Fermi National Accelerator Laboratory
Particle Physics Division

Mechanical Department Engineering Note

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Title: ***DES Imager Focal Plane Support Plate Design***

Author(s): *Greg Derylo (derylo@fnal.gov)* *FNAL/PPD/MD*

Reviewer(s):

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Abstract/Summary:

The Focal Plane Support Plate (FPSP) is the precision plate to which the CCD modules are mounted. The design of the V3 production plate and its support legs are presented here, primarily as a comparison to the existing V2 prototype hardware as only small changes are made between V2 and V3. The results of FEA studies are shown. The lowest predicted natural frequency of the plate/mount system is 97 Hz.

Applicable Codes: *N/A*

1.0 INTRODUCTION

WBS 1.5.2.2.2.1 covers the Focal Plane Support Plate (FPSP) design, including the plate's supports and its cooling braids. The design is based on the prototype system design with relatively small changes. A discussion of each of the design elements is discussed in Section 2.

V2 prototype assembly drawing	436544 Rev A
V3 production assembly drawing	480066

This report will document the following items in support of this effort:

Section	Topic	Page
2.0	Description of Hardware	2
2.1	FPSP	2
2.2	Bipods	3
2.3	Bipod Base Ring	5
2.4	Alignment Shims	5
2.5	Cooling Braids	6
2.6	Grounding Braids	6
3.0	Evaluation	6
3.1	Deflections & Temperatures	6
3.2	Natural Frequency	12

2.0 DESCRIPTION OF HARDWARE

The design of the various items of hardware in the assembly are discussed below.

2.1 FOCAL PLANE SUPPORT PLATE

The V3 FPSP (480077) is nearly the same as the existing V2 prototype (436584 Rev. B) with the following exceptions:

- The front surface of the plate, in the regions exposed to the light cone, is to be painted black. DES project scientist Darren DePoy recommends use of Aeroglaze Z306, which is a low-outgassing polyurethane coating routinely used on space-based projects. Use of a painting facility at the University of Chicago will be pursued. A significant amount of masking will need to be done to keep paint off the precision mounting surfaces and out of the variety of holes.
- The pattern of raised pads on the front surface was altered in order to help facilitate painting.
- CCD module loading rod holes have a slightly increased diameter (nominally 0.173 vs. 0.170 inches).
- Unused holes removed from the front surface near the perimeter.
- Revised mounting hole pattern for the copper braids.
- The springs used for CCD module mounting are currently being studied on the V2 FPSP in the test vessel. Stiff springs have been observed to grind against the softer aluminum plate during tightening. Thin custom stainless steel spring pocket liners (see drawing 480041) are currently being investigated to provide a harder surface. These may be included in the final assembly to address this issue but does not directly impact the design of the plate. Since the shims are considerably thinner than the accumulated tolerance stackup of the various parts involved, the depth of the spring pocket will not be adjusted to accommodate the resulting small difference in the spring length.

Fabrication of the FPSP will proceed as follows:

1. Machine plate in FNAL Lab 4 shop except for final finishing of the precision front surface.
2. CMM inspection in Lab C.
3. Final surface lapping by local offsite vendor[1].
4. CMM inspection in Lab C.
5. Thorough cleaning at NWA (see below).
6. Mask precision surfaces and through-holes in preparation for front surface painting.
7. Paint front surface.
8. Install & align bipod hardware (described below).

After lapping, the V2 FPSP was cleaned at building NWA by Bill Miner (PPD) and Bill Dymond (AD) using the following recipe:

1. Dawn detergent & water, with Q-tips, for 2+ hours
2. Dry with N2
3. 5 minutes 1 – 2% Citranox in DI water, with ultrasonic
4. 10 minute rinse in first tank
5. 30 minute rinse in DI second tank, with ultrasonic
6. Dry with N2
7. Alcohol rinse
8. Dry with N2
9. Plate was bagged

The finished plate was found to be discolored, with some etched-looking patches, after cleaning. Per Bill Dymond & his manager, this routinely happens when they ultrasonic aluminum and is not the effect of the Citranox, which is good for use with this material. They recommend the following for the future:

- No ultrasonic
- Run a sample of material through the process
- Provide an eye bolt (316SS) that fits in one of the edge holes

2.2 BIPOD ROD ASSEMBLY

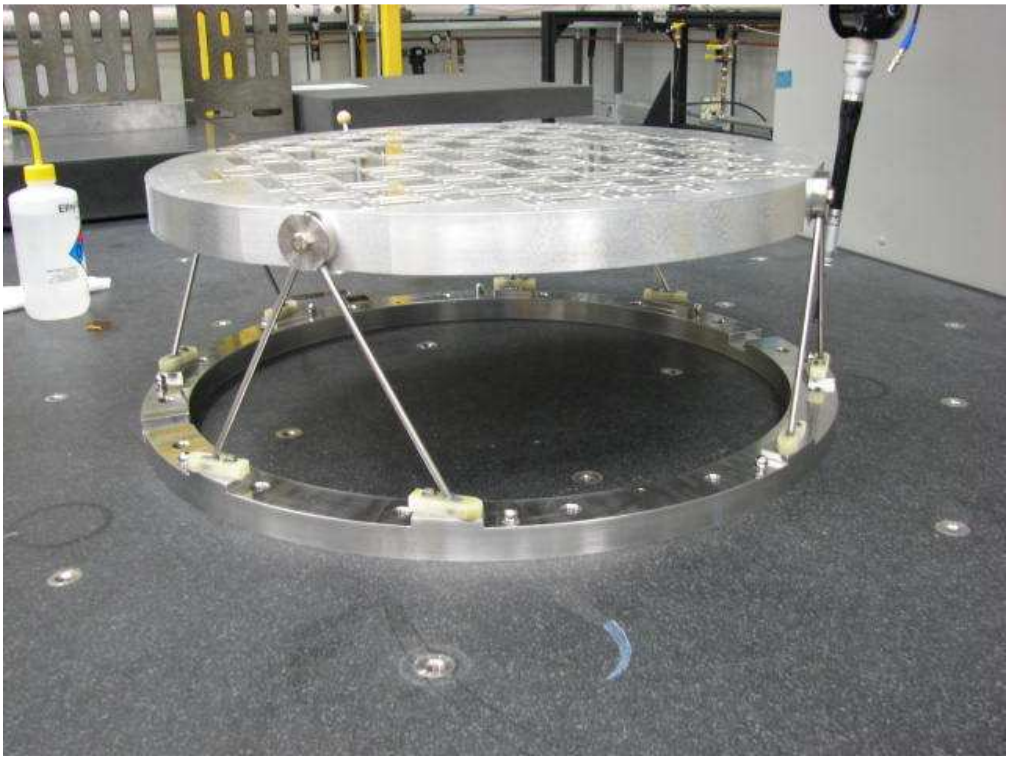
The bipod hardware was changed only slightly from the existing V2 design. A list of drawings and a description of the changes are shown below:

Part	**V2 Prototype Drawing**	**V3 Production Drawing**	**Comments**
Mounting Plug	436194	480086	Tighter fit to receiver & added thread relief
Mounting Plug Screw	HHCS ¼-20 x 1”	HHCS ¼-20 x .75	
Receiver	436197	480082	Tighter fit to the plug and rods. Also added grounding braid threaded hole.
Titanium Rod	436196	480081	Earlier rod diameters measured .1878±.0001 inch
Foot	436195	480080	Centered pin guide hole
Foot Screw	436547	McMaster Carr 93235A197	Use of custom vented screw unnecessary

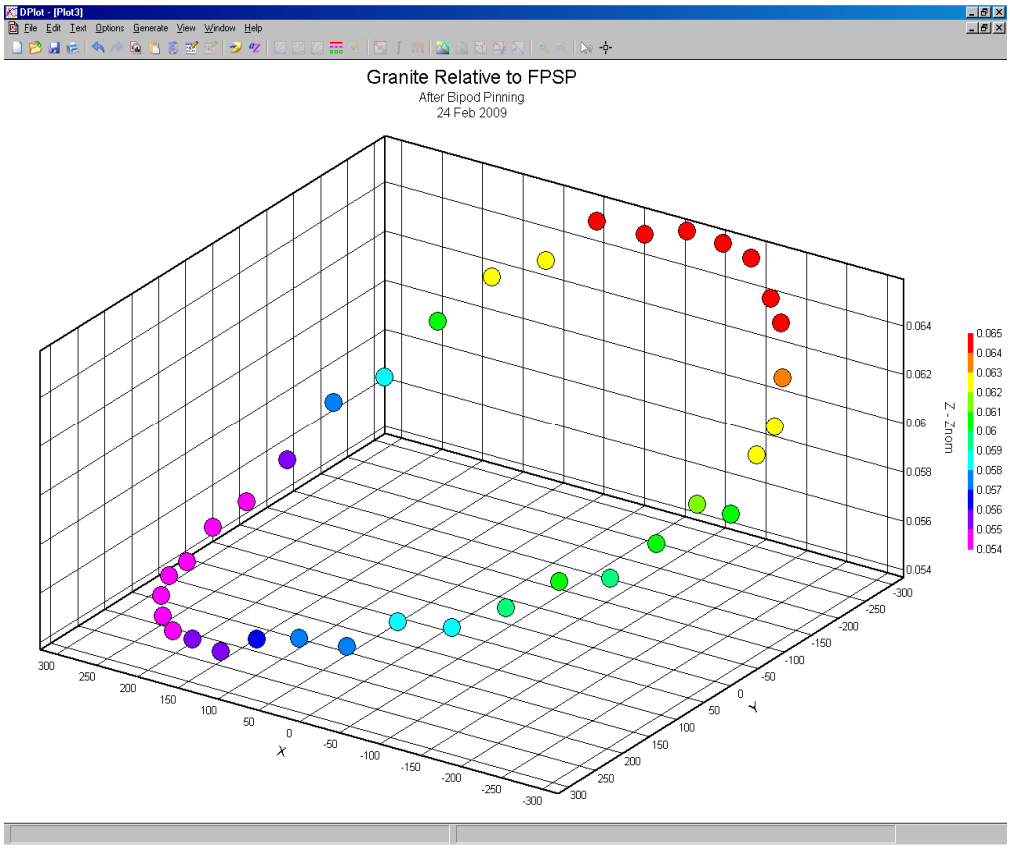
The basic assembly sequence used for the V2 FPSP bipods is described below. This same process will be followed for the V3 assembly.

[1] The V2 FPSP was lapped by Cabot Microelectronics in Addison, Illinois, http://www.surfacefinishes.com .

1. Rough align FPSP to granite base of CMM
2. Rough align bipod base ring to the FPSP and clamp to table
3. Rough align the G10 feet to the Ti rods (which are not yet pinned to the receiver)
4. Epoxy and screw the G10 feet to the bipod ring (Scotchweld DP190)
5. Take bipods off and drill & pin on the benchtop
6. Reinstall bipod assemblies and verify electrical isolation. Grind rod ends if necessary.
7. Epoxy the mounting plug into the FPSP (just a little DP190)
8. Reinstall rod assemblies and recheck electrical isolation
9. Align centers & clocking by adjusting the base ring and parallelism by adjusting the jack screws holding up the FPSP
10. Add Epotek 301-2 epoxy between receiver and threaded insert. Torque bolts with lock washer.
11. Recheck alignment & electrical isolation
12. Add DP190 to rod slots in G10
13. Recheck alignment & electrical isolation while epoxy still wet
14. Allow to cure
15. Drill & pin G10/rod joints
16. Recheck alignment



Unclamped V2 FPSP assembly being surveyed



Assembled parallelism ($Z-Z_{nom}$, mm) between the V2 FPSP and the CMM granite

2.3 BIPOD BASE RING

During the V2 prototype assembly effort this ring was found to be relatively flexible prior to its mounting in the vessel. The ring was therefore thickened in order to improve its rigidity during the assembly process. Also, the mounting screw size was reduced to facilitate the use of MDC's silver-plated screws in order to address the risk of stainless-on-stainless thread binding. Finally, additional threaded holes were added in case it later becomes necessary to develop VIB-to-CCD cable supporting hardware.

V2 prototype ring drawing	436545
V3 production ring drawing	480083

2.4 FOCAL PLANE ALIGNMENT SHIMS

The FPSP must be aligned to be perpendicular to the optical axis. This will be achieved by shimming between the bipod base ring and the mounting flange in the vessel weldment prior to installation of any CCDs. Rather than machine a wedge shape into a large, ring-shaped shim, a set of 16 shims (drawing 480084) will be individually modified in order to achieve the desired thickness in sections. The shims will be individually serial numbered for tracking during the iterative alignment process, which is planned as outlined below:

1. Install serial-numbered shims on the mounting surface in the imager vessel weldment (held in place with temporarily screws)
2. Install FPSP assembly (FPSP / bipods / base ring)
3. Install C5 flange (without its window)

4. Measure relative alignment between the C5 flange and the CCD mounting surfaces on the FPSP
5. Determine the desired thickness modifications to the shims by serial number
6. Disassemble the imager and remove shims
7. Modify shims
8. Repeat until alignment requirement is satisfied

2.5 COOLING BRAIDS

The design of the braids was tweaked slightly by Herman Cease to reduce their resistance (extra braids, beefier ends, larger contact surface to the FPSP with changes made to ease installation) and make a few other improvements (threaded inserts, increased clearances to warm hardware).

V2 prototype braids	436402 Rev B
V3 production braids	480067 / 480068 / 480069

2.6 GROUNDING BRAIDS

It is the request of DES management to electrically isolate the FPSP from the rest of the imager (accomplished with the G10 feet on the bipod rods), but then to jumper across the insulation with multiple significant grounding braids. A short path to the vessel wall would result in a large heat leak and gradients in the vessel wall, and jumpering to the cold copper braids would require extra handling due to repeated cooling system installation & removal. It was finally agreed upon to run a set of braids between the bipod receivers and the bipod base ring. Although there is a large temperature differential across these braids, the effect is reduced by using a stainless steel braid instead of copper. Crimp-on eyelets will be used on each end with a vented screw and star washer. The estimated heat leak assuming just the braid itself is estimated below. Due to the extra resistances at the ends, the actual leakage should be less than this.

Q_{tot} = N * k * A * DT / L

N = 4 braids of McMaster Carr PN 1478T1
k = 16 W/m-K
A = (24*16 wires/braid) * (0.25 * pi * .000120^2 m^2) = 4.34E-6 m^2
DT = 120K
L ~ 0.15 m

Q_{tot} = 0.22 Watts

3.0 EVALUATION

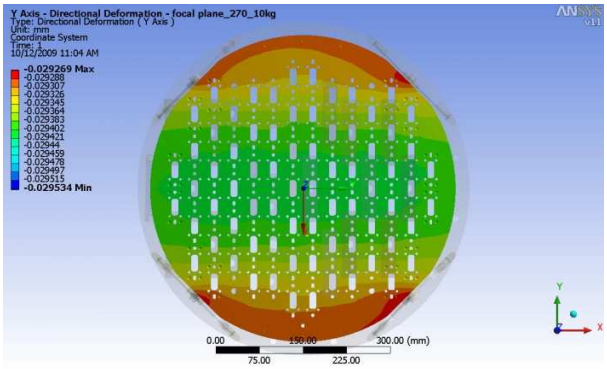
3.1 DEFLECTIONS AND TEMPERATURES

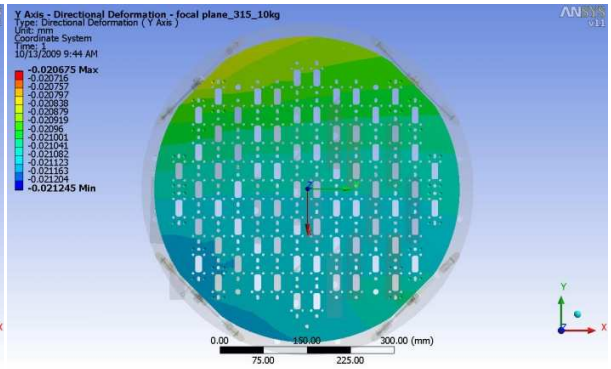
Imager performance relative to the alignment specifications, based on using the V2 prototype hardware designs, is documented in MD-Eng-201 (a copy is provided in DES docdb 2630). The V2-to-V3 changes are small, as discussed above, and do not invalidate the conclusions of the previous FEA analyses[2].

Of special note here is that a density error was found in the previous FEA work that impacts the results found in the MD-ENG-201 report section on “Specification TOM.10 – Operational Transverse Motion of the Focal Plane”. As

[2] Note that the total thickness of the bipod base ring + alignment shim is the same between V2 and V3; the increased V3 ring thickness is offset by a thinner shim.

documented there, the FEA deflections were found to be much less than the deflection observed during actual system testing. By correcting the density, the deflection agreements are improved, but still not perfect. Since the comparison to the specification was based on the test data rather than the FEA results themselves, this does not invalidate the conclusion of the previous report. A copy of the reanalyzed deflections is shown below assuming a 10kg CCD module load. For the case with gravity applied in between the bipods, the Uy deflection shown in the plot should be multiplied by (1 / sin(45°)) since only one component of the motion is shown and Ux values would be comparable.

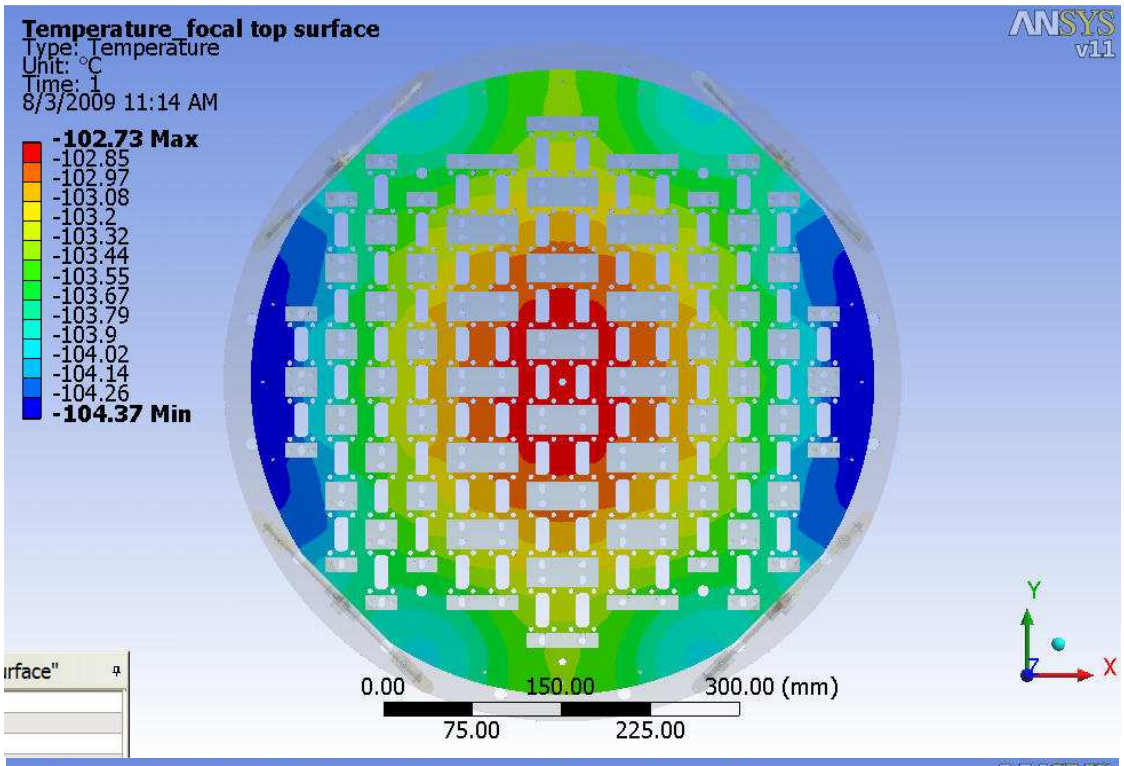


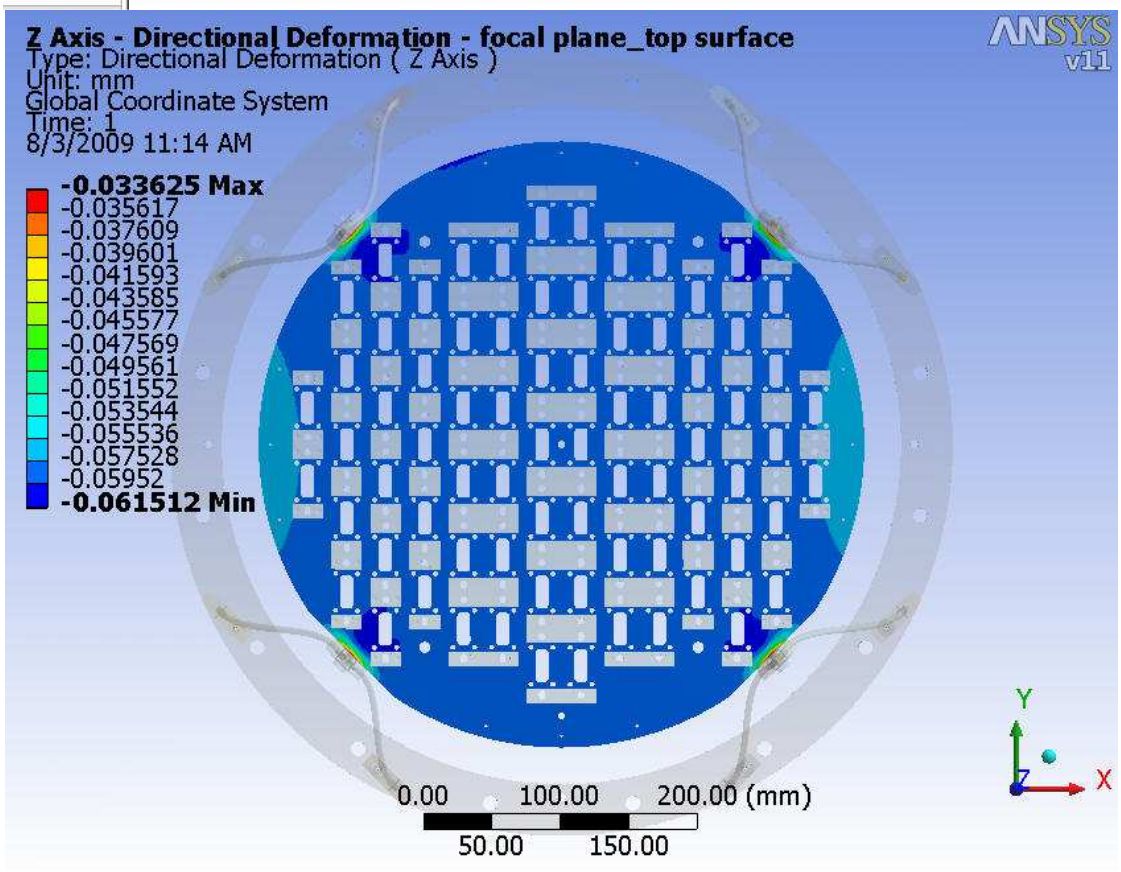


Gravity vector applied towards left
Predicted transverse deflection = 29 microns

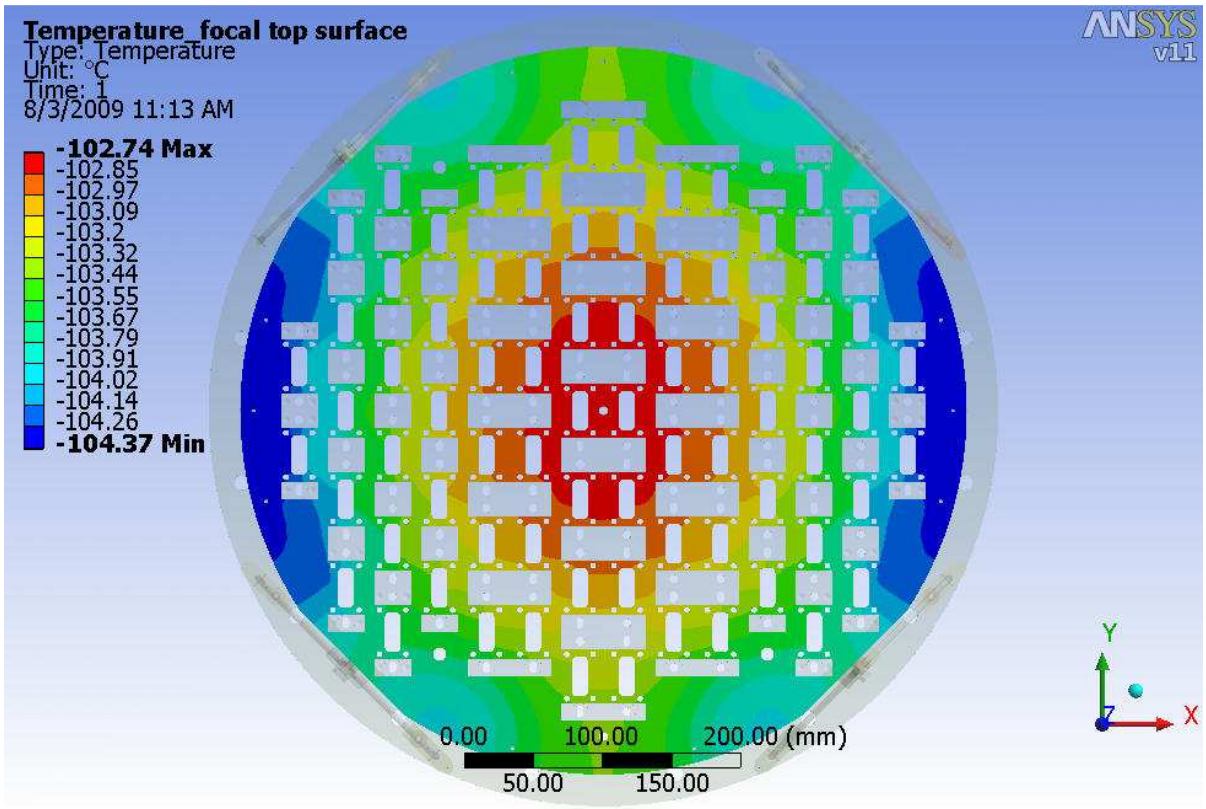
Gravity applied towards 7:30 clock position
Total predicted deflection = 21 * 1.414 = 30 microns

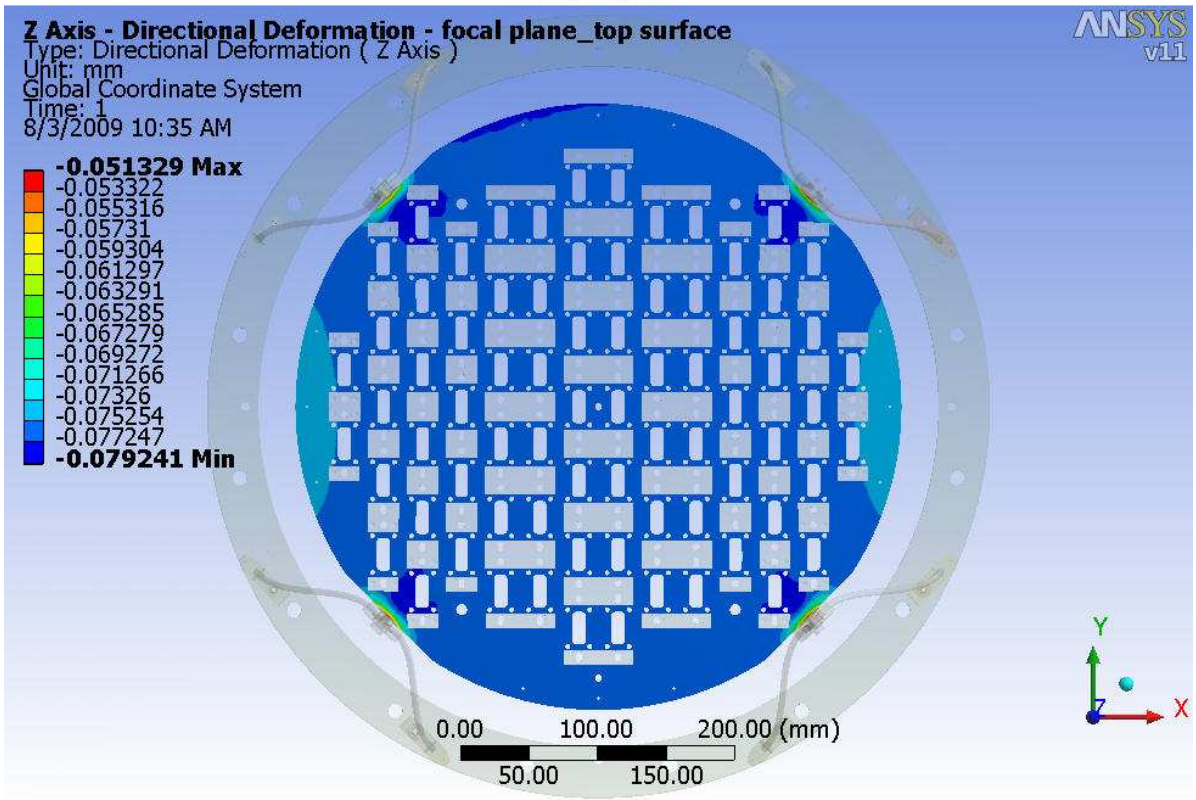
Selected results from the previous FEA studies performed by Ingrid Fang are presented below. As noted, some of these results were also documented in MD-Eng-201. The thermal results remain valid despite the previously-mentioned density error.



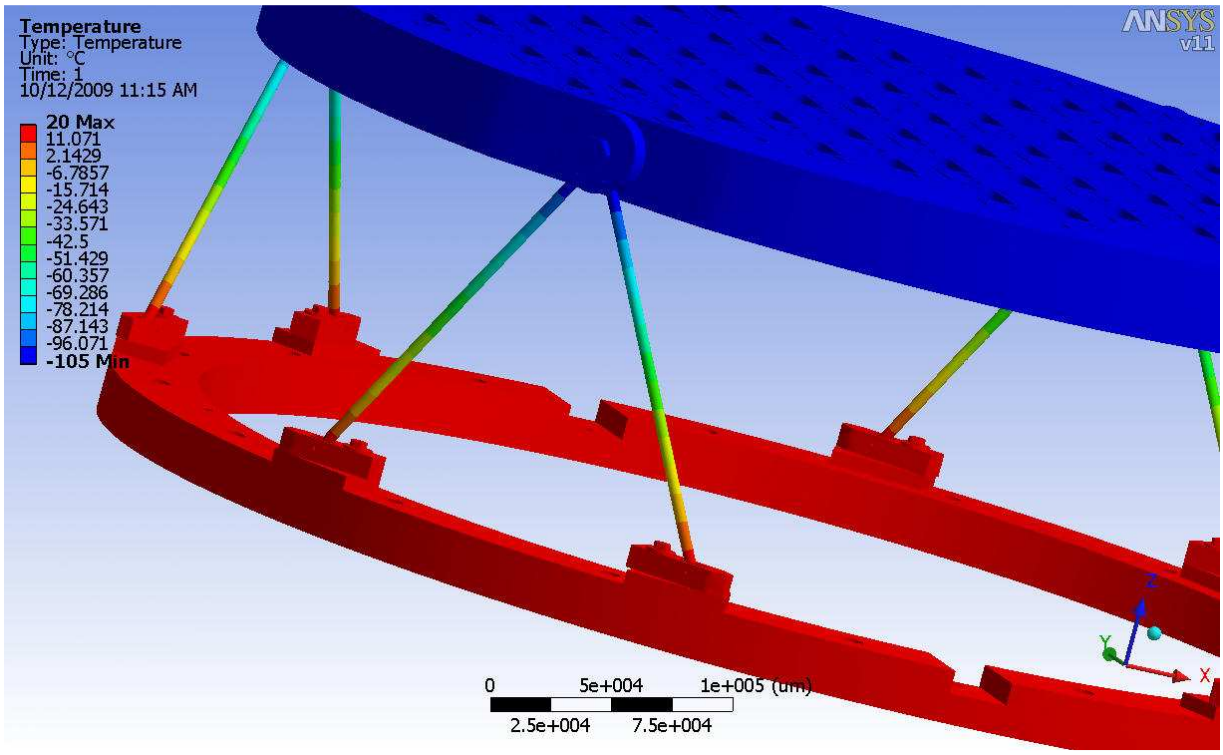


Effect of FPSP Thermal Gradient and Radial Shrinkage with Bipod Base Ring at +20ºC Ambient
Front Surface Temperatures and Z Distortions
Z Variation over Survey Area ~ 2 microns
[Copied from MD-Eng-201]



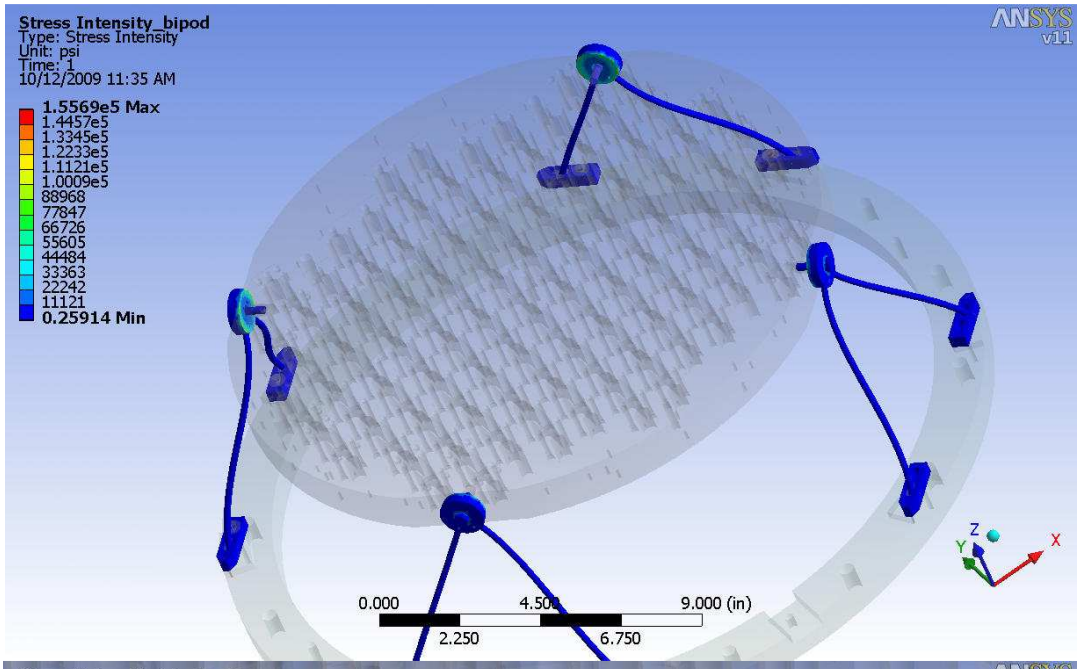


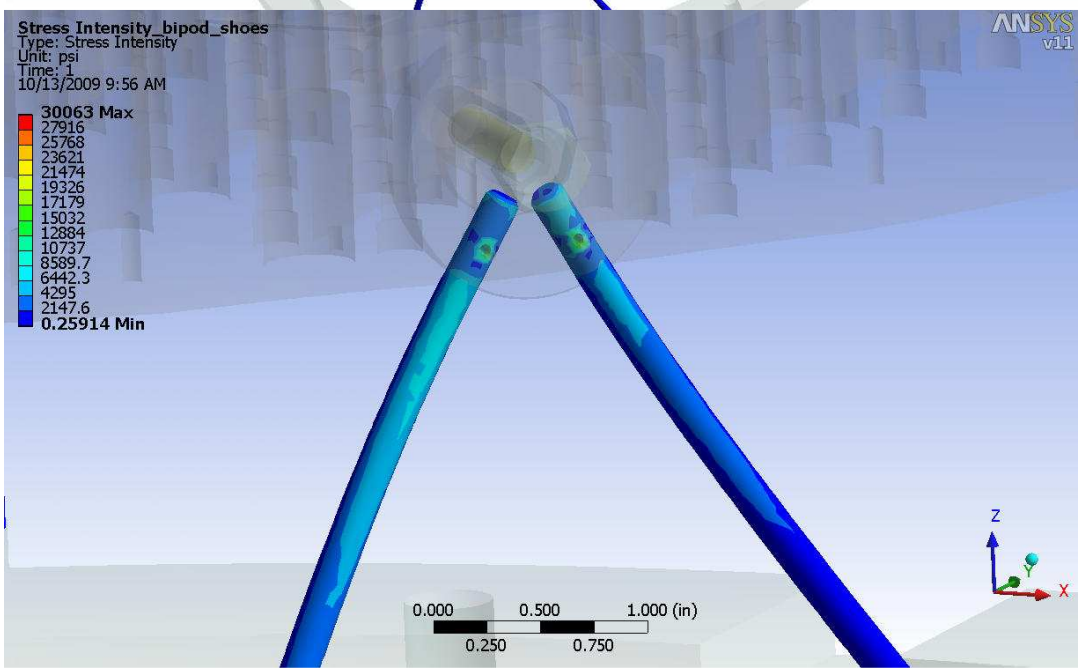
Effect of FPSP Thermal Gradient and Radial Shrinkage with Bipod Base Ring at -5ºC Ambient
Front Surface Temperatures and Z Distortions
Z Variation over Survey Area ~ 2 microns
[Copied from MD-Eng-201]



Temperature Gradient in the Assembly with a +20ºC Ambient

The previous model was also reanalyzed to determine the stresses in the bipods. The largest thermal gradient was assumed (+20ºC ambient) and a 300N (67 lbf) force was applied to the face of one of the bipod receivers to simulate gravitational load when pointing the telescope at the horizon. Since gravity is simulated as an applied load, part density has no impact on these results.





Part	Predicted Stress (psi)	Allowable Stress (psi)
Bipod Rod (Titanium)	< 20 ksi	Y = 128 ksi
Bipod Foot (G-10)	< 11 ksi	U = 65 ksi

3.2 NATURAL FREQUENCY

The FEA model was used by Ingrid Fang to investigate the first six natural frequency modes. The FPSP weight was adjusted to include the 10kg contribution of the CCD modules. Movies of the mode motions have been archived in DES docdb 3721 along with a copy of this report.

Mode	Hz	Description
1	97	Transverse FPSP motion, perpendicular to two opposing sets of bipods (45° off the VIBs)
2	97	Pistoning of the FPSP in the axial direction
3	187	FPSP rotation about the optical axis
4	198	"Drum-head" deformation of the FPSP
5	275	"Teeter-totter" of the FPSP about a transverse axis perpendicular to the VIBs
6	287	"Teeter-totter" of the FPSP about a transverse axis parallel to the VIBs

The lowest natural frequencies are therefore larger than the 60 Hz power frequency and the lower frequencies of a concern during earthquakes.

6.2 Design requirements 217

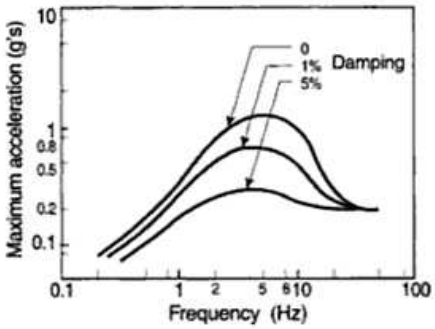


Fig. 6.14. Typical earthquake acceleration response spectrum for three values of damping of the structure. (After Ref. [7].)

factors if their natural frequencies are in the same range as those of the telescope. This can be avoided by specifying that all equipment mounted on the telescope must have a natural frequency significantly higher than that of the predominant mode of the telescope — 30 Hz or more, for example.

[from "The Design and Construction of Large Optical Telescopes", ed. by Pierre Bely]