Taming the 1.2 m Telescope

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ABSTRACT

Achievable residual jitter on the 1.2 m telescope at MSSS has historically been limited in moderate wind conditions due to the combination of the dynamics associated with the twin telescopes on the common declination axis shaft, and the related control system behavior. The lightly damped, low frequency fundamental vibration mode shape of the telescopes rotating out of phase on the common declination axis shaft severely degraded the performance of the prior controllers. The relatively poor historic performance was due to a combination of the low error rejection of external disturbances, and the controller exciting the mode. The new control architecture described in this paper has made it possible to achieve greatly improved pointing performance.

1.0 INTRODUCTION

Fig. 1 – 1.2 m Telescope

The 1.2m telescope was commissioned in 1969 and had supported many experiments until its de-commissioning in 2008. The decommissioning was due to obsolete equipment and challenges with sustainment costs. The area of greatest concern was the jitter. At last measurement, jitter levels were unacceptable and initial attempts to correct the problem had failed due to the combination of the dynamics associated with the twin telescopes on the common declination axis shaft, and the related control system behavior. This paper describes the new architecture which removes jitter as a concern for the system.

2.0 VIBRATION DATA

A limited modal test conducted on the 1.2 m telescope to confirm the mode shape and frequency of the vibration mode that had been noted in previous observations using the 1.2 telescope. The cartoon in Fig. 2 illustrates the modal test excitation and measurement positions.

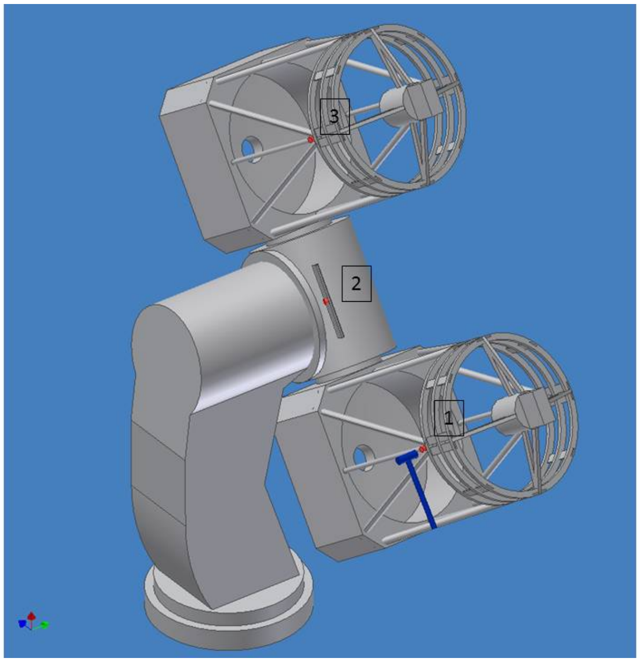


Fig. 2 – Cartoon of 1.2 with accelerometer and hammer positions

The 1.2 was tested in the orientation shown with the sensitive axes of the accelerometers oriented approximately in the negative y direction corresponding to the green arrow in the axes shown at the bottom left of Fig. 2. The modal test was performed with a 3 lb modal hammer input (shown in blue) at position 1 in Fig. 2. The resulting exaggerated mode shape derived from the data is shown in Fig. 3 and was measured at a modal frequency of 6.0 Hz. This mode results in the B37 and B29 telescopes (Telescopes have different optical prescriptions and are denoted B37 and B29) to going in opposite angular directions on the declination axis.

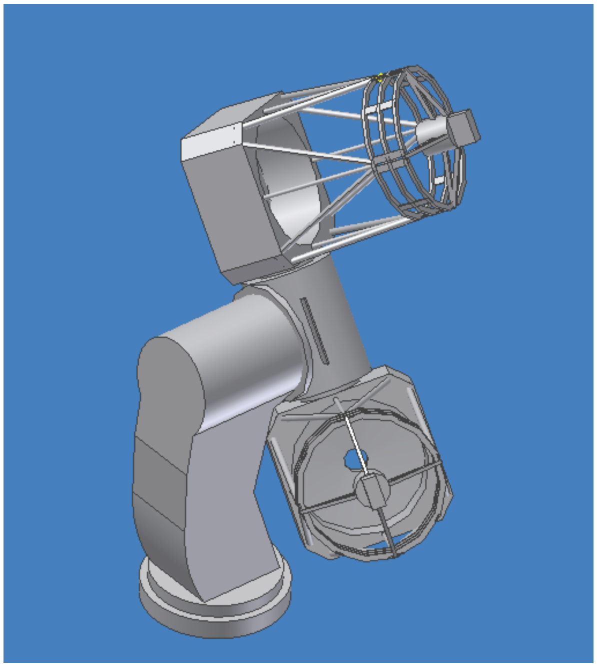


Fig. 3 – Exaggerated illustration of 6.0 Hz mode

The mode is very lightly damped (<1% of critical) and easily excited by external wind loading and command signals. The cause of the low damping coefficient is suspected to be that most of the strain energy is stored in the relatively thin shaft connecting the two telescopes, which has been designed not to have loss mechanisms to allow for easy rotation of the declination axis. This mode is especially problematic to servo control of the affected axis (declination) since the resolver and the inductosyn are located on opposite ends of the shaft and relative motion of these components limit the capability of angular sensing.

3.0 ANALYSIS

A finite element model of the telescope was constructed to evaluate different remediation approaches to address poor pointing performance and the 6.0 Hz mode. The predicted first mode of the model is shown in Fig. 4.

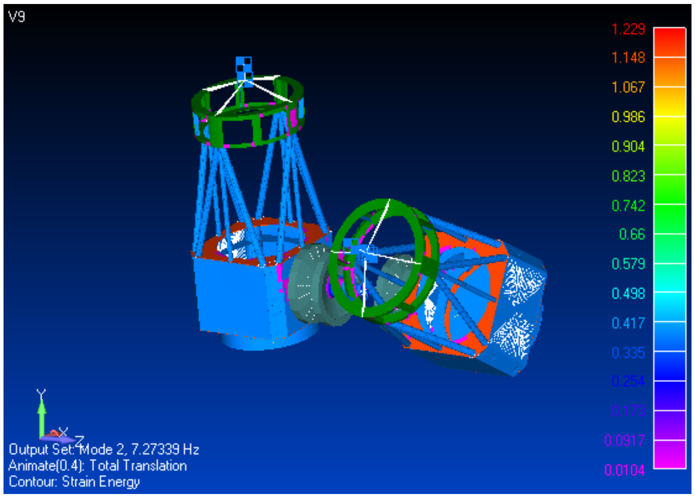
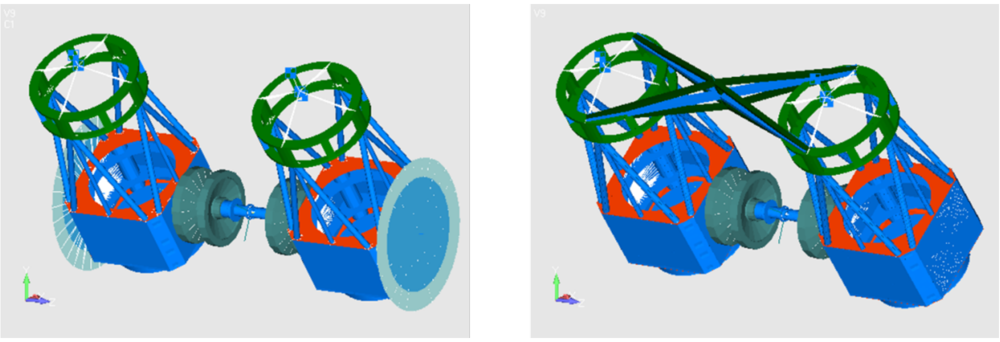


Fig. 4 – Predicted first mode of FE model

The model predicted a similar mode shape to the one that was measured at a higher frequency of 7.3 Hz. This agreement was considered adequate as a basis of a state space model to evaluate potential improvements, and no model tuning was attempted. The state space model was implemented in Simulink using mode superposition [1] with control and torque disturbances on the declination axes as inputs and angular displacement and rate as outputs. A torque disturbance was synthesized in the declination axis so that the state space model displayed angular performance that was similar to measured historical results in amplitude and in power spectrum when the historical controller was applied. The resulting disturbance was then used to compare potential solutions including

- Adding passive damping to mode using tuned mass dampers with high bandwidth control
- Adding active damping with high bandwidth control
- Adding stiffness to increase frequency of mode above frequencies of excitation with high bandwidth control

The passive damping solution required relatively massive rotational, tuned mass dampers to be affixed to the trunnion of each telescope with a total added weight on the declination axis of over 2000 lbs as shown in Fig. 5. The stiffness solution required a lightweight frame to be attached to the headrings of each of the telescopes as is also shown in Fig. 5 with a total added weight to the declination axis of over 500 lbs. Each of these solutions resulted in a new state space model. A high bandwidth servo control loop was implemented on each of the resulting state space models.

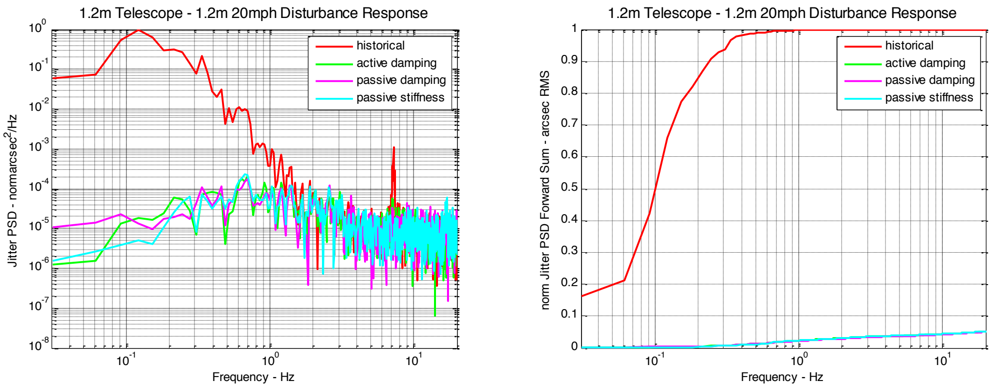


Added dampers

Added stiffness

Fig. 5 – Added passive damping and stiffness solutions

The active damping solution assumed that the two declination axis motors on either side of the shaft could be accessed individually. It was also assumed that the accelerometers in positions 1 and 3 in Fig. 2 could be used as feedback sensors. Active damping was then implemented in the original state space model with a high bandwidth servo control loop. Fig. 6 shows the relative performance of all three solutions normalized by historical performance with the resulting angular power spectrums and forward sums.



Power Spectrums

Forward Sums

Figure 6 – Comparison of proposed solutions

The analysis results show that all of the solutions predict similar closed-loop performance with most of the gains resulting from the high bandwidth servo loop. Based on a trade of the effort associated with each approach, the active damping approach was pursued in a hardware implementation.

4.0 CONTROL APPROACH

The new control approach, including active damping, was implemented using xPC Target with Simulink as the programming environment and a Speedgoat target computer to implement control designs. A simplified version of the control architecture is illustrated in Fig. 7.

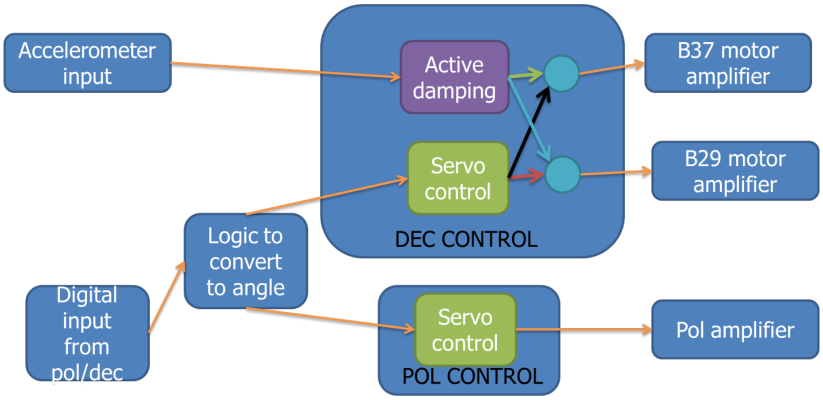


Fig. 7 – HIL Control Architecture

Each block in Fig. 7 represents Simulink S-Functions that performs tasks in the control architecture. The accelerometer input block on the far left of Fig. 7 samples the analog inputs from accelerometers located on the headrings of the B37 and B29 telescopes as shown in positions 1 and 3 of Fig. 2. The digital input block samples the inductosyn/encoders on each axis which are converted to angular data using a custom Simulink block. The angular data was used as inputs for the servo control blocks implemented in both the polar and declination axes. A hardware modification was implemented to allow separate control of each motor in the declination axis, named B27 and B39 motors to denote proximity to each telescope. This modification allowed for implementation of a control loop between the accelerometers and the motors to address damping of the 6.0 Hz mode and also had the added benefit of allowing trimming of the servo control loop to minimize excitation of the 6.0 Hz mode. Trimming was achieved by adjusting individual gains on each motor until excitation of the mode was minimized. The outputs of the control architecture were analog control signals to the individual declination and polar axis amplifiers.

Active damping was implemented using generalized active damping [2]. This method was selected because it allows targeted damping of individual modes while minimizing the increase in overall system noise associated with an additional feedback loop. The method is also tolerant of phase delays caused by system latencies associated with sampling and computational delays present in a discrete control implementation. Measured reductions of the 6 Hz mode of ~20 dB were easily achievable using this approach as is shown in a measured transfer function in Fig. 8 of the active damping loop using the motors as inputs and accelerometers as outputs.

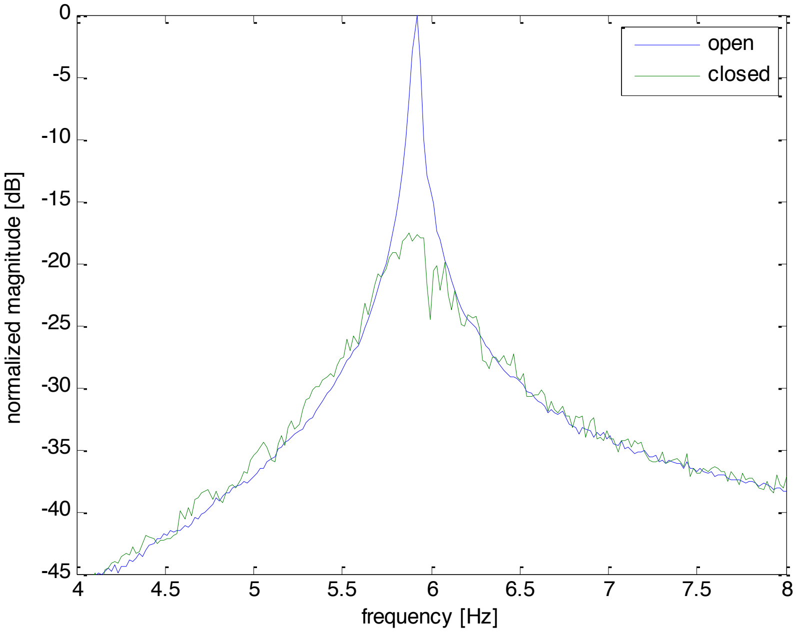


Fig. 8 - Measured hardware transfer function of active damping path

Servo control was implemented in each axis using standard PID control techniques. With the declination axis properly trimmed and active damping implemented, bandwidths of four to eight times that of historical controllers were achievable on the 1.2 telescope. An example of greatly improved transient declination axis performance of the implemented control approach compared to historical performance is shown in Fig. 9.

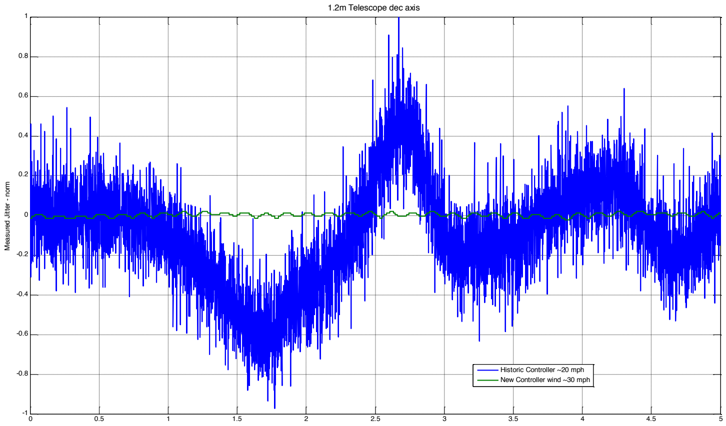


Fig. 9 – Comparison of historical and current measured performance

4.0 CONCLUSION

A new control approach is described that achieves much improved pointing performance on the 1.2 m telescope at MSSS. This approach addresses telescope dynamics that have proven to be a limitation. Implementation on the mount has demonstrated great improvements in both angular sensor and on-sky performance.

5.0 REFERENCES

1. Huebner, K. et al, *The Finite Element Method for Engineers,* John Wiley & Sons, New York, NY,
2. Griffin,S. et al, "Active Vibroacoustic Device for Noise Reduction in Launch Vehicles," *AIAA Journal of Spacecraft and Rockets*, 45, 6, 2008.