. Conclusion and futural study

In the study, the FSM we designed based on GMM has advantages of big diameter (155mm), fast response time, high precision and low driving voltage (0~10V). It was applied in the fine tracking loop of the tilt correction system for atmospheric laser beam propagation, and correct the tilt lower than 50Hz introduced by turbulent current. In order to enhance the performance of the FSM. There are still some things to improve. The GMM's thermal expansion coefficient is a little higher than other materials, the current in the coil around the GMM created quantity of heat, when the heat can't distribute in time, the GMM's temperature will rise, then the precision would reduced. So we will develop a constant-temperature system to ensure the GMM work in a constant -temperature environment. And also the parameter of the flexible bearing axes should be studied further.

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