Paramount Taurus Direct Drive User Guide

Revision 1.9
May 2023

Disclaimer

Information in this document is subject to change without notice and does not represent a commitment on the part of Software Bisque. The software products described in this document are furnished under a license agreement or nondisclosure agreement. They may be used or copied only in accordance with the terms of the agreement (www.bisque.com/eula). It is against the law to copy the software on any medium except as specifically allowed in the license or nondisclosure agreement. The purchaser may make one copy of the software for backup purposes. No part of this manual and/or databases may be reproduced or transmitted in any form or by any means, electronic or mechanical, including (but not limited to) photocopying, recording, or information storage and retrieval systems, for any purpose other than the purchaser's personal use, without the express written permission of Software Bisque.

TheSky™ and Paramount Taurus™ are trademarks of Software Bisque, Inc.

Table of Contents

Introduction

The Paramount Taurus represents the state-of-the-art in modern astronomical equatorial fork mount designs. Taurus achieves superior performance for a myriad of astronomical data acquisition through precision machining, high-resolution absolute encoders and high-torque direct-drive motors on all axes and the world's most advanced and flexible software for observatory control. Taurus employs the TPoint Telescope Pointing Kernel (TCSPk) and SLALIB astronomical library, which are the same multi-axis technology that makes the world's largest professional telescopes function superbly. The Taurus is in good company.

Altazimuth vs. Equatorial Designs

The goal of any robotic telescope mount is precise pointing and stable tracking, whether the system follows a single object for hours or quickly darts between, or tracks, fast-moving targets.

As the optical tube assembly or other payload increases in size and weight, the physical size of the mount must also be larger to minimize flexure and vibrations. For telescopes 0.50 m (20 inches) and larger, the inherent benefits of the altazimuth design begin to become favorable.
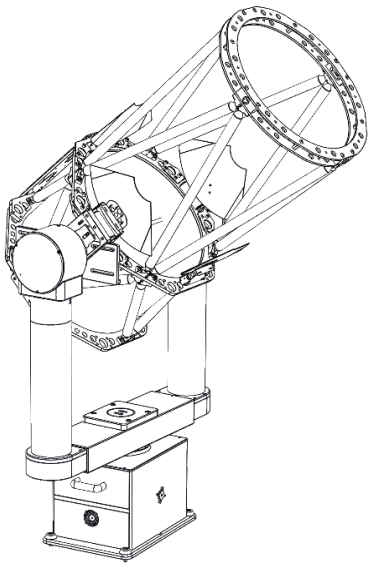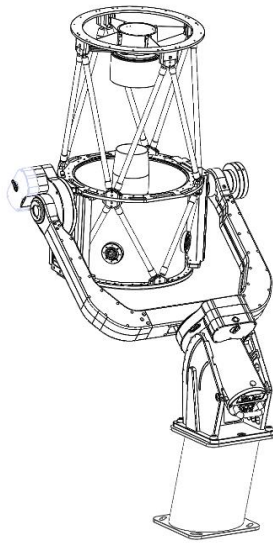
Figure 1: Altazimuth mount.

Figure 2: Equatorial fork mount.
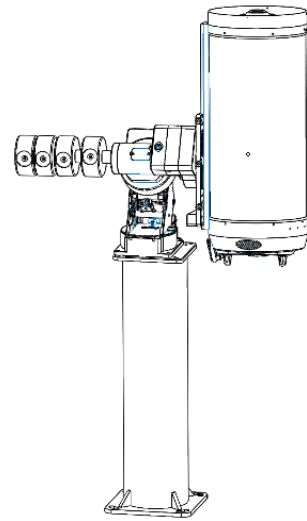
Figure 3: German equatorial mount.

Equatorial Mounts

Equatorial mounts align their primary axis with the earth's rotational axis which means that to track an object in the sky only the hour angle (HA) axis rotates. In practice, the second axis (declination) does have to be minimally adjusted to account for various geometric errors and other physical realities that influence the tracking rates in both axes.

As equipment payloads become heavier, the exercise of accurately aligning the HA axis of the mount with the earth's axis, or polar alignment, is burdensome. In the case of an equatorial fork mount, polar alignment is latitude dependent and requires a significant cantilevered mass. In the case of a German equatorial mount, the counterweights effectively double the payload mass and require larger and more massive components to optimize system stability.

The equatorial design in general does not require an instrument rotator so there are benefits for various imaging applications, especially when placing multiple optics or arrays of optics on a single mount. The cost and complexity of having rotators for each optical system becomes burdensome.

Altazimuth Mounts

Altazimuth mounts have several key benefits for carrying larger telescope systems. As the volume and mass grow exponentially with increasing telescope aperture, the equatorial design becomes impractical for larger telescopes. The inherently stable altazimuth design rules this space.

One big challenge of the altazimuth design is that instead of tracking in a single axis at a slowly changing speed, three axes must be changed to track objects, each with constantly changing rates. And though the mathematical transformations that convert between the celestial coordinate system and the mount coordinate system are straightforward, in practice, accurately driving the three axes to account for all things astronomical, layered with system imperfections, becomes an extreme computational challenge.

While the altazimuth design is exceptionally suitable for small robotic systems, driving three axes precisely makes these systems much more expensive.

Direct Drive Motors

The Taurus employs direct-drive motors, each with high-resolution (26-bit with 0.02 arc seconds per tic resolution) absolute on-axis encoders.   Direct drive motor control is an exceptional choice for most telescope axis control. Although traditional, larger worm-gear driven systems can be manufactured to exceptional accuracies, a direct drive motor employing a high-resolution encoder has a lower noise floor and insignificant backlash.

Direct drive motors provide exceptional performance when high-speed slewing and tracking rates are required. Where worm gear driven systems typically have top speeds around five degrees per second, direct drive systems can move at 50 degrees per second and beyond. And, with no material-to-material contact, direct drive motors also generally have lower maintenance costs over the life of operation.

Telescope Control System

Telescope control systems (TCS) require an extremely wide dynamic range of speeds from zero to 30 degrees per second and higher, or any speed in between. The demands of controlling a three-axis, direct-drive system for telescope control can only be met with a state-of-the-art, high-bandwidth TCS.

The Taurus mounts employ a very capable off-the-shelf industrial controller with a built-in computer to service the servo control and external communications. This controller has been integrated with TheSky astronomy software which contains a *virtual telescope* that computes TCS position demands with a precision of fractions of an arc second, all the while correcting both slewing and tracking demands for system imperfections.

TheSky Astronomy Software

The Taurus series of mounts includes TheSky astronomy software which is currently used in observatories throughout the world. The world-renowned TPoint and TCSpk are fully integrated into the control loop, supported by a host of tools, and feature an advanced user interface to facilitate setup and nightly operation. TCSpk has been developed over the last forty years and all or a portion of this software is used on most three-meter and larger systems deployed over the last twenty-five years.
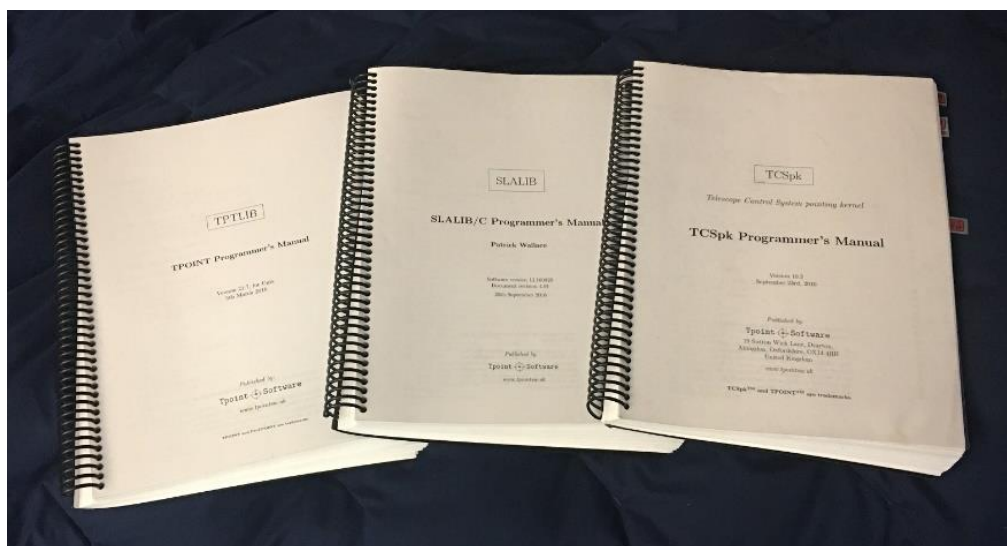
Figure 4: Photo of the TPoint Professional manual, TCSpk Programmer's manual and the SLALIB library that are all integrated into TheSky astronomy software.
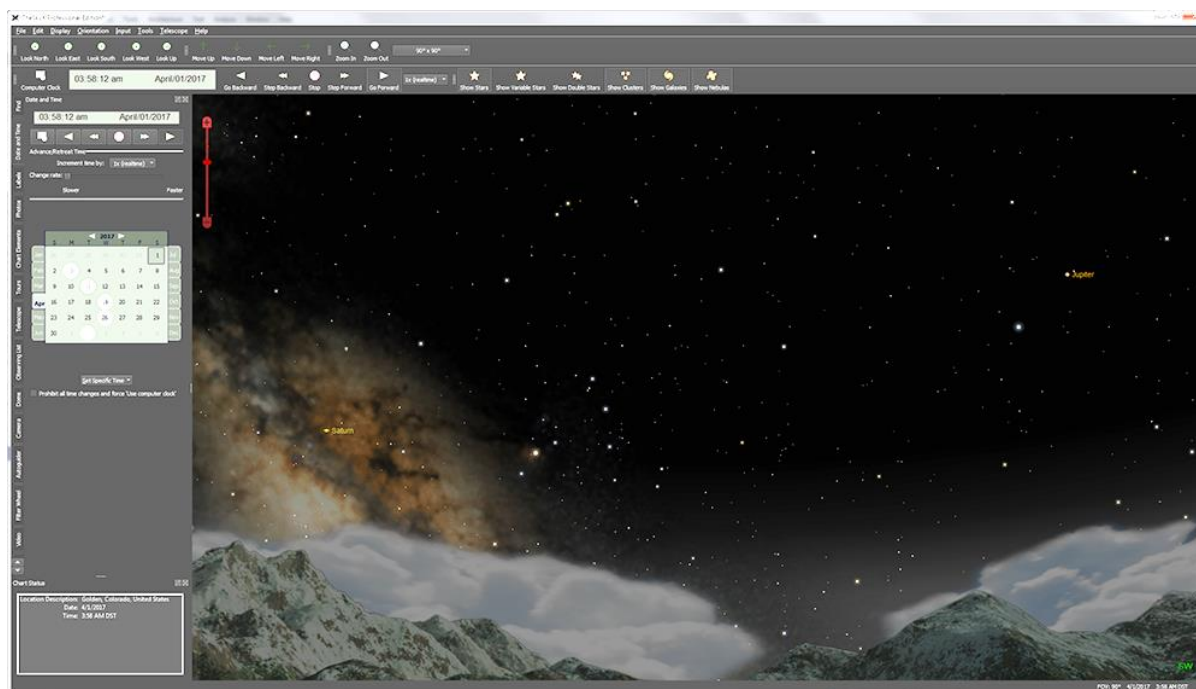

Figure 5: A screen capture of TheSky astronomy software.

Figure 6: A wide-field, full-screen capture of TheSky astronomy software.

Assembling the Taurus

Taurus Components

The Taurus mount is shipped in six separate components. The main components include:

- The *pedestal* is secured to a level surface in the observatory.
- The *wedge* allows for latitude adjustment.
- The *HA assembly* houses the HA motor and brake.
- The *fork center* is mounted to the HA drive plate and accepts the tines on both sides.
- The *drive tine* houses the direct drive motor.
- The *support tine* contains a self-aligning bearing and a brake.
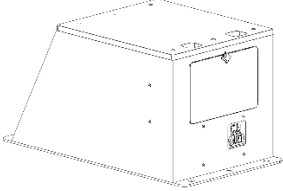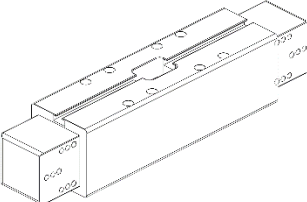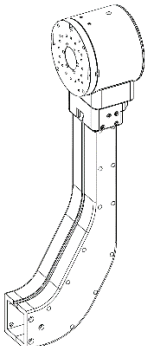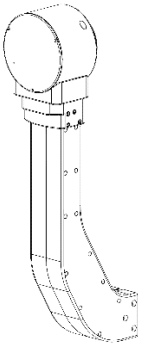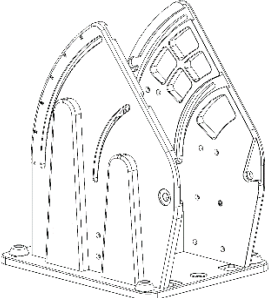
Figure 7: Exploded view of the Taurus components.
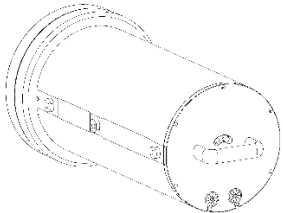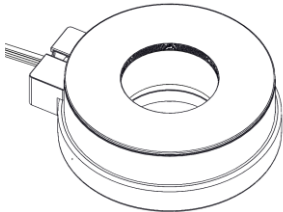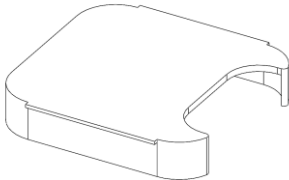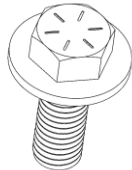
Software Bisque recommends employing two or three people to assemble the mount. The first-time setup process may take as few hours to complete once the components are unboxed and staged.
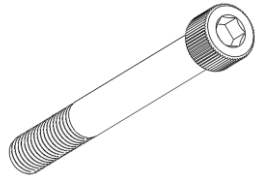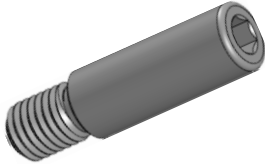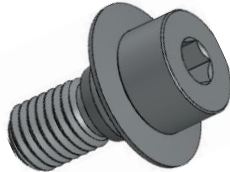
The assembly tools are shipped inside the Taurus accessory kit. Assembling the Taurus involves lifting the six major components into place and adding the fasteners connect them together and directing the cables from the fork tines down through the HA axis into the controller compartment located in the pedestal.

Packing List

The table below lists the components that are included with the Taurus mounts.

Item	Quantity	Notes	Graphic
Pedestal	1	Contains the TCS electronics and PCB distribution board.	
Fork center	1	Sized for OTA.	
Drive tine	1	Holds the motor, instrument rotator interface panel and internal cabling.	
Support tine	1	Holds the declination brake and cabling.	
Wedge	1	Accepts the HA drive assembly and allows for latitude adjustment.	

HA drive assembly	1	Contains the HA drive and brake.	
Instrument rotator (optional)	1	The instrument rotator has two cables that must be connected to the *rotator interface panel* on the drive tine.	
Cover	2	Covers to minimize access to the mount's internal components (by insects and vermin).	
Base mounting bolts with washer	4	1/2-in x 13 TPI x 1.75-in. long socket head cap screws (SCHS)	
Lock nuts	8	Four lock nuts are used to mount the wedge to the pedestal, and four are used to mount the HA drive assembly to the wedge.	
Dec axis lock pin	1	The declination axis locking pin can be inserted into the declination axis locking holes to prevent rotation.	
HA axis lock screw	1	This 3/8-16 TPI x 2.5 in. screw holds the HA axis in place when assembling fork tines and mounting instrumentation.	
Axis lock hole cover	1	Cover for the declination axis locking hole.	

Fork center mounting screws	8	Fork center to HA drive place SHCS (1/2-13 TPI, 4.25 in. long).	
Power cord	1	The TCS AC power cord (the plug is located on the pedestal).	
Azimuth adjustment anchor	1	The polar alignment adjusters push against this anchor to rotate the mount's azimuth axis.	
Shoulder bolts (azimuth and latitude)	3	One for the wedge rotation center, and two for the HA drive assembly.	
Hex key set	1	13-piece Imperial L-key hex key set.	
Slotted screwdriver	1	This small flathead screwdriver is used to tighten the motor and brake wires to the terminal connectors.	
Security key	1	This USB security key must be plugged into the computer's USB port before TheSky is started. (See page 59 for details.)	

CAT6 cable	1	Connect from the PC's NIC to the Ethernet port on the Taurus pedestal for PC to mount communication.	
Ratchets	2	One 3/8-in. drive and one 1/4-in. drive ratchet.	
Ball-end hex wrench	1	One 3/8-in. L-key ball-end hex wrench.	

Note: See *Appendix B: Taurus OTA Mounting System* on page 88 for the *Scope Rail* packing list.

Pedestal

The Taurus pedestal houses the industrial motor controller, connections and distribution of the power and signals for up to three axes. An internal distribution printed circuit board (PCB) routes the internal wiring using standard off-the-shelf cables. Each axis has cables for motor power, sensors, and encoder input. The drive tine contains the cables for connecting the declination drive and the optional rotator to the controller.

The switched power input block (120V or 220V AC) and Ethernet connection can be found on the rear panel of the Taurus pedestal. Space for additional cables is available in the conduit running up through the HA drive, through the fork center and through each of the fork tines.

The front and rear panels of the pedestal are fastened by a single knob that allows each panel to be removed for easy access to the inside of the pedestal. While most of the cabling comes from the factory already connected and in place, once the tines are physically placed in

position, the declination drive, brake, and the optional instrument rotator cables must be connected.
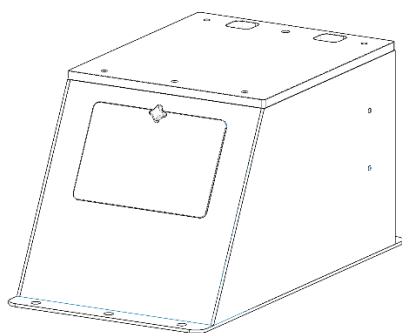
Figure 8: Access panel on the front of the pedestal.
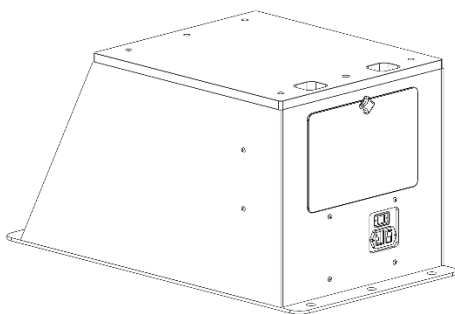
Figure 9: Access panel on the rear of the pedestal.

Taurus Pedestal Mounting Hole Pattern

The Taurus mount is normally permanently attached to the floor of an observatory or other adapter plate using six socket bolts, either 1/2-in. or 5/8-in. diameter.
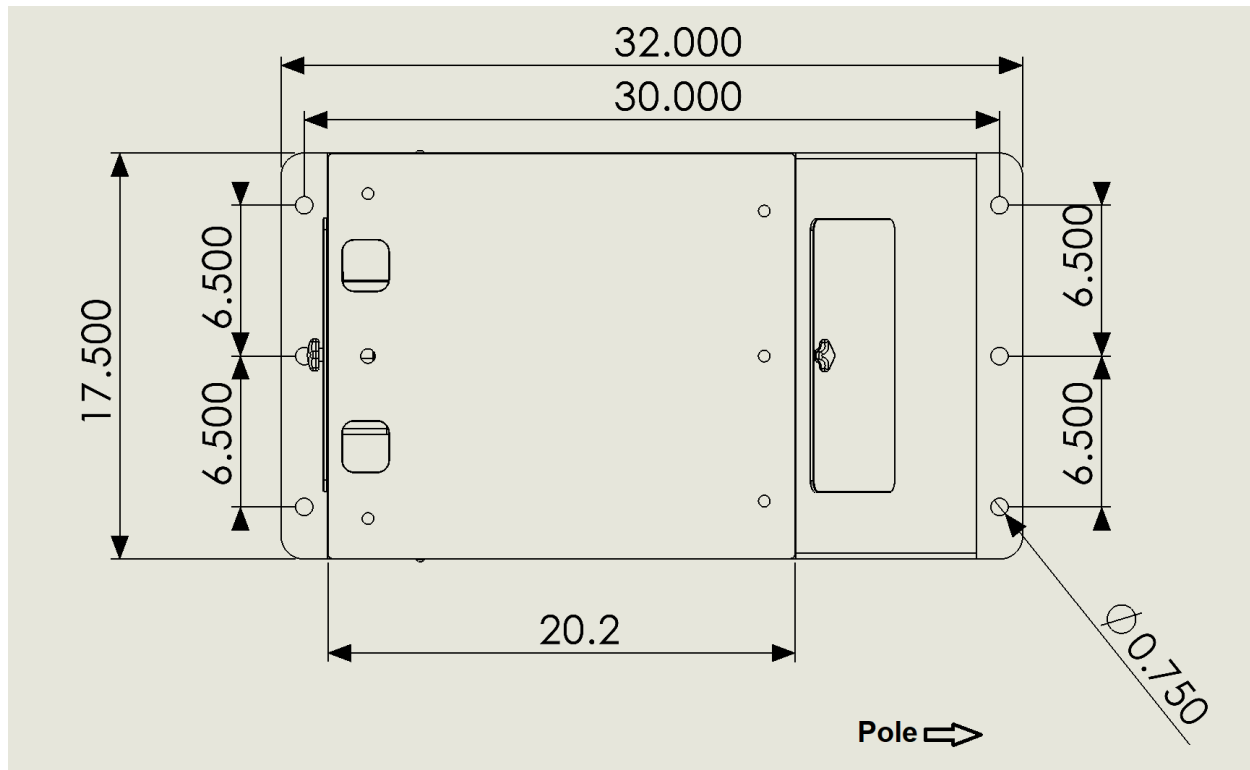
Figure 10: The Taurus pedestal mounting holes.

The six 19 mm (0.75 in.) diameter holes in the base plate of the pedestal are used to permanently attach the pedestal to a concrete pier or other mounting surface.

In Figure 10, the celestial pole is to the right. In the east/west direction, the three holes are spaced 165 mm (6.5-in.) apart. In the north/south direction, the sets of holes are spaced 762 mm (30-in.) apart.

Six 0.5-in. x 3-in. (minimum) bolts with washers should be permanently anchored to the concreate pier or the floor of the observatory using a high-strength anchoring adhesive or other concrete anchoring system (Figure 11).
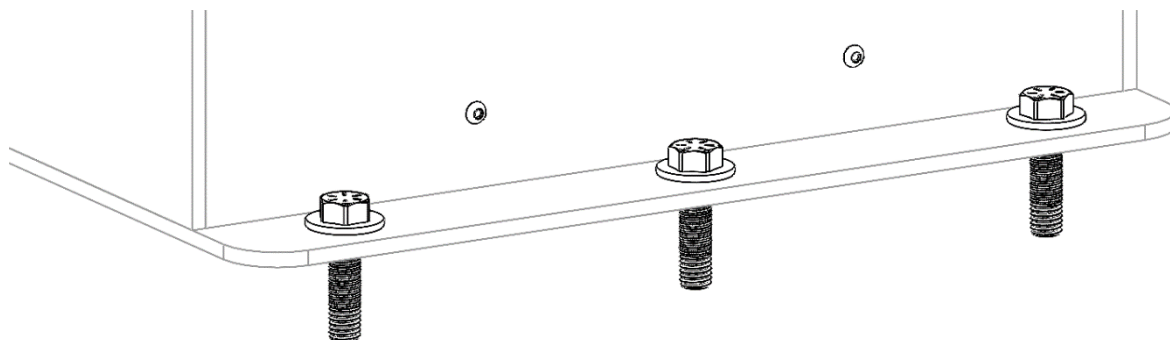
Figure 11: Three of the six pedestal anchor bolts.

Mounting Wedge Assembly to the Pedestal

Once the pedestal is securely mounted to the pier or observatory floor, the next step is to attach the wedge assembly to the top of the pedestal.

Before proceeding, loosen both of the horizontal azimuth adjustment screws on the wedge assembly until there is about 2.5 cm (1 in.) distance between the ends of the screws.

Figure 12: The azimuth adjustment screws must be separated to make room for the azimuth anchor.

Figure 13 shows the azimuth anchor that must be threaded into the top center hole of the pedestal. The azimuth anchor can be installed before or after placing the wedge on the top of the pedestal using a 5/16-in hex wrench.

Carefully lower the wedge assembly on to the pedestal in as shown in Figure 13. If the azimuth anchor is installed, make sure the azimuth anchor passes through the gap between the two azimuth adjustment screws. Thread the four lock nuts in each corner of the wedge base plate and securely tighten each with the supplied 3/8-in. hex wrench.

Shoulder bolt

Lock nut and bolt (qty 4)

Azimuth anchor
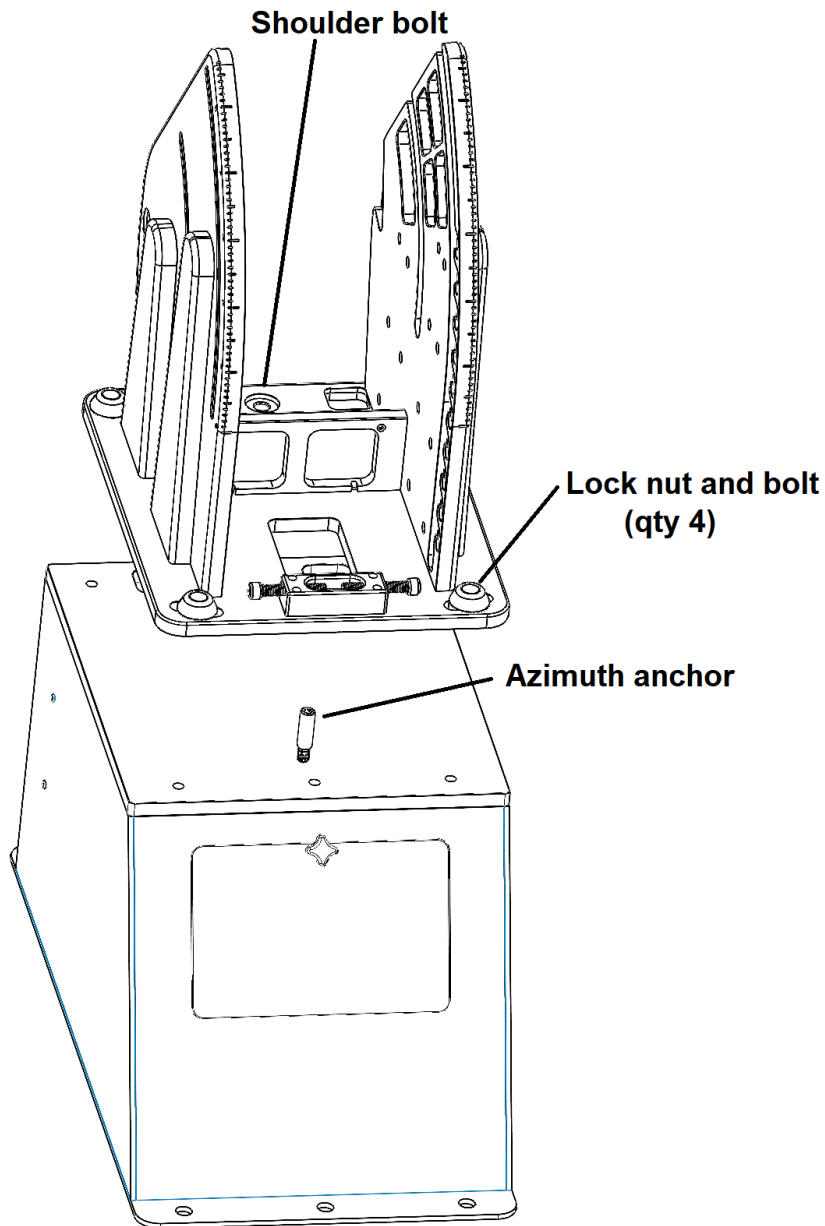
Figure 13: Installing the wedge assembly.

Page 18

Attaching the HA Drive Assembly
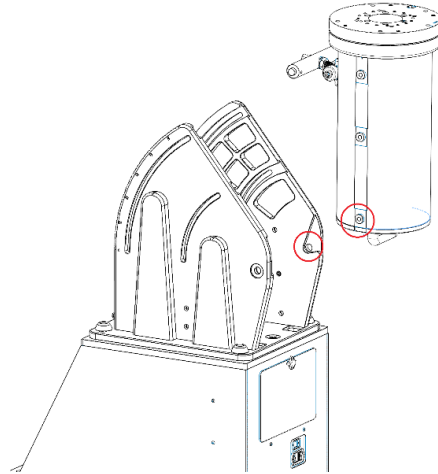
Figure 14: Installing the HA drive assembly.

The HA drive assembly is heavy so this step may require the aid of a motor hoist, overhead load lifter, or the strength of two people. Lift the drive assembly in the orientation shown in Figure 14. Keeping the long axis of the assembly near vertical, place the lower portion (circled in red) into the slots on the lower side of the wedge assembly.

Once the rear of the assembly has been lowered into the wedge, its weight rests on the stainless-steel threaded anchors that protrude from the HA drive assembly. Figure 14 shows the anchor (on the HA drive assembly) and the bottom of the slot where it rests. Figure 17 shows the HA drive assembly in place.

Slowly rotate the vertical HA drive assembly toward the wedge. When doing so, direct the latitude adjustment mechanism into one of the slots on the side of the wedge. The latitude adjustment mechanism has internal springs that must be compressed with a small amount of force while directing the adjustment bar into the slots.

The latitude adjustment bar's internal springs force the bar to click into one of a series of detents spaced approximately six degrees apart. These detents are the course latitude adjustment. The threaded rod in the center of the latitude adjustment bar provides fine adjustment of latitude. The HA assembly should be lowered into place down to the correct latitude of the installation. This requires pushing the latitude adjustment mechanism inward so that the latitude adjustment bar drops into the correct detent for your latitude.
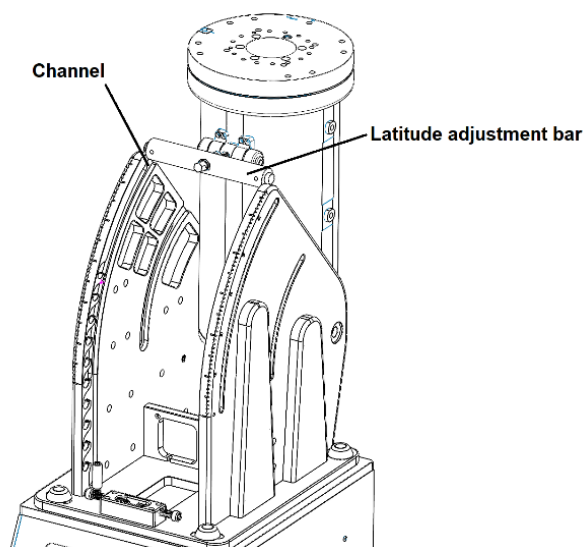
Figure 15: Latitude adjustment bar and mounting channels.
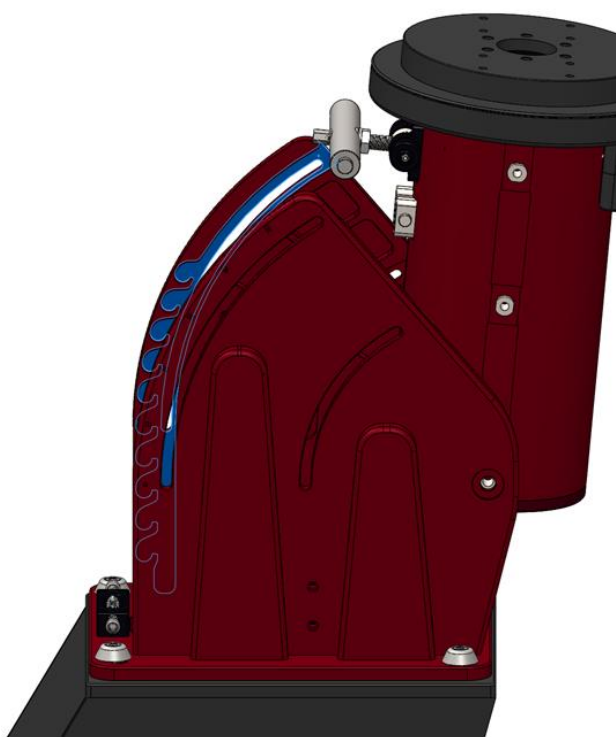
Figure 16: The blue highlighted area shows ten distinct positions for the latitude adjustment bar.

Figure 17: The HA drive assembly in place.

Figure 18: The spring-loaded latitude adjustment bar in slot position 5 (from the bottom of the wedge).

Page 21
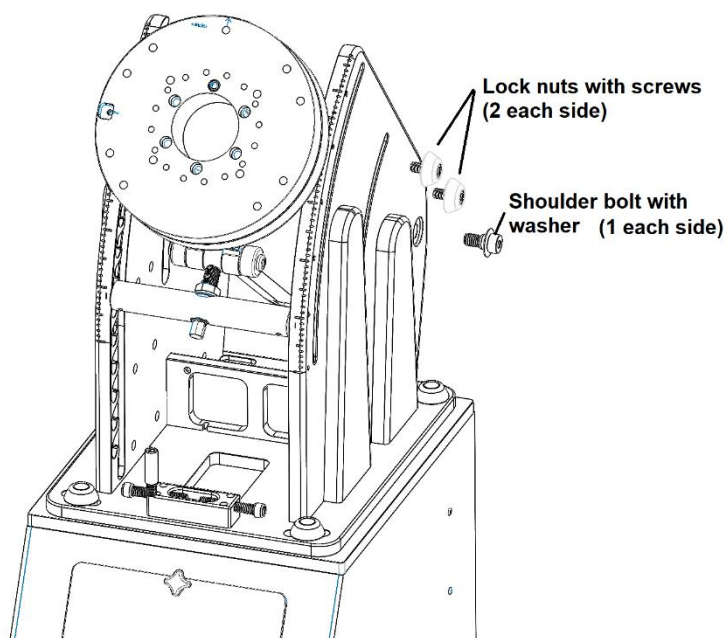
Figure 19: Wedge lock nuts and shoulder bolts.

HA Cable and Access Cover
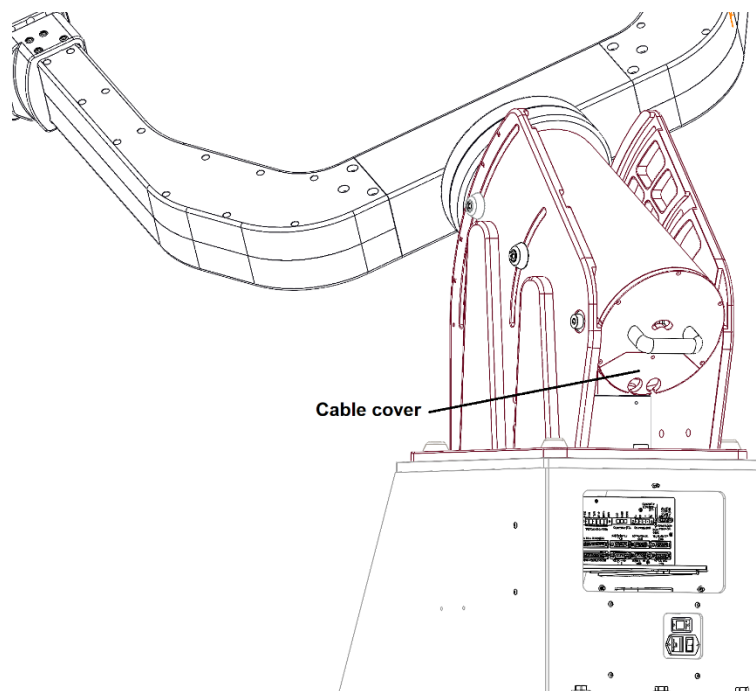
Figure 20: HA assembly cable cover.

The cable cover is held in place with a single black knob. When this cover is removed, you can see a portion of the brake in the middle portion of the housing. The HA cables (motor, sensor, and encoder) are visible departing from the bottom of the HA assembly. The cables for the declination axis follow a similar path, but they must be guided through the HA shaft after the fork has been assembled.
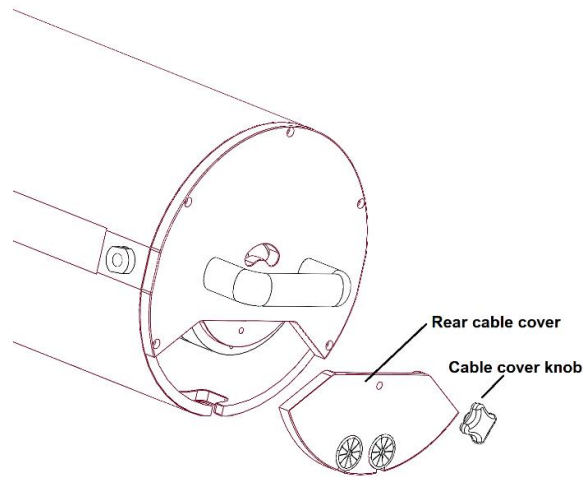
Figure 21: Rear cable cover and knob.

Insert the declination motor wire first, as it is the largest and stiffest of the cable. When removed, the *rear cable cover* provides access to the cables that are directed through the HA shaft. Once the cables are pushed through the HA shaft, they will appear inside the HA tube and can be directed through the base into the pedestal that contains the controller.
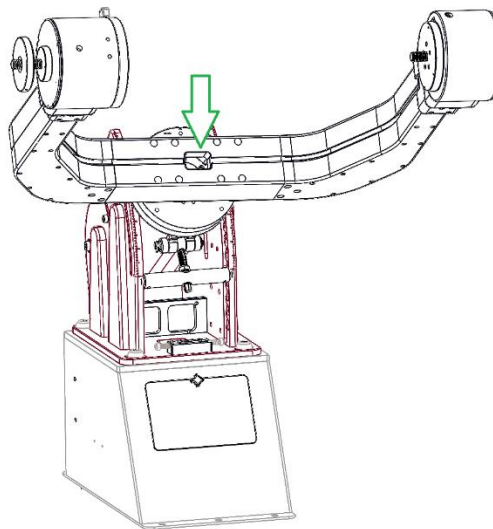
Figure 22: The green arrow shows where the declination cables are routed through the HA shaft.

Removing the HA Rear Panel (Only if Necessary)

The HA axis includes an integrated brake to stop rotation in case of power loss.

Do not remove the HA Rear Panel and brake when assembling the mount unless you are absolutely sure you know what you are doing!

There is normally no reason to remove the upper portion of the HA rear panel as it holds the brake and is difficult to re-install when removed. The following instructions should be used if the need ever arises to remove the brake plate.

The brake is permanently attached to the upper portion of the HA rear panel. The removable panel cover (Figure 23) provides access to the internal motor and brake cables and allows custom cables to more easily be passed through the mount.
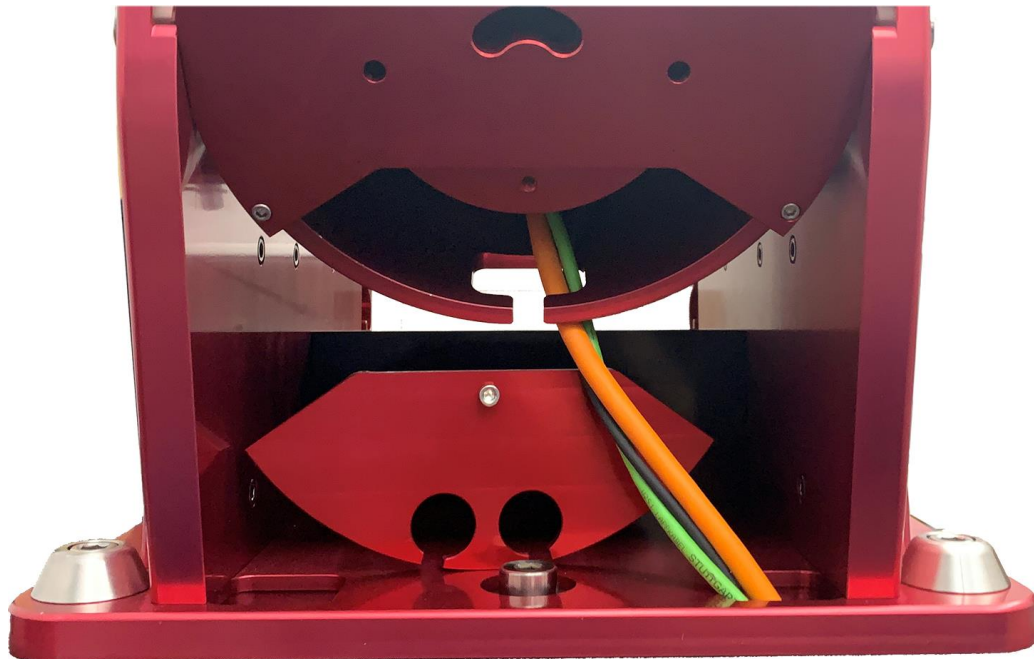
Figure 23: Photo showing the HA access panel removed from and sitting beneath the rear cover.

HA rear panel with
brake and handle
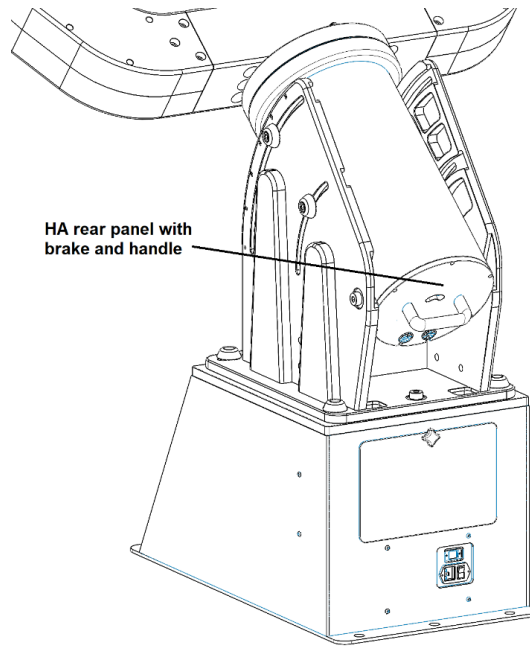
Figure 24: The HA rear panel and removable cable access cover.

The photo below shows the inside of the HA rear panel with the HA brake attached to the HA rear panel.

DO NOT REMOVE THE UPPER PORTION OF THE HA REAR PANEL.

The HA brake is installed at the factory and the HA rear panel should normally not need to be removed.

Removing the upper portion of the rear panel separates the brake pinions and causes them to become misaligned. In order to re-install the HA rear panel, a 12V DC power source must be applied to release the brake and provide some play in the position of the pinion.
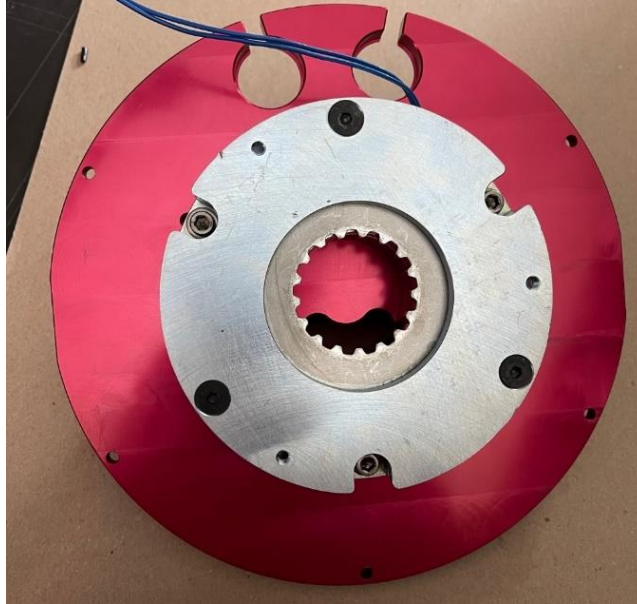
Figure 25: Photo of the integrated hour angle brake.

Once you have positively identified the drive tine, the following steps must be completed before attaching it to the fork center.

1. Remove the cable package from inside of the drive tine base assembly so that it can be unwrapped from the protective shipping material.
2. Move the cables so that they are not interfering with the drive tine assembly when it is lifted up to be attached to the fork center.

Figure 26: The arrow on the HA drive points to drive tine.

The drive tine must be attached in the correct orientation with respect to the HA drive plate. The small arrow next to the word Motor (**< Motor)** points to the side of the fork center that holds the drive tine.

If you are standing at the rear of the Taurus mount (facing the celestial pole behind the mount) the drive tine goes on the right side.

Two people are needed to lift the drive tine into place and "wiggle" it onto the fork center. Once in place you will be able to insert the six socket head screws that attach the tine to the fork center.

Figure 27: Installing the drive tine.

HA Axis Locking Screw

The HA axis can be locked in place by inserting the locking screw into the hole shown in Figure 28, and rotating the HA axis to hour angle 0, +3, +6, −3, or −6.
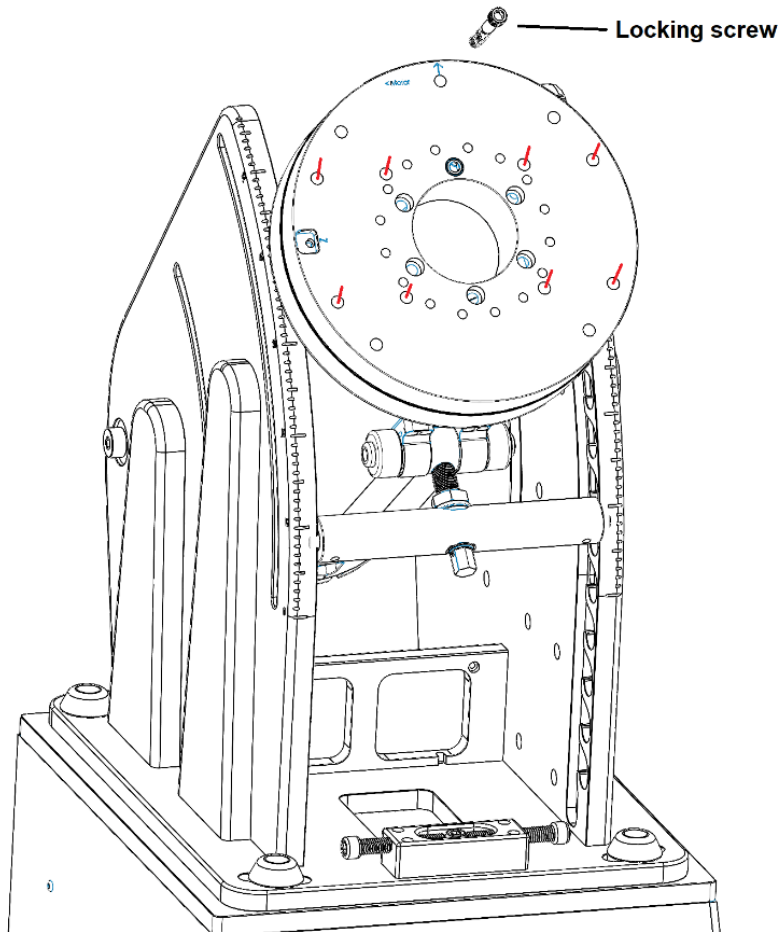
Figure 28: Install the locking screw to prevent rotation when the HA drive plate is in this orientation.

Before attaching the fork center component (page 22), follow the procedure below to install the HA locking screw (a 3/8-24 TPI x 2.5-in. SCHS) to prevent rotation in HA:

1. Rotate the HA so that the machined arrow points at HA 0 (straight up).

2. Gently insert the locking screw into the hole directly below the machined arrow.

3. Carefully and slowly rotate the HA drive plate back and forth until you feel the locking screw dip into the threaded hole, the then stop rotating the HA plate.

4. Fully tighten the screw by hand.

> ### *Warning*
>
> *The locking screw should not be used to hold excessive out of balance loads.*

The locking screw is designed to prevent the HA drive plate from rotating while the fork center and the fork tines are being installed, or when attaching instrumentation to the fork arms.

The locking pin is not intended to hold imbalances that are greater than those resulting from having a single tine attached to the HA assembly.

Note: The Scope Rail System provides an effective mechanism to mount payloads to the Taurus mount and allow the system to achieve balance. Please see Appendix B: Taurus OTA Mounting System for additional information on the Scope Rail System.

There are many ways to attach an OTA or other sensors between the tines. The following section describes how to attach an OTA using the Software Bisque *Scope Rail System.*

Attaching the Fork Center

The fork center is attached using 8 x 1/2-13 x 4.25-in. socket head cap screws. The fork center's eight counterbores must be aligned with the eight threaded holes in the drive plate (see the red marks in Figure 29).

This step in the assembly requires two people, one to hold the fork center in place, and one to insert and tighten the screws. When two screws are in place (do not tighten them fully just yet) the remainder of the screws are easier to install.
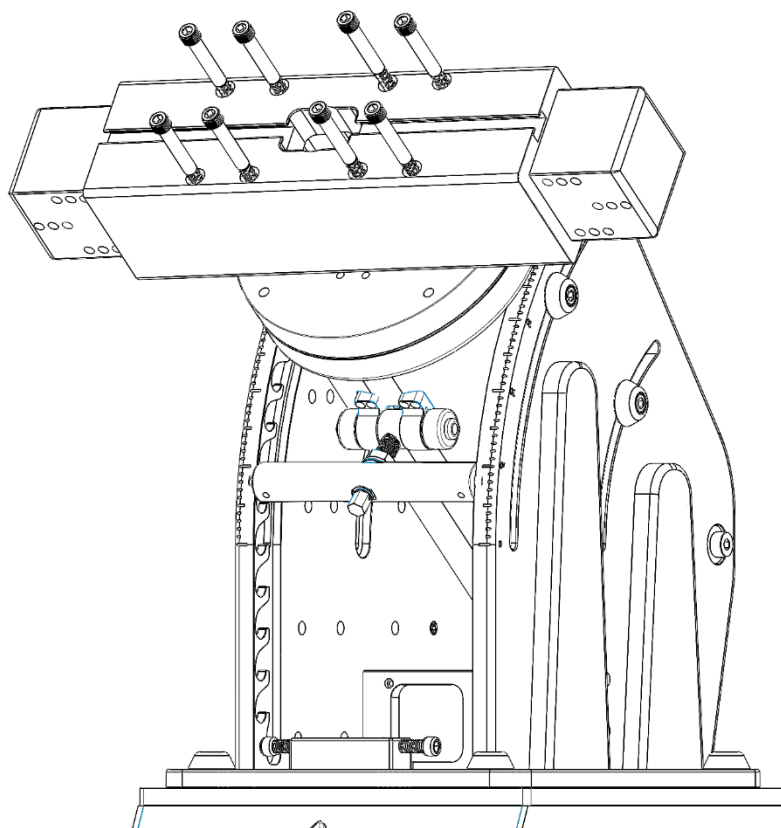
Figure 29: Attaching the fork center.

Attaching the Drive Tine
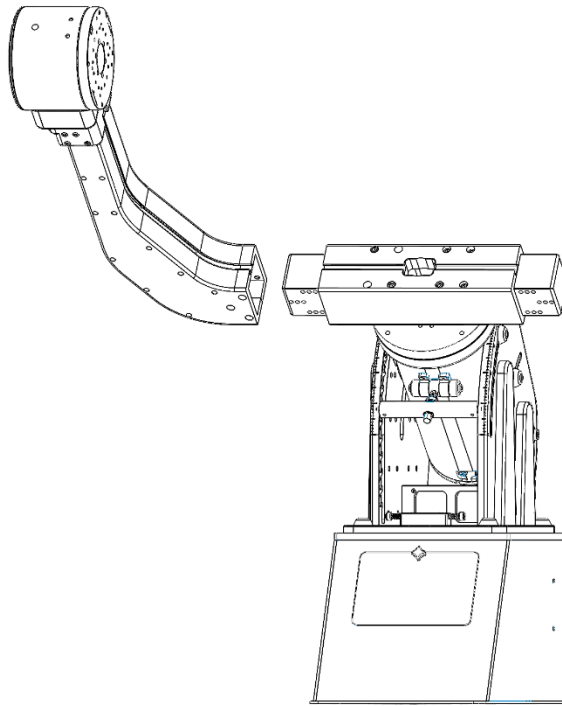
Figure 30: Attaching Taurus drive tine.

Caution!

When the mount is not secured to the floor or a pier, the entire assembly is not stable, especially when a single tine is in place. The motor tine is heavy and could cause the entire assembly to unexpectedly tip over.

The drive tine contains the direct-drive motor, high-resolution encoder, and a precision bearing assembly. The drive tine has several cables that are tucked into the base of the tine, including the motor cable (orange), the sensor cable, and the encoder cable.

Once you have positively identified the drive tine, the following steps must be completed before attaching it to the fork center.

1. Remove the cable package from inside of the drive tine base assembly so that it can be unwrapped from the protective shipping material.
2. Move the cables so that they are not interfering with the drive tine assembly when it is lifted up to be attached to the fork center.
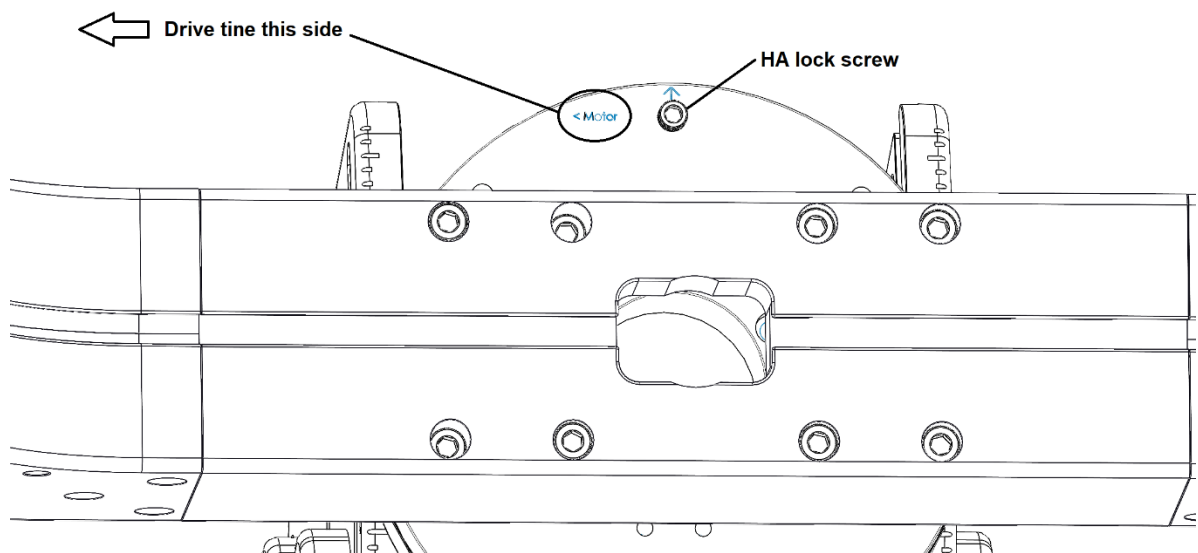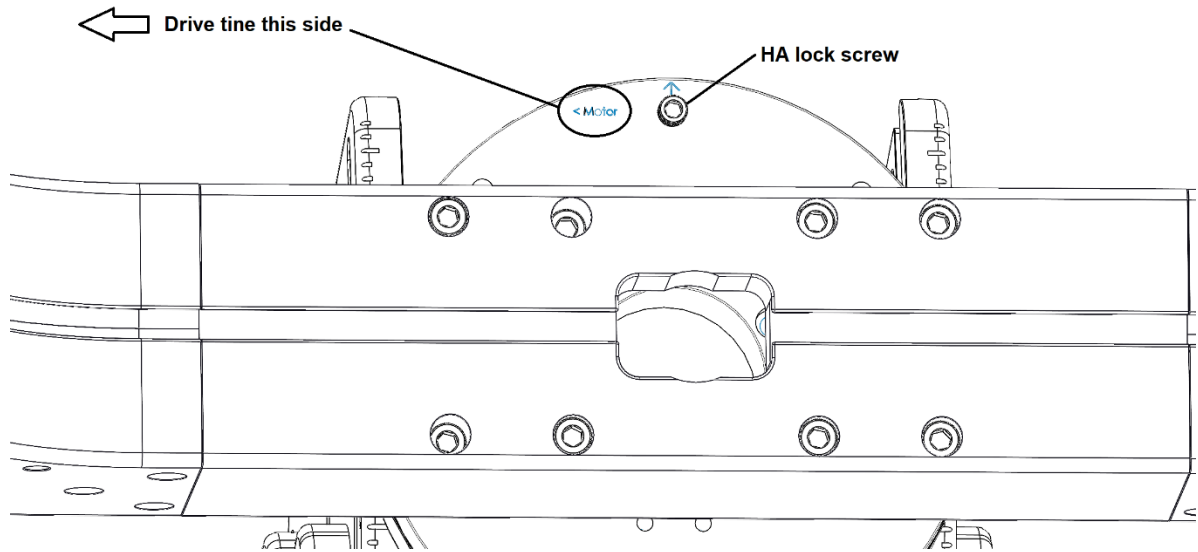
Figure 31: Use the arrow on the HA drive to ensure the drive tine is installed in the correct position.

The drive tine must be attached in the correct orientation with respect to the HA drive plate. The HA drive plate has an indicator that specifies on which side the drive tine must be attached. The small arrow next to the word Motor (**< Motor)** points to the side of the fork center that holds the drive tine.

If you are standing at the rear of the Taurus mount (facing the celestial pole behind the mount) the drive tine goes on the right side.

Two people are needed to lift the drive tine into place and "wiggle" it onto the fork center. Once in place you will be able to insert the six socket head screws that attach the tine to the fork center.
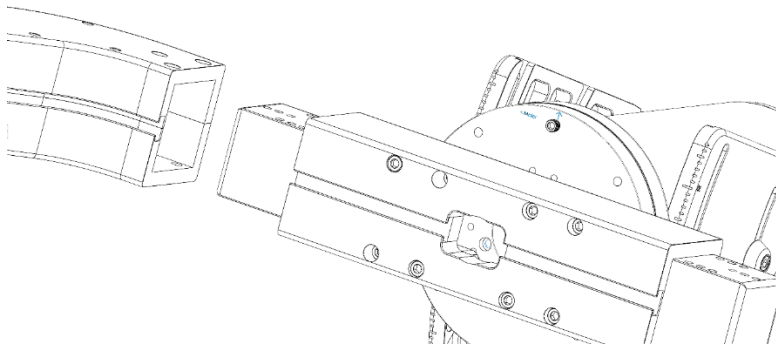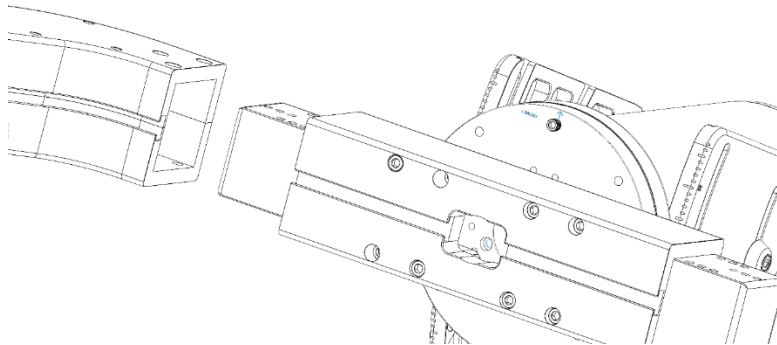

Figure 32: Inserting the drive tine.

Attaching the Support Tine

Once the drive tine is in place, install the support tine in the same manner described above. The support tine has a single harness carrying the brake and HA axis inside the mount.
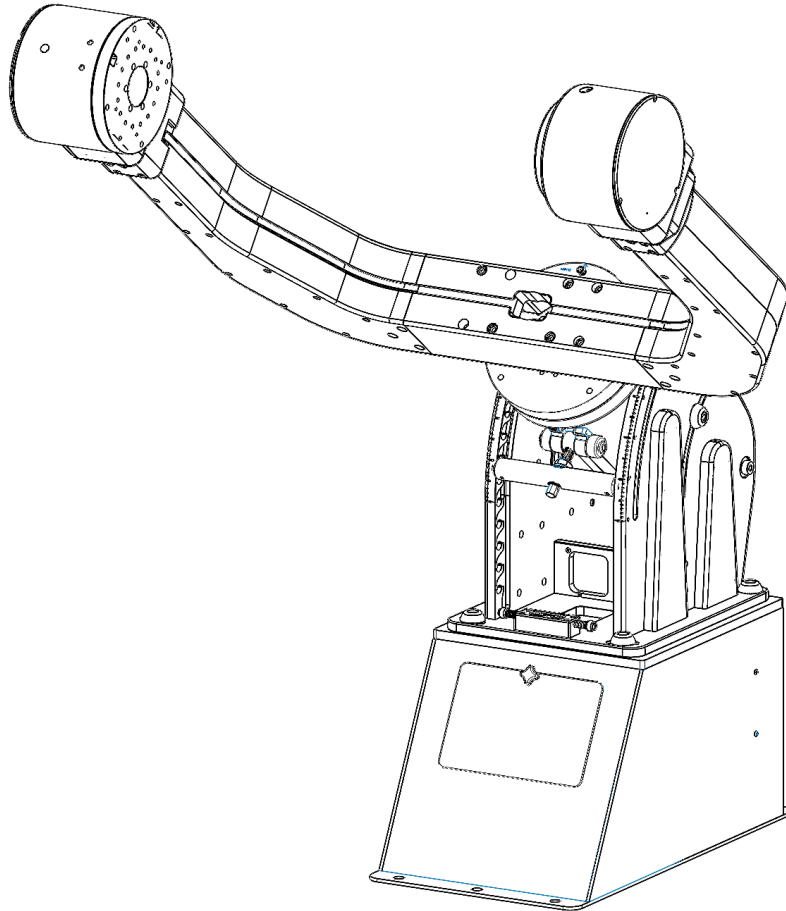
Figure 33: Taurus with the fork components fully assembled.

Caution!

The drive tine is heavier than the support tine, so when the locking screw is removed the forks will rotate and may cause injury.

Routing and Connecting the Cables

The cables that connect the various components are labeled with a numbering system that is described in "Appendix A: Taurus Internal Cabling Details" on page 84.

Once the tines have been attached to the fork center, cabling from the various axes must be routed into the pedestal and connected to either the distribution PCB or the controller.

The first step is to route the declination cables through the fork center, then down through the HA axis. The drive tine contains three cables including:

- Declination motor cable
- Declination encoder cable
- Declination sensor cable

The support tine contains two wires for the brake that must also be routed through the HA axis.

HA rear panel with brake removed

All cables for HA and declination drives pass through opening

Pass cables through these two cable passages

Rear access panel removed
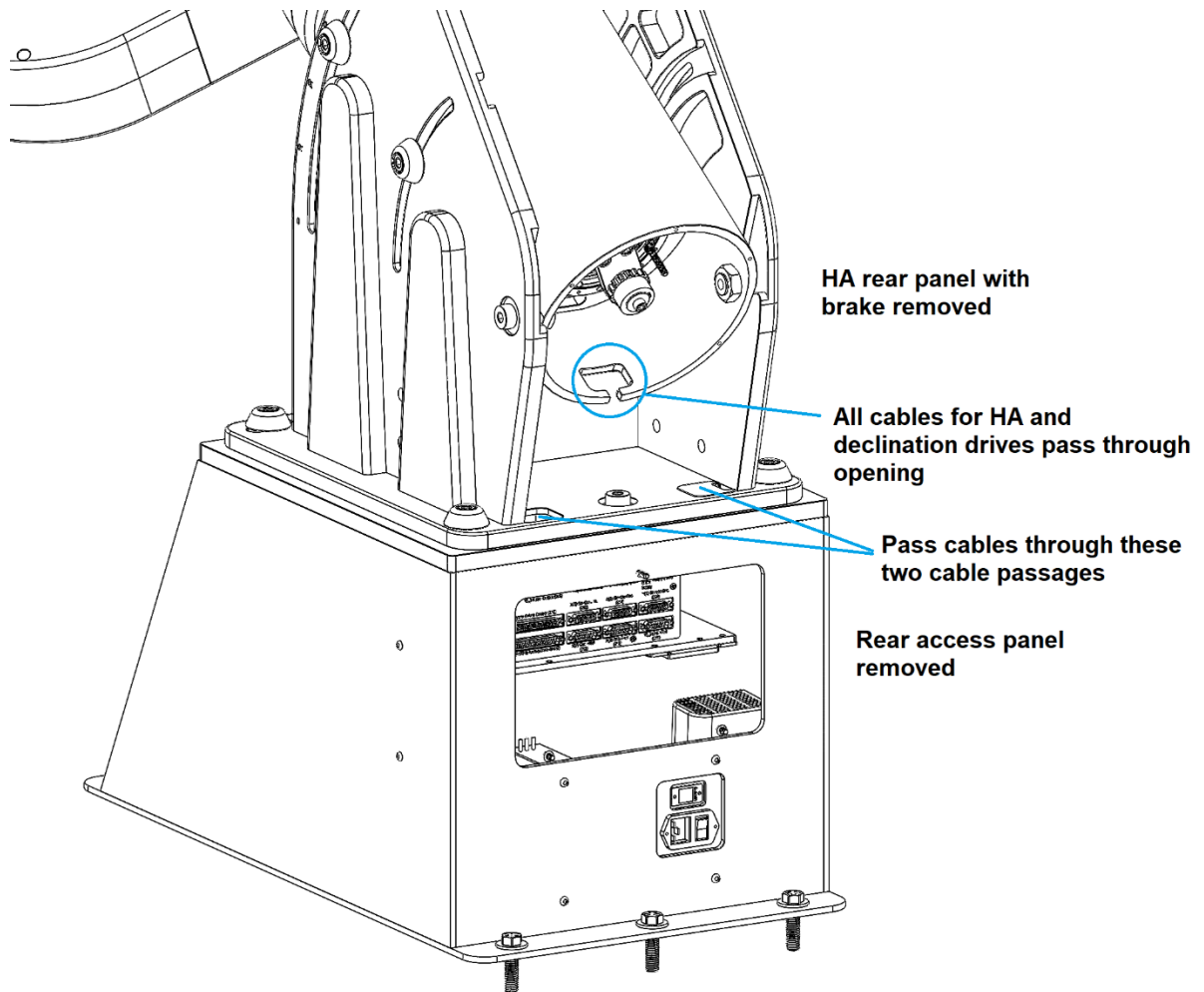
Figure 34: Diagram shows the route of the mount's motor and other cables.

Insert the harnesses in the HA assembly through the two rectangular holes in the base of the wedge plate. The best practice is to route the HA cables through one hole and the declination cables through the other to mitigate confusion when connecting them to the cable distribution PCB.

Cable Distribution PCB

When the rear access panel is removed from the base, the cable distribution PCB is located on the upper left side (Figure 35).
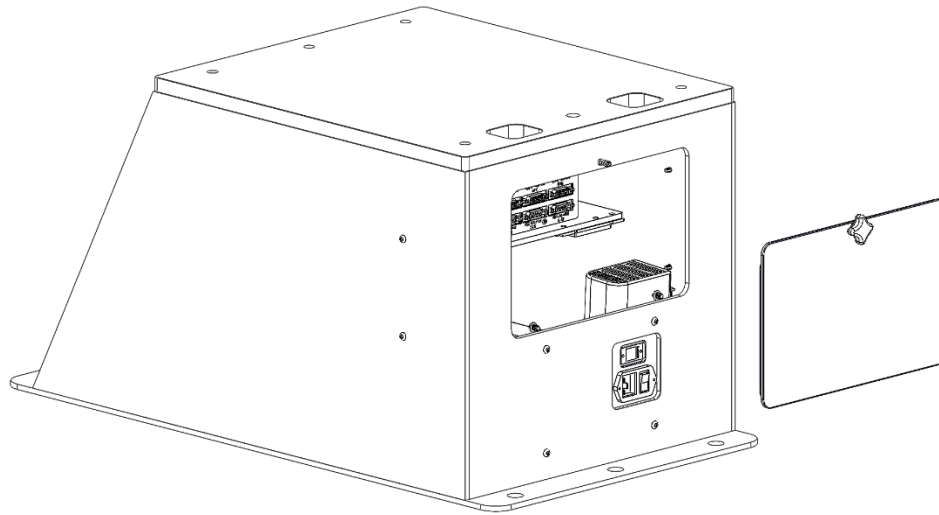
Figure 35: Pedestal rear access panel.
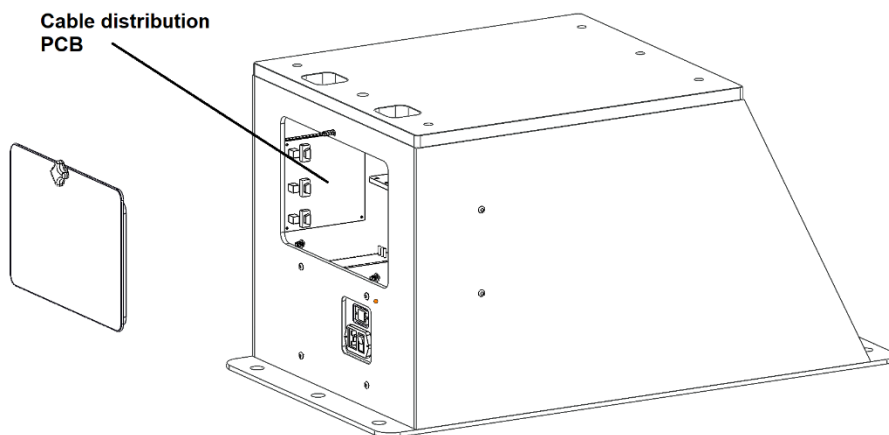
Figure 36: Location of the cable distribution PCB.

The cable distribution PCB is split into the three axes inputs on the left side of the board with additional inputs on the right side.

The Taurus is shipped with many of the controller cables pre-connected. The declination and instrument rotator axes are housed in the drive tine, and these cables must be routed down through the HA axis before connecting them to the distribution PCB.
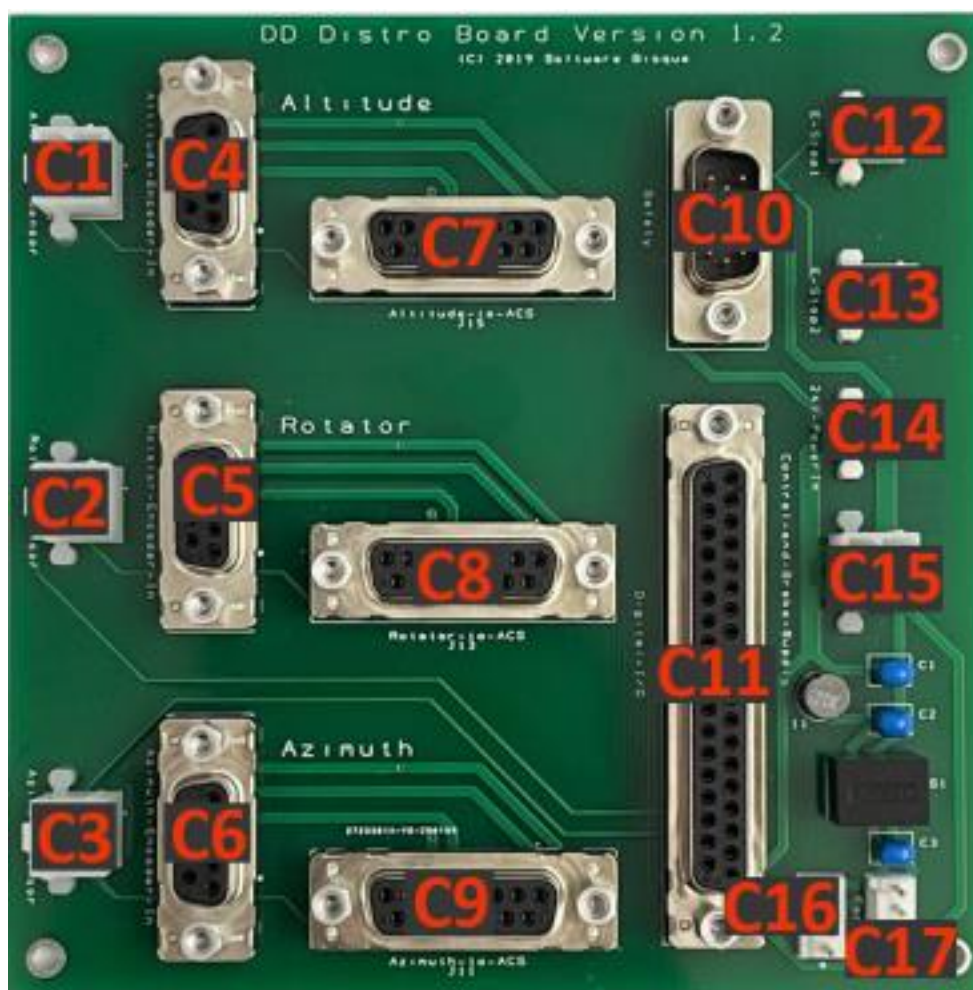
Figure 37: The Taurus cable distribution PCB. Note that the axis labeled altitude is synonymous with declination, and the axis labeled azimuth is synonymous with hour angle (HA) and right ascension (RA).
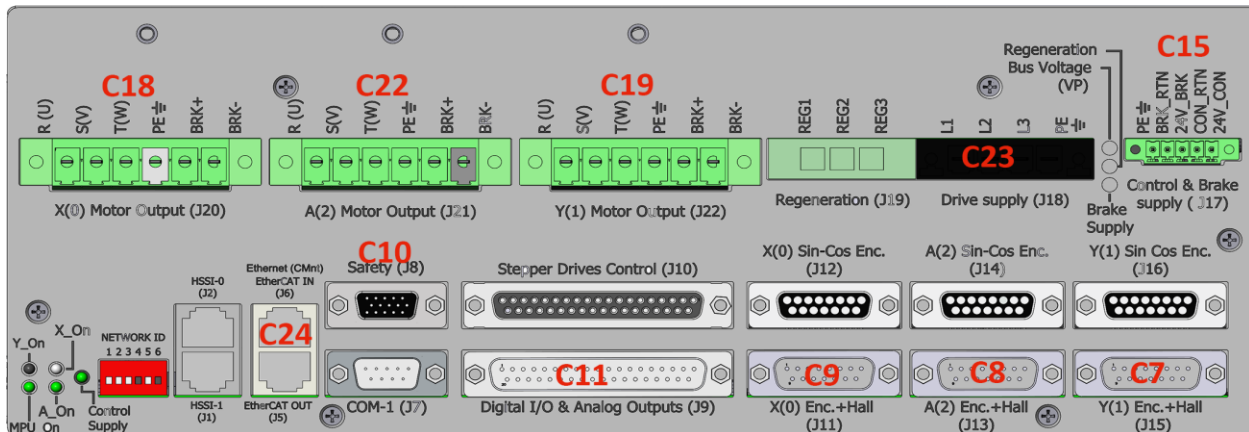
Figure 38: Controller Panel connections.

The HA axis is labeled as X(0), the declination axis is labeled as Y(1), and the optional rotator axis is labeled as A(2).

Note About Screw in Terminals

Do not tin the ends of the cables before they are inserted into the terminal connectors.

- *The tinning changes over time and will cause the cable to become loose.*
- *When tinned, the actual points of electrical contact end up being smaller compared with using just the bare wire.*

If these cables ever need to be removed from the connector, remember that quite a bit of torque on the small screws is required to make full contact with, and retain the wires. Take note that the required torque is about as much as one can muster using the supplied flat-head screwdriver.

Connecting Cables

Step One

For each axis, the brake leads need to be inserted into the corresponding motor connector for that axis. On the declination axis, the brake leads are labeled C25, and they need to be joined into the declination motor cable labeled C19.

On the HA axis, the brake leads are labeled C27, and they are joined into cable C18.
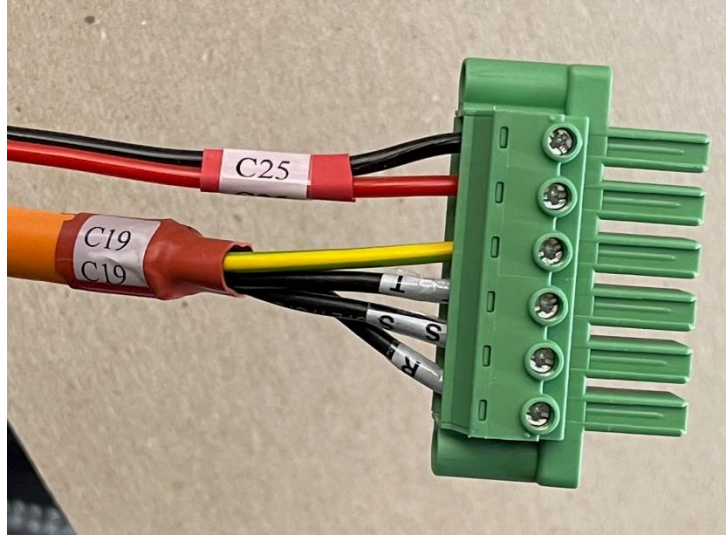
Figure 39: The declination motor connector with brake wires in positions 5 and 6 (red and black, polarity is not important). In the controller, the motor leads are labeled R, S, T.

Step Two

Plug each of the motor cables into the controller according to the cabling guide (C18 and C19).

Step Three

Plug the HA encoder cable into C6 and the declination encoder cable into C4 on the distribution board.

Step Four

Plug in the two sensor cables, cable C1 (4-pin Molex) into connector C1, and cable C3 into connector C3 on the distribution board.

Note: If the instrument rotator is going to be used with the system, repeat steps three and four for the rotator cables.

Motor Wiring

The motor leads are labeled as shown in Figure 40.
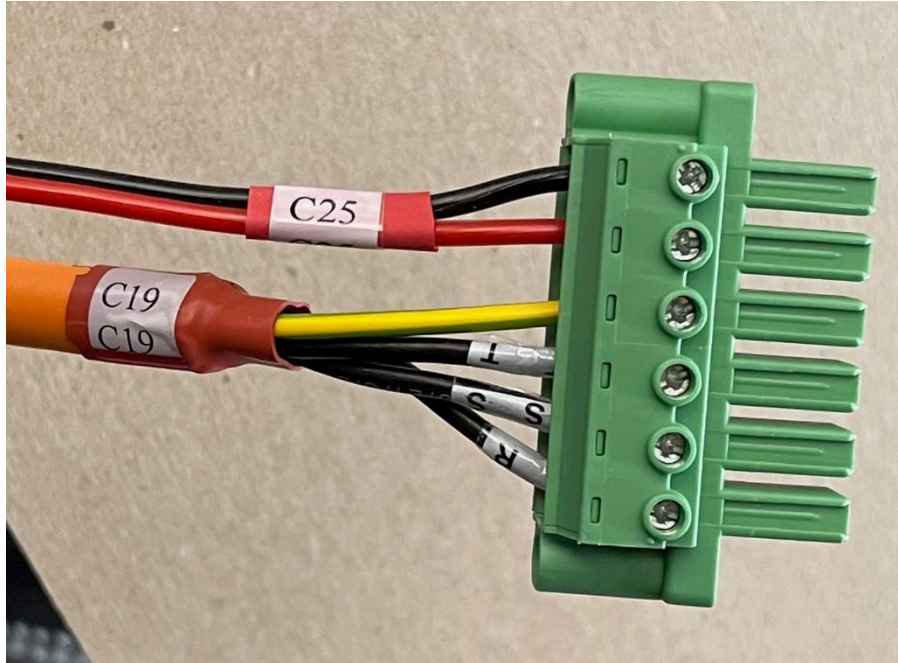
Figure 40: Motor leads and PCB plug.

Normally, when guiding cables down through the HA axis, there is sufficient space so that the declination and rotator motor connectors do not have to be removed from the motor leads. If you find that you must remove the large connector, do so while routing the cables. Be sure to return each wire to the correct position. Use the labeling on the Controller (J20-J22) to see the order from left to right. The green wire is ground and should go into the fourth position.
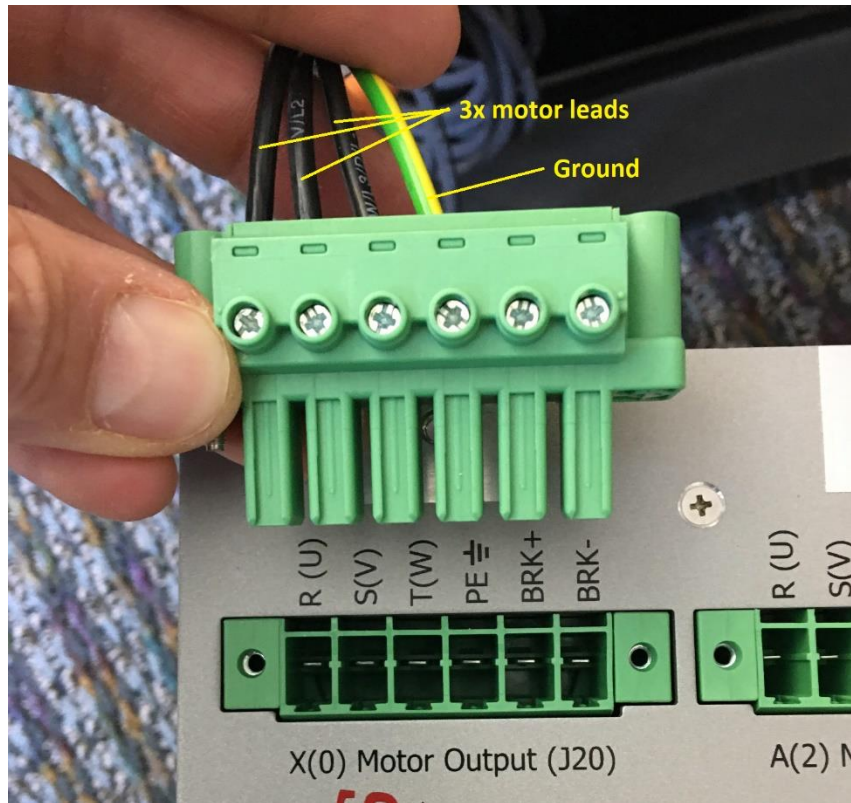
Figure 41: Cable connection terminals.

Attaching the Optional Instrument Rotator to the Telescope

Like the other axes, the Taurus instrument rotator has encoder, motor and sensor wires that are contained in the drive tine. The rotator interface panel has two connectors that are placed at the bottom. The rotator plugs into these two connectors (a 9-pin D-sub connector and a round 7-pin connector). Take care to ensure that the cables are screwed into place as they may otherwise become disconnected.
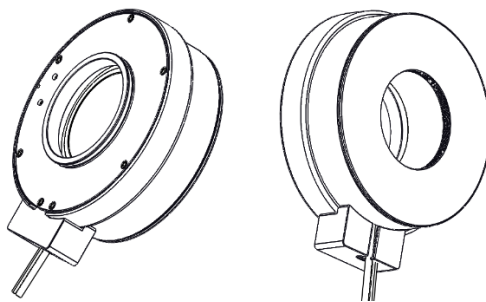
Figure 42: The left graphic shows the OTA side with dovetail. The right graphic shows the image train side with 3.5-in. thread (24 TPI)
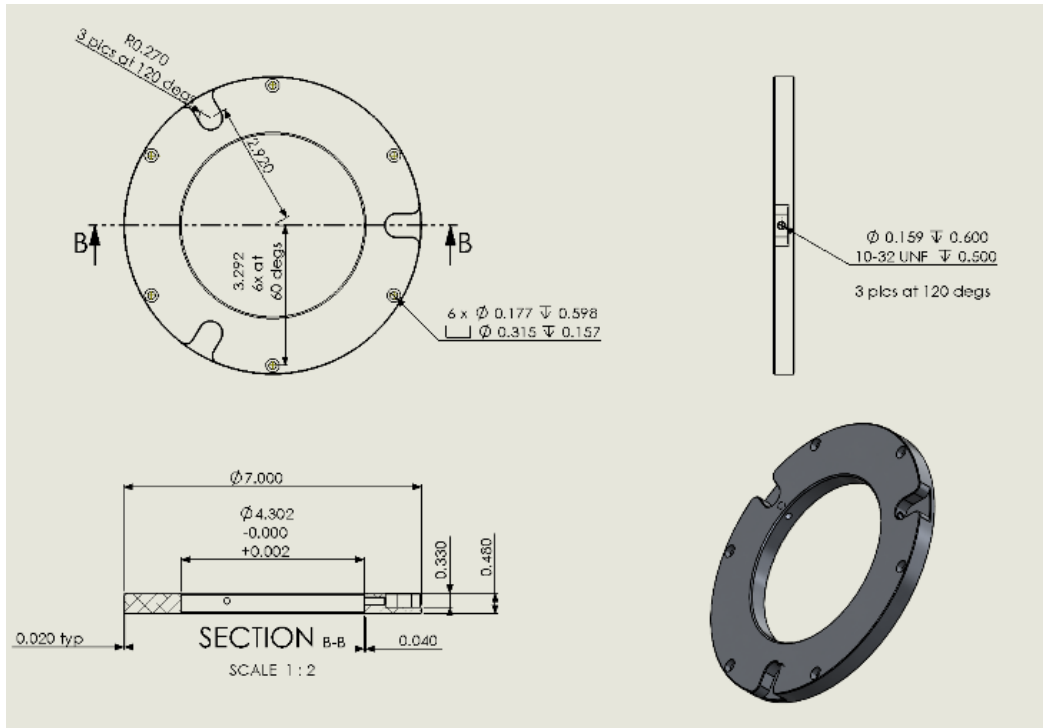
Figure 43: The OTA plate is compatible with the Optec 4300 dovetail.
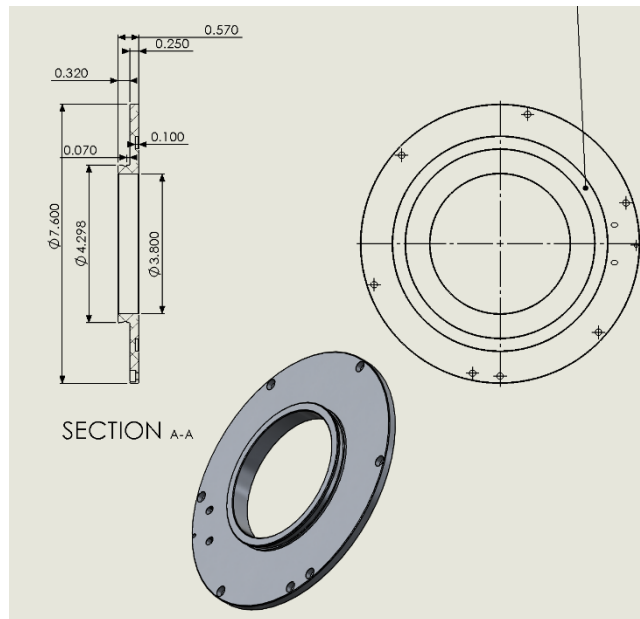
Figure 44: The OTA mounting dovetail dimensions (Optec).

Initial Power Up

Once all the cables are connected, and double-checked for continuity, turn on the power switch. The controller takes about 90 seconds to boot and initialize. Note that attempting to connect to the control system from TheSky or other software before the controller is fully initialized will result in a command failed error.

To verify power is connected properly, inspect the six LEDs on the left side of the control system unit, and the three LEDs on the right side.
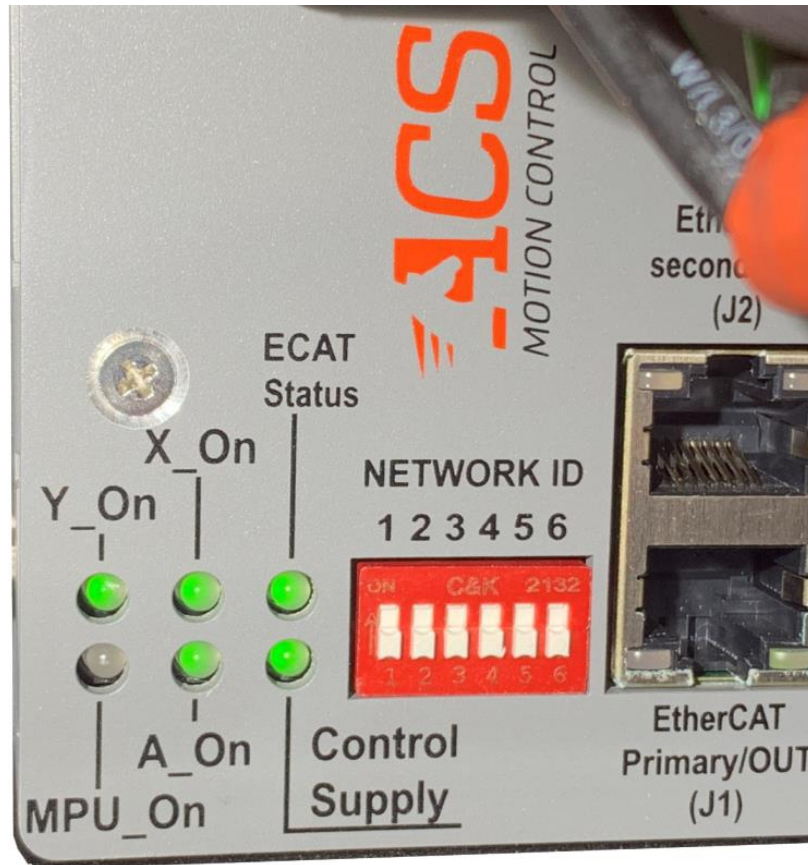
Figure 45: Six control system status LEDs.
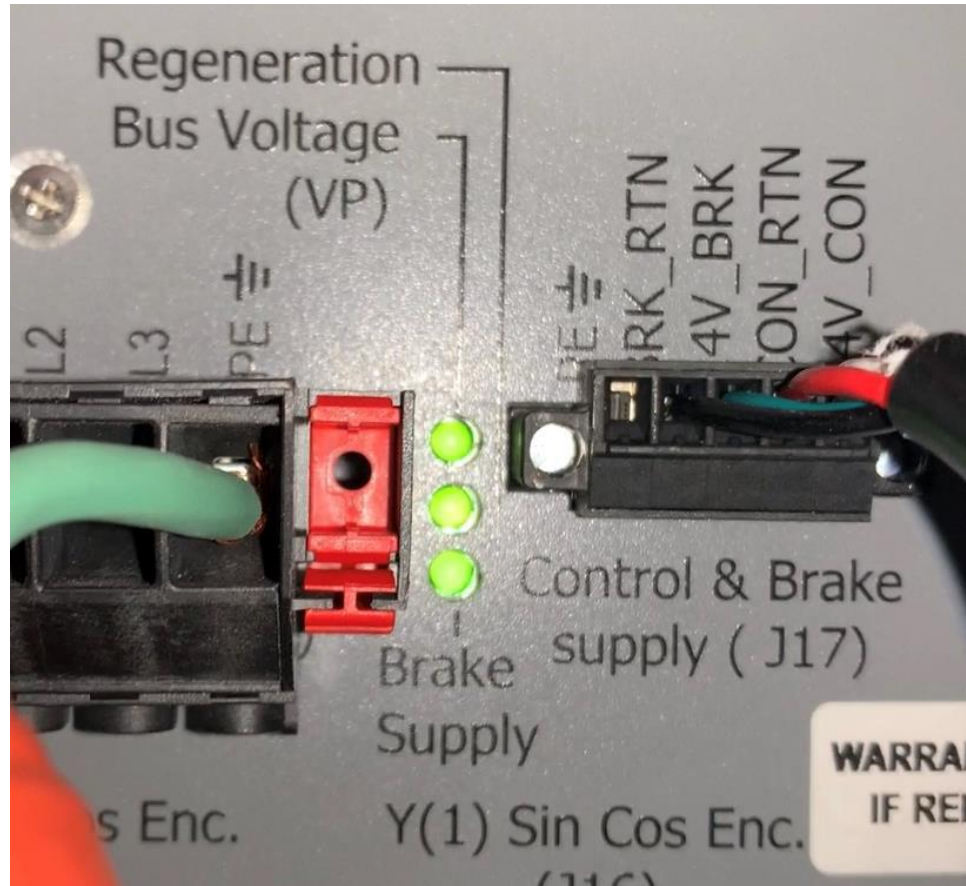
Figure 46: Three status LEDs on the right side of the control system.

When all the cables are wired and connected properly, the LEDs should emit light as described below.

Left side LEDs:

- The *Y-On*, *X_On*, *ECAT Status*, *A_On* and *Control Supply* LEDs emit steady green.
- The *MPU_On* LED continuously flashes green.

Right side LEDs:

- The Bus Voltage (VP), Regeneration, and Brake Supply LEDs emit steady green.

If any of these LEDs are red, double-check the power connectors, and make sure the harnesses are all plugged into the distribution PCB.

Mounting the Optical Tube Assembly

Safety Precaution!

Attaching a large, cumbersome, and heavy optical tube assembly or sensor package can be the most dangerous step in assembling the Taurus mount. Before the payload is in place and balanced, it may unexpectedly rotate, spin, slide, or drop.

Anytime a large mass, for example, when installing a maximum Taurus payload of 200 kg, is moving but not in balance, stopping the motion can be difficult and potentially cause severe harm to anyone that may be in the way.

Each axis has a locking pin that, when in place, restricts the rotation of that axis. These safety pins are especially important to install on the declination axis when adding the payload.

The scope rail system also includes safety pins that prevent the payload from passing through the fork, but extreme care must be taken while installing the OTA.

Note: The Scope Rail System provides an effective mechanism to mount payloads to the Taurus mount and allow the system to achieve balance. Refer to the *Scope Rail System User Guide* for details about attaching common commercial optical telescope assemblies to the Paramount Taurus equatorial fork mount and the scope rail hardware.

There are many ways to attach an OTA or other sensors between the tines. The following section describes how to attach an OTA using the Software Bisque *Scope Rail System.*

Attaching a Scope Rail Equipped OTA

Mounting a telescope between the tines using the Scope Rail System involves the following steps. Please first attach the scope rails to the OTA before proceeding.

1. Add a fork rail to each tine.
2. Adjust the tines so that the spacing is approximately 12 mm (0.5 inches) wider than the measured distance between the two scope rails that are mounted on the optical tube.
3. Tighten the fork clamp on the drive tine (see page 31).
4. Install the safety pins on the scope rails.
5. Add the axis locking pin to the declination and HA axes.
6. Lift the OTA above the fork rails and lower it into position so that the safety pins are resting on the fork rails.
7. Add at least one clamp nut and screw (which pass through the fork rails and thread into the scope rails) to each side of the telescope.
8. Gently push and rock the support tine inward until the fork rail contacts the OTA.
9. Roughly balance the OTA by sliding it parallel to the optical axis.
10. Tighten the support tine clamp.
11. Relieve the stress on the system by loosening the support tine plate.
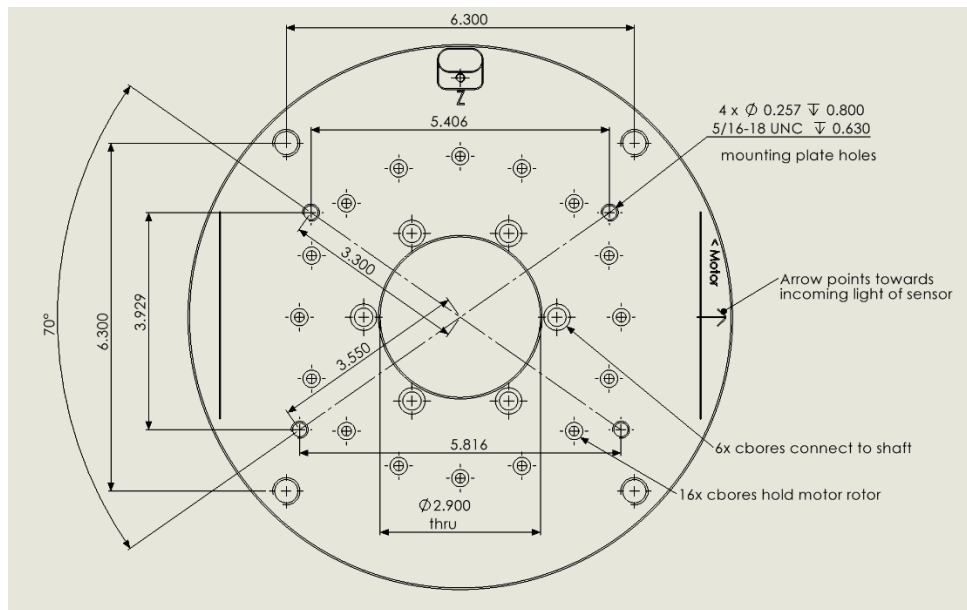
Figure 47: The drive plate and support plate hole pattern.

The drive plate and support plate have four tapped holes (5/16-18 TPI) for adding a mounting plate. This pattern is not symmetric which ensures that the scope rail plates are attached in the correct manner. If custom mounting plates are fabricated for attaching the sensor package, the required dimensions are shown above.
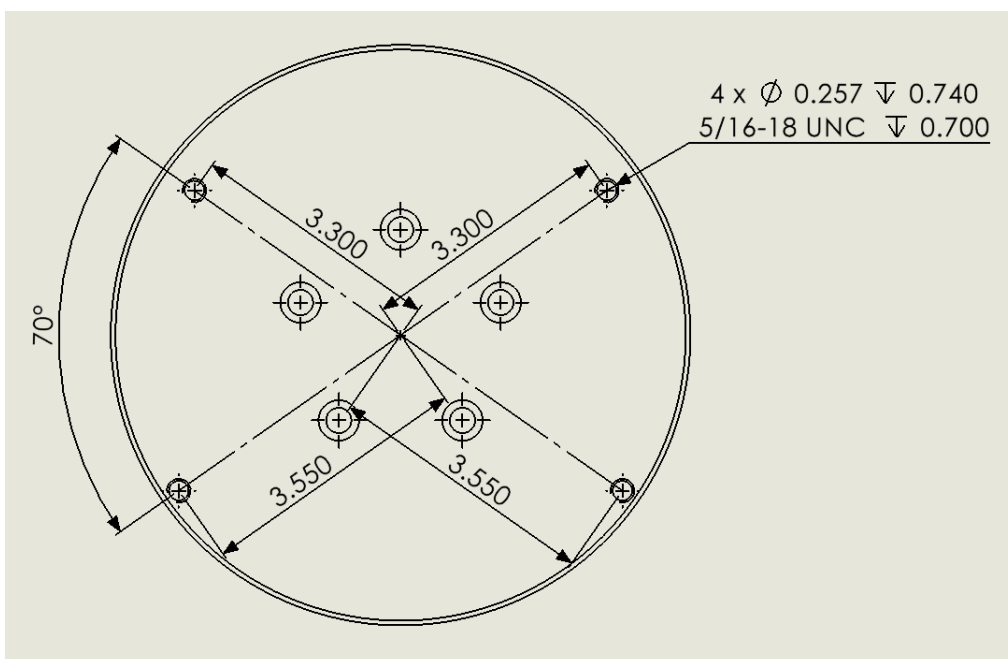
Figure 48: Drawing showing the Support plate hole specifications.

The support plate hole pattern is the same as the drive plate.

Step 1: Add the Scope Rails
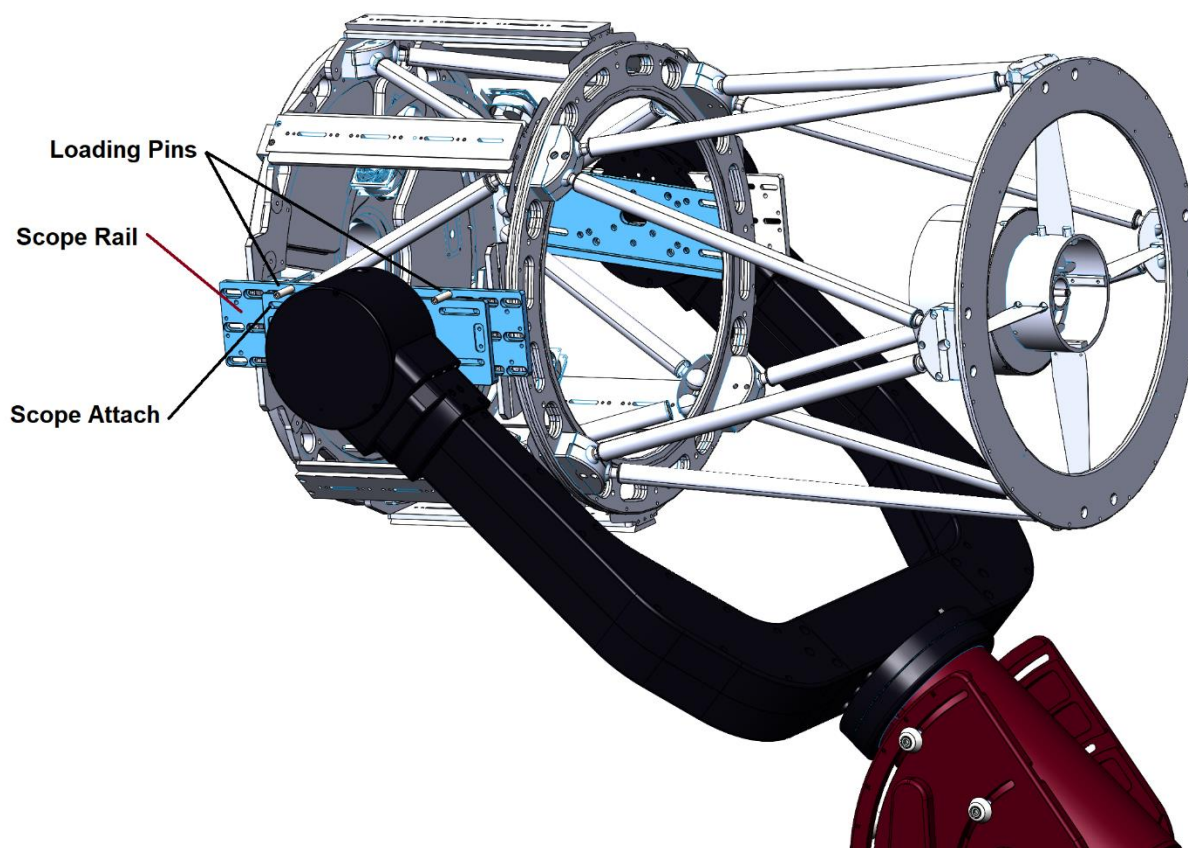
Figure 49: Adding the fork rails during OTA installation.

Step 2: Fine-Tune the Tine Spacing
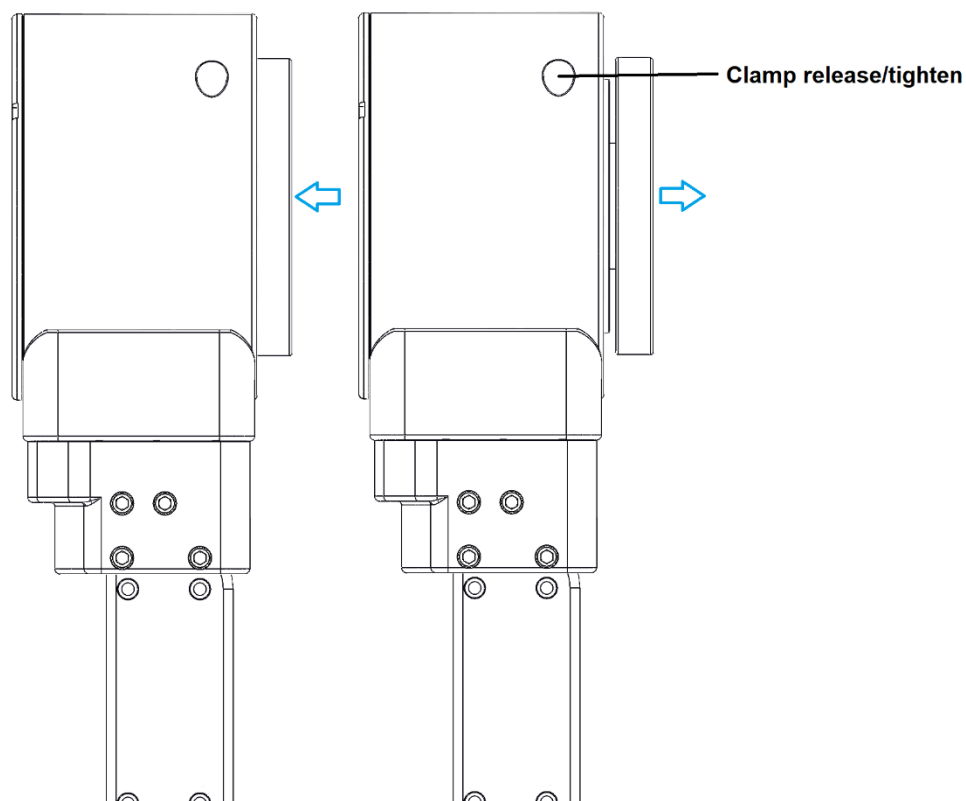
Figure 50: Fine-tuning the tine spacing.

The spacing of the tines should be adjusted so that the optical tube fits comfortably between them. In practice, loosen the clamp on the support tine and move the plate as far in as it will go. This will provide additional spacing to allow the insertion of the optical package between the support tine and the drive tine. The full range of motion is about 10 mm (0.4 in.).

Step 3: Install the Loading Pins
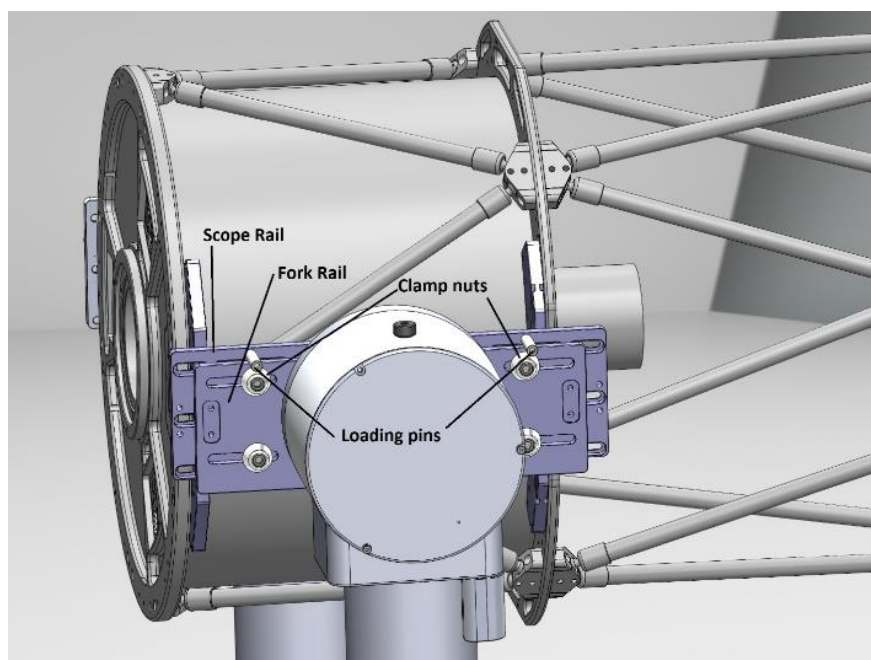
Figure 51: The Loading pins are used temporarily to support the OTA while the clamp nuts are installed.

Step 4: Insert the Dec Axis Lock Pin

Insert the declination axis lock pin into the hole on top of the drive tine and slowly rotate the axis. When the fork rail is near horizontal, the pin will drop into the axis locking hole.
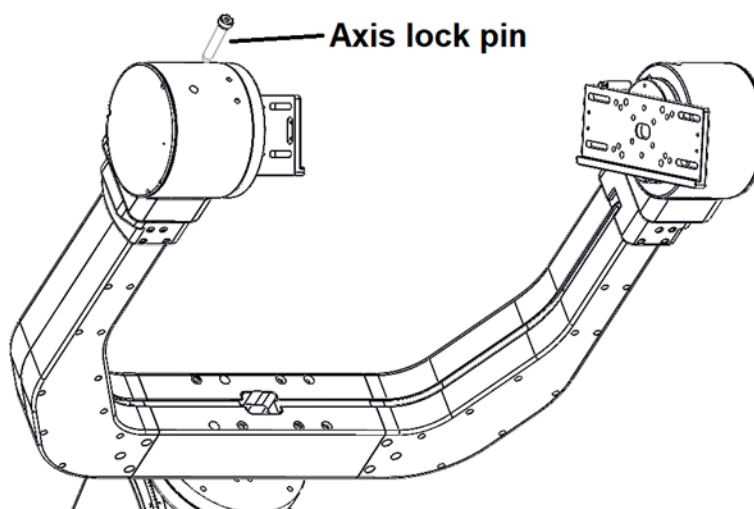
Figure 52: Location of the dec axis lock pin.

Step 5: Lift the OTA into Place
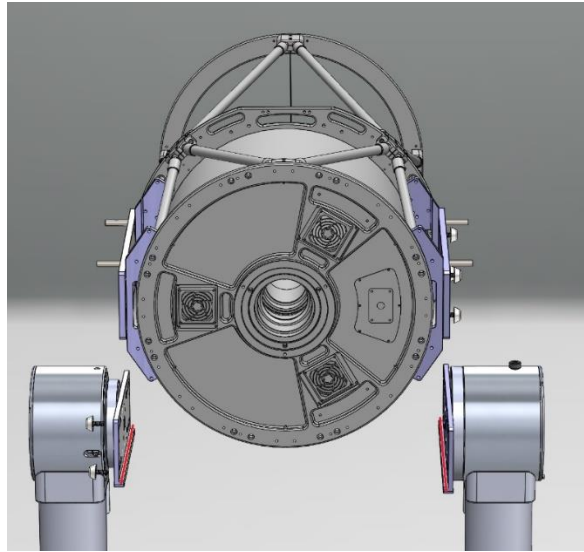
Figure 53: The fork plate spacing is the distance between fork plates, and the OTA plate spacing is the outer distance between the two plates on the OTA.

The tines should be adjusted so the *fork plate spacing* is slightly larger than the *OTA plate spacing* by about 1-2 centimeters. This makes it easy to lower the scope into place without collisions with the tines. It can be an awkward and challenging moment as the OTA is lowered until the *loading pins* rest on top of the *fork rails.* Once the loading pins are in contact with the *fork rails* the OTA will be in a stable but unattached position. At this point, the OTA should be pushed towards the Drive tine so that one or more *clamp nuts* can be threaded into the OTA Scope Rail.

Step 6: Add the Clamp Nuts
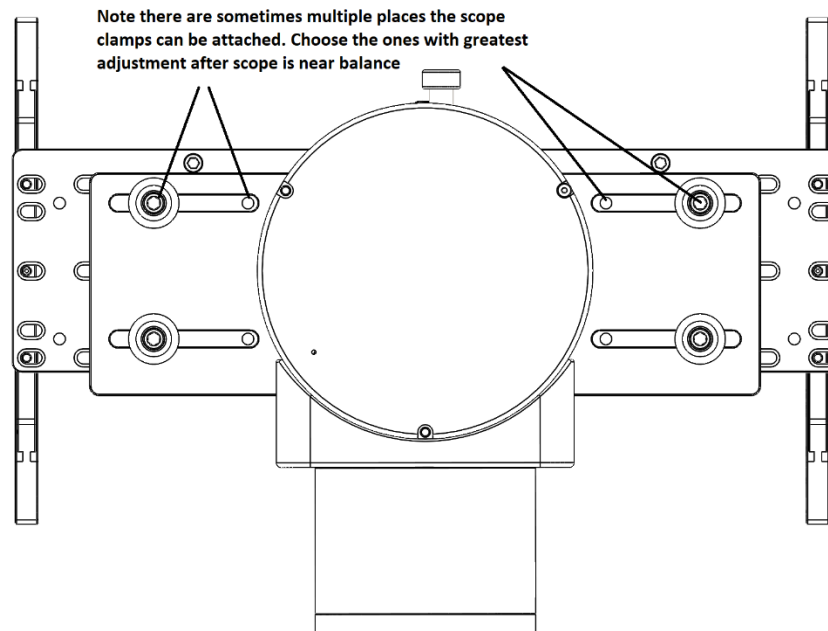
Figure 54: Carefully choose where to attach the mounting clamps.

Once close to balance, the four fork rail clamps should be fitted through the slots in the fork rail where there is a visible threaded hole. There may be more than one position both fore and aft of the fork center. Be sure to select the hole that provides the widest amount of adjustment on either side of the slot. Once one or more of these are engaged on both sides of the OTA, the weight of the telescope rests on the bottom of the Scope Attach plate.

Once the full instrument package is added, the location of these clamps may need to be adjusted to accommodate the new balance position.

Step 8: Push Support Tine Inwards
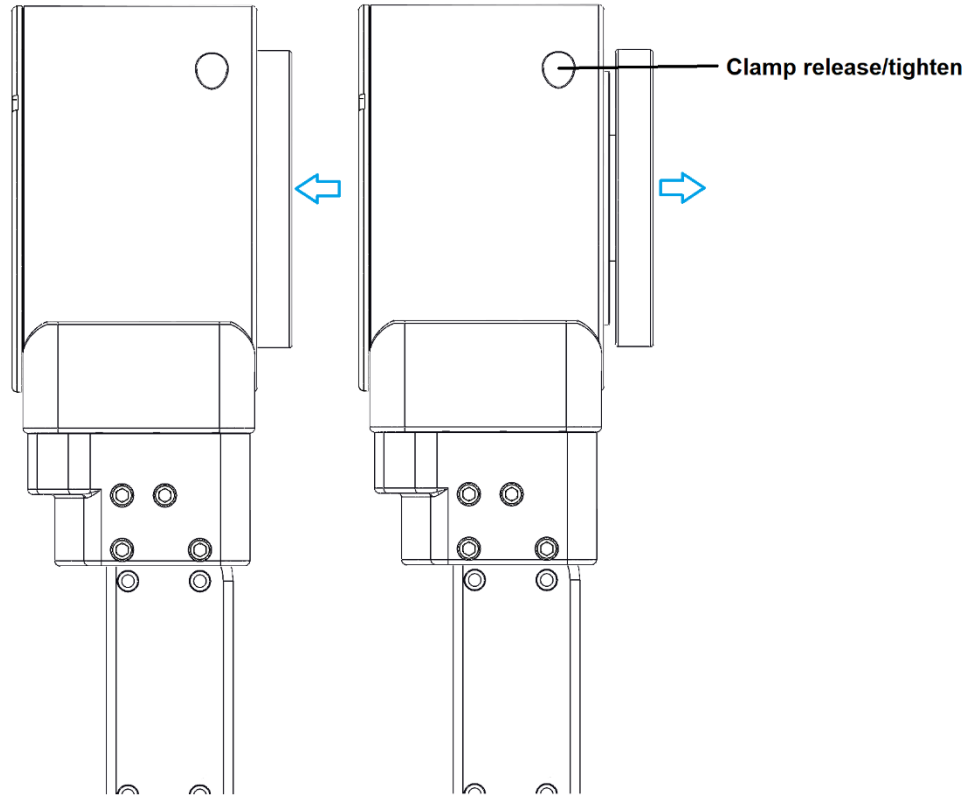
Figure 55: The blue arrows show the direction of motion in the support tine.

In addition to the adjustment in the fork base, the support tine has a small amount of adjustment in the mechanism that holds the support tine bearing. The purpose of this adjustment is to be sure that when the forks are tightened into place there is no stress on the optical tube, or undue stress on the forks. The graphic above shows the extent of the adjustment. On the left, the round OTA plate is inwards as far as it can go, and in the graphic in the middle, it is extended outward to the maximum amount. The starting position should be in between these two positions with approximately 6 mm (0.25-in.) of the bearing plate exposed (the bearing plate is shown inside of the round OTA in the right graphic).

Step 7: Roughly Balance the OTA

Slide the tube assembly fore and aft along the optical axis to achieve a reasonable balance. Final balance will happen after the optional rotator and other components of the optical train have been added.

Figure 56: The OTA can be moved along the axis defined by the red line to achieve balance.

Step 8: Relieve the Tine Strain

Using a ¼-inch hex drive, loosen the support tine plate screw to relieve the stress between the tines. You should notice the drive plate adjusting inwards or outwards depending on any stresses in the system from the fork distance not being exactly the same as the spacing on the OTA. After loosening the screw, retighten it in its new position.

Note that it is possible that there is not enough adjustment in the support plate to accommodate the current fork spacing. In this case the fork itself must be moved a small amount so that the support plate is withing its adjustment range.
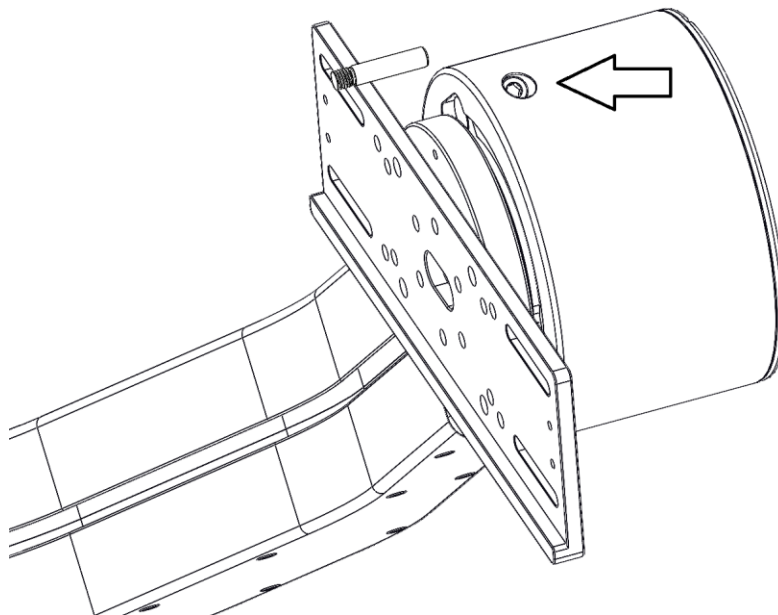
Figure 57: Location of the clamp release nut.
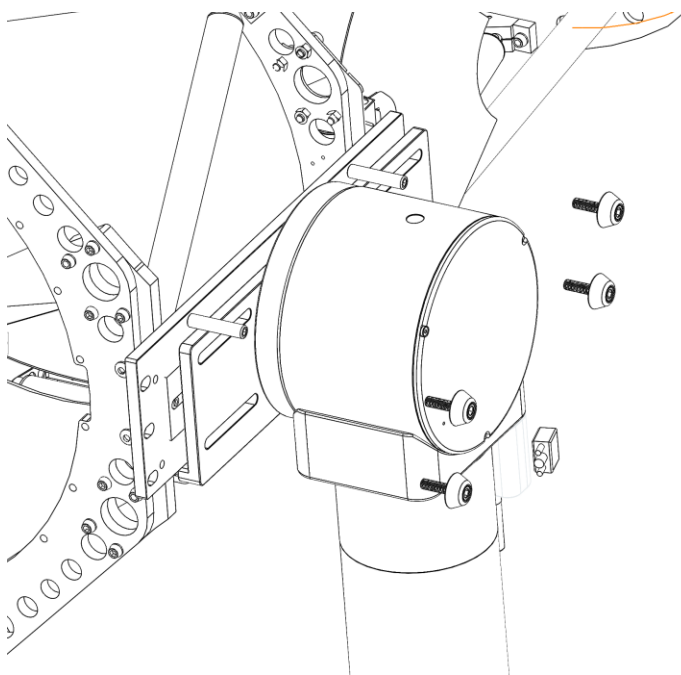
Figure 58: Installing the clamp nuts.

Balancing the HA Axis

Once the optical payload is secured, it must be balanced. Depending on the type of optical system(s) that are mounted, the imbalance can range from negligible to several kilograms. For many OTAs, the imbalance is small, and weight must be added to the support tine because the motor tine is heavier. The support tine includes a counterweight attachment plate that accepts two different counterweight systems. Normally, the lighter counterweight system accepts counterweights that are 1.3 kg or 2.6 kg (3 lb. or 6 lb.).

If the imbalance is more than 4 kg (10 lb.) then larger counterweights can be used by adding a Software Bisque 1.5-in counterweight extension shaft to the attachment plate (1/2-20 TPI threads). The attachment plate must be reversed to accept the extension shaft. This shaft accepts 5 kg and 10 kg (10 lb. and 20 lb.) counterweights manufactured by Software Bisque.
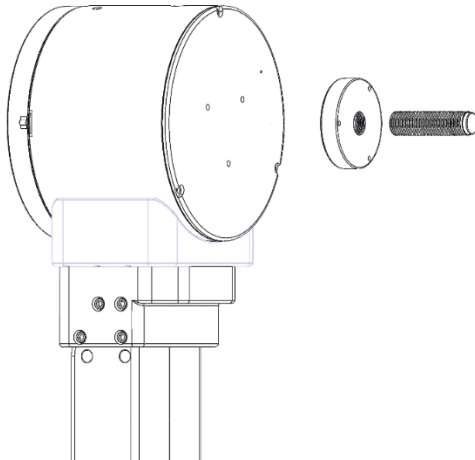
Figure 59: Taurus HA balance system.
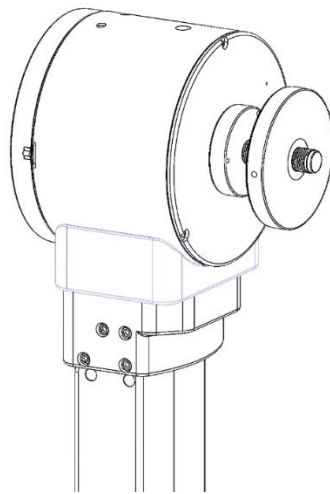
Figure 60: A threaded counterweight install to balance the hour angle axis.
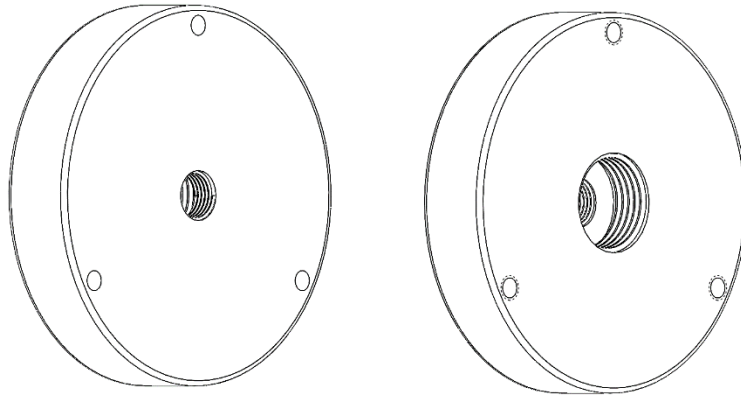
Figure 61: The counterweight plate can be reversed to accept a 1.5-in. counterweight extension shaft.

Software Bisque Instrument Rotator

For three axis gimbals to work in concert, it is important that all axes are precisely coordinated. The Software Bisque direct drive instrument rotator uses a high torque density direct-drive motor with a high-resolution encoder to achieve accurate positioning and fast rotation (as fast as the HA axis).

Though the required precision of the rotator is relaxed compared with the HA and Dec axes, the instrument rotator should have the same upper speed limit as the HA axis, otherwise the mount completes its slew before the rotation is complete.

Note: The instrument rotator is integrated into the Taurus's three axis industrial controller. As such, the rotator is only compatible with the Taurus controller, and is not compatible with other direct drive controllers.

If an instrument rotator is not required, from TheSky, click **Telescope > Telescope Setup**, highlight **Rotator**, select <**No Rotator**> and click **OK**.
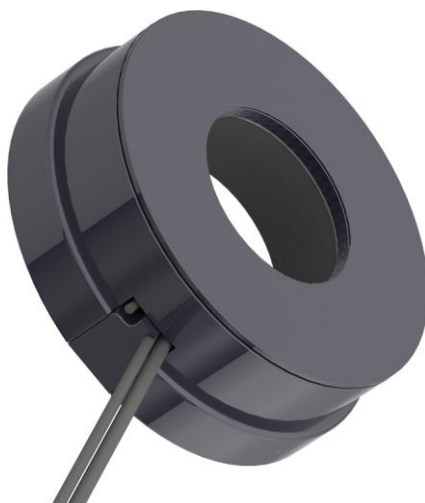
Figure 62: The Software Bisque instrument rotator.

Instrument Rotator Attribute	Specification
Clear aperture	89 mm (3.5 inches)
Physical size	200 mm (8 inch) OD, 70 mm (2.75 inch) thickness
Weight	4.5 kg (10.2 lbs.)
Torque	9 Nm (7 ft-lbs.)
Telescope adapter	Optec-style 4300 dovetail
Camera adapter	3.5-inch 24 TPI
Back focus	2.75-inch
Resolution	26-bit absolute encoder
Power	120V DC power supplied by three-axis industrial controller
Construction	Machined aluminum case
Full travel	540 degrees
Controller	Commanded by Taurus's three-axis industrial controller
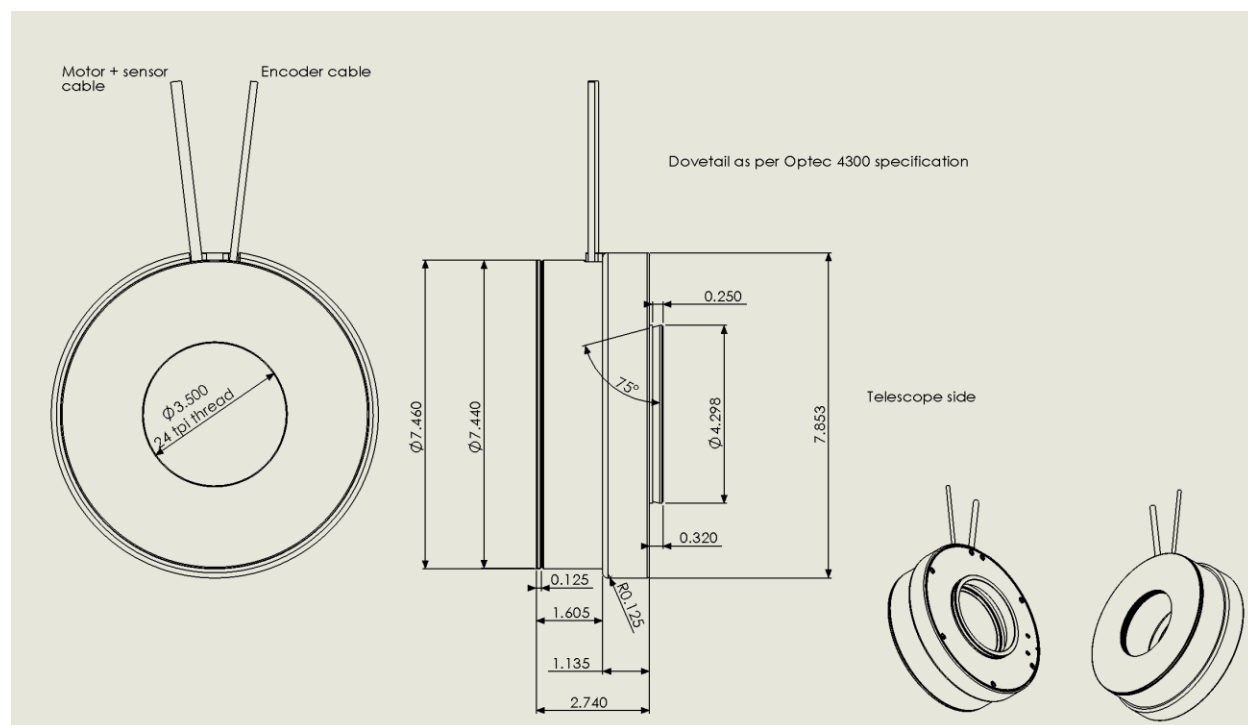
Figure 63: The Software Bisque instrument rotator dimensions.

Powering the Taurus Mount

The Taurus mount requires a 110V-240V AC at 15A maximum power source for normal operation. The total current draw depends on several factors including the acceleration speed, slewing speed, deceleration speed, the total weight of the instrumentation and system balance.

When the speed and accelerations are 10 degrees per second or less, a balanced system of 100 kg (220 lbs.) draws less than 3 amps. Faster slewing and acceleration quickly increase the current draw, as does an out of balance system.

Figure 64: The axis-locking component.

Note: the axis lock cover should be placed in the axis lock pin hole once the telescope is mounted to prohibit insects or debris from entering the drive housing.

Connecting to the Taurus with TheSky

To enable Taurus direct drive operation from TheSky,

1. The AADD branch of TheSky Version 10.5.0 Build 13311 or later must be installed before it can control the Paramount Taurus direct drive mount.
    a. Register your Paramount Software Suite Serial number as described in the Paramount Software Quick Start Guide.
    b. Launch TheSky.
    c. Click **Help > Check for Updates.**
    d. Download and install the latest Daily Build from your Software Bisque account.
2. TheSky also requires that the supplied security key must be plugged into one of the computer's USB ports before TheSky is launched, and *while TheSky is running*.

    Also note that the security key must be plugged in:

    - During TheSky installation.
    - *Before TheSky is launched*. Plugging in the security key after TheSky is launched is not supported, and the security key will not be recognized.

- While running TheSky and operating the Taurus mount. If the security key is removed after launching TheSky, Taurus direct drive operations will be restricted.
- A security key is *not* required when controlling the Taurus with software other than TheSky.

When the correct version of TheSky is run, and the security key is present, TheSky's main caption shows the aadd branch:
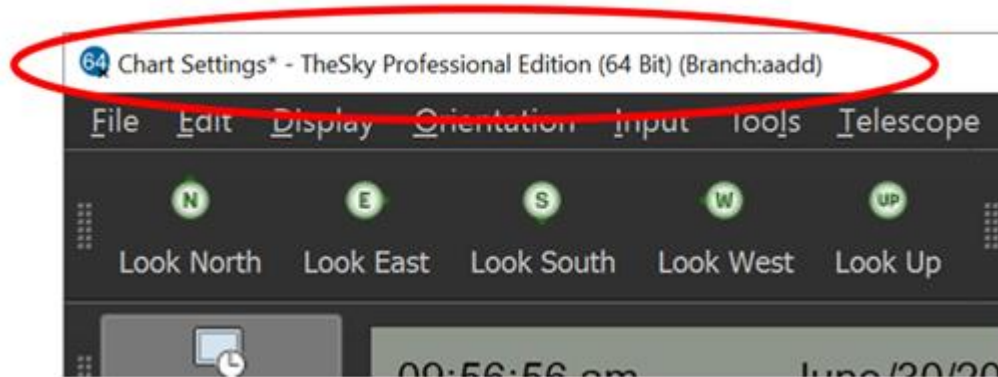
Figure 65: The aadd branch of TheSky is required to operate a Paramount Taurus mount

TheSky communicates with the TCS is done through an Ethernet connection. By default, the controller is configured with an IP address of 10.0.0.100. Please see the MMI Application Studio User Guide for information on resetting the IP address in the controller, or the ACSPL+ Commands and Variables reference guide.

The Ethernet port is located on the Taurus pedestal on the same side as the AC power outlet. There are three Keystone ports present on the base, and the ethernet port utilizes one of them. The other two are available for user requirements.
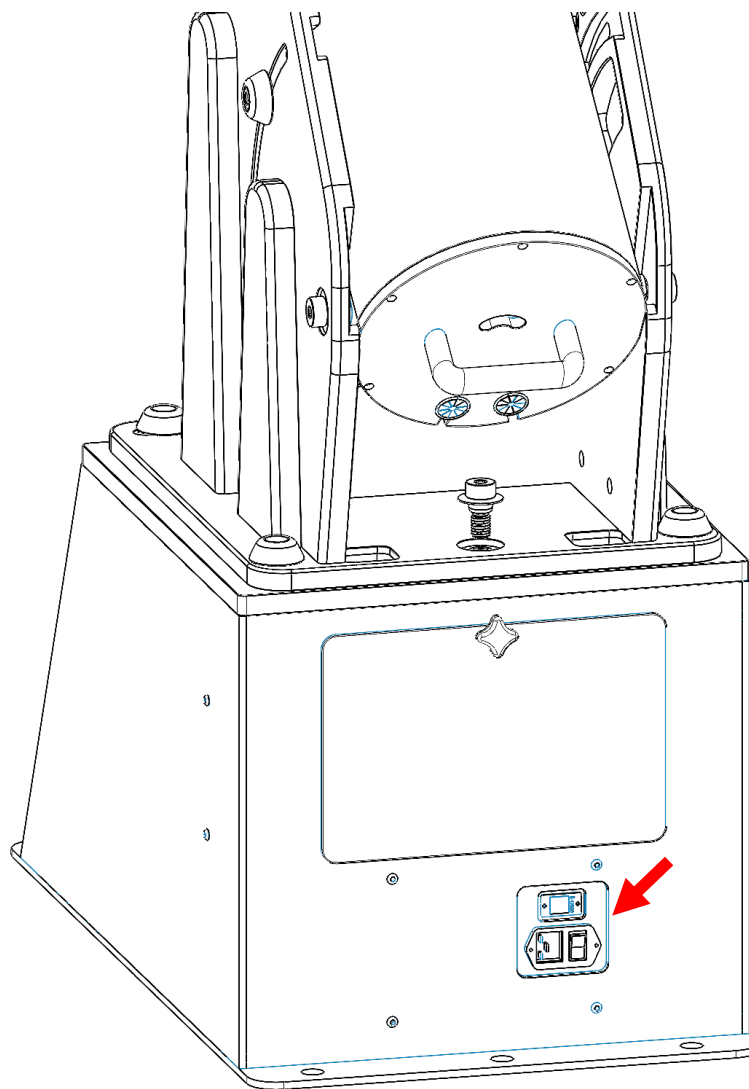
Figure 66: Location of the Ethernet communication port on the pedestal.

The IP address must be set within TheSky software. Click **Telescope > Telescope Setup > Mount Setup > Settings**. The **Find IP Address** button searches for the controller on your network. Locating the IP address searches all networks connected to your computer and will find ACS hardware on those networks with a mask of 255.255.255.0. If you have an ACS on a network with a different subnet mask, you will have to enter the IP address directly.
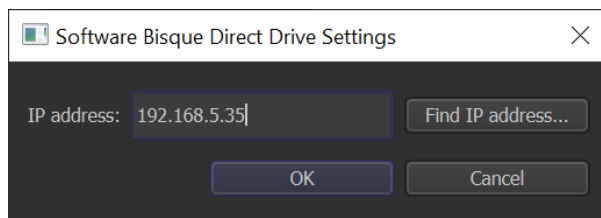
Figure 67: Enter the IP address of the controller.

Page 61

Once the IP address is established, you can connect to the controller by choosing Connect from the Telescope window or the Telescope Setup window. Upon connect, you should see the telescope status change to Tracking Off and if the Sky Chart contains the position of the mount, the telescope bullseye appears.

MMI Studio

The ACS controller is supplied with the MMI Studio application that has many options for setting up and operating the controller. In most circumstances the only requirement for using this software is to set the IP address and to aid in tuning the direct drive motors.
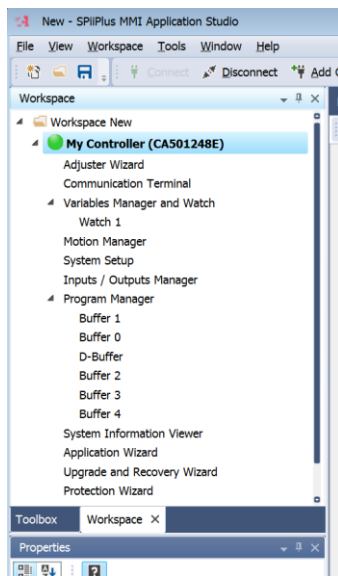
Figure 68: MMI Studio screen capture.

To connect to the controller, right click **My Controller** in the workspace tree and choose **Connect**. The first time you connect, you can also choose **Change Controller** to display a list of IP addresses, including the default address 10.0.0.100.
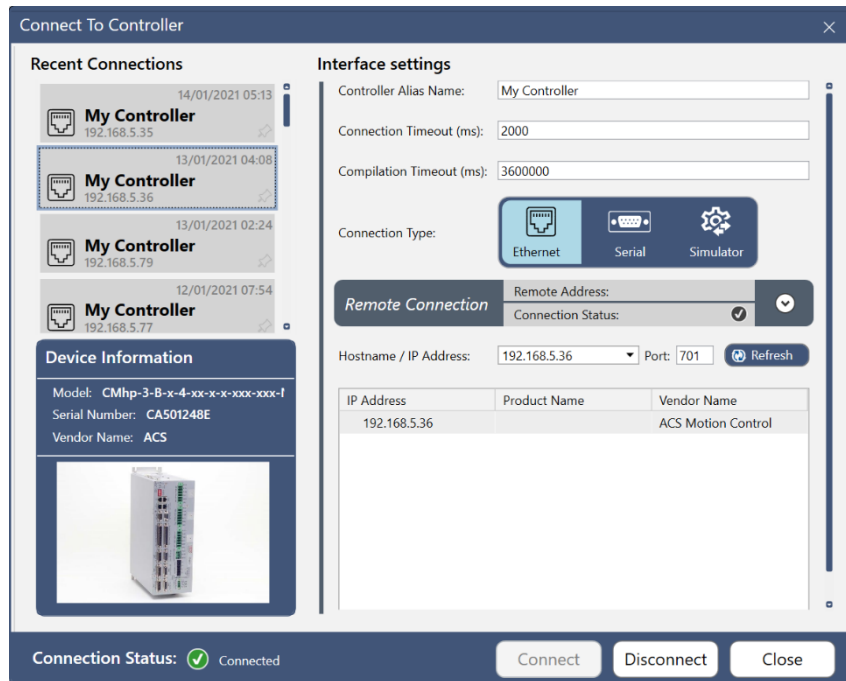
The IP address can be changed by selecting Communication Properties. After changing the IP address, if the controller is rebooted the connection may be lost if the IP address of your computer.

Tuning Direct-Drive Systems

Direct-Drive Tuning Disclaimer

The process of tuning can cause equipment damage or personal injury or death if not performed carefully. Tuning a system iteratively pushes the envelope of stability vs. instability and an unstable system can move quickly and unexpectedly. Although settings for safety have been set, Software Bisque cannot be held responsible for damages caused by tuning a system. Be ultra-careful. Always stand clear of a system being tuned. Always start out with conservative settings and gradually work up to more aggressive settings.
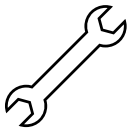
Before You Start Tuning…

Make sure that every component of the system is bolted tight and securely fastened.

When *any component* is loose (for example, the base of the pier, the pier to mount bolts, the polar axis wedge nuts, the telescope, camera, focuser, etc.), it vibrates and makes the tuning process difficult or impossible.

To achieve optimal performance, all direct-drive systems must be tuned. The nature of direct-drive motors necessitates the need for tuning primarily because there is no gearing. Therefore, the direct-drive control system itself must be able to accommodate all the differing aspects of a given system that are unique to that system, including loads, inertia, balance, friction, varying speeds, and eternal disturbances.

In general, a well-tuned astronomical system quickly slews to its specified target and begins tracking with minimal overshoot or undershoot. It should also be said that a well-tuned system is one that meets the requirements, and there can be tradeoffs and payoffs. For example, if sidereal tracking is of the utmost importance, some overshoot/settling in slews may be acceptable especially if tuning out the slew issues negatively affect sidereal tracking.

The following sections offer tips that have been used to successfully tune Taurus mounts with various instrument packages from less than 50 kg up to 300 kg.

System tuning can be performed by TheSky and or the OEM software called SPiiPlus MMI Application Studio that accompanies the direct-drive controller used by the Taurus.

Tuning in SPiiPlus MMI Studio

The Taurus comes with a separate software package (SPiiPlus MMI Application Studio) that has extensive controller functionality, but only a small subset of this functionality is necessary to turn your system. Remember, tuning is specific to the characteristics of your system (its mass, mass distribution, inertia, etc.). Advanced tuning with SPiiPlus MMI Application Studio goes beyond the scope of this document. For additional resources on tuning a direct drive system and additional tuning background, see www.bisque.com/direct-drive-tuning.

The following is an overview on how to use SPiiPlus to tune your Taurus system.

You will find the SPiiPlus tuning functionality by clicking **Adjuster Wizard, Axis Setup and Tuning, Position and Velocity Loops**. Note, all other features of the Adjuster Wizard, like Initialization, Axis Architecture, Components, etc. are factory configured and should not need to be changed. You will only need to perform tuning as described below. Remember, motor tuning is dependent on the characteristics of your payload and cannot be pre-set at the factory.

There are two methods of Position and Velocity Loops tuning, namely Manual and Automatic. Each is described below.

Position and Velocity Loops: Manual Tuning

When connected to the ACS controller using the OEM MMI Application Studio, open the *Adjuster Wizard* from the *Workspace* window, then go to **Axis Setup and Tuning**, **Position and Velocity Loops , Select Tuning Method**, click **Manual**, then click **Next**.
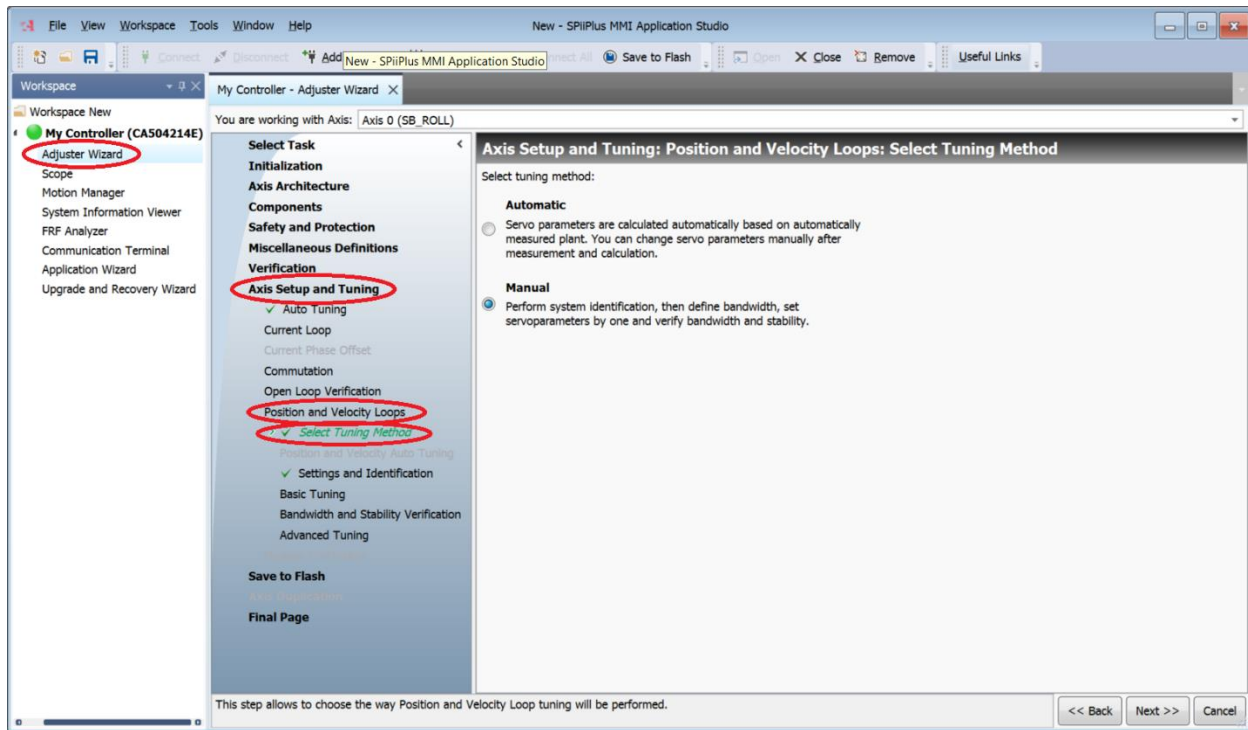
Figure 69: To choose Manual Turning *in Simplus, click* **Adjuster Wizard** > **Axis Setup and Tuning** > **Position and Velocity Loops**, *select* **Tuning Method**.

The first step in SPiiPlus manual tuning is to perform a **System Identification**.

System Identification

A column of setup screens and utilities is listed in the **Adjuster Wizard** window. The first choice is **Axis Setup and Tuning**, followed by **Settings and Identification** . Use this option to have the software suggest values for five of the most typical tuning parameters. Note that the **Adjuster Wizard** works with one axis at a time. The selected axis is displayed near the top of the window next to the **You Are Working With Axis** text.

Before starting the identification process, the motion limits should be set so that that they include the present feedback position. Simply subtracting and adding five degrees from the present feedback position typically works well. For example, if the **Feedback Position** is 236 degrees, the **Start Position** should be set to 231 and the **End Position** to 241 degrees.

The **System Type** should be set according to the load on the system. Typically, **Medium Load/Mildly Stiff System**, or **Heavy Load** work best. The azimuth axis has a reasonable load before adding any instruments, while the altitude may be lighter. Set the **Friction Level** option to **Low**.

Clicking the **Start Identification** button starts a lengthy process. The software imparts a range of frequencies to the controller and measures the response. As the frequencies get into the audible range you may hear them as they increase in somewhat of a melodic fashion.

If the ***Identification*** process fails (the results are shown in the ***System Identification Results*** output screen at the bottom of the window) then consider a different **System Type**. If that does not work, try increasing the ***Excitation Current*** from 2.5 to 5.0, then slowly increase. On systems with heavy payloads, for example 300 kg, you may have to use a value as high as 10-12%. Refer to the ACS documentation for additional help.

After a successful system identification, the next step *is Basic Tuning* on the following page. When asked to confirm resetting the current five base tuning parameters, click ***Yes***. At the top of the ***Basic Tuning*** page, the ***Bandwidth*** input defaults to ***30***. Setting this to ***10*** or so yields tuning parameters that typically work with Taurus mounts. In general, you strive for the highest bandwidth that does not lead to instability.
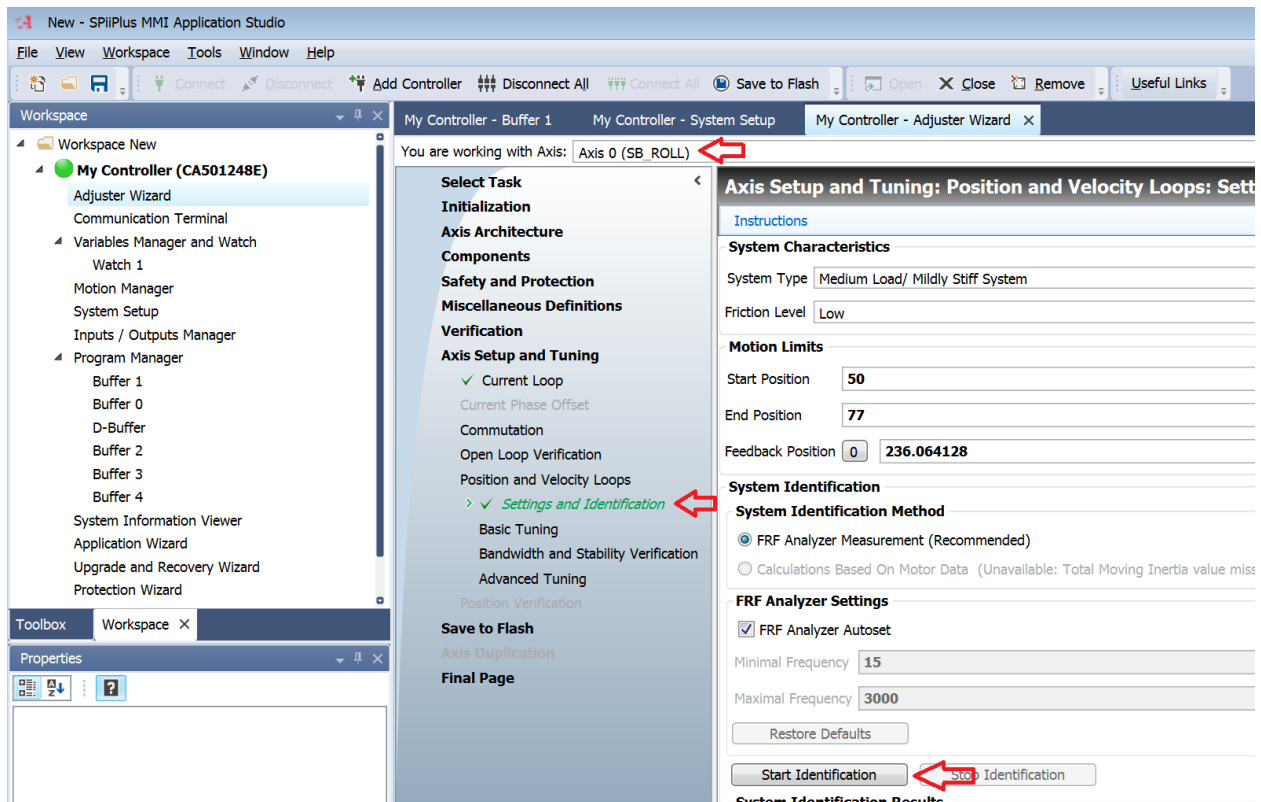
Figure 70: A screen capture showing the Axis 0 (SB_ROLL) Settings and Identification.

Once the system identification is complete, the suggested tuning parameters can be viewed from the ***Basic Tuning*** window. This type of tuning is referred to as ***One Parameter Based Tuning***. Changing the ***Bandwidth*** (Hz) input value from 30 to 10 causes the five gain suggestions to be recomputed linearly, applied to the mount and re-displayed.

These suggested terms are typically good starting points though the final gains values used may be lower. The parameters that make the most difference are the ***Velocity Proportional Gain***, ***Position Proportional Gain,*** and ***Integral Gain***. The relative magnitude of these should remain

linear as adjustments are made. For example, if the velocity proportional gain is reduced by half, so should the position proportional gain and integral gain.

After a successful system identification, click "Enable Motor" to see if the determined (or modified) turning parameters are workable. Note, always be prepared to immediately disable the motor if the system emanates loud noises in which case, you would systematically and interactively decrease the bandwidth or tuning parameter(s) and repeat. Once the motor can be enabled, appears stable and does not emit objectional noises, you will want to validate the motion of system by clicking the **Motion Manager Autoset**. Setup a "back and forth" move, start out with a motion of say 5 degrees at 1 degree a second.

Click **Scope Autoset** to graph the motor's motion and adjust turning parameters. The goal is to have the (red) velocity feedback closely follow the (yellow) reference velocity along with a reasonable (green) position error that doesn't overshoot and dampens nicely.   If you reach this goal, you may move on to turning and fine tuning within TheSky.

Figure 71: SPiiPlus Scope output giving validity to tuning parameters during a Motion Manager back and forth move. Feedback velocity follows reference velocity and a low, steady-state position error. Note the scale of the position error is 0.1 units/division.

Position and Velocity Loops: Auto Tuning

The SPiiPlus application can also be used to automatically tune a system. Under **Axis Setup and Tuning** > **Select Tuning Method** choose **Automatic**. Click the **Start** button to subject the Taurus

to a range of frequencies, record the response and from that derive the corresponding turning parameters.

Autotuning has an additional advantage over manual in that beneficial digital signal filters can be automatically added, for example add a notch filter to attenuate a detected resonance.

You can validate the autotuning determined parameters using the motion manager, see above, before using TheSky for tuning the motors.

Using TheSky for System Tuning

TheSky has several unique tuning features that are tailored for astronomical use, i.e., slewing to targets and tracking them at the sideral rate.

Tuning: Coarse and Fine

Tuning can be broken down into two steps. The first step is to simply get the tuning parameters set so that the Taurus can be successfully *slewed* between various targets. The fine-tuning concentrates on *minimizing tracking error* while tracking at the sidereal rate.

Coarse Tuning the Motors

The first step is to get the tuning parameters set so that the instrument load can be *slewed* between various coordinates without large oscillations, over-currents, critical position errors, etc. This step requires a certain amount of patience because if you set tuning parameter values too high, that is too aggressive, very loud sounds may emanate from the system, or even cause instability and produce a system fault, when negative feedback becomes positive, that will automatically disable motor(s). The controller has built-in safety features that ensure the current load is not excessive and that impossible motion requests are not executed and instead produce a corresponding error.

Fine Tuning the Motors

Once the coarse tuning parameters are set and the system can be slewed to various positions at the desired velocity and acceleration, the fine-tuning process can begin. Fine tuning is just a continuation of the initial tuning steps but focuses on minimizing position error during low, sidereal tracking velocities.

> Systems that use high maximum velocities with high maximum accelerations are more challenging to tune. Initial tuning with lower maximum velocities and accelerations is strongly recommended.

When using the Taurus to track stars and other slow moving celestial bodies, the goal of *fine-tuning* is to get the position error for each axis to settle down to as low as possible, typically to a fraction of an arc second when tracking at the sidereal rate. Note, this level of precision is

Page 69

usually not necessary or even possible when tracking faster moving objects since the requirements are typically not as critical as sideral tracking.

To access TheSky's system tuning options, from the **Telescope** window, click **Tools > Bisque TCS – Direct Drive**.

The **Controller Tuning** options on the **Utilities** tab allow adjusting the five primary tuning parameters. When using TheSky with the Taurus, understanding where the variables are stored, and how they are loaded on future sessions, is important.

When an axis is selected, the five tuning parameters are read from the controller, namely **SLVKP**, **SLVKI**, **SLPKP**, **SFVSOF** and **SLAFF**. The SL prefix is short for s*ervo loop* and these variables are read from and saved to controller similar to all other parameters.
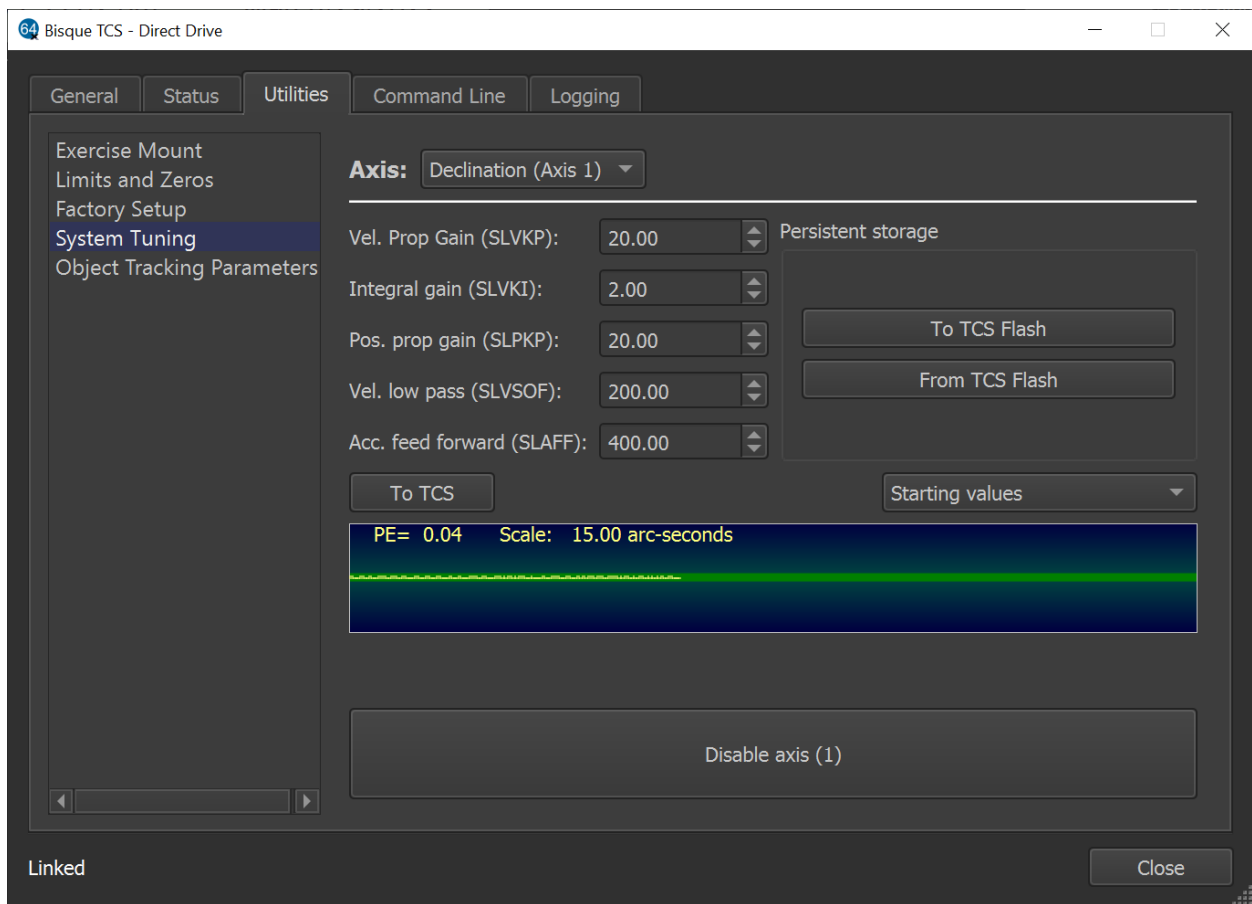

Figure 72: TheSky's Bisque TCS > System Tuning > Utilities tab.

Axis

Tuning is performed one axis at a time. Though the final tuning parameters may be similar, each axis has different loads and tuning requirements. Use this pop-up menu to select the desired axis.

To TCS Button

Click the **To TCS** button to immediately apply the values shown on the **System Tuning** window to the Taurus. Importantly, these parameters are not permanently stored in the flash memory when clicking this button. This is by design to allow easily and iteratively apply different values while watching the position error and the same time without altering the bootup behavior.

To TCS Flash Button

Once the tuning parameters are working satisfactorily or have exhibited better behavior than the parameters that were in place before the adjustment, click the **To TCS Flash** button to commit the change and permanently save them to the controller's flash memory. These values will be restored each time the TCS is powered on.

From TCS Flash Button

If you have modified a parameter(s), and it has not produced improvement and you haven't yet clicked **To TCS Flash**, you may click the **From To Flash** button to restore the tuning parameters to the values before modification. After this operation is performed, to have the parameters applied, press **To TCS Flash**.

This button displays the *last committed servo parameters saved to TCS flash*.

Position Error Graph

This graphic displays the position error of the system on an extremely small scale to show how the servo loop is performing while tracking at the sidereal rate. The height of green band is plus or minus one arc-second. On a well-tuned system, steady state errors will be less than approximately 0.2 arc seconds. When a system is not tuned for the slow velocities needed for sidereal tracking, noise or oscillations become apparent in the graph and further tuning will be required and aided by this information. Scroll the mouse wheel over the graph to change the scale.

Disable Axis

When tuning values are selected that cause loud noises or oscillations that are diverging in the wrong direction, otherwise known as instability, click the **Disable Axis** button to disable the motor in the currently selected axis.

General Tuning Procedure Summary Using TheSky

A general tuning procedure is to iteratively slew to a nearby star, watch the behavior of the on-screen telescope crosshair, and gradually increases the primary tuning parameters, higher and higher until short of instability, until the slew has little or no overshoot, and the axis feels rigid to the touch.

Instability occurs when you set a parameter too high and as soon as you press "To TCS" the system makes a loud vibration noise and or the control system "gives up" and motors are automatically disabled.

1. When starting out and learning to tune, lower the maximum slew rates. (**General** tab, choose the slow rate preset).

2. Set **Axis** to **Declination**. (Start with the altitude axis as it is less dependent than the azimuth axis as the azimuth axis has some dependency on the altitude axis.)

3. Click Starting Values and choose an appropriate selection to match your system, primarily based on weight of payload.

4. Orient the star chart so that small altitude motion is obvious (mentally ignore azimuth motion since that axis is not yet being tuned).

5. Slew to a nearby star.

6. If there is overshoot or oscillation, slightly increase **SLVKP** and **SLPKP**, click **To TCS**.

7. Repeat the above steps until instability and back off slightly as necessary.

8. Finally, and perhaps occasionally, increase Integral gain parameter **SLVKI** to increase the rigidity to the touch.

When you are satisfied tuning an axis, click the **To TCS Flash** button so that the tuning parameters are persistent.

Repeat the above steps for the declination axis.

Bisque TCS/DD Window

The Bisque TCS/DD window provides access to information about the mount, controller and other settings related to the function of the Taurus mount. From the **Telescope** window, click **Tools**, **Bisque TCS/DD**.

Overview

The bottom left of the dialog shows the status of the connection and/or motor state. During normal operation, the status shows Linked. If one or more of the motors is disabled, the status indicates the motor state.

Note: When not connected to the controller, many options are disabled. Upon connection, these options are ungrayed.
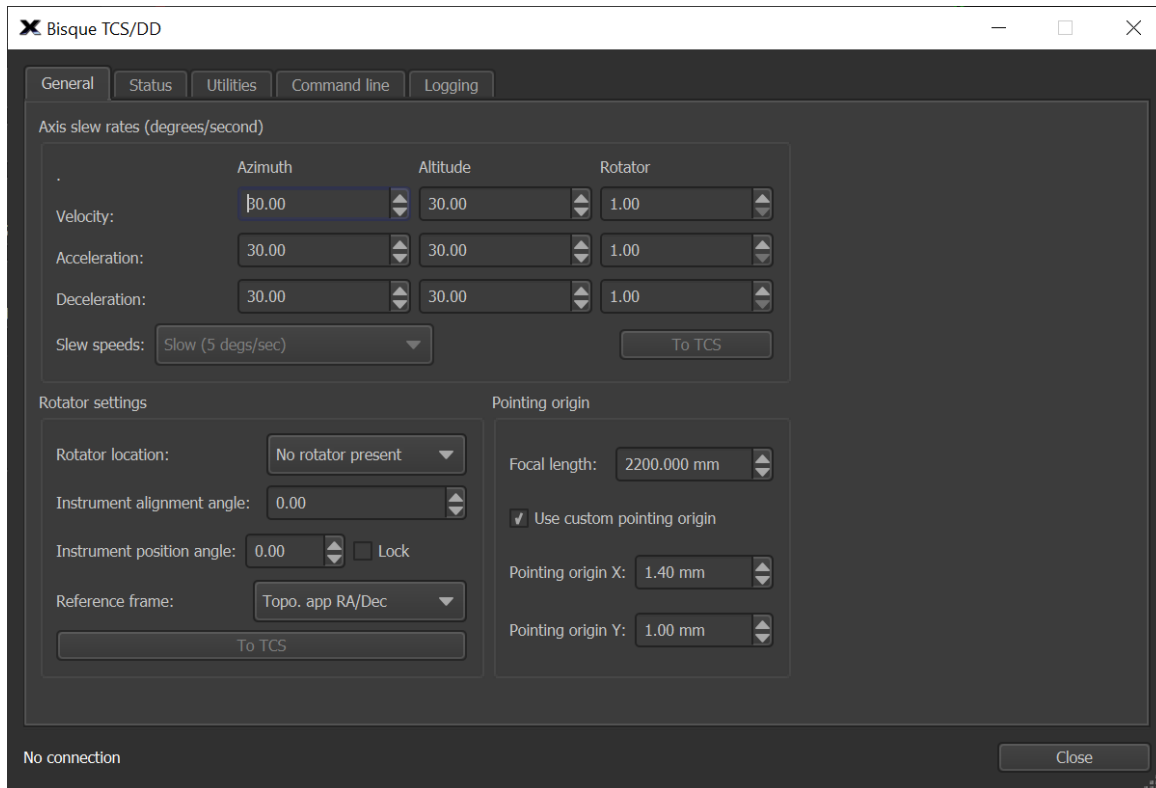
Figure 73: The Bisque TCS/DD General tab.

General Tab

Slew Rates

The velocity, acceleration and deceleration can be set separately for each axis. The units are in degrees per second. The maximum achievable velocity is dependent on several factors including the comfort level of the user and the mass of the system. During the initialization of the system slower slew speeds (less than 10 degrees per second) are recommended. Once a

system is balanced and tuned the user can experiment with increasing the speeds and accelerations.

Use the **Slew Speeds** pop- to set the speeds for all three axes. When the **Slew Axis Rates** have been entered as desired, click the **To TCS** button to send the rates into the controller.
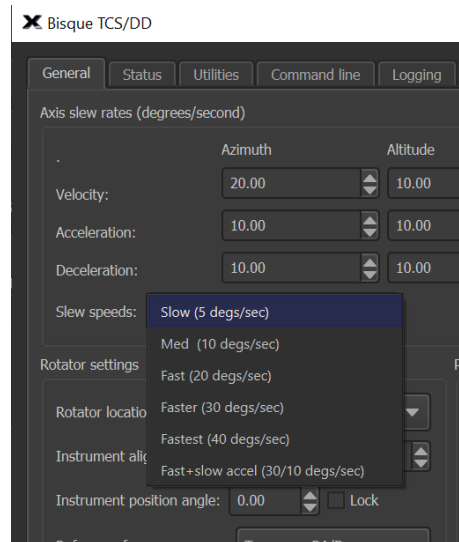

Figure 74: The Rates pop-up menu.

Instrument Rotator Settings

If used, several settings are required to insure the correct operation of the instrument rotator.

Instrument Rotator Location

There are six options for the location of the instrument rotator, depending upon which part of the mount the rotator is located.

- OTA: the instrument mount is fixed to the telescope tube. This option embraces Cassegrainian, Gregorian, prime focus, Newtonian, Cassegrain-Newtonian, Gregory Newtonian and so on. (OTA stands for "Optical Telescope Assembly." The term is used here in a completely generic sense: it could equally well be the dish of a radio telescope.)
- Nasmyth: the instrument mount moves with roll but not pitch.
- coud´e: the instrument mount is fixed to the ground.
- generalized: rather than nominating a physical location for the instrument mount, the respective influences of roll and pitch on the field orientation are specified explicitly.

Instrument Alignment Angle

IAA is the Instrument Alignment Angle, the orientation of the instrument on the rotator. It is measured as part of calibrating the instrument on the telescope and will remain constant until the instrument is removed.

Instrument Position Angle

IPA is the user-specified Instrument Position-Angle. It can be with respect to any of the supported sky coordinate systems—J2000.0 [α, δ], topocentric [Az, El] etc. As a rule, it will remain constant during one observation.

Reference Frame

The reference frame specifies how the rotator will behave as the mount is slewing or tracking across the sky. The altitude/azimuth reference frame maintains the rotation relative to the azimuth coordinate, while the equatorial options will maintain relative to hour angle.

The *To TCS* button sends the rotator settings to the virtual telescope.

Pointing Origin

The pointing origin feature permits adjusting the pointing center, as in the case of an off-axis instrument, without changing the current target. The units are in millimeters. The amount of offset is computed based on the entered focal length of the system. For example, if the pointing origin X is set to 5 mm, when the *Use Custom Pointing Origin* checkbox is turned on, the center of the pointing will move 5 mm on the focal plane.

Status Tab

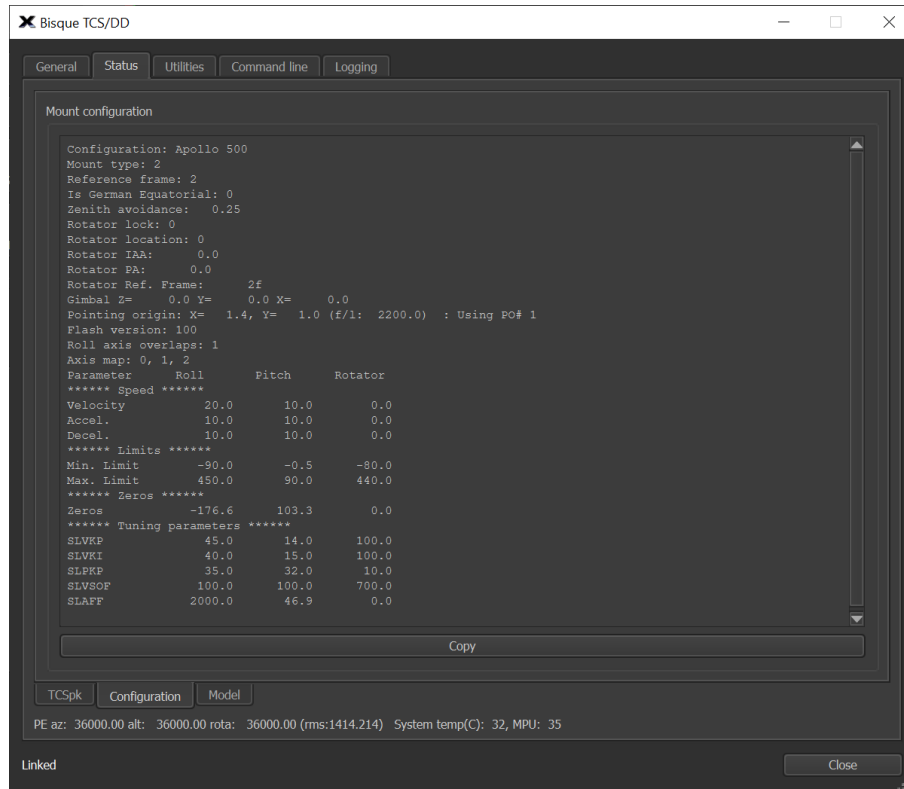The Status tab shows the control system's configuration settings.

Figure 75: The Bisque TCS/DD Status tab.

Utilities Tab

While this tab has multiple optional functions, the **Controller Tuning** tab is required for mount setup and initialization.

Exercise Mount

This page allows moving a single axis of the mount to absolute coordinates or in relative "jogs." Several inputs are provided making it easy to slew to different targets for testing purposes. The units are in degrees, and the current coordinate of the selected axis is displayed near the top of the window. Clicking the **Abort Motion** button immediately stops the motor rotation.

Sidereal tracking must be turned off before exercising the motors. To do so, from the **Telescope** window, click **Tools, Turn Tracking Off**. Note that when sidereal tracking is turned off, it is turned back on when the mount is slewed to a target.
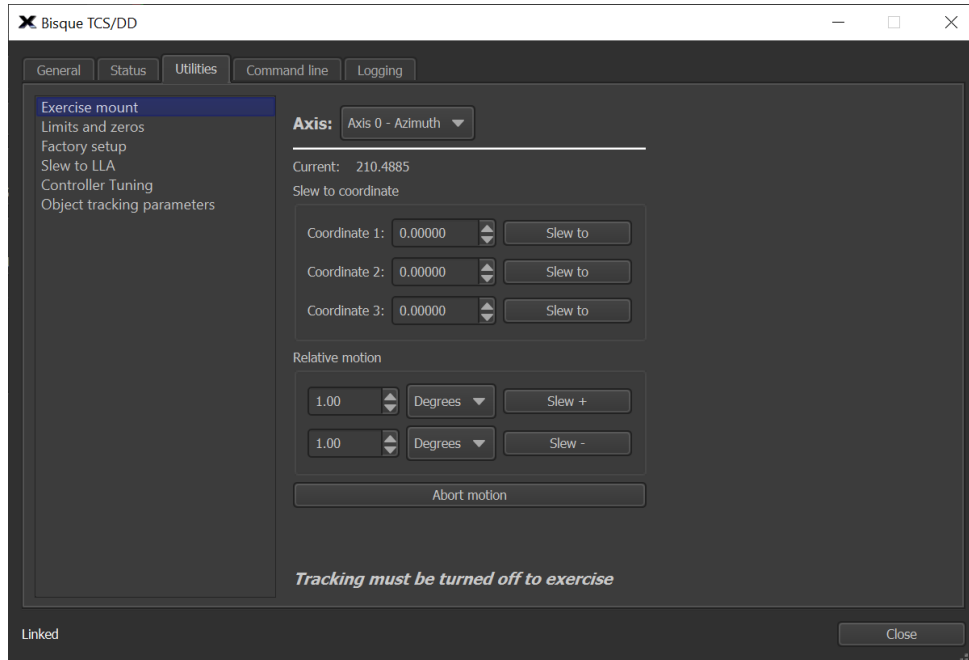
Figure 76: The Exercise Mount option on the Utilities tab.

Limits and Zeros

Use these options with caution, as entering incorrect values can render the system inoperative. The factory settings should work for most circumstances. Because the azimuth axis has 90 degrees of overlap in each direction, it is sometimes helpful to reset the azimuth zero when the mount physically cannot be mounted in the expected orientation. For example, if the mounting plate in the observatory is rotated 90 degrees, reset the zero point to account for this offset.

Factory Setup

These options are available for setting the low-level kernel settings and are rarely changed. The *Zenith Avoidance* input and the reference frame choice are the exceptions.

Slew to LLA

This utility page allows entering a Latitude-Longitude-Altitude coordinate and pointing the telescope to the target.

Controller Tuning

Please refer to "Tuning Direct-Drive Systems" on page 64 for details on using TheSky to help tune the TCS.

Object Tracking Parameters

These options allow changing the PID loop that is used for sidereal tracking rates, with separate inputs for satellite rates. The default values should work in most circumstances.

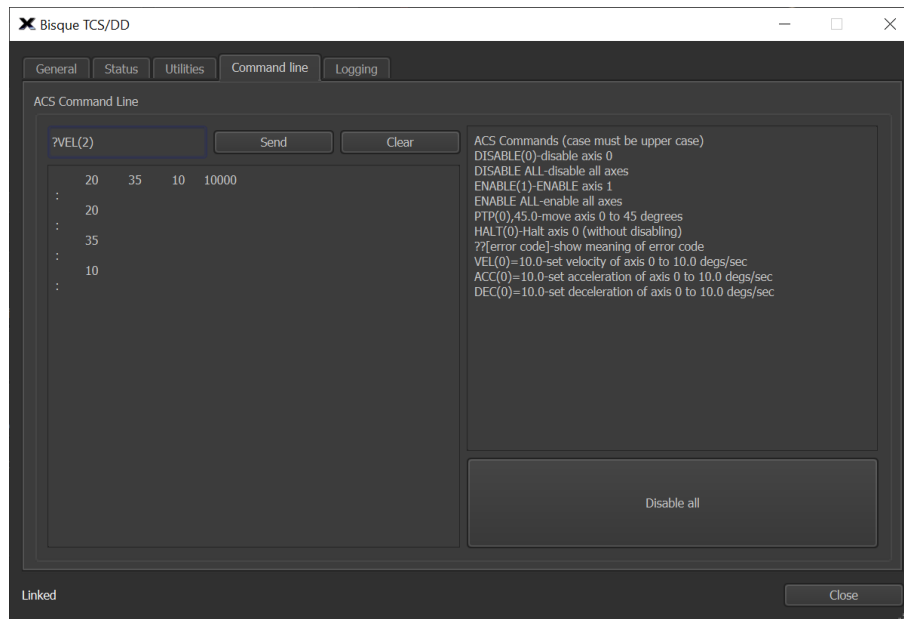Page 77

TheSky's Command Line Tab

Figure 77: TheSky allows command-line control of the Taurus's position.

When used for astronomical purposes, it is uncommon to send commands directly to the mount control system. However, there are times when having direct access can be helpful, or even necessary. The **Command Line** tab allows text-based commands to be entered and sent directly to the controller. This can happen even when pointing kernel running in TheSky has control of motion. Of course, typing in commands that conflict with the tracking functions will yield unpredictable results and should be avoided. (With power comes responsibility.)

Several of the more commonly used ACS commands are listed on the right side of the window. ***All commands must be typed in upper case.*** When reading a variable, the ? is used in front of the variable name. For example, `?VEL(0)` returns the current velocity setting for axis 0.

The **Disable All** button is available in case it is desired to turn off all axes quickly. When clicked, it issues the `DISABLE ALL` command to the controller and all axes will be disabled.

Logging

The **Logging** tab is available for troubleshooting and displaying messages (which are sometimes errors) sent by the TCS. The default output shows errors only, but several other choices are available depending on the type of output desired.

Taurus Mount Control System

Taurus direct-drive mounts employ the state-of-the-art industrial three-axis motion controller manufactured by ACS Motion Control (ACS). The ACS motion controller is one of the most versatile and high-performance controllers available on the market today. With all three axes contained in a single box, the requirement for separate power and communications to each axis node is eliminated.

Important note: With any gimbal system, precise pointing throughout the sky can only be achieved by calibrating the mount under the night sky and applying a mount model. The mount model corrects for zero offsets, non-perpendicularities, flexures, harmonics, atmospheric refraction, and other systematic errors. The included TheSky astronomy, with integrated TPoint modeling, along with tools for automatic calibration, can be used to perform these tasks.

Direct Taurus Control

While TheSky astronomy software performs the necessary communications and control of the mount for most astronomy-based purposes (including initialization, creating mount models, slewing, and tracking etc.), you may wish to bypass TheSky and communicate directly with the mount using the protocol of the controller.

The ACS controller contains a complete set of commands and settings for direct control which are well documented in the various ACS documents.

Coordinate Convention

The coordinates for the Taurus mounts were chosen to follow the commonly used astronomical HA/Declination convention. The units are degrees, on the HA axis, the meridian is 0 degrees, and the sign convention is -HA (i.e., opposite of hour angle). On the declination axis, 0 degrees declination is zero, and increases moving towards the pole.

Axis	Minimum Limit	Maximum Limit
Hour Angle	-150	150
Declination	-80	150
Rotator	-45.0	360.0

MMI Studio

To support their line of controllers, ACS Motion Control offers a comprehensive tool for programming, tuning, and exercising the controller and associated drives. The software package (Windows only) is available at acsmotioncontrol.com (search for SPiiPlus MMI) for download. The current version is 3.10 as of mid-2021, though future versions should be backward compatible.

We refer you to the extensive documentation and users guides that are available supporting the controller. In particular, the ACSPL+ Commands and Variables Reference guide and the SPiiPlus Low Level Host Communication Guide.

After installing the MMI Studio Software, the documentation can be found here:

```
C:\Program Files (x86)\ACS Motion Control\SPiiPlus ADK Suite
v3.02\Documentation\Software Guides
```

Name	Date modified	Type	Size
ACSPL+ Commands & Variables Reference Guide.pdf	10/1/2020 11:06 AM	Microsoft Edge PDF Document	5,622 KB
ACSPL+ Programmer's Guide.pdf	10/1/2020 10:59 AM	Microsoft Edge PDF Document	7,152 KB
EtherCAT DS402 Drives User Guide.pdf	10/1/2020 10:59 AM	Microsoft Edge PDF Document	1,665 KB
GSP Reference Guide.pdf	10/1/2020 11:06 AM	Microsoft Edge PDF Document	2,367 KB
SPiiPlus .NET Library Programmer's Guide.pdf	10/1/2020 11:12 AM	Microsoft Edge PDF Document	2,080 KB
SPiiPlus ADK Suite 3.02 Release Notes.pdf	10/1/2020 10:56 AM	Microsoft Edge PDF Document	2,342 KB
SPiiPlus C Library Reference Programmer's Guide.pdf	10/1/2020 11:01 AM	Microsoft Edge PDF Document	3,027 KB
SPiiPlus COM Library Programmer's Guide.pdf	10/1/2020 11:02 AM	Microsoft Edge PDF Document	2,473 KB
SPiiPlus EthernetIP User Guide.pdf	10/1/2020 11:06 AM	Microsoft Edge PDF Document	1,167 KB
SPiiPlus Low Level Host Communication User Guide.pdf	10/1/2020 11:06 AM	Microsoft Edge PDF Document	935 KB
SPiiPlus MATLAB Library Programmer's Guide.pdf	10/1/2020 11:07 AM	Microsoft Edge PDF Document	2,180 KB
SPiiPlus MMI Application Studio User Guide.pdf	10/1/2020 11:10 AM	Microsoft Edge PDF Document	12,549 KB
SPiiPlus Modbus Setup Guide.pdf	10/1/2020 11:11 AM	Microsoft Edge PDF Document	1,070 KB
SPiiPlus Setup Guide.pdf	10/1/2020 11:13 AM	Microsoft Edge PDF Document	11,771 KB
SPiiPlus Utilities User Guide.pdf	10/1/2020 11:14 AM	Microsoft Edge PDF Document	1,261 KB

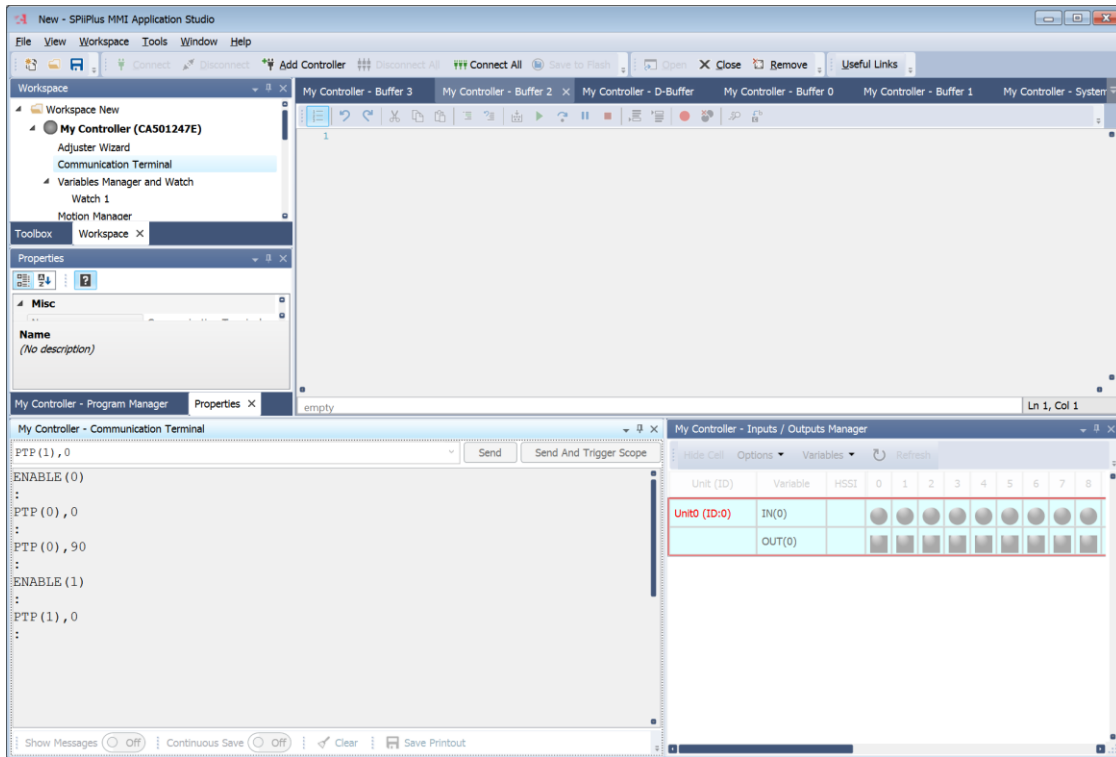*Figure 78: Control system PDF documentation.*

Figure 79: Screen capture of the MMI Studio software.

Overview of ACS Commands

The following table lists commonly used motion commands for directing the Taurus mount. Note that when typing in commands in the MMI studio application or from TheSky's **Command Line** window, all commands are upper case.

The axes are numbered 0, 1, 2 where the roll axis (azimuth or HA) is axis 0, the pitch axis (altitude or declination) is axis 1, and the rotator is axis 2.

Table showing the common ACS motion commands.

Command	Description
ENABLE(0)	Enable the motor for the altitude axis.
ENABLE ALL	Enable all motors
DISABLE(0)	Disable axis 0
DISABLE ALL	Disable all motors
JOG/V (0),5.4458	Start motion for axis 0 at 5.4458 degrees per second using the current acceleration and deceleration values.
VEL(0)=10.0	For motion commands like point-to-point, use this as the maximum velocity
ACC(0)=10.0	For motion commands like point-to-point, use this as the maximum acceleration
DEC(0)=10.0	For motion commands like point-to-point, use this as the maximum deceleration
TRACK(0)	Turn on track mode for axis 0, followed by TPOS points
TPOS(0)=90.0	Set a destination position for the TRACK command. These can be updated during the motion.

Operating Temperatures

The operating range for the Taurus TCS is 0–40° C. The TCS generates sufficient heat so that the mount can still operate below the control system's minimum temperature specification. If the TCS is not heated by the built-in heater, the mount's minimum operating temperature is near –10° C, provided the unit is turned on for about 30 minutes or more before use so that it warms up.

Control System Heater

The Taurus' built-in heater regulates the minimum temperature of the TCS. The thermostat turns the heater on when the ambient temperature is 5° C or lower, and turns it off when the temperature is above 10° C.

If the ambient temperature is too cold, the TCS will issue a temperature fault and not operate. In this case, make sure the built-in heater is connected (see "Connecting Cables" on page 37) and operating so that the TCS can warm up before use.

The temperature of the TCS CPU and the MPU are displayed near the bottom of the **Status** tab in the **Bisque TCS/DD** window. *Note: There is a known issue with the most recently tested TCS firmware versions. When the temperature falls below 0° C, the TCS incorrectly reports temperature values that decrease from 255.*

Cooling Fans

The two cooling fans located on the sides of the Taurus pedestal provide airflow to cool the TCS if necessary. From the factory, only one of these fans is connected, as a one fan normally provides sufficient airflow to keep the TCS below the maximum operating temperature. If the mount is operated when the ambient temperature is above about 30° C, the second fan can be connected to the cable distribution PCB to increase air flow when necessary.

Appendix A: Taurus Internal Cabling Details

The following graphics and table enumerate the cables and connections that are found inside the Taurus mount, including the cables that depart from the drive components, such as the encoder and motor cables.

This information is provided primarily for reference and troubleshooting purposes, or any portion of the electronic cabling needs to be dissembled for any reason. The table is cross referenced to the graphics below showing the connections on the Distribution board and the ACS controller.
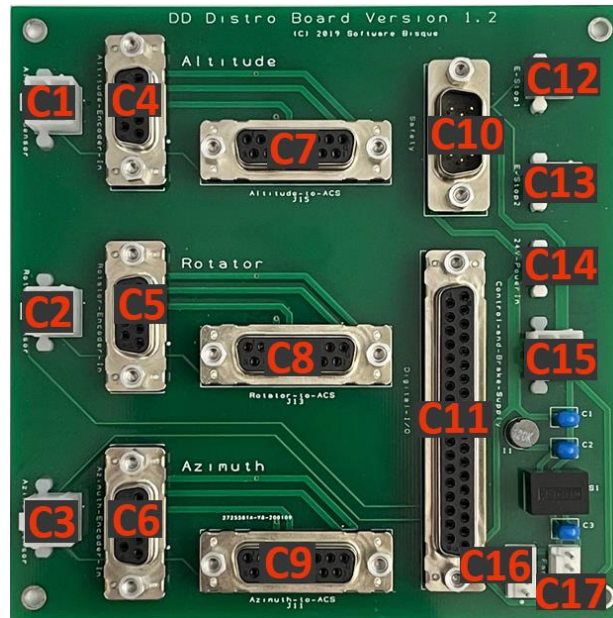

Figure 80: Taurus direct drive distribution printed circuit board (PCB).

Note: Some of the connectors on the above PCB are optional. For example, connectors labeled C12 and C13 can be used to add one or two emergency stop buttons on the outside of the mount. Likewise, a given system may use one or both of the cooling fans (C16, C17).
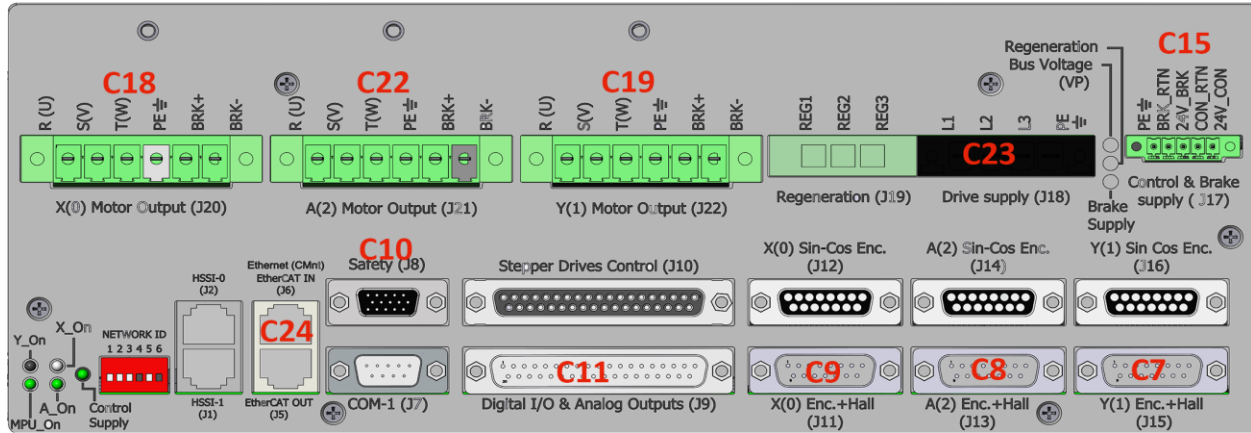
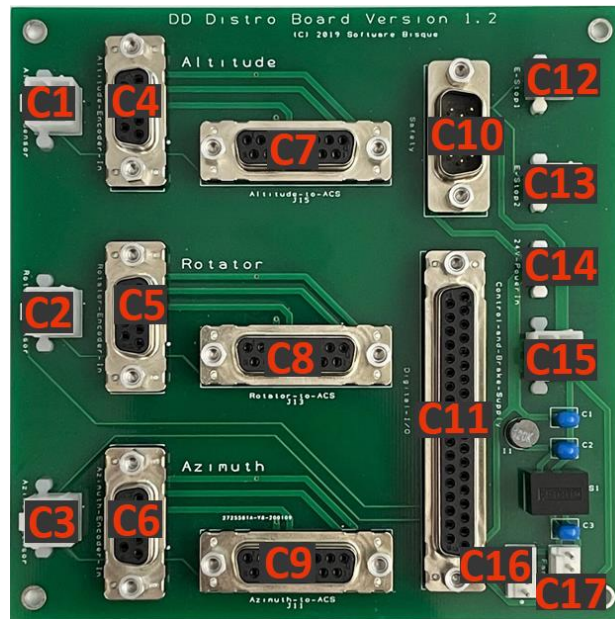*Figure 81: Control system cable connection points.*

Figure 82: The direct-drive cable distribution PCB.

Table of Internal Cables and Connectors

| Cable	Description	Connector	From	Connects to
C2	Sensor portion of harness	4-conductor Molex+(3x motor)	Distro PCB + (ACS J21)	Rotator panel
C3	Az/HA sensor	4-conductor Molex	Distro PCB	Az/HA drive
C4	Alt/Dec encoder	9-conductor DB-9	Distro PCB	Alt/Dec encoder
C5	Rotator encoder extension	9-conductor DB-9 MF, 10 feet	Distro PCB	Rotator panel
C6	Az/HA encoder	9-conductor DB-9	Distro PCB	Az/HA encoder
C7	Alt/Dec encoder	15-conductor MF DB-15 2-row	Distro PCB	ACS J15
C8	Rotator encoder	15-conductor MF DB-15 2-row	Distro PCB	ACS J13
C9	Az/HA encoder	15-conductor MF DB-15 2-row	Distro PCB	ACS J11
C10	Safety	15-conductor MF DB-15 3-row	Distro PCB	ACS J8
C11	Digital IO	37-conductor MF	Distro PCB	ACS J9
C12	E-stop 1	2-conductor Molex	Distro PCB	Optional switch
C13	E-stop 2	2-conductor Molex	Distro PCB	Optional switch
C14	24V power-in	2-conductor Molex	Distro PCB	24V power supply
C15	Control and brake supply	4-conductor Molex	Distro PCB	ACS J17
C16	Fan1	3-conductor header	Distro PCB	Fan 1 cable
C17	Fan2 (optional)	3-conductor header	Distro PCB	Fan 2 cable
C18	Az/HA motor + (brake)	6-conductor Phoenix	Az/HA drive	ACS J20
C19	Alt/Dec motor + (brake)	6-conductor Phoenix	Alt/Dec drive	ACS J22
C20	Rotator encoder	9-conductor DB-9	Rotator	Rotator panel
C21	Rotator motor/sensor	Turck female 7-conductor	Rotator	Rotator panel
C22	Motor portion of rotator harness	6-conductor Phoenix	Rotator panel	ACS J21
C23	Drive supply	4-conductor	Terminal block	ACS J18
C24	Ethernet in	Ethernet	External panel	ACS J6
C25	Alt/Dec brake	2-conductor combined with C19	Brake on Alt/Dec axis	ACS J22 (with motor leads)
C26	Enclosure heater power (AC)	2-conductor 18-gauge	Stego 50W heater	Terminal block
C27	Azim/HA brake	2-conductor combined with C18	Brake on Azim/HA axis	ACS J20 (with motor leads)
C28	AC in to 24V supply	3-conductor	Terminal block	24V power supply

Electronics Schematic
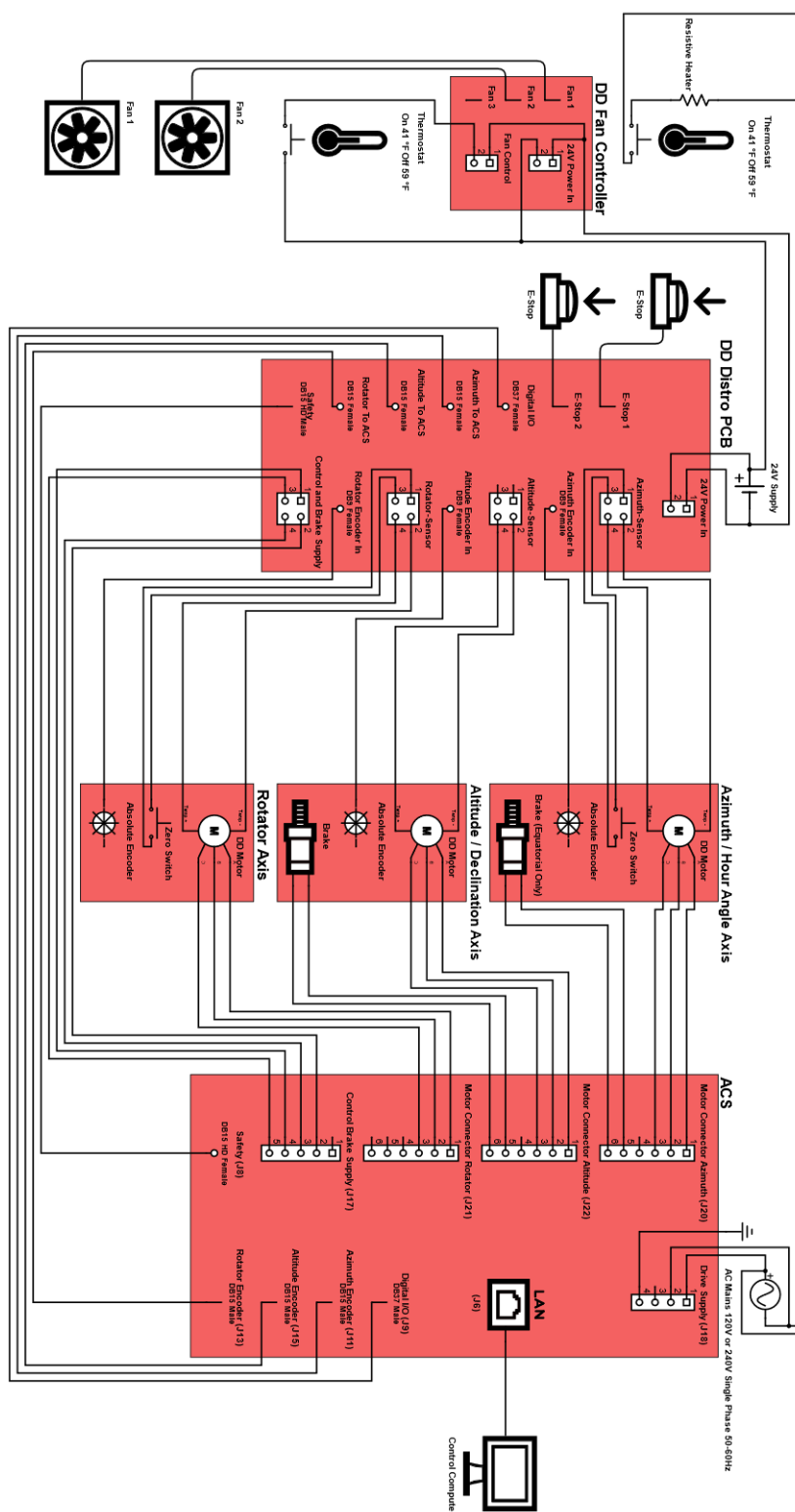
Figure 83: Taurus electronics schematic.

Appendix B: Taurus OTA Mounting System

Refer to the *Scope Rail System User Guide* for details about attaching common commercial optical telescope assemblies to the Paramount Taurus equatorial fork mount.
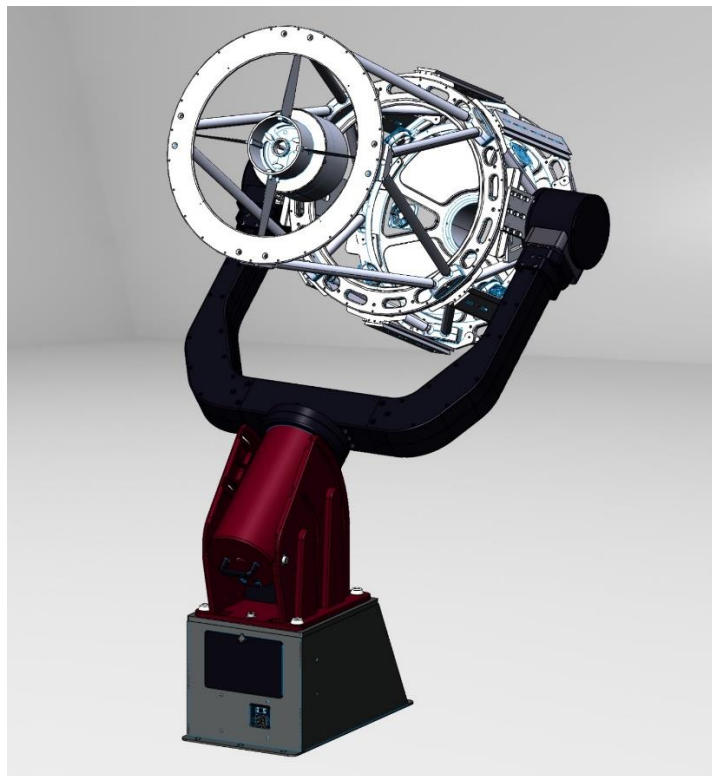

Figure 84: OTA mounting system carrying a 0.6 m OTA.

Appendix C: Revision History

The table below describes the changes in each revision of this user guide.

Revision Number	Changes
1.9	• Minor grammatical corrections and revisions.
1.8	• Added missing figure descriptions. • Minor corrections and revisions.
1.7	• Updated mount tuning procedures. • Added network setup instructions. • Describe the control system status LEDs for a normal power up.
1.6	• Clarified TheSky's minimum system requirements to operate the Taurus direct drive.
1.5	• Clarified USB security key requirements. • Added missing photos to packing list items.
1.4	• Updated graphics. • The scope rail documentation has moved to the *Scope Rail System User Guide*. • Updated the documentation to better help the assembly and setup processes. • Minor miscellaneous corrections.
1.3	• Clarified fastener dimensions.
1.2	• Corrected typographical errors related to the TCS operating temperatures.
1.1	• Initial public release.