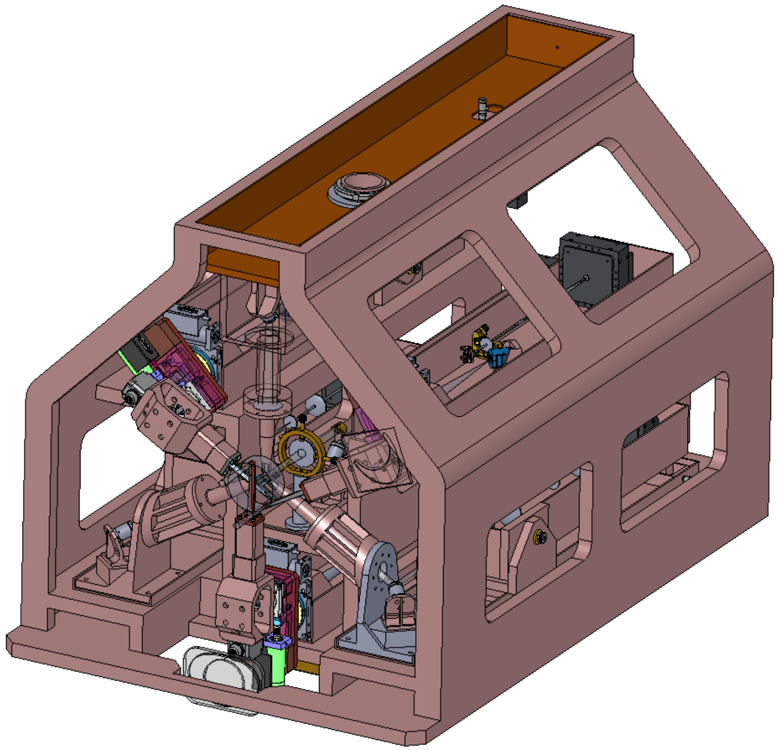
NGAO

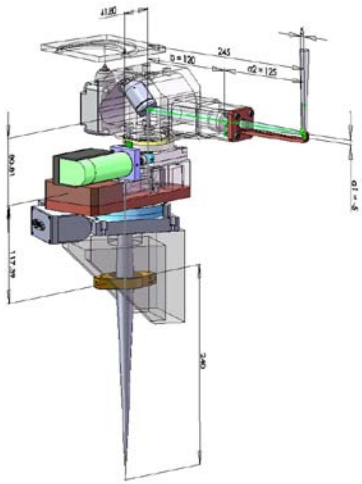
Laser Guide Star



12/07/2009
MINI-REVIEW

NGAO

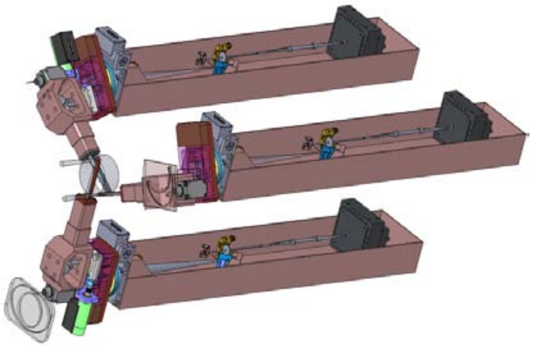
Laser Guide Star



1) Object Selection Mechanism

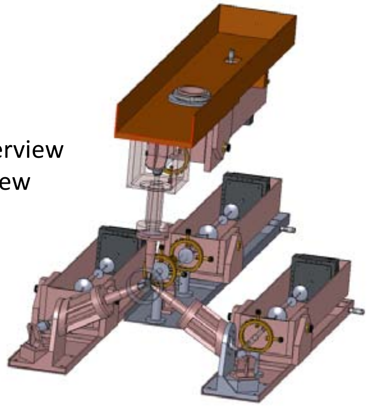
2) Laser Guide Star Architecture

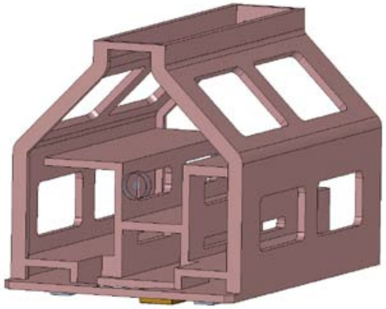
3) Patrolling Asterism



NGAO

Laser Guide Star





1) Object Selection Mechanism

1.1) Conceptual design and operation

Three probes cover the entire Ø 120” (87.24 mm) Field of View.

Each probe is mounted on a 2 degrees of freedom articulated arm composed of a crank arm and a lever arm, driven by 2 corresponding rotation motors: The crank and lever motors. (See Fig. 1)

Any position in the OSM field of view can be acquired by calculating appropriate values for theta and phi, noting that two possible solutions could be found due to symmetry.

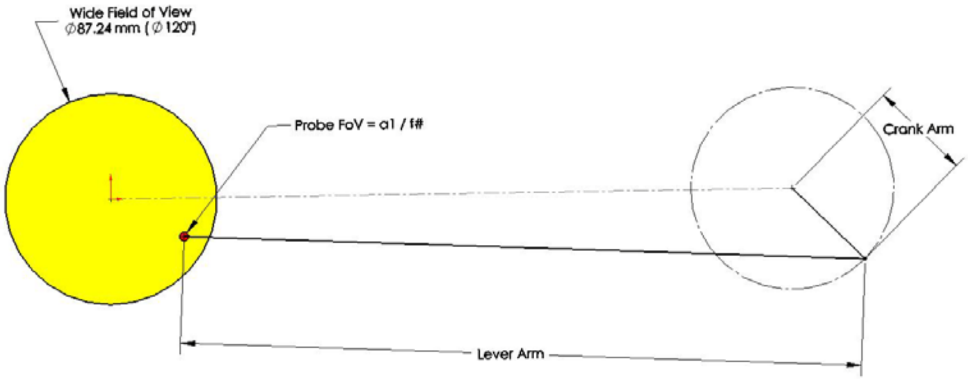


Fig. 1

The crank motor is secured to the Sensor and rotates the crank arm, precisely about the rotation axis of the crank motor referred to as the theta axis. The lever arm motor provides the necessary second degree of freedom by rotating the lever arm and all associated optics, about the phi axis.

Each probes are a at a different distance from the Focal plane, 15mm apart, with the closest probe 10 mm upstream from the focal plane. This design allow each probe to freely roam the entire field without risk of colliding into an other probe. The fixed 3 probes are located 45mm behind the focal plane. (See Fig. 2)

1.2) Design requirements:

Mechanism Type: ϕ/θ

FR-1920 : The 3 PnS WFS's shall be deployable anywhere over the 120" (87.24mm) FoR.

Focal Plane FoV : Ø 5” (3.635mm)

FR-1526 : Acquisition accuracy >100 mas (0.07mm)

Stability: 5 mas / 3600s (1 µm)

Operating Temperature: -10°C +/- 0.3
FR-512: The optical components of the LGSWFS shall be capable of operation at -5° C.

FR-1908 : PnS LGS WFS channels shall be able to pick off LGS beacons that are separated by 10" (from any other LGS sensor pick off) over the field

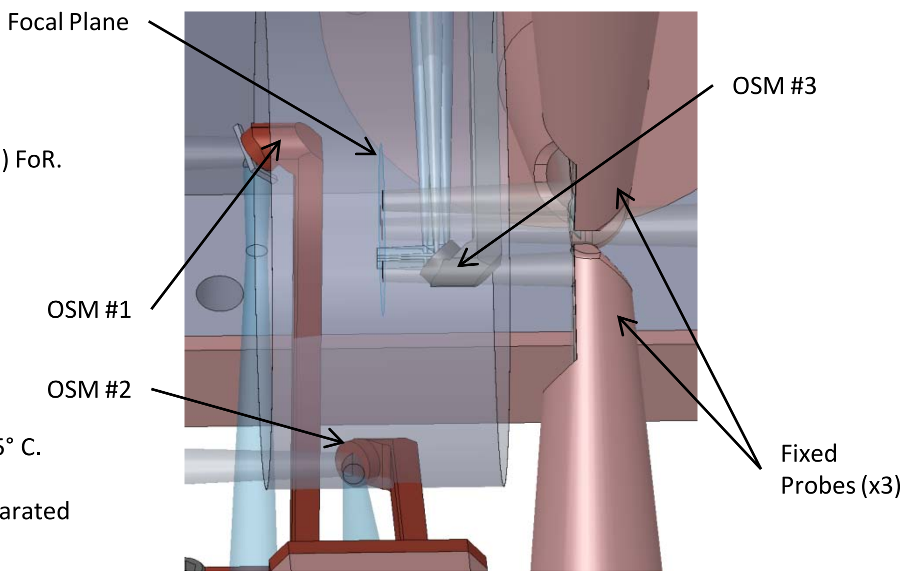
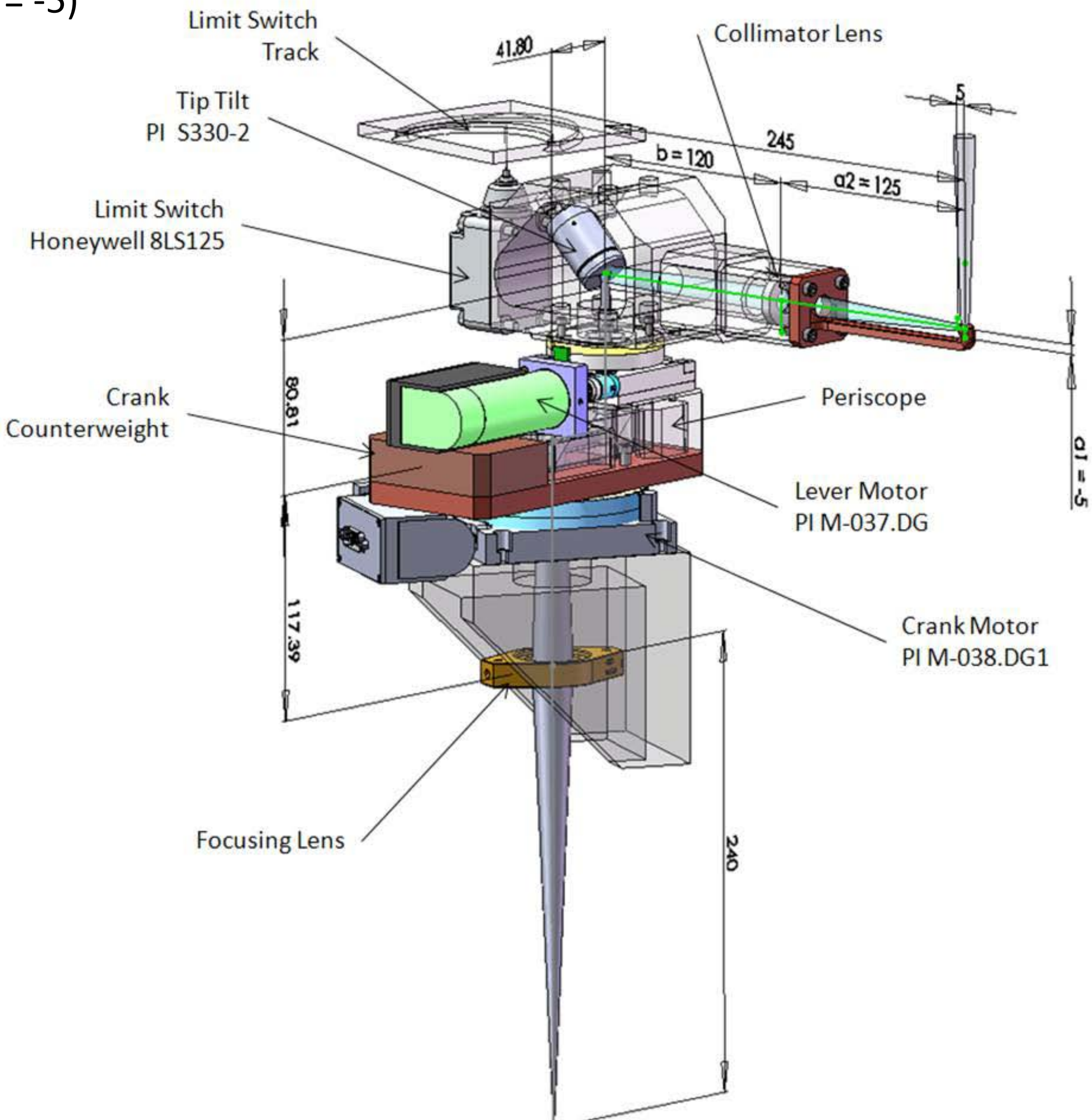


Fig. 2

1.3) Design Overview

OSM # 2 Shown (a1 = -5)



1.4) Optical equation applied to the mechanical design

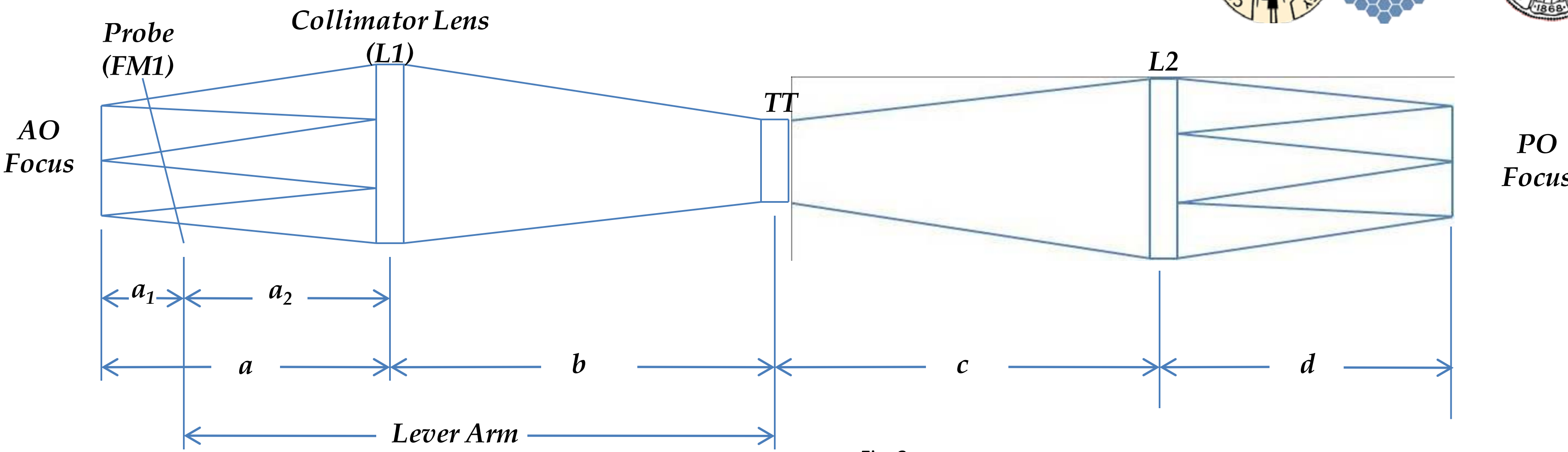


Fig. 3

Optical Layout (Fig. 3) is optimized when the following equations are verified:

1.4.1) a = b & c = d

1.4.2) a + b = x (c + d)
Keeping the AO Focus away from the Probe mirror (FM1) gives:

1.4.3) $a = a_1 + a_2$
Keeping each Lever arms on a different plane to avoid collision between each other gives a different value of a1 for each OSM
The Lever Arm Length previously determined gives:

1.4.4) Lever Arm length = $b + a_2$
Replacing 1.4.3 & 1.4.4 in 1.4.1 gives: a = b ➔ $a_1 + a_2$ = Lever Arm length - a_2
Solving for a_2 ➔ $2a_2$ = Lever Arm length - a_1 ➔ **a_2 = (Lever Arm length - a_1)/2**

1.4.5) With a = b = 120, Table 1 gives all the design dimension of the 3 OSMs

OSM#	a_1	$a_2 = a - a_1$	$a = b = a_1 + a_2$	$Arm = b + a_2$
I	10	110	120	230
II	-5	125	120	245
III	-20	140	120	260

Table 1

1.5) Sizing the Probe to 8mm Diameter

The Field of View at the Focal Plane is Ø 5" (3.635mm)
The Field of View at the probe is defined by it's distance from the Focal Plane / f#
The probe Fold Mirror intercept the light beam at a 45 degree angle creating an elliptical projection at a distance a1 from the Focal plane. (See Fig. 4)
The minimum diameter of the mirror needs to be larger than the Ellipse Major Diameter.
The Larger Fold mirror will be at the furthest distance from the Focal plane OSM #1 (a1 = -20)

⚠ Each Probe FoV is a potential vignetting of an other probe.

1.5.1) Largest FoV at the Fold Mirror #1 (FM1) is at OSM #1 (a1 = -20) Probe

Ellipse Minor Diameter:
d = d at Focus Plan + (a1 / f#)
= 5 X 0.727 + (20 / 13.66)
= 3.635 + 1.464
d = 5.10 mm

Ellipse Major Diameter:
D = $d\sqrt{2} = 5.1\sqrt{2}$
D = 7.21 mm

1.5.2) Smallest FoV at the Fold Mirror #1 (FM1) is at OSM #2 (a1 = -5) Probe

Ellipse Minor Diameter:
d = d at Focus Plan + (a1 / f#)
= 5 X 0.727 + (5 / 13.66)
= 3.635 + .366
d = 4.00 mm

Ellipse Major Diameter:
D = $d\sqrt{2} = 4\sqrt{2}$
D = 5.66 mm

1.5.3) Medium FoV at the Fold Mirror #1 (FM1) is at OSM #3 (a1 = 10) Probe

Ellipse Minor Diameter:
d = d at Focus Plan + (a1 / f#)
= 5 X 0.727 + (10 / 13.66)
= 3.635 + .732
d = 4.37 mm

Ellipse Major Diameter:
D = $d\sqrt{2} = 4.37\sqrt{2}$
D = 6.18 mm

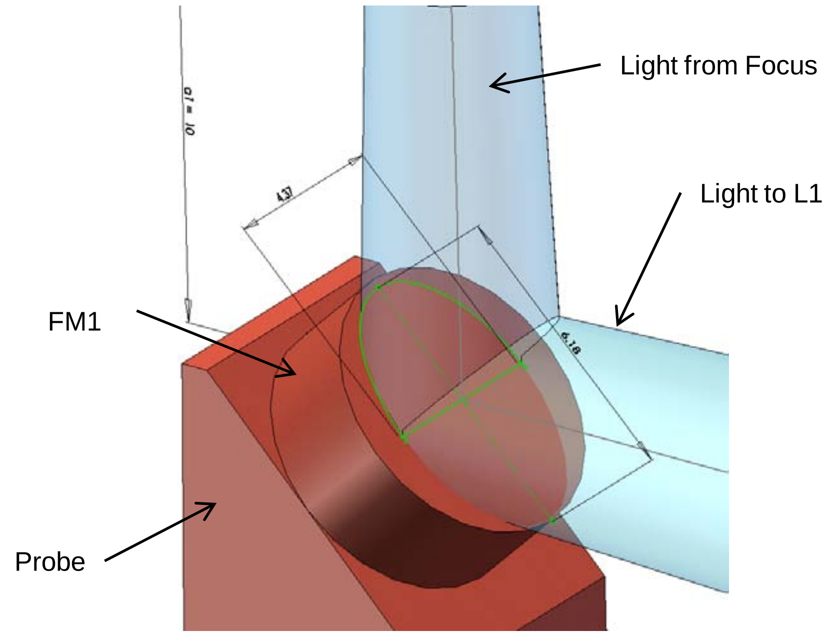
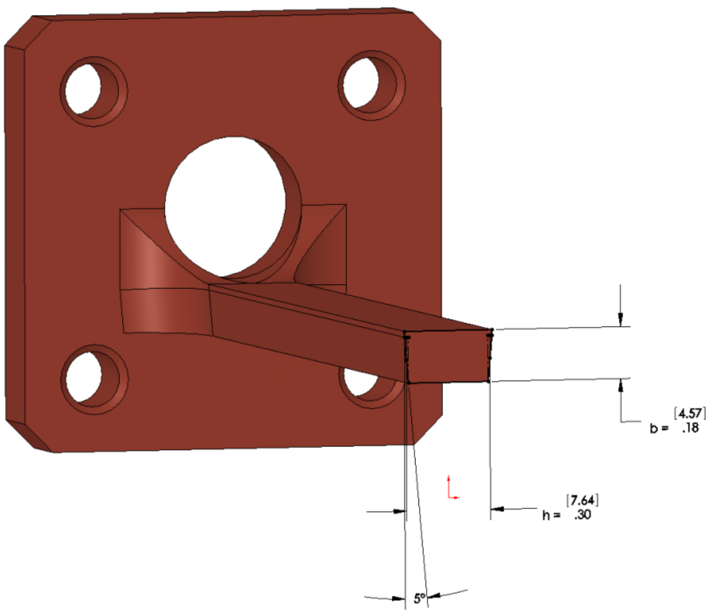


Fig. 4

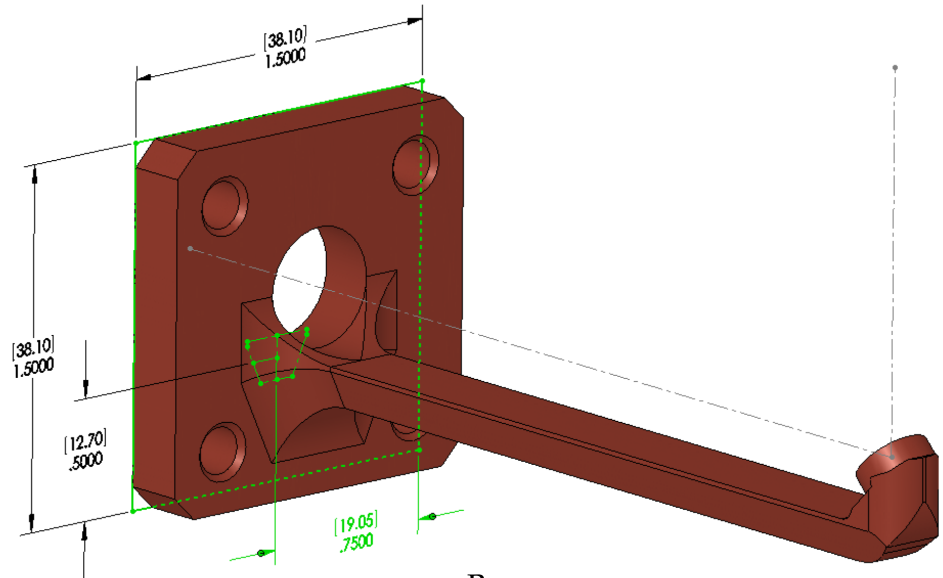
1.6) Probe Design

1.6.1) Design Features Common to all Probes



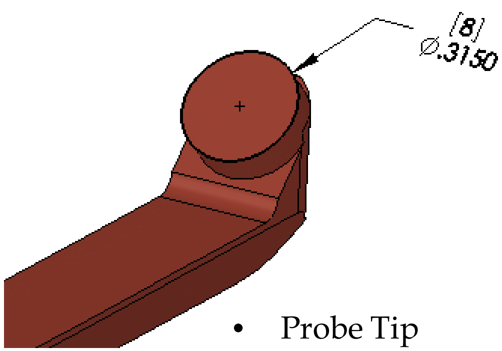
- Probe Cross Section

Fig. 5



- Base

Fig. 6



- Probe Tip

Fig. 7

1.6.2) Probe Deflection, at rest, under it's own weight: 1µm

- Deflection analyzed on the longest Inclined probe (OSM #2)

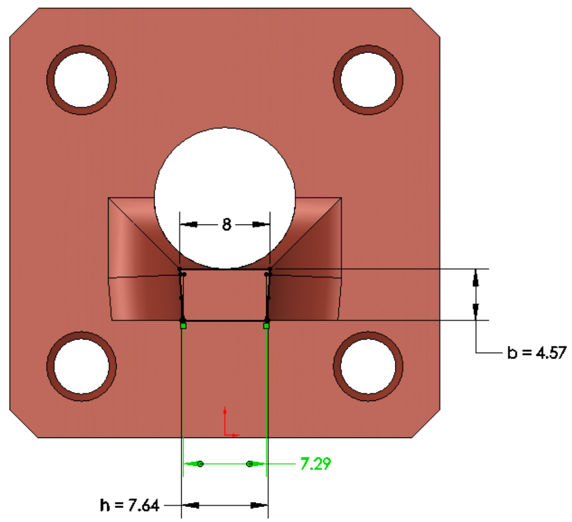
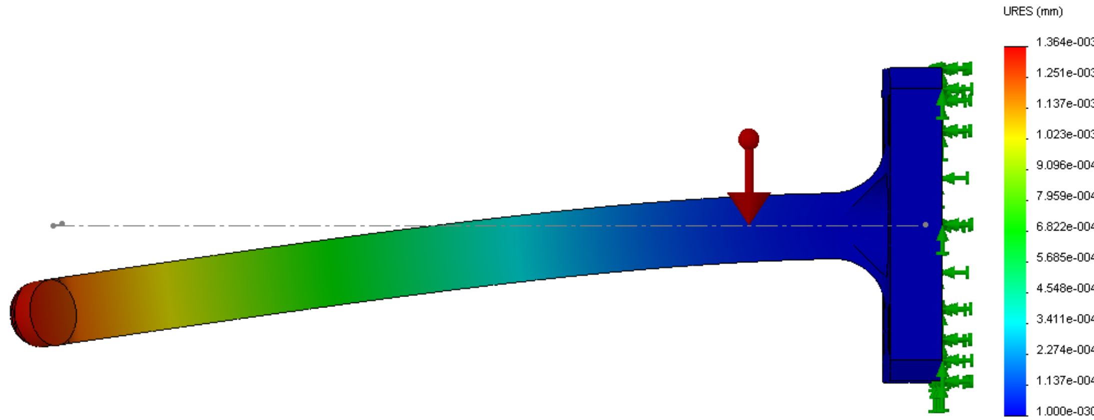


Fig. 10



Probe Deflection

Fig. 9

-Mass of the probe w = mg = 0.01 Kg x 9.81 ms^{-2} = 0.098N

-Moment of Inertia: $I = bh^3/12 = 4.57 \times 7.64^3/12 = 169.8\ mm^4$

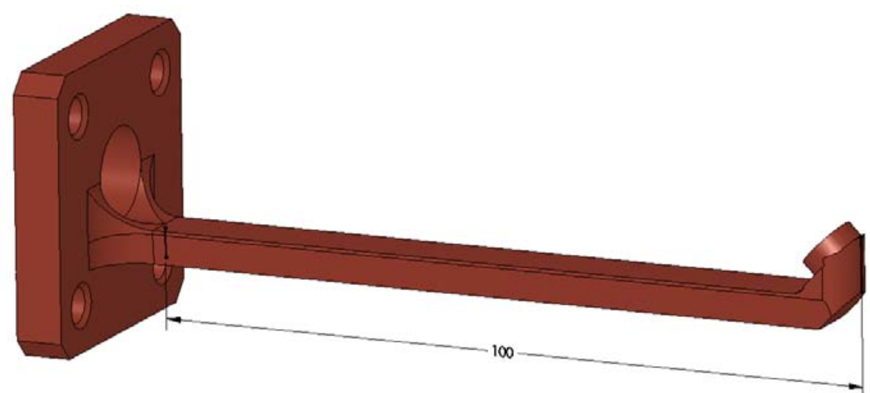
-6061-T6 Module of Elasticity: E = 68,800 N/mm^2

-Max Deflection: $v = wL^3 / 8EI$

$v = 0.098 \times 100^3 / (8 \times 68{,}800 \times 169.8)$

v = 98000/ 93457920

v = 0.001mm



Probe Length

Fig. 8

1.6.3) Frequency Analysis

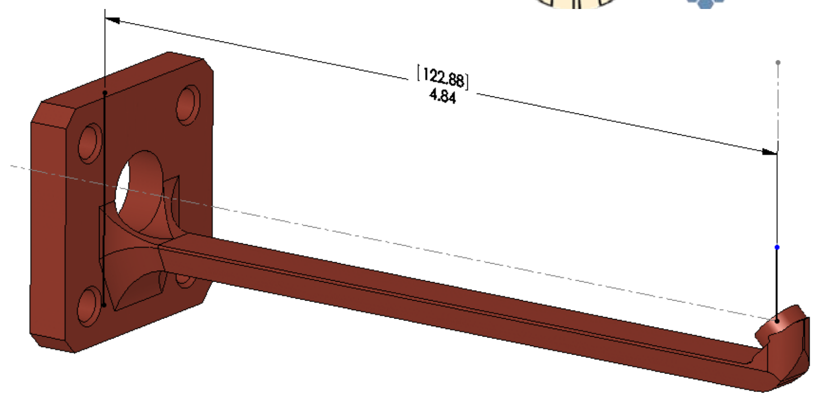
OSM #3

List Modes

Study name: Frequency

Mode No.	Frequency(Rad/sec)	Frequency(Hertz)	Period(Seconds)
1	1480.3	235.59	0.0042446
2	2512	399.79	0.0025013
3	9407	1497.2	0.00066792
4	15592	2481.6	0.00040296
5	25594	4073.5	0.00024549

Close Save Help



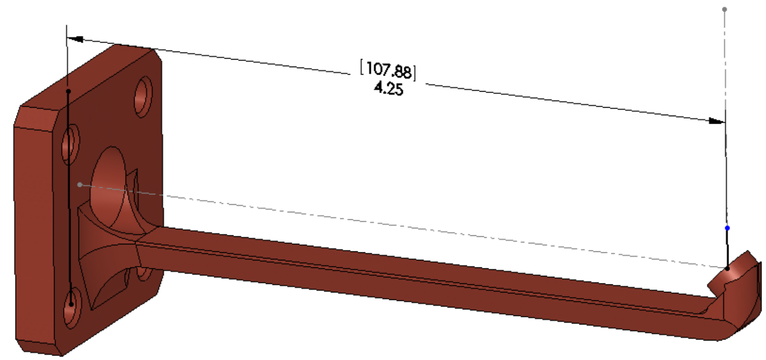
OSM #2

List Modes

Study name: Frequency

Mode No.	Frequency(Rad/sec)	Frequency(Hertz)	Period(Seconds)
1	1911.6	304.24	0.0032869
2	3246.5	516.7	0.0019354
3	12159	1935.1	0.00051677
4	19832	3156.3	0.00031683
5	29325	4667.2	0.00021426

Close Save Help



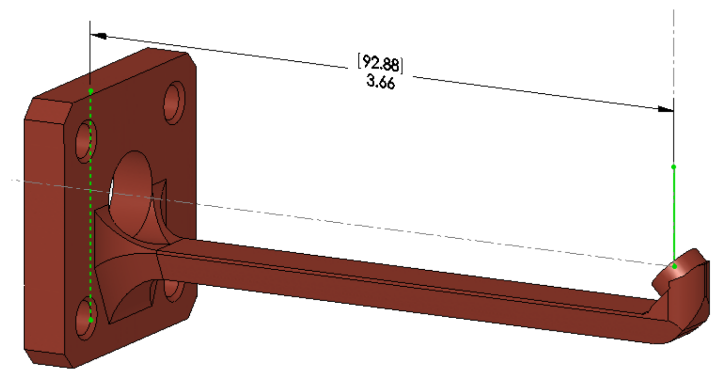
OSM #1

List Modes

Study name: Frequency

Mode No.	Frequency(Rad/sec)	Frequency(Hertz)	Period(Seconds)
1	2514.5	400.2	0.0024987
2	3706.5	589.9	0.0016952
3	16237	2584.2	0.00038696
4	22491	3579.5	0.00027937
5	32890	5234.6	0.00019103

Close Save Help

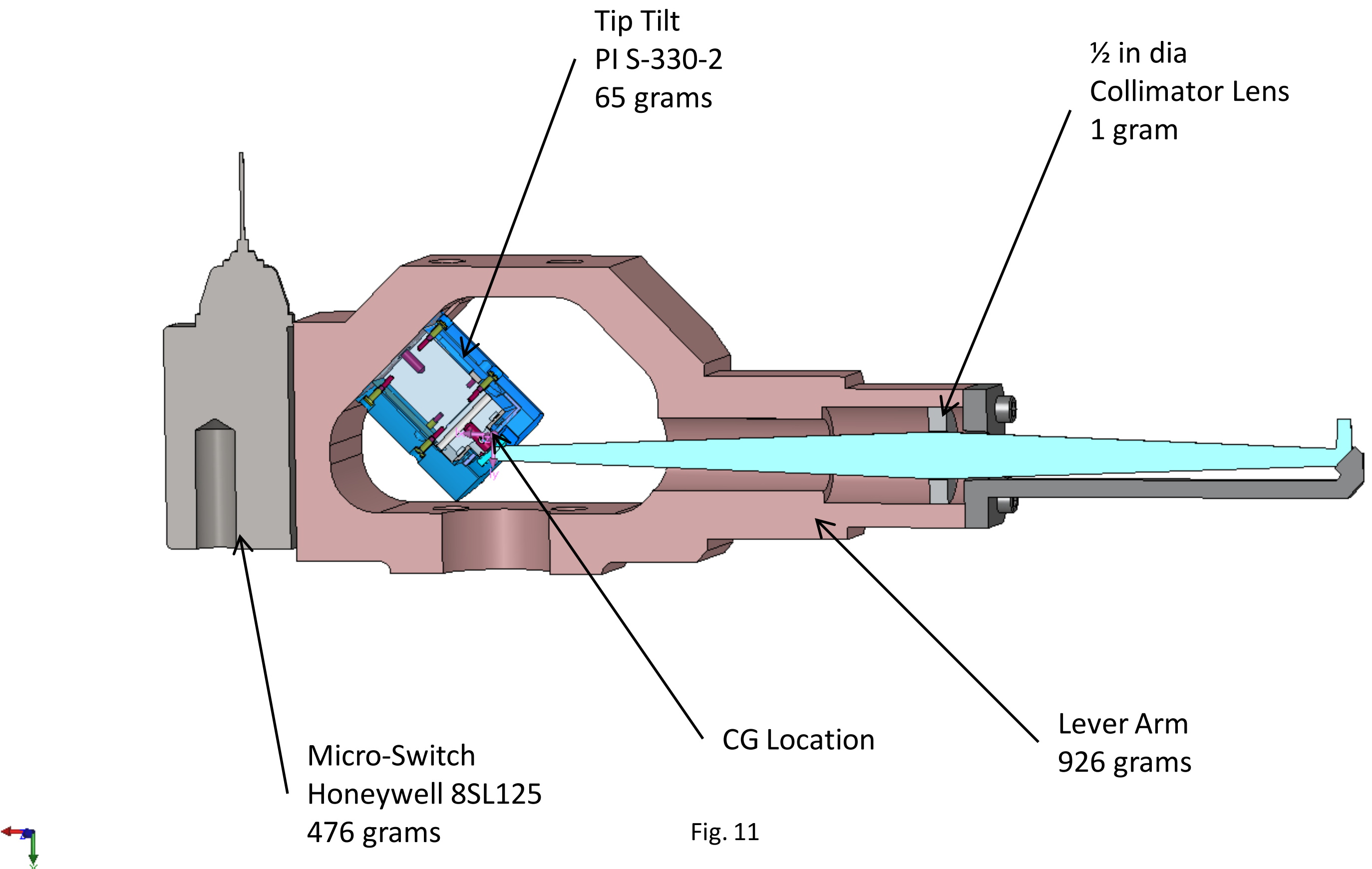


1.7) Mass and CG of the Lever Arm Assembly

Total Mass: 1,570 grams (15.4N)

CG located at the Axis of rotation, 36 mm above the Lever motor Interface.

Torque at the Lever Rotation Stage Interface: 0.036 X 15.4 = 0.55 Nm



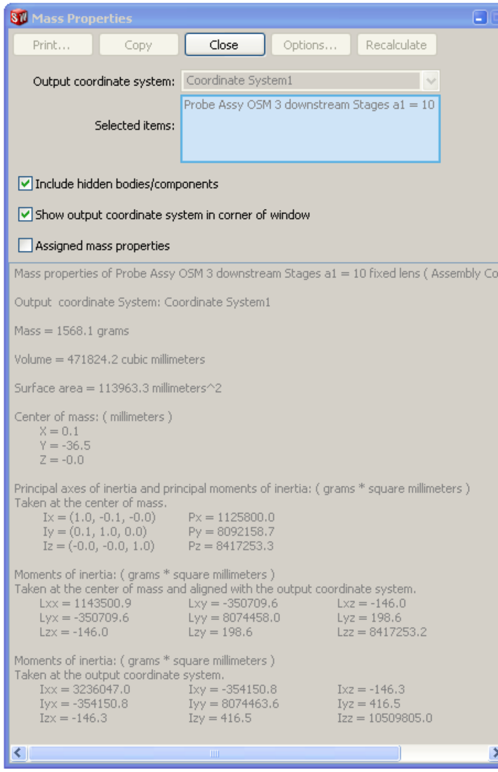


Fig. 11

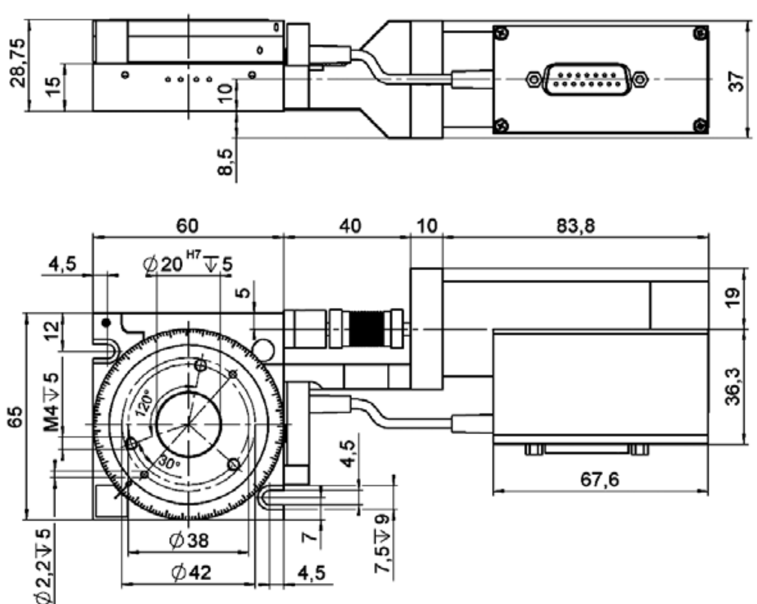
1.8) Static load on the lever motor

PI M-037.DG Rotation stage

M-037 rotation stages are equipped with ultra-precise worm gear drives allowing unlimited rotation in either direction.
An integrated spring preload eliminates backlash.
Double-row ball bearings allow zero backlash, high load capacity and extremely low wobble.

Model M-037.DG is closed-loop DC motors with shaft-mounted position encoders and precision gearheads providing 3.5 μrad at a design resolution of 0.6 μrad.

$$\boxed{\text{Torque FS} = 3/0.55 = 5.5}$$



Technical Data

Model	M-037.00	M-037.DG	M-037.PD	M-037.2S	
Active axes	Rotation	Rotation	Rotation	Rotation	
Motion and positioning					
Rotation range	>360	>360	>360	>360	°
Integrated sensor	–	Rotary encoder	Rotary encoder	–	
Sensor resolution	–	2000	4000	–	cts./rev.
Design resolution	–	0.59 (34 x 10⁻⁶)	8.75 (0.0005)	5.45* (0.00031)	µrad (°)
Min. incremental motion	–	3.5	27	21	µrad
Backlash	–	200	200	200	µrad
Unidirectional repeatability	–	30	30	30	µrad
Wobble	<150	<150	<150	<150	µrad
Max. velocity	–	6	45	10	°/s
Mechanical properties					
Worm gear ratio	180:1	180:1	180:1	180:1	
Gear ratio	–	$(28/12)^4$ = 29.6:1	–	–	
Motor resolution	–	–	–	6400*	steps/rev.
Load capacity/axial force, self-locking	±300	±300	±300	±300	N
Max. torque (θ_X, θ_Y)	±3	±3	±3	±3	Nm
Max. torque clockwise (θ_Z)	1	1	1	1	Nm
Max. torque counter clockwise (θ_Z)	0.5	0.5	0.5	0.5	Nm
Drive properties					
Motor type	–	DC motor, gearhead	ActiveDrive™ DC Motor	2-phase stepper motor*	
Operating voltage	–	0 to ±12	24 (PWM)	24	V
Electrical power	–	3	30		W
Reference switch	–	Hall-effect	Hall-effect	Hall-effect	
Miscellaneous					
Operating temperature range	-20 to +65	-20 to +65	-20 to +65	-20 to +65	°C
Material	Aluminum	Aluminum	Aluminum	Aluminum	
Mass	0.3	0.65	0.62	0.64	kg
Recommended controller/driver	–	C-863 (single-axis) C-843 PCI-Karte (for up to 4 axes)	C-863 (single-axis, p. 4-114) C-843 PCI-Karte (p. 4-120) (for up to 4 axes)	C-663 (single-axis, p. 4-112)	

incl. motor cable, 3 m, sub-D connector 15-pin
*2-phase stepper motor, 24 V chopper voltage, max. 0.8 A/phase, 400 full steps/rev., motor resolution with C-663 stepper motor controller

M-037.DG rotation stage with DC Motor and gearhead

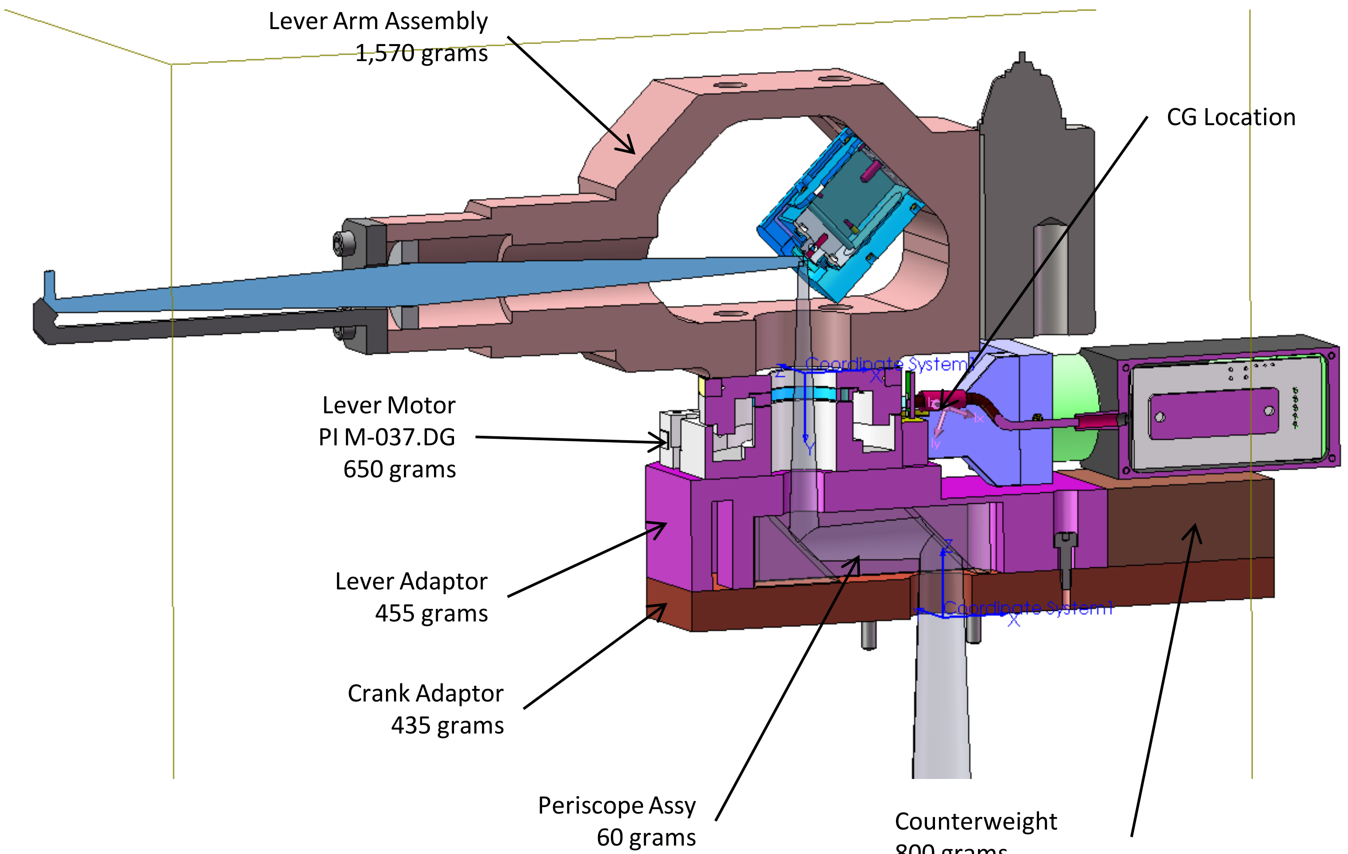
Table 2

1.9) Mass and CG of the OSM #1 Assembly

Total Mass: 3,874 grams (38N)

CG located at the Crank Axis of rotation, 60 mm above the Lever motor Interface.

Torque at the Crank Rotation Stage Interface: 0.060 X 38 = 2.3 Nm



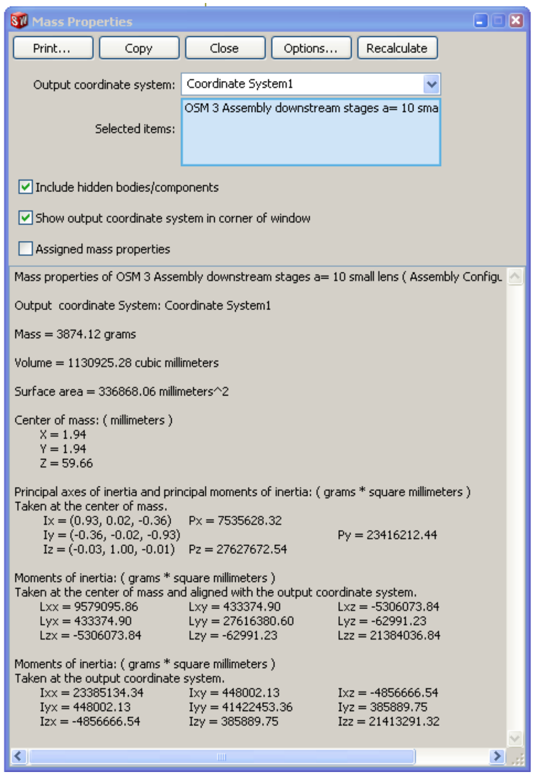


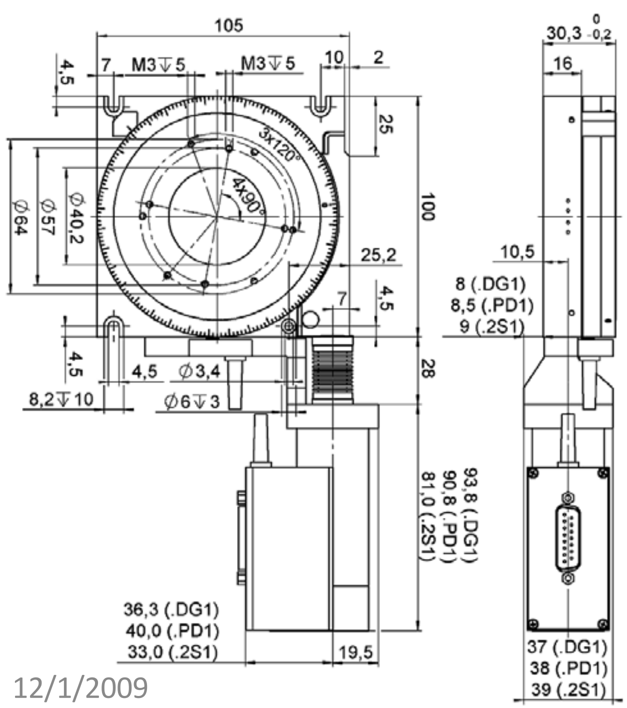
Fig. 12

1.10) Static load on the crank stage

PI M-038.DG Rotation stage

Model M-038.DG1 is equipped with a closed-loop DC motor with shaft-mounted position encoder and precision gearhead providing minimum incremental motion of 3.5 µrad at a design resolution of 0.6 µrad.

Torque FS = 6/2.3 = 2.6



Technical Data

Model	M-038.001	M-038.DG1	M-038.PD1	M-038.2S1	Units
Active axes	Rotation	Rotation	Rotation	Rotation	
Motion and positioning					
Rotation range	>360°	>360°	>360°	>360°	
Integrated sensor	–	Rotary encoder	Rotary encoder	–	
Sensor resolution	–	2000	4000	–	steps/rev.
Design resolution	–	0.60 (35 x 10⁻⁶)	8.95 (0.0005)	5.58* (0.00032)	µrad (°)
Min. incremental motion	–	3.5	27	21	µrad
Backlash	–	200	200	200	µrad
Unidirectional repeatability	–	20	20	20	µrad
Wobble	<75	<75	<75	<75	µrad
Max. velocity	–	6	90	10	°/s
Mechanical properties					
Worm gear ratio	176:1	176:1	176:1	176:1	
Gear ratio	–	2401:81 ≈ 29.6:1	–	–	
Motor resolution	–	–	–	6400*	steps/rev.
Max. load/axial force	±400	±400	±400	±400	N
Maximum torque (θ_x, θ_y)	±6	±6	±6	±6	
Maximum torque CW**	2	2	2	2	Nm
Maximum torque CCW**	0.8	0.8	0.8	0.8	Nm
Drive properties					
Motor type	–	DC Motor, gearhead	ActiveDrive™ DC Motor	2-phase stepper motor*	
Electrical power	–	3	30		W
Reference switch	–	Hall-effect	Hall-effect	Hall-effect	
Miscellaneous					
Operating voltage	–	12 V differential	24 (PWM)	24	V
Operating temperature range	-20 to +65	-20 to +65	-20 to +65	-20 to +65	°C
Material	Aluminum	Aluminum	Aluminum	Aluminum	
Mass	0.9	1.25	1.35	1.25	kg
Recommended controller/driver		C-863 (single-axis) C-843 PCI board (for up to 4 axes)	C-863 (single-axis, p. 4-114) C-843 PCI board (p. 4-120) (for up to 4 axes)	C-663 (single-axis, p. 4-112)	

*2-phase stepper motor, 24 V chopper voltage, max. 0.8 A/phase, 400 full steps/rev., motor resolution with C-663 stepper motor controller
**CW: clockwise; CCW: counter-clockwise

M-038.PD1 Rotation Stage


Custom M-038 with folded drive

Table 3

1.11) Probe Position Accuracy

Position Accuracy at the longest probe: OSM #3, a1 = -20

Lever Arm Length: 260mm
Crank arm Length: 41.8mm

Lever Stage M-037.DG Design resolution: 0.000034°
Crank Stage M-038.DG1 Design resolution : 0.000035°

Lever arm position accuracy: 250mm X tan 0.000034° = 0.00015mm

Crank arm position accuracy: 290mm X tan 0.000035° = 0.00018mm

= 0.00033mm
= 0.00045”

Resulting position accuracy at the tip of the probe = 0.00033mm = 0.45 mas

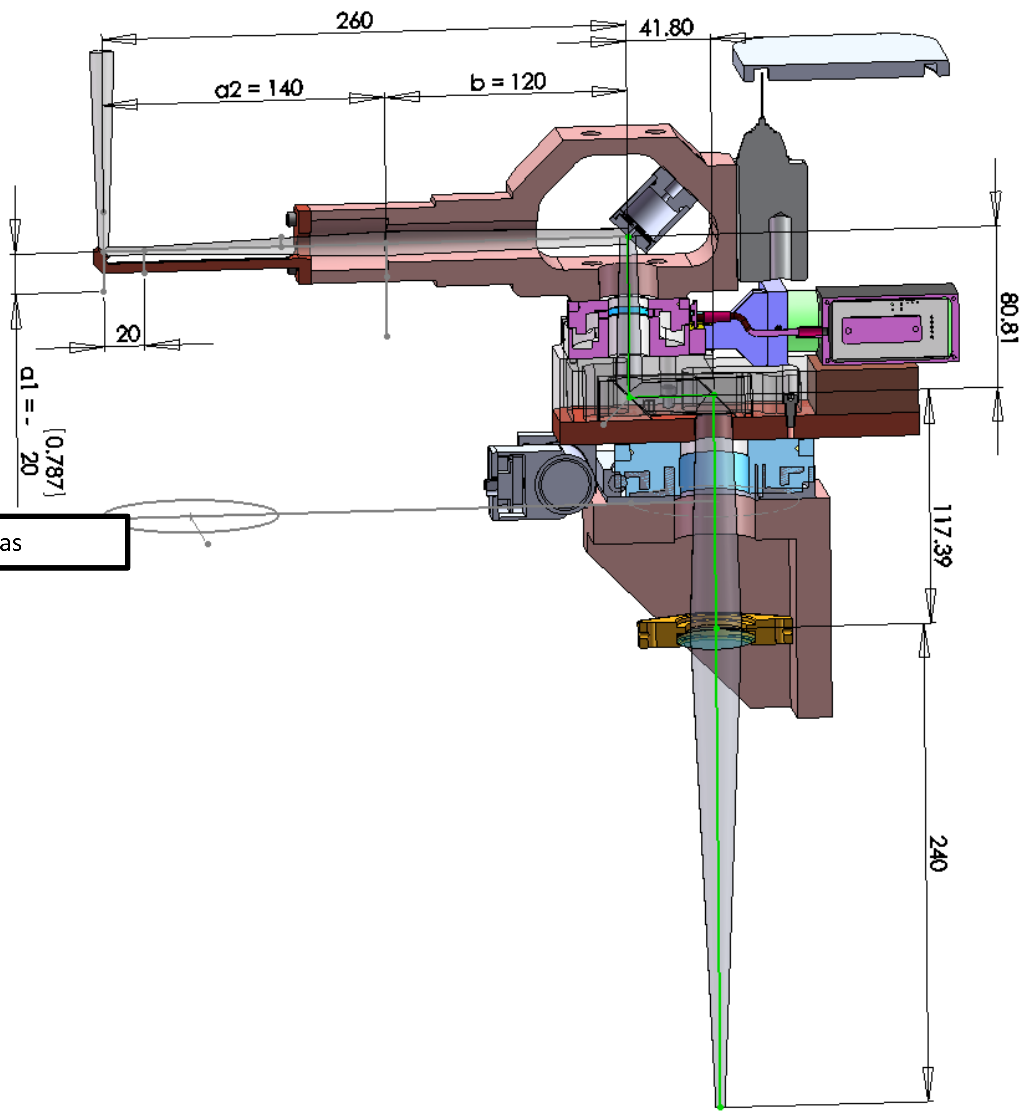


Fig. 13

1.12) Probe Position Repeatability

Position Repeatability at the longest probe: OSM #3, a1 = -20

Lever Arm Length: 260mm
Crank arm Length: 41.8mm

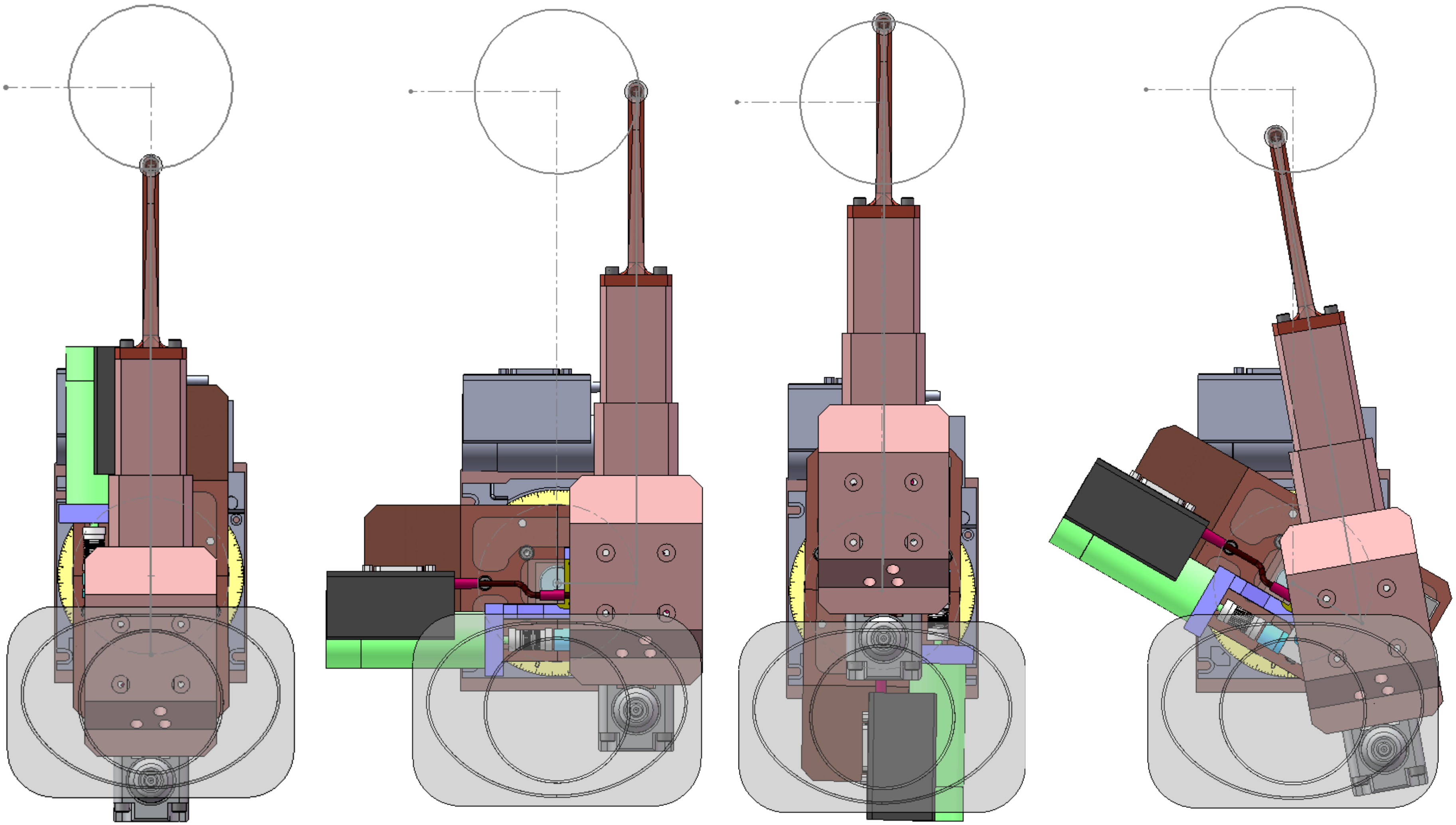
Lever Stage M-037.DG Design repeatability: 30 µrad = 0.0017°
Crank Stage M-038.DG1 Design repeatability : 20 µrad = 0.0011°

Lever arm position repeatability: 250mm X tan 0.0017° = 0.007mm
Crank arm position accuracy: 290mm X tan 0.0011° = 0.005mm

= 0.012mm = .016”

1.13) Probe Patrolling range

The probe patrolling range is limited by a contact switch (Wobble type) that, in case of software glitch, would trip the stages when contacting a track simulating the desired probe range.



Probe at 0°

Probe at 45°

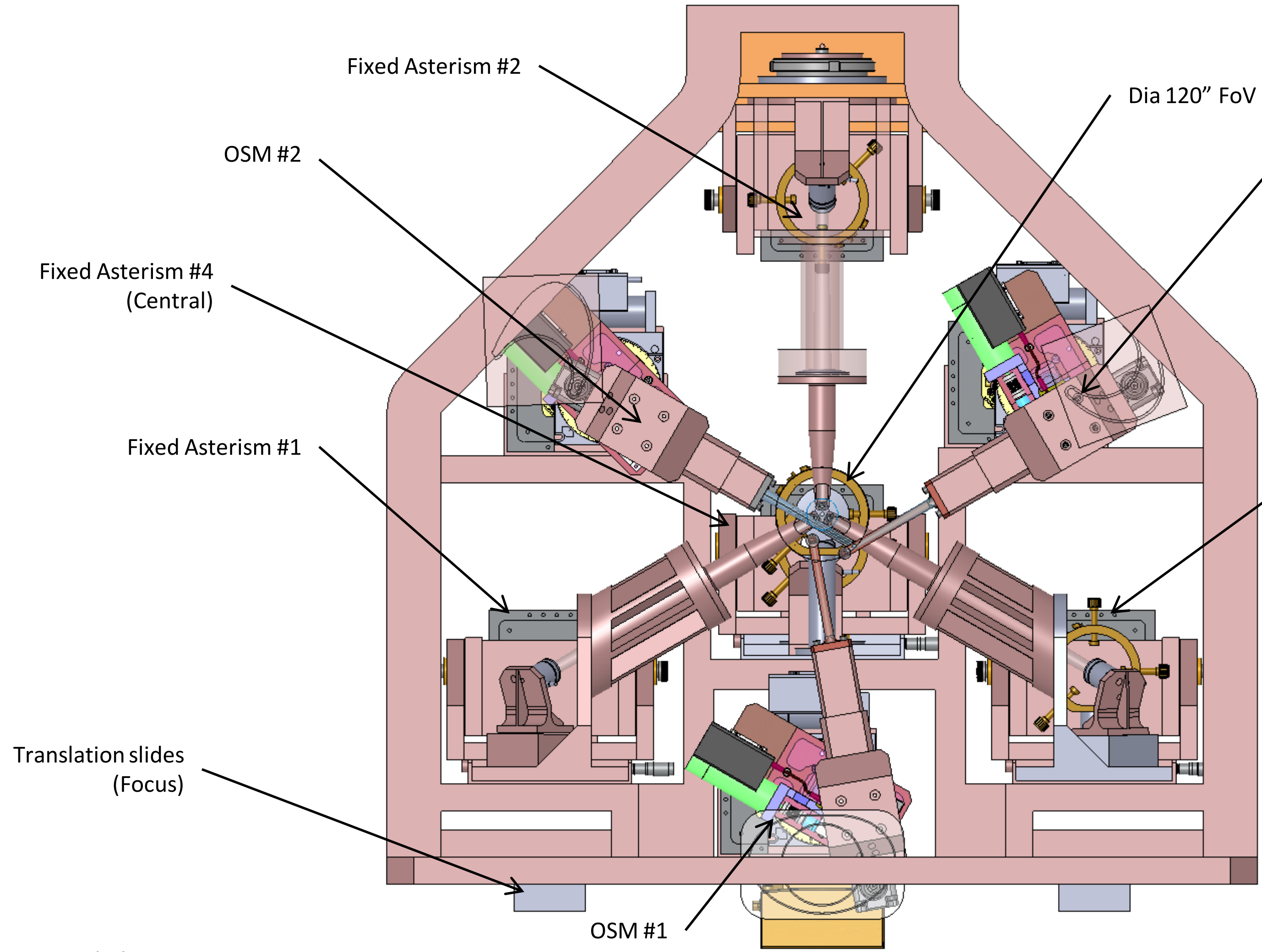
Probe at 180°

Probe randomly across the field

2) Laser Guide Star Architecture

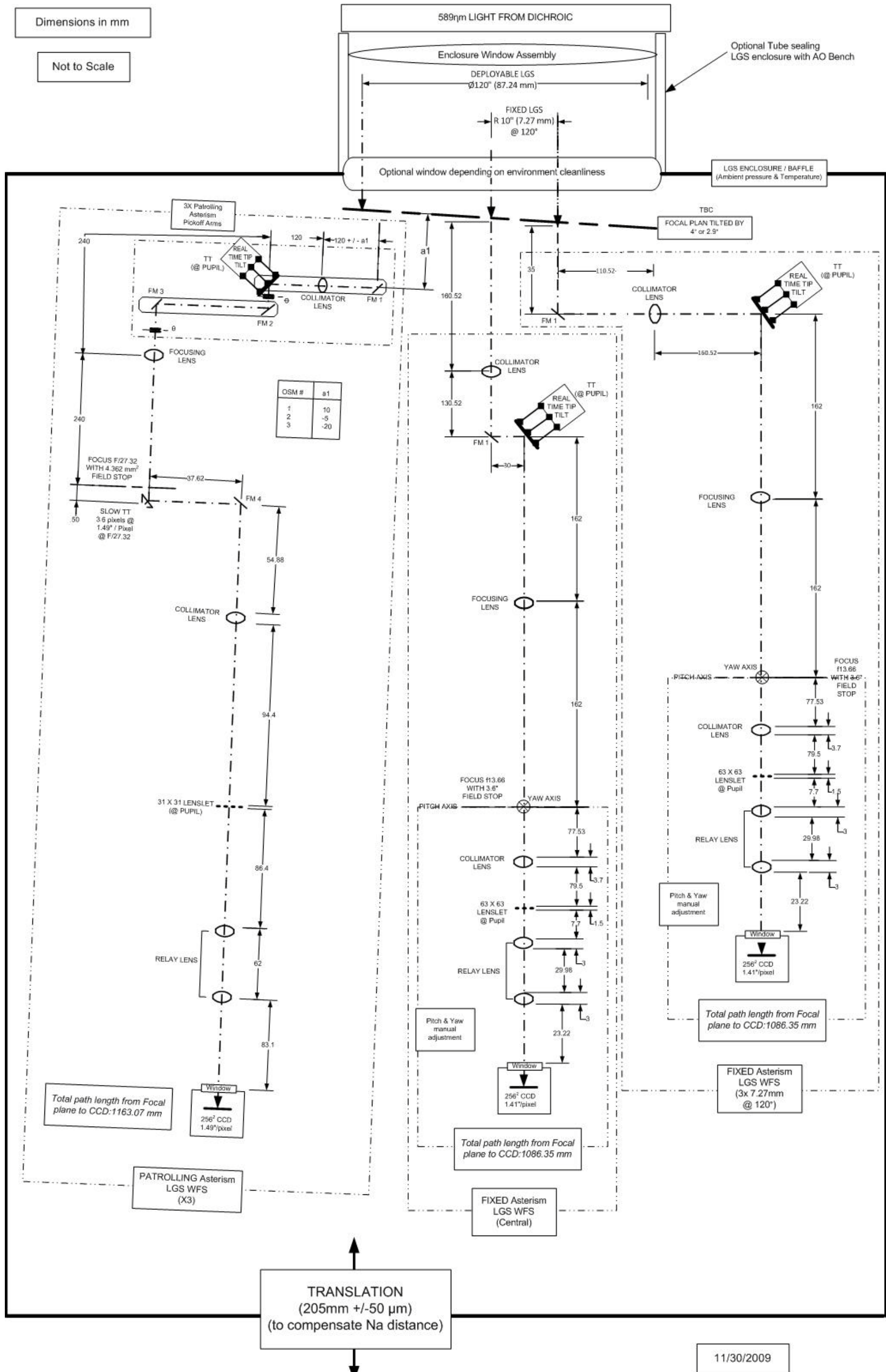
2.1) Design requirements

FR-509: The LGSWFS shall support 7 laser guide stars. Of these lasers, one is located at the center of the field of view and the other three are on the vertices of a equilateral triangle around the central star. The remaining 3 guide stars can be positioned at random around the field of view.



Mass Estimate: 200Kg

2.2) Design Overview

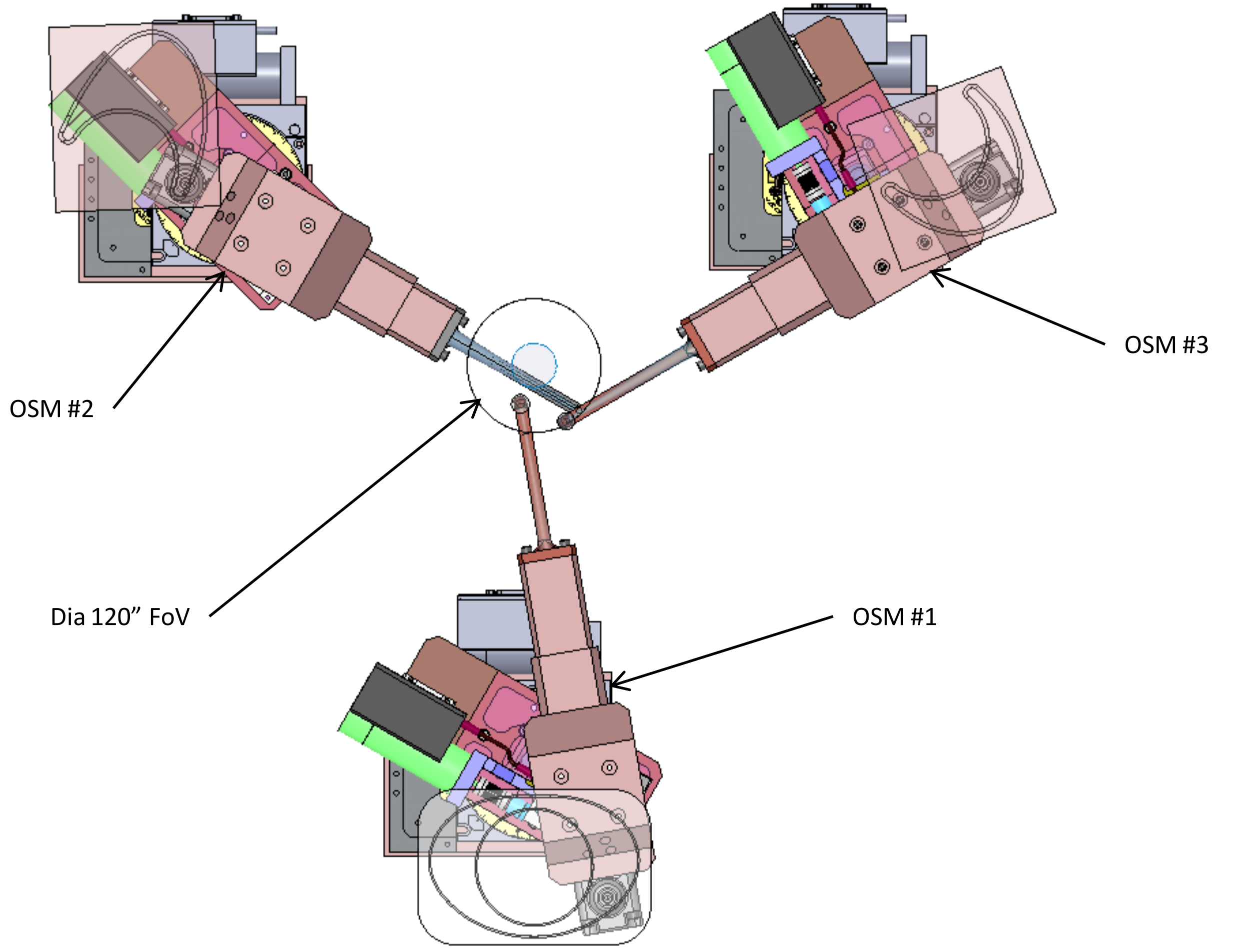


[Pdf Version]

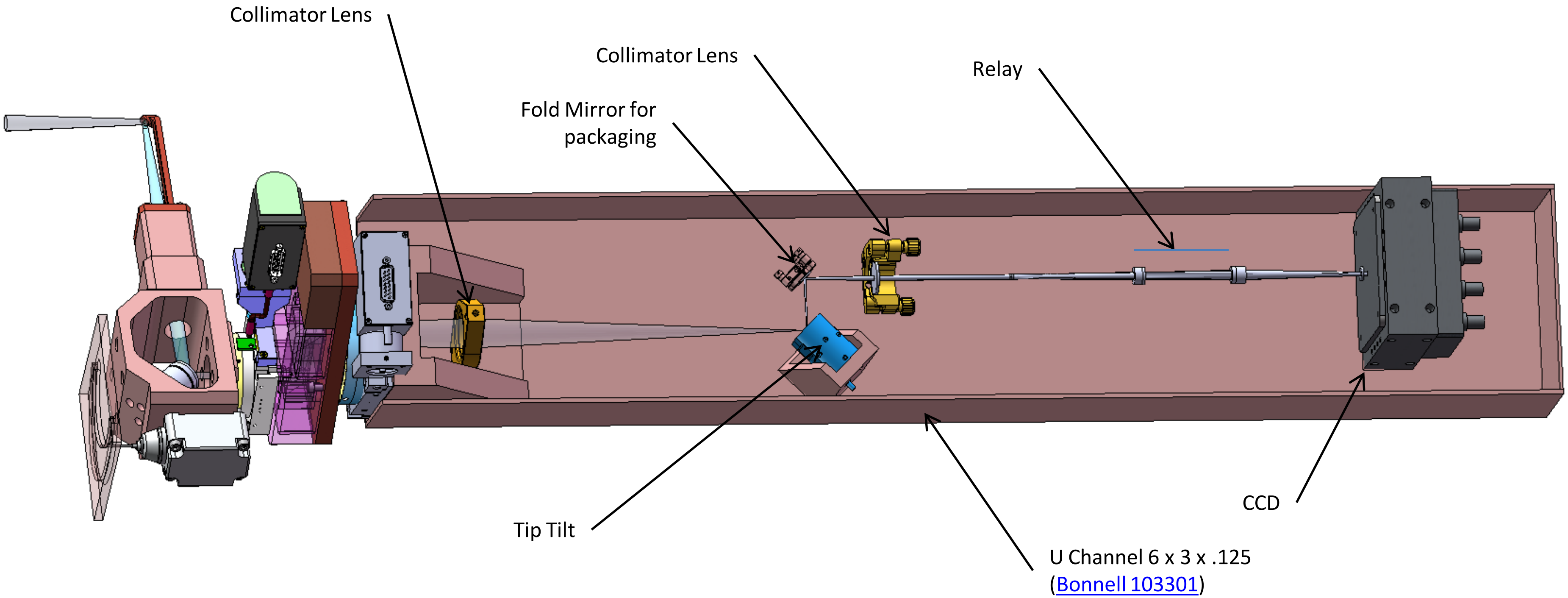
3) Patrolling Asterism (Deployable)

3.1) Design requirements

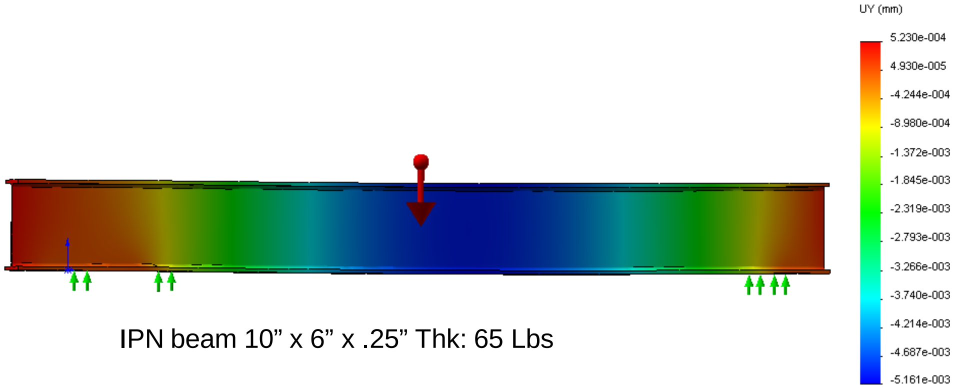
-FR-519: The 3 PnS LGSWFS's shall patrol and pick off any LGS in the 120" FoR



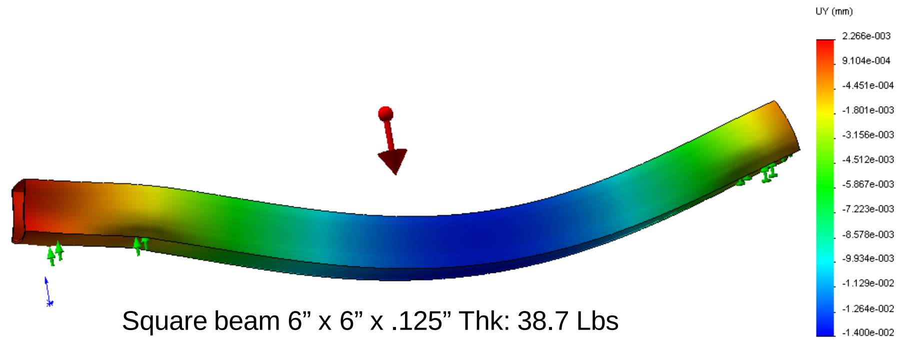
3.2) Design Overview



3.3) Stress Analysis of Standard material



IPN beam 10" x 6" x .25" Thk: 65 Lbs



Square beam 6" x 6" x .125" Thk: 38.7 Lbs

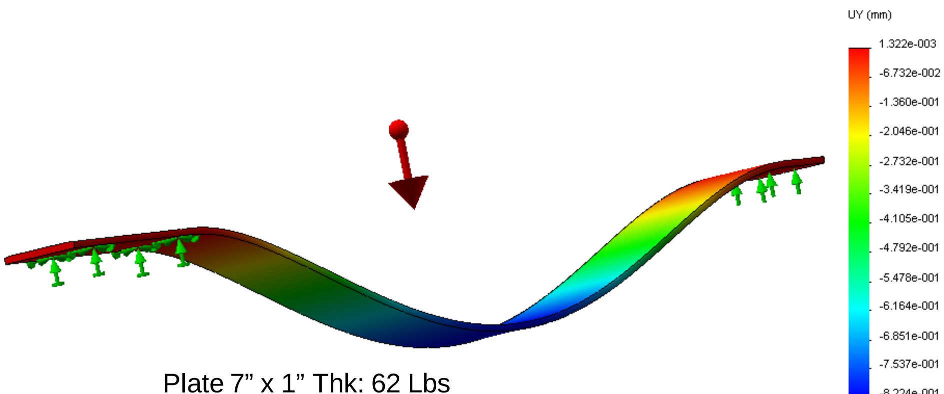
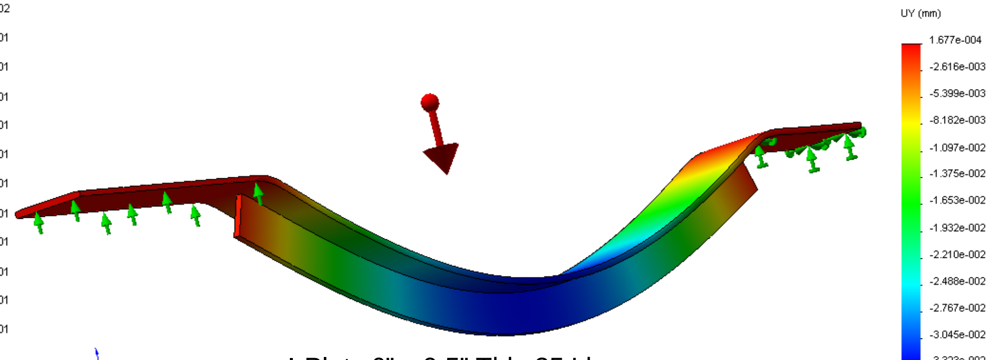
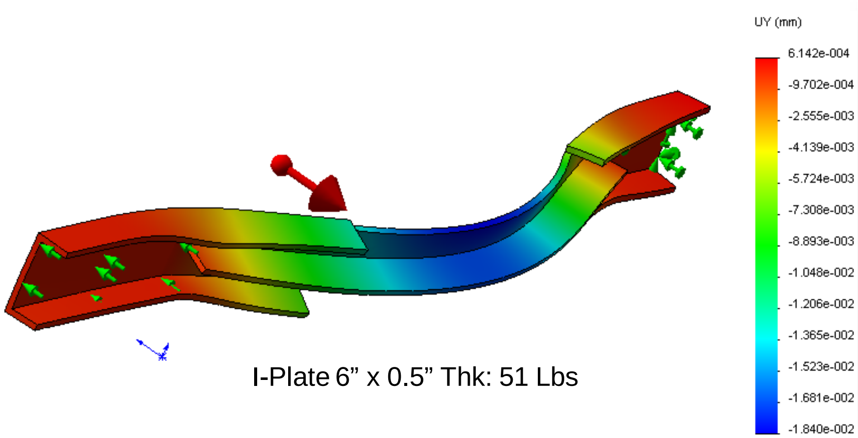


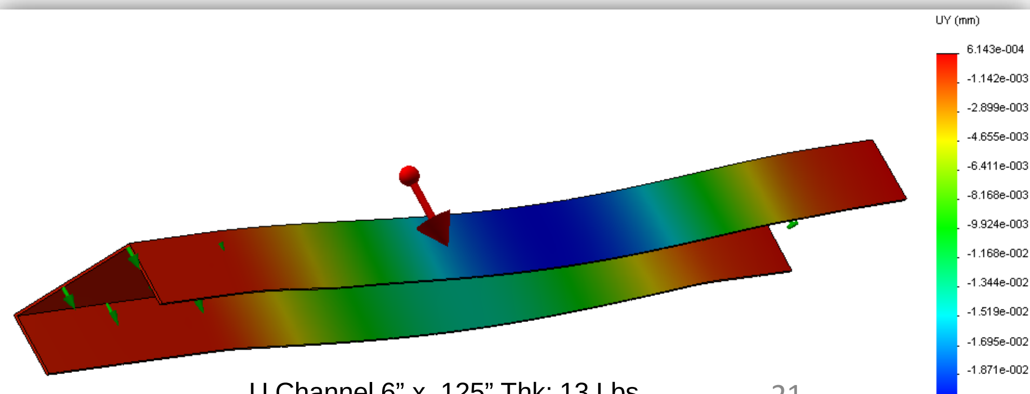
Plate 7" x 1" Thk: 62 Lbs



I-Plate 6" x 0.5" Thk: 35 Lbs



I-Plate 6" x 0.5" Thk: 51 Lbs



U Channel 6" x .125" Thk: 13 Lbs

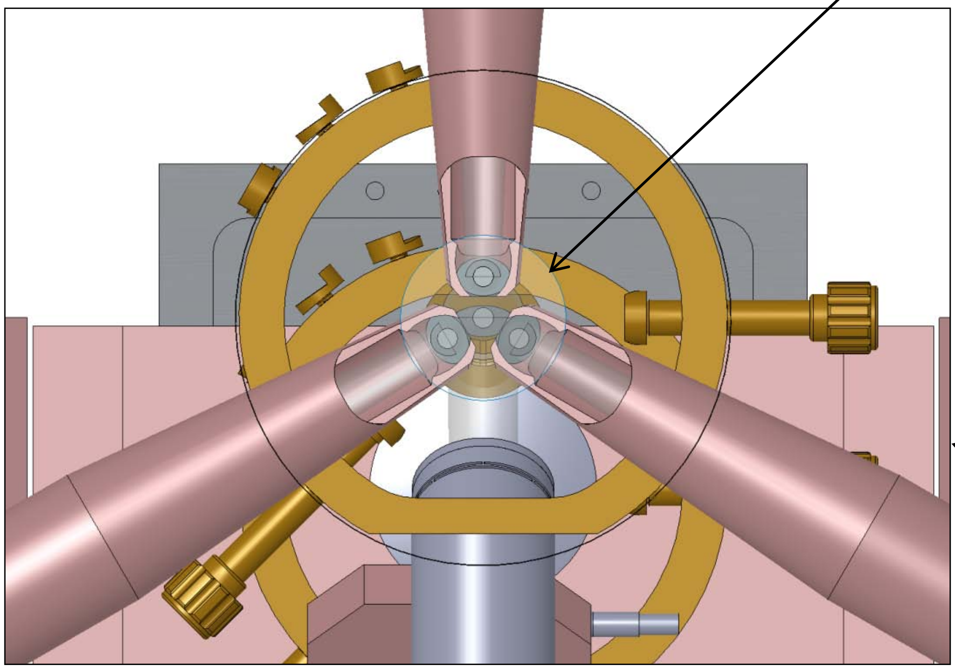
4) Fixed Asterism (Tomography)

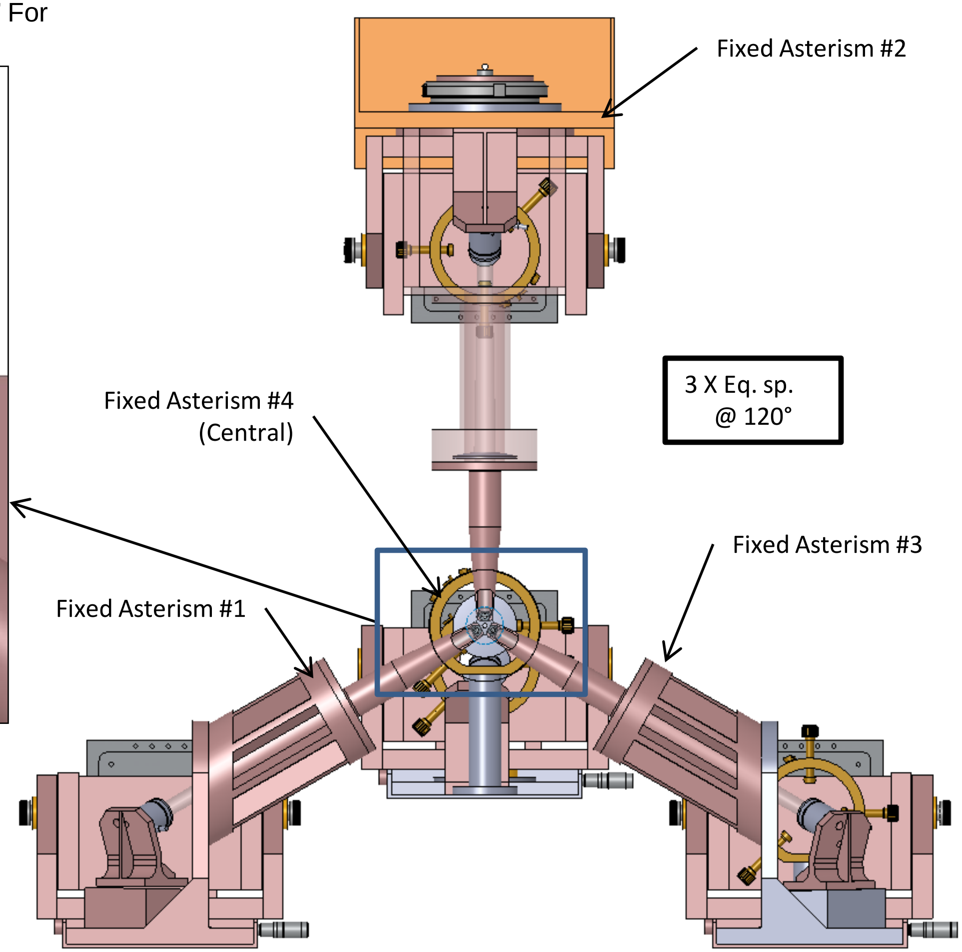
4.1) Design requirements

-FR-1867: There shall be one central LGS WFS and 3 LGS WFS's that are fixed at 10" dia. with equal angular separation.

4.2) Design Overview

10” For

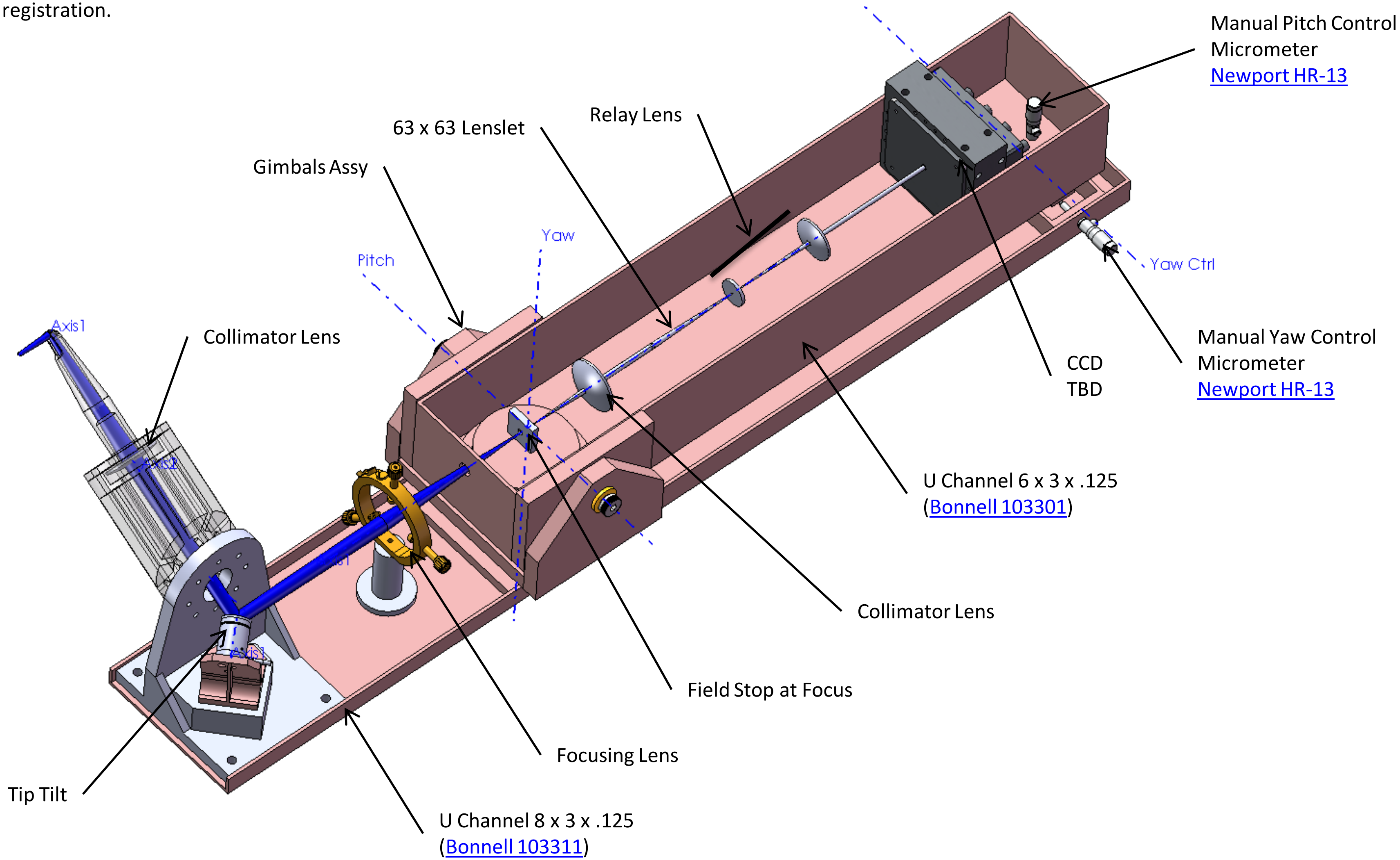




4.3) Peripheral Fixed LGS WFS Design

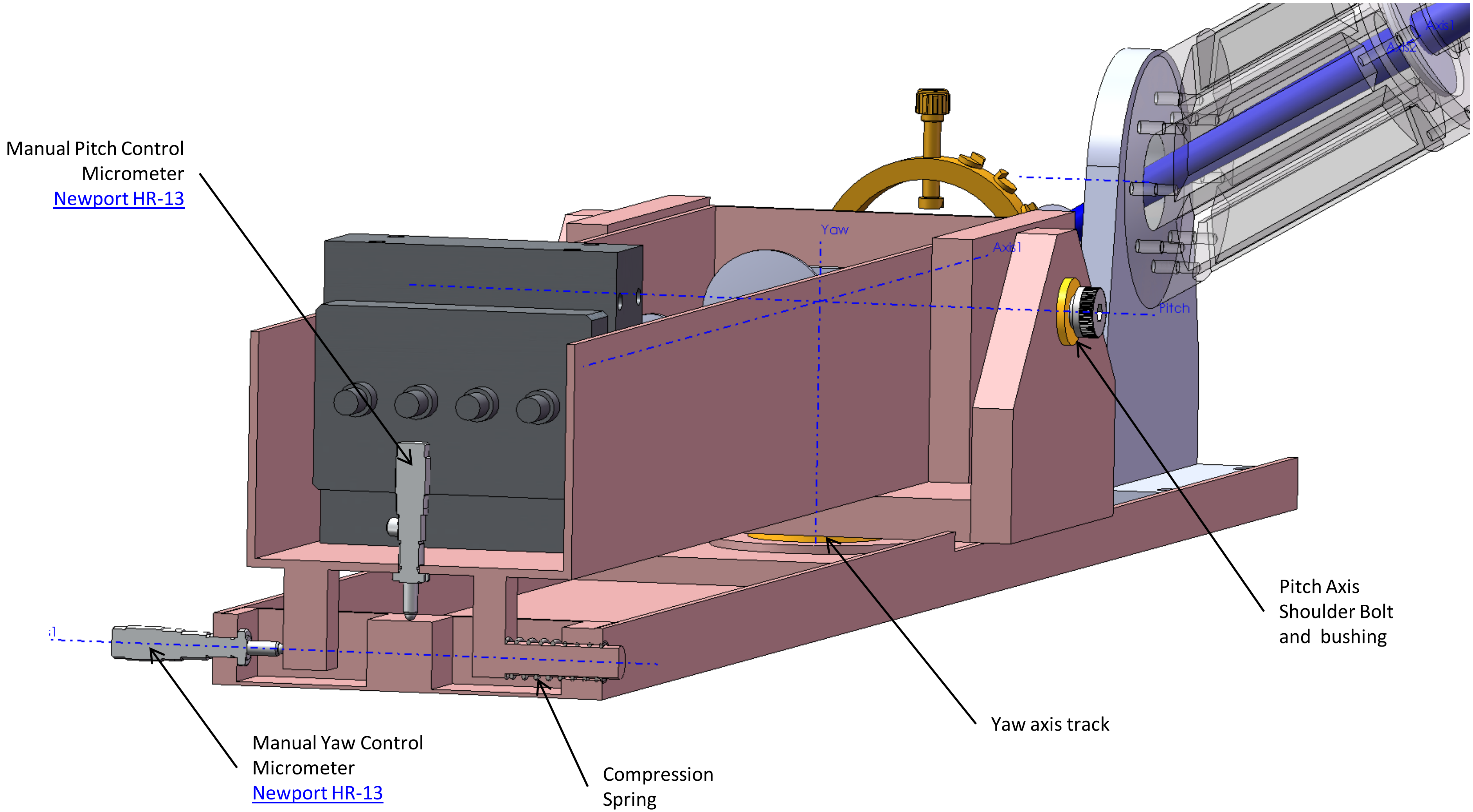
4.3.1) Overview

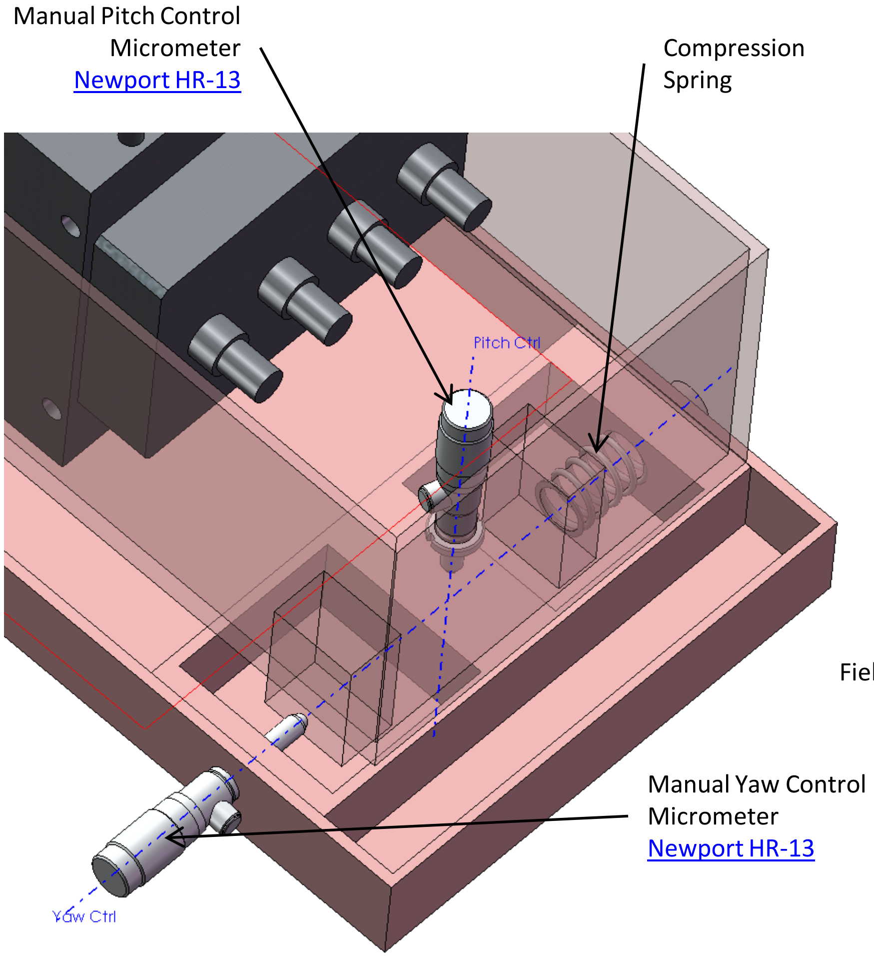
The fixed probe pick-off the 10" Fov to relay with the downlink tip-tilt mirror at the pupil location. Each Fixed LGS WFS is equipped with yaw and pitch motion about the Focus point which along with the downlink TT mirror can be used to align each channel to the incoming beam and keep the lenslet to LODM registration.

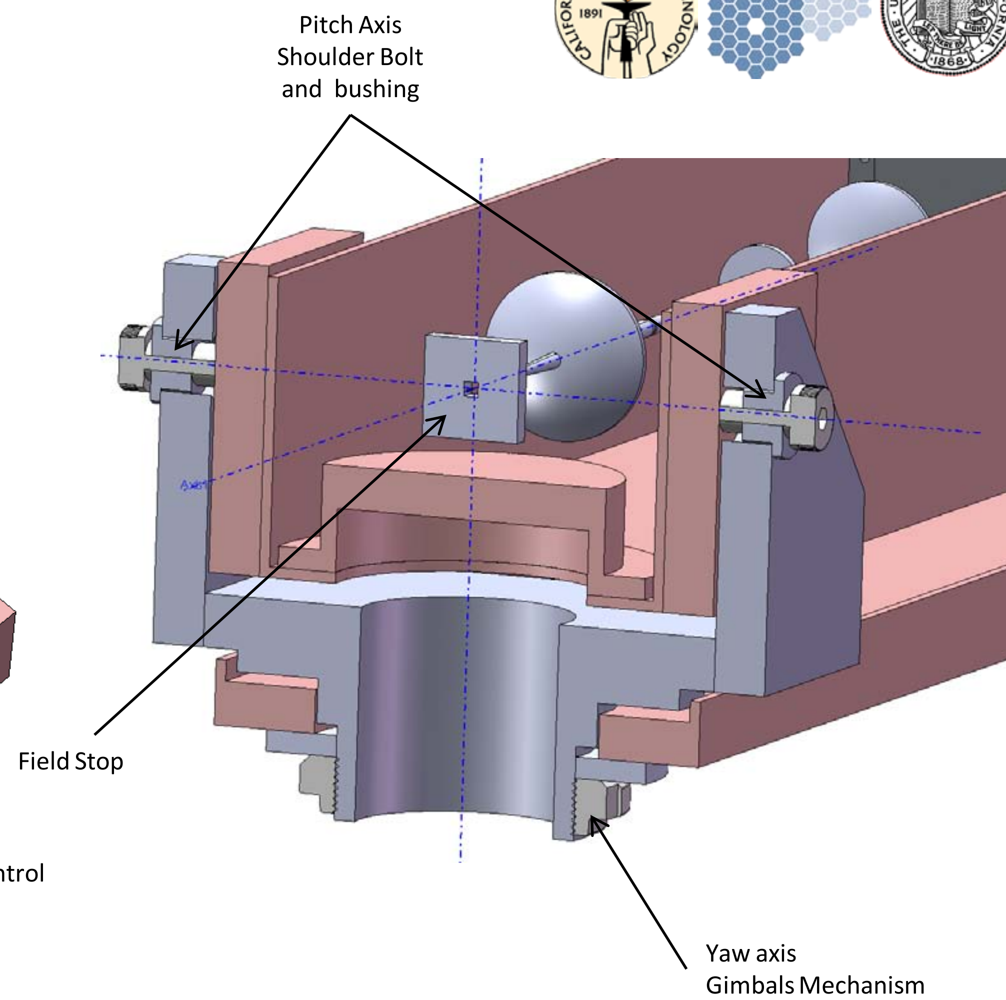


4.3.2) Pitch & Yaw Adjustment

-Pitch & Yaw about the Focus is adjustable using 2 manual Micrometers ,0.5µm Sensitivity, 13mm Travel, located 555.8mm (21.88in) away from the Focus, giving 180mas Sensitivity with 84” Travel.







-The Yaw control Micrometer is maintained in contact with the U-Channel by a compression spring guided by a plunger.

-The Pitch Control Micrometer is maintain in contact with the base by gravity.

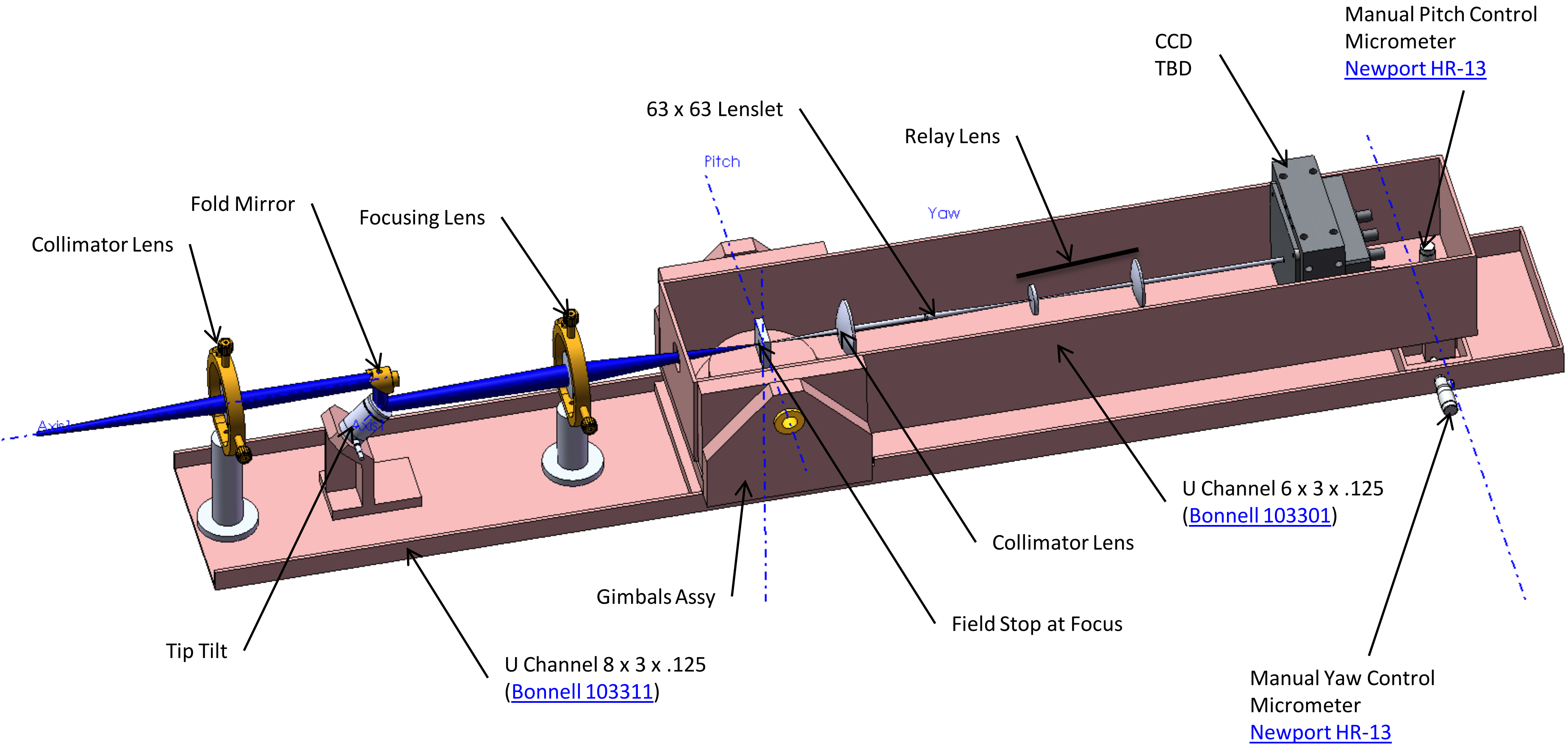
-The Yaw Axis, running thru the Focus, rotates the Gimbals mechanism thru the base of the channel, held by a Bearing Nut. A friction track and bearing should be sufficient to achieve the rotation.

-The Pitch Axis, running through the Focus as well, rotates the U-Channel thru the Gimbals mechanism by the alignment of 2 opposed shoulder bolts slide fitted with press fitted bushings.

4.4) Central (On-Axis) Fixed LGS WFS Design

4.4.1) Overview

The Central fixed LGS Asterism does not require a probe as it receive straight light from the AO Fov to relay with the downlink tip-tilt mirror at the pupil location thru a Packaging Fold Mirror. The Central Fixed LGS WFS is also equipped with yaw and pitch motion about the Focus point which along with the downlink TT mirror can be used to align each channel to the incoming beam and keep the lenslet to LODM registration.

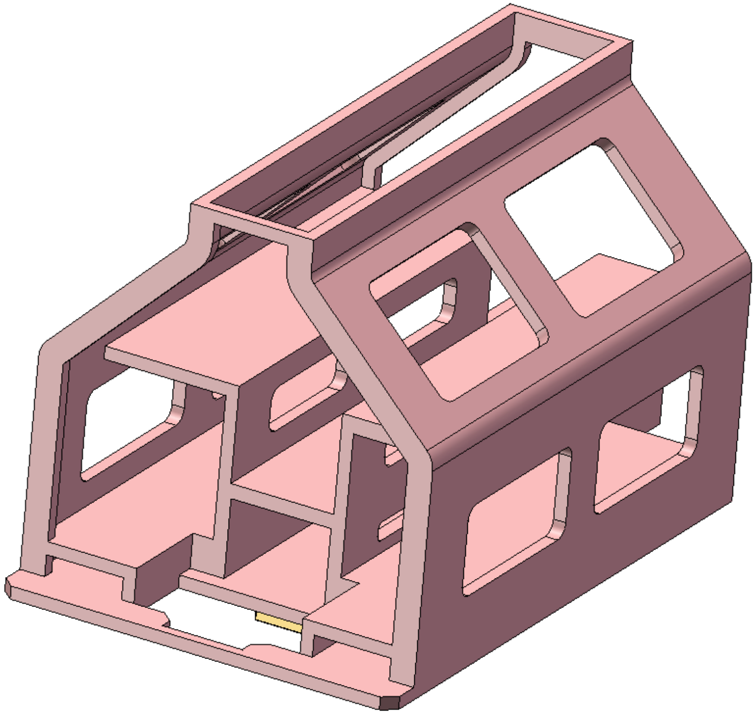


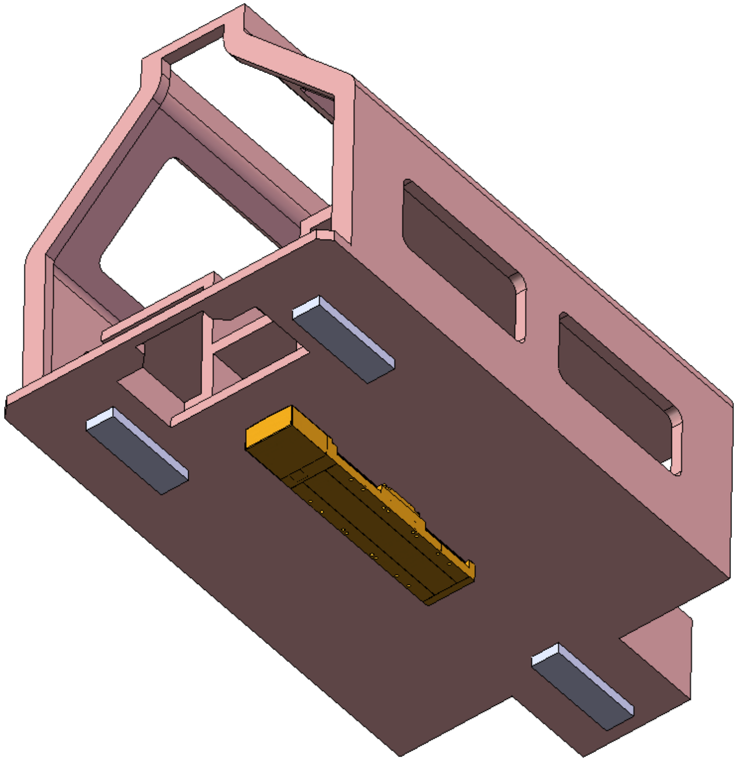
5) Structure

5.1) Design requirements

FR-525: The LGSWFS optics shall reimage the DM onto the LGSWFS lenslets to an accuracy of TBD mm in focus.

5.2) Design Overview





The LGS Structure needs to rigidly accommodate with the installation of each 7 Channels and allow relatively easy access to each optical components for Installation, adjustments, replacements and maintenance. A Honeycomb panel Structure would weigh around 100 Kg compared to 250 Kg of plain welded Aluminum and would be at least twice as rigid.

The structure is mounted on three Delron Slides HPRSA4-9FB rated each at 182 Kg for 225mm travel with a .00005mm repeatability and a straight line accuracy of .001mm/25mm travel. (See Delron Catalog p. 23) The assembly is actuated using the Newport Stage ILS-250CC

6) Mechanism motions (FR-540)

-FR-539: The LGSWFS shall have mechanisms controlled by the RTC and/or the supervisory control system to keep each individual LGS WFS in focus

Device	DOF per stage	TL DOF	Type	Axes	Range	Accuracy / Repeatability	Tracking Device?	Tracking Rate	Slew Rate	Control Category	
~~LGS WFS Unit Focus~~	~~1~~	~~3~~	~~Linear~~	~~z~~	~~10 mm~~	~~10 mm~~	~~Yes~~			~~4~~	TBC
~~LGS WFS Unit rotation~~	~~1~~	~~3~~	~~Rotational~~	~~θ~~	~~360 deg~~	~~0.01 deg (36")~~	~~Yes~~			~~4~~	Un-necessary See Demo
LGS WFS Pickoff	2	6	Rotational	θ Φ	360 deg	115 arc-sec 300 arc-sec	No TBC			6	
LGS WFS Assy focus	1	1	Linear	z	~~130 mm~~ 205mm	0.5 mm Or 0.05mm?	Yes			4	
Tip Tilt Stabilization Mirror	2	20	Tip Tilt		10 mrad	0.05 microrad	Yes				

Would 204mm work?

These numbers seem quiet large…
We get 0.45mas / 16mas (See P. 15)