MULTIPLE MIRROR TELESCOPE OBSERVATORY

TECHNICAL REPORT NO. 4

MMT MOUNT CONTROL SYSTEM

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MARCH 1980

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ABSTRACT

The basic principles of operation of the Multiple Mirror Telescope mount control system are described. Measurements and calculated parameters are presented which characterize the static and dynamic behavior of the servos according to a mathematical model which is a reasonable approximation to the electromechanical system. The current performance in terms of tracking accuracy, transient response, and disturbance sensitivity is both qualitatively and quantitatively described. System deficiencies are noted and in some cases remedies are proposed.

I. INTRODUCTION

The Multiple Mirror Telescope (MMT) is in several ways a departure from conventional optical telescope design. The optical support structure (OSS) contains six identical optical systems with 1.8 m diameter primary mirrors. The six optical axes can be coaligned with that of a central 0.8 m guide/alignment telescope using a closed-loop active optics control system. The OSS is carried by an altitude-over-azimuth telescope mount similar to that used by conventional radio telescopes. The required precision of star tracking and the desired accuracy of star acquisition, however, are considerably greater than that of radio telescopes. The mechanical drives and electronic circuits form a position control system which follows commands from the mount computer. Preliminary goals for this system are as follows:

1. Point by dead reckoning to 5 arcsec RMS.
2. Offset over 1 deg to within 2 arcsec RMS.
3. Track within 2 arcsec RMS for 10 minutes.

All specifications apply to elevation angles between 15 deg and 85 deg, and wind limits between 0 and 30 km/hour in the telescope chamber are being considered. Final goals are as follows:

1. Point by dead reckoning to 2 arcsec RMS.
2. Offset over 1 deg to within 1 arcsec RMS.
3. Track within 0.2 arcsec RMS for 10 minutes.

The preliminary goals and the first two final goals are all met with the existing control system. More work, however, is required to achieve the third final goal during significant wind loading. This report will describe the present performance of the mount control servo systems and identify problem areas which require further work.

II. SYSTEM DESCRIPTION

A block diagram of one axis of the position control system is shown in Figure 1. The mount computer (a 16 bit NOVA 800 with 32K core memory) sends out a commanded (incremental) position at 10 Hz which is digitally subtracted from the actual (incremental) encoder reading in an up/down counter. The position error is converted to an analog voltage in a 13 bit D/A converter. This voltage is integrated and frequency compensated to produce a velocity command signal. A toggle switch is used to select either manual or computer control. The velocity command signal is compared with the tachometer outputs and the error is amplified and frequency compensated to produce a torque command. Two power amplifiers and drive motors are used on each axis with equal and opposite torque biases to remove backlash in the gear trains. Each motor is reduced by a factor of 4.77 in a transmission coupled to a pinion gear which meshes with a bull gear attached to the telescope axis. The pinion/bull gear reduction is a factor of 21.0, resulting in a total gear reduction of N = 100.

A 24 bit Inductosyn with 1024 poles is the absolute encoder, and its associated electronics package feeds position information (incrementally) into the up/down counter. The output of the counter changes whenever it receives a pulse from the encoder electronics or from a rate multiplier which distributes the proper number of incremental position pulses commanded by the computer over the 100 ms interrupt cycle. Thus, the absolute position command is recalculated in the mount computer only every 100 ms, but in fact, the rate multiplier produces an approximately linear interpolation of commanded position during the 100 ms cycle. This faster updating of the position error allows smooth tracking on a fine scale.

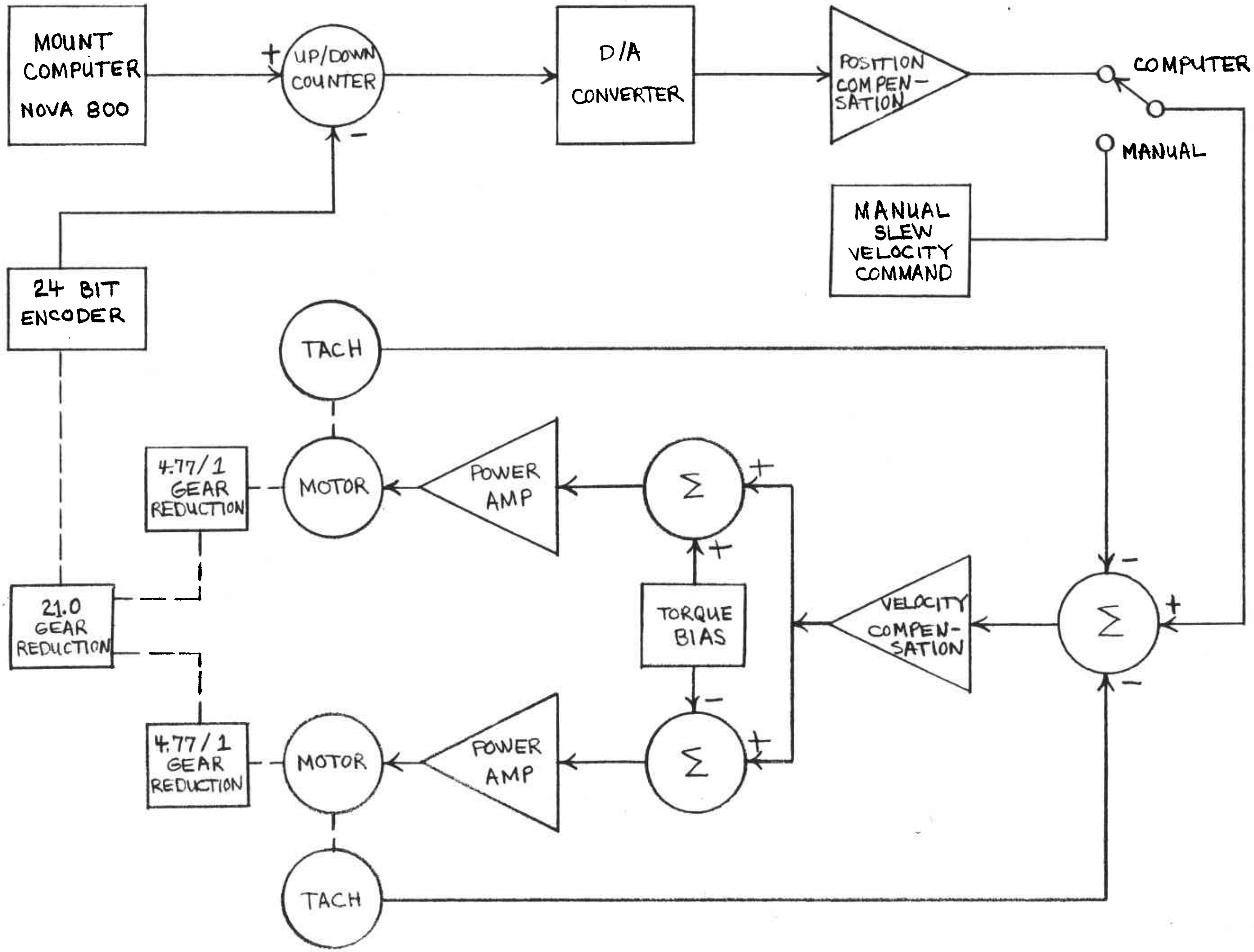

Figure 1. MMT Position Servo
Block Diagram

A somewhat simplified dynamic model of the position control system is shown in Figure 2. The function S is the Laplace complex frequency domain equivalent of the time derivative operation d/dt, and the frequency response is simply obtained by setting $S = j\omega$. Several assumptions have been made to simplify the analysis. First, the poles due to the position subtractor, the position loop amplifier, the velocity subtractor, the velocity loop amplifier, the current drivers, the tachometer amplifier, the encoder position amplifier, and the electrical and mechanical poles of the motors and tachometers are assumed to be much higher in frequency than the pole and zero frequencies of the position and velocity loop electronic compensation circuits. Thus, their effects can be neglected if we restrict the range of frequencies in our analysis to less than the zero in the velocity loop compensation. Second, we have modeled the drive train and telescope structure as a lumped-element second order system, whereas in fact it is distributed. Table I lists the values of electronic constants used (as of 3/1/80) to produce the test results reported here. The significant mechanical and software parameters are listed in Table II. Tests showed that the moment of inertia about the azimuth axis varied less than 10% over the full range of elevation angle, and the value listed in Table II is for 45° elevation angle. While the performance of the MMT mount servos is not optimum in every respect, it is generally good and stable. Future refinements of the model in Figure 2 will allow improvements in performance, particularly in the suppression of position errors due to torque disturbances.

Figure 2

MMT SERVO DYNAMIC MODEL

θ_C = Commanded telescope position (rad)
θ_D = Position disturbance (rad)
θ_E = Position error (rad)
θ_T = Telescope position (rad)
θ_M = Motor position (rad)

ω_C = Commanded telescope velocity ($\text{rad}\cdot\text{sec}^{-1}$)
ω_D = Velocity disturbance ($\text{rad}\cdot\text{sec}^{-1}$)
ω_E = Velocity error ($\text{rad}\cdot\text{sec}^{-1}$)
ω_T = Telescope velocity ($\text{rad}\cdot\text{sec}^{-1}$)
ω_M = Motor velocity ($\text{rad}\cdot\text{sec}^{-1}$)

T_C = Commanded motor torque ($\text{lb}\cdot\text{ft}$)
T_D = Torque disturbance ($\text{lb}\cdot\text{ft}$)
T_E = Torque error ($\text{lb}\cdot\text{ft}$)

K_A = Acceleration constant (sec^{-2})
Z = Position loop zero frequency ($\text{rad}\cdot\text{sec}^{-1}$)
P = Position loop pole frequency ($\text{rad}\cdot\text{sec}^{-1}$)
N = Gear reduction ratio
J = Moment of inertia of telescope ($\text{lb}\cdot\text{ft}\cdot\text{sec}^{2}\cdot\text{rad}^{-1}$)

G_v = Velocity error gain ($\text{lb}\cdot\text{ft}\cdot\text{sec}\cdot\text{rad}^{-1}$)
z = Velocity loop zero frequency ($\text{rad}\cdot\text{sec}^{-1}$)
p = Velocity loop pole frequency ($\text{rad}\cdot\text{sec}^{-1}$)
B = Viscous damping coefficient ($\text{lb}\cdot\text{ft}\cdot\text{sec}\cdot\text{rad}^{-1}$)
K = Spring constant of drive train ($\text{lb}\cdot\text{ft}\cdot\text{rad}^{-1}$)