Application of Passive Damping to Increase Performance of the Sodium Guidestar on the AEOS 3.6 m Telescope

Steven Griffin, Shawn Haar

The Boeing Company

Christopher Wood

Air Force Research Laboratory

1. ABSTRACT

A sodium guidestar will be incorporated into the AEOS 3.6 m telescope and is scheduled for completion in early 2014. The optical path of the guidestar includes a beam expander and transfer optics ending with a relatively large elevation flat before the laser beam is launched into the sky. The elevation flat is cantilevered off the elevation axis to maintain boresight with the telescope. While this simplifies alignment, it introduces a challenging structural dynamics problem since vibration of the cantilevered optic translates directly into guidestar jitter. Initial measurements of the elevation flat show that vibration levels are high enough to impact guidestar performance in relatively benign ambient conditions. To decrease this vibration, a tuned mass damper has been designed for the elevation flat and will be integrated into the system. This damper will significantly decrease vibration of the elevation flat by adding damping to the elevation flat's first vibration mode. This paper presents the initial vibration measurements that quantified current vibration levels and the analysis used to design the tuned mass damper treatment.

2. INTRODUCTION

The Advanced Electro-Optic System (AEOS) 3.6 m telescope's mission is broad, encompassing pure research as well as supporting the Department of Defense (DoD) as a contributing sensor in the Space Surveillance Network (SSN) for satellite and astronomical phenomena. The DoD mission provides Space Situational Awareness (SSA) for numerous orbital objects assisting in the protection of US space assets. The most exciting new capability to support SSA on the AEOS 3.6 meter telescope is the ability to image dim and extended targets in terminator or full dark conditions with a Sodium Guidestar (NaGS) Adaptive Optics (AO) system. This capability is similar to other science and operational assets such as that at the 3.5 meter telescope at Starfire Optical Range (SOR) with the unique aspects of Mount Haleakala's fourth best seeing conditions in the world and most accessible 10,000-foot mountain observatory coupled with the extremely agile AEOS telescope. In addition to the agile nature of the telescope, the AEOS telescope provides sensor access through four trunion ports, the coude path, the coude room, and seven experiment rooms allowing an expansive array of sensor capability. Any sensor operating in the coude room or one of the seven experiment rooms can optionally receive NaGS AO corrected light.

A critical component of the NaGS capability is a stable, mount-synchronized, laser launch system. The NaGS laser produces a 40 watt, 589 nm wavelength laser that reflects off the sodium layer at approximately ninety kilometers above the earth creating an artificial guide star. To safely and accurately launch the laser, the final output stage of the AEOS solution involves a turning flat mounted directly in line with the elevation axis on a cantilever beam. This allows the elevation flat to direct the guidestar with the elevation axis of the telescope but introduces a structural resonance in the optical mount. For the agile 3.6 m telescope, disturbances multiply through the long cantilever to inject uncorrectable jitter in the laser beam output space. Jitter in the output space directly results in degradation of the received beam and ultimately less received power and therefore must be minimized. This paper describes the passive damping treatment designed to reduce jitter in output space and improve overall performance.

3. ANALYSIS

The last optic in the sodium guidestar optical path as the laser exits the system is an optical flat, referred to as the elevation flat, shown in Fig. 1. A cantilevered shaft passes through a hole in the yoke that supports the elevation axis to connect the elevation flat to the elevation axis.

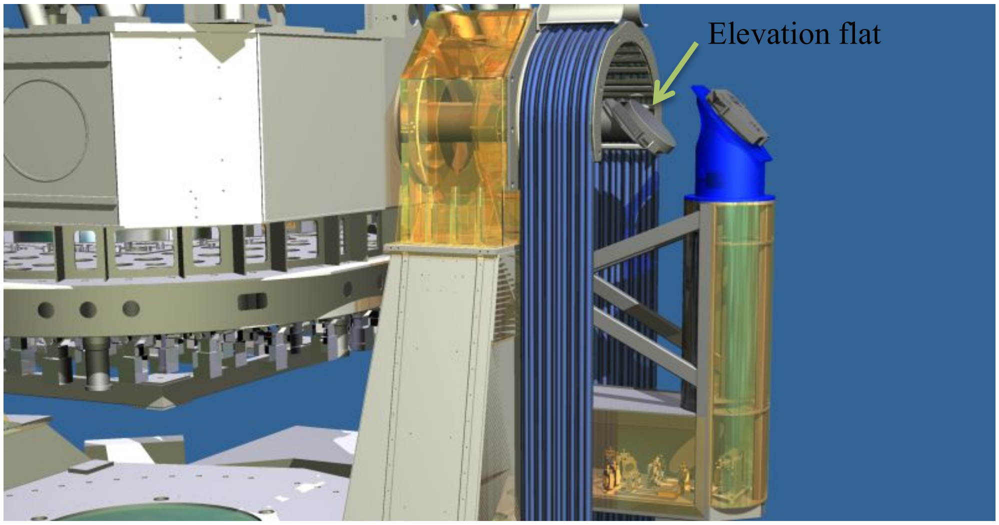


Fig. 1 – Elevation flat supported by cantilevered shaft

This allows the laser beam projected by the sodium guidestar to stay within the field of view of the telescope as it changes angle in elevation and azimuth. While this is a convenient means of alignment, it introduces the potential for the dynamics of the elevation flat mount to introduce jitter between the laser beam and the telescope. Since the return from the guidestar has significant latency caused by the round trip path to the sodium layer, it is difficult to correct for this jitter using feedback control. An inertial measurement of the elevation flat angle in Fig. 2 shows a two axis mechanical angular RMS value of .65 μRad from 25 Hz to 150 Hz that is dominated by a peak in the power spectrum at around 45 Hz. This equates to > 1 μRad of jitter in optical output space. It was assumed that vibration below 25 Hz would not induce relative jitter between the elevation flat and the AEOS telescope. This measurement was made under relatively quiet conditions with the dome closed. Modal testing confirmed that the peak at around 45 Hz was due to the first cantilever mode of the elevation flat on its shaft.

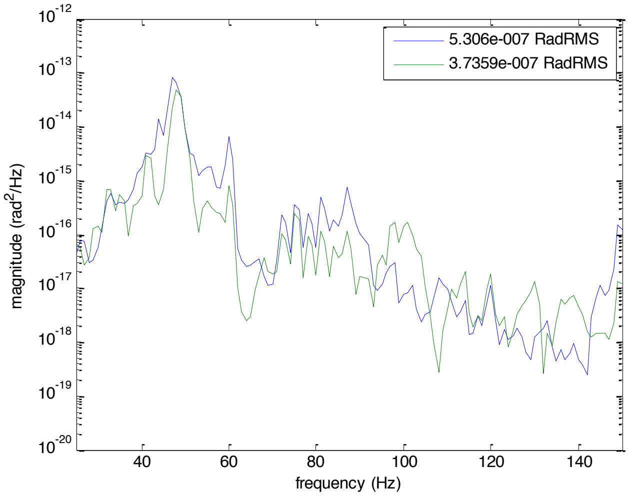


Fig. 2 – Power spectrum of elevation flat mechanical jitter

A finite element model of the shaft with a rigid mass and inertia representing the elevation flat was generated and is shown in Fig. 3. A modal analysis of the model gave mode shapes and frequencies that were used to generate a state space model in Matlab using mode superposition [1].

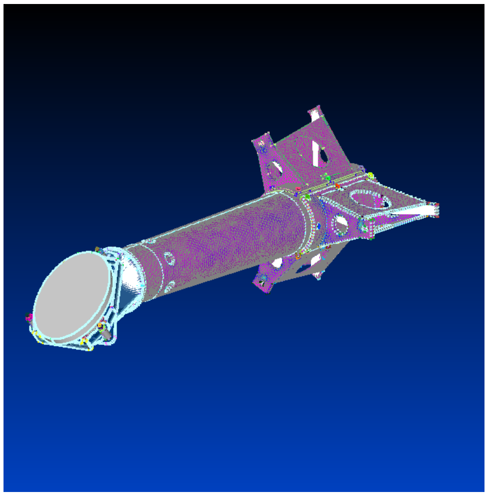
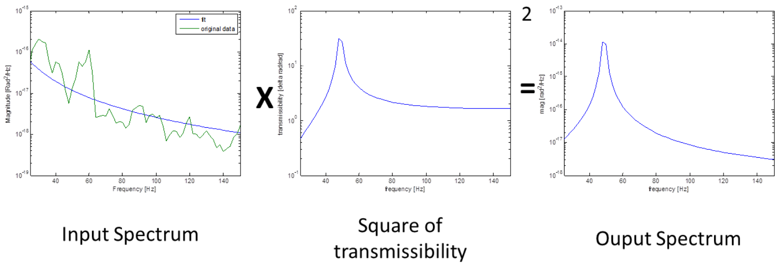


Fig. 3 - FE Model of Elevation Flat

The state space model was used to generate transfer function predictions of the baseline elevation flat hardware and to evaluate the effect of passive damping augmentations. In order to do this, inertial tilt was measured at the approximate mounting location of the elevation flat on the telescope in relatively quiet conditions. A function was fit to this data that had an equal RMS over the bandwidth of interest. This function was multiplied by the square of the transfer function relating base motion of the elevation flat to differential tilt between the base and the flat. The resulting power spectrum was a prediction of jitter on the elevation flat in one direction. This process is illustrated graphically in Fig. 4.



Input Spectrum

Square of transmissibility

Ouput Spectrum

Fig. 4 – Process of Predicting Elevation Flat Jitter

The output spectrum resulting from the process illustrated in Fig. 4 is similar in its shape and magnitude to the measured elevation flat jitter shown in Fig. 2.

The model was then used to examine the effect of adding tuned mass dampers to the elevation flat. Two commercially available tuned mass dampers were considered from CSA/Moog Engineering. Both dampers are capable of a damping ratio of 25% of critical in the frequency range of the elevation flat resonance using magnetic damping. These units display very little temperature dependence when compared to tuned mass dampers that use a viscoelastic loss mechanism. The difference between the models compared was a moving mass of 1 lb for the M1 model versus 2.1 lb for the M2 model. A scaled, custom version was also considered with a 4 lb moving mass and the same damping ratio. It was assumed the tuned mass dampers would be added to the shaft in close proximity to the elevation flat in a direction normal to the surface of the shaft. Fig. 5 shows the effect of the added tuned mass dampers on the ouput spectrum of the elevation flat along with the normalized RMS reduction in angle over the frequency band from 25 to 150 Hz.

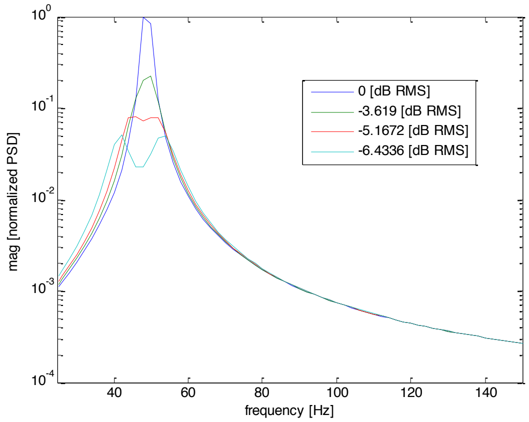


Fig. 5 – Predicted Effects of Adding Tuned Mass Dampers

(blue no treatment, green M1, Red M2, Cyan 4 lb custom)

Fig. 5 shows that all of the tuned mass damper treatments studied yield a significant reduction of mechanical jitter. The M2 result represents the best compromise between cost and performance, since it does not require development and is almost as effective as the custom device at reducing angular motion.

4. CONCLUSION

An analysis is presented of the sodium guidestar elevation flat that shows that the addition of relatively simple, commercially available tuned mass dampers can significantly reduce the vibration of the mirror, which should result in improved guidestar performance.

5. BIBLIOGRAPHY

[1] K. Huebner, D. Dewhirst, D. Smith and T. Byrom, The Finite Element Method for Engineers, NY: John Wiley and Sons, 2001.