Bull. Astr. Soc. India (1992) **20**, 345-351

Instrumentation

The design and installation of the secondary mirror motor control for 2.34 m Vainu Bappu Telescope

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Received 1991 July 30; accepted 1992 August 10

Abstract. The 2.3m Vainu Bappu Telescope (VBT) has been designed to have prime, cassegrain and coudé foci. Till third quarter of 1989, VBT was used in the prime focus mode. The cassegrain installation work started from second quarter of 1989 at Kavalur and was completed within a month. This paper explains how the motor control system was designed, checked and installed.

Key words : telescope focus—DC motor control—speed loop—current loop—power amplifier

1. Introduction

In optical telescopes, the secondary mirror is moved up or down to focus the star on the detector while the primary mirror position is kept constant. In VBT, the secondary mirror assembly is moved up and down by a saginaw screw driven by a DC torque motor. A gear box with a speed ratio of 70 : 1 is attached between the motor shaft and the saginaw screw. A fail safe electromagnetic brake (EM brake) is attached at the other end of the saginaw screw. The secondary mirror is housed in the mirror cell. To adjust the mirror position during alignment, a flat table with movements in two perpendicular planes and with provision for tilting the bed with respect to optical axis is provided. The drum which carries the adjustment tables and mirror cell moves up and down on four guide rods. The driving saginaw screw nut is fixed to the drum. When the motor rotates, the saginaw screw rotates after speed reduction through the gear box. The carriage moves up and down as the saginaw rod nut is fixed to the carriage. The loads of mirror, mirror support and adjustments bed are taken by the four guide rods. The saginaw screw and motor give the required drive for movement. The total weight carried up and down is about 750 kg. A schematic of the secondary mirror assembly is shown in figure 1.

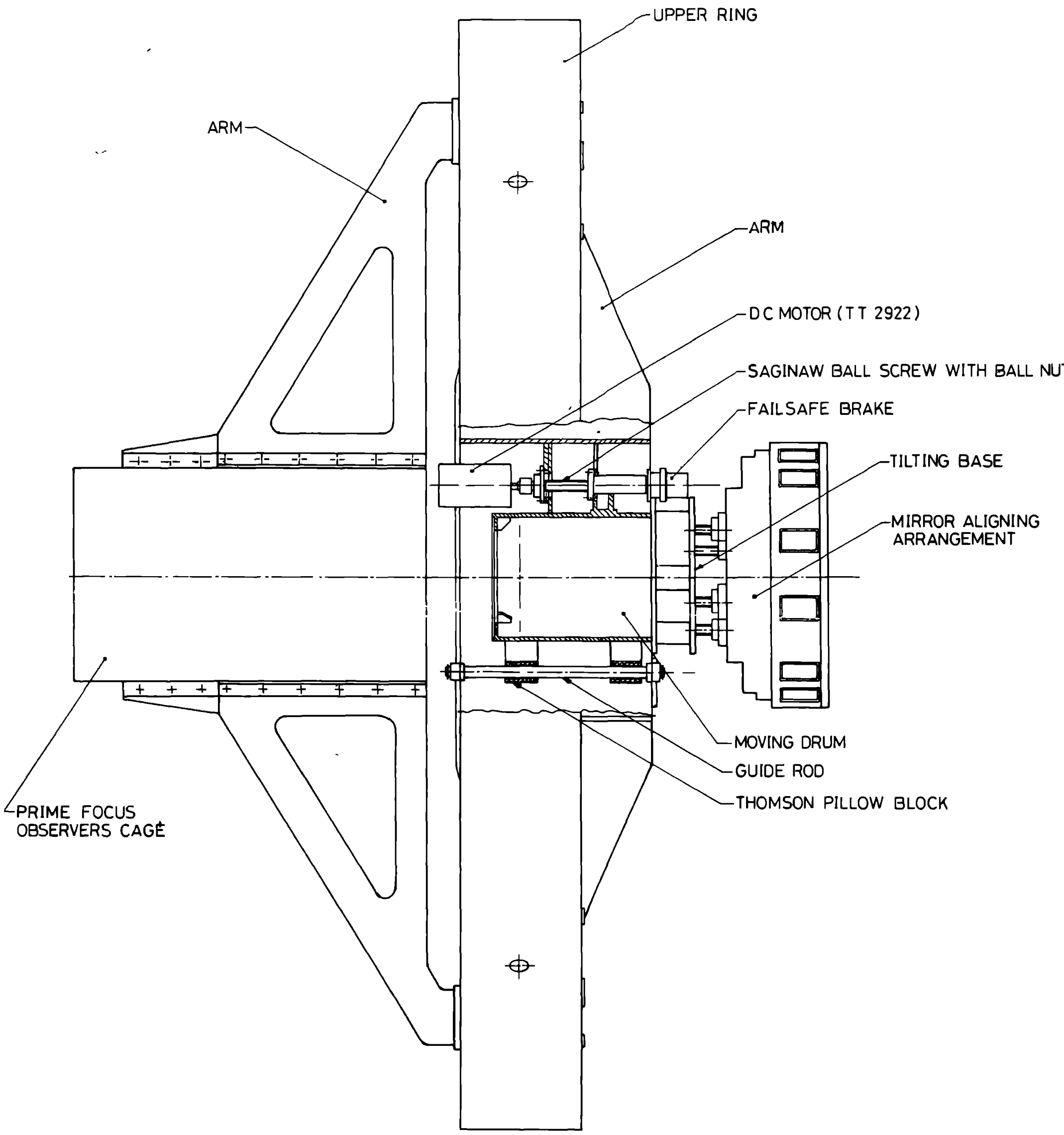

Figure 1. Schematic diagram of the secondary mirror assembly.

If the secondary mirror assembly weight is less than 50 kg, even stepper motors can move the mirror assembly. Stepper motor drive for focus motor movement is implemented in the 76 cm telescope at Vainu Bappu Observatory (Chinnappan 1991). If weight moved is greater than 100 kg, then DC servo motor drive is preferable.

2. Requirement of a focus motor drive

The secondary mirror assembly should be able to move up and down in less than 5 microns displacement for single tapping of a button for fine adjustments and about 50 microns per second for coarse movements. The coarse movement is required to quickly move the mirror position and to estimate the focus point when new instruments are attached to the telescope. The fine focus speed is used for final adjustment and to change the focus position during experiments as in the case of introduction of various filters in the optical path and focus changes due to temperature variations during the course of experiment in night time. Even finer focus control may be required for some high resolution observations like speckles.

The main requirement for the drive is that the motor should be able to stop immediately and should carry the weight against gravity without reduction in speed. The speed should be constant irrespective of load and telescope position. The mechanical supports should be such that there is no buckling due to the mirror and mirror cell weight in various orientations of the telescope.

The secondary mirror carriage assembly mechanical design for VBT was done by M/s Tekcons, Hyderabad, while the fabrication was done by M/s Vani Machine Tools at Hyderabad. The mechanical engineering group of IIA supervised and installed the system.

3. Drive motor and control system

The drive motor selected for this application is the DC servo motor manufactured by M/s Inland Motors, USA. This was purchased in early eighties but now similar motors are available in India with M/s Ralli Wolf, Bombay. The specification of the motor selected for this application is shown below :

Maximum speed	:	2000 RPM
Continuous torque	:	4.1 Nm
Peak torque	:	24 Nm
Current (continuous torque)	:	9.1 A
Current during peak torque	:	54.4 A
Maximum terminal volt	:	91 V
Torque sensitivity (*Kt*)	:	0.28 Nm/A
Mechanical time constant	:	8.4 m. sec.

The motor has built in tacho-generator mounted in the same shaft of the motor. Techno-generator has a voltage sensitivity of 12V per 1000 RPM. Voltage sensitivity is nothing but the voltage generated by the tacho when it is driven at 1000 RPM. Torque sensitivity is the torque developed by the motor for 1 ampere current flow through the motor winding.

Torque motor of this type is required because they have ample power for fast and accurate positioning. Acceleration to 1000 RPM is possible within 14 milli seconds. Speed range capability is in excess of 20000 : 1. With this range of speed, this type of motors are more suitable for telescope drives and only one motor is enough to give all the required speeds (Chinnappan 1988). Speeds as low as 6 revolutions per hour may be achieved without cogging.

4. Motor drive requirements

The motor is normally driven by a power amplifier in a closed loop configuration. As the motor speed reduces with increase in load, it is not advisable to use the motor in open loop configuration. The mirror carriage assembly with mirror cell, X and Y, and tilting adjustments all weighs about 750 kg. The saginaw screw used in this application cannot hold the weight in the vertical direction and the secondary mirror system will automatically come down due to action of gravity. To arrest this, either an electromechanical brake or a gear coupling is required. The present arrangement has both a gear box of 70 : 1 and a 24V EM brake.

5. Closed loop control

In open loop, motor speed keeps varying depending on the load reflected on the motor shaft. In order to achieve constant speed and to have constant torque irrespective of telescope position, speed loop and current loop are used. In speed loop, a reference speed is set as a voltage with the help of a potentiometer. The actual speed at which the motor runs is measured with the help of a tacho-generator, which generates a voltage proportional to the speed. When the motor runs at the set reference speed, the reference voltage and the voltage generated by the tacho-generator will be equal. If there is a mismatch between these two speeds, the difference between the reference voltage and the voltage generated by the tacho gives the amount of mismatch in speeds. The speed loop is designed such that the actual speed always matches the reference speed set. In current loop, the torque developed by the motor is held constant. Without current loop, the power amplifier may not deliver enough current to lift the weight when the telescope is in vertical position. The voltage and current requirements for the motor to move smoothly carrying the weight are computed as follows :

$$Eg = Ke \times n,$$

where Eg is voltage applied to the motor; Ke is back EMF constant and n the speed in RPM.

$$Kt = 0.0095493 \times Ke,$$

where Kt is torque sensitivity. Kt for the motor = 0.28 Newton-metre/ampere.

$$Ke = 29.3 \text{ V/1000 RPM.}$$

The Ke value indicates that the motor needs 29.3 volts to run at 1000 RPM. Supply voltage required to run at 1 RPM is 29.3 milli volts.

Current required for continuous torque rating of 4.1 Nm is 9.1 amps.

For 0.4505 Nm torque current requried = 1 amp.

For 4.1 Nm (motor torque rating) current required = 4.1/.4505 = 9.1 amps.

Torque reflected on motor due to secondary mirror = 6.2 Nm.

Motor current required for secondary mirror assembly = 6.2/.4505 = 13.7 A.

As the current required is higher than rated current, the motor was getting hot after a few hours of operation. The mirror carriage assembly was checked in vertical position during testing because only at this position the maximum load is transferred to the motor. For a weight of 765 kg, the motor was drawing 21 amps to move up and 12 amps to come down. Even though the motor has a peak current rating of 55 A, the duration with which this current can flow is limited to a few seconds.

As the motor took more than its continuous rated current, to lift the secondary mirror assembly, it got heated up soon. To overcome this problem, two methods were suggested; first one was to the motor with another one having the same diameter but with a large value of *Kt* so that current drawn by motor will be less. But later it was decided to introduce a reduction gear between motor and the saginaw screw, so that the reflected torque on the motor is less. Introduction of the gear box would give backlash; but since the weight of the assembly is always acting downwards the amount of backlash is less. With the introduction of 70 : 1 gear box, the motor draws only 1.5 A for a load of 765 kg. The motor never becomes hot even after continuous use for more than an hour.

6. Implementation of closed loop control

In order to maintain constant speed, the voltage generated by the tacho generator is compared with that of a reference voltage. The error output from the comparator is given to the current loop circuit. In the current loop circuit, voltage proportional to current is generated by passing the load current through a series resistor. This signal is compared with the signal from the speed loop and the resultant error drives the power amplifier. The circuit diagram of speed loop and current loop is shown in figure 2.

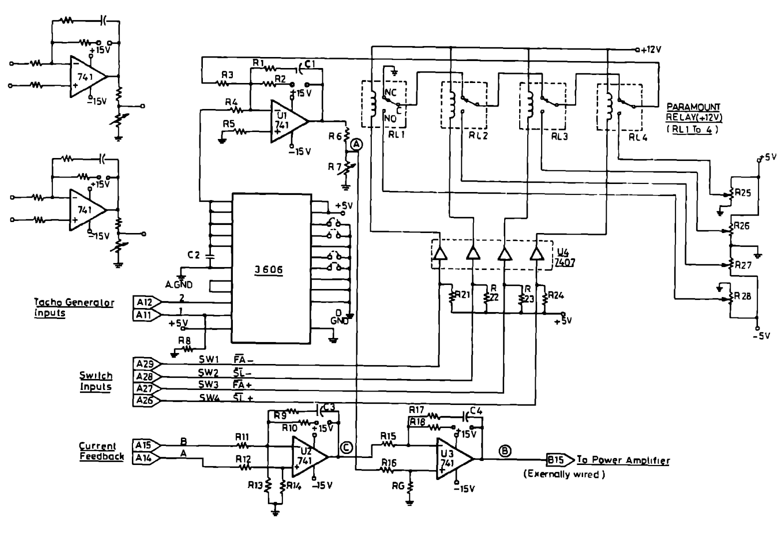

Figure 2. Focus motor control circuit.

When fast motion down switch is pressed in the console, the switch closes the ground to the circuit, the 7407 buffer drives the coil of relay mounted in the same circuit board (PCB). Negative reference voltage which is adjustable with pot R27, is fed to the operational amplifier U1. The signal reaches the power amplifier input and the motor starts moving. As the motor rotates, the tacho-generator which is attached in the same shaft of the motor, generates voltage proportional to the speed. This voltage is given to a programmable gain amplifier (3606). The output of the amplifier is added to the reference at the non inverting input of OP-amp U1. Input at U1 is the difference between the reference voltage and the tacho-generator feedback. Resistor R1 and capacitor C1 forms the proportional and intgral (PI) components. The output of the PI control from U1 is given to the current feedback stage.

The power amplifier is an H type bridge, hence the motor terminals cannot be ground referenced. Low value resistors are put in series with the power amplifier and when current is taken by the motor, a voltage drop which is product of the motor current and resistance occurs. The voltage between two arms of the H bridge is given to Op-amp U2. This Op-amp also has proportional and integral components. The output of Op-amp U2 is added with the output of speed loop. Output of Op-amp U3 drives the power amplifier.

Suitable values for proportional and integral components are chosen by actually loading the motor at site during installation. The best suitable value was chosen for good performance.

7. Power amplifier

The DC servo amplifier is imported from M/S Inland Motors, USA. It is powered by a 48V supply. The power amplifier does not need bipolar supply. When the mirror assembly moves down, the motor is to oppose the downward movement by acting as a voltage generator and thus resisting the motion and holding it in place. This action is called a four quadrant drive operation. Power amplifier can supply a maximum current of 22 A. Suitable current limiting resistors can be put to limit the maximum current drawn to any value less than 22A. The power amplifier is in two stages. The first one is a driver stage and the second one is a H type bridge with many power transistors wired in parallel. Amplifier output is bipolar in nature to cater for bidirectional operation.

8. Installation and operation

As the secondary mirror is at the end of the telescope tube, about 70 meter cable runs between the focus motor cage and console room. The power amplifier and power supply are kept in the console room. Two different speeds are provided. In each speed, the drum can move up or down. The slow speed inching gives movements less than 5 microns. The high speed given 50 microns per second. Tacho-generator signal is run on a separate shielded cable to avoid pick ups. Operation switches are provided in the control console. Focus position readings are provided in the same console. Initially fast speed switches are pressed till one gets near the desired focus reading. Slow speeds are used for final focusing of image on the detector. In the prime focus of VBT, a Wyne corrector is installed to give wide corrected field. As the Wyne corrector has to be at fixed distance from primary mirror, separate instrument focus is provided to move the instrument alone. The instrument focus is through a stepper motor. Readings are provided in the console for instrument focus also. The focus drum is held in position by a power fail safe EM brake. When the telescope is not operational, the drum assembly is held by the EM brake.

9. Conclusion

The focus motor control system for VBT was designed, fabricated and installed during 1989. DC torque motor and servo amplifier are used for control. For accurate speed control, speed loop using an integral tacho-generator and current loop feed back from the power amplifier are used. The system performance is found to be good. The system is able to maintain constant speed at all orientation of the telescope with very fine movements.

Acknowledgements

I thank Electronics Laboratory personnel at Bangalore and at Kavalur for their help. C.V. Sri Harsha made PCB and A. S. Babu wired and checked the system. K. Ravi, S. Ramachandran, F. Gabriel and A. Mani rendered help at VBO. I thank Dr R. Srinivasan for useful discussions during the design of the circuits.

References

Chinnappan V., 1988, Proceedings of National Symposium on tracking technology, published by Aeronautical Development Establishment, Bangalore, p. A-1.

Chinnappan V., 1991, Kodaikanal Obs. Bull. (submitted).