Developing Improved Servos for the Multiple Mirror Telescope

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***Abstract*—The Multiple Mirror Telescope (MMT), a joint project of the University of Arizona and the Smithsonian Institution, is in many ways a pioneering instrument that helped pave the way for the new class of 8 to 10 meter optical telescopes in use today. Part of the telescope facility upgrade is improved servos for pointing and tracking of sufficient quality to support the latest generation of wide-field and adaptive-optics instruments. This discussion presents the current and future work in servo development at the MMT.**

I. INTRODUCTION

The MMT was originally commissioned in 1979 as an at the time quite unusual arrangement of six 1.8m primary mirrors in a single optical support structure. The structural design was also unusual in that it utilized a compact altitude-azimuth mount with a co-rotating 550-ton building. The MMT continued to pioneer advancements in local seeing control, high-accuracy pointing and tracking, mirror coating, and co-phased optical operation of multiple telescopes, while doing scientific observations for 94% of its scheduled time. The Steward Observatory Mirror Lab began work on spin-casting 3.5m optical mirrors in the 1980s, and casting even larger mirrors was proven feasible. In 1986, MMTO agreed to replace the six 1.8m primary mirrors with a single 6.5m spin-cast mirror, along with a provision for three secondary mirrors, one at *f*/9 (the same as the existing focal length), an infrared adaptive secondary at *f*/15, and a wide-field secondary at *f*/5. The MMT, see Fig.1, was taken out of commission in March 1998. During the next two years, the new telescope hardware and primary mirror installed. In May of 2000, the telescope saw first light at f/9 Cassegrain focus. The ensuing years have seen commissioning of the other secondary mirror systems, new wide-field imaging and spectroscopy instruments, improved adaptive-optics equipment [1]. The servo control system, designed early in the upgrade project, has proven to be adequate for most astronomy, but the even more stringent requirements for wide-field and adaptive-optics science have driven us to seek improvements to the servo system.

II. TELESCOPE DRIVES

The MMT conversion changed only the top end of the existing altitude-azimuth mount. The azimuth drive consequently remained the same, while the elevation drive changed radically. The old elevation drive used a pair of DC-brush motors with 100:1 gearboxes that drove a common bull gear attached to the optics support structure. With the MMT upgrade the bullgear was eliminated in favor of a pair of steel arcs below the primary mirror cell with a friction drive wheel at each arc, each driven by a new DC-brush motor assembly.

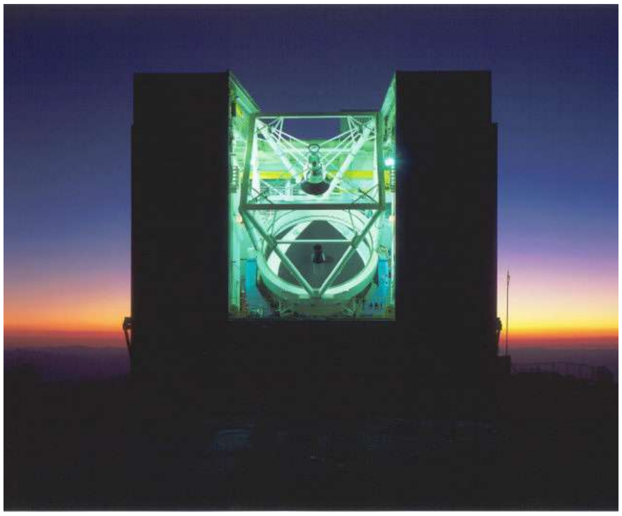

Fig. 1. The Converted MMT at sunset. Photo by H. Lester.

The azimuth drives are four DC-brush motors with a 100:1 gearbox driving a common bull gear attached to the telescope pier. Both elevation drive motors and one of the azimuth motors have a Heidenhain RON905 incremental encoder mounted on the shaft. Elevation has in addition a Heidenhain tape encoder along each drive arc. Absolute position encoding is provided by on-axis rotary Inductosyn units reused from the original telescope system. The “third axis”, to correct the natural field rotation inherent in an alt-az mount, an instrument rotator, has in-house designed gearboxes and DC-brush motors using another Heidenhain tape encoder wrapped around the rotator bearing for semi-absolute positioning (i.e. a short calibration at startup provides absolute position information). New amplifiers for all axes were built in-house, using a mix of Copley Controls PWM units and redesigned linear-output units reused from the old telescope. The absolute encoder electronics were also brought up to a newer revision, work that was the basis for the Very Large Array telescopes' new encoder electronics developed in 1999.

The telescope control system is housed in a VME computer that runs all three servo axes under Wind River Systems' VxWorks real-time operating system, along with a safety interlock system and some ancillary input/output systems. In addition, the VME computer also calculates alt-az and rotator positions based on the LST (local sidereal time) acquired from a GPS clock and the catalog coordinates for the object to be observed.

The servo code itself implements a “dual-loop” servo, see Fig.2, with a velocity loop closed around an incremental encoder and an outer position loop closed on the absolute encoder. For elevation, the velocity loop feedback comes from one of the two tape encoders. Azimuth uses the motor shaft encoder for this feedback, and the rotator uses the counting-mark feedback from its tape encoder. The azimuth and elevation outer loops use their on-axis Inductosyns, while the rotator acquires absolute positions from the semi-absolute index marking provided on the Heidenhain tape. The velocity loop is controlled by a National Semiconductor LM628 controller IC, while the position loop is a scheduled-gain PID run in software on the VME cpu.

Fig. 2. Simplified MMT Servo Block Diagram. All three axes similar in layout and operation.

The initial servo design was done by Steward Observatory, and implemented by MMTO personnel. After getting the system up and running, we turned our attention to measurement of the actual performance of the servo in hopes of gaining insight into how to improve tracking.

Early measurements with a Hewlett-Packard 35670A Dynamic Signal Analyzer (DSA) applying a swept-sine chirp signal as an input to the servo while getting the LM628 response as the output allowed capturing the servo's closed-loop response.and good insight to the closed-loop behavior of the servo, see Fig.3.

III. ADVANCEMENTS IN TESTING

We developed data collection, analysis, and controller design. Tools using MatLab and Simulink tools, (including Real-Time Workshop, Control System Toolbox,) and xPC Target. Using Real-Time Workshop and xPC Target, we built a data-collection and prototype controller from a standard desktop PC with an Athlon 750MHz CPU and some IndustryPack (IP) modules in hand. This became a target machine for real-time code represented in a Simulink diagram, see Fig.4, taking full advantage of the automated code-generation tools in Simulink. Custom Simulink S-function blocks were created for handling i/o drivers and other necessary tasks to a) collect open-loop data, and b) become the nucleus of a new controller.

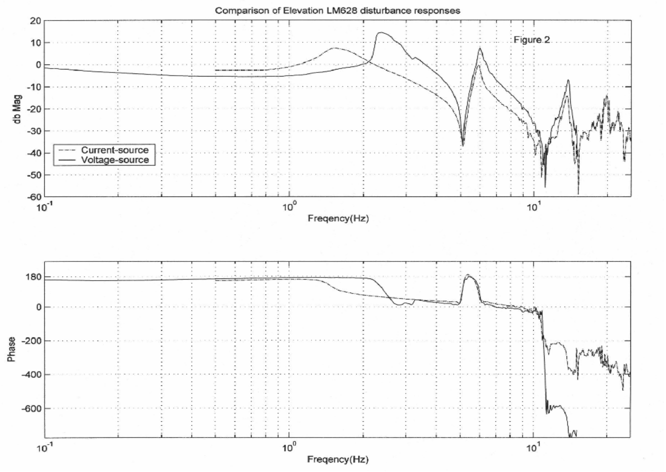

Fig. 3. The response of the elevation servo during swept-sine tests, showing the improvement gained by changing the amplifier mode from current- to voltage-source [2].

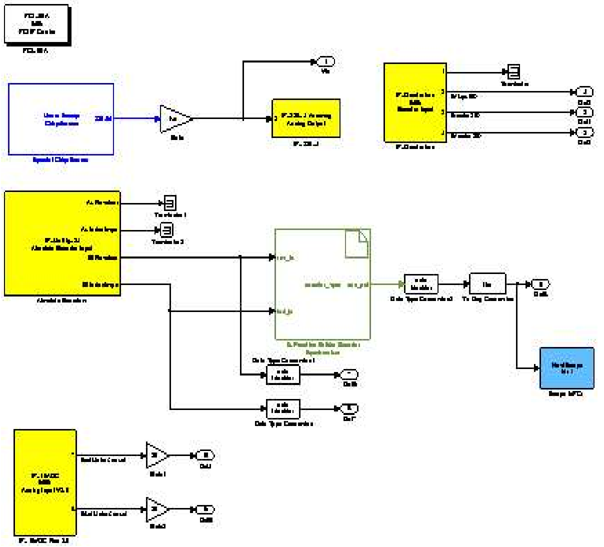

Fig. 4. Simulink Diagram for Open-loop Data Collection on the MMT Elevation Axis

Using the real-time code running under xPC Target on the test PC, we could drive the servo amplifiers with a chirp signal and simultaneously collect the outputs of the incremental encoders, motor currents, and absolute encoder over an Ethernet connection to the host machine running MatLab. Using the analysis tools in MatLab, we generated models of the telescope, see Fig.5, and begun controller design with confidence that the design would work in the field.

Once we had captured the system behavior in a model with acceptable fit, see Fig.6, we could test the elevation axis with the same target PC and MatLab interface used to collect the open-loop data. The native telemetry methods available between the host PC and the target PC running the xPC Target kernel are very useful for quickly collecting data, adjusting parameters, and visualizing results.

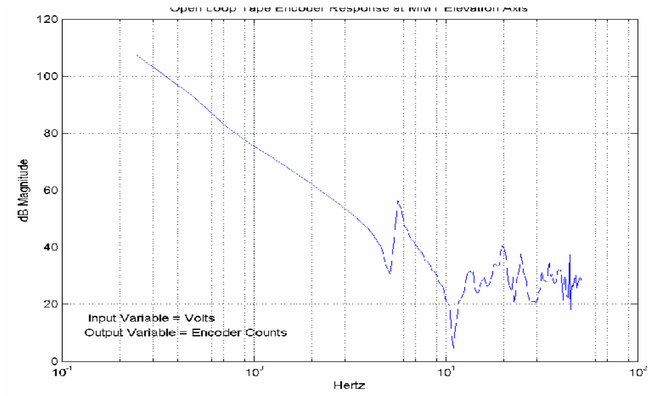

Fig. 5. Sample Open-loop Magnitude Response of the MMT Elevation Axis with a Swept-Sine Input Signal

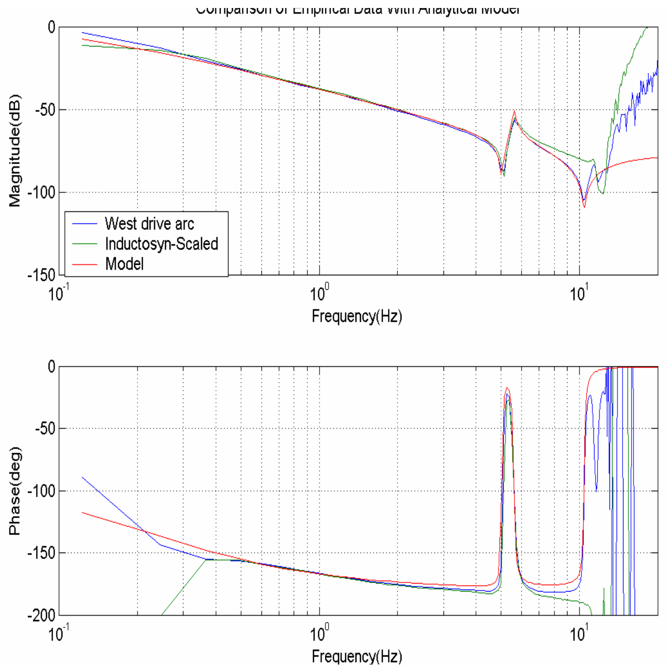

Fig. 6. Comparison of Analytical Model Fit to Actual Open-loop Data [3]

IV. Future Work

We plan to continue with identification and servo design using the xPC Target machine environment. Once the main servo axes (azimuth and elevation) have had a new controller implemented in software and tested, we will be installing the test controller in place of the existing VME control electronics. The VME computer will remain as the “astronomy code” computer to preserve our investment of man-years of programming for astronomy and safety-interlock related functions. The ability to use Ethernet for communication to the target controller makes interfacing the two computers straightforward. We can then fully road-test the controller during actual science observing.

The final system is planned to have the xPC Target code migrated to VxWorks, and attaching the legacy code from the VME machine to the Simulink-generated code, giving a completely integrated PC solution for MMT servos.

References

[1]D. Blanco, "The New MMT", SPIE Conference 2004, Glasgow.

[2]D. Clark, "MMTO Internal Technical Memorandum #03-06, *Selected Results of Recent MMT Servo Testing.*

[3]K. Powell, Steward Observatory, private communication.