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NO. 70

MULTI-OBJECT SPECTROGRAPH
LICK OBSERVATORY 120" TELESCOPE
FIBER AND CORRECTOR OPTICS ASSEMBLY

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MULTI - OBJECT SPECTROGRAPH
LICK OBSERVATORY 120" TELESCOPE
FIBER AND CORRECTOR OPTICS ASSEMBLY

LIST OF DRAWINGS, TABLE OF WEIGHTS AND MOMENTS,
SUGGESTED ASSEMBLY PROCEDURE AND
DEVELOPED SPECIFICATIONS AND CRITERIA

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CUSTOMER LICK OBSERVATORY PROJECT MULTI-OBJECT SPECT.

DRAWING NO.	TITLE
MS500	FIBR. & COR. OPTICS ASSY ELEVATION
MS501	FIBR. & COR. OPTICS ASSY PLAN VIEW
MS502	SECTION A-A, B-B AND C-C
MS503	CAGE
MS504	SUPPORT ARM
MS505	LOWER LENS BARREL
MS506	UPPER LENS BARREL
MS507	SUPPORT BARREL
MS508	DRIVE MOTOR, GEARHEAD & PARTS
MS509	SUPPORT BARREL AUXILIARY VIEWS
MS510	FOCUSING DRIVE ASSY. & PARTS
MS511	FOCUSING DRIVE PARTS
MS512	MISCELLANEOUS PARTS
MS513	MISCELLANEOUS PARTS
MS514	CAGE LOCATOR ASSY. & PARTS
MS1400	ADC PRISM ASSEMBLY
MS1430C	ADC PRISM BASE
MS1434A	SLEW GEAR DETAIL
MS1435B	ADC PRISM DETAILS
MS1436B	ADC PRISM DETAILS

08/20/93

C.G. TABLE FOR FIBER AND CORRECTOR OPTICS ASSY.
"0"-REFERENCE AT THE BOTTOM SURFACE OF THE CAGE
DISTANCE FROM PRIMARY TO "0" REF. = 501.77

DESCRIPTION	DWG. NO.	WEIGHT POUNDS	C.G. DISTANCE INCHES	MOMENT LB-IN
Cage	MS503	3,940	23.5	92,590.0
Support Arms	MS504	468	42.5	19,890.0
Support Barrel	MS507	929	65.5	60,849.5
ADC Prism Assy.	MS1400	172	69.5	11,954.0
Lower Lens Barrel	MS505	431	61.5	26,506.5
Upper Lens Barrel	MS506	420	85.7	35,994.0
FOP Stage	AAA88-10235(LLL)	385	100.5	38,692.5
C1 Lens	MS1100	160	52.0	8,320.0
C2 Lens	MS1200	100	66.0	6,600.0
C3 Lens	MS1300	60	92.0	5,520.0
		=======		========
	Total	7065		306,916.5

C.G. FOR THE SYSTEM FROM "0" REF. 43.44 IN

C.G. FOR ASSEMBLY FROM PRIMARY = 545.21 IN

FOCUSING ASSEMBLY WEIGHT= 1728 LB

SUGGESTED FIBER AND CORRECTOR OPTICS ASSEMBLY PROCEDURE

ADC PRISM DWG. MS1400:

Insert bearing, item #39, in Inner Ring, item #2, two times. Fasten these items with Bearing Cap, item #4, and #8-32unc x .75 screws, item #28, to Base, item #1. Attach One Hole Spacer and Two Hole Spacer, items #8 and #7 respectively, to Base with 1/4-20UNC x 2.0 screws, item # 33, six times total to provide support for further assembly. The screws in the Two Hole Spacers which will mount the optical switches need not be tightened, for they will need to be removed for assembly of the optical switches. It is important that the Two Hole Spacers be located between the drive motors. This location is between the two large cutouts in the Base. With the assembly resting on the Spacers, working on one side at a time, install ADC Prism, item #13, O-Rings, items #37 and #38, and Slew Gear, item #5, using screws and lockwashers, items #32 and #35. Line up the .25 diameter holes in the Inner Ring with same size holes in the Slew Gear and locate at 180 degrees from one side to the other when the prisms are in their nominal operating positions. See note #2 on the assembly drawing. Next, install the Vane, item #10, on each Slew Gear using #4-40 x .25 set screws, item #24. For orientation of Prisms and the Vanes with respect to the prisms consult with optics engineer and follow his instructions. Remove the two Two Hole Spacers one at a time and attach the optical switches , item #23, using item #27. Reinstall and tighten the mounting screws.

Assemble drive package consisting of items #'s 20, 21 and 22 to Pinion Mount, item #3, using items #29 and #40, two assemblies. Make sure that the Pinion Mount is in correct orientation to allow it to mate to the assembly. Install Pinion Gear, item#6, on each assembly and secure with item #24, #4-40unc x .25 set screw. Mount these assemblies on the Base with item #28, #8-32unc x .75 screws. Slide the assembly to engage the Slew Gear with minimum of clearance and secure in place on both sides of the Base.

With assembly in upright position, attach the Curtain Dust Seal, item #9, to the upper Slew gear with items #'s 25 and 26. Install Cover, item #11, using items #31 and #35, followed with Dust Seal Cover, item #12, and screws, item #30. Install the swivel hoist rings, item #34, three places.

Turn the assembly over and install lower Curtain Dust Seal. Now turn the assembly back upright and support it on spacers with spacer blocks under to clear the Curtain Dust Seal. See note #1 on the ADC Prism Assembly, Dwg. No. MS1400. Install O-Ring, item #36. Now the assembly is ready for installation on the lower lens barrel.

<u>DRIVE MOTOR, GEARHEAD AND PARTS, DWG. MS508:</u>

Install bearings, item #10, in the Brake Adapter Plate and Motor Adapter, items #2 an d #3 respectively. Install shaft seal, item #9, in the Brake Adapter Plate. Attach the Motor Adapter Shaft, item #4, to the motor, item #21, drill and pin with spring pin, item #22, per instructions on the drawing. Cut #6-32UNC x 1.75 screws, item #14, to 1.63 length and use to fasten the Motor Spacer, item #6, and Motor Adapter to the motor. Use lockwashers, item #18, with the screws.

Fasten the brake, item #8, loosely to the Brake Adapter Plate with #4-40UNC x .375 screws, item #15, and lockwashers, item #19.

Using previously assembled motor, pass its shaft through the brake with key, item #20, in place and fasten the package to the Brake Adapter Plate with #10-32UNF x .50 screws, item #11, and washers, item #16. Tighten the clamp on the brake to secure it to the motor shaft. Install pinion gear supplied as par of the gearhead on the motor shaft to the dimension specified on the drawing and clamp in place.

Fasten the Adapter, item #1, to the gearhead, item #5, with #8-32UNC x .75 screws and lockwashers, items #13 and #17. Attach the previously assembled motor package to the gearhead Adapter by engaging the pinion gear with the gearhead planetary and fastening in place with #8-32UNC x .875 screws, item #12, and washers, item #17. At this point the assembly is complete and can be set aside for later mounting to the upper lens barrel.

FOCUSING DRIVE ASSEMBLY AND PARTS, DWG. MS510:

Starting with Gearhead/Motor Assembly, item #3, install Coupling, item #11, on the gearhead shaft and secure with set screw, item #22. Attach the gearhead to Gearhead Adapter Plate, item #10, with #10-32UNF x .875 screws, item #21, and lockwasher, item #26. To this assembly fasten an optical switch, item #16, with #4-40UNC x 5/16 screws, item #18.

To the Drive Base Plate, item #9, attach loosely the ball screw pillow block, item #17, with screws and lockwashers, items #'s 24 and 28. Install the Focusing Drive Screw, item #8, in the pillow block. To this package attach loosely the previously assembled Gearhead Adapter Plate with screws and lockwashers, items 24 and 28, by engaging the Coupling, item #11, with the Drive Screw, item #8, and securing with the set screw,item #22. Now proceed to tighten the screws which attach the pillow block to the Drive Base Plate to bring the assembly in alignment. Next tighten the screws which hold the Gearhead Adapter Plate to the Drive Base Plate making sure that the assembly stays in alignment and no binding occurs in the pillow block. If everything is turning smoothly, drill and pin four places with dowel pin, item #25. Next attach the Travel Limit and Travel Failure Trip, items #'s 5 and 6, with #6-32UNC x 1.50 pan head machine screws, item #19, to the Drive Base Plate. Rest of the assembly shown on this drawing will be done when the Focusing Dive is installed on the Upper Lens Barrel and Support Barrel, reference items #1 and #2.

<u>ELEVATION, DWG. MS500, AND SECTIONS A-A, B-B AND C-C, DWG. MS502:</u>

Start with Support Barrel, item#5, and place it on a surface plate with the finished set up surface of the barrel in contact with the surface plate. Install Barrel Guidance Track loosely, item #10, four places on the finished pads in barrel interior, two at the bottom and two at the top, using 1/2-13UNC x 2.0 screws and lockwashers, item #'s 32 and 37. Align the tracks such that they are perpendicular to within .001" to the surface plate and fasten in that position. Drill, ream and pin with dowel pin, item #39, two places on each track. The perpendicularity requirement applies to all three exposed sides of the track. When completed, set aside for later use.

Next, take the Lower Lens Barrel, item #3, and install the Bearing Pad and Bearing, items #8 and #9 respectively using metric shoulder screws, item #30, at two locations 180 degrees apart. On the backside of the Bearing Pad install two 1/2-20UNF flat point set screws, item #35, with nut, item #28, at both locations. See section A-A on Dwg. MS502. On each side of the bearing mount a cam follower, item #25, with lockwasher, item #36, and nut, item #27, leaving the nuts loose. Similarly, prepare the Upper Lens Barrel, item #4, by mounting the above mentioned hardware to it via Upper Barrel Bearing Plate, item #7, and securing it in place with 3/8-16UNC x 2.0 screws, item #34, and pinning with dowel pins, item #40. See section C-C on Dwg. MS502.

FOCUSING DRIVE ASSEMBLY, DWG. MS510:

Referring back to Focusing Drive Assembly, item #6 of Dwg. MS500, attach Zero Position Tab, item #4 of MS510, to the Upper Lens Barrel with screws, item #18. Position the ball screw nut approximately half way on the ball screw length and attach the assembly loosely to the Upper Lens Barrel with 1/4-20UNC x 1.75 screws, item #23, and lockwashers, item #27. The assembly should be tied temporarily to the barrel for it is not well supported at this point. Next, to each side of the ball screw nut bracket on the barrel, mount two Microswitches, item #15, interspaced with Insulator, item #7, and using screws, item #20. One switch on each side should have the actuator up and the other one down. The switches should line up with the trips attached to the Drive Base Plate. item #9.

FIBER AND CORRECTOR OPTICS ASSY., DWG'S MS500 AND MS502:

With the Upper Lens Barrel prepared as described above, refer back to Dwg's MS500 and MS502, attach it to the Lower Lens Barrel adhering to the proper orientation. Looking at the assembly from top, the Lower Lens Barrel bearing and cam follower assemblies should be located in the northeast and southwest quadrants with cutouts in the barrel in northeast and northwest locations. See section B-B. The Upper Lens Barrel bearing and cam follower assemblies should be located in northwest and southeast quadrants and the drive in the northeast quadrant. See section C-C. Use 1/2-13UNC x 1.75 screws, item #33, and lockwashers, item #37, but do not tighten. Adjust the upper barrel to the lower barrel such that the cam follower surfaces radially to the barrels are at 90 degrees from lower to the upper barrel. Some of the cam followers may need to be secured firmly in order to do this alignment. The alignment should be within .001" across the cam follower width or better. When this alignment is achieved the fasteners holding the barrels together should be tightened firmly. At this point, referring to section C-C, the drilling and reaming operation for the tapered pin, item #26, should be performed and the pin inserted. If any of the cam followers were tightened to align, they should be loosened at this point. Optionally, the tapered pin insertion operation can be postponed till this subassembly is mated and adjusted to the Support Barrel to insure proper tracking prior to pinning.

PLAN VIEW, DWG. MS501:

Referring to Plan View, Dwg. MS501, attach the Support Arms, item #3, to the Support Barrel with 1/2-13UNC x 1.75 screws, item #13, and lockwashers, item #12. Mount the assembly into the Cage, item #2, with similar screws and flat washers, item #11. Make sure that proper orientation is observed with focusing drive mounting surface in the support barrel being located in the northeast quadrant. By running the fasteners into the Cage holes progressively center the Support Barrel assembly within the Cage loosely. Drill, ream and insert dowel pins, item #14, two places on each pad at the Support Barrel end of the Support Arms. Progressively tighten the screws in the Support Arms at the upper pads of the Cage to 190-200 inch-pounds of torque to put the assembly in tension through the lower end of the Support Barrel while keeping the assembly centered in the Cage. Tighten the screws in the lower Cage pads to zero gap between the Support Arm pads and washer screw head combination. Measure the resulting space between the Cage pads and the Support Arm pads to obtain the required thickness for the Support Arm Shims, item #4. Install the shims and torque all screws to 240 inch-pounds of torque. Do not install the dowel pins in the pads on the Cage, for it may be required to reposition the assembly after installation on the telescope due to uncertainty in telescope centerline location. Install Assembly Mounting Bolts, item #5, with washers, item #10, by threading into the Cage screw capturing thread. Do not thread through this hole at this time to avoid the bolts from protruding through at the bottom of the Cage. For installation of items #'s 6 and 7 refer to Dwg. MS514.

CAGE LOCATOR ASSEMBLY AND PARTS, DWG. MS514:

Assemble the Angular Locator Brackets and install on the Cage per this drawing. Likewise, install the Radial Locator Bars but without the indicated shims. The shims will need to be determined at assembly on the telescope. Additional mounting holes in the Angular Locatin Brackets may be required and the Radial Locating Bar width may need to be increased if the assembly is shimmed up and away from the telescope top to locate at proper focus distance. It may be desirable to make these parts after the unit has been installed on the telescope and located so that the required configuration for these parts may be determined.

FIBER AND CORRECTOR OPTICS ASSY. ELEVATION, DWG. MS500:

Referring back to Dwg. MS500 and the lens barrel assembly described above, install three lifting rings in the threaded 1/2-13UNC holes in the top of the Upper Lens Barrel. Carr-Lane swivel hoist ring #CL-2500-SHR-2 is suitable for this operation. Temporarily wire in the focusing drive motor and its limit switches. Using the lifting rings place the assembly inside the Cage / Support Barrel assembled previously. To alleviate interference while installing make sure that all of the cam followers on the lens barrels are loose and that the bearing pads are pushed all the way back into their respective counterbores. When the Focusing Drive Assembly, item #6, rests on the mounting plate in the Support Barrel, secure it in place with 3/8-16UNC x 1.75 screws and lockwashers, items #24 and #28 of Dwg. MS510 respectively. At this point the cam followers in the lens barrels should be lined up with the adjustment access holes in the Support Barrel. By adjusting the cam followers and the bearing pads, line up the lens barrels to the support barrel track and centerline. Actuate the assembly with the focusing drive motor by running it to the limits of its travel. The cam followers and the bearing pads should be adjusted to be as snug as possible without stalling the focusing drive. Now the screws, which attach the ball screw nut to the Upper Lens Barrel, may be tightened to secure the ball nut.

The lens barrel assembly may now be removed from the Support Barrel for installation of the lenses. First separate the Upper

Lens Barrel from the Lower Lens Barrel. Turn both lens barrels over for lens installation. In the lower barrel install the Element #2 Cell Assembly, item #18, with hardware items #42, #45 and #47. Next, in the same barrel, install Element #1 Cell Assembly, item #17, with hardware items #41, #44 and #46. Turn the assembly right side up and install the ADC Prism, item #15, with 1/2-13UNC x 6.0 screws, item #31. At this point any wiring of the ADC drive motors and interlocks should be done for these items will not be accessible after the Upper Lens Barrel is reinstalled. Also, if it is anticipated that dry nitrogen purge will be required for operation, the lens barrels and the ADC should be plumbed. With Upper Lens Barrel in inverted position, install the Element #3 Cell Assembly, item #19, with hardware items #43, #45 and #47. Remount the Upper Barrel assembly onto the Lower Barrel assembly, perform all necessary wiring of motors and interlocks and plumbing for dry nitrogen, and reinstall into the Support Barrel. The bearings and their pads may need to be backed off during this operation but a record of number of turns of each screw should be kept so that after installation the pads may be adjusted to their previous aligned positions.

In the MOS Stage FOP, item #16, insert FOP Locating Cup, item #13, at bottom of the mounting tube and the FOP Mounting Cap, item #12, at the top of the tube. In the top flange of the Upper Lens Barrel screw in the FOP Tension Rod, item #11, three places. These rods replace the lifting rings used in assembly. Over these rods install the MOS Stage FOP and after appropriate alignment, secure in place with flat washers and nuts, items #48 and #49. Drill and taper ream two paces on each FOP Locating Cup, six total, for tapered pin, item #14. Secure the pins in place with washer and nut, items #29 and #38.

MULTI-OBJECT SPECTROGRAPH
LICK OBSERVATORY 120" TELESCOPE NEW TOP END CAGE
SCOPE OF THE PROJECT

A. Barrel to support prime focus corrector lenses (PFCL) and atmospheric dispersion corrector (ADC), which is to be removable.

B. Support for fiber optics positioner (FOP).

C. Axial drive for focusing of PFCL and ADC.

D. Axial drive for fiber optics positioner. } COMBINED

E. New telescope top end cage to support items A through D.

DETAIL REQUIREMENTS FOR EACH ITEM LISTED.

A. 1) Individual lens tilt not to exceed 2′ of arc. NOT KNOWN! REASONABLY ACHIEVABLE

2) Individual lenses to be within +/-.005 " of true center line. O.K.

3) Distance between lenses to be within .005

4) Distance from lens C2 to ADC to be within No No.

5) Flatness of ADC assembly to be within .005 IN 20"

6) Tilt of corrector package not to exceed 1′ of arc.

7) Corrector package to be within +/-.015" of telescope centerline.

8) Assembly focusing travel of +/-.50" with resolution of .001" O.K. CHANGED TO ± 1.00

QUESTIONS:

a) Will the individual lens cells need adjustments or can they be fixed as long as the tolerances required are met? NO!

b) Lenses have adjustments in their cells, will those adjustments need to be accessible after installation? NO!

c) For mounting the lenses in the barrel, may it be assumed that they are perfectly mounted in the cells? YES!

d) Weight of lenses with cells? Weight on the drawing, is that the blank or finished lens weight? FINISHED WT.

e) Weight of ADC assembly? 190#

f) Location accuracy of ADC with respect to barrel centerline? SAME AS A2

g) Is it possible to modify the ADC such that it could be mounted on rails for insertion into a rectangular cavity between the lenses for ease of removal for servicing? SERVICE SAME AS OTHER LENSES – YR. OR SO

B. 1. Support system for FOP to the top end of cage independent of PFCL and ADC.

QUESTIONS:

a. Maximum allowable tilt of the fiber optics positioner (FOP) with respect to telescope axis 1" WITH 2" MAX.

b. Weight of the assembly 418 lb ?

C. 1. Focusing travel to be +/-.50" with resolution of .001" OK.

2. Guidance system to satisfy the position requirements and resolution per A6-8. YES! (.001) FIXED

QUESTIONS:

a. Is position of the assembly critical or only the resolution?

b. If position is required, will it require a readout? YES!

D. 1. Two position focusing +/-1.50" (±.25) at 13.0" (12.0") apart. Accuracy between end adjustment points not critical. YES. ELIMINATED

2. Resolution of FOP axial adjustment to be 10 microns or .0004" (Is this a correct interpretation?) .001

QUESTIONS: WITH READOUT!

a. Is the actual position critical or only the resolution?

E. 1. New top end cage to support prime focus corrector lenses and ADC as a unit via axial drive and an appropriate guidance system. YES.

2. Separate support for FOP via axial drive and appropriate guidance system. Approximate total travel 15" 13"

3. Top end to be sufficiently rigid to provide for near zero" deflection at all telescope positions with respect to o the main telescope frame. YES.

GENERAL QUESTIONS:

351.2" FROM AXIS 500 DISC.

a. Distance from primary mirror to top of mounting ring? 450.39 +/-1.5 + 50.12=500.51" +/-1.5? ~~500.5~~ 501.5 ±.25

b. Mounting ring O.D.=151.5" x 131" I.D.? O.K.

c. Total maximum/minimum moment required or permissible in the top end assembly? 7300 lb WT. C.G. 44" ABOVE FLANGE ADJ. ±3000 ft lb ABOUT AXIS

d. Top of telescope mounting ring to face of the first lens is 549.70 - ~~500.51~~ 501.5 = ~~49.19~~? 48.2

e. How true is the telescope centerline to the top of the mounting ring and to the mounting bolt circle. ±.25"

f. Is the primary mirror adjustable to align centerline? NO!

g. What are the possible telescope movements and the extent with respect to N, S, E and W? 90° IN ANY DIRECTION

h. What kind of alignment tools are available for installation and alignment of the required components? COLLIMATOR

j. What is meant by "image blur? Dos this refer to out of focus? OR MISALIGNMENT

k. What is meant by "image shift"? Does this refer to sideways displacement?

m. The top of the mounting ring is not a machined surface? SHIMMED TO .015

CLERICAL QUESTIONS:

1. Will the drawings be done on LICK OBSERVATORY drawing formats with LICK title blocks etc.? YES!

2. What are your standard drawing formats and do you have CAD forms that can be obtained in DXF format.

3. Do you have drawing numbers for this project or anything goes? NO.

PLAN OF ATTACK

I Develop barrel design for mounting of lenses and ADC.

II Develop guidance, support and drive system for barrel.

III Design guidance, support and drive system for FOP. — eliminated

IV Design an envelope to accommodate the items in I - III.

V Design the top end to support all of the above.

ITEM II & III HAVE BEEN COMBINED INTO FOCUSING DRIVE FOR THE ASSEMBLY.

A Tolerance Analysis
for the
Prime Focus Corrector
for the
Lick Observatory 120" Telescope

August 25, 1992

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Introduction

A tolerance analysis has been performed for the prime focus corrector (PFC) for the Lick Observatory 120 inch telescope. This instrument will be used in two modes: high resolution imaging over 30 arc-sec and multiple object spectroscopy using 200 μm fiber optics over a 1° field of view. These two modes have different performance requirements. High resolution imaging requires the smallest spot size possible without much consideration of positional accuracy. Fiber-fed spectroscopy simply requires images smaller than the fiber, but they must be very accurately positioned.

Effect of telescope flexure

The flexure of the truss for varying elevation angles was measured to cause about 20 arc-sec tilt and 3 mm decentration of the mounting ring for the PFC. This motion causes two problems:

1. The image shifts about 3.3 mm in the focal plane. The positioning of the fiber optics must take this into account.
2. The image is slightly degraded. For the full motion of the PFC, the on-axis image will be degraded from 20.6 μm rms (.25 arc-sec) diameter to 29.4 μm rms (0.36 arc-sec.)

The following spot diagrams, which are calculated images of point objects, illustrate these effects. The reference cross is 200 μm across (the fiber diameter.) The field angle for each image and the centroid position at the focal plane are given. The rms spot sizes given in the plots are approximate.

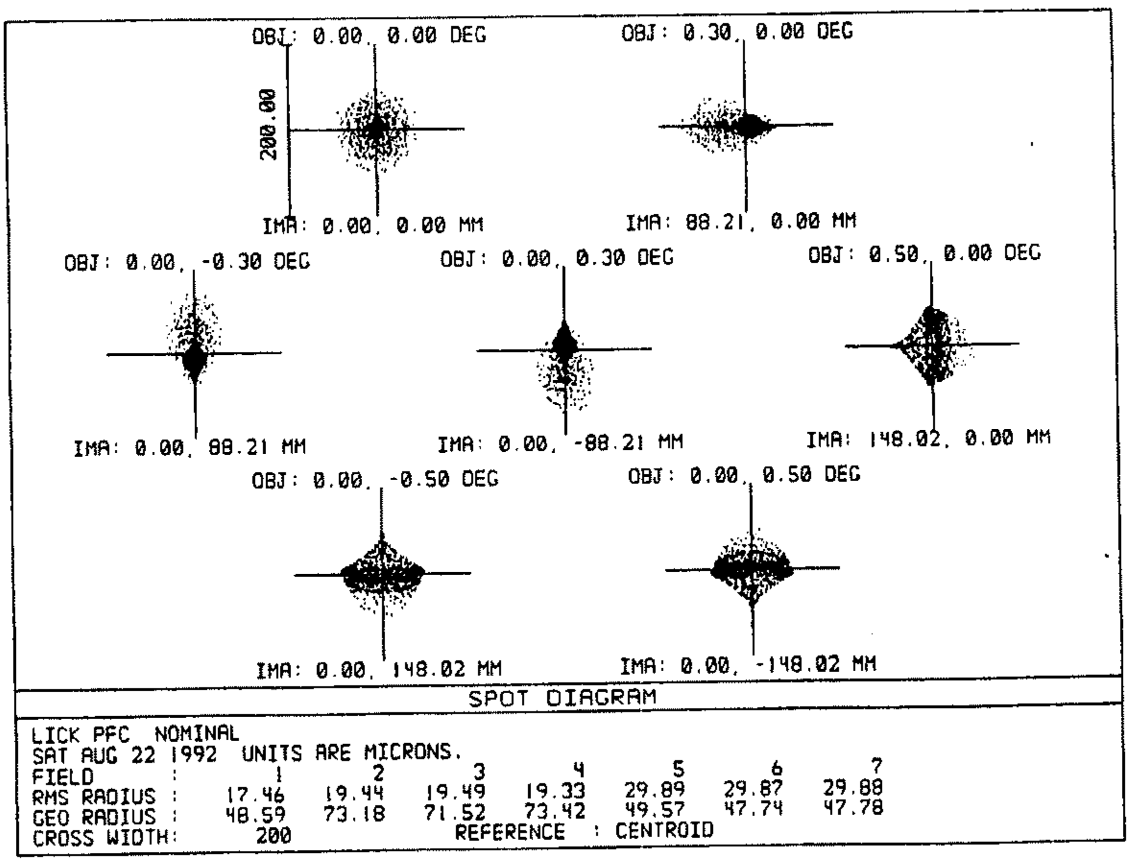

Figure 1. Nominal spot diagram showing images of point sources over ±0.5° field of view

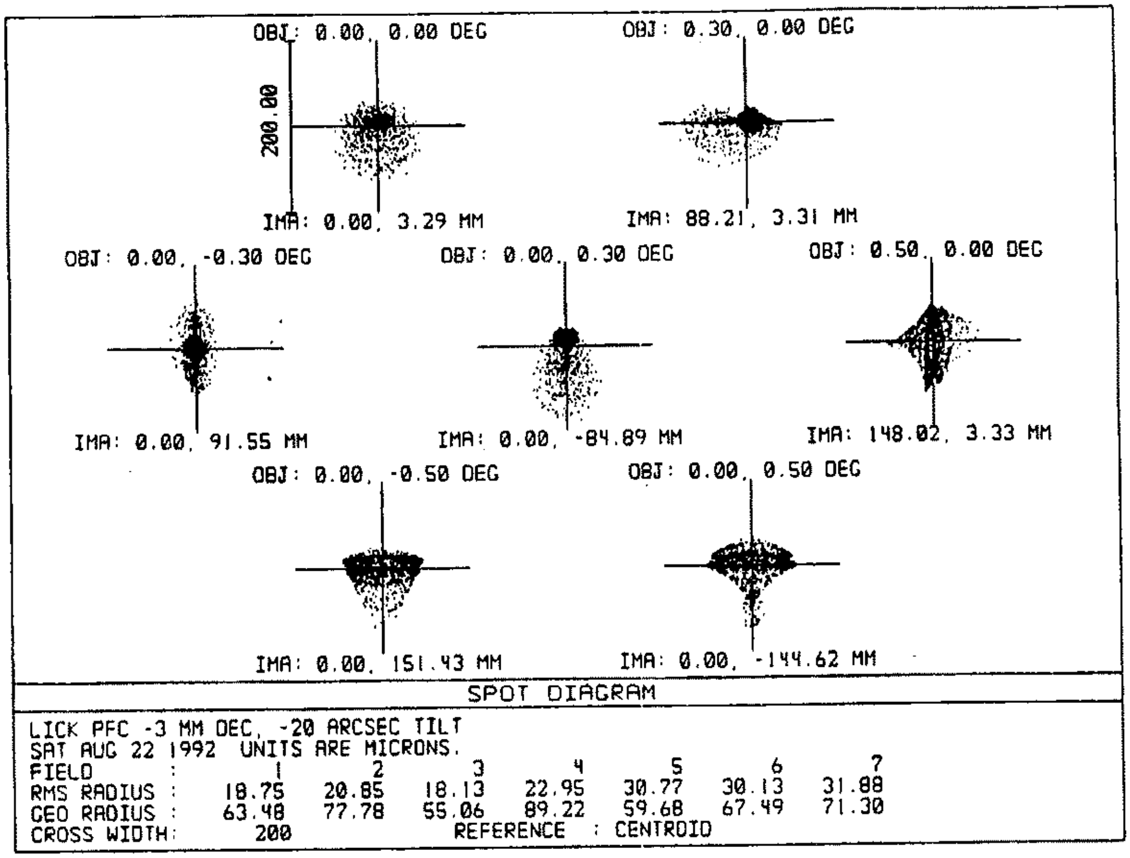

Figure 2. Spot diagram for PFC with -3 mm decenter and 20 arc-sec tilt.

The table below summarizes the image motion and degradation for a 3 mm decentration and a 20 arc-sec tilt of the PFC in the y direction:

Table 1. Variation of image size and position for PFC decenter of 3 mm and tilt of 20 arc-sec

Field angle (deg)	Nominal image position (mm)	Image shift (mm)	Nominal rms image diameter (arc-sec)	Degraded rms image diameter (arc-sec)
(0, 0)	(0, 0)	-3.29	.253	.361
(0.3, 0)	(88.21, 0)	-3.31	.385	.462
(0.5, 0)	(148.02, 0)	-3.33	.887	.924
(0, -0.3)	(0, -88.21)	-3.32	.385	.376
(0, -0.5)	(0, -148.02)	-3.41	.887	.900
(0, 0.3)	(0, 88.21)	-3.34	.385	.535
(0, 0.5)	(0, 148.02)	-3.40	.887	.819

$\Delta = 100\mu$!

Analysis Procedure

The tolerance analysis was performed using the commercial lens design software Zemax. The optical system was modeled in the computer and a merit function describing performance was created. Each element spacing, tilt, decenter, curvature and thickness was varied by its tolerance and the effect on the merit function was found. This produced a table of sensitivities. The position of the PFC with respect to the primary was always adjusted to best focus. Also, to simulate the system performance with all of the uncertainties, a Monte Carlo analysis was performed.

The nominal design, which produces .25 arc-sec images, has over 1 λ rms variation in the wavefront. The figure errors on the surfaces and the variation of the refractive index of the glasses are certain to be negligible with respect to this, so these parameters were not treated in this analysis. Also, the refractive index of the glass is known very accurately so it is not used in this tolerance analysis.

The rms spot size for the on-axis image was chosen as the figure of merit because it is easily calculated and represents system performance. The spot size requirements for narrow-field high resolution imaging are more stringent than for fiber-fed spectroscopy. The image degradation due to system misalignments will effect all fields nearly equally, so only the on-axis image was evaluated in detail, although the full-field images were verified. One possible complication could be the varying distortion of the 1° FOV. It is assumed in this analysis that the mapping of the sky to the focal plane will be measured and used for the fiber optic positioning.

The assumed tolerances the PFC parameters were estimated based on discussions with Harland and Dave. The values used are given in the table below and also are shown in figure 3.

Table 2. Assumed PFC optical and mechanical tolerances

parameter	assumed tolerance
radius of curvature*	$\Delta R = 0.0001R$ or 2.5 μm sag whichever is greater
curvature of flats	2.5 μm sag
thickness of lenses*	$\Delta t = 10$ μm for all lenses
spacing between lenses	$\Delta t = 0.001\ t$ for all spacings
tilt of lenses	runout due to tilt ± 50 μm (.004") across clear diameter
decentration of lenses**	$\Delta x, \Delta y = 100$ μm (0.004")

* These parameters will be measured and the system re-optimized based upon the results. The numbers given are the estimated measurement uncertainties.

** This analysis does not consider using intentional mechanical misalignment to compensate for the measured wedge in the lenses.

Results

This analysis indicates that the mechanical tolerances may be loosened up without significantly degrading the system performance. The details of the analysis may be found in the appendix. The sensitivities of the rms spot radius are given in the table below. The tolerances used were arrived at by the above descriptions. The effect on the rms spot diameter was calculated from the computer simulation using the following approximation:

$$d\theta_i = \sqrt{\theta_i^2 - \theta_0^2}$$

$d\theta_i$ = influence of i^{th} parameter on rms diameter in arc-sec
θ_i = rms spot diameter in arc-sec for system with i^{th} parameter perturbed
θ_0 = rms spot diameter for nominal system

The cumulative effect of all of the tolerances is estimated by computing a root-sum-squared spot diameter given by the following equation:

$$d\theta = \sqrt{\theta_0^2 + \sum_i (\theta_i^2)}$$

$d\theta$ = total rms diameter in arc-sec from root-sum-square

The PFC layout is shown in Fig. 3 on the following page. The parameters are nominal and will be updated as each element is fabricated.

The table on the next page shows the complete sensitivity of the rms spot diameter to the assigned tolerances.

Prime Focus Corrector for Lick 120" Telescope

Focal plane (~300 mm diam)

Spacing 325.57 ± 0.3 mm

Lens 3
R2 2425.9 ± .72 mm
thick 43.010 ± 0.01 mm
R1 661.41 ± .066 mm
tip/tilt ± .03°
(± .05 mm runout)
dec ±0.1 mm

Spacing 489.856 ± 0.5 mm

ADC
curv 4 ±2.5 µm sag
thick 3 10.16 ± 0.01 mm
curv 3 ±2.5 µm sag
thick 2 15.24 ± 0.01 mm
curv 2 ±2.5 µm sag
thick 1 10.16 ± 0.01 mm
curv 1 ±2.5 µm sag
tip/tilt ±0.03°
(± .05 mm runout)

Spacing 108.515 ± 0.1 mm

Lens 2
R2 432.09 ± .043 mm
thick 21.08 ± 0.01 mm
R1 1181.8 ± .17 mm
tip/tilt ± .028°
(± .05 mm runout)
dec ±0.1 mm

Spacing 322.28 ± 0.3 mm

Lens 1
R2 630.02 ± .063 mm
thick 73.25 ± 0.01 mm
R1 529.423 ± .053 mm
tip/tilt ± .022°
(± .05 mm runout)
dec ±0.1 mm

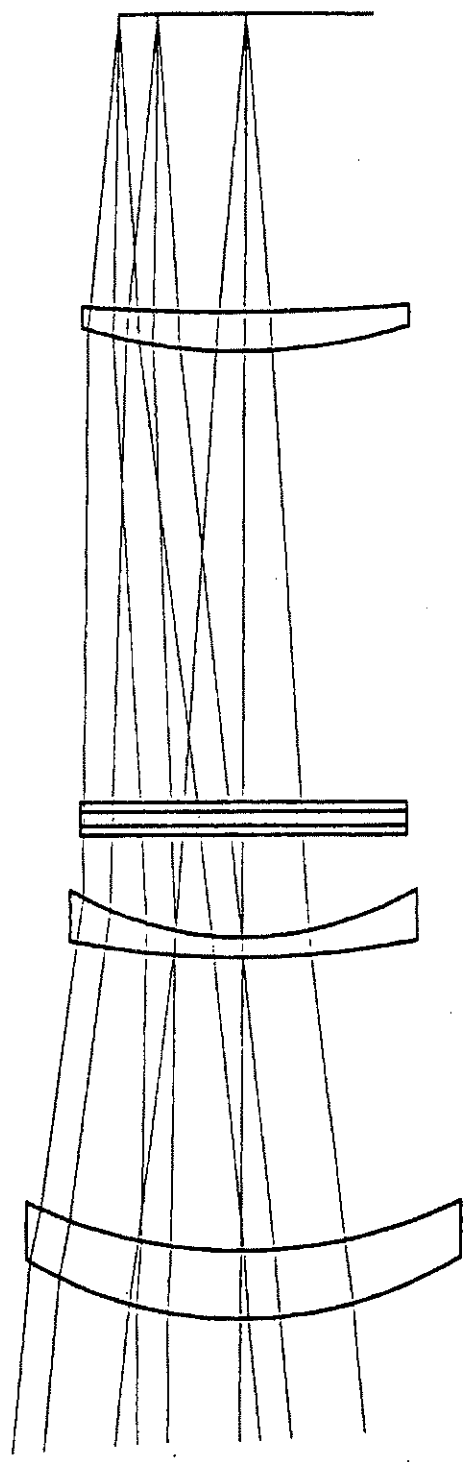

Figure 3. Layout of the prime focus corrector with the parameter and tolerance values used for this analysis. The atmospheric dispersion compensator (ADC) was modeled as plane parallel plates. A detailed prescription of the system is given in the appendix.

Sensitivities for Lick Prime Focus Corrector

	value	tolerance	arc-sec diam
			(rms)
Nominal design			0.2537
Lens 1			
Radius 1 (mm)	529.423	0.053	0.0141
thickness (mm)	73.250	0.01	0.0050
Radius 2 (mm)	630.020	0.063	0.0218
tip/tilt (deg)		0.022	0.0177
decenter (mm)		0.1	0.0154
spacing (mm)	322.280	0.3	0.0187
Lens 2			
Radius 1 (mm)	1181.797	0.168	0.0162
thickness (mm)	21.080	0.01	0.0050
Radius 2 (mm)	432.090	0.043	0.0112
tip/tilt (deg)		0.028	0.0209
decenter (mm)		0.1	0.0218
spacing (mm)	108.515	0.1	0.0128
ADC			
Curvature 1 (μm sag)		2.5	0.0127
thickness 1 (mm)	10.160	0.01	0.0036
Curvature 2 (μm sag)		2.5	0.0094
thickness 2 (mm)	15.240	0.01	0.0036
Curvature 3 (μm sag)		2.5	0.0094
thickness 3 (mm)	10.160	0.01	0.0036
Curvature 4 (μm sag)		2.5	0.0359
tip/tilt (deg)		0.03	0.0036
spacing (mm)	489.856	0.5	0.0283
Lens 3			
Radius 1 (mm)	661.410	0.066	0.0036
thickness (mm)	43.010	0.01	0.0036
Radius 2 (mm)	2425.900	0.72	0.0036
tip/tilt (deg)		0.03	0.0082
decenter (mm)		0.1	0.0087
spacing (mm)	325.570	0.3	0.0218
RSS			0.2657

Lick prime focus corrector tolerance analysis

The resulting rms spot diameter of 0.266 arc-sec is dominated by the residual aberrations in the nominal design. If the system is built to these tolerances, it will clearly perform exceptionally. There is room for some of the mechanical tolerances to be relaxed somewhat without any significant loss in imaging quality.

A Monte Carlo statistical analysis was also performed on the system to check the cumulative effect of all of the tolerances. For each of 25 simulations, each parameter was varied randomly according to a normal distribution with the standard deviation set to one fourth the tolerance value. The PFC was always positioned at best focus and the rms spot size was found. The average spot size was 0.256 arc-sec and the standard deviation 0.002 arc-sec. This shows the rss value above to be somewhat conservative. The maximum spot diameter was .259 arc-sec and the maximum motion required of the PFC to find best focus was 1.04 mm. A complete listing of the simulation output is given in the appendix.

Conclusion

The detailed tolerance analysis performed on the prime focus corrector for the 120 inch Lick Observatory telescope indicates that the performance of the system will be limited by the motion of the PFC relative to the primary mirror. The optical and mechanical tolerances for the PFC fabrication may be tighter than they are required to be based on imaging performance.

Appendix

Details of prescription, sensitivity analysis, and Monte Carlo analysis

Part One PFC computer model

GENERAL LENS DATA:

Lens Title	LICK PFC TOLERANCE ANALYSIS
Number of surfaces	23
Effective Focal Length	-16789.4
Image Space F/#	5.508333
Working F/#	5.508985
Entrance Pupil Diameter	3048
Entrance Pupil Position	0
Exit Pupil Diameter	1997.489
Exit Pupil Position	-11003.31
Total Track	15381.81
Paraxial Magnification	0
Paraxial Image Height	0
Primary Wavelength	0.550 microns
Stop Surface	1
Units	Millimeters

Defined Wavelengths	3	
Wavelength Number 1	0.358 microns	0.250 weight
Wavelength Number 2	0.550 microns	0.500 weight
Wavelength Number 3	0.850 microns	0.250 weight

SURFACE DATA SUMMARY:

Surf	Type	Radius	Thickness	Glass	Diameter	Conic
OBJ	STANDARD	Infinity	Infinity		3048	0
STO	STANDARD	-30571.44	-15285.72	MIRROR	3048	-1
2	COORDBRK	-------	0		0	-------
3	STANDARD	Infinity	1323.317		0	0
4	COORDBRK	-------	0		0	-------
5	STANDARD	-529.423	-73.25001	SILICA	508	0
6	STANDARD	-630.02	0		508	0
7	COORDBRK	-------	-322.283		0	-------
8	COORDBRK	-------	0		0	-------
9	EVENASPH	-1181.797	-21.08	SILICA	406.4	1.014939
10	STANDARD	-432.09	0		406.4	0
11	COORDBRK	-------	-108.5154		0	-------
12	COORDBRK	-------	0		0	-------
13	STANDARD	Infinity	-10.16	FK5	381	0
14	STANDARD	Infinity	-15.24	LLF6	381	0
15	STANDARD	Infinity	-10.16	FK5	381	0
16	STANDARD	Infinity	0		137.5285	0

17	COORDBRK	-------	-489.856		0	-------
18	COORDBRK	-------	0		0	-------
19	STANDARD	-661.41	-43.01	SILICA	381	0
20	STANDARD	-2425.9	0		381	0
21	COORDBRK	-------	-325.8487		0	-------
22	STANDARD	Infinity	0.279338		5.08e-005	0
IMA	STANDARD	Infinity	0		0.03838324	0

SURFACE DATA DETAIL:

Surface 9 : EVANASPH
Coeff on r 2 : 0
Coeff on r 4 : 6.180889e-011
Coeff on r 6 : 4.925445e-016
Coeff on r 8 : 3.098444e-021
Coeff on r 10 : -7.187621e-026

INDEX OF REFRACTION DATA:

Surf	Glass	0.358300	0.550000	0.850000
0		1.00000000	1.00000000	1.00000000
1	MIRROR	1.00000000	1.00000000	1.00000000
2		1.00000000	1.00000000	1.00000000
3		1.00000000	1.00000000	1.00000000
4		1.00000000	1.00000000	1.00000000
5	SILICA	1.47555135	1.45991088	1.45249829
6		1.00000000	1.00000000	1.00000000
7		1.00000000	1.00000000	1.00000000
8		1.00000000	1.00000000	1.00000000
9	SILICA	1.47555135	1.45991088	1.45249829
10		1.00000000	1.00000000	1.00000000
11		1.00000000	1.00000000	1.00000000
12		1.00000000	1.00000000	1.00000000
13	FK5	1.50505303	1.48897169	1.48140752
14	LLF6	1.56165360	1.53404117	1.52283782
15	FK5	1.50505303	1.48897169	1.48140752
16		1.00000000	1.00000000	1.00000000
17		1.00000000	1.00000000	1.00000000
18		1.00000000	1.00000000	1.00000000
19	SILICA	1.47555135	1.45991088	1.45249829
20		1.00000000	1.00000000	1.00000000
21		1.00000000	1.00000000	1.00000000
22		1.00000000	1.00000000	1.00000000
23		1.00000000	1.00000000	1.00000000

ELEMENT VOLUME DATA:

Units are cubic cm.
Values are only accurate for plane and spherical surfaces.
Element surf 5 to 6 volume : -13750.434635
Element surf 13 to 14 volume : -1158.333297
Element surf 14 to 15 volume : -1737.499946
Element surf 15 to 16 volume : -536.375482
Element surf 19 to 20 volume : -3744.165829

Part Two Sensitivity analysis

Analysis of Tolerances
Input File: TOL3.TOL
LICK PFC TOLERANCE ANALYSIS
Sat Aug 22 1992

Radius tolerances are fringes at wavelength: 0.550000 microns.
Thickness tolerances are in millimeters.
Decenter tolerances are in millimeters.
Tilt tolerances are in degrees.

Mnemonics:
TRAD: Tolerance on radius of curvature in fringes.
TTHI: Tolerance on thickness.
TDCX: Tolerance on decentering in x.
TDCY: Tolerance on decentering in y.
TUDX: Tolerance on user surface decentering in x.
TUDY: Tolerance on user surface decentering in y.
TTLX: Tolerance on tilt (degrees) around the x-axis.
TTLY: Tolerance on tilt (degrees) around the y-axis.
TUTX: Tolerance on user surface tilt (degrees) around the x-axis.
TUTY: Tolerance on user surface tilt (degrees) around the y-axis.
TIND: Tolerance on index of refraction.

Compensator: DISZ 2

Sensitivity Analysis:
Nominal Merit Function is 0.01032597 rms spot radius in µm

Type	Surf	Minus	Plus	MF Minus	MF Plus
TRAD	5	-22.000000	22.000000	0.010329	0.010342
TRAD	6	-18.600000	18.600000	0.010364	0.010296
TRAD	9	-9.100000	9.100000	0.010347	0.010306
TRAD	10	-17.400000	17.400000	0.010317	0.010336
TRAD	13	-9.000000	9.000000	0.010339	0.010314
TRAD	14	-9.000000	9.000000	0.010319	0.010333
TRAD	15	-9.000000	9.000000	0.010333	0.010319
TRAD	16	-9.000000	9.000000	0.010249	0.010429
TRAD	19	-10.000000	10.000000	0.010326	0.010326
TRAD	20	-9.000000	9.000000	0.010325	0.010327
TTHI	5	-0.010000	0.010000	0.010324	0.010328
TTHI	7	-0.300000	0.300000	0.010354	0.010308
TTHI	9	-0.010000	0.010000	0.010328	0.010324
TTHI	11	-0.100000	0.100000	0.010339	0.010313
TTHI	13	-0.010000	0.010000	0.010327	0.010325
TTHI	14	-0.010000	0.010000	0.010327	0.010325
TTHI	15	-0.010000	0.010000	0.010327	0.010325
TTHI	17	-0.500000	0.500000	0.010390	0.010264
TTHI	19	-0.010000	0.010000	0.010327	0.010325
TTHI	21	-0.300000	0.300000	0.010365	0.010287
TUDX	4 7	-0.100000	0.100000	0.010345	0.010345
TUDY	4 7	-0.100000	0.100000	0.010345	0.010345

TUTX	4	7	-0.022000	0.022000	0.010351	0.010351
TUTY	4	7	-0.022000	0.022000	0.010351	0.010351
TUDX	8	11	-0.100000	0.100000	0.010364	0.010364
TUDY	8	11	-0.100000	0.100000	0.010364	0.010364
TUTX	8	11	-0.028000	0.028000	0.010361	0.010361
TUTY	8	11	-0.028000	0.028000	0.010361	0.010361
TUDX	12	17	-0.100000	0.100000	0.010326	0.010326
TUDY	12	17	-0.100000	0.100000	0.010326	0.010326
TUTX	12	17	-0.030000	0.030000	0.010327	0.010327
TUTY	12	17	-0.030000	0.030000	0.010327	0.010327
TUDX	18	21	-0.100000	0.100000	0.010332	0.010332
TUDY	18	21	-0.100000	0.100000	0.010332	0.010332
TUTX	18	21	-0.030000	0.030000	0.010331	0.010331
TUTY	18	21	-0.030000	0.030000	0.010331	0.010331

Merit Function Statistics:
Mean MF : 0.010334
Standard Deviation : 0.000025

Part Three Monte Carlo analysis

Monte Carlo Analysis:
Number of trials: 25

The Monte Carlo analysis includes TRAD: TTHI: TIND: TUDX: TUDY: TUTX and TUTY tolerances. It excludes the TDCX: TDCY: TTLX: and TTLY tolerances.

Trial Number 1 :
Merit Function : 0.010358
Compensator Values :
DISZ 2 -0.3196527

Trial Number 2 :
Merit Function : 0.010499
Compensator Values :
DISZ 2 -0.1052127

Trial Number 3 :
Merit Function : 0.010507
Compensator Values :
DISZ 2 0.5443226

Trial Number 4 :
Merit Function : 0.010439
Compensator Values :
DISZ 2 0.261265

Trial Number 5 :
Merit Function : 0.010537
Compensator Values :
DISZ 2 -0.03173577

Trial Number 6 :
Merit Function : 0.010453
Compensator Values :
DISZ 2 0.01787667

Trial Number 7 :
Merit Function : 0.010567
Compensator Values :
DISZ 2 -0.09207374

Trial Number 8 :
Merit Function : 0.010372
Compensator Values :
DISZ 2 -0.03875054

Trial Number 9 :
Merit Function : 0.010492
Compensator Values :
DISZ 2 1.03854

Trial Number 10 :
Merit Function : 0.010437
Compensator Values :
DISZ 2 -0.2140899

Trial Number 11 :
Merit Function : 0.010283
Compensator Values :
DISZ 2 -0.4196084

Trial Number 12 :
Merit Function : 0.010322
Compensator Values :
DISZ 2 0.09109981

Trial Number 13 :
Merit Function : 0.010437
Compensator Values :
DISZ 2 0.7470415

Trial Number 14 :
Merit Function : 0.010477
Compensator Values :
DISZ 2 -0.2918588

Trial Number 15 :
Merit Function : 0.010445
Compensator Values :
DISZ 2 0.06391495

Trial Number 16 :
Merit Function : 0.010517
Compensator Values :
DISZ 2 0.4508592

Trial Number 17 :
Merit Function : 0.010428
Compensator Values :
DISZ 2 0.4011665

Trial Number 18 :
Merit Function : 0.010416
Compensator Values :
DISZ 2 0.328057

Trial Number 19 :
Merit Function : 0.010526
Compensator Values :
DISZ 2 0.7715817

Trial Number 20 :
Merit Function : 0.010445
Compensator Values :
DISZ 2 0.5844057

Trial Number 21 :
Merit Function : 0.010416
Compensator Values :
DISZ 2 0.565759

Trial Number 22 :
Merit Function : 0.010365
Compensator Values :
DISZ 2 0.2372637

Trial Number 23 :
Merit Function : 0.010415
Compensator Values :
DISZ 2 -0.09085575

Trial Number 24 :
Merit Function : 0.010389
Compensator Values :
DISZ 2 -0.02454638

Trial Number 25 :
Merit Function : 0.010271
Compensator Values :
DISZ 2 -0.4419227

Merit Function Statistics:
Mean Merit Function : 0.010433
Standard Deviation : 0.000074
End of Run.