MACE TELESCOPE

Control Servo System

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The main goal of the MACE telescope servo controller is to support precision tracking of a gamma-ray source to facilitate the formation of high resolution shower image by the camera electronics. This requires low pointing errors, even under disturbing wind conditions (~ 30 km/hr). Servo system supports Slew, Position and Track modes of operation. Slew mode is used for quick re-positioning of the telescope to a desired location while switching between sources. In Position mode, precision encoders are used as feedback sensors for accurate positioning at the designated angle. The telescope is held at the commanded position continuously while correcting for wind induced disturbances. The Track mode is the normal operational mode wherein the demand angles are generated using the Ephemeris of various sources. A requirement very specific to this telescope is to quickly reposition the telescope within a minute to capture an astronomical transient event as reported by other telescopes around the globe. This requires a high speed slew mode of steering of the telescope. This is realized by changing the servo drive's transmission gear ratio on the fly. Pointing accuracy is defined as difference between telescope bore sight and the stationary target look angles, whereas tracking accuracy is a measure of error between telescope bore sight and look angles of a moving target.

Azimuth (AZ) slew range	-270° to $+270^\circ$
Elevation (EL) slew range	-26° to $+165^\circ$
Min. Tracking velocity	0.5 mdeg /s
Max. Tracking velocity	$\geq$0.5 deg /s
AZ and EL track acceleration	$\geq$0.2 deg /s^2
AZ and EL slew velocity	$\geq$3 deg /s
AZ and EL slew acceleration	$\geq$0.6deg /s^2
Pointing Accuracy	1 arc-min (0.016°)
Tracking Accuracy	1 arc-min (0.016°)
POSITION MEASUREMENT	
-Accuracy	0.5 arc-min (0.008°)
-Resolution	25 bit

System Architecture

Telescope Control Servo System (TCSS) is designed to provide adequate servo control, operational and safety interlocks, safe travel limits, telescope stowing with camera parking, local and remote operations, system configuration, servo calibration and tuning with capabilities for test signals injection, monitoring points and hardware/software diagnostics support. TCSS is divided into the following sub systems:

- Telescope Drive Unit (TDU) with motor, drive amplifiers, switch-gear, Operational and safety Interlocks
- Angle Sensors (Encoders)
- Telescope Control Unit (TCU)
- Test Computer (TC) for TCU

Servo system consists of three cascaded loops– Position loop, Speed loop and twin Current loops with torque sharing, backlash correction and differential speed compensation. The current loops are implemented in the drive amplifiers and the position and speed loops are implemented in Telescope Control Unit.

Telescope Drive System

The Telescope Drive System consists of two servo motors per axis in counter torque mode to eliminate backlash. The motors are coupled to gear boxes.

Motors

Two numbers of permanent magnet Synchronous motors (4 pole, 3-phase) drive each axis through gear reducers. The motors are capable of delivering full torque through-out the speed range from 1 rpm to 3000 rpm. There is sufficient head-room in the torque rating of motor, so that even a single motor can drive the antenna to stow at 60 km/hr wind. Natural convection cooled motors are fitted with fail-safe brakes. The interlocks ensure that brakes are released before the motors are commanded to rotate. Motors are driven from TDU cabinet.

Gear box

Specially designed gear boxes provide two gear ratios of 36000 (HIGH for tracking) and 6000 (LOW for high speed slew). The gear boxes use solenoid controlled friction clutches for faster switching between the high and low gear ratios.

Drive Amplifiers

The motor drives are four-quadrant digital PWM drives with 40A continuous current and 80A intermittent current capability. The amplifiers can operate in torque or speed control mode. During normal mode of operation all amplifiers are configured in torque mode. The torque (current) set points are sent from the TCU via hardwired analog channel or CANBUS. In maintenance mode all amplifiers are set in speed mode. Speed demand is set from a potentiometer on the maintenance panel of TDU. In this mode, only one motor is used to drive the Telescope. The TDU houses all the four drive amplifiers along with associated hardware, switchgears, hardwired interlocks and Maintenance panel. Maintenance Panel allows easy access for troubleshooting and configuration using vendor supplied software.

Interlocks

Hardwired operational and safety interlocks are independently implemented using hermetic military grade relays on a purpose built interlock board.

Dynamic Braking Resistors (DBR)

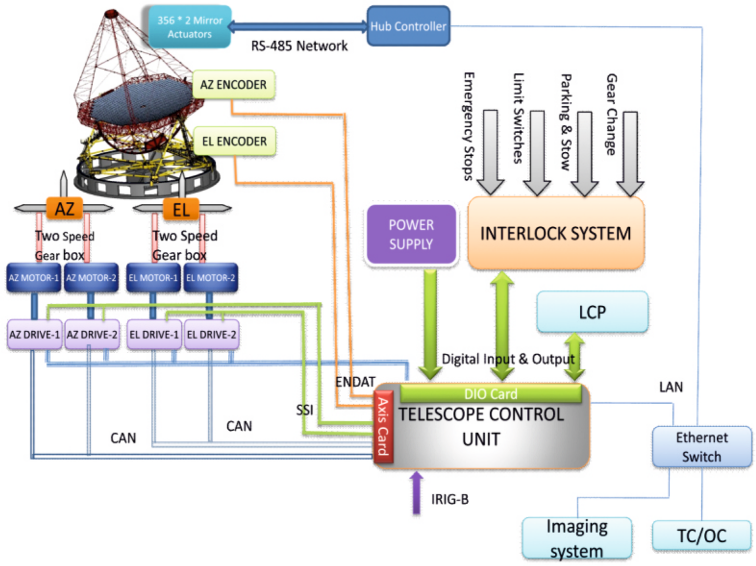
Dynamic braking resistors are used to dissipate energy produced in the motor as the drive provides braking torque to stop the motor and telescope. DBRs are housed in a separate convection cooled cabinet with proper spacing, ensuring good thermal management.

Angle Sensor

There are two precision absolute angle encoders- one for each axis. For azimuth, a multi-turn solid shaft absolute encoder with 25-bit resolution/ turn and 20 arc-sec accuracy is used. For elevation, a single turn solid shaft absolute encoder with 25-bit resolution and 20 arc-sec accuracy is used.

Telescope Control Unit

TCU is built around a Commercially-Off-The-Shelf (COTS) cPCI (compact PCI) chassis having Pentium processor CPU board and customs designed DIO & Axis I/O cards containing motion control peripherals. Entire chassis is powered by redundant power supplies. This provides a motion control platform for hosting TCU software. Axis-1 card caters to azimuth axis and Axis-2 card caters for elevation axis.



THE System Architecture (Top).

EL Drive Train (Middle)

DRIVE amplifier and TDU Rack (Bottom)

Telescope Control Unit Software

TCU Software is real time software running on RT-Linux, a real time extension to Linux operating system. TCU application periodically monitors the digital inputs and uses them for telescope operation and safety interlock. Telescope position is sensed using absolute encoders. It issues current demands to the drives on CAN bus. Telescope Control Software (TCS) read motor speeds via the amplifiers' SSI interface. TCS implements closed position loop Type-II servo for AZ and EL axes to compensate the angle errors and generate rate commands. The rate command is compared with the motor speed feedback. The torque demand, which is the output of rate loop, is used to control drive amplifiers after adding torque bias. TCS also implements the slew control for quick repositioning of the telescope. On reception of transient event capture command it changes the gear ratio to LOW and moves the telescope to the designated look angle at a faster speed (3m/sec). Rate/acceleration feed-forward control achieves high pointing/tracking performance with minimum overshoots and settling times.To track the

Interlock	Action
Limit Switch	Power Withdrawn to Drives
Drive Internal Faults	Power Withdrawn to Drives
Release Brake	Release brake before enabling Drives
Apply Brake	Apply Brakes at Low Motor velocities
Camera Shelter Avoidance	Drives will be disabled in Interlock Condition
HGR, LGR	Ensures that both the Gear Boxes of the same axis are in the same reduction ratio

celestial bodies TCS calculates the target look angles using the star's Right Ascension (RA) & Declination (DEC) angles, along with Site coordinate (latitude, longitude and altitude) and current time from the IRIG-B interface. The RA-DEC angle is obtained in Real time from the Operator's console or from pre-defined source table. The TCS supports local mode of operation through Local Console Panel (LCP) which contains push buttons, lamps and hand-wheels. For servo performance testing and tuning of control loops, signal injection point, signal type and monitoring points can be selected. Other built-in tests permit user initiated testing of motors, amplifiers etc. TCU accomplishes the entire task to close all control loops at 100 Hz rate.

Test Computer (TC) for Telescope Control Unit

TC provide graphical user interface to TCU, acting as the telescope servo system console for control and monitoring. This application can run from anywhere. It provides intuitive Graphical user interface with graphs, pictures, meters, lamps and buttons. It provides screens for normal operation, system configuration, calibration, software diagnostics and hardware diagnostics. It can also log different data for analysis.

System Installation & Commissioning

Considering the constraints at Hanle site, PDR committee had recommended proof assembly of the major subsystems of the telescope to validate the various design & integration aspects of the system. Accordingly, the alidade structure of the telescope was fabricated and assembled at ECIL, Hyderabad. The servo system with all its components was installed and verified for its functionality and cleared for assembly of the system at Hanle. Servo System commissioning at Hanle was initiated and completed in various phases. The servo parameters were re-tuned and optimized with all mirror panels assembled. The obtained servo performance test results were found to meet the required specifications.

THE SERVO controller system of MACE supports precision tracking of a gamma-ray source to facilitate the formation of high resolution shower image by the camera.

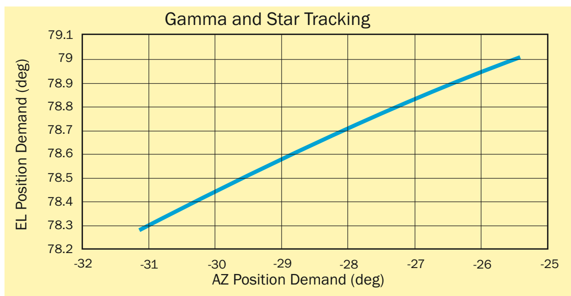
AZ Axis Test Results

The position loop is tuned with type II compensator. The axis performance is tested by injecting a small signal of 50mdeg & large signal of 10 deg. From the step response of small signal, the rise time of 840msec and overshoot of 25% is obtained. For large signal, the overshoot is minimized by using slew controller. The peak speed observed is 0.35deg/s.

Position error was measured in very low speed and high speed track profiles. The observed RMS errors were 0.57mdeg and 0.495mdeg respectively.

EL Axis Test Results

The step response of EL PLC for 50mdeg & 10 deg inputs has been calculated. From the step response of small signal, the rise time of 1.2s and overshoot of 26.5% is obtained. Position error was measured in very low speed and high speed track profiles. The observed



▲ **SOURCE** Tracking performance.

Site Latitude	17.7674 deg N
Site Longitude	78.5760 deg E
Peak AZ error	53 mdeg (blind spot)
Peak AZ Speed	0.286 deg/s
Peak EL reached	89.07 deg
Source Declination	18.39 deg
Source Right Assertion	14.262 h
RMS AZ error	1.9 mdeg
Peak AZ Accleration	0.05 deg/s^2
Total Track duration	8 hours

THROUGH high speed slew mode of steering, the telescope is repositioned automatically within a minute to capture an astronomical transient event as reported by other telescopes around the globe.

RMS errors were 0.032mdeg and 1.18mdeg, respectively.

Conclusion

Telescope Control Servo System for MACE Telescope is operational at Hanle Site. Development of TCSS for MACE telescope has been a challenging effort with constraints in terms of design to meet the stringent requirements and Site location.

Usage of proven design and qualified COTS products has helped in realizing a very cost effective, operations friendly and maintainable system meeting the specifications.

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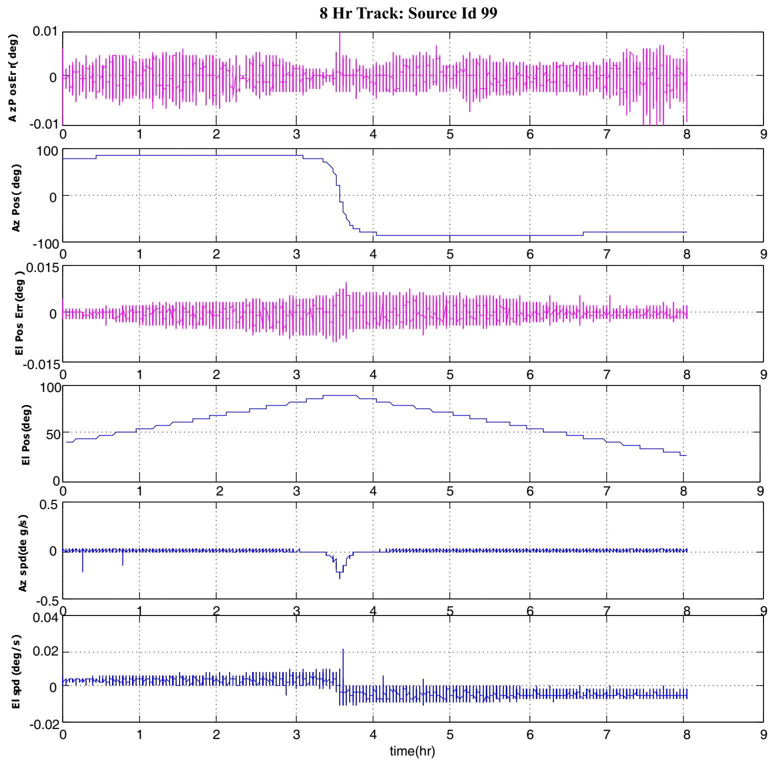

▲ SOURCE Tracking Results.

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