Hectospec Hardware Reference Manual

Draft of September 16, 2003

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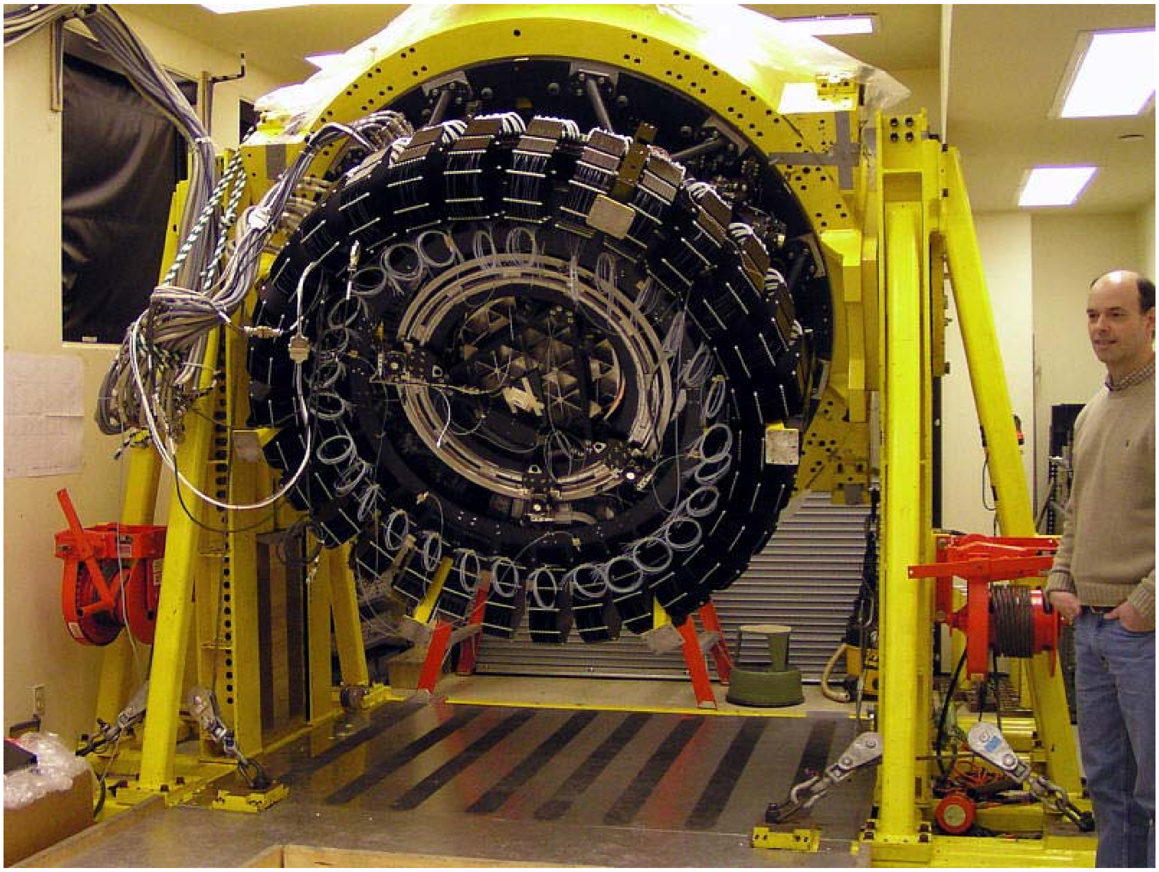


Figure 1. Hectospec on the test stand with covers removed.

1 INTRODUCTION

The Hectospec is a multiobject, moderate-dispersion spectrograph that uses a pair of six-axis robots to position 300 optical fiber probes at the f/5 focus of the converted MMT. The converted MMT's f/5 focus uses a refractive corrector designed by Harland Epps to provide a 1° diameter field optimized for fiber-fed spectroscopy. The Hectospec consists of three major parts: (1) the fiber positioning unit that is mounted on the telescope, (2) a large stationary spectrograph mounted on a 1.8x3.7 m Invar-surfaced optical bench and (3) a 26 m-long bundle of optical fibers connecting the fiber positioner and spectrograph.

The main specification for the fiber robots is to position 300 fibers in 300 s to an accuracy of 25 μm. This level of performance has been achieved in the laboratory; the major error source is the interaction of the fiber button gripper and the fiber buttons, as well as the button magnets and the focal surface. The robots are calibrated to an accuracy of ~8 μm and and the positioning servo loops close to 5 μm or better in each axis.

The purpose of this document is to serve as a reference for the maintenance of the Hectospec system; a separate document will serve the needs of the observer at the telescope.

The Hectospec owes its existence to a number of dedicated scientists and engineers. Ed Hertz served as project engineer and chief mechanical engineer for the Hectospec fiber positioner from its conception until the summer of 2000. Bob Fata served as project engineer for the Hectospec Bench Spectrograph from early in the project, and took over as project engineer for the positioner in 2000, upon Ed's departure. John Roll has served as chief software engineer of Hectospec, and has played a huge role in its development and testing. Dave Becker worked out some of the key software concepts early in the project while he was a Harvard undergraduate. Andy Szentgyorgyi and Brian McLeod have provided scientific guidance in many areas. Nelson Caldwell and Warren Brown led the alignment of the Hectospec Bench Spectrograph. Tom Gauron served as chief electrical engineer, and was assisted by Everett Johnston and Dave Weaver. Mark Ordway, Mark Mueller, Henry Bergner, Jack Barberis, Mike Honsa, Roger Eng, Dave Caldwell, Bill Davis, Dale Noll, and Art Gentile have contributed their mechanical design expertise in key areas. John Geary and Steve Amato designed and tested the CCD readout electronics. Florine Collette wired the fiber positioner and the bench spectrograph. Peter Cheimets performed simulations of the servo control system that gave us confidence that we could meet our speed and positioning accuracy goals. We hail three generations of robot mechanics: Dave Bosworth, Corey Sassaman, and Mark Mueller. Charlie Hughes, Kevin Bennett, and the staff of the Harvard Model Shop have provided superb fabrication and assembly support. Joe Zajac led the manufacturing and testing of the optical fiber run, a monumental effort. We thank Margaret Geller for supporting this instrument from the beginning.

2 HECTOSPEC/HECTOCHELLE FIBER POSITIONER

2.1 INTRODUCTION

The fiber positioner can be separated into two parts to allow servicing of the robots and the optical fibers. The upper unit contains the two six axis robots and most of the electronics. The lower unit contains the fiber probes, the fiber shelves (to prevent tangling of the fibers), the three guider probes and their track, the intensified camera for the guider probes, and the fiber derotator assembly that allows the fibers to follow instrument rotation. The two units are separated by unbolting the upper end of the struts that connect the two assemblies.

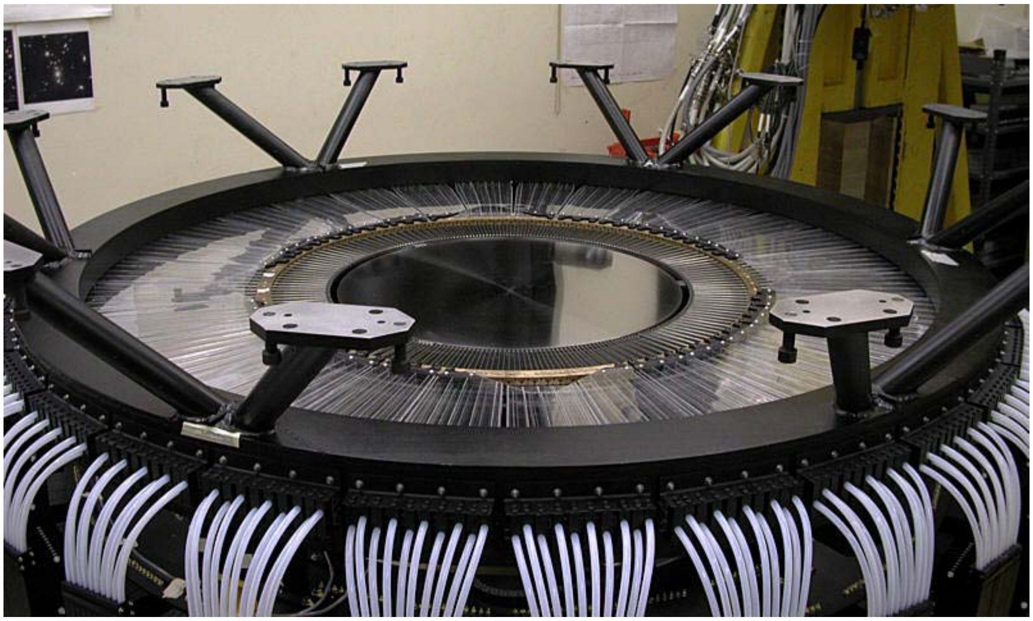


Figure 2. Lower assembly of the fiber positioner. The mounting pads are bolted to machined surfaces on the upper positioner assembly. Spacers (not shown here) 0.3 inches thick have been attached to the mounting pads to increase the separation of the upper and lower units.

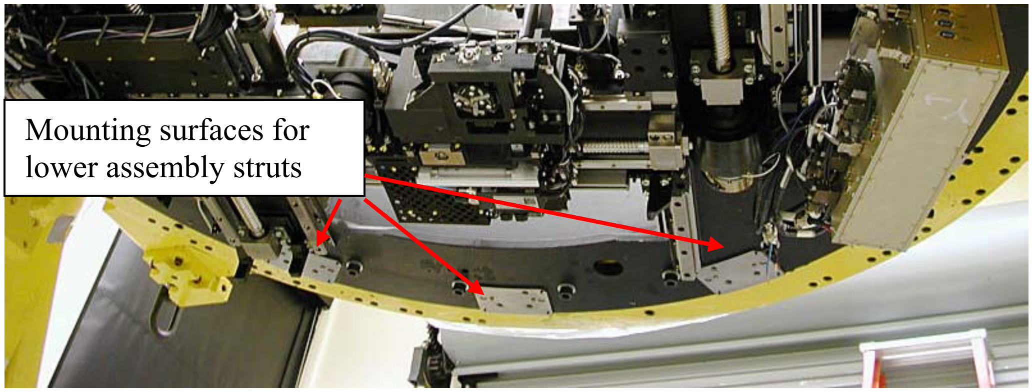


Figure 3. Upper assembly of the fiber positioner.

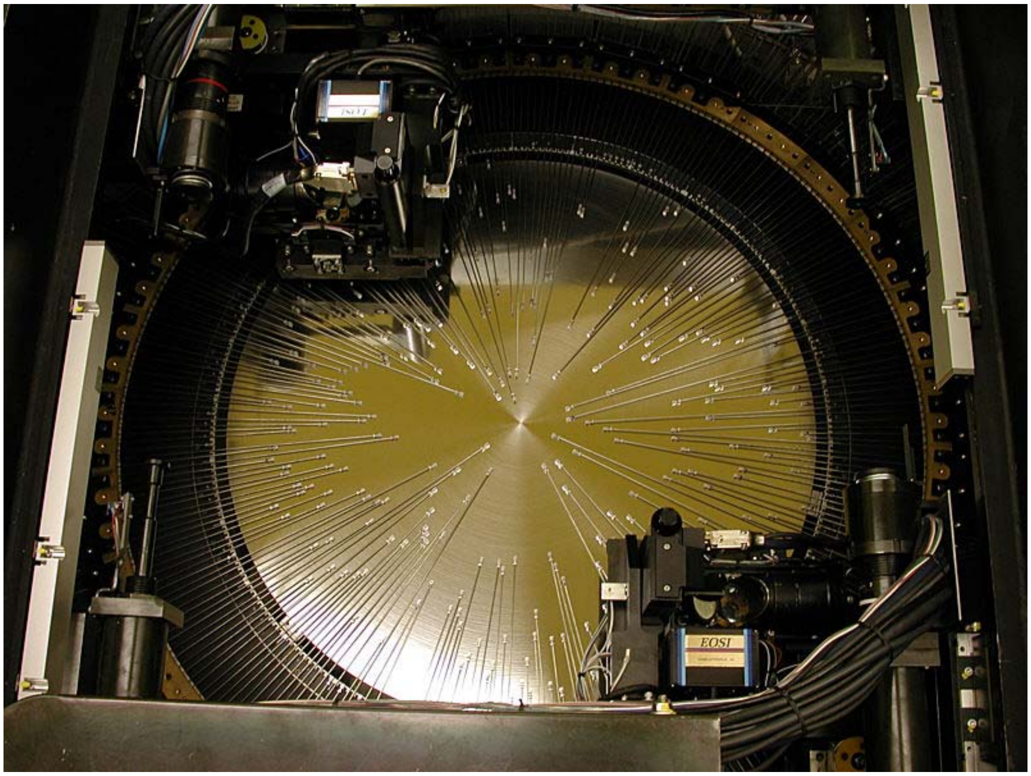


Figure 4. Looking down at the focal surface from above with the entrance window removed. The two positioning robots are visible to the upper left and lower right.

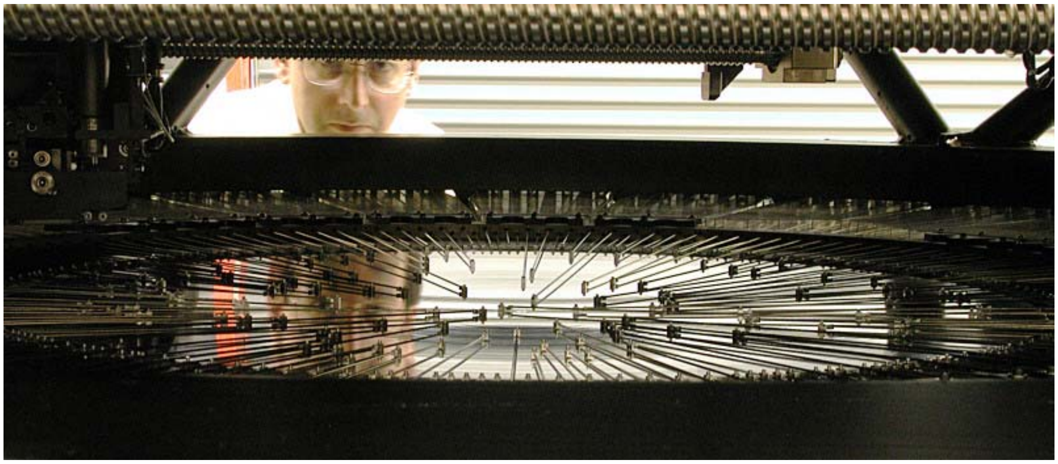


Figure 5. Looking at the focal surface from the side with the covers removed. One robot is visible to the top left.

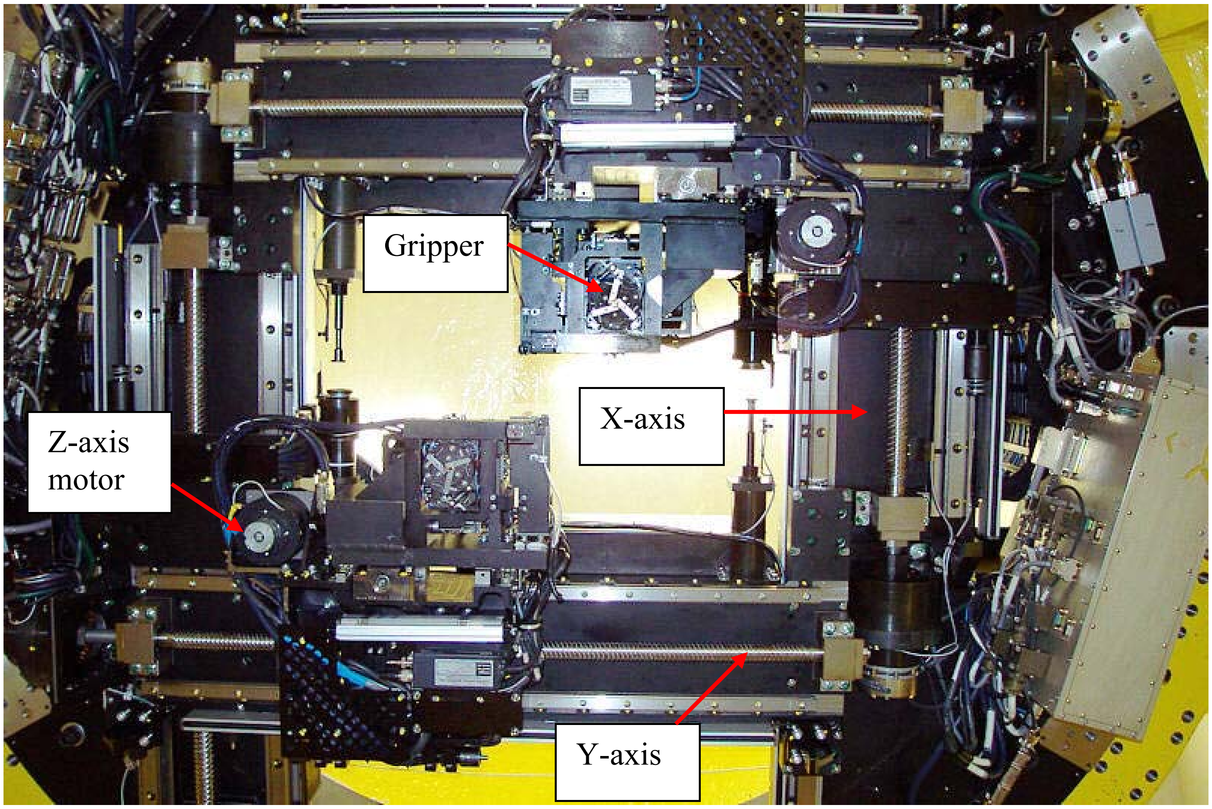


Figure 6. Looking up at the robots from below with the lower assembly (focal surface and fibers) removed. The X-axes run vertically and the Y-axes run horizonatally. The X-axis collision bumpers are visible near the center of the picture.

The robots each have six axes of motion: three linear motions (X, Y, Z), two tilt motions (Theta and Phi, usually contracted to T and P), and the gripper that closes around the barrel of the fiber button. The T axis tilt causes motion along the X axis and the P axis tilt causes motion along the Y axis. The T and P axes are implemented in a nested gimbal arrangement: the P axis is the inner gimbal and the T axis is the outer gimbal.

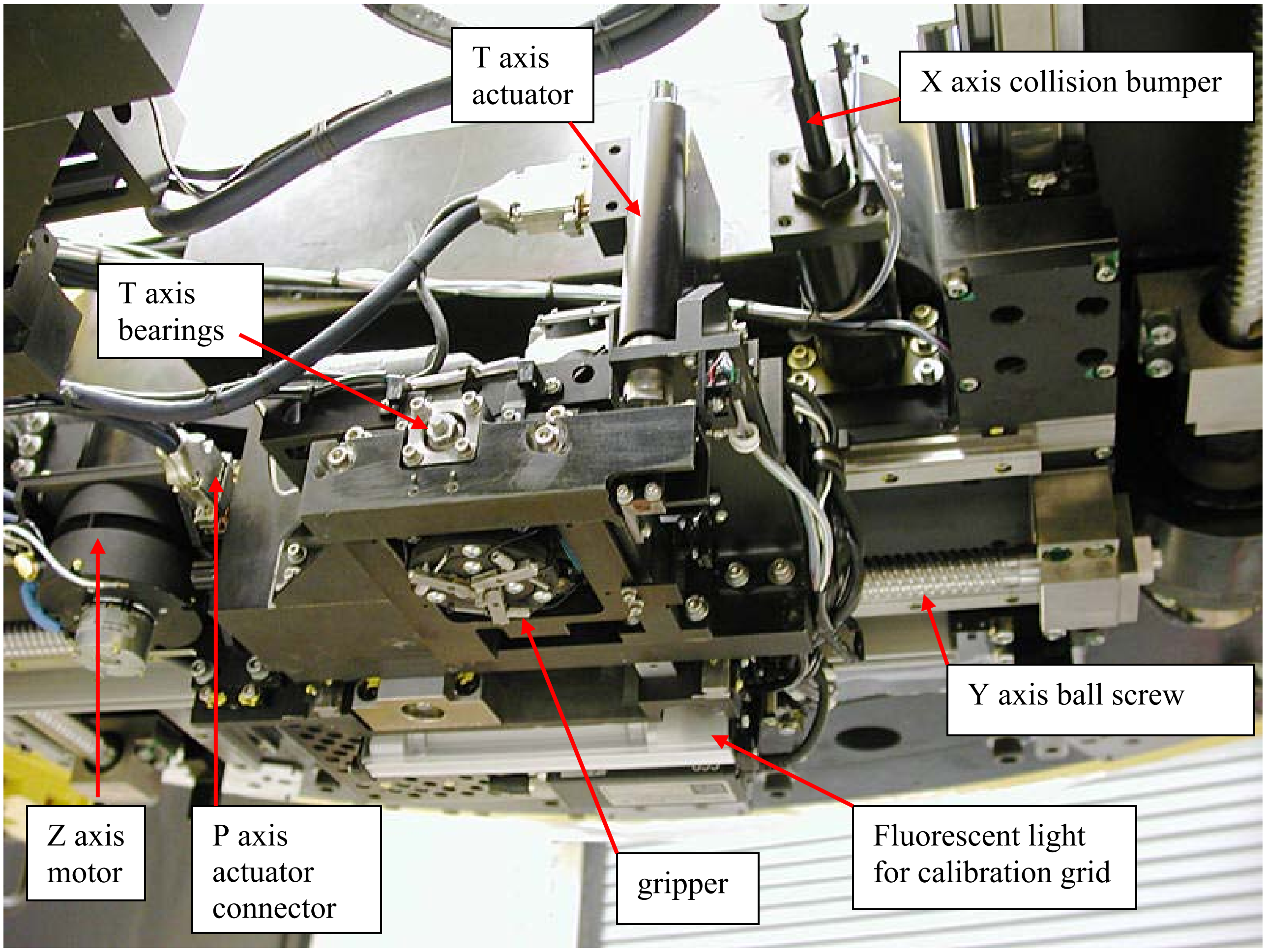


Figure 7. Closeup of gimbal assembly. The P axis actuator is hidden behind the gimbal assembly. The entire gimbal assembly rides on the Z axis stage.

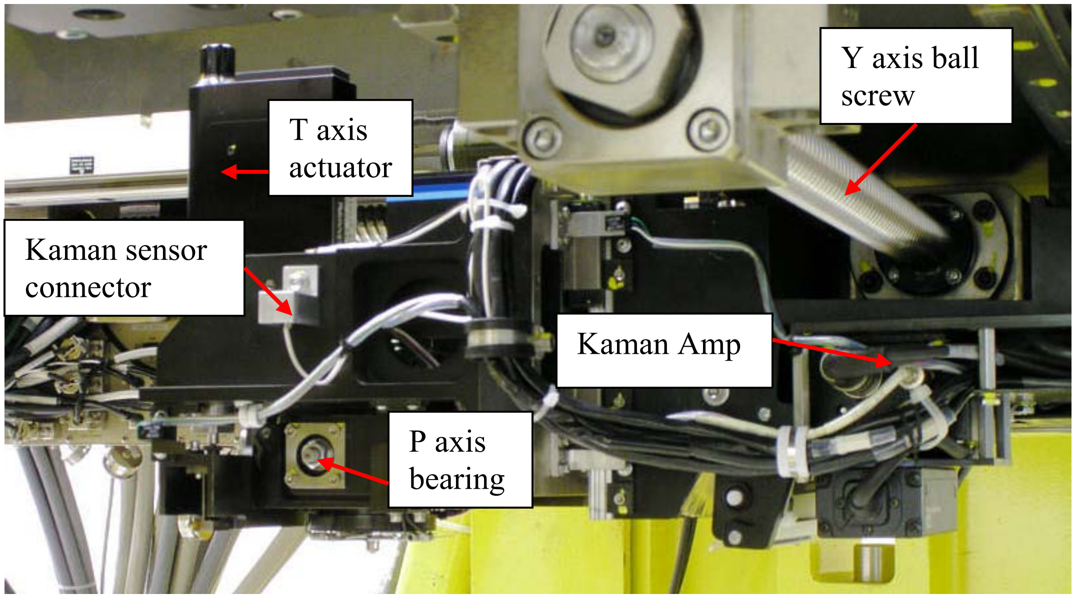


Figure 8. Side view of gimbal and Z--axis assembly.

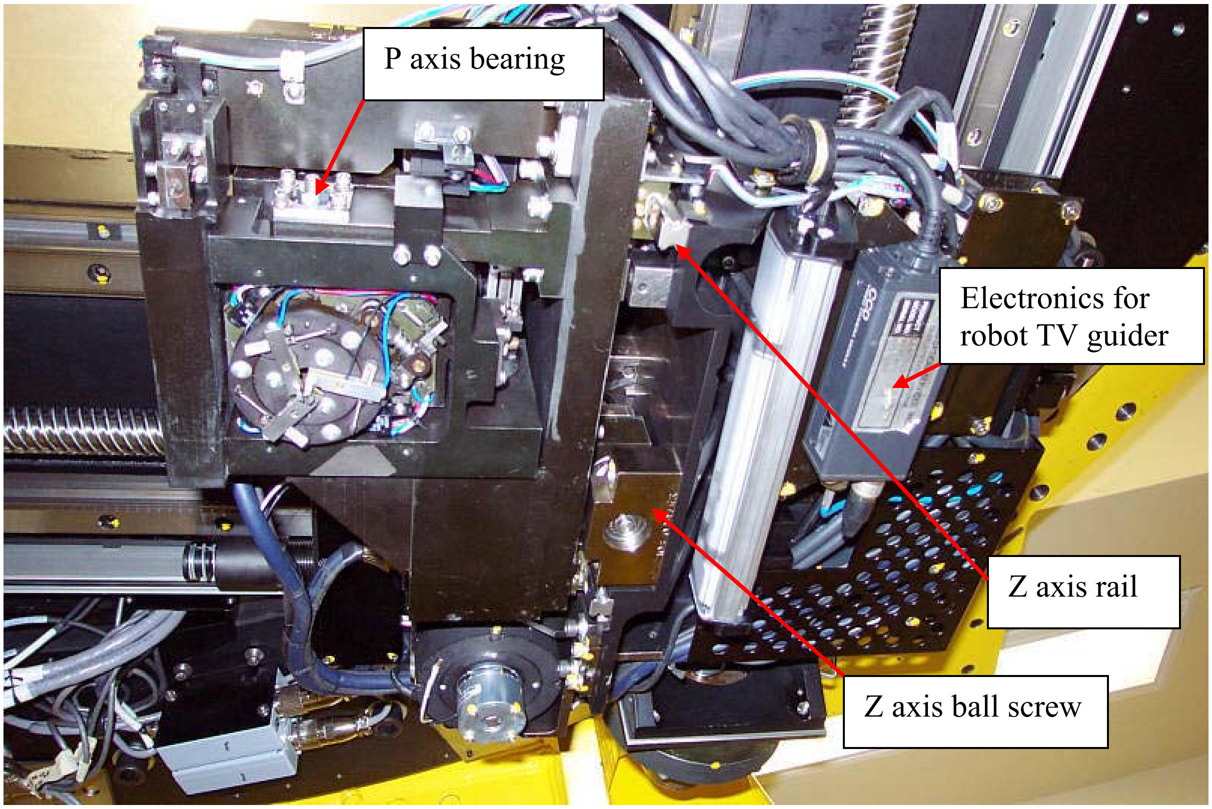


Figure 9. Gimbal and Z axis assembly viewed from below with the focal surface assembly removed.

2.2 FIBER POSITIONER MECHANICAL LAYOUT

2.2.1 FOCAL SURFACE GEOMETRY

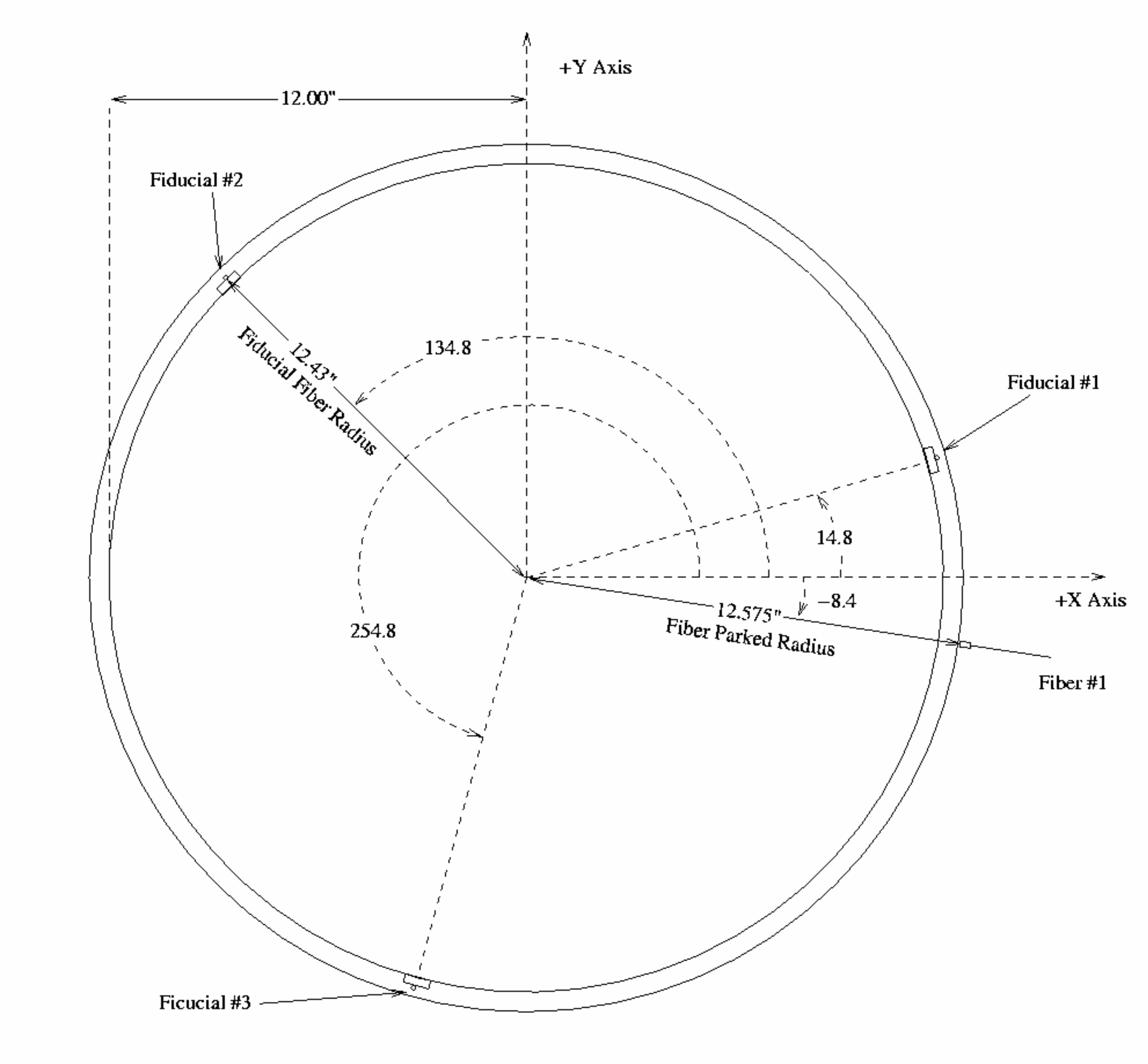


Figure 10. Location of fiducial fibers and science fiber number 1.

Table of Fiducial Fiber Locations Relative to Center of Focal Surface

	X Centroid (mm)	Y Centroid (mm)
Fiducial Fiber 1 (Robot 2)	305.135	80.918
Fiducial Fiber 2 (Robot 1)	-222.586	223.753
Fiducial Fiber 3 (Robot 1)	-82.555	-304.668

SHAPE OF THE FOCAL SURFACE

The focal surface of the telescope is an hyperbola of revolution when the f/5 corrector optics are configured in spectrocopic mode. In this mode the field of view is 1° in diameter. The focal plate, to which the fibers buttons attach, in principle has a different shape than the focal surface of the telescope because the entrance apertures of the optical fibers sit ~2.43 mm above the focal plate. However, the error incurred by neglecting the offset is small, reaching 3.3 µm at the edge of the focal surface. A 3.3 µm focus error leads to less than 1 µm image blur, a trivial amount. To avoid confusion, we use the telescope focal surface shape for the Hectospec focal plate.

The sag of a conic surface is given by:

$$z = \frac{cr^2}{1 + \sqrt{1 - (1 + k)c^2 r^2}}$$

For our hyperbolic focal surface, k = -665 and c = $-2.937720\text{x}10^{-4}$ mm^{-1} (equivalantly, c = $-7.461810\text{x}10^{-3}$ inches^{-1}.) A sag table in mm is given below.

FOCAL SURFACE (AND FOCAL PLATE) SAG

Radius (mm)	*Sag (mm)*
0.000000E+000	0.000000E+000
2.000000E+001	-5.842152E-002
4.000000E+001	-2.298643E-001
6.000000E+001	-5.040136E-001
8.000000E+001	-8.667918E-001
1.000000E+002	-1.303214E+000
1.200000E+002	-1.799374E+000
1.400000E+002	-2.343376E+000
1.600000E+002	-2.925530E+000
1.800000E+002	-3.538149E+000
2.000000E+002	-4.175216E+000
2.200000E+002	-4.832040E+000
2.400000E+002	-5.504959E+000
2.600000E+002	-6.191104E+000
2.800000E+002	-6.888208E+000
3.000000E+002	-7.594470E+000
3.055654E+002	-7.792430E+000

FIBER PIVOTS AND BUTTON LIFT HEIGHT

The fiber pivots are brass blocks with conical pivots that locate the fibers at the outside of the focal surface. The pivot radius is 17 inches. The fibers are arranged in two alternating levels. The lower pivot level is 0.15 inch (3.8 mm) above the parked position and the upper pivot level is 0.30 inch (7.6 mm) above the parked position. The pivots allow the fibers to rotate by +/-5° in any direction. The pivots are 4.425 inches from the nominal parked position of the fibers.

If a fiber is lifted by a nominal 2.5°, this corresponds to a height of 0.193 inches (4.9 mm) at the park radius. However, we can add to this safe nominal lift height the difference between the fiber height at the pivot position and the fiber height at the parked button. The lower pivot position is 0.15 inches and the fiber height at the button is 0.096 inches; the difference is 0.054 inches (1.4 mm). Therefore, the button can be lifted 6.3 mm from the parked position without exceeding a 2.5° nominal lift height for the lower pivots. An additional 0.15 inches (3.8 mm) is available without exceeding the nominal lift height for the upper pivots (a total of 10.1 mm).

The overall height of the buttons is 0.20 inches (5.08 mm). Therefore, to have zero nominal clearance, we need to lift the gripper jaws by 5.08 mm. If we want nearly 2 mm of clearance, a lift of 7 mm above the park position is necessary. This exceeds the 2.5 degree nominal lift angle by 0.36°.

The sag of the focal surface is 7.8 mm, so we need a lift height of 14.8 mm to clear the parked fibers by 2 mm. The upper flag (closest to the entrance window) on the Z-axis is set to come on at ~14.5 mm, and will stay on as the Z-axis is raised further. This flag is used to indicate that it is safe to translate the robots (X and Y axes) over the focal surface. The procedure to set up the correct Z height for moving buttons is referred to as "registering".

The lower flag (closest to the focal surface) comes on at about 20.5 mm, and is the Z upward travel limit flag. The Z downward travel limit is built into the gripper jaws and is triggered by a collision of the gripper jaws with a button, the focal surface, or another object. In order to clear the fiber shelves outside the focal surface, the robots must be raised to 20 mm after first leveling out the gimbals. This is referred to as "tagging up". The intensified robot TV camera can collide with the structure if the Y axis is translated at the full Z up position with tilted gimbals.

The Z axis positioning is discussed in more detail below in the "Z Axis Characteristics" section.

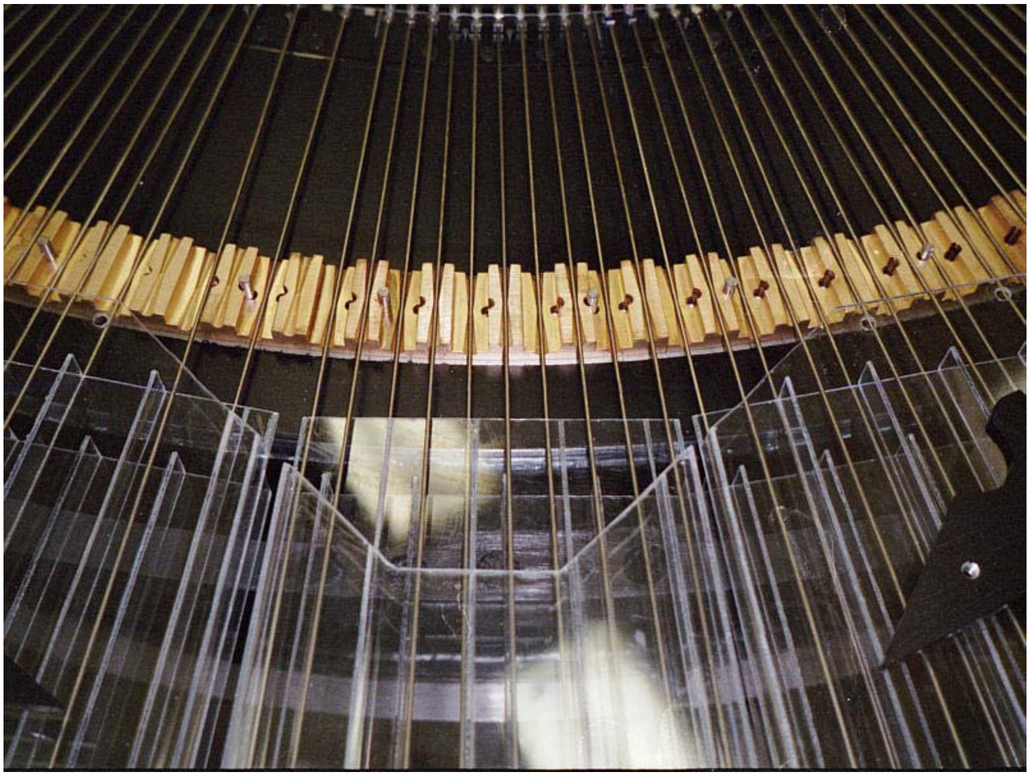


Figure 11. Fiber pivot blocks, top half removed.

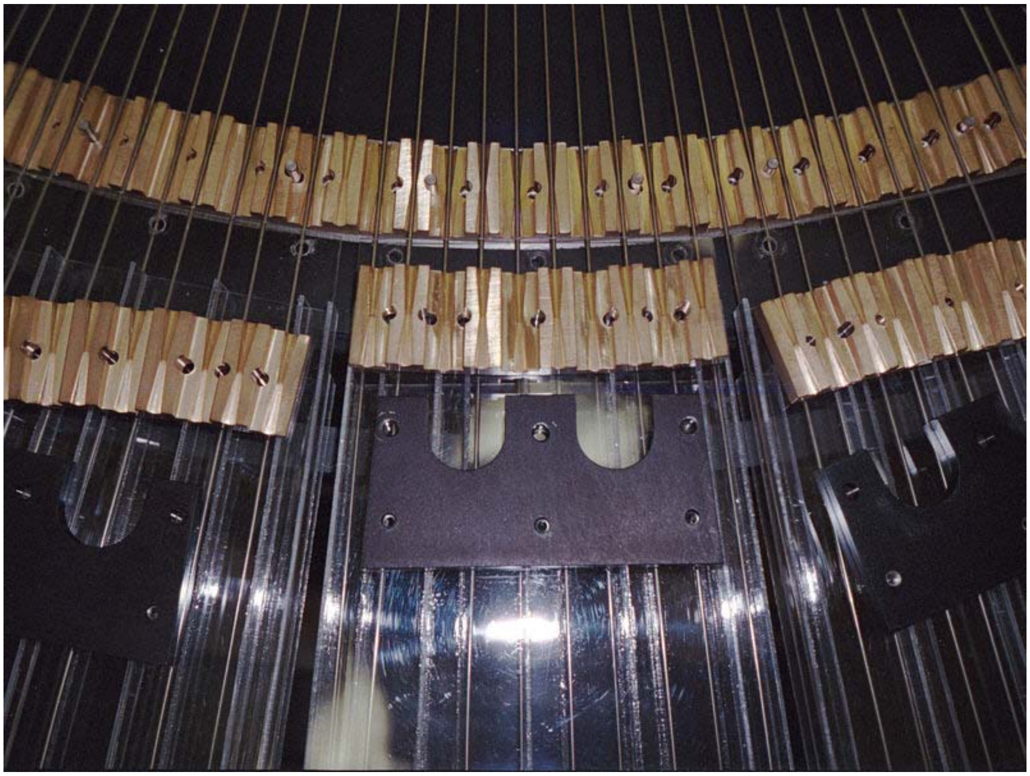


Figure 12. Pivot assemblies disassembled.

POSITIONER FIBER PARKING RING

The width of the fiber button bases is between 0.117 and 0.120 inches. At the parking ring radius. 12.575 inches, the buttons are located in comb-like structure with parking places 0.140+/-0.002 inches wide. These parking places or slots are used to define the button positions with adequate precision so that the robot can pick them up. If the buttons are replaced in the shelves manually, the gripper jaws must be open extra wide to allow for the less precise positioning.

FIDUCIAL FIBERS

The fiducial fibers are three 250 µm core fibers identical to the fibers used in the Hectospec, mounted at the outer edge of the focal surface on a 12.430 inch radius circle.

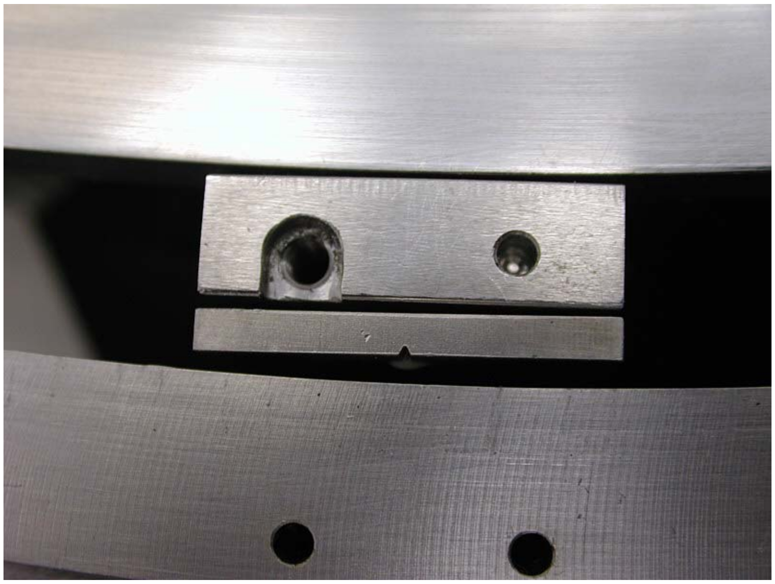


Figure 13. Fiducial fiber mount (small notch).

KAMAN SENSORS

The relative tilts of the XY coordinate systems of Robots 1 and 2 and the focal surface are calibrated with Kaman sensors, which are displacement sensors with an effective working distance between 0 and 1 mm. They are variable impedance transducers. We use modified KD2300-.5SUM devices; the mounting threads have been machined off. For calibration, the Kaman sensors are temporarily mounted to an outside point on the Theta axis stage. The Kaman electronics boxes mounted on the Y slider are tuned for a specific probe; the probes for Robot 1 and Robot 2 can be told apart because the probe for Robot 2 has a splice in its wiring. The Kaman signals are digitized by a PMAC accessory board, and the gains have been set so that ±0.5 mm of travel (zero is at 0.5 mm from focal plate) corresponds to approximately ±11000 ADU.

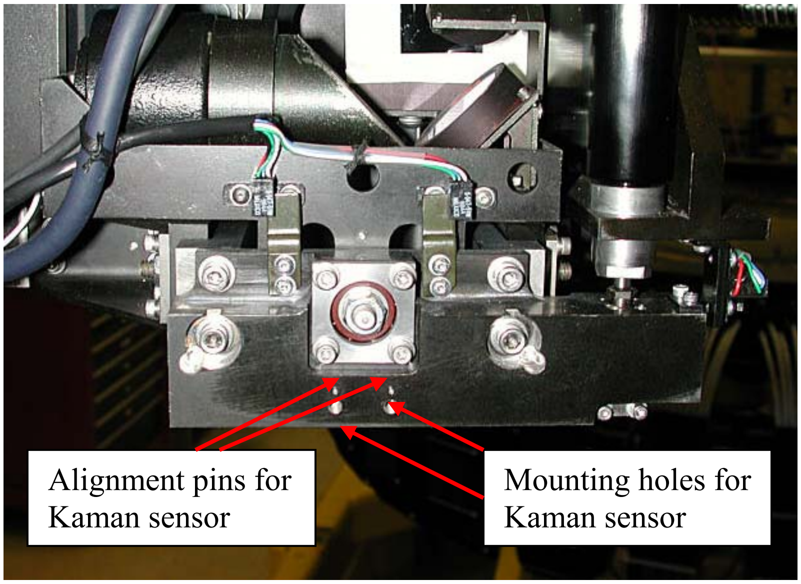


Figure 14. Mounting for Kaman sensor on outer gimbal. When the Kaman sensor is mounted, care must be taken not to lower the Z-axis so that a collision takes place. A special Kaman sensor mode allows safer operation during calibration with the Kaman sensor.

Hectospec is operated in a special Kaman mode during calibration with the Kaman sensor to add an appropriate displacement to avoid collisions with the focal surface.

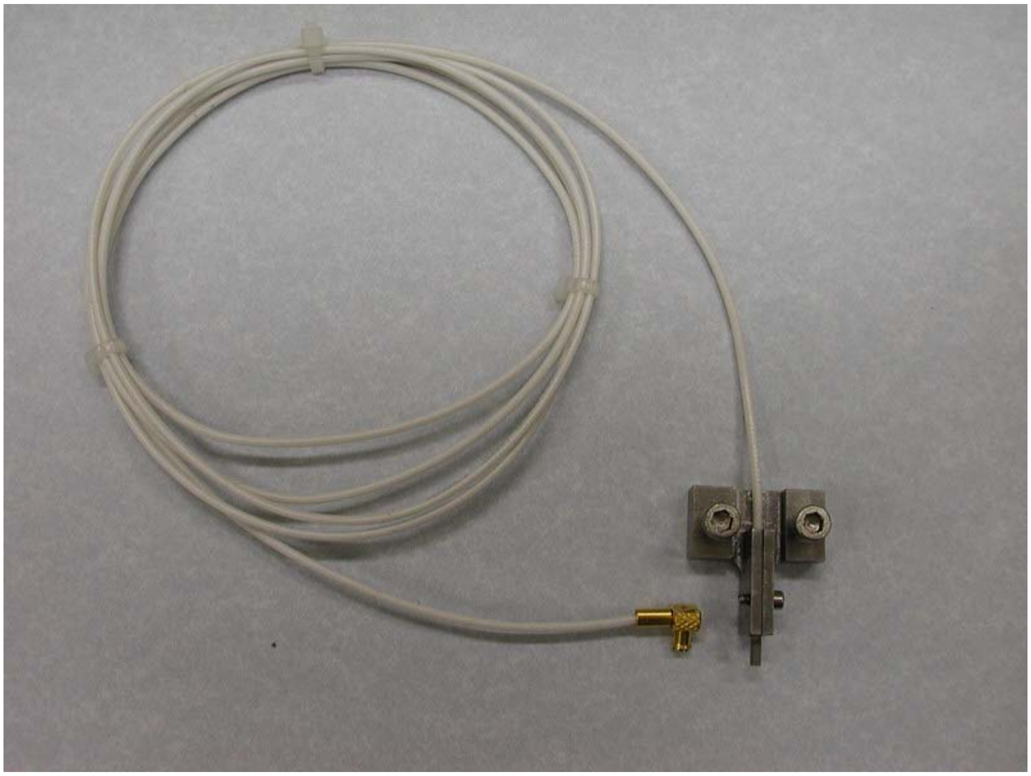


Figure 15. Kaman sensor in its mount with connector.

2.2.2 PHYSICS OF TORQUE CALCULATIONS

HOW MUCH MOTOR TORQUE IS REQUIRED TO OVERCOME GRAVITY?

The energy equation for one turn of the screw is:

$$eT\theta = Fd$$

e	all screw efficiency (dimensionless)
T	motor torque (in N-m)
θ	$2*\pi$ (angle of motor rotation per turn in radians)
F	m*g (gravitational force in N)
m	mass (in kg)
g	9.8 meter s^{-2}
d	lead of ball screw per turn (m)

For the X-axis, e=0.9, m=114 kg, d=0.032, giving T = 6.32 N-m = 894 oz in
For the Z-axis, e=0.9, m= 10 kg, d=0.004, giving T = 0.069 N-m = 9.8 oz in
(1 N-m = 141.6 oz-in)

HOW MUCH MOTOR TORQUE IS REQUIRED TO ACCELERATE THE LOAD?

The equation is the same except that ``g'' is replaced by ``a'', the acceleration. Accelerating to 1 m/sec speed in 0.1 sec corresponds to 1 g.

HOW MUCH TORQUE IS REQUIRED TO OVERCOME THE INERTIA OF THE MOTOR AND BALL SCREW?

$$T = I\xi$$

I	inertia (in kg m^2)
ξ	angular acceleration (in radians s^{-2})

For the X-axis, an acceleration of 10 m s^{-2} corresponds to:

$$\xi = (10 \text{ m s}^{-2}) * (2\pi \text{ radians turn}^{-1}) * (31.25 \text{ turn m}^{-1}) = 1963 \text{ radians s}^{-2}$$

The motor inertia is 9.04×10^{-4} kg-m^2; the ball screw inertia (0.5*mass*radius^2) is 8.06×10^{-4} kg-m^2. The total torque to accelerate the motor and ball screw to 10 m s^{-2} is therefore 3.4 N-m, or 481 oz-in.

2.2.3 X AXIS CHARACTERISTICS

DESCRIPTION

There are two X axes. Each X axis carries a Y Axis subassembly, which in turn carries a Z axis subassembly, a two axis gimbal assembly and a gripper. The maximum velocity is 1 m s^{-1}, the maximum acceleration is 15 m s^{-2}, and the peak motor velocity is 1900 rpm.

LOAD

The weight of all parts riding on each X axis is approx 100 kg. The NSK LPFC-3232-6 ball screw lead is 32 mm and its diameter is 32 mm. This is a custom ball screw assembly with a #2 Morse taper for the motor armature. See MMTS-2026 drawing for details.

MOTOR

The motor is a custom Kollmorgen brushless DC servo motor (RBE-03013-A13) with a peak torque of 10,800 oz-in and an average torque of 4740 oz-in. Commutation is provided by Hall effect sensors in the motor body. The custom features of the motor are shown in the drawing MMTS-2088.

The X axis motor is driven by a Copley Controls servo amplifier Model 5424AC capable of 10 amps average current and 20 amps peak current with a 264 max VAC input (we run at 208VAC). A Copley Controls Model 145 Reverse Energy Dissipator is connected to each axis to prevent over voltage from tripping the servo amps when the motor returns energy to the amp. This
is an issue when the positioner is pointed off the zenith.

FEEDBACK

There are two linear incremental encoders glass (RSF MSA-2217) and one rotary encoder for each X axis. The rotary encoder is used only as a safety device to protect against a failed or disconnected linear encoder. Rotary counts are compared with the linear encoder counts and the motion is stopped if a preset difference is reached. In normal operation the primary difference between linear and rotary encoders arises from motion within a single (440 microsec) servo cycle.

X1 linear incremental encoder glass slide mounted on the driven rail.
X2 linear incremental encoder glass slide mounted on the follower rail.
XR rotary encoder mounted behind the X Axis motor.

Encoder	Length	Scale*	PMAC Input	Index Marks
X1	620 mm	2000 cts/mm	ENC1	50, 350 & 550 mm
X2	620 mm	2000 cts/mm	ENC9	70, 270 & 570 mm
XR	1 rev	625 cts/mm	ENC10	0 deg

*After 4X edge sensing by the PMAC. The glass substrate of the linear encoder has rulings every 20 microns that are subdivided to 2 µm by the RSF read electronics. The linear encoder accuracy is 3 µm. The rotary encoder produces 5000 counts/revolution, which is interpolated by the PMAC to 20000 cts/rev by 4X edge sensing.

BRAKE

A power off brake is mounted behind the X Axis rotary encoder. The brake for each X Axis is controlled by a TTL signal connected to PMAC machine output #1. This pin is available on the PMAC J5 connector. PMAC variable M1 is used in software to access this pin.

LIMITS AND RANGE OF TRAVEL

There is an opto sensor at each nominal end of travel (+/-320 mm). Beyond this, energy absorbing bumpers begin to act. When bottomed out, the bumpers act as hard stops. Bumpers are also provided to absorb X axis to X axis collisions.

USING THE TWO X AXIS ENCODERS TO COMPENSATE Y AXIS TILT

The Positioner X Axis has an encoder on both the motor (driven) and follower ends of the Y Axis beam. The encoder on the driven end of the beam is used to close the servo loop on all moves. All X Axis motions are carried out in two steps. The majority of the motion is accomplished by moving to the target position on the motor side encoder. The X Axis tilt is determined by reading the difference between the motor and follower side encoders. The Y Axis position in used to compute an X Axis motor side position that will bring the gripper head to the desired X Axis target position. A smaller corrective move is then executed to bring the gripper head to the original target position.

X_{cor}	the tilt corrected X Axis Motor side target position
X_{tar}	the desired X Axis position of the gripper head
X_{fol}	the encoder reading of the follower side
X_{mot}	the encoder reading of the motor side
Y_{enc}	the encoder reading of the Y Axis

$$X_{cor} = X_{tar} + \left(X_{fol} - X_{mot}\right) * \left(\frac{Y_{enc} + 643.9}{1013.5}\right)$$

All units are mm.

2.2.4 Y AXIS CHARACTERISTICS

DESCRIPTION

There are two Y axes. Each Y axis carries a Z Axis subassembly, a two axis gimbal assembly and a gripper. The maximum velocity is 1 m s^{-1}, the maximum acceleration is 15 m s^{-2}, and the peak motor velocity is 2400 rpm.

LOAD

The weight of all parts riding on each Y axis is approx 24 kg. The NSK LPFC-2525-6 type ball screw lead is 25 mm, and is 25 mm in diameter. This is a custom ball screw assembly with a #2 Morse taper for the motor armature. See MMTS-2027 drawing for details.

MOTOR

The motor is a custom Kollmorgen brushless DC servo motor (RBE-03010-A13) capable of a peak torque of 2900 oz-in and and average torque of 1200 oz-in. Commutation is provided by Hall effect sensors in the motor body. The custom features of the motor are shown in MMTS-1053.

The Y axis motor is driven by a Copley Model 5424AC servo amplifier capable of 10 amps average current and 20 amps peak current with a 264 max VAC input (we run at 208VAC). A Copley Controls Model 145 Reverse Energy Dissipator is connected to each axis to prevent over voltage from tripping the servo amps when the motor returns energy to the amp. This
is an issue when the positioner is pointed off the zenith.

FEEDBACK

Each axis has one linear incremental encoder (RSF MSA-2217) and one rotary encoder. The rotary encoder is used only as a safety device to protect against a failed or disconnected linear encoder. Rotary counts are compared with the linear encoder counts and the motion is stopped if a preset difference is reached. In normal operation the primary difference between linear and rotary encoders arises from motion within a single (440 µsec) servo cycle.

Y1 linear incremental encoder glass slide mounted on the driven rail.
YR rotary encoder mounted behind the Y Axis motor.

Encoder	Length	Scale*	PMAC Input	Index Mark
Y1	720 mm	2000 cts/mm	ENC2	60, 360 & 660 mm
YR	1 rev	800 cts/mm	ENC11	0°

*After 4X edge sensing by the PMAC. The glass substrate has rulings every 20 µm that are subdivided to 2 µm by the RSF read electronics. The linear encoder accuracy is 3 µm. The rotary encoder produces 5000 counts/revolution, which is interpolated (by the PMAC) to 20000 cts rev^{-1} by 4X edge sensing.

BRAKE

Power off brake mounted behind the Y Axis rotary encoder. The brake for each Y Axis is controlled by a TTL signal connected to PMAC machine output #2. This pin is available on the PMAC J5 connector. PMAC variable M12 is used in software to access this pin.

LIMITS AND RANGE OF TRAVEL

There is a opto sensor at each nominal end of travel (+/-320 mm). Beyond this, energy absorbing bumpers begin to act. When bottomed out, the bumpers act as hard stops.

2.2.5 Z AXIS CHARACTERISTICS

DESCRIPTION

There are two Z axes. Each Z axis carries a two axis gimbal subassembly and a gripper.

LOAD

The weight of all parts riding on each Z axis is approx 10 kg. The NSK PFT-1004-2.5 type ball screw lead is 4 mm and the ball screw diameter is 10 mm. This is a custom ball screw assembly; see MMTS-2028 drawing for details.

MOTOR

The motor is a Kollmorgen brushless DC servo motor (RBETH-01811-B10) capable of 430 oz-in peak torque and 273 oz-in average torque. The custom features of the motor are shown in MMTS-2067. The Z axis motor is driven by a Copley Controls Model 5424AC servo amplifier with a 264 max VAC input voltage (we run at 208VAC). The amp is capable of 10 amps continuous current and 20 amps peak current. A Copley Controls Model 145 Reverse Energy Dissipator is connected to each axis to prevent over voltage from tripping the servo amps when the motor returns energy to the amp. This is an issue when the positioner is pointed off the zenith.

FEEDBACK

There is one rotary encoder for each Z axis. The rotary encoder is the primary feedback and position sensing device. Since the motor is coupled to the ball screw with a metal band that may slip slightly, a home sensor is used to reset the position on up cycles of the Z-axis.

ZR rotary encoder mounted behind the Z Axis motor.

Encoder	Length	Scale	PMAC Input	Index Mark At
ZR	--	2500 cts/mm	ENC3	0°

The rotary encoder counts 2500 counts/revolution, which is interpolated by the PMAC (4X edge sensing) to yield 10000 counts per revolution.

BRAKE

A power off brake is mounted behind the Z Axis rotary encoder. The brake for each Z Axis is controlled by a TTL signal connected to PMAC Machine output #3. This pin is available on the PMAC J5 connector. PMAC variable M12 is used in software to access this pin.

LIMITS AND RANGE OF TRAVEL

An opto sensor (backed by a hard stop) sets the upper limit of travel; it activates at about 20.5 mm above the button placement position at the center of the focal surface. The lower limit of travel is defined in practice by the activation of the gripper finger switches, although a hard stop will be reached just past the range of travel necessary to place a button at the center of the focal surface. There is a second opto sensor set at 14.5 mm above the button placement position at the center of the focal surface. This second opto sensor is closer to the fiber positioner entrance window; counterintuitively, the upper limit opto is closer to the focal surface. When the robots move within the parking ring radius, the Z position is kept at 14.8 mm, and the second opto sensor is activated. The Z position must be raised to 20 mm when the robots are moved outside the parking ring radius.

HOMING THE Z AXIS

The Z axis is initially homed against the Z axis upper limit switch. This switch is the closer to the focal surface of the two Z axis opto switches (see Z-axis description). This limit switch activates when the nominal button position is (20.92 mm: Robot 1, 20.52 mm: Robot 2) above the focal surface. When the this home procedure has been sucessfully executed and the ztagup offsets (-0.82 mm: Robot 1, -0.42 mm: Robot 2) are executed in a Z movement, the Z axis position is set to 20.12 mm.

No X, Y, T or P axis motions are allowed until the Z axis has been homed.

REGISTERING THE Z AXIS

The final Z axis coordinate system is registered to the Z axis home flag. The robots are first positioned over the parking ring area and the Z axis is moved down by 6.5 mm. The Z axis is then homed on the home flag, which activates at (14.9 mm: Robot 1, 14.5 mm: Robot 2) above the focal surface. This opto sensor is physically located further from the focal surface than the upper limit switch. The home offsets are (0.3 mm: Robot 1, 0.7 mm: Robot 2). After these home offsets are executed in a Z movement, the final position is set to 15.2 mm. No pick and place operations are allowed until the Z axis has been registered.

Z AXIS HARD STOPS

The Z axis hard stops allow travel between Z=-0.5 mm and Z=20.9 mm.

Pivot Ring Collision Avoidance

Whenever an X, Y move would cause the positioner to move outside a radius of 320mm the Z axis is forced to "tag up". (The nominal fiber park radius is 319.405 mm). This repeats the home move against the Z axis upper limit switch to positively ensure that the Z axis is all the way up to clear the brass pivot blocks. An X, Y move which causes the Z axis to tag up loses registration on the Z axis. The registration procedure must be repeated before making another Z axis move. The code will not let the user move in Z if the registration has not been run.

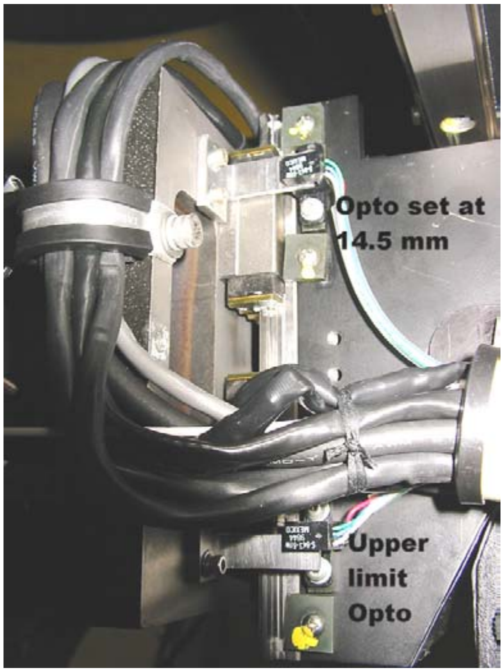


Figure 16. Z-axis opto sensors for Z=14.5 mm above focal surface and upper limit of travel.

2.2.6 GIMBAL CHARACTERISITICS

DESCRIPTION

There are two gimbals. Each gimbal assembly carries a gripper. Each of the gimbals has a Theta and Phi Axis. The gimbal must achieve a +-2.5 deg rotation on each axis. The Newport PM500-A1 linear actuator pushes on a tangent arm at a distance of 43.69 mm from the Theta axis pivot and a second actuator pushes on a tangent arm 25.4 mm from the Phi axis pivot. The Phi axis operates at a significant mechanical disadvantage (a small actuator movement produces a larger movement at the focal surface). The distance from the pivot to the telescope focal surface (2.438 mm above the focal plate) is 47.676 mm.

LOAD

The weight of all parts riding on the inner gimbal assembly (Phi) is 1.9 kg. The weight carried by the outer gimbal axis (Theta) is about 4 kg.

MOTOR

The Newport PM500-1A is capable of 9 kg thrust. The PM500 brush-type DC motors are driven by a Copley Controls Model 421 servo amplifier with a 48 volt bus voltage.

FEEDBACK

There is one linear incremental encoder glass slide on each axis built into the PM500 actuator. The output of the incremental encoder is fed to a 25x subcount multiplier before going to the PMAC. The PM500 glass scale has 1250 lines/inch, so there are 25x4x1250 quadrature (125000) counts/inch, or 4921.26 counts/mm.

Encoder	Length	Scale	PMAC Input	Index Mark
Theta	3.8 mm	4921 cts/mm	ENC5	0.5 mm*
Phi	2.2 mm	4921 cts/mm	ENC6	0.5 mm*

*Built into PM500. The PM500 scales are actually longer. The tabulated values are the range required for +/-2.5 degrees.

LIMITS

There is an opto limit switch at each end of travel for each gimbal axis.

GIMBAL CALIBRATION REPORT (MAY 2001)

The nominal gripper pivot to telescope focal surface distance is 1.877 inches. This assumes an 0.010 inch gap between the gripper jaws and the button body. The distance from the bottom of the gripper jaw to the telescope focal surface is 0.054 inches.

We measured a spacing between the bottom of the gripper jaw and the grid of 0.090 inch for robot 1 and 0.163 for robot 2. This implies a pivot distance of 1.913 inches for robot 1, and 1.986 inches for robot 2.

If the geometry is exactly nominal, this is the scale factor that we will measure, if we had assumed that the pivot length is 1.955 inches. The scale factor is defined as the scale required to convert nominal gimbal displacement to actual gimbal displacement. In other words:

(actuator disp) = (arm length)/(pivot length)*(scale factor)*(foc surf disp)

If we use a nominal pivot length that is incorrect, we will have to appropriately adjust the scale factor. The ratio of scale factor to pivot length must be kept constant to get the correct relation between focal surface displacement and actuator displacement. The code assumed an (incorrect) pivot length of 1.955 inches for our calibration. If we decide that the real pivot length is smaller, we must decrease the scale factor. This whole business is only important if we want to be able to scale the motion to a different pivot length. Because the TV's are not focussed exactly at the nominal telescope focal surface, we will need to rescale the motion.

Robot 1 1.913/1.955 = 0.9785
Robot 2 1.986/1.955 = 1.0159

For robot 1, we need to multiply the scale factor by 0.9785, and for robot 2, we need to multiply the scale factor by 1.0159. Using the 1.955 inch pivot length, we measure a scale factor of 1.0381 (T-axis) and 1.0393 (P-axis) for robot 1 and 0.9941 (T-axis) and 0.9963 (P-axis) for robot 2. These scales used gimbal movements in the focal surface of +/-1 mm, and left fitted residuals of less than 5 microns.

We calculate final scale factors of:

	T-axis	P-axis	Ave
Robot 1	1.0158	1.0169	1.0164
Robot 2	1.0099	1.0121	1.0110

We should use these numbers and a pivot length of 1.877 inches.

2.2.7 GRIPPER CHARACTERISTICS

DESCRIPTION

The gripper is driven by an API Portescap (P1110 064 2.5 12) 15° per full step stepper motor through an API Portescap (R16 2R 0 88) 88:1 planetary gear box ratio. This yields 0.17° per full step. The IM804 stepper driver is set to microstep at 32 microsteps per full step.

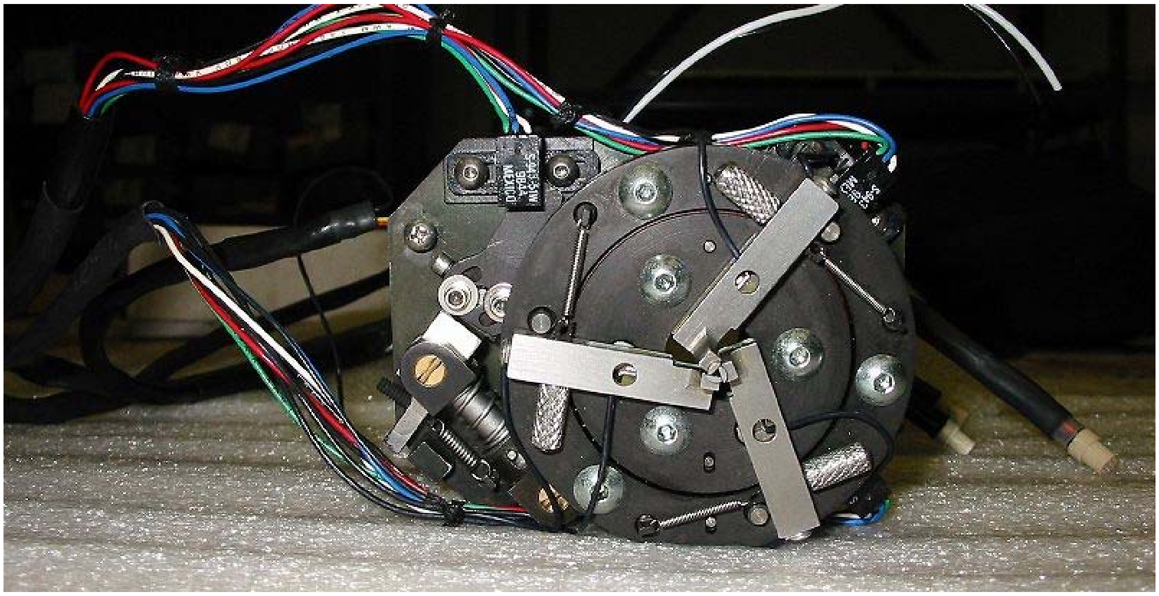


Figure 17. Bottom view of gripper.

Approximately 38 full steps (1200 microsteps) are required to move between the nominally open and closed positions. The gripper can be opened about 32 full steps (1000 microsteps) further to pick up buttons with uncertain positions, e.g., after parking manually or picking up a misplaced button.

The gripper opens approximately 2.34 mm in the nominally open position. The button snout is 1.83 mm in diameter, so the nominal clearance for picking up a button is .25 mm (in radius).

GRIPPER JAW OPENING

Microsteps Past Open	Robot #1 Jaw opening in inches	Robot #2 Jaw opening in inches
25	0.092	.098
100	0.095	
200	0.102	.108
300	0.108	
400	0.115	.120
500	0.121	.125
750	0.137	.141
1000	0.152	Not Reachable

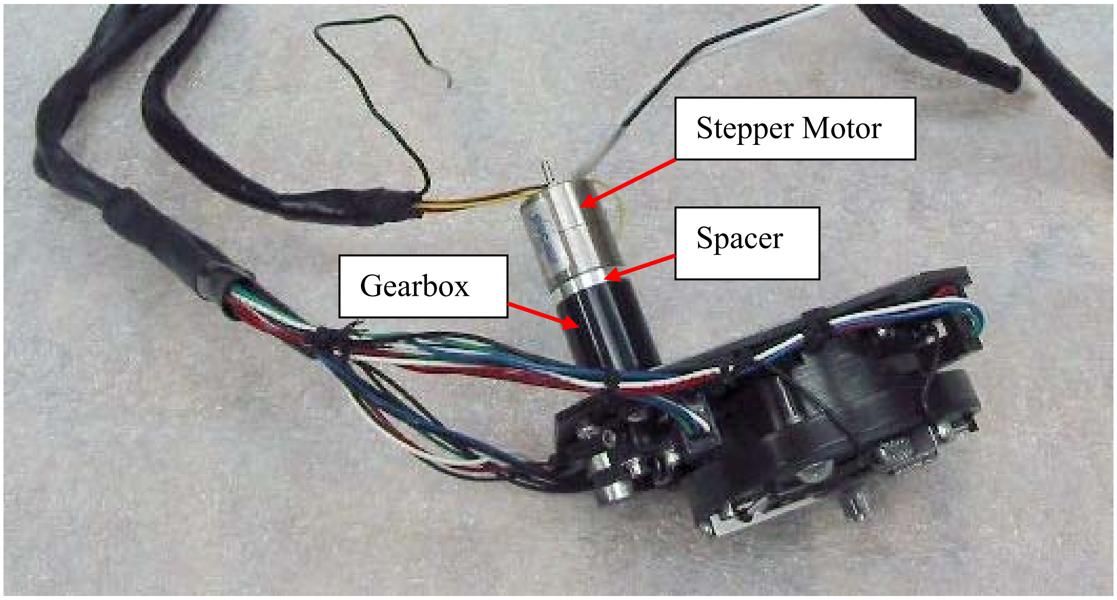


Figure 18. Side view of gripper.

OPERATION

We use a trapezoidal move profile with 40 millisec acceleration and deceleration times. The peak speed is set at 30,000 microsteps s^{-1} or 938 full steps s^{-1}. A nominal move of about 1200 steps takes about 80 millisec, so we actually have a triangular profile.

FEEDBACK

There is no encoder feedback from the gripper; the gripper stepper motor is moved open loop. A basic level feedback is provided by 3 opto-switches: (1) near the nominal open position, (2) near the gripper closed position and (3) at the "trouble" limit. The trouble limit is activiated when the gripper is (over) closed without a button in the fingers.

We have adopted a mode of operation in which we check for activation of the open and closed flags in the normal operation of the gripper, and issue extra steps to reach the flagged positions if the gripper should lose steps. The extra-open position required to retrieve buttons in the parking ring has no limit switch feedback.

GRIPPER SPRING LOADED MOUNT

The entire gripper assembly is spring mounted on three linear bearings. When in position, three flat head screws locate the gripper accurately. If the gripper strikes a button or the focal surface, first the jaws deflect and then the gripper assembly breaks away from its preload.

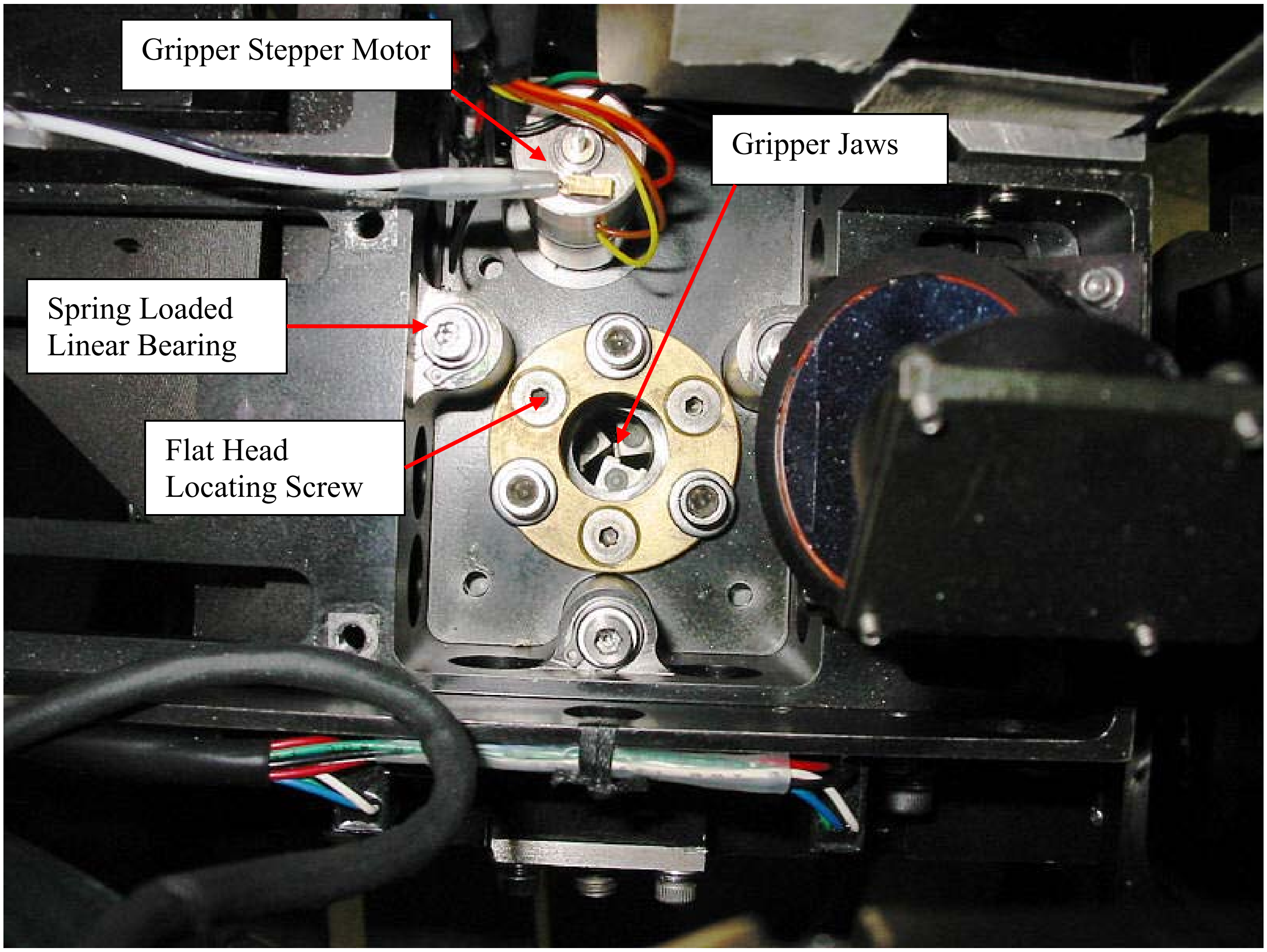


Figure 19. Looking down at the gripper assembly mounted in the gimbal assembly with the beamsplitting pellicle and corner cube removed.

SERVICE NOTES

The 88:1 planetary gear box is attached to the motor through an aluminum adapter flange. The adapter flange is attached to the motor with two tiny screws. The gear box threads onto the adapter flange. A spur gear pressed onto the motor shaft engages three gears in the planetary gear box. The planetary gear train in the gear box has substantial axial play on the input end (a much smaller amount on the output shaft). The adapter flange supplied with the motor is about 0.116 inches thick, and if the axial play in the planetary gear system is away from the motor, the motor gear to gear box tooth engagement is only 0.004 inches. We machined the adapter flange to 0.086 inches thick, and added two new shallower counterbores for the motor attachment screws.

Figure 20. Gripper motor and gearbox disassembled.

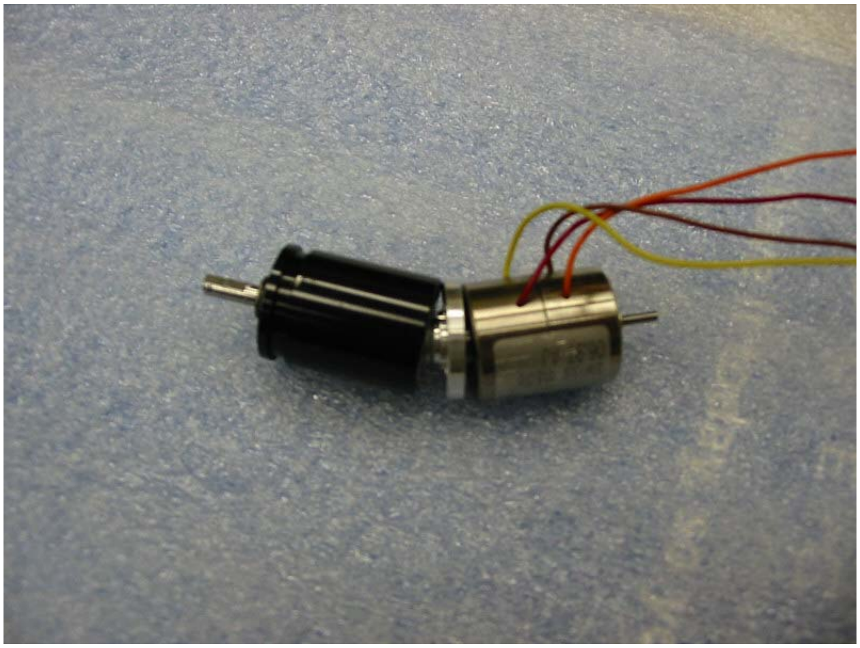


Figure 21. Gripper motor and gearbox partially assembled.

2.2.8 GUIDER CHARACTERISTICS

DESCRIPTION

There are three guider axes. Each guider axis carries one leg of a trifurcated coherent optical bundle. The maximum velocity is ~10° s^{-1}, and the peak motor step rate is 500 steps s^{-1}. A 24 tooth pinion gear attached to the motor shaft drives against an 864 tooth fixed gear, yielding a reduction of 36/1. The steppers are microstepped at 16 microsteps per full step.

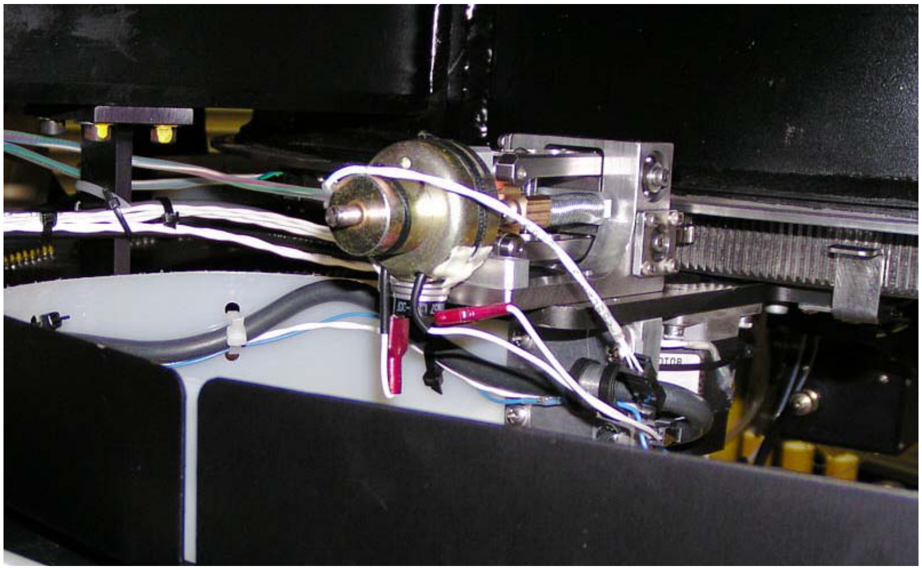


Figure 22. Guider drive assembly.

MOTOR

The motor is a Pacific Scientific Powermax stepper motor (M21NR-XBLNN-NS00) with a holding torque of 137 oz-in. The motor has 200 steps/rev corresponding to 1.8 degrees/step. With a 36/1 gearing each step corresponds to 0.05° at the focal surface. At a radius of ~305 mm, each step corresponds to ~0.27 mm, or about 1.6″.

FEEDBACK

These motors are operated open loop with an opto sensor reference.

BRAKE

A power off brake is mounted to each guider assembly. The three power-off brakes are disengaged simultaneously. To avoid overheating the brake solenoid, a safety timer turns off brake power after 15 s. In addition, a temperature sensor is mounted to each brake solenoid.

LIMITS AND RANGE OF TRAVEL

86° of travel in each of three arcs.

2.2.9 ROBOT TV CAMERAS AND GUIDE CAMERAS

The ease with which the fibers can be initially aligned with respect to the observation targets and the accuracy with which they are kept aligned will affect the overall observing efficiency with Hectospec. The design of the acquisition and guiding hardware deserves a fair share of engineering effort along with high speed positioning robots and efficient reconfiguration algorithms to conserve precious observing time. Hectospec is guided with at least two guide stars at all times to measure instrument rotator errors as well as telescope altitude and azimuth pointing errors. To avoid occulting prime observing real estate, guiding will be performed by three independently actuated probes at the circumference of the focal surface. The probes move along three 86° arcs and each contains relay optics to carry the guide star image to coherent fiber bundles. The three coherent bundles form a trifurcated assembly; the three bundles are brought together to form a single bundle at the input to an intensified CCD guide camera.

In addition, each fiber robot carries an intensified CCD camera that is capable of simultaneously viewing a target object and a backlit fiber through a beam splitter. This feature was introduced on the Argus multi-object spectrograph at CTIO. After the fibers are positioned for a given observation, the gripper heads will be sent to the intended position of the guide stars and the rotation and pointing errors of the telescope will be removed. The guide stars will then be acquired in the coherent bundles and guiding can begin. If desired, the gripper heads can then be commanded to one or more target objects and the alignment can be checked with reference to a backlit fiber.

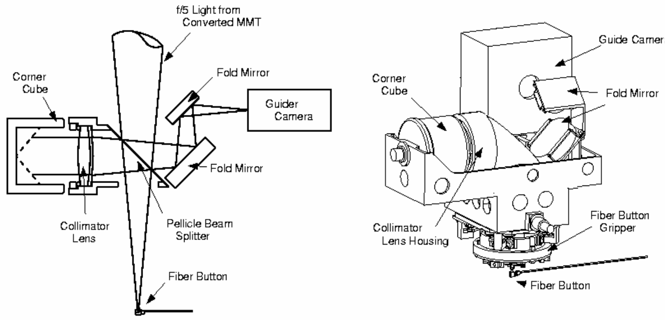


Figure 23. Robot TV guiders that can view the sky and backlit buttons simultaneously.

The guide cameras, manufactured by Electro-Optical Services, Inc., use Gen III image intensifiers with maximum gains of 70,000 and quantum efficiencies of >20% from 4250 to 8750 Å. The camera receiving the trifurcated coherent bundle has its image intensifier photocathode deposited on the back surface of its fiber optic input to avoid defocusing at the photocathode. The image intensifiers are coupled through a reducing fiber optic (1.6:1 ratio for the robot cameras and 2.3:1 for the guide camera) to a 768x493 pixel

CCD (each pixel is 11 13 µm). The cameras in the fiber positioning robots have a field of view of ~60″x80″, while the three coherent bundle guiders each have a field of view of ~30″x 60″.

Figure 24. Photo of trifurcated coherent bundle and guide probes from beneath the focal surface.

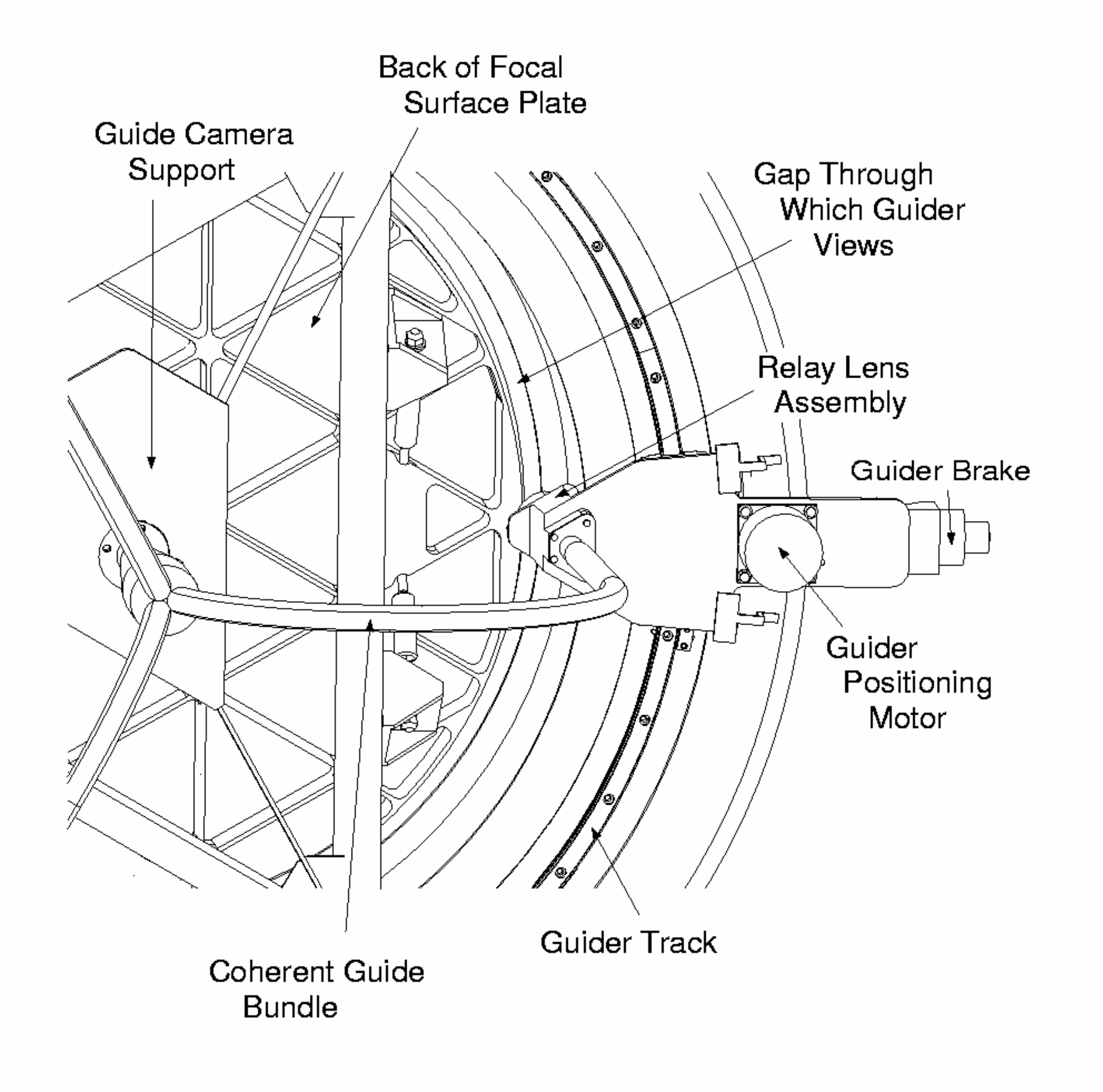


Figure 25. Diagram of coherent guide bundles from beneath the focal surface.

2.3 FIBER POSITIONER ELECTRONICS

2.3.1 INTRODUCTION

The Hectospec electronics racks contain five main assemblies: (1) the interface box that accepts the instrument electrical cables and redistributes the signals into internal electronic cables, (2) the PMAC accessory box that contains conditioning electronics and breakout assemblies to format signals for the flat ribbon cables that the PMAC motion control boards accept, (3) the two servo electronics boxes that contain the X, Y, Z, T, and P servo amplifiers and the gripper stepper driver, (4) the stepper rack bay that conditions and distributes signals from the VME stepper controllers to the stepper drivers for the guide probes and the spectrograph axes (grating rotation, shutter, and focus), and (5) the power supply box that holds power supplies for the gripper stepper and the gimbal servos.

At the positioner there are four electronic boxes: (1) the main interface box for signals coming from the electronics rack, (2) a secondary interface box for the X, Y, and Z servo motor signals, (3) an electronic processing box, and (4) an auxiliary box containing a photodiode sensor (to detect overillumination and to protect the intensified TV cameras) as well as the power supply for the fluorescent lamps that illuminate the calibration grid when it is installed.

2.3.2 RACK INTERFACE BOX

The rack interface box provides a transition between the heavy-duty Mil-C circular connector cables (that lead to the fiber positioner) and the internal rack electronics assemblies, which use D-subminiature connector cables. The interface board in the rack interface electronics is identical to the interface board in the positioner I/F box and provides over voltage protection suitable to the type of signal involved.

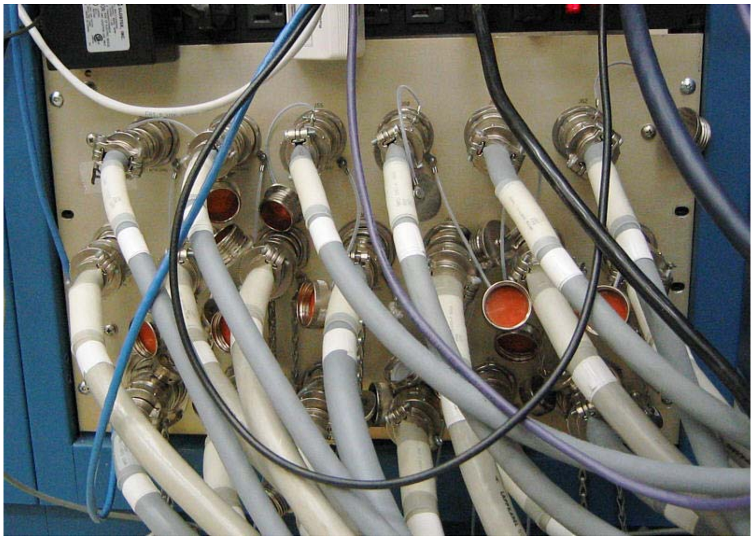


Figure 26. Front panel of the rack interface box.

2.3.3 PMAC ACCESSORY BOX

The PMAC Accessory Box provides an interface between the Delta Tau PMAC motion control electronics boards, the fiber positioner feedback signals, and the servo boxes. Each PMAC interface consists of three sixty-pin ribbon cables, connecting to JMACH1 and JMACH2 on the PMAC controller, a thirty-four pin ribbon cable for the PMAC JOPT digital I/O signals, and a ten pin ribbon cable for the JS1 serial interface of each PMAC. These ribbon cables carry the encoder feedback signals (linear and rotary) and end-of-travel limit signals from the positioner robots to the PMAC. Robot limit signals are buffered and are end-for-end jumper selectable on the printed wiring board. Encoder signals pass through directly to the PMAC. For the X, Y, Z, P, and T axes for robots 1 and 2, the PMAC drive command analog signals pass through the interface PWB to the two servo drive boxes. For the gripper axis of each robot, a Delta Tau Accessory ACC8D-OPT2 Voltage to Frequency board allows the PMAC controller to close a servo loop around the stepper motor. Two ACC28A A/D modules digitize the proximity sensor outputs of each robot and are read out via the JS serial interface. The PMAC Accessory box also contains low voltage power supplies for powering the PMAC opto-isolation interface as well as the local interface buffers and optical isolation. The printed wiring board provides these functions as well as the signal mapping between the high-density ribbon cables and the more robust D-subminiature connectors of the cables running to the rack interface box and the servo boxes.

Figure 27. Front panel of PMAC accessory box.

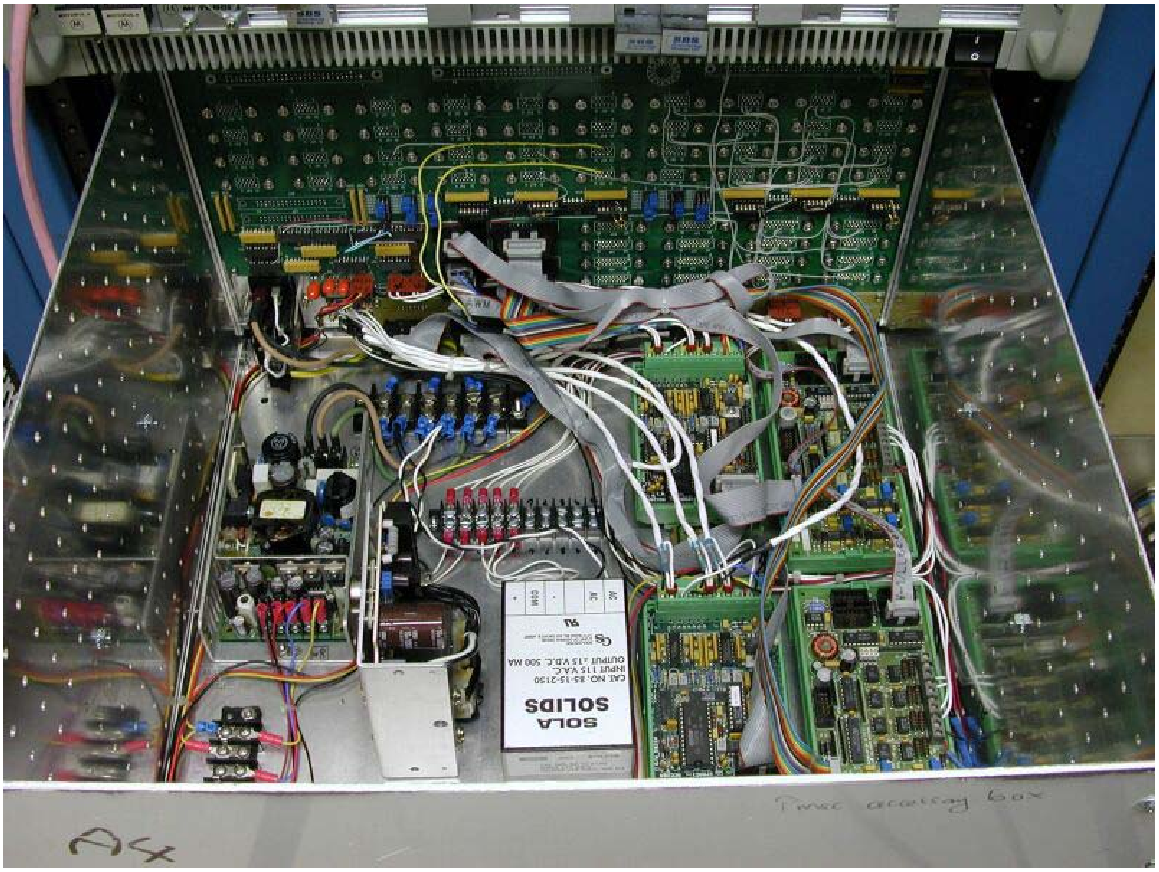


Figure 28. Interior of PMAC accessory box.

2.3.4 SERVO ELECTRONICS BOX

The servo boxes contain the servo drive amplifiers for each positioner robot. Three Copley Controls 5424AC brushless motor amplifiers are used for the X, Y, and Z axes. Two Copley 421 brush motor amplifiers are used for the P and T axes. An Intelligent Motion Systems IM804 microstepping motor drive is used for the gripper axis. For each of the high power axes (X, Y, and Z) there is a three-pole relay and an array of power resistors that are connected to each motor phase and switched to ground when the corresponding axis is disabled. This allows the stage to brake dynamically, reaching a safe terminal velocity in the event of a drive fault, or other unplanned drive shutdown. The interface board of each servo box provides the interface to the rack cables to the PMAC accessory box and rack emergency stop. This board also contains opto-isolation and safety interlocks for each axis. Motor drive power passes through this box transitioning from internal combo-D style connectors to robust metal circular connectors.

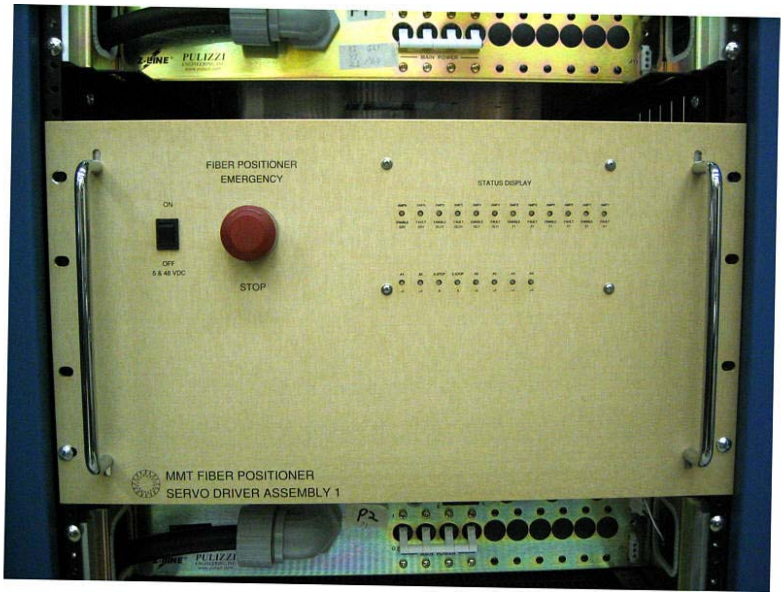


Figure 29. Front panel of positioner servo electronics box.

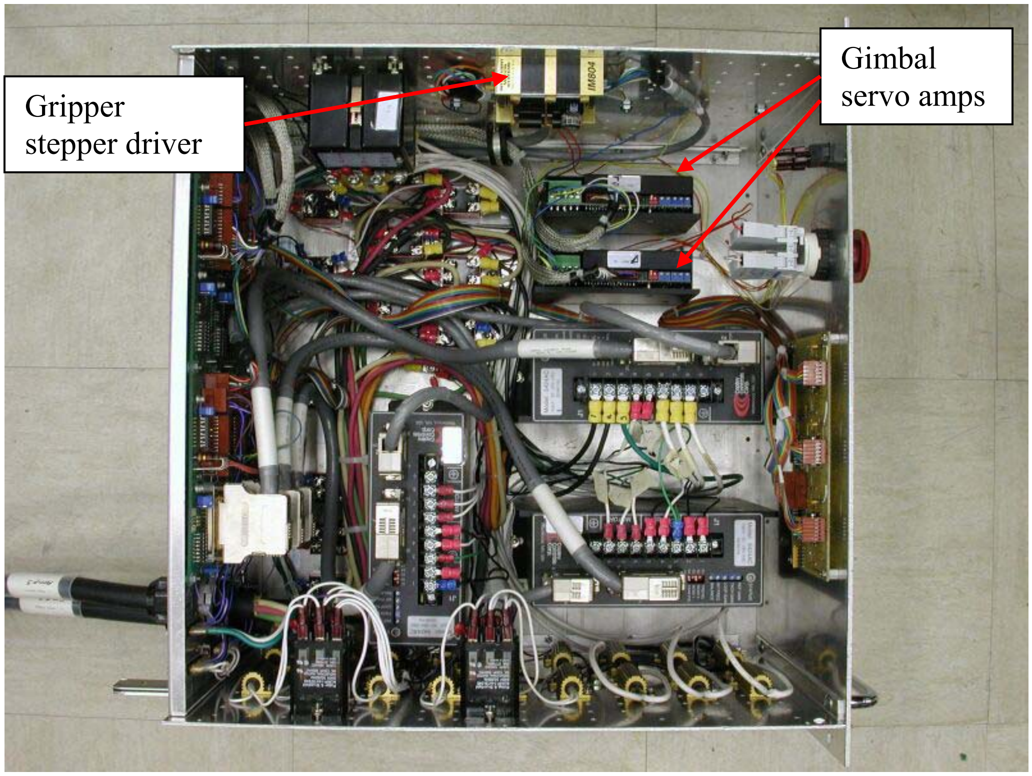


Figure 30. Interior of positioner servo electronics box.

2.3.5 STEPPER SYSTEM

The Stepper System consists of the Stepper Interface Panel, Stepper Drive Plate, Stepper Power Plate, Stepper Controllers, and cable interface panels. The Stepper I/F Panel is a multi layer PWB, mounted on a nineteen-inch standard rack panel. It provides the interface between the SBS Greenspring, VME Bus, multi axis stepper control boards residing in the VME control crate, the stepper drives, and the stepper stage limit and encoder feedback (where present). Its function is analogous to the PMAC Interface Box except that it serves the all of the instruments stepper motors except the Positioner Grippers and the WFC motors. The I/F panel contains opto-isolators, buffer logic, analog muxes, and interlock logic to implement fail-safe motion control on the two spectrograph stepper stages. A state machine controller is also implemented on this board to control the Guider brake solenoids of the Fiber Positioner.

The drive plate contains the Intelligent Motion Systems IM805 stepper drives for each motor as well as the current control drive for the Positioner Guide brake solenoids.

The Power Plate contains the low voltage power supplies for the stepper system, including optical relay control for the drive power of each spectrograph.

The Stepper controllers are SBS Greenspring IP format stepper control modules, optical I/O modules, and analog/digital I/O modules mounted on multi-module carrier on the VME bus. Connection to the Stepper I/F PWB is accomplished by multiple 50-pin SCSI type cables.

The Cable Interface Panels are nineteen-inch aluminum rack panels, cut for D-keyed circular connectors. These connectors are cabled to the interface PWB and are routed, by robust facilities cables to the spectrographs on the third floor. There are matching pairs of cable interface panels for both spectrographs.

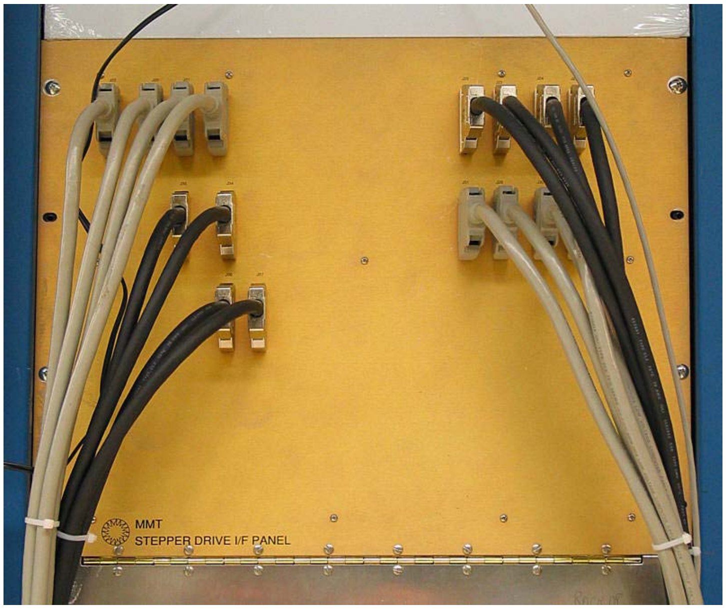


Figure 31. Front panel of stepper interface panel.

2.3.6 RACK POWER SUPPLY BOX

The rack power supply box contains auxiliary power supplies for the gimbal servos, the guider steppers, etc.

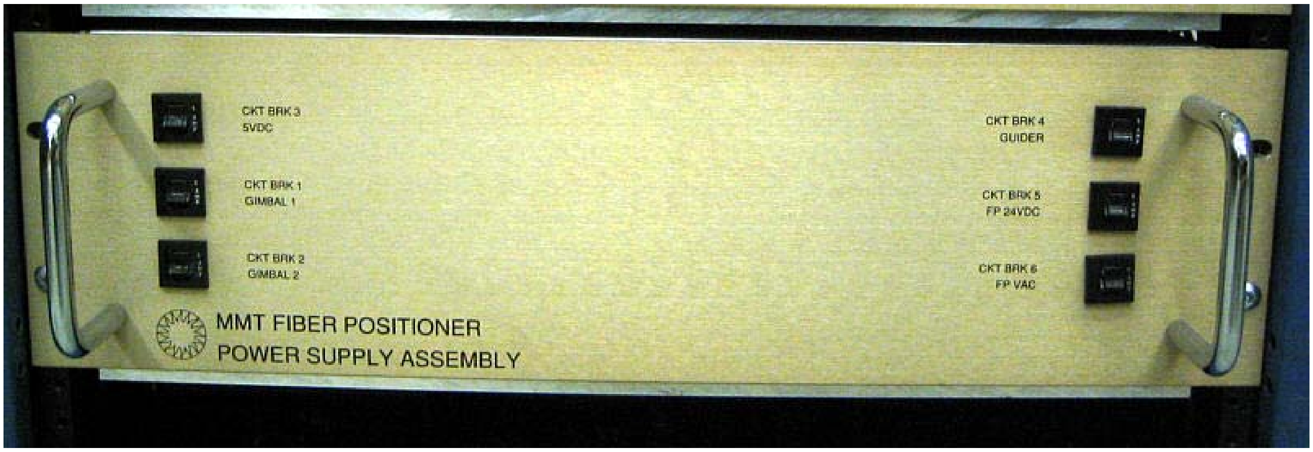


Figure 32. Fiber positioner power supply box.

2.3.7 POSITIONER INTERFACE BOXES

The positioner interface box provides a transition between the heavy-duty Mil-C circular connector facility system cables to the Control Racks and the positioner internal robotic stage assemblies, which use D-subminiature connector cables. The interface board in the positioner interface electronics is identical to the interface board in the positioner I/F box and provides over voltage protection suitable for the type of signal involved. The positioner interface box also contains solid-state relays for switching AC power to the positioner calibration lamp control box. X, Y, and Z motor power is processed through a separate, smaller I/F box located next to the main I/F box.

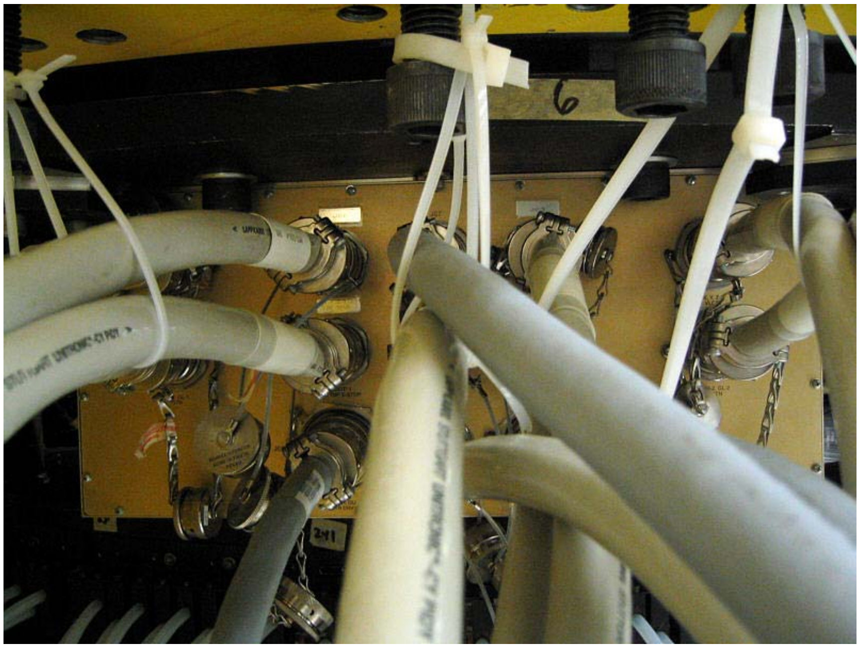


Figure 33. Front panel of main positioner interface box.

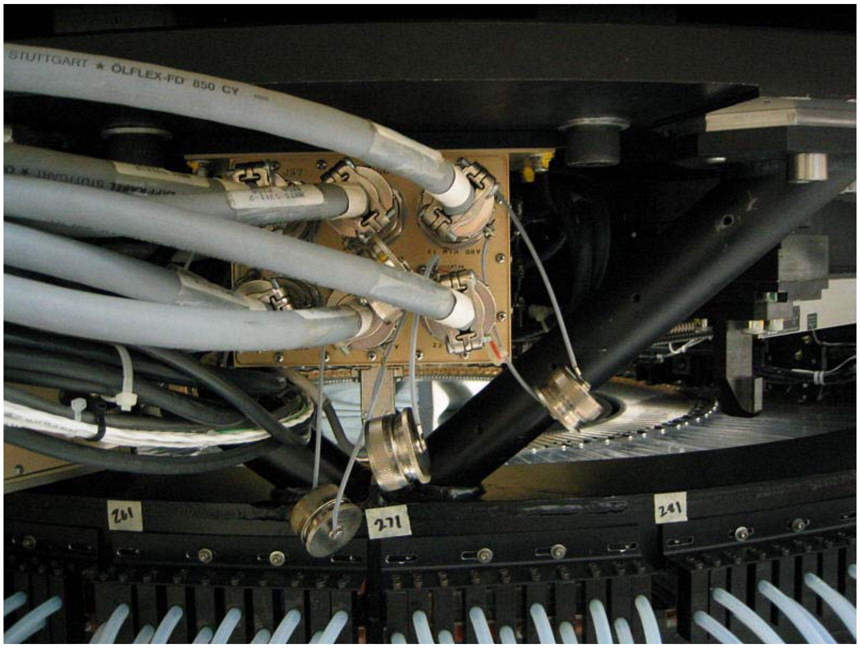


Figure 34. Front panel of secondary X,Y,Z motor power positioner interface box.

2.3.8 POSITIONER ELECTRONICS PROCESSING BOX

The Positioner E/P box provides a number of critical functions. (1) The analog encoder outputs of the Robot One and Robot two T and P axis Newport PM500 actuators are conditioned on separate motherboard daughter cards for subsequent sub count multiplication in external RSF multiplier modules. (2) All of the positioner temperature signals are processed and digitized on an on-board microcontroller PWB. The board has an RS-232 serial interface to the rack electronics which is used to deliver the temperature data and to respond to camera control commands. The camera control electronics section of the controller board provides an ambient light interlocked switched power and analog gain control to each positioner ICCD camera and switched power to each house camera. Separate switched signals are provided to the external positioner calibration lamp control box.

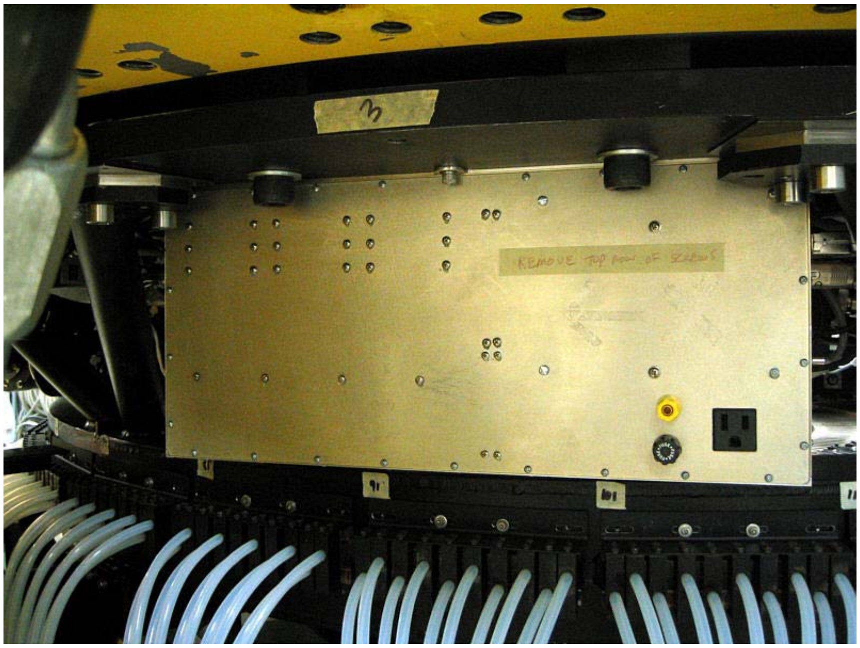


Figure 35. Front panel of EP box on positioner. This contains processing electronics for the temperature sensors, etc.

2.3.9 POSITIONER CALIBRATION LAMP CONTROL BOX

This box receives switched AC power under VME computer control from the Positioner I/F box and two control lines from the E/P box. This allows independent control of each lamp. The camera ambient light sensor is located in this assembly.

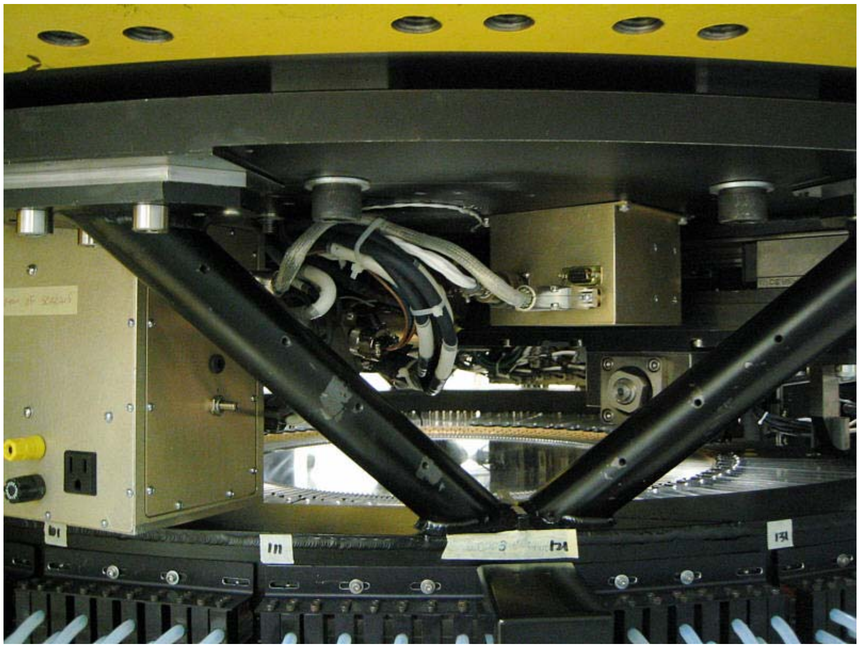


Figure 36. The auxiliary electronics box containing power supplies for the fluorescent lights to illuminate the calibration grid and the photodiode to detect excessive light levels for the intensified TV cameras.

2.4 FIBER POSITIONER SERVO AMP & STEPPER SETTINGS

Axis	Servo Amp	Motor K_t (oz-in/amp)	Induct. (mH)	RH20	Cont Current (amps)	RH14	Peak Current (amps)	RH15
X Axis	Copley 5424AC	217.0	6.4	120K	6.53	6.8K	53.9	out
Y Axis	Copley 5424AC	58.4	1.9	47K	7.58	10K	53.9	out
Z Axis	Copley 5424AC	24.0	5.1	220K	2.76	510	11.5	39K
		Peak Current Duration	RH17	RH20	Cont Current (amps)	RH16	Peak Current (amps)	RH15
T Axis	Copley 421	0.5 sec	1.5M	15K	1.0	1K	6.0	33.3K
P Axis	Copley 421	0.5 sec	1.5M	15K	1.0	1K	6.0	33.3K
		Peak Current Setback[1]			Hold Current (amps)	R(1-2)	Step Current (amps)	R(2-3)
Gripper	IM804 (stepper)	1.5 sec			1.0	1.5K	1.4	680
Guider	IM805 (stepper)	1.5 sec			2.2	open	4.4[2]	2.13K

[1] Setback countdown on steppers occurs after the last commanded step.

[2] ~2.2X rated I_{ct} for the motor.

2.5 FIBER POSITIONER PMAC SERVO PARAMETERS

2.5.1 ROBOT 1

PMAC Parameter	X	Y	Z	T	P	G
Axis Ratio				0.879	0.511	
Proportional Gain	150000	160000	160000	22000	30000	3000000
Derivative Gain	300	500	300	400	300	0
Velocity Feed Forward	300	500	300	400	300	500
Integral Gain	40000	70000	50000	40000	40000	0
Integral Mode	1	1	1	1	1	0
Integration Lim (1/16 cnt)	8000	8000	8000	8000	8000	0
Big Step Limit (1/16 cnt)	8000	8000	8000	8000	8000	400000
Feed Rate (mm/sec)	700	700	120	7	7	30000(cnts/s)
Acceleration Time (msec)	100	100	30	70	70	50
S-curve Time (msec)	30	30	15	20	20	3
Home Offset (mm)	3.299	-20.156	0.871	0.516	-0.351	0(cnts)
Z Fiducial Offset (mm)			10			
Follower Home Offset (mm)	103.334					
Tagup Offset (mm)			-0.820			
Max Velocity (cnt msec^{-1})	2000	2000	2500	25	25	100
Max Accel (cnts msec^{-2})	35	35	80	10	10	10
Position Tolerance (mm)	0.005	0.005	0.005	0.005	0.005	-
In Posit'n Band (1/16 cnt)	160	160	200	320	320	32
Follow Warn (1/16 cnt)	0	0	0	0	0	0
Following Error (1/16 cnt)	16000	16000	4000	16000	16000	5000
Hold Deceleration Rate	6576	6576	6576	6576	6576	6576
Err Decel Rate (cnts msec^{-2})	32	32	80	20	10	10
Dead Band Factor	0	0	0	32	12	-
Dead Band Size (1/16 cnt)	0	0	0	3200	800	-
Gripper Opened (steps)						-100
Gripper Closed (steps)						1100
Backlash Size (1/16 cnt)						0.0
Backlash Take Up Rate						32

2.5.2 ROBOT 2

PMAC Parameter	X	Y	Z	T	P	G
Axis Ratio				0.879	0.511	
Proportional Gain	150000	170000	160000	15000	30000	3000000
Derivative Gain	300	400	300	400	200	0
Velocity Feed Forward	300	400	300	400	200	500
Integral Gain	40000	70000	50000	40000	40000	0
Integral Mode	1	1	1	1	1	0
Integration Lim (1/16 cnt)	8000	8000	8000	8000	8000	0
Big Step Limit (1/16 cnt)	8000	8000	8000	8000	8000	400000
Feed Rate (mm/sec)	700	700	120	7	7	30000(cnts/s)
Acceleration Time (msec)	100	100	30	70	70	50
S-curve Time (msec)	30	30	15	20	20	3
Home Offset (mm)	-0.842	-19.659	0.971	0.003	0.420	0(cnts)
Z Fiducial Height (mm)			10			
Follower Home Offset (mm)						
Tagup Offset (mm)			-0.420			
Max Velocity (cnt msec^{-1})	2000	2000	2500	25	25	100
Max Accel (cnts msec^{-2})	35	35	80	10	10	10
Position Tolerance (mm)	0.005	0.005	0.005	0.005	0.005	-
In Posit'n Band (1/16 cnt)	160	160	200	320	320	32
Follow Warn (1/16 cnt)	0	0	0	0	0	0
Following Error (1/16 cnt)	16000	16000	4000	16000	16000	5000
Hold Deceleration Rate	6576	6576	6576	6576	6576	6576
Err Decel Rate (cnts msec^{-2})	32	32	80	20	20	10
Dead Band Factor	0	0	0	16	12	-
Dead Band Size (1/16 cnt)	0	0	0	3200	800	-
Gripper Opened (steps)						0
Gripper Closed (steps)						1500
Backlash Size (1/16 cnt)						0.0
Backlash Take Up Rate						32

2.6 FIBER POSITIONER SAFETY FEATURES

The Hectospec instrument is a powerful computer controlled positioning system which may best be compared with an industrial machine tool. As such it presents physical safety hazards that are not typically associated with telescope instrumentation. This document outlines the Hectospec operating safety features and procedures to safeguard both the instrument and the operators.

2.6.1 OPERATOR SAFETY

No service procedure should be attempted before the emergency stop button is pushed and the power to the two servo boxes is removed. The telescope should be slewed to zenith before any on-telescope service procedure is attempted.

2.6.2 INSTRUMENT SAFETY

Numerous operation safety checks are designed into the instrument control software to prevent crashing of the two X-axes, as well as crashes into the focal surface at the low end of Z travel and into stage parts at the upper limit of Z travel.

SYNCHRONOUS ROBOT OPERATION: the robots start and complete each move segment before going on to the next segment. Each pick and place motion is broken down into 8 segments:

* XY Motion and Gripper Tilt
* Z Down
* Close Gripper
* Z Up
* XY Motion and Gripper Tilt
* Z Down
* Open Gripper
* Z Up

The two PMAC controllers are connected by a ribbon cable that communicates the segment that the controller is executing to the other controller. A robot is not allowed to proceed to the next segment of a motion until the other controller is also at that segment.

THE ROBOTS ARE CLOCKED BY THE SAME MASTER SERVO CLOCK generated in PMAC 0 (Fred leads, Ginger follows).

HOLD ON ERROR FROM OTHER ROBOT: the cable between the PMAC controllers allows an error bit to be exchanged.

BUFFER ZONE: a minimum distance of ~6 inches is maintained between the two grippers at all times.

SAFE MOVE OPERATION: each paired fiber move is itself safe with regard to robot – robot collision. No complex model of robot motion is needed to predict and avoid robot collisions.

NO XY MOVE OUTSIDE FOCAL SURFACE UNLESS Z IS TAGGED UP: the Z up flag must be on before an XY move outside the focal surface radius is begun. The Z tag up procedure can only begin after the gimbals are leveled.

LIMIT DETECTION: the PMACs will bring all axes to a controlled stop if a limit is detected.

FOLLOWING ERROR: the PMACs can detect a failure to follow the requested trajectory except where the programmed maximum following error is larger than the requested move. If a following error is detected the motion is aborted and the axes are decelerated at the feed hold rate. The control loop remains closed.

ENCODER COMPARISON: for the X and Y axes, the PMACs run a background program that compares the positions obtained from the linear and rotary encoders. The motion is aborted if the two positions differ by more than a predetermined amount.

GRIPPER JAW LIMIT SWITCHES: each of the gripper jaws have a horizontal cut that makes them compliant in the Z direction. If the jaws strike a button or the focal surface by accident, an internal contact between the two jaw sections is activated as a limit switch and motion is halted.

GRIPPER ASSEMBLY IS SPRING MOUNTED: the entire gripper assembly is spring mounted on three linear bearings. When in position, three flat head screws locate the gripper accurately. If the gripper strikes a button or the focal surface, first the jaws deflect and then the gripper assembly breaks away from its preload.

OVER TEMPERATURE SENSORS: each of the motors except the Newport gimbal actuators has a temperature sensor that is displayed on the monitor screen and checked by the software for an out of limit condition.

PMAC WATCH DOG TIMER TRIP: the PMACs output a logic line that indicates if its CPU has failed. If so, motion is halted.

AMPLIFIER FAULT DETECTION: an amplifier fault line runs from each servo amp to the PMAC. Motion is haled if an amplifier fault is detected.

EMERGENCY STOP BUTTON: several emergency stop buttons are available, at the operator's console, at the electronics rack, and on the positioner. If one of these buttons is pressed, motion is halted.

GRIPPER TROUBLE LIGHT: if the gripper jaws are commanded to close and a button is not present in the jaws, the jaws will close more than normal, activating a limit sensor. This is an indication that a button has been dropped, and motion is halted.

AXIS TIME OUT: if the commanded motion profile is not completed within the expected time (plus a little extra time), motion is halted. This prevents motor overheating if a catastrophic failure occurs.

OVER ILLUMINATION SENSOR: a photodiode monitors the light levels in the instrument and turns off power and the gain control voltage to the intensified cameras (in the EP Box) if a threshold light level is exceeded.

2.6.3 START UP PROCEDURE

There are two aspects of starting up the Hectospec: turning on the power to the fiber positioner and bench spectrograph and then initializing (homing) the stages in both the fiber positioner and the bench spectrograph. The power turn on sequence is controlled through Pulizzi power controllers that are network-controllable.

2.6.4 SHUTDOWN PROCEDURE

Before powering down at the end of each observing night, the fibers are returned to their parked position. The automated power down sequence is then initiated.

2.7 FIBER POSITIONER CALIBRATION GRID

Our basic tool for testing and calibrating Hectospec's positioning accuracy is a glass calibration plate (containing an accurate grid of small etched dots) that can be placed on the Hectospec's focal surface. The grid of white dots is illuminated by 25 kHz fluorescent lights carried on board each of the robots. The TV camera aboard each of the robots is used to centroid the images of the etched dots and to calibrate the motion of the robots at various instrument orientations. The spacing between dots is 5 mm over most of the grid. In addition, perpendicular 4 mm-wide bands with 1 mm dot spacing run through the center of the grid. The grid axes are approximately aligned with the X and Y robot axes. The grid is pinned into position (on the focal plate ears that also hold the fiducial fibers) when the grid is in use, so the grid placement is repeatable to high accuracy. The grid sits on top of the focal surface, and the grid surface sits ~6 mm above the edge of the focal plate. The accuracy of the dot positions is advertised to be 6 μm.

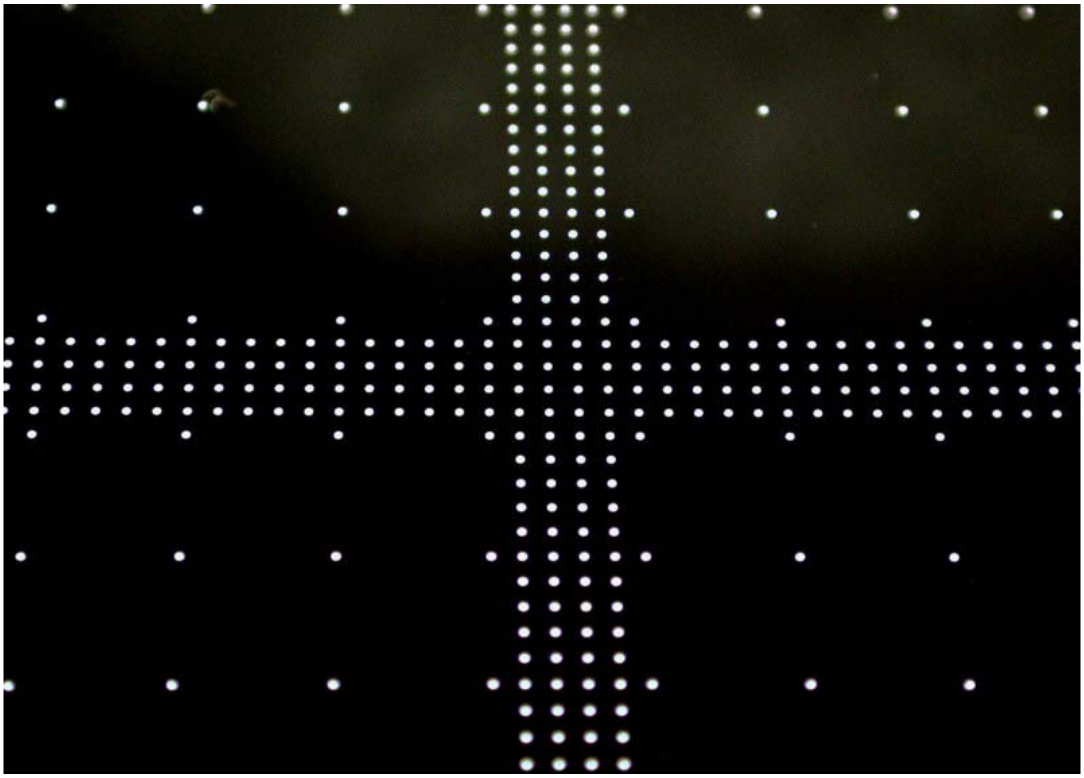


Figure 37. Central portion of calibration grid.

3 HECTOSPEC BENCH SPECTROGRAPH & FIBERS

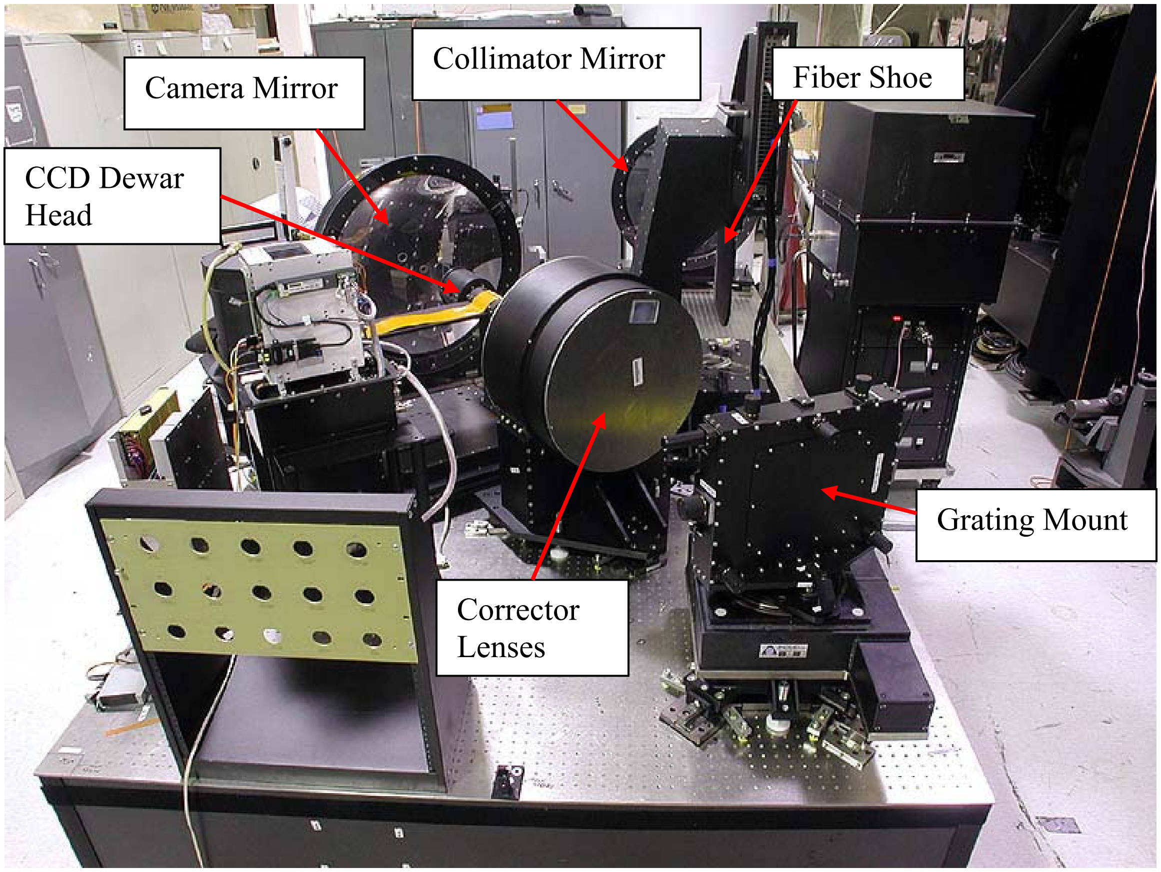


Figure 38. Hectospec Bench Spectrograph in the lab just prior to shipment.

3.1 INTRODUCTION

The optics of the bench spectrograph are quite simple. A spherical collimator mirror operating at f/5.4 is used because the imaging is independent of field angle if the fibers are arranged so as to point at the local normal to the mirror. At f/5 the spherical aberration is negligible. The camera is also a reflective system with a spherical mirror and two all-spherical silica corrector lenses and a silica field flattener lens that serves as the dewar window. The camera is based on the Keck HIRES camera, and was designed by Harland Epps.

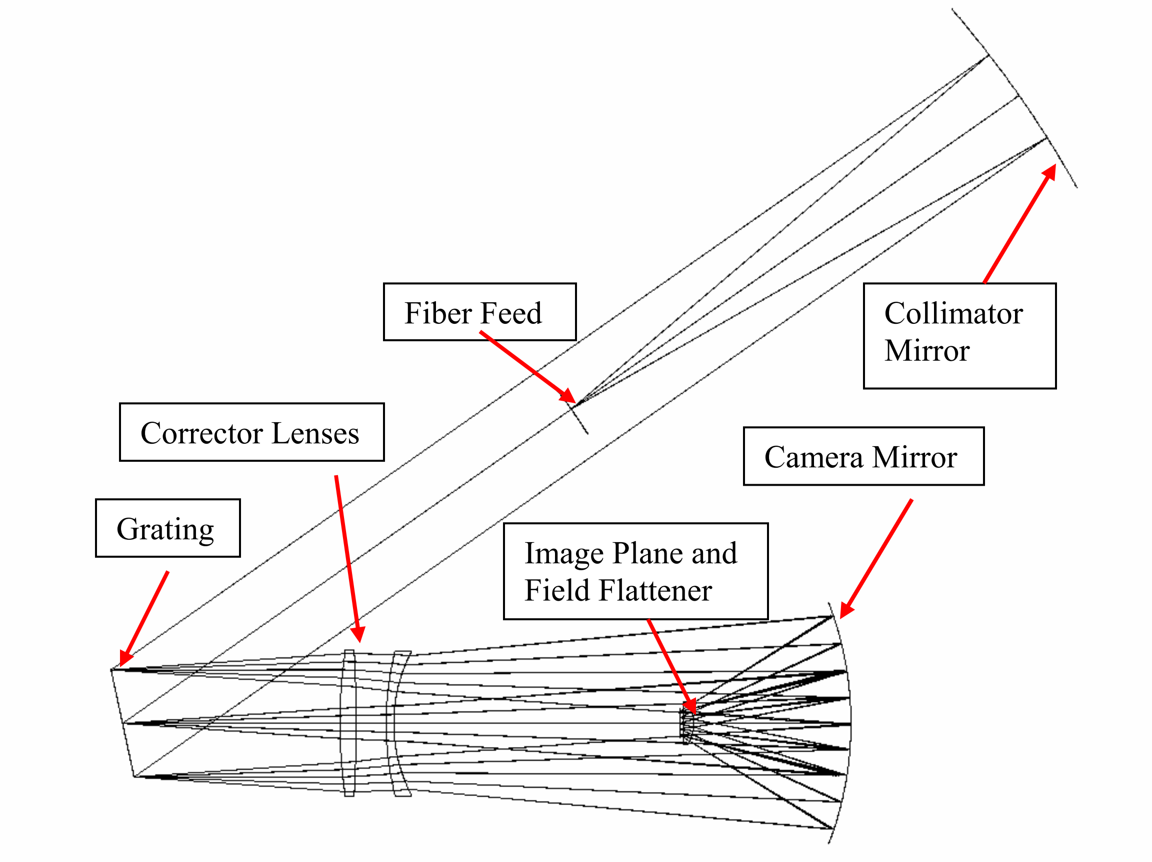


Figure 39. Optical layout of the bench spectrograph. The fibers are arranged in a line perpendicular to the plane of the page.

3.2 OPTICAL FIBER RUN

3.2.1 OPTICAL FIBER SPECIFICATIONS

Originally, we planned to place the bench mounted spectrograph in the back of the telescope, which would have allowed a total fiber length of ~10 m. However, the logisitics of storing the fiber positioner and two bench spectrographs forced us to move both spectrograph benches to a permanent, but more remote home above the observing floor. As a result, the required fiber length grew to 26 m, and transmission losses in the fiber became of greater concern. Traditionally two types of all-silica optical fibers have been available: high OH fibers that transmit well into the blue, but that have OH absorption features in the red, or low OH fibers that transmit well from ~0.5 to 2 μm. Neither of these choices appeared ideal so DGF contacted Hereaus-Amersil, a large supplier of fiber optic preforms to explore the limitations of fiber preform technology. After a period of research, Hereaus-Amersil developed a new type of broad-band, low OH fiber preform (“STU”) that transmits well from 0.35 to 1.8 μm. We restrict ourselves here to comparing the transmissions of 26 m of the conventional low OH, high OH and STU fibers in Figure 40. The STU transmission for the Hectospec fiber exceeds the minimum performance specified by Hereaus-Amersil. The intrinsic focal ratio degradation in this fiber is very low: ~95% of all the light transmitted by a 25 m length of fiber remains within an f/6 cone if the fiber is fed with an f/6 beam and care is taken to avoid stressing the fiber.

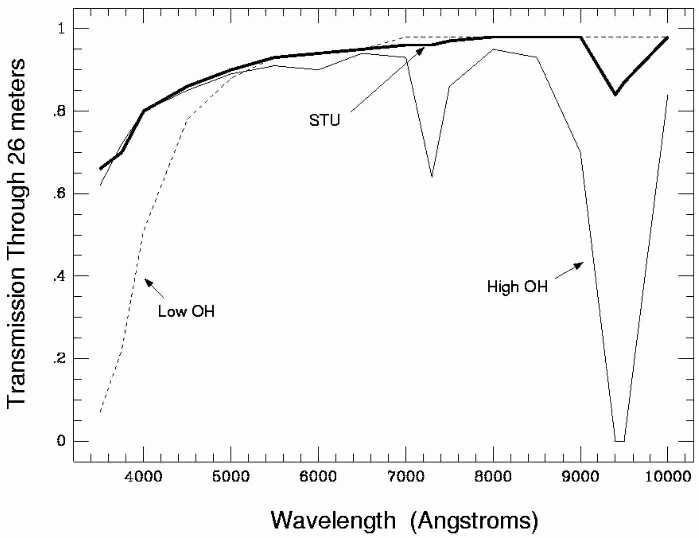


Figure 40. Comparison of the adopted STU fiber with previously available options.

3.2.2 FIBER MOUNTING AND ROUTING

The mounting of the optical fibers in their magnetic buttons and at the spectrograph input slit as well the handling of the fibers between the fiber positioner and the spectrograph can have a large effect on the spectrograph throughput. The focal ratio of the light emerging from the fiber is easily degraded (made faster) if the fiber is stressed. The overall transmission of the fiber is usually unaffected, but to avoid degrading the image quality we place a mask on the Hectospec grating that limits the collimated beam diameter. For us, therefore, focal ratio degradation (FRD) translates directly to a loss of throughput. Attention to detail is important if the excellent focal ratio preservation that we measure under ideal conditions in the laboratory is to be realized at the telescope. We have invested a good deal of time in prototype testing in an effort to uncover and liminate sources of focal ratio degradation.

We have known at least one good method of terminating fibers for some time: attaching them to carefully machined and deburred V-grooves with small drops of silica-filled epoxy. We have had such good luck with this approach that we adopted it for Hectospec. Both the fiber button and the spectrograph input slit have machined grooves as shown in

Figure 41 and Figure 42, although the button groove has a rectangular cross section rather than a V cross section. We spent most of our time worrying about the 26 m of fiber between these V-grooves!

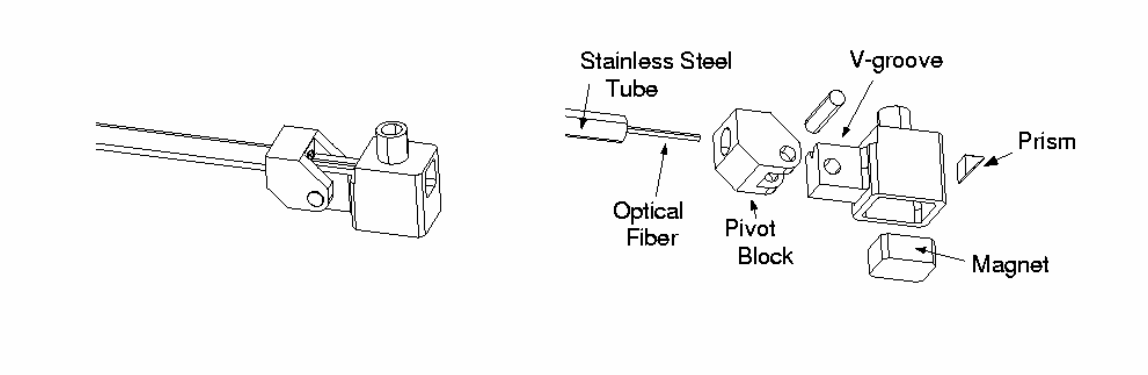


Figure 41. Hectospec Fiber Button

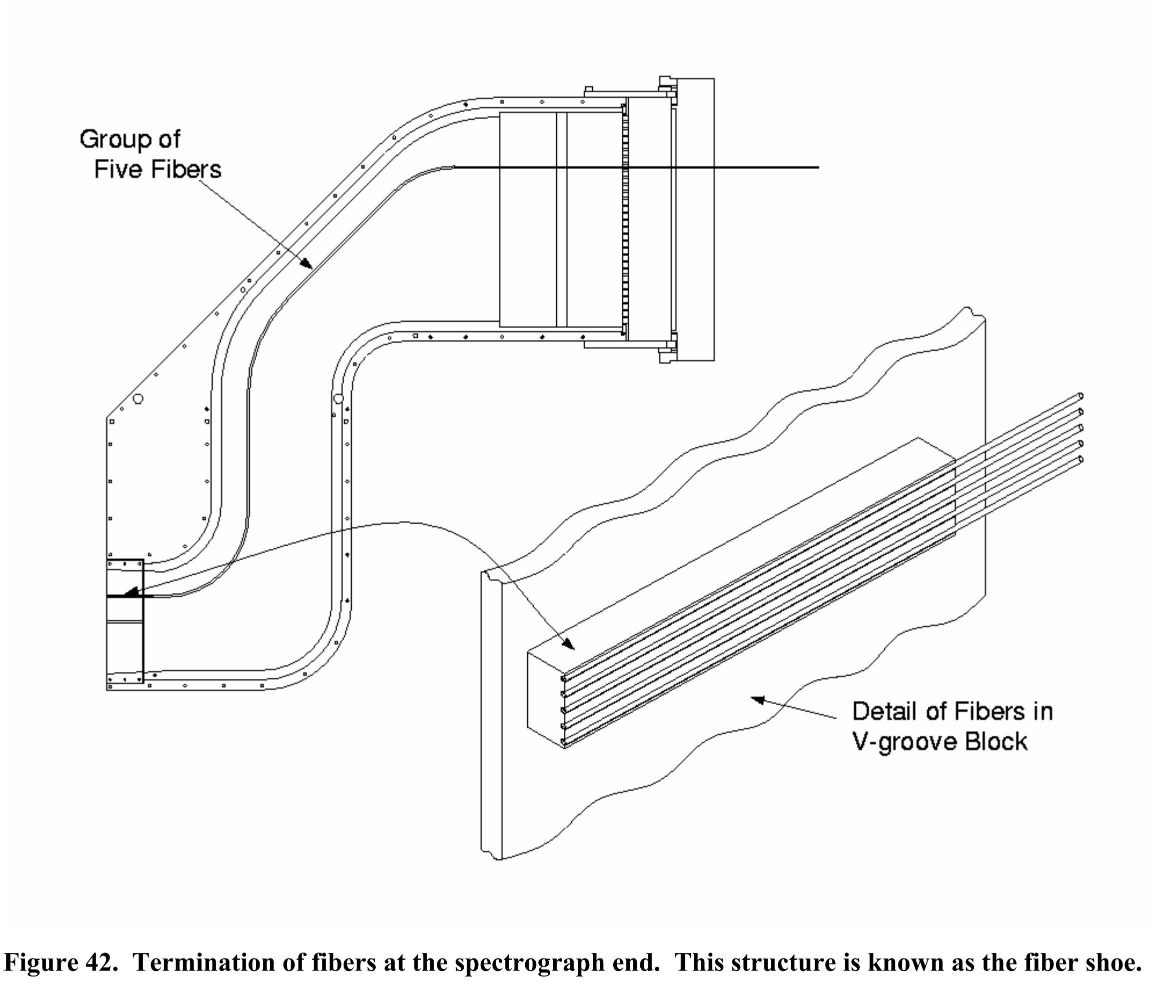


Figure 42. Termination of fibers at the spectrograph end. This structure is known as the fiber shoe.

Optical fibers are commonly placed in plastic tubes of some variety as a first level of protection, and we have found no way of improving upon this plan. The ideal plastic tube would be very slippery (to avoid putting frictional loads into the fibers), kink-proof and with no ``memory'' (for ease of handling). We find that TFE Teflon tubes have the first two properties, which we think are most important. To reduce frictional loads further, we find that a loose fitting Teflon tube is advantageous: we use a tube with a 1.4 mm ID surrounding an 0.3 mm OD fiber. We group five teflon-clad fibers together in a woven, slippery, nylon tube for additional protection, ease of handling and fiber identification.

Even though friction between our polyimide buffered fibers and the Teflon tubes is low, we have experimentally determined that the large difference in the coefficients of thermal expansion of Teflon (or any other plastic) and the silica fiber can lead to stress and FRD. We constructed a long optical fiber refrigerator in the laboratory to search for FRD associated with the differential contraction at the low temperatures encountered at the telescope. Our fiber refrigerator was constructed from nested copper tubing, cooled by liquid flowing between the tubing. This configuration allows efficient cooling and a dry fiber. During such a test the fiber should *not* be coiled, because in this case the clearance between the fiber and its protective tube may take up much of the differential contraction. The most severe case appears to be the most realistic one: when a few bends are introduced in an otherwise straight run of fibers. Here, the increased friction at the bends prevent the Teflon tube from freely slipping by the fiber and the shrinking tube pulls the fiber against the bend.

THERMAL BREAKS TO AVOID THERMAL STRESS

We developed a simple means of relieving the stresses caused by the shrinking Teflon tube that we call a “thermal break”. A thermal break is simply a break in the Teflon tube to ease differential thermal contraction. The cut ends of the Teflon tube must be carefully deburred and kept in alignment (we use metal tubing) to avoid creating stress points. A schematic thermal break is shown in Figure 43. We place thermal breaks at every major bend in our fiber run.

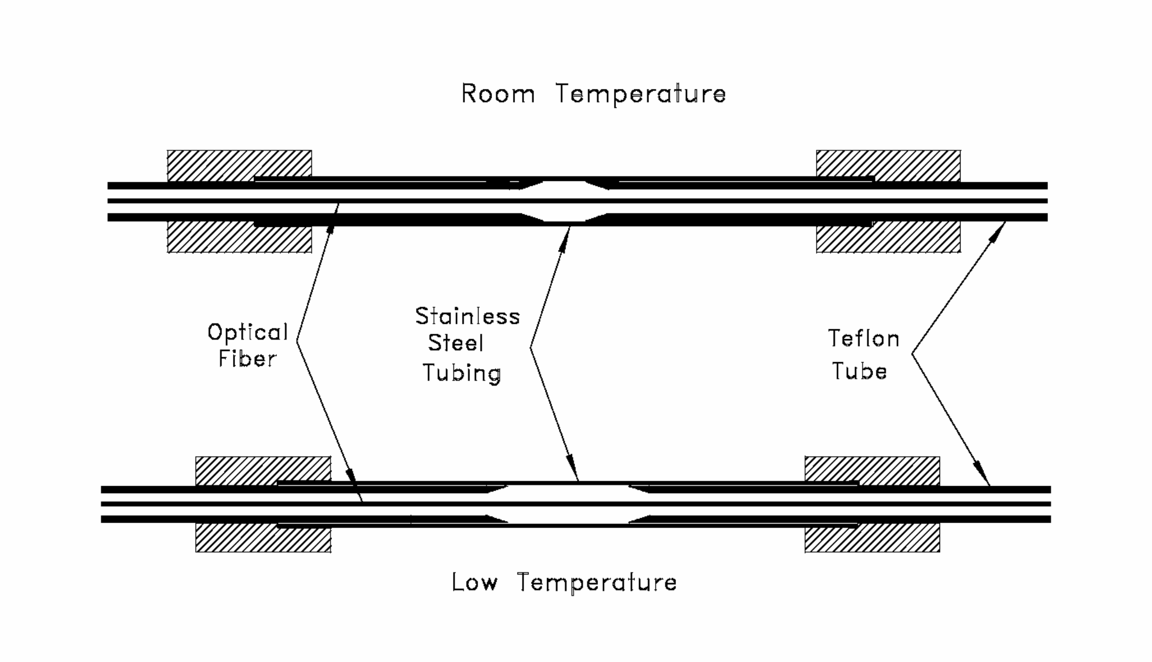


Figure 43. Thermal break in fiber run.

GUIDE CHAIN FOR FIBER PROTECTION

Fibers are sometimes gathered in large diameter metal or plastic tubes for protection over the long run between the telescope and spectrograph. Although this bundling technique is straightforward mechanically, it may introduce stress and FRD as the bend direction of the tubing changes. The path length differences for fibers on the inside and outside of the bend are potentially large, and the fibers will attempt to move sideways past each other in the tube as it is bent in opposite directions. We have minimized stresses due to changing path lengths by adapting cable carriers (see Figure 44) that were designed to carry electrical cables between a stationary point and a moving linear stage. These cable carriers are constructed as chains, and can be designed to bend in only one direction or to bend into S-shapes. We use both types in our fiber run. We minimize the path length changes imposed on the fibers by holding them very near the central axis of the guide chain with soft Velcro strips.

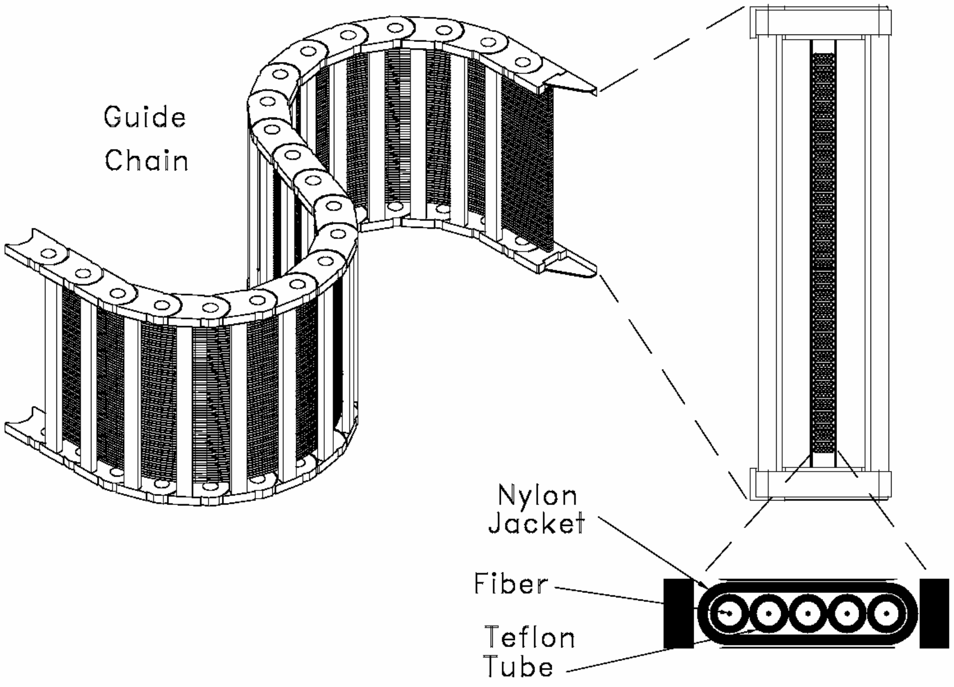


Figure 44. Fiber guide chain.

FIBER ROUTING INSIDE HECTOSPEC

The most complex part of the fiber run between the focal plane and the spectrograph is inside the fiber positioner as shown in Figure 45. The fibers must be gathered from their radial positions at the edge of the focal surface into a more compact arrangement, and run through a derotator that compensates for the motion of the MMT's (alt-azimuth mount) instrument rotator. After leaving the focal surface, the fibers pass through: (1) pivot points, (2) bi-level horizontal separator trays that allow ±3° of lateral motion, (3) Teflon guide tubes and (4) vertical separator trays where a fiber coil takes up the length changes associated with the radial fiber travel across the focal surface. Upon exiting the vertical shelves, the fibers are gathered into groups of five and dressed around a central cone to take up differences in the fiber lengths between the focal surface and the entrance to the fiber derotator. The derotator uses a length of guide chain and is passively driven by the MMT's instrument rotator.

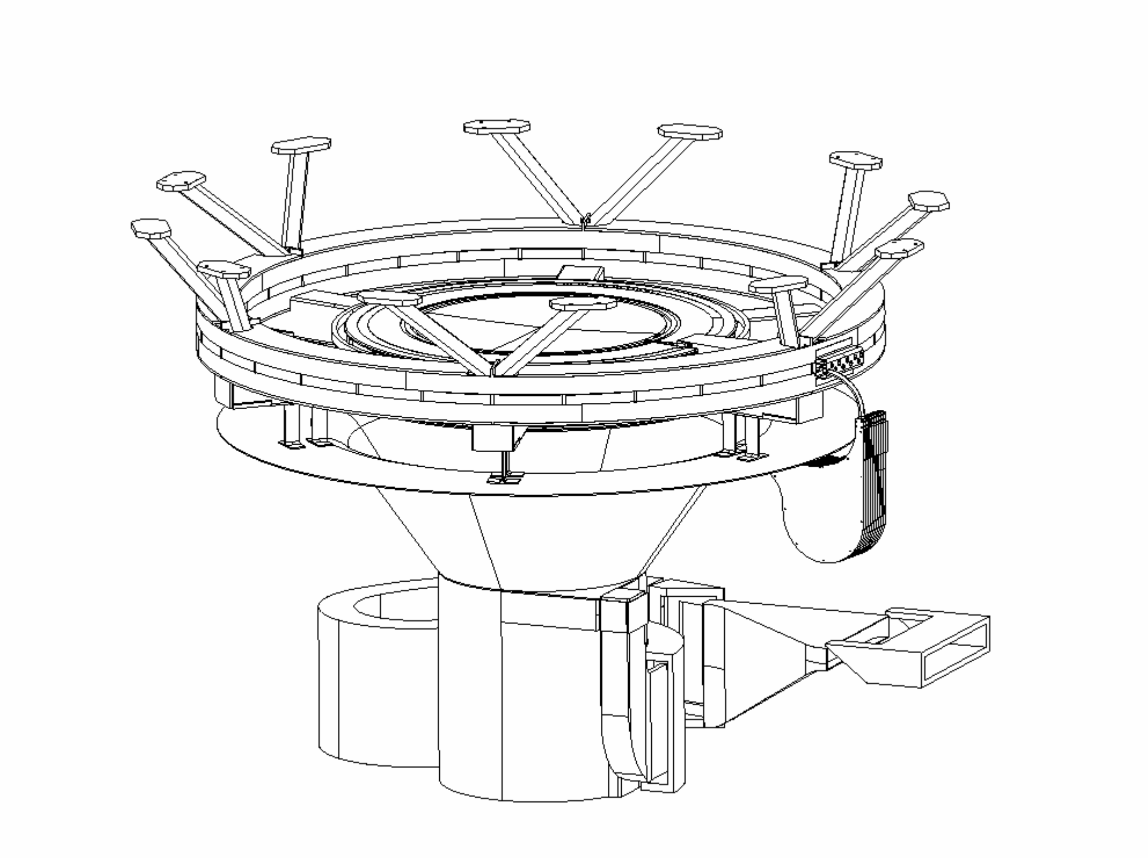


Figure 45 . Fiber routing from the focal surface to its exit from the fiber positioner. The upper portion of the fiber positioner containing the mounting flange and positioning robots is removed for clarity.

3.2.3 MOVING FIBER SHOE BETWEEN HECTOSPEC AND HECTOCHELLE

The fiber shoe is mounted on a trolley mechanism that supports the fiber shoe and fiber chain when it is moved between Hectospec and Hectochelle. The shutter travels with the shoe, and so do the shutter's electrical cable. Switches on the shoe mounts allow remote sensing of fiber shoe/dummy shoe/no shoe conditions.

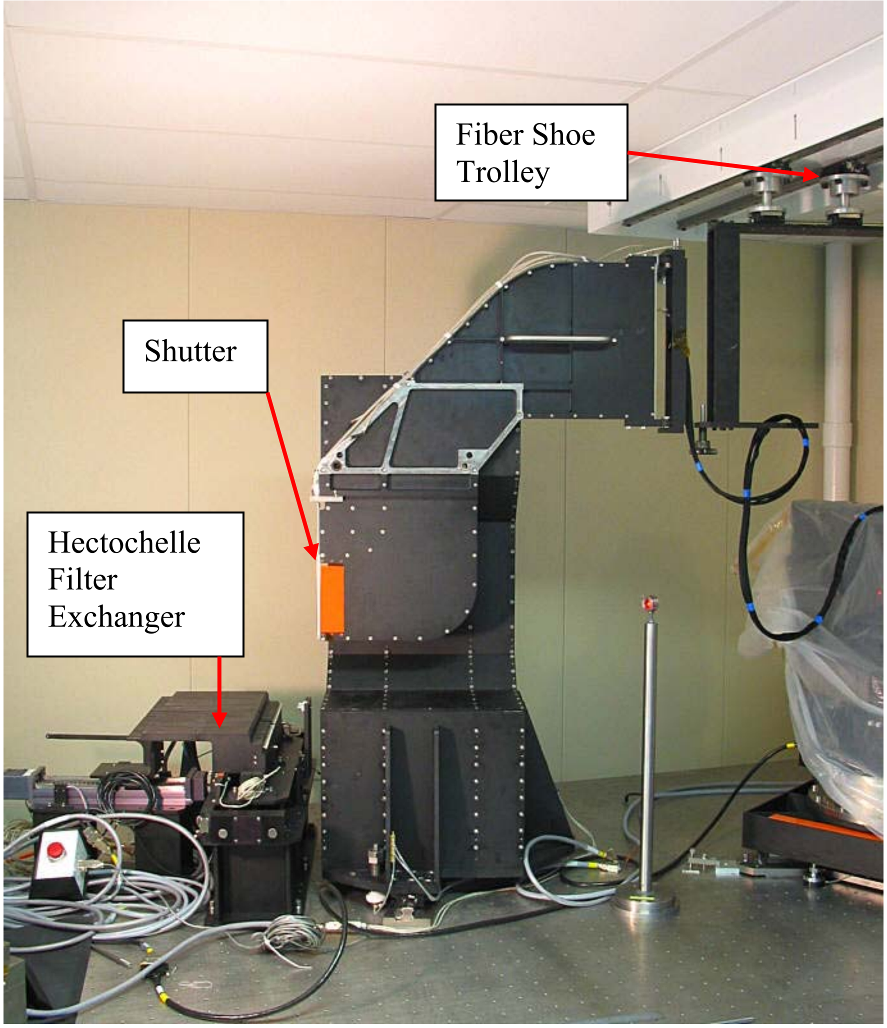


Figure 46. Fiber shoe and trolley. The fiber chain is not installed in this picture.

3.3 BENCH SPECTROGRAPH

3.3.1 OPTICAL DESIGN PARAMETERS

Collimated beam diameter	259 mm
Camera focal length	397 mm
Fiber core/cladding/buffer	250/275/300 µm
Reduction (spatial)	3.45
CCD format (max)	4608x4096 pixels
CCD format (nominal)	3400x3400 pixels
CCD pixel size	13.5 µm
250 µm fiber sampling	5.4 pixels
Max. monochromatic beam to camera	259x344 mm
Camera field radius	4.7°
Camera-collimator angle	35°
Camera-grating distance	546 mm
Camera entrance aperture	411 mm

SPECTROGRAPH OPTICAL PRESCRIPTION (MM)

```
File : C:\docs\Zemax_Files\hecto\R815_270_as_built_thk.ZMX
Title: HECTOSPEC, RUN 815, 5/17/94
Date : WED MAR 19 2003

Surf   Type        Radius     Thickness   Glass  Diameter   Conic
 OBJ STANDARD     -1375.105   -1371.600           148.345      0
 STO STANDARD      Infinity    1371.600           254.000      0
   2 STANDARD     -1375.105    1373.060           148.350      0
   3 STANDARD     -2748.153   -2748.788   MIRROR  548.278      0
   4 COORDBRK            -        0            -    -
   5 DGRATING      Infinity       0       MIRROR  275.647      0
   6 COORDBRK           -       546.100           -    -
   7 STANDARD      1247.082      40.749    SIL5C  364.794      0
   8 STANDARD     -3195.945      75.446           365.375      0
   9 STANDARD       748.157      19.164    SIL5C  363.988      0
  10 STANDARD       387.373    1147.005           357.365      0
  11 STANDARD      -844.093    -394.829   MIRROR  605.782      0
  12 STANDARD      -102.083     -25.105    SIL5C  106.132      0
  13 STANDARD      -582.981      -9.446            90.059      0
 IMA STANDARD      Infinity                        71.338      0
```

For a central wavelength of 6563 Å:

```
Coordinate Break    Surface 4:      Tilt About X   : 22.83°
Diffraction Grating Surface 5:      Lines / Micron :  0.27
Coordinate Break    Surface 6:      Tilt About X   : 12.17°
```

3.3.2 GRATING CHOICES

The initial grating is a 270 groove/mm grating blazed at 5200 Å purchased from David Richardson Grating Laboratory. The spectral coverage, spectral resolution, anamorphic magnification, grating angles and RMS image diameters with this grating and two possible higher dispersion gratings, all set up with Hα as the central wavelength, are shown below.

Ruling Density (gpm)	Spectral Coverage (Å)	Spectral Resolution (Å)	Anamorph. Mag.	Angle of Incidence	Angle of Diffraction	RMS Image Diameter (pixels)
270	4488-8664	6.2	1.06	22.83	12.17	1.3-1.8
600	5609-7522	2.6	1.14	29.41	5.59	1.3-1.8
1200	6084-7038	1.1	1.33	41.89	-6.89	1.4-1.7

3.3.3 FIBER SHOE LAYOUT

AT THE SHOE THERE ARE TWO ROWS OF 150 FIBERS

- Radius of Curvature of Fiber Ends (Fiber Direction): 54.138 inches

- Separation between rows is 0.065 inches equivalent to 0.0688 deg, +/-0.0344 deg. The left row is on your left as you face the collimator.

- In each row, the fibers are spaced by 0.040098 degrees but the rows are offset such that the fiber to fiber spacing in opposite rows is 0.020049 degrees.

- The gap at the center of the fiber shoe is larger to accommodate the gap between the CCDs. This gap is 0.212666 degrees.

Left Row Positive angles are rotations away from the optical bench.
+3.093634 deg for outermost top fiber
+0.126382 innermost positive
-0.106333 innermost negative
-3.073585 deg outermost negative fiber

Right Row
+3.073585 deg for outermost fiber
+0.106333 innermost positive
-0.126382 innermost negative
-3.093634 outermost negative fiber

AT THE CCD

- The fiber images are spaced by 0.1379 mm center-to-center in the spatial direction at the center of the field. This corresponds to 10.2 pixels.

3.3.4 CCD AND DEWAR

The CCDs are mounted in a dewar head at the end of a long cold strap to minimize the vignetting in the on-axis camera.

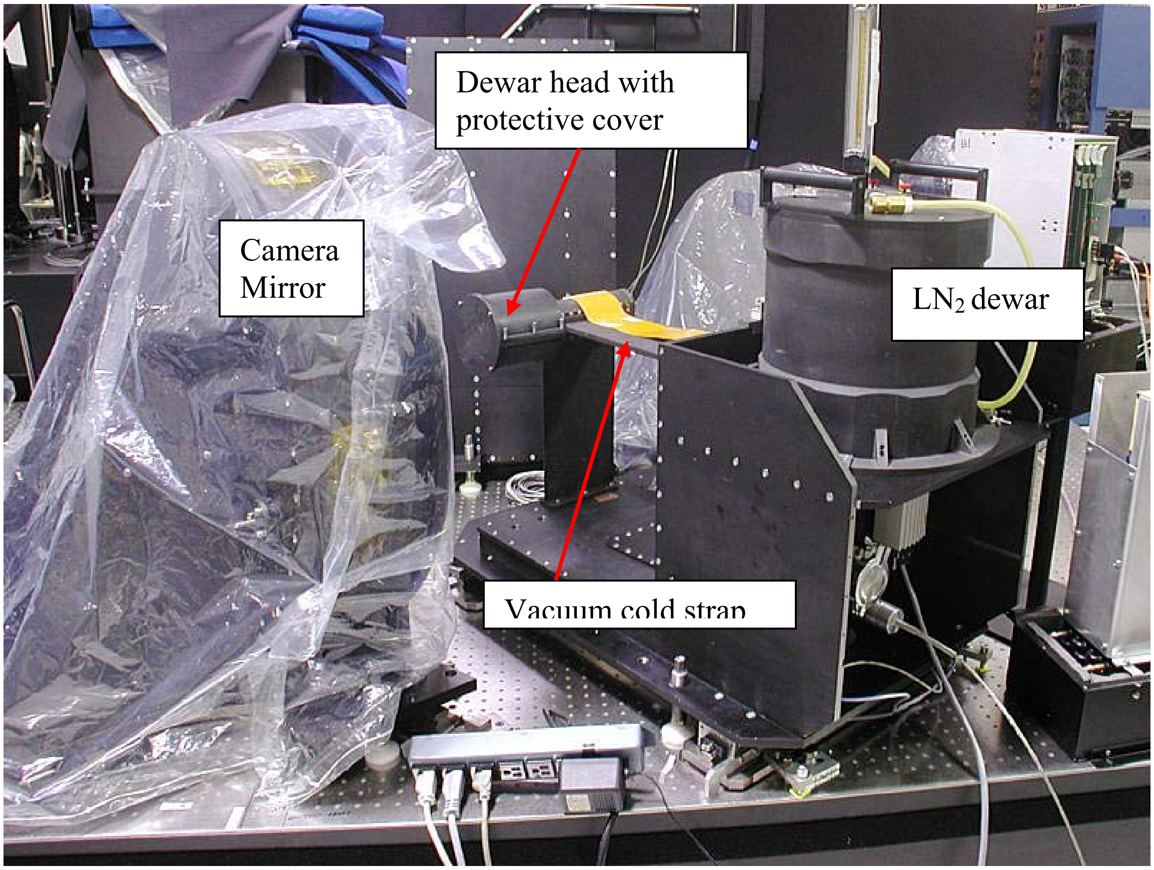


Figure 47. Dewar assembly. The field flattener is covered with a protective enclosure.

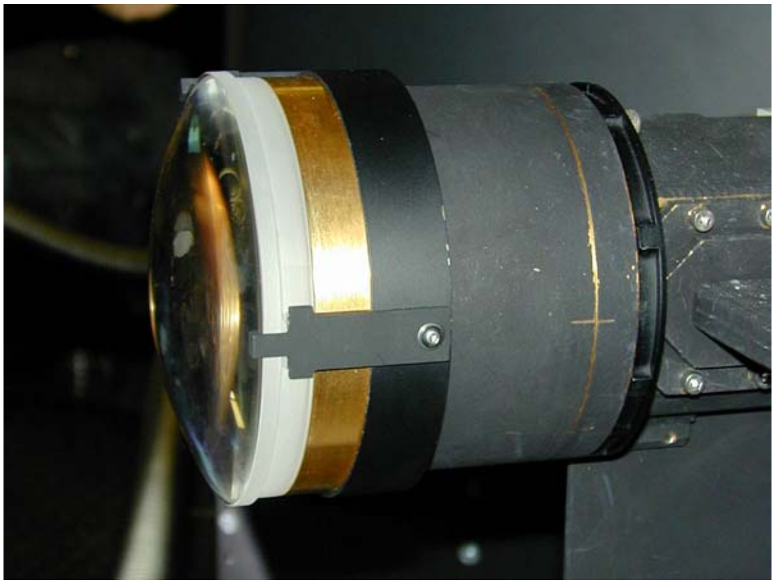


Figure 48. Closeup of dewar head and the field flattener lens that serves as the dewar window.

3.3.5 BENCH SPECTROGRAPH THROUGHPUT

THROUGHPUT

The Hectospec optical layout is simple enough that very high throughput can be achieved if good reflective coatings are used on the mirrors (2 surfaces) and good antireflection coatings are used on the lenses (6 fused silica surfaces). We have used the same dielectrically-enhanced silver reflective coatings and Sol-gel antireflection coatings that we used in the efficient FAST spectrograph. Our predictions for Hectospec's overall throughput are shown below. The column labeled "Add. Fiber Losses" includes FRD, end reflection losses, and the losses from misalignments of the fiber axis with respect to the chief ray at the f/5 focal surface.

Wavelength	Mirror Refl. (2 surf.)	Lens Throughput (6 surf.)	Fiber Throughput (26 m)	Add. Fiber Losses	CCD Effic.	Camera Vign.	Grating Effic.	Final QE
3650	0.81	0.89	0.70	0.80	0.66	0.80	0.37	0.08
4000	0.96	0.92	0.80	0.80	0.80	0.80	0.49	0.18
5000	0.96	0.98	0.90	0.80	0.85	0.80	0.66	0.30
6000	0.97	0.98	0.94	0.80	0.80	0.80	0.61	0.28
7000	0.96	0.98	0.96	0.80	0.75	0.80	0.53	0.23
8000	0.97	0.95	0.98	0.80	0.60	0.80	0.43	0.15
9000	0.97	0.91	0.98	0.80	0.30	0.80	0.37	0.06

3.4 BENCH SPECTROGRAPH MOTION AXES

3.4.1 SHUTTER

DESCRIPTION

LOAD

MOTOR

FEEDBACK

3.4.2 GRATING ROTATION

DESCRIPTION

LOAD

MOTOR

FEEDBACK

3.4.3 CAMERA FOCUS

DESCRIPTION

LOAD

MOTOR

FEEDBACK

3.5 BENCH SPECTROGRAPH STEPPER SETTINGS

		Peak Current Setback[1]			Hold Current (amps)	R(1-2)	Step Current (amps)	R(2-3)
Shutter	IM805 (stepper)	1.5 sec			low	21	0.416	208
Grating	IM805 (stepper)	1.5 sec			~0.25	140	2.7	1363
Focus	IM805 (stepper)	1.5 sec			~0.25	140	2.7	1363

[1] Setback countdown on steppers occurs after the last commanded step.

4 FIBER POSITIONER SOFTWARE

The Hectospec fiber positioner uses three computers: (1) ***hecto***, a VME Motorola 167 single board computer that handles communications with the PMAC motion control boards, (2) ***snappy***, a rack mounted PC that contains three frame grabbers for the two intensified robot cameras and the intensified guide camera, as well as the serial interface to the EP Box, and (3) ***fiber***, a free standing PC that runs the high level control software. All three computers run LINUX.

All Hectospec software conforms to a series of standards: …

4.1 HOBBS DISPLAY AND CONTROL WINDOW

This large window displays the current position and status of all of the motion axes. In addition, pop up windows allow the properly authorized user to change the servo parameters, home offsets, etc. This function will not be enabled for the observer.

4.2 FIBER PROBE POSITION DISPLAY WINDOW

This window provides a graphical near real time display of the position of the robots and the fiber probes on the focal surface.

4.3 FIBER POSITIONER CONTROL SOFTWARE

4.3.1 TOP LEVEL USER COMMANDS

```
powerup
poweroff

home
stow

seq2cfg <configfile>
abort   <robot>
```

4.3.2 HIGH LEVEL COMMANDS

```
zregs

placert <robot> <fiber> <radius> <angle>
place   <robot> <fiber> <x> <y>
pick    <robot> <fiber>
park    <robot> <fiber>
```

```
gobtn   <robot> <button>
gofid   <robot> <fiducial>
goidle  <robot>
```

4.3.3 LOW LEVEL COMMANDS

POSITIONER CONFIGURATION STATE

```
stowedsafe

init
config
status
statusof <fiber>

atpark   <fiber>
atxy     <fiber> <x> <y>
caste    <robot> <x> <y>
casteon
```

OPERATING ON FIBER CONFIG FILES

```
seqfibs
fitfibs
adjfibs

cfgdump
chkfibs
prkfibs
```

POSITIONER AXES

```
sequence

mxytp   <robot> <x> <y>
mxytprt <robot> <fiber> <radius> <angle>

xymov   <robot> <x> <y>
rtmov   <robot> <fiber> <radius> <angle>
xyz     <robot> <x> <y> <x>
xyzd    <robot> <x> <y> <x>

tpmov   <robot> <t> <p>
phome   <robot>
thome   <robot>
tmove   <robot> <t>
pmove   <robot> <p>
```

```
xhome1  <robot>
xhome2  <robot>
xmove   <robot> <x>
xbrake  <robot> <on|off>

yhome   <robot>
ymove   <robot> <y>
ybrake  <robot> <on|off>

zhome   <robot>
zmove   <robot> <z>
ztagup  <robot>
zup     <robot>
zdown   <robot>
zbrake  <robot> <on|off>

ghome   <robot>
gmove   <robot> <g>
gopen   <robot>
gclose  <robot>
gripoff <robot>

gforceopen <robot>

g1home

g2home
g3home

g1move   <angle>
g2move   <angle>
g3move   <angle>
g123move <angle1> <angle2> <angle3>
```

MISCELLANEOUS

```
checktrouble <on|off>
clear
comp
hconfig
pmac
pulzpow
state
testnumber
usetpgrid
```

```
usexygrid
value
```

4.4 FIBER POSITIONER CALIBRATION SCRIPTS

A series of calibration scripts are used to acquire and reduce fiber positioner calibration data.

HIGH LEVEL SCRIPTS

```
hctcal_dots_scan
hctcal_fid_center
hctcal_flat_scan
hctcal_kamen_scan
hctcal_run_seq2cfg
hctcal_xyrep_place
hctcal_xyrep_placert

measfids

measbtn <robot> <button>
measdot <robot> <x> <y> <z>
measfid <robot> <fiducial>
measnotsodummies

movecenter <robot>
```

CAMERA AND LIGHT CONTROL

```
house <on|off>
light <n> <on|off>
centertable      <robot> <box> <number of centroids> <frames per centroid>
centertablebias <robot> <box> <number of centroids> <frames per centroid>

setbox <image> <x> <y> <exposure> <radius> <bkradius> <bkwidth> <width> <height>
setbias
setmode <robot> <mode>


getbox  <image>
getmode <robot>
getxyz  <robot>

clrbias
```

4.4.1 TV GUIDER COORDINATES

The TV guider is used to image calibration grids and fibers for calibration purposes. The scale of the TV guider is ~20 µm pixel^{-1}. The TV guider image is sent to a framegrabber for analysis.

All code in the framegrabber part of the snappy image acquisition code indexes the framegrabber buffer with 0 (zero) based coordinates. All guider, guide image and ds9 display code uses IRAF style 1 based image coords. All parameters passed to the code from clients and values returned for use and display are 1 based.

The position of the accumulator box that is extracted from the framegrabber for processing (frame averaging) is computed with integer values. The center of this box may be up to 1.5 pixels off from specified TV center.

4.4.2 X, Y GRID CALIBRATION

The large calibration grid has been used to calibrate the X and Y axis of the Hectospec fiber positioner. After measuring the positions of every fourth dot on the grid data were smoothed and reduced to a table of linear fits of subsections of the grid in a format acceptable to the Hectospec positioner control software.

We obtained the data in four successive subgrids at 20 mm spacing, ending with sampling on a 10 mm spacing. We smoothed these data over a 40 mm spacing (5 grid points) producing a smoothed data grid sampled at 10 mm intervals. For every 10 mm box defined by 4 grid points, we select all the points within +/-16.5 mm (up to 16) and fit a bilinear function X_cor = a + b*X + c*Y, etc.

Data Acquisition Scripts	
hctcal_grid_cal	Make a grid scan of one subgrid
hctcal_grid_scan	Make a generalized grid scan
hctcal_grid_snap	Snap a sequence of centroid to assess camera noise
Data Analysis Scripts	
hctcal_grid_cal_reduce	Reduce a sequence of offset subgrids to a single grid file
hctcal_grid_gridreduce	Reduce a data log file to a grid file
hctcal_gridfit	Fit measured grid points from a grid file to their actual positions
gridsmooth	Smooth a grid five with a 5x5 box

Printing Scripts	
hctcal_print_grid_scan	

4.4.3 KAMAN SENSOR SCRIPTS

The Kaman scans are executed with the script **hctcal_kamen_scan**. This script now automatically computes the rotations that need to be entered into the PlateToPositioner matrices for each robot.

In the analysis of the Kaman data, the offset of the Kaman probe that places it at the center of the focal surface must be determined. If the Kaman probe scans about an offset position, a spurious tilt will be intoduced because a tilt and offset are degenerate. The offset of the Kaman probe can be determined by scanning over a dummy button that has been placed at the center of the focal surface. The Kaman offsets are stored in the file:

These script parameters run a Kaman scan from the center up to 101 steps 60 mm apart, averaging 25 readings at each sample point:

```
hctcal_kamen_scan 1 0 0 101 101 60 25
```

4.4.4 FIDUCIAL FIBER SCRIPT

The X and Y robot axes are centered over the focal surface by adjusting their home offsets. These offsets are determined with the **hctcal_fid_centerscript**. There are no parameters for this script.

The test requires setup on the CCD cameras before execution.

```
> setmode 1 flat
> setmode 2 flat
> setbox 1 -exp 2 -rad 10
> setbox 2 -exp 2 -rad 10
```

Set Robot 1 and Robot 2 TV camera gains to 34 and 37, respectively.

4.5 FIBER POSITIONER OPERATING MODES

There are four Hectospec operating modes: (1) Button Mode, (2) Grid Mode, (3) Small Grid Mode, and Kaman mode. Button Mode is the only mode that most users will encounter; the other three are only used for calibration. In Grid Mode the T and P gimbal axes are not used, and the “down” position of the Z axis is adjusted upwards to prevent collisions with the flat calibration grid that sits on top of the focal plate. The Small Grid mode accommodated use of a small dot grid that can be magnetically attached to the center of the focal plate. This grid is easier to insert and remove than the large calibration grid and is useful for checking robot to robot registration. The Small Grid Mode limits the downward travel of the Z axis to avoid striking the grid. The Kaman Mode also limits the downward travel of the Z axis, but by an amount that varies with position over the focal plate. The “down” position of the Z axis is offset from the focal plate by about 0.5 mm. Care must be taken to place the Kaman probe in the correct position and to check that the chosen offset is safe.

4.6 COORDINATE SYSTEM CALIBRATION

When operating in the normal button mode and placing a button on the focal plate, the desired Z, T, and P positions are slaved to the desired X and Y positions according to the shape of the focal surface. The position (X,Y,Z,T,P) = (0,0,0,0,0) is defined as the center of the focal surface with the grippers at the height appropriate to placing a button on the focal surface. At the center of the focal plate the T and P gimbal axes should be level. Z increases upwards.

The slope of the focal surface is given by:

$$\frac{\arctan(cr)}{\sqrt{1-(1+k)(c^2r^2)}}$$

where c is the focal surface vertex curvature ($c = -2.937720\text{x}10^{-4}$ $\text{mm}^{-1)}$ and k is the conic constant ($k = -665$). The T and P coordinates are adjusted to maintain this slope. Since the T and P axes are not pivoted about the button, they produce an X and Y offset that must be removed by moving the X and Y axes to compensate.

In reality, we have encoder readings along the robot axes, not true orthogonal coordinate measurements at the gripper head. The zero positions of the T and P gimbal axes are determined by mechanical measurements. This not perfect, but it is more important that the grippers repeat very accurately, rather than place the buttons perpendicular to the focal surface at arcsecond tilt accuracy.

4.6.1 LEVELING THE GIMBAL AXES

The home offset on the T and P axes is adjusted so that the zero position corresponds to a physically level gimbal as shown in the next two pictures.

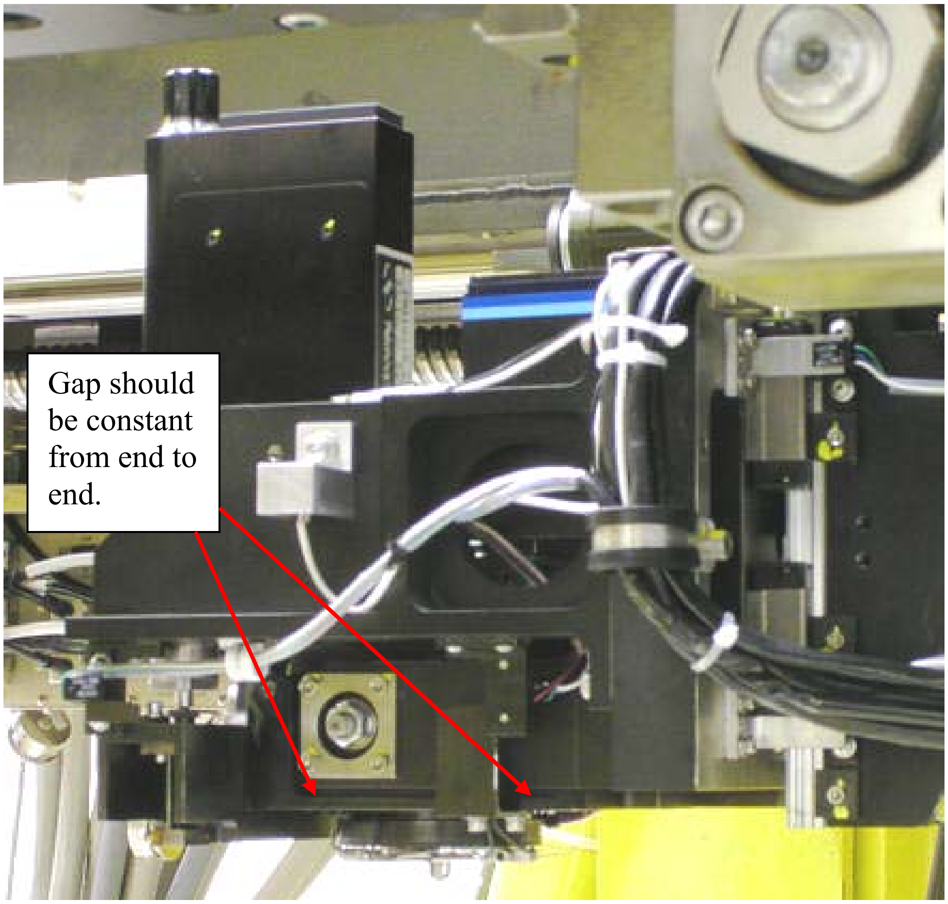


Figure 49. Leveling the T axis. The gap can be checked with gauge pins.

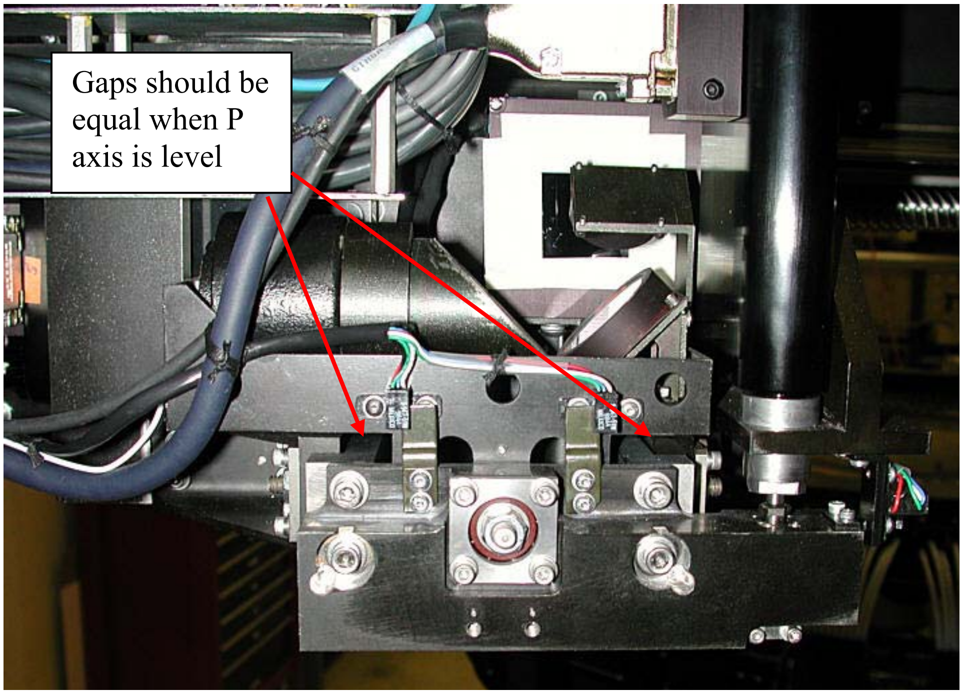


Figure 50. Leveling the P axis. The gaps can be checked with gauge blocks and shim stock.

4.6.2 GRID COORDINATE COMPENSATION

Because the X and Y rails are not placed on perfectly flat machined surfaces, as the gripper head translates in X and Y, the resulting tilts will result in X and Y positioning errors. If the rail is tilted out of plane by 0.025 microns over the spacing of the X and Y sliders, the gripper head will be tilted in the XY plane by approximately the same amount since the slider spacing is comparable to the distance from the rails to the focal surface. The rail ways are flat to about 0.050 microns, and indeed, the largest XY errors that we measure are about 0.050 microns. We measure the displacement errors by observing a precision dot pattern etched into a (low thermal expansion) Astrosital plate.

The desired robot X Y coordinates are transformed to robot X and Y encoder coordinates in a two step process: (1) first, the overall axis rotation, offset and nonparallelism is removed with a simple three term polynomial: a + bX + cY, (2) local position errors are removed using a lookup table of smoothed data from the grid measurement.

OVERALL LINEAR GRID CORRECTION

These example values were computed during the initial grid calibration in the lab during May 2001.

	a	b	c
Robot 1 X	0.27899855146570	0.99999620269749	-0.002749
Robot 1Y	0.21201543625324	0.00274900481718	0.999996
Robot 2 X	0.27899872477115	0.99999624632863	-0.002749
Robot 2 Y	0.21201551427254	0.00274877446826	0.999996

The X, Y Home Offsets at the time that this grid calibration was done were:

Robot 1 X	2.641
Robot 1 Y	-19.362
Robot 2 X	1.362
Robot 2 Y	-20.212

On July 20, 2001 we used a reference dot (magic marker, not grid) and observed the position of the gripper jaws over that dot. The X axis home offset for Robot 2 was adjusted to make its 0,0 coincide with that of Robot 1. At the same time we moved the Robot 2 Y +limit to allow -320.608 mm of travel.

Robot 1 X	2.641
Robot 1 Y	-19.362
Robot 2 X	-0.378
Robot 2 Y	-20.212

If the robot home offsets are changed independently the center of the focal surface will not be at 0,0 in both robots. In addition the grid correction will not be applied exactly. The current home offsets are listed in the Servo Parameters Table.

This polynomial is computed by fitting the entire set of grid data to the nominal grid dot locations. The transformation is stored in the "Coeff" header value in each grid compensation table file. This initial transformation to grid coordinates allows an offset and rotation to be applied before the actual grid compensation. It is used to adjust for changes in the home offset and rotation caused by upper/lower unit mount up errors.

FINE SCALE GRID CORRECTION

The grid data are smoothed over a 40x40 mm box. (The data were obtained on a 10x10mm grid and then smoothed). Since the changes in these offsets are likely to be very small (a few mm at most) getting the offsets exactly right is not critical.

After the desired coordinates are transformed to grid coordinates the grid coordinates are used to look up the appropriate zone in the grid table. The grid coordinates are transformed to axis coordinates using the polynomial specified for the appropriate zone.

4.6.3 FINDING THE CENTER OF THE ROBOT TV CAMERAS

Since the coordinate systems of the two robots are registered using the intensified TV cameras aboard the robots, it is important to establish and maintain a reference position in these cameras. We use the position of a test backlit fiber held in the gripper jaws as a reference. The centration of the fibers in the buttons will vary by up to 50 µm, so a button by button calibration of the placed fiber buttons must be applied (see below). Because a button by button calibration will be performed, this centration need only be close and held constant.

4.6.4 SUPERPOSING ROBOT COORDINATE SYSTEMS

After the XY coordinates are linearized, made orthogonal and rotated to a common system, it is important to remove any remaining offset between the two robots by observing a common object. Observing the position of a dot on the small calibration grid is a straightforward means of accomplishing this. If an offset is observed, it can be removed by adjusting the home offsets. The only tricky issues are making sure that both robots are observing the same dot and getting the signs right.

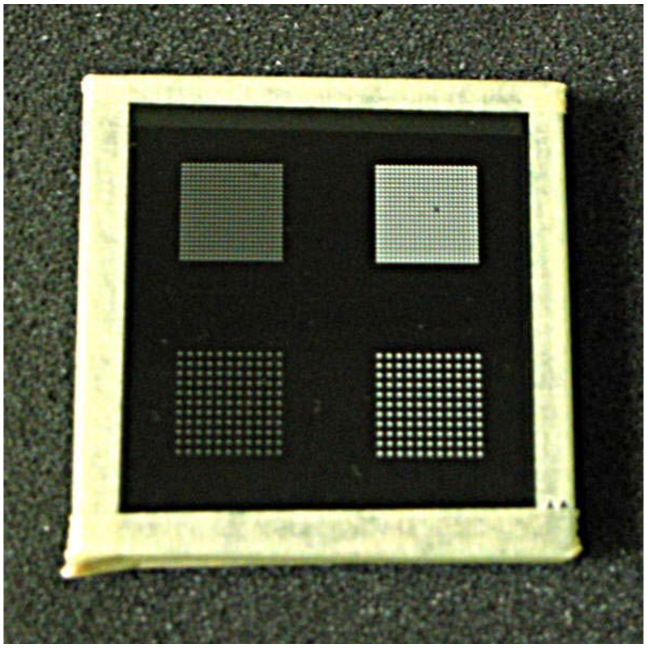


Figure 51. Small calibration grid with magnetic backing.

PROCEDURE TO MEASURE THE ROBOT TO ROBOT OFFSETS

(a) Place the grid at the center of the focal surface

(b) Move robot 1 over a dot and use movecenter command to center the dot at the TV center. Record the X, Y robot Actual Positions.

(c) Repeat step (b) for robot 2.

(d) R1_X - R2_X = x_offset

(e) R1_Y - R2_Y = y_offset

(f) Leave robot 1 home offsets alone.

(g) Subtract x_offset from existing R2 x home offset -> x new home offset

(h) Add y_offset to existing R2 y home offset -> y new home offset

*(i) Rehome the robots to get new coordinates systems.

4.6.5 CENTERING ROBOT COORDINATE SYSTEM ON FOCAL PLATE

The final centering of the robot coordinate system is accomplished with the three optical fiber fiducials that have been placed at 120° intervals around the focal plate. An automatic analysis routine calculates the necessary home offsets that maintain the registration between the robots discussed above.

4.6.6 ROTATION OF FOCAL PLATE WRT POSITIONING ROBOTS

When the preceding steps have been carried out, the X and Y coordinates should be appropriately calibrated. Two steps remain: removing small tilts of the robot X and Y planes with respect to the focal plate, and removing the rotation of the coordinate system around the optical axis.

The preceding calibration is insensitive to small tilts of the robot axes with respect to the focal plate since the cos(θ) errors are tiny. However, the sin(θ) errors will lead to small Z button placement errors. These can be removed with a Kaman sensor calibration.

The following 3 matrix is used to transform Hectospec normalized plate coordinates to Robot 1 coordinates (calibration date 2/22/02).

Axis	Scale	Rotation (degrees)	Translation
X	1.0	0.00869488	0.0
Y	1.0	0.00534931	0.0
Z	1.0	0.0	0.0

The following 3 matrix is used to transform Hectospec normalized plate coordinates to Robot 2 coordinates (calibration date 2/22/02).

Axis	Scale	Rotation (degrees)	Translation
X	1.0	0.00167986	0.0
Y	1.0	0.00203479	0.0
Z	1.0	0.0	0.0

Presumably the difference between the two robots is a result of the machining of the ways for the X and Y rails. The overall correction is small: 0.009° across 300 mm corresponds to a 47 μm displacement in the Z direction.

4.6.7 REMOVAL OF ROTATION ABOUT THE OPTICAL AXIS

There are two important rotations to consider: rotation of the parked fibers so that the fibers can be picked up, and the rotation registration with respect to the telescope and celestial coordinates.

4.7 CELESTIAL COORDINATES TO ROBOT COORDINATES

4.7.1 APPLYING ATMOSPHERIC REFRACTION

Atmospheric refraction corrections are calculated using the actual time of observation.

4.7.2 MAPPING ANGULAR COORDINATES TO X AND Y

This is accomplished using an azimuthally symmetric polynomial fit to ZEMAX raytrace data.

5 BENCH SPECTROGRAPH SOFTWARE

6 POSITIONER SPARE PARTS

6.1 SIZING THE ACE CONTROLS SHOCK ABSORBERS

(Local Rep is Pearse-Pearson Company in Millis)

The original shock absorbers Ed Hertz selected are:

MC1401-2	X-axis to X-axis collision
MC1201-3	X-axis inboard travel limit
MC225H2 (in pairs)	X-axis outboard travel limit
MC225H2 (single)	Y-axis travel limits

CALCULATIONS TAKEN FROM THE ACE CONTROLS CATALOG:

W	weight of moving object (lbf)
V	velocity of moving object at impact (ft s^{-1})
F	propelling force (lbf)
C	cycles per hour
S	stroke of shock absorber (in)

The required energy absorption is the kinetic energy (E_1) plus the energy deposited over the stroke of the shock absorber by the driving force (E_2).

$g = 32.2$ ft s^{-2}
M = mass corresponding to W
$M = W/32.2$ lbf-s^2-ft^{-1}

$$\begin{aligned} E_1 &= ½ * M * V^2 \\ &= (0.5/32.2) * W * V^2 \quad \text{ft-lbf} \\ &= (6/32.2) * W * V^2 \quad \text{in-lbf} \\ &= 0.19 * W * V^2 \quad \text{in-lbf} \end{aligned}$$

$E_2 = F * S$ in-lbf

$E_{tot} = E_1 + E_2$

Ace Controls defines an effective weight, W_e, as:

$$W_e = (E_1 + E_2)/(0.2 * V^2)$$

We have to consider three types of collisions:

(1) X-axis to X-axis
(2) X-axis end of travel
(3) Y axis end of travel

The X-axis weighs 250 lbs, and the Y-axis weighs 60 lbs. The maximum speed is 0.7 meters s^{-1} or 2.3 ft s^{-1}.

Ignoring the driving force, the effective weight is just the weight. If we include a 1-g gravity drive force plus a 1-g motor drive force, we have to add in another 2-g energy term for the worst case:

500 in-lbs for the X-axis (for one inch stroke)
250 in-lbs for the X-axis (for 0.5 inch stroke)
60 in-lbs for the Y-axis (for 0.5 inch stroke)

At 2.3 ft s^{-1}, $(0.2 * V^2)$ is approximately 1, so the additional effective weight is 250 to 500 lbs for the X-axis, and 60 lbs for the Y-axis.

TO SUM UP:

We need a shock absorber with 250-750 lbs effective weight for the X-axis and 60-120 lbs effective weight for the Y-axis.

Ed's original parts:

X-axis to X-axis collision:	MC1402-2 (350-1700 lbs)
X-axis inboard stop:	MC1201-3 (200-1000 lbs)
X-axis outboard stop:	two MC225H (100-1000 lbs together)
Y-axis:	one MC225H (50-500 lbs)

The 1402-2 and 1201-3 are no longer made. They have been replaced by units with the same mounting threads and similar dimensions.

X-axis to X-axis collision:	MC4525-2 (170-680 lbs)
X-axis inboard stop:	MC3325-3 (230-920 lbs)

6.2 X AXIS

Item	Vendor	Part Number	Quantity/Status	Reference Requisition
Ball Screw	NSK	MMTS-2026	one assembly	AF6253
Ball Screw Support (bearing pair)	NSK	WBK25-02	two	
Guide Rails	THK	HSR30R2SSCOM+920LPM	one pair	AF6448, AF6508
Motor	Kollmorgen	MMTS-2088 RBE-03013-A13	two on order	AF6310, WF0510
Rotary Encoder	Daido	LHF 049-5000	two for X	AF6023
Main Linear Encoder	RSF	MSA-2217-620/3/RI-TBA/9DM/4M-VINYL/LDL/999 Ref Marks at 50mm, 350mm, 550mm, 4m cable, 620 mm active length	two on order, due 9/20/2000	WF0273
Follower Linear Encoder	RSF	MSA-2217-620/3/RI-TBA/9DM/4M-VINYL/LDL/999 Ref Marks at 70mm, 370mm, 570mm, 5m cable, 620 mm active length	two on order, due 9/20/2000	WF0273
Collision Bumpers (a)	Ace Controls	MC1401-2	two, three on order	BF1110, WF1384
Collision Bumpers (b)	Ace Controls	MC1201-3	one, three on order	BF1110, WF1384
End of Travel Bumpers	Ace Controls	MC225H2	ten on order	BF1110, WF1384
Brake	Inertia Dynamics	1819-4521, type SAB-90, hex hub, 0.375 in bore	two	BF5346

6.3 Y AXIS

item	Vendor	Part Number	Quantity/Status	Reference Requisition
Ball Screw	NSK	MMTS-2027, W2508W-21PGS2X	one assembly	AF6253
Ball Screw Support (bearing pair)	NSK	WBK20-02	two	
Guide Rails	THK	HSR20R2SSCOM+940LPM	one pair	AF6448, AF6508
Motor	Kollmorgen,	MMTS-1053, RBE-03010-A13	two on order	AF6310, WF0510
Rotary Encoder	Daido	LHF 049-2500	two for Y	AF6023
Linear Encoder	RSF	MSA-2217-720/3/RI-TBA/9DM/5M-VINYL/LDL999 Ref Marks at 60mm, 360mm, 660mm, 5m cable. 720mm active length	two on order, due 9/20/2000	WF0273
End of Travel Bumpers	Ace Controls	MC225H2	see X-axis (10)	BF1110
Brake	Electroid	44-MFSB-15-6-115V, hex hub, 0.375 bore	two on order	BF5347, WF1383

6.4 Z AXIS

item	Vendor	Part Number	Quantity/Status	Reference Requisition
Ball Screw	NSK	MMTS-2028	one assembly	
Ball Screw Simple Support	NSK	WBK10S-02	two	
Ball Screw Support (bearing pair)	NSK	WBK10-02	two	
Guide Rails	THK,	HSR12R2UUC1M+150LPM	three+low prec pair	
Motor	Kollmorgen	MMTS-2067, RBEH-01811-B10	two	AF6310, WF0510
Rotary Encoder	Daido	LHF 050-5000	two	AF6023, WF1388
Brake	API Deltran	SB15B24E06S	two	
Drive Band	Belt Technologies	MMTS-207X	two, six on order	BF1114, WF1387
Drive Pulleys (motor-crowned)	Belt Technologies	MMTS-207X	one, three on order	BF2778, WF1387
Belt Technologies	MMTS-207X	one, three on order	BF2778, WF1387	

6.5 GIMBALS

item	Vendor	Part Number	Quantity/Status	Reference Requisition
Linear Actuator	Newport	PM500-1A	two (used for tests)	
Bearing (pair)	MPB Corp, Timken	SR6M7P000, radial play P811, lube LYV314	!must order!	BF1106
Flexures	Model Shop	MMTS-	!must order!	
Displacement Sensor	Kaman Instrumentation	KD2300-.5SUM	?	

6.6 GRIPPERS

item	Vendor	Part Number	Quantity/Status	Reference Requisition
Complete Assembly	misc.		two	
Gripper Body Bearing (pair)	MPB Corp, Timken	S2428M5P000, radial play P38, lube LYV314	!must order!	BF1106
Gripper Finger Bearing (pair)	MPB Corp, Timken	S418M7P000, radial play P35, lube LYV314	!must order!	BF1106
Stepper Motor	API-Portescap, Danaher Motion	P110-064-2.5-12	six on order	WF1286
Gearhead	API-Portescap, Danaher Motion	R16-2R-0-88	six on order	WF1286

6.7 GUIDERS

item	Vendor	Part Number	Quantity/ Status	Reference Requisition
Stepper Motor	Pacific Scientific Powermax	M21NR-XBLNN-NS00	five	
Pinion Gear	Southern Gear and Machine		three	
Brake Release Solenoid	Lucas Controls	9633(198044-001)	one	
Drive Wedge	Model Shop		three	
Brake Arms	Model Shop		two	
Brake Pads	Model Shop		six	
Brake Bearing (pair)	MPB,Timken	SR2M7-800, radial play P35, Lube LYV314	four pairs	BF4989
Spring Plunger	Vlier	SSM56	four	
Bearing End Plate	Model Shop		one	
Relay Lens	Melles Griot	01-LAO-124/073	two,!must order four (postponed due to $1K "073" AR-coating lot charge)	AF7269, WF1412-postponed
Trifurcated Bundle	Schott Fiber Opt Tech	Custom	!make decision on purchase!	
Intensified Camera	EOSI		!order after testing!	

6.8 VIEWING OPTICS

item	Vendor	Part Number	Quantity/Status	Reference Requisition
Pellicle	Melles Griot	3BPL005/02	five	BF5858, WF1118
25 mm Fold Mirror	Melles Griot	02-MPG-007/023	2 on order	AF7269, WF1414
38 mm Fold Mirror	Melles Griot	02-MPG-009/023	2 on order	AF7269, WF1414
Retroreflector	Spindler and Hoyer		2 on order	AF7280, WF1416
Intensified Camera	EOSI		!order after testing complete!	
Collimator Lens	Melles Griot	01-LAO-145/073	two	
Fluorescent Cal Lamps	Stocker&Yale	13-204-P1KDD	have two spares	

6.9 FOCAL SURFACE AND ACCESSORIES

item	Vendor	Part Number	Quantity/Status	Reference Requisition
Focal Plate	Hollis Line Machine	MMTS-679	!make decision on purchase!	
Fiducial Fiber Assembly	Joe Zajac		!make spare after testing!	
Mounting Flexures	Model Shop		!make decision on fabrication!	

6.10 FIBER SHELVES

item	Vendor	Part Number	Quantity/Status	Reference Requisition
Lexan Horiz Shelves	Poly-Fab (Wakefield)	MMTS-2305 rev.2	!must order!	WF0981
Aluminum Vert Shelves	Commercial Sheet Metal (Canton)		five?	

6.11 VME RACK/PMAC SPARES

item	Vendor	Part Number	Quantity/Status	Reference Requisition
VME CPU	Motorola	MVME167	!must order!	
Shared Memory Card	Motorola	MVME216	!must order!	
Transition Module	Motorola	MVME712M	!must order!	
PMAC Controller	Delta Tau	PMAC-1 VME	1 defective unit needs repair	AF2208?
PMAC Axis Expansion	Delta Tau	Acc. 24	???	AF2208?
PMAC Voltage to Freq Conv	Delta Tau	Acc. 8d Opt 2		AF2208?
VME IP Carrier Card	SBS-Greenspring	VIPC618	???	BF1023? WF0278?
Stepper Daughter Card	SBS-Greenspring	IP-STEPPER	???	""
Opto-Isolated IO Daughter Card	SBS-Greenspring	IP-OPTO-INT	???	""
Multi-Function IO Daughter Card	SBS-Greenspring	IP-ADIO	???	""

6.12 SNAPPY FRAMEGRABBER SPARES

item	Vendor	Part Number	Quantity/Status	Reference Requisition
PCI Framegrabber	Data Translation	DT3155	one spare, one flaky	

6.13 SERVO BOX

item	Vendor	Part Number	Quantity/Status	Reference Requisition
X, Y, Z Servo Amp	Copley Controls	5424AC	???	
T, P Servo Amp	Copley Controls	421	???	
Energy Dissipator	Copley Controls	145	???	
Large Contactor			???	
Opto Relays	OPTO22	7052-03-C-25-S	???	
Gripper Step Driver	Intelligent Motion Systems	IM804	two?	
30 Ohm/50W Resistor	Huntington	TMC50-30	???	
Mechanical Relay	Potter&Brumfield	KUMP-14AT8-240	??	
Display Circuit Board	SAO	MMTS-xxxx	???	
Servo Board (Rev 3)	SAO	MMTS-xxxx	???	
19" Rack, 10" deep Chassis	Bud		???	

6.14 PMAC ACCESSORY BOX

item	Vendor	Part Number	Quantity/Status	Reference Requisition
Triple Pwr Supply	Power One	MAP55-4003	???	
5V Supply	Sola	SLS-05-030-1T	???	
+/-15 V Supply	Sola	85-15-2150	???	
PMAC Volt/Freq Conv	Delta Tau	Acc. 8d Opt 2	???	
PMAC A/D Module	Delta Tau	Acc. 28a		
PMAC ACCY A PWB	SAO	MMTS-5257	???	
PMAC ACCY B PWB	SAO	MMTS-5258	???	

6.15 AC POWER CONTROL BOX

item	Vendor	Part Number	Quantity/Status	Reference Requisition
Din Rail 24V Estop System	Phoenix Contact	CM 125-PS-120AC/24 DC U/5	???	
Circuit Breaker	Siemans	W69-X2Q12-30	???	
Circuit Breaker	Siemans	W68-X2Q12-30	???	
Circuit Breaker	Siemans	W68-X2Q12-20	???	
Circuit Breaker	Siemans	W69-X2Q12-10	???	
Circuit Breaker	Carlingswitch	MB1B346101A27BC	???	
Circuit Breaker	Carlingswitch	MB1B346151A27BC	???	
Circuit Breaker	Carlingswitch	MB1B346201A27BC	???	
Relay	Magnecraft	W199AX-9	???	
Relay	Magnecraft	W199X-3	???	
Opto Relay	Carlo Gavazzi	RZ4855HDPO	???	
Opto Relay	Carlo Gavazzi	RA2450-D06	???	

6.16 SPECTROGRAPH/GUIDER CONTROL

item	Vendor	Part Number	Quantity/Status	Reference Requisition
Stepper Driver	Intelligent Motion Systems	IM805	four?	

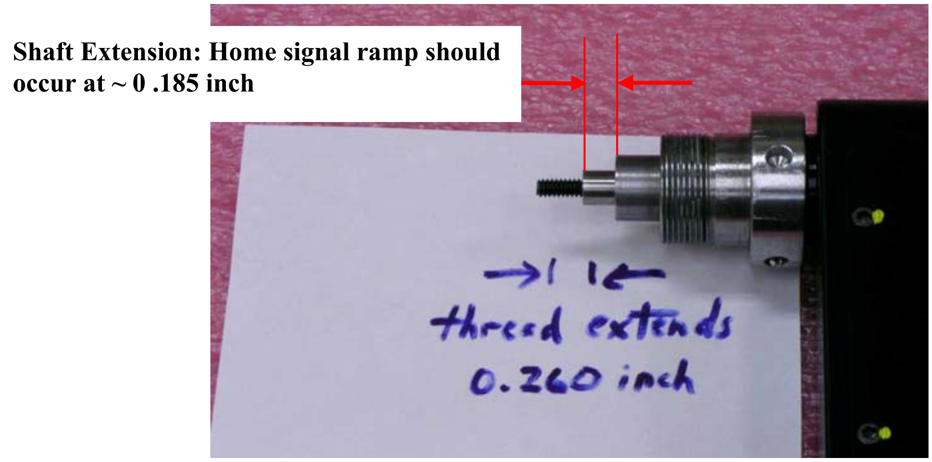
6.17 MISC RACK PARTS

item	Vendor	Part Number	Quantity/Status	Reference Requisition
5V Power Supply	PowerMate	EMA5BV	???	
RS232 AC Ctl	Pulizzi	IPC3302	???	

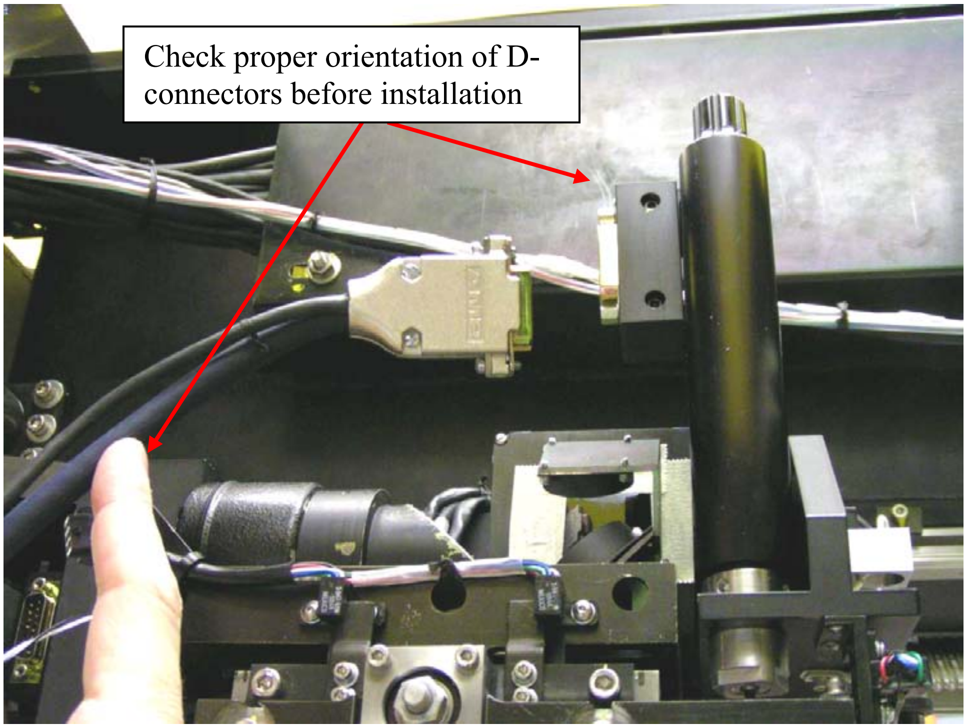
7 SERVICE NOTES

7.1 GIMBAL SERVICE

7.1.1 VERIFY ACTUATOR OPERATION BEFORE INSTALLATION


Shaft Extension: Home signal ramp should occur at ~ 0 .185 inch

• Verify Newport actuator home signal positions prior to installation by connecting cables to actuator. Home signal should be between .16” and .21” shaft extension (ideally, directly in the middle or .185”).

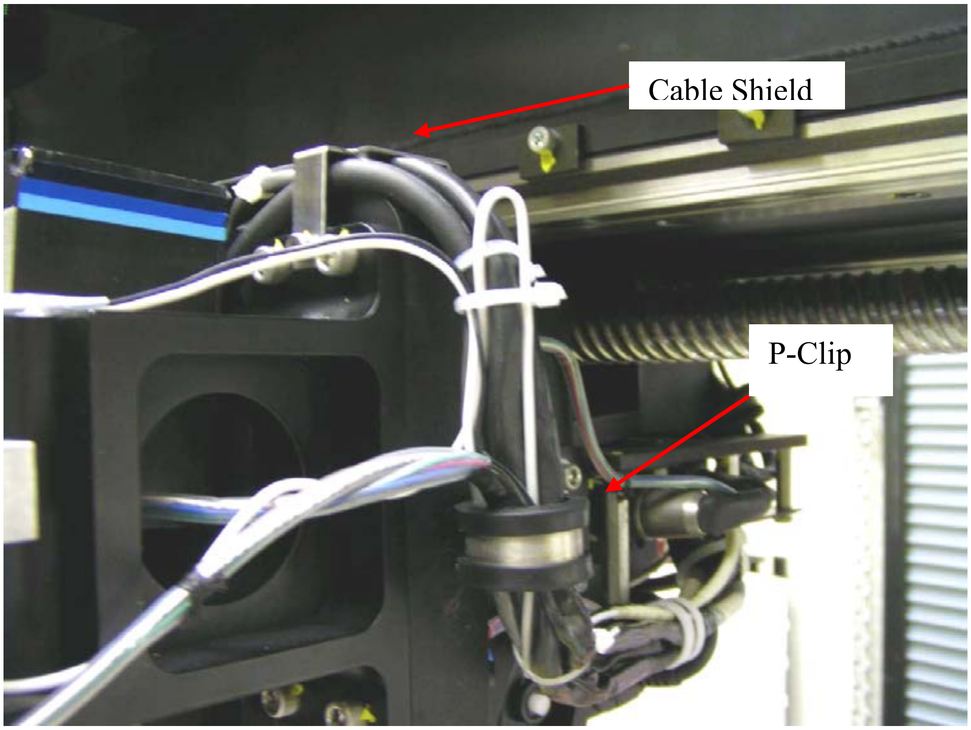

Check proper orientation of D-connectors before installation

- Check orientation of D-shell connector to ensure that it matches the orientation of the D-shell on the actuator cable. Adjust if necessary.

7.1.2 DISCONNECTING CABLING

- Remove cables from both actuators Outer Gimbal (T) and Inner Gimbal (P) actuators.

- Disconnect limit switch connectors on Outer Gimbal (T) and Inner Gimbal (P) actuators.

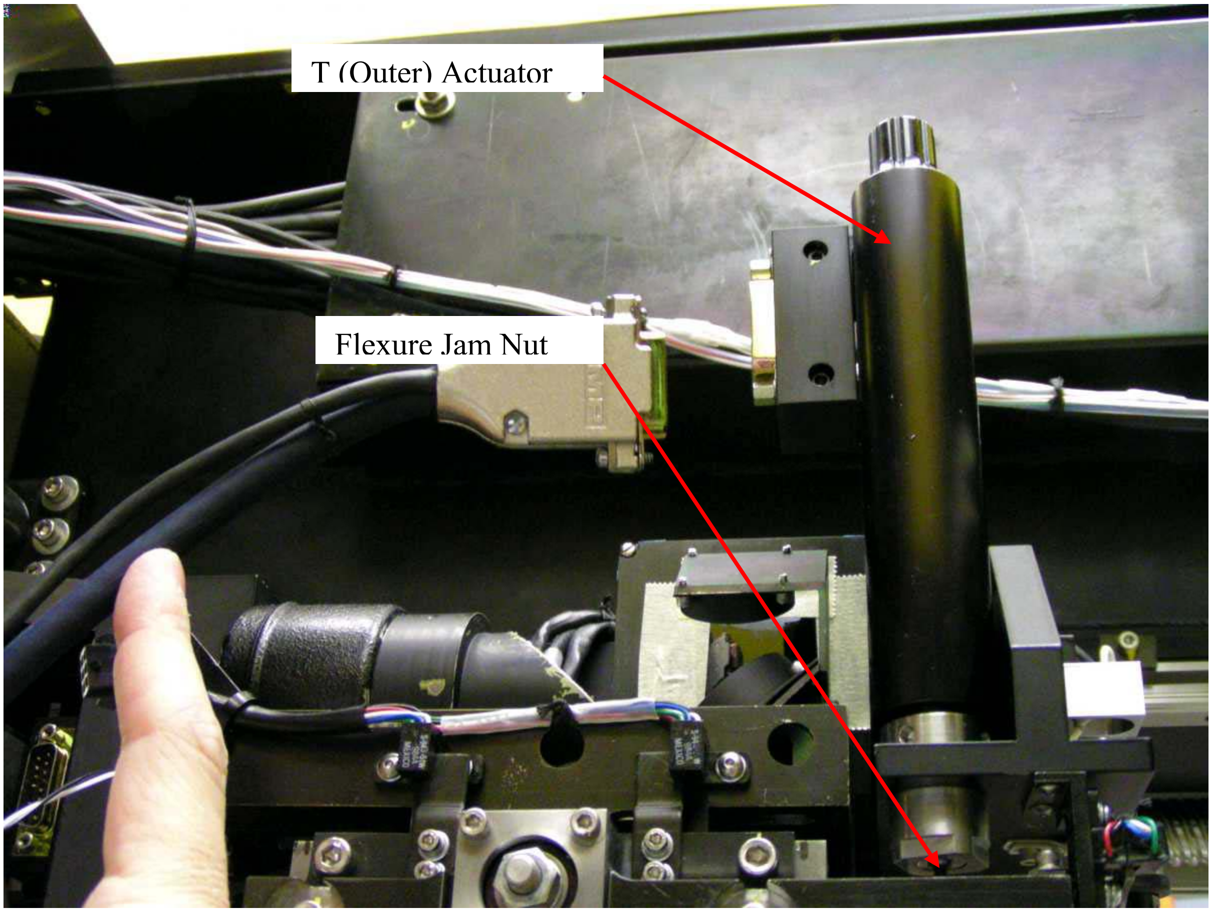


- Remove screws holding cable shield without removing any wire ties or clips

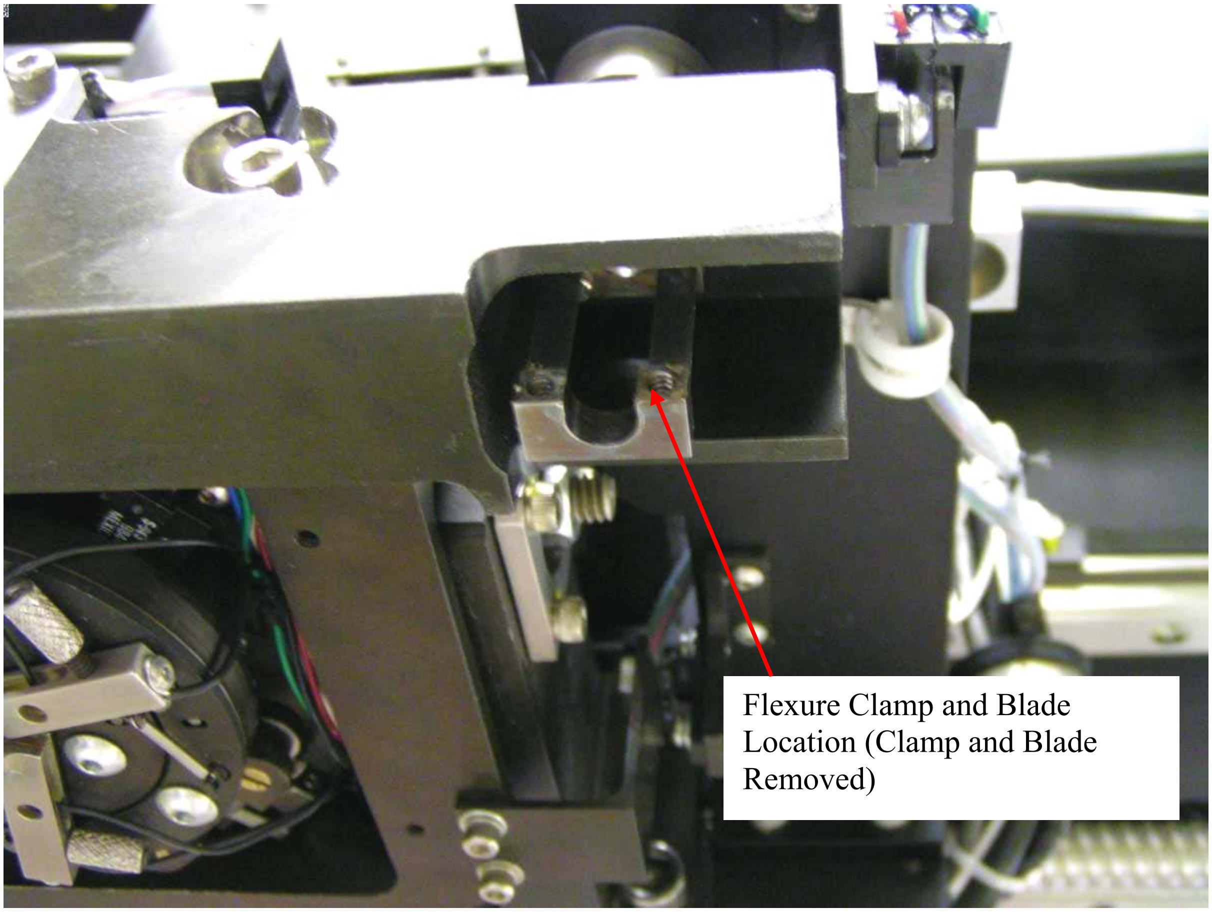
- Remove rear P-clip cable clamp to free up P actuator, gripper and camera cabling prior to component removal.

- Wiring must be free to move when P and T actuator assemblies are removed and rotated out of the way.

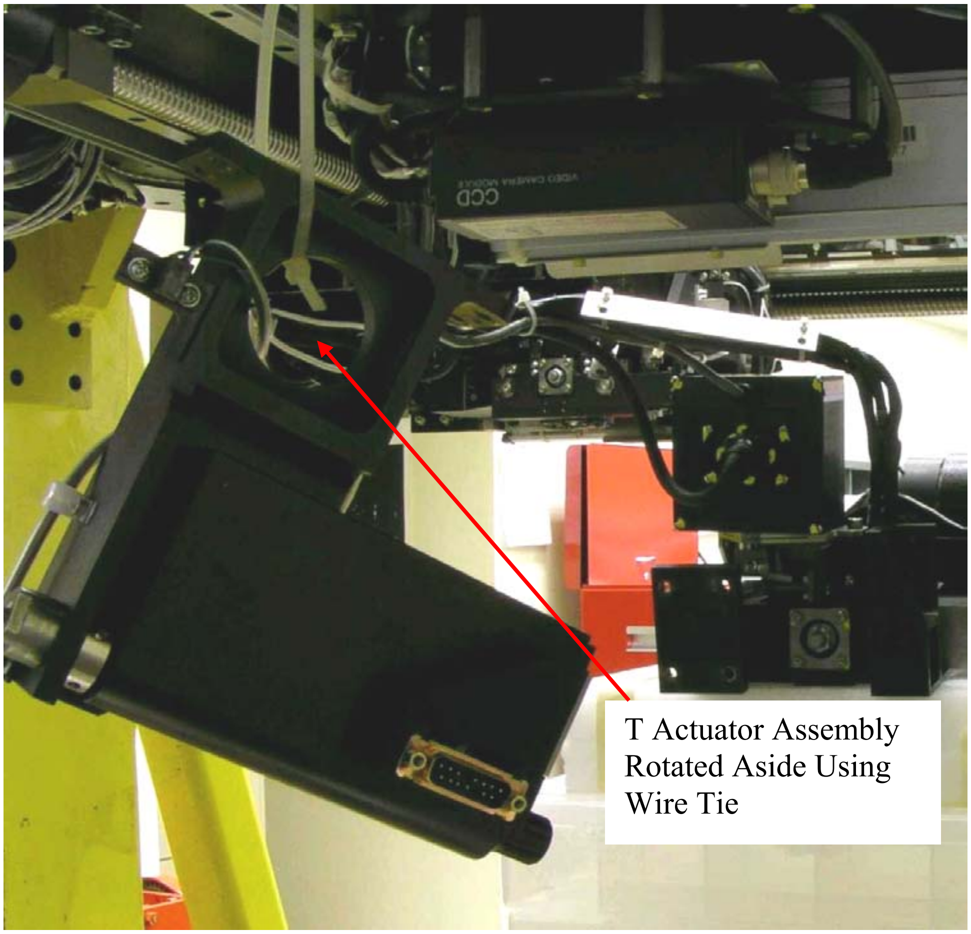
7.1.3 REMOVAL OF T (OUTER) ACTUATOR ASSEMBLY



- On T actuator, loosen the flexure jam nut. While loosening the jam nut, prevent rotation of the flexure by using a wrench with taped jaws.

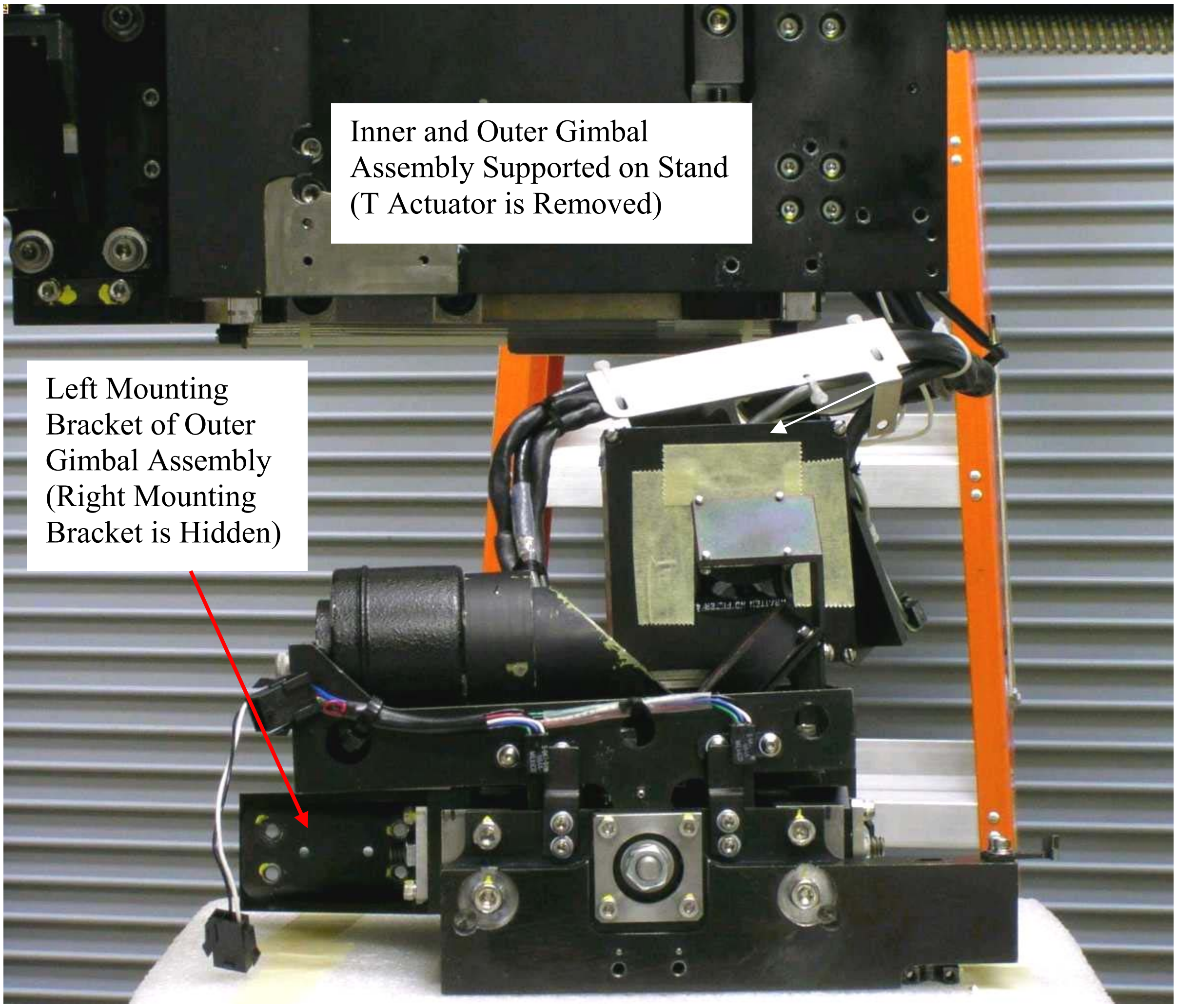


- Remove flexure clamp on T actuator. Support the weight of the Outer Gimbal, as it will rotate when the clamp is released.
- Remove 4 screws from T actuator rear support bracket.



- Slide actuator and mounting bracket off of locating pin, rotate out of the way and hang assembly using a wire-tie to take stress off of the connecting cables.

7.1.4 REMOVAL OF P (INNER GIMBAL) ACTUATOR ASSEMBLY

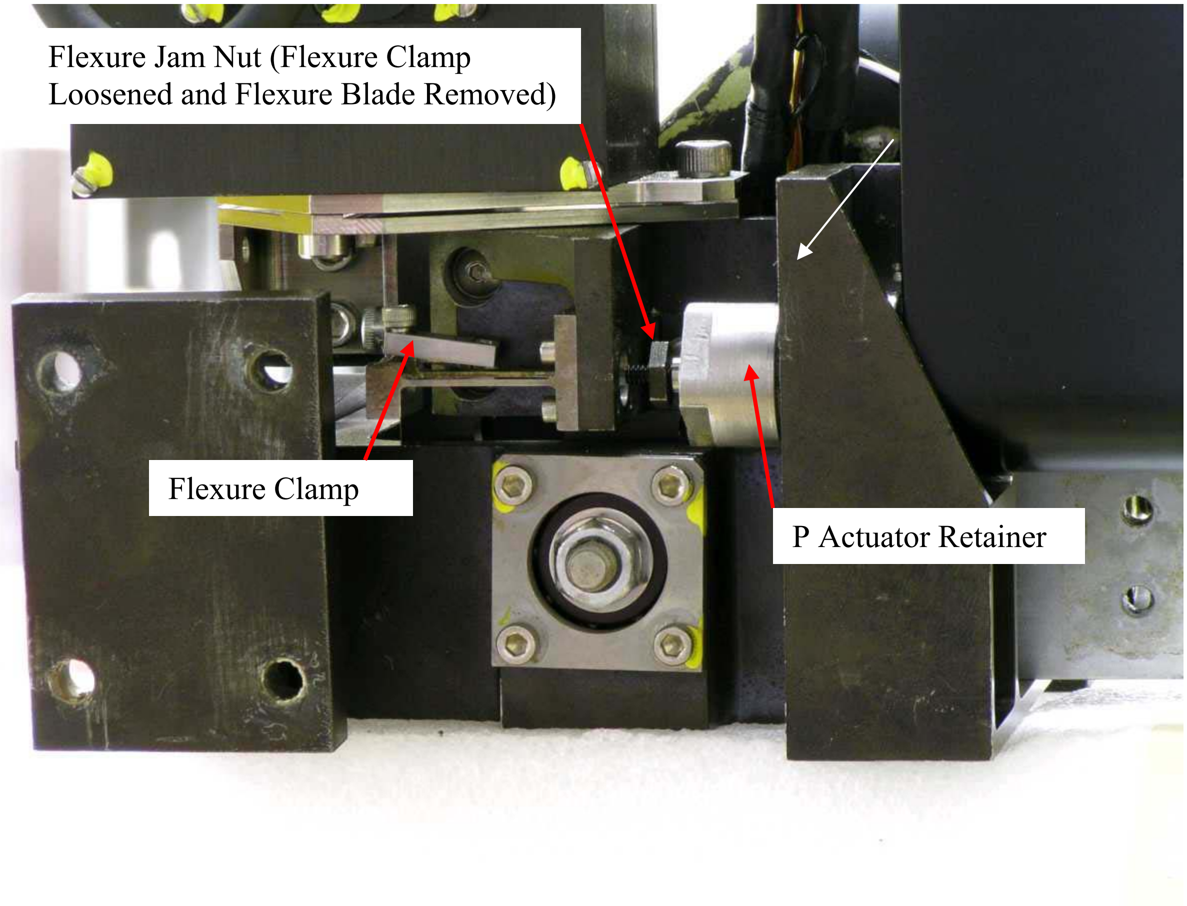


Inner and Outer Gimbal Assembly Supported on Stand (T Actuator is Removed)

Left Mounting Bracket of Outer Gimbal Assembly (Right Mounting Bracket is Hidden)

- Remove 4 screws from left bracket of Outer Gimbal assembly.
- Remove 4 screws from right bracket of Outer Gimbal assembly.
- Move Outer Gimbal assembly forward so that P (Inner) actuator clears mounting brackets.
- Support gimbal assemblies on a stand. Make sure that robot grippers are not damaged while resting on the stand. They should not support the weight of the gimbal assemblies.

7.1.5 REMOVAL OF P (INNER) ACTUATOR FROM GIMBAL ASSEMBLY



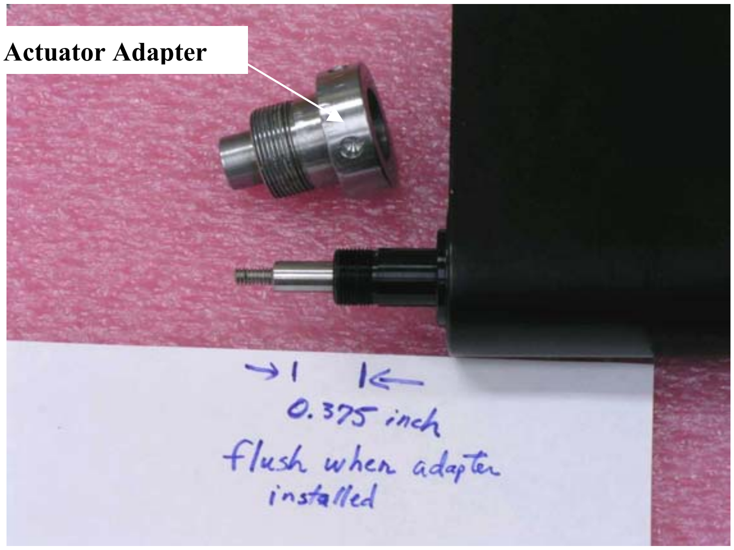
- On P actuator, loosen the flexure jam nut. While loosening the jam nut, prevent rotation of the flexure by using a wrench with taped jaws. A shortened Allen wrench will be required to reach the socket head screws holding this clamp.

- Remove flexure clamp on P actuator. Support the weight of the Outer Gimbal, as it will rotate when the clamp is released.

- Loosen P actuator retainer, jam nut must be removed to completely remove actuator retainer. Use a 1 ¼ inch open-ended wrench to hold the actuator bracket while loosening the P actuator retainer. An Allen wrench must be inserted into the holes of the actuator adapter to ensure that it does not rotate while P actuator retainer is being loosened.

- Remove the P actuator retainer. The P actuator may now be removed from the sub-assembly.

7.1.6 PM500 ACTUATOR SERVICE NOTES



- Threaded set-screw should be glued into the actuator end using 5-minute epoxy extending 0.26 inch beyond actuator shaft end as shown.

7.1.7 REASSEMBLY NOTES

USE OF LOCTITE:

Loctite is NOT used:

- On any screws or threads in the flexure assemblies (flexure thread, jam nut, clamp screws)
- In the actuator adapter

Loctite IS used:

- On all other fasteners in these assemblies

USE OF PAINT INDICATORS:

Yellow Paint is used:

- As a note indicating the use of loctite on a screw or thread. A dab of yellow paint is bridged from the screw head to the mating surface.

- In a case where loctite is not used on a screw or thread, a dab of yellow paint is used as in aid to prevent backing out of the screw. The application is similar to the case with loctite. Yellow paint is used on the flexure assembly (flexure thread, jam nut, clamp screws).

Green Paint is used:

- As a note indicating that a fastener has been epoxy-bolted. A dab of green paint is bridged from the screw head to the mating surface.

REASSEMBLY OF THE GIMBAL ACTUATOR ASSEMBLIES:

- Install P actuator in the actuator bracket by installing and tightening the actuator retainer.

- Install the flexure jam nut on the threaded set-screw on the actuator end.

- Install the flexure blade on the actuator end.

- Install the flexure clamp such that the flexure blade is flush with the end of the clamp and mating flexure.

- Tighten the jam nut.

- Move the outer gimbal assembly into place and install the outer gimbal trunions (8 screws).

- Reinstall T actuator.

- Install cable guard.
- Install flexure blade and flexure clamp such that the flexure blade is flush with the end of the clamp and mating flexure.
- Tighten the jam nut.
- Reconnect all actuator and limit switch cables.
- Ensure that all cables are routed neatly and out of the way of moving components. Use wire ties as necessary to ensure stress free operation of the cabling.
- Yellow paint should be used to mark positions of all screws during reinstallation.