REQUIREMENT DOCUMENT

UPGRADATION OF SECONDARY DRIVE SYSTEM
AND
TELESCOPE CONTROL SYSTEM
OF
A 2 METER OPTICAL, INFRA-RED TELESCOPE
(HIMALAYAN CHANDRA TELESCOPE)

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Place: Bengaluru
Date : _______________

1. Introduction of Telescope (HCT)

Indian Astronomical Observatory (IAO), operated by Indian Institute of Astrophysics (IIA), is located in a remote location in the Himalayan Mountains known as Hanle-Ladakh (J&K). IAO houses the Himalayan Chandra Telescope (HCT), a 2 meter Optical, Infra-red telescope that is in regular scientific use since 2003. It is the second highest telescope in the world for optical and near-infrared astronomy, after the University of Tokyo Atacama Observatory (TAO).

The HCT was installed at Hanle during 2000 by EOS technologies Inc. Tuscon, Arizona, USA and the telescope saw first light in September 2000. The remoteness of the telescope and the health complication arising due to high altitude makes it difficult for astronomers to carry observations on site. A dedicated satellite link allows remote access of the telescope controls from CREST campus, Hosakote, Bangalore, in real time.

The telescope optics is a modified Ritchey – Chretien system with its primary, a 2 meter mirror made of Ultra low expansion material that can withstand extreme weather conditions at the site. Instruments mounted on the instrument cube of the telescope are always available for observations, the observer just needs to divert the light beam to the desired instrument using feed mirrors, mounted on a mirror turret, housed inside the instrument cube.

This telescope uses friction coupled directly driven capstan drives for high stiffness and zero backlash DC torque motors, matched to peak loads, drive the capstans. Large drive surfaces provide high torque and smooth tracking while the encoders compensate for the smallest axis errors and provide absolute position sensing to better than 0.01 arc seconds.

The existing working control system is all-digital and uses a motion control software and hardware with all facets of servo control including the Telescope Primary axes (Azimuth & Elevation), field de-rotator, focus control (Secondary Drive System) and active collimation systems. The control software runs the entire observatory. One of the principal features of this software is to support fully remote operation, a critical requirement for observatories situated on remote sites.

Indian Institute of Astrophysics, Bengaluru is looking for upgrade for the 2m HCT
(a) Secondary drive system and
(b) Telescope Control System (TCS).

1.1 Site Information and Climatic Conditions

Latitude:	32d46m46s N	
Longitude:	78d57m51s E	
Altitude:	4500 meters above msl	
Outdoor Temp:	-30 deg C to +30 deg C	
Humidity:	0-95%	
Wind Speed:	0 – 35 m/s (range)	
	5 m/s	Yearly Median at day
	4 m/s	Yearly Median at night

2. Secondary Drive System Upgrade

2.1 Background

Telescope's secondary mirror (M2) is actively controlled to keep the system in proper focus at different climatic conditions and at different orientation/elevation of the telescope. This is achieved by secondary drive, a three axis drive system, which has freedom to move all the three axes for secondary focus movement and either of the individual axis to introduce tip and tilt in the secondary mirror to correct for possible de-centering and collimation error in the primary-secondary system. The relative motion on each individual link is obtained through the lead screw nut interface. The secondary flexure rod connects the nut end of the micrometer to the secondary focus plate, which finally delivers the movement to the secondary mirror. This is also known as Quasi Static Tip/Tilt (QSTT) focus mechanism. The secondary drive is housed inside secondary can. The complete secondary module is suspended from the upper truss of the telescope by four spider vanes.

2.2 Requirements

Hardware

Our primary need is to replace the existing three actuator secondary control assembly with a better and stable secondary drive system such as Hexapod or equivalent.

Mechanical

In order to keep the optical specification of the telescope intact, the new Secondary Drive system should fit in the existing Secondary Can. A summary of secondary mount and the existing QSTT system is as under:

Weight and size of the secondary mirror:	8.84 Kg and 437.2mm (diameter)
Diameter of the central hole of secondary mirror:	96mm.
Weight of secondary mount plate:	3.61 Kg
Cylindrical can length and dimension:	length 594mm, clear diameter 342.9mm

Total present weight of secondary module with QSTT system is 23 Kg (excluding mirror).

Weight of new Secondary drive system should be within ±20% of the present load.

Secondary Module/Can drawings are in Annexure I

Technical Specifications for New Secondary Drive System

The new mechanism should provide active focus control of the secondary mirror with following specifications or better.

Parallelism
The primary and secondary mirrors should be maintained parallel to 0.5 arcsec over full travel range of secondary for temperature changes of less than ±5° C.

Tip/Tilt

Range (Mechanical Tip/Tilt):	± 3600 arcsec from center of travel
Slew Rate (maximum) for tip/tilt :	5 arcsec/sec
Resolution(Tip/Tilt):	0.1 arcsec
Repeatability:	± 0.5 arcsec

Focus

Focus Travel Range:	± 10mm from center of travel
Slew Rate (maximum) for focus:	100µm/sec
Resolution/minimum incremental motion	0.5 µm
Repeatability:	±1 µm
Encoder Resolution:	1.25nm

X-Y movement
There should be provision for X-Y translation of the secondary mount plate with mechanical (manual) adjustment to give lateral travel to the secondary mirror for proper centering of the secondary mirror with the following specifications:

Range:	± 4 mm from center of travel
Resolution/minimum incremental motion :	1µm
Repeatability:	±5 µm

Control System for Secondary Drive System

Control system for secondary drive should be preferably based on open source architect such as *Linux*. The secondary drive should be controlled by the telescope control software, following the architecture used in the existing secondary module. The details of the existing control system architecture are described later in this document, which is also planned for upgradation. All Applications should be preferably based on open source architect such as *Linux platform*.

3. Upgradation of Telescope Control System

3.1 Background

As mentioned earlier, this telescope uses friction coupled directly driven capstan drives for high stiffness and zero backlash DC torque motors, matched to peak loads, drive the capstans. Large drive surfaces provide high torque and smooth tracking, while the encoders compensate for the smallest axis errors and provide absolute position sensing to better than 0.01 arcseconds.

The existing working control system is all-digital and uses a motion control software and hardware with all facets of servo control which includes Telescope Primary axes (Azimuth & Elevation) , Rotators, Focus control (Secondary Drive System) and Active collimation systems. The control software runs the entire observatory. It consists of following parts:

a. Servo Control System (PMAC Card and other I/O Cards installed on an TCC Industrial PC running on Windows NT)
b. Telescope Control Software (Keystone TCS on TCC-Windows NT, Observatory Server and Telescope Control Client on Linux)
c. GPS and Time card.
d. Mets Weather Station.

TCC Cabinet

The Telescope Control Computer(TCC) is responsible for controlling the Telescope. It is located in the Telescope Electronics Cabinet. A user interacts with the TCC using the keyboard and monitor situated nearby, or communicate with it over the Local Area Network. Under normal circumstances this computer is designed to run remotely without an operator.

An important component of the servo control system is the PMAC (Programmable Multi-Axis Controller). PMAC is a PC based motion control system, designed by Delta Tau (U.S.), which is used to control the motion of the motors with very high precision and is installed in TCC. The specific model used is the “Turbo PMAC”. To extend the basic capabilities of the PMAC to allow accurate tracking of celestial objects a set of special programs called PLCs (Programmable Logic Controllers) have been written and installed onto the card.

Other components of the control system include the Digital I/O Planar (DIOP), sub-assembly which handles digital signals relating to the telescope, a temperature monitoring system, and timing subsystem. The timing subsystem consists of a GPS receiver which supplies accurate timing signals to the PMAC and a True Time time-card mounted in the TCC. These signals include a 1MHz pulse stream, a 1 PPS signal, and an IRIG-B time signal which is all used to synchronize the telescope to the UTC.

The Cabinet also houses the power amplifiers, the timing subsystems and other support circuitry for the telescope.

The emergency stop button with a built-in light is located at the top of the cabinet. When pressed this button removes power from the motors, preventing the telescope from moving. This is provided as a safety feature. A second Emergency stop button is available on a flying lead.

The Software on the TCC that is responsible for controlling the telescope is made up of several distinct components. At the lowest level a set of small programs (PLCs) running on the PMAC provides basic control of the various telescope axes. Several high level applications running under Windows NT make up the rest of the operational software. Principal among these is the Mount application which controls the telescope via the PLCs. High Level Applications such as Telescope VCP and StarCal allow a user to communicate with the Mount application to perform specific tasks with the telescope. LogView, Router, BootStrapper and other applications provide additional services. Many of these applications can be run on a remote computer as well.

3.2 Requirements

3.2.1 Hardware

A new compatible Servo Control System, new Computer and any other important hardware required for the fully functional, efficient and reliable new Telescope Control System that can sustain for next 15 years or more.

3.2.2 Software

All Telescope Control system software and it's parts should be preferably based on open source architect such as *Linux platform*.

3.2.3 Telescope Drive Efficiency Specification

Jitter and Periodic Errors

When tracking as specified, the motion must be such as to meet the optical performance specification within 70° of zenith.

When measured independently, the peak-to-peak jitter shall be less than 0.25 arcseconds in azimuth and less than 0.25 arcseconds in elevation. Any longer term periodic drive errors may not affect the absolute pointing specified below.

Axis Motion

Azimuth:	+/-240°, measured from center of rotation
Zenith angle, observing:	2.5° < z ≤ 70°
Zenith angle, hard stops:	90° nominal, -10°
Zenith blind spot (keyhole):	≤ 5° diameter

Pointing and Tracking

The following specifications require that operation is under computer control with the pointing model active and within 70° of zenith.

The position of the telescope will be digitally encoded with a resolution of less than 0.10 arcseconds.

Pointing and Offsetting

Pointing accuracy for move ≤ 17 arcseconds:	≤ 0.4 arcseconds rms
Offset >10" (pointing, "z" <60°):	≤ 1.4 arcseconds rms. in each axis
Settling time:	< 1 second

Tracking

Track rate:	≤ 0.5°/second
Track ramp:	≤ 0.10°/ $second^2$
Track accuracy, computer controlled:	≤ 0.5 arcseconds rms for 10 minutes
Track accuracy, auto-guiding:	≤ 0.3 arcseconds rms
Scanning Rate:	≤ 50 arcseconds/second of the sidereal rate

Slewing

Slew rate:	≥ 4°/second
Slew ramp:	≥ 1.5°/$second^2$
Settling time:	≤10 seconds
Time for track to track:	≤ 100 seconds, < 360° azimuth rotation
	≤ 20 seconds, < 10° offset & <10° azimuth

Instrument Rotator Control - Cassegrain Focus Position

The instrument rotator provides means of mechanically de-rotating the optical field to compensate for the field rotation and to keep instruments and autoguider at the Cassegrain focus of the telescope.

Weight capacity:	500 kilograms
Center of gravity location	< 400 millimeters from mounting surface
Imbalance about axis:	< 40 N-m
Rotation angle:	≥ 360°
Rotation rate:	≤ ±5°/second
Ramp Rate:	≤ ±1°/$second^2$
Runout:	≤ 10 arcseconds on sky
Wobble:	≤ ± 20 arcseconds on sky

Feed mirror control: 45° angle of incidence mirrors are mounted on mirror turret that diverts the light beam towards side ports of Instrument cube and moves out of the optical path to allow the beam to pass through the direct port. This movement is to be controlled by the telescope control system.

Thermal Stability

The telescope shall incorporate active focus control to compensate for change of focus with temperature over the operating temperature range of -30°C to +30°C. The live temperature can be obtained from the following sources.

Temperature Sensors on telescope

Existing Temperature sensors details:
There are eight thermo-couple based temperature sensors attached to different parts of the telescope. The data from all the sensors needs to be logged and processed (say, average of all or a few specific ones).

Resolution/accuracy: ≤ 0.5°C

Temperature from Mets Weather Station

Temperature can also be obtained from the Mets weather station.

Protective Covers

The telescope is provided with a primary mirror cover which -
Protects primary mirror against moisture and dust when closed
Protects against blunt impacts of less than or equal to 20 N-m
Presents minimal cross section for wind shake
Provides access for mirror cleaning.
The mirror cover should be remotely opened and closed through the telescope control system, including close on power failure feature.

3.3 Control Requirements

Power

The telescope drives, control system and any other system requiring power will operate from a 230 V AC, 50 Hz power source supplied by IIA.

Automation

A new technology, fast and reliable Computer Control System, preferably operating on an open source architect such as *Linux platform*, is required, allowing for efficient and convenient operation of the telescope in either a manual or fully automatic mode.
The telescope operation (remote/local) should be through TCP/IP in Client-Server Architecture. A central server should be provided to which all the subsystems shall connect with data logging option.

New Servo control system should be preferably on an open source platform.

Two computers with solid state hard disk drives should be supplied that can be interchanged by the manual reconnection of cables, separate dual hard drives running in parallel, a computer monitor, keyboard and peripherals for a single system as appropriate, for the local control of the telescope.

Time signals should be supplied from a GPS-based system providing 100 nanoseconds accuracy to UTC with a frequency lock to 1 part in 10^{12}.

Parameters Available for Display

The Control software should display specific parameters as selected by the user. The control computer should monitor critical telescope parameters and notify the user of unusual conditions. Some of the important parameters are listed below.

a) Date (in universal Time, UT)

b) UT accurate to 0.01 second

c) Sidereal Time - ST derived from the UT, accurate to 0.1 second.

d) Actual position of the telescope (current position including any offsets executed after the most recent slew) in an epoch which can be selected by the user with a precision of < 0.01 seconds of time in azimuth and elevation.

e) Base position of the telescope (position after the most recent Slew) an epoch which can be selected by the user, with a precision of < 0.01 seconds of time in azimuth and elevation.

f) Base position in Current epoch with a precision of < 0.01 seconds of time in azimuth and elevation.

g) Azimuth offset from base position, with a precision of < 0.01 seconds of time.

h) Elevation offset from base position with a precision of < 0.1 arcseconds.

i) Tracking rate in azimuth and elevation with a precision of < 0.001 arcseconds/seconds in both azimuth and elevation.

j) Dome azimuth, with a precision of < 0.1°.

k) Telescope azimuth and elevation, with a precision of < 0.1 arcseconds in both co-ordinates.

l) Air mass or secant of zenith distance, with a precision of < 0.01.

m) RA, Dec and hour angle.

n) Position angle of rotator.

o) Status of mirror cover: open or closed.

p) Dome mode: manual or automatic.

q) Telescope motion command mode. Slew, track or scan.

r) Position of focus encoder, accurate to < 2 micrometers.

s) Observatory status: telescope and dome.

t) Time estimates to acquire object.

u) Status of Mets Weather station connection.

v) For a given pointing, estimated time for the field derotator to rotate in the opposite direction due to limitation of cable wrap.

The new control software should be able to achieve the following objectives

1. Homing of all individual axis and display the commanded and actual position of all the axes in the main control window as calculated by feedback from the motor encoders.

2. Complete computer control of the telescope.

3. There should be a provision to move/jog all the axes individually as well as altogether, as focus(z), tip, tilt (both in low level and high level).

4. All the monitoring and calibration tools necessary for operation of the telescope should be displayed/present on the main control window.

5. Should be able to track celestial objects on feeding coordinates (RA, DEC) and it's epoch and display the commanded and actual telescope positions in the main control window as calculated by feedback from the motor encoders.
6. Should be able to track the telescope with non-sidereal track rate from a given ephemeris for observing comets, planets, moon etc.

7. The main control window should have option to operate the field de-rotator (Instrument rotator) to a specific absolute position using Fixed mode, or it can be commanded to track a particular orientation on the sky using Position mode.

8. The control system should have capabilities for obtaining information from major catalogues and computing current local coordinates. It should display the available objects in graphical form and by selecting any displayed object the telescope should point and track the object.

9. Software for generating and updating the pointing model and other look-up tables as an integral part of the control software. The telescope should be able to do accurate pointing converting from celestial coordinates to apparent coordinates, correct for atmospheric refraction and pointing model during every pointing.

10. The control software should be able to work in client-server mode. It should be able communicate and operate the existing client instruments namely Autoguider, Mets (Automatic weather station) and Dome in close loop. There should be provision to add other instruments also as clients. The TCS should also have provision to record telescope related parameters at shortest technically feasible time interval.

11. Sharing of all the necessary software, source code required for normal operation, function libraries for future development and integration with third party instruments.

12. The software should be able to display the nature of fault if any.

13. The control software should be able to operate the existing primary mirror cover with its status displayed on the console.

14. The software should be able to connect the existing temperature sensors mounted on the telescope and use its values for dynamically compensating the focus and other parameters which changes with temperature. It should also consider live temperature from Mets weather station for applying relevant corrections to the telescope.

15. The software should also be able to apply various compensations to account for the mechanical imperfections of the existing system and other terms which depend on elevation/flexure, such as azimuth compensation for rotation, elevation compensation for rotation, focus and tip compensation for elevation, azimuth compensation for tilt and elevation compensation for tip etc.

16. Network or remote operation of telescope should also be possible with the control software using client-server architecture.

17. All the high level applications should record significant events and errors on an event logger system, on the control PC and on central server, as it will be useful for analyzing operations and diagnosing problems.

18. There should be provision to apply offset to the telescope position either on graphical user interface or through command line. The provision for resetting the offset should also be available.

19. Should Control the feed mirrors to deflect the light to the desired port and show its status.

Pointing Model Capability

The telescope control system should incorporate an all-sky pointing model (using T-point or similar) which corrects for refraction at the operating wavelength, and mount and drive errors. The control system should have provision for easily updating the pointing model.

System Safety Requirements

The telescope control system should reject commands that exceed the safety limits specified, and shall display an error message on the telescope parameter display device and send an error interrupt to the observatory/instrument computer. An emergency stop button is to be available on the observing floor to allow disabling the telescope drives.

Operating Environmental Conditions

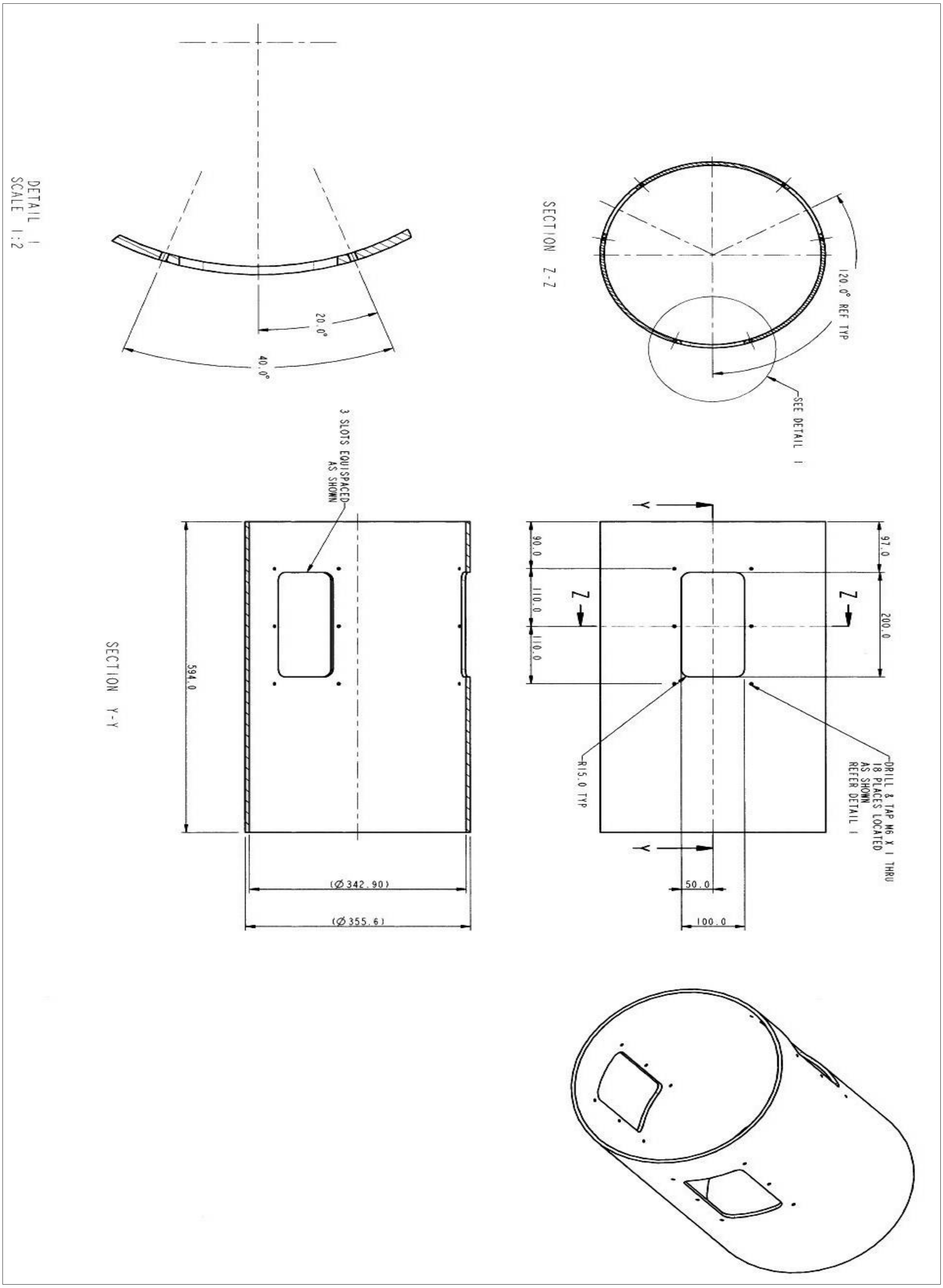
Telescope operating temperature range. -30°C to +30°C.
Telescope operating relative humidity environment of 15% to 90% (non condensing).
Telescope operating wind speed in the enclosure up to 10 m/second constant flow or gusts.
Computer operating ambient temperature range: +10°C to +30°C.
Telescope and control computer storage: -40°C to +40°C.
The operating pressure range of telescope and other related hardware should be 570 – 600 hpa.

Integration of new Secondary drive system as listed above

The upgraded Telescope control system should be able to integrate the new Secondary drive control system.

Simulator – A simulator software of telescope control system is required, for testing and analysis purpose.

Annexure I
Secondary Module Drawings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SECTION Y-Y
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(Ø342.90)
(Ø355.6)
Y
Z
90.0
110.0
110.0
97.0
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DRILL & TAP M6 X 1 THRU
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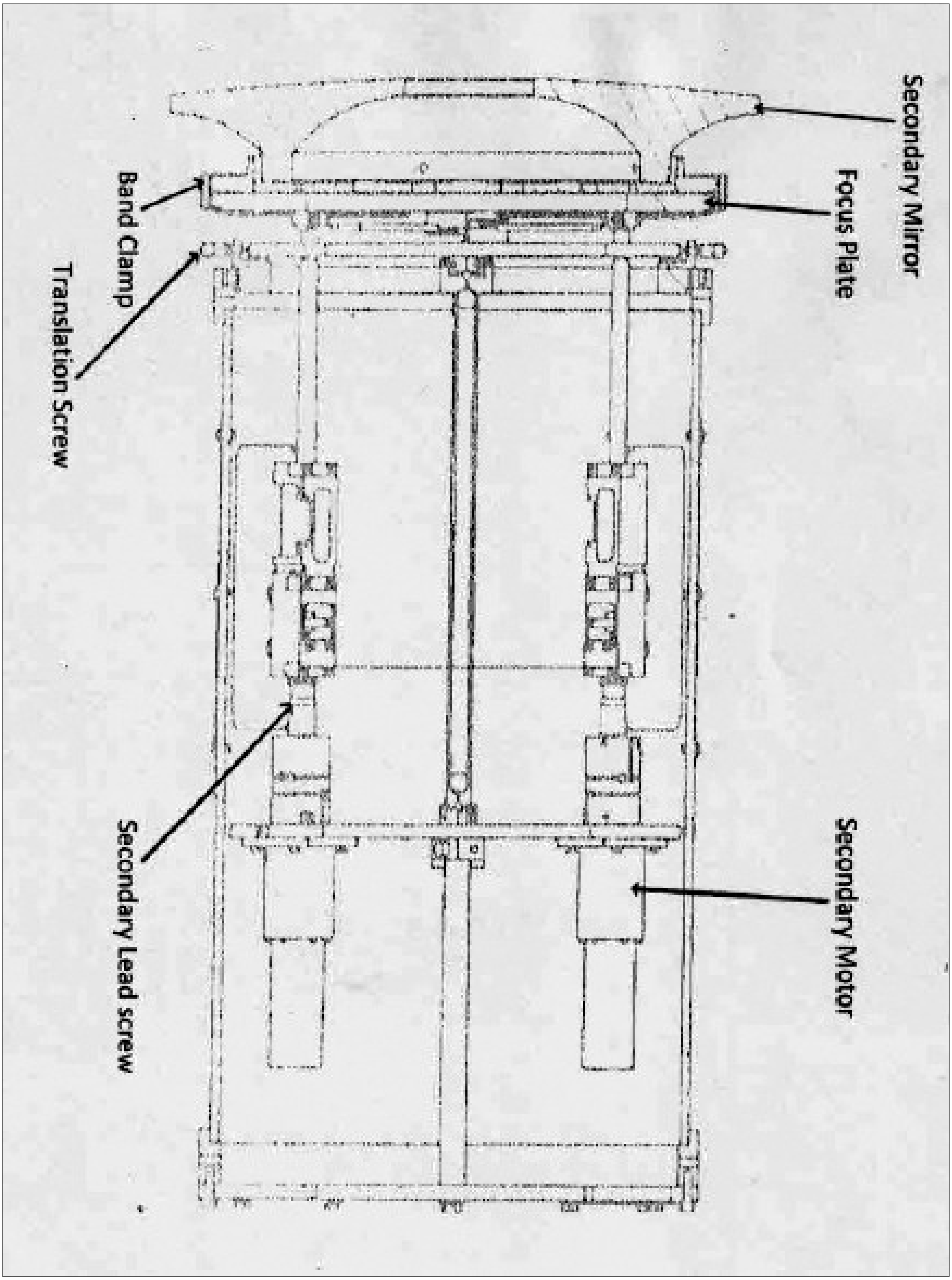
Secondary Mirror
Focus Plate
Band Clamp
Translation Screw
Secondary Lead screw
Secondary Motor