P-077

PhoENiX衛星計画に向けた高精度Wolterミラー保持機構の検討

Study of mount structures for soft X-ray precision Wolter mirrors towards PhoENiX

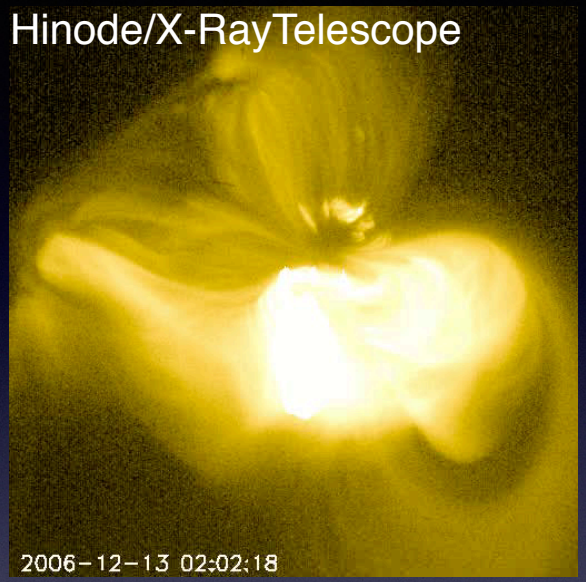
坂尾太郎*[1], 松山智至[2,3], 山内和人[3], 三宅明[4], 野村伊玖磨[5],
原玲丞[5], 竹中久貴[5], 成影典之[6]

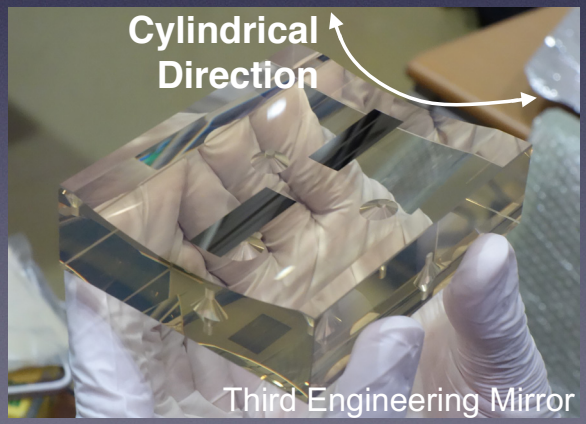
** e-mail: sakao@solar.isas.jaxa.jp*

1: JAXA宇宙研、2: 名大工、3: 阪大工、4: JTEC、5: トヤマ、6: 国立天文台

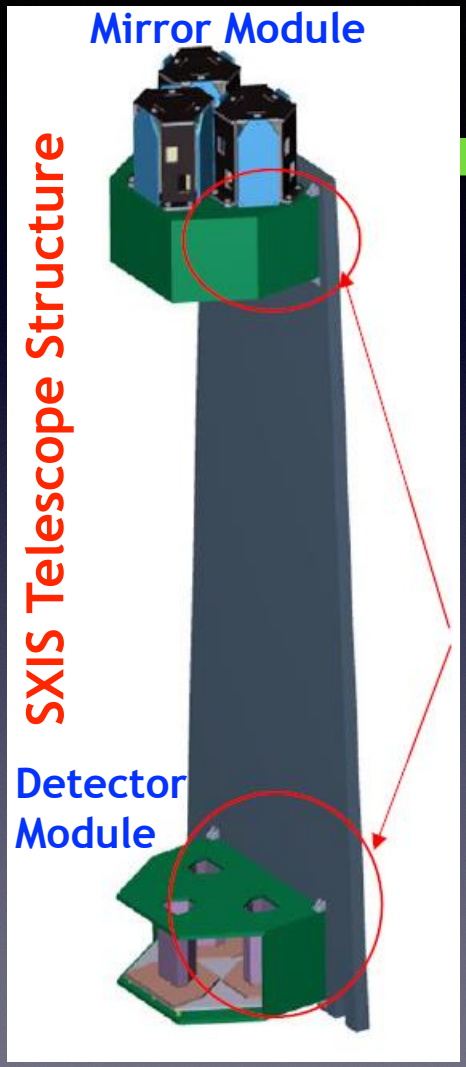
Introduction

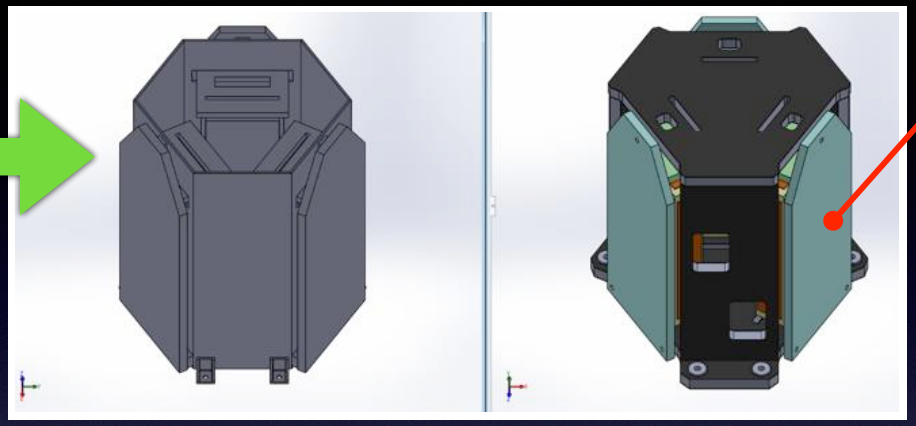
- High precision X-ray imagery of the solar corona (esp. solar flares) with Wolter optics
  - ~1"-level spatial resolution
  - Low scattering especially in ~10"–20" off-axis positions
    [where the electron acceleration site could be located above the very bright post-flare X-ray loop]
- Development of Precision Wolter mirrors:
  - Goodrich abandoned fabrication of Wolter mirrors
  - Lightweight & large aperture Wolter mirrors:
    - ✳ Mono-crystalline Si mirrors towards Lynx
    - ✳ Si pore optics towards Athena
    - ✳ Electro-formed mirrors for solar applications
    - ✳ Direct polishing of segmented glass substrates





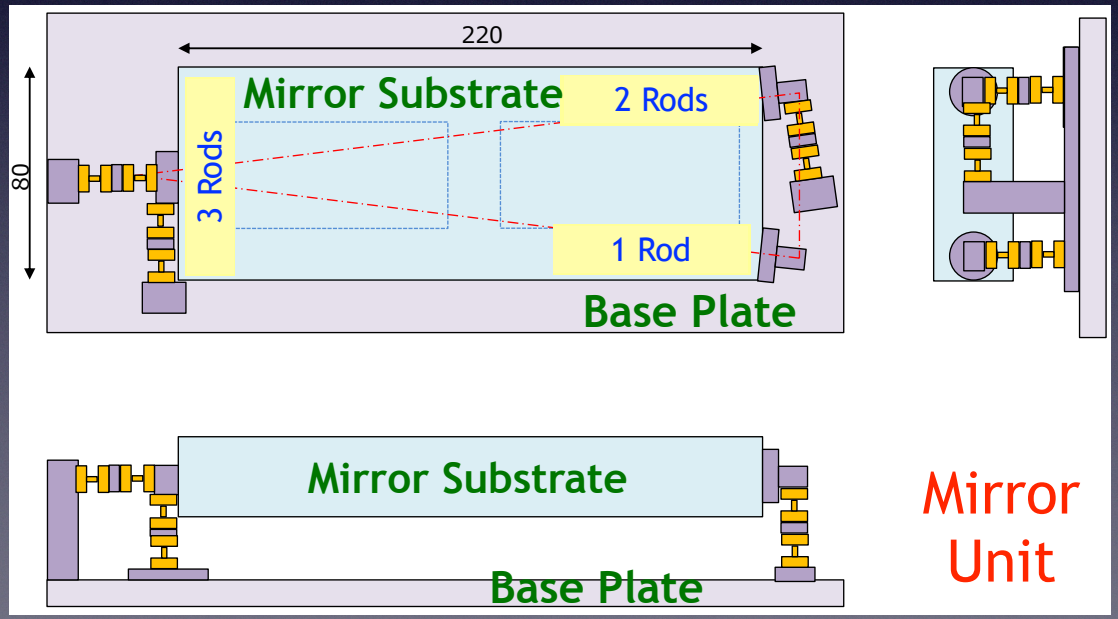
PhoENiX/SXIS Mirror Assembly Concept





Mirror area:
W38 x D90
for both P & H
Mirror substrate:
W80 x D220 x H30

Total 9 mirror units

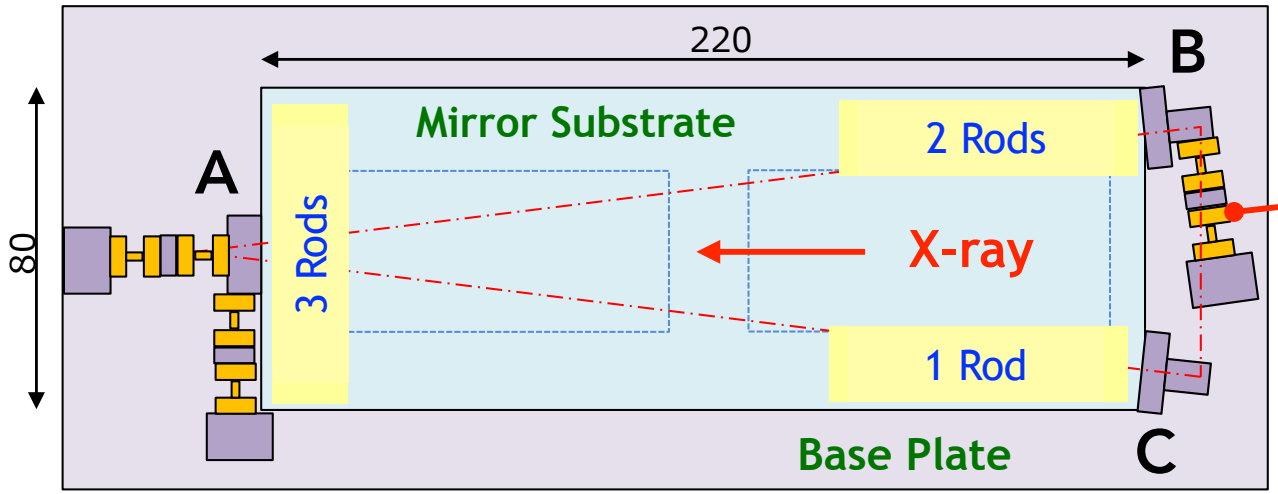


Features of SXIS Mirror Mount

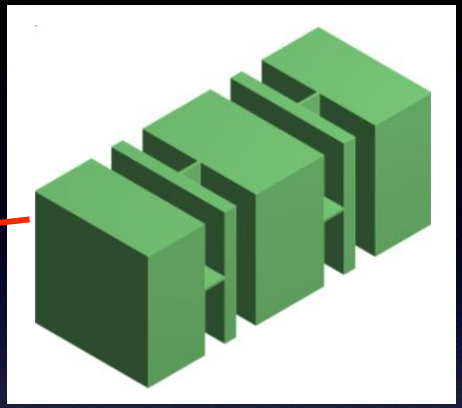
- 6-DOF constraint with 3 mounting points (3 lateral, 3 rotational DOFs).
- Mounting flexures:
  - Axial stiffness (restraining directions) should be high enough against launch load.
    - ✳ Static load: 30 G in any direction, Eigenfrequency: ≥200 Hz;
      for ~3 kg component, launch with Epsilon

      [Margin of safety > 0.5 for static load; c.f., M.S. > 2.0 for repetitive load]
  - Stiffness for non-restraining directions should be low enough not to deform the mirror.
    - ✳ Against possible mis-alignment in assembling the mirror mount.
- Suppress gravitational deformation during optical tests on ground.
- Feasibility of fabrication and adjustment.

Mirror Mounting Concept



Mirror substrate (CLEARCERAM) 220 x 80 x 30t



Flexure Rod
Constrain shift and rotation along the rod axis.

- Support at the two ends along the optics axis direction.
- This introduces large shift in the meridional focus position (≳100 mm) if the mirror is placed horizontally, but saves space in the "width" direction.
- X-ray optics test to be performed with the mirror set vertically.
  (Suppress meridional focus shift down to ~1 mm while the focus shift allowance is 68.4 mm for 1.5" HPD.)

Flexure Design - Axial Stiffness

Flexure material: Super Invar (baseline)

Z-axis (optics axis) direction to be supported by a single flexure structure (k_{Az}).

→ Determine

(1) cross sectional area size, A

(2) axial stiffness, k_n

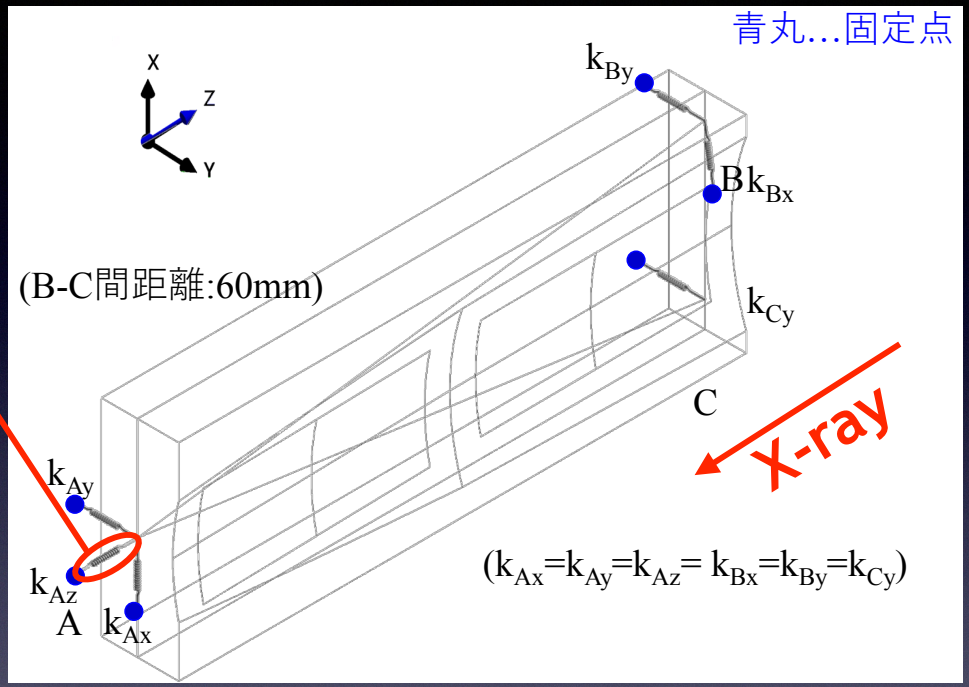
to meet the static load (30 G) and eigenfreq. (≥200 Hz) requirements.

$$A = \frac{m\alpha(MS+1)}{\sigma_y} \qquad k_n = \frac{E \times A}{L}$$

σ_y: 0.2% proof stress

E: Young's modulus

L: Flexure length



Flexure structure with

A = 1.8 mm² (k_n = 2.4 × 10⁴ N/mm)

[for L (flexure length) = 10 mm]

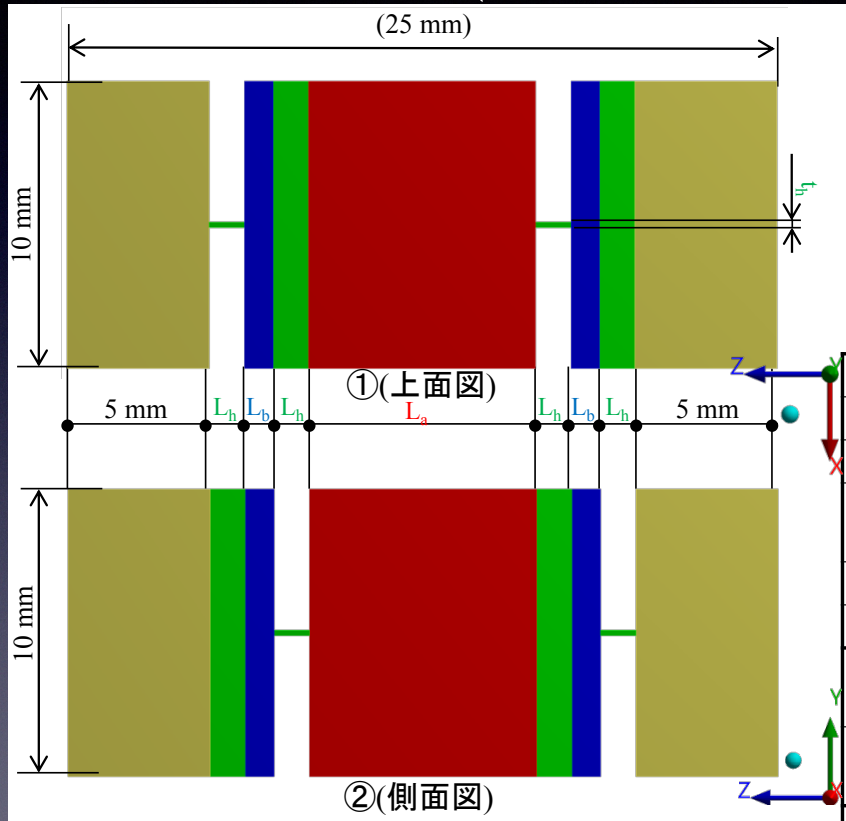
can comfortably withstand the launch load and at the same time meet the eigenfreq. requrement.

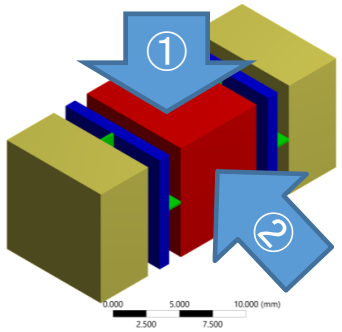
(Also OK against buckling.)

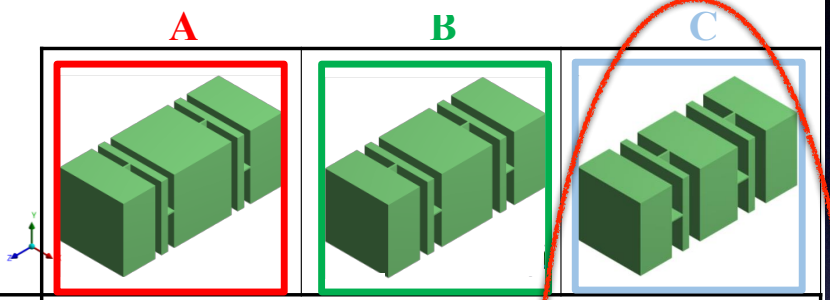
ばね定数[N/mm]	固有振動数[Hz]					
	1次モード	2次モード	3次モード	4次モード	5次モード	6次モード
1800	188	267	295	318	440	577
2000	198	281	310	334	464	607
2100	203	288	318	342	475	621
2200	208	295	325	350	486	635
(振動方向)	Z軸方向	X軸方向	Y軸方向	Z軸まわり	Y軸まわり	X軸まわり

Flexure Design Investigation

(Flexure width = 10 mm being considered)



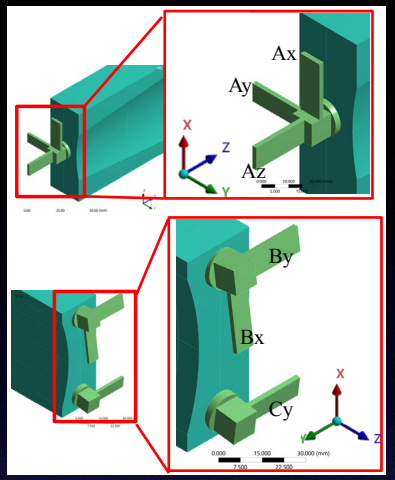




		A	B	C
t_h ヒンジ厚さ	mm		0.2	
L_h ヒンジ長さ	mm	1	1.25	1.75
座屈荷重	**N**	**2237**	**1432**	**730**
最大加速度(30[G])に対するMS		**5.1**	**2.9**	**0.99**
L_a 中央ブロック長さ	mm	9.0	8.0	6.0
L_b 中間ブロック長さ	mm		1.0	
ミラーに加わる反力合計	N	5.31	4.67	4.02
ミラーに加わるトルク合計	N・mm	138.96	102.49	72.51
回転双曲面 サグ	nm	6.73	5.11	3.75
回転放物面 サグ	nm	6.30	4.79	3.52
焦点距離移動量	**mm**	-57.58	-43.74	-32.16

Effect of Mis-Alignment in the Mirror Mount Assembly

- Assume (maybe) worst-possible amount of mis-alignment both in lateral and rotational directions.
  Lateral shift: ±0.1 mm
  Rotation: ±0.1 deg.
- Also assume reaction-force and reaction-torque are to be exerted on the mirror substrate in such a way as to maximize the mirror bend.
- Type-C flexure design can well suppress the focus shift even in such a case.

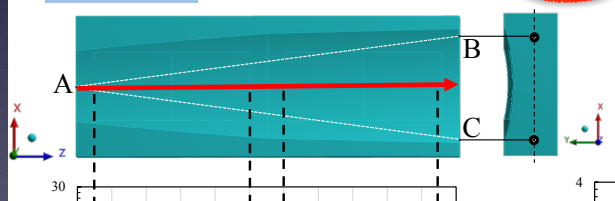


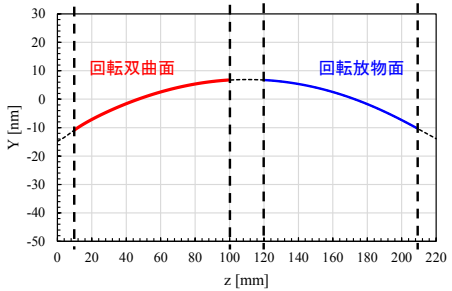
	並進方向 [mm]		回転方向[°]
	Δy	Δz	θx
Ax	-	-	+0.1 or -0.1 (ねじり)
Ay	-	-0.1 or +0.1	+0.1 or -0.1 (曲げ)
Az	+0.1 or -0.1	-	+0.1 or -0.1 (曲げ)
Bx	-	-	-0.1 or +0.1 (ねじり)
By	-	+0.1 or -0.1	-0.1 or +0.1 (曲げ)
Cy	-	+0.1 or -0.1	-0.1 or +0.1 (曲げ)

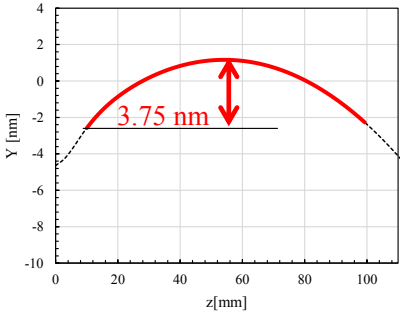
赤字…ミラー凹
青字…ミラー凸

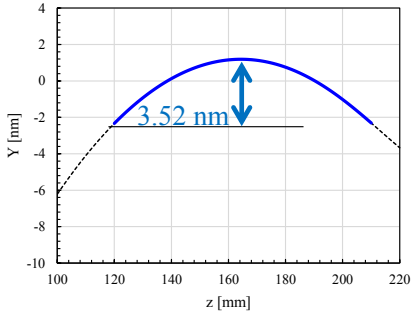
	回転双曲面	回転放物面
slope [μrad]	0.19	-0.19
sag [nm]	3.75	3.52
焦点距離移動量 [mm]	-32.16	

	反力 [N]			反トルク [N・mm]		
	Ny	Nz	Mx	Ny	Nz	Mx
Ax						7.41
Ay		1.01			13.93	0.49
Az	-1.01			13.93		0.49
Bx						-7.41
By		-1.01			-13.93	-0.49
Cy		-1.01			-13.93	-0.49
	トータル		4.02	トータル		72.51



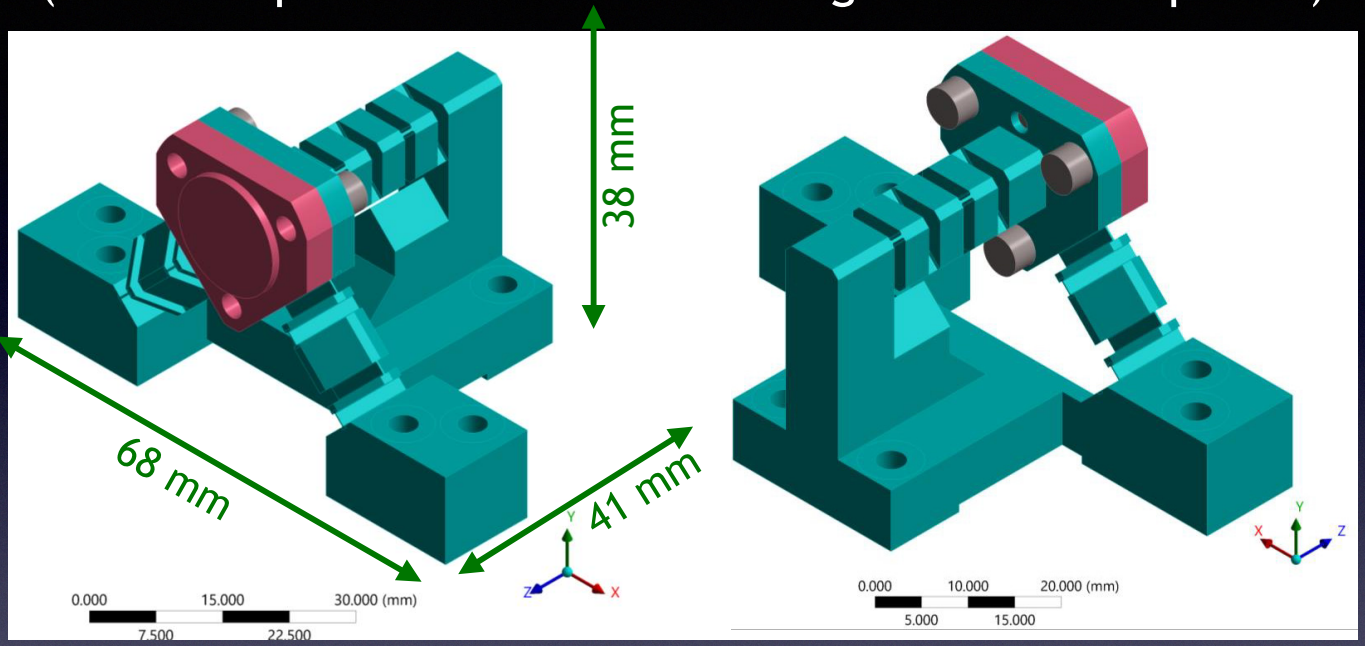


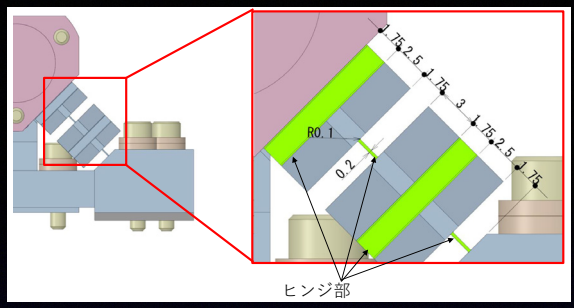


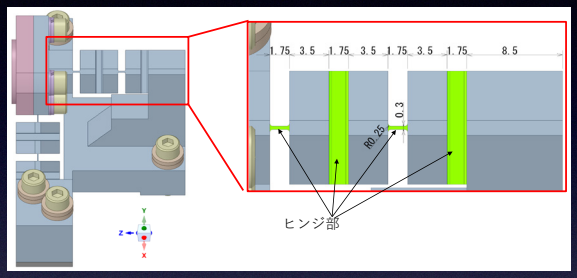


Mirror Mount Design for Point-A

(Most complicated structure among the 3 mount points)

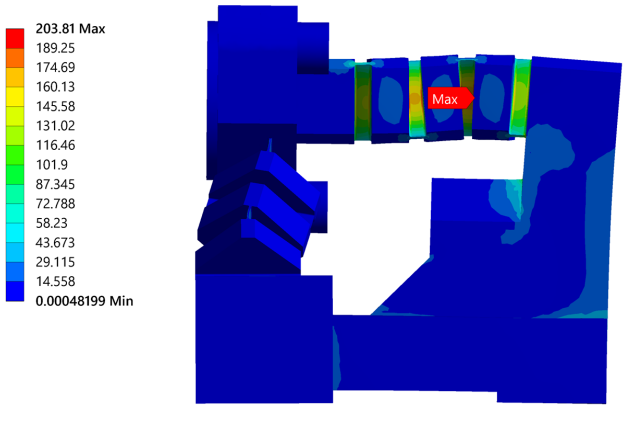






- Monolithic structure with electric discharge machining.
  - Suppress lateral shift/rotational error in flexure assembly.
  - Height/tilt adjustment to be performed by shims in btwn. the mirror mount and the base plate.
- Again verified the structure meets static load, eigenfrequency, buckling, and mirror deformation req's.
- Weight saving by machining to be performed.

Max. Mises stress (204 MPa; along Z axis) below 0.2% proof stress (308 MPa) for the static launch load, ensuring the M.S.



Summary

- Mount design for PhoENiX/SXIS mirror(s) in progress.
- Developed conceptual design for the flexure structure of the mount rods.
  - Meets static launch load and minimum eigenfrequency requirements for a component on Epsilon launcher.
- Designed the mount rod structure for the 3-axes-restraining mount point (Point-A).
  - Most complicated rod structure among the 3 mount points.
  - Fabrication procedure taken into account. (Monolithic fab. with electric discharge machining.
  - Again confirmed the structre meets Epsilon requirements.
- Assembly procedure being developed at the same time.
- Future prospects:
  - Verification of the adhesive for attaching the mirror pads together with the attachment procedure.
  - Design remaining two mount rods.
  - Weight saving of the mirror unit (esp. the base plate).
  - Verification of the mount structure.