



High bandwidth fast steering mirror

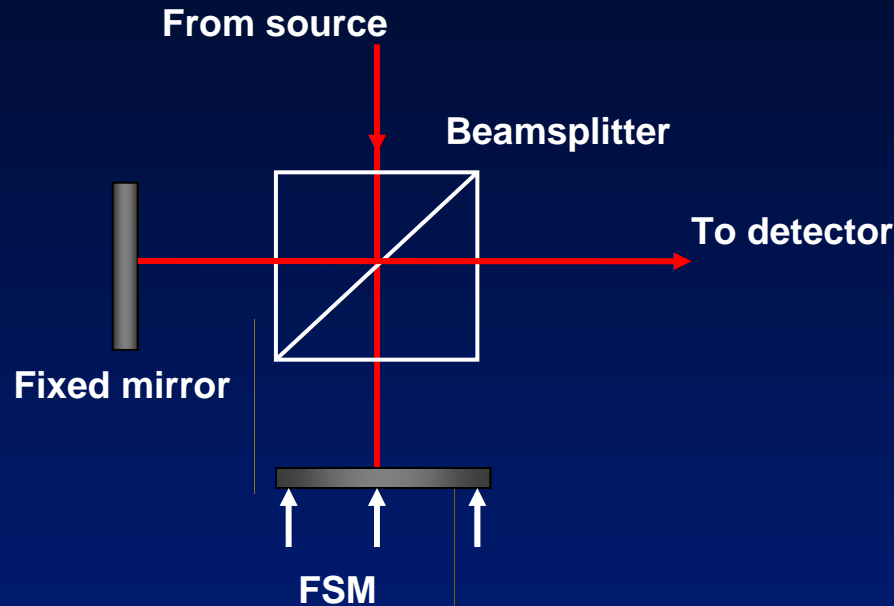
**Presenter
Francisc M. Tapos**

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Application and Requirements

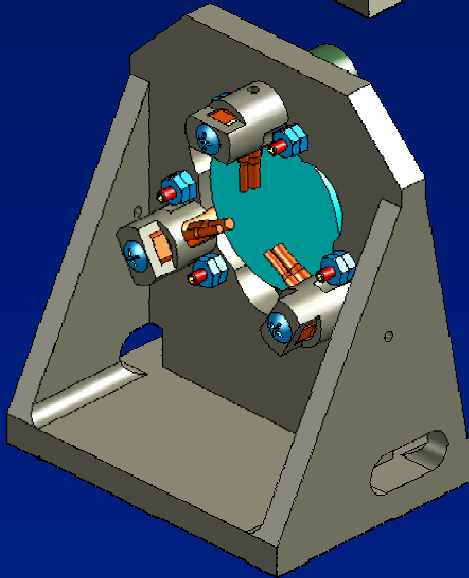
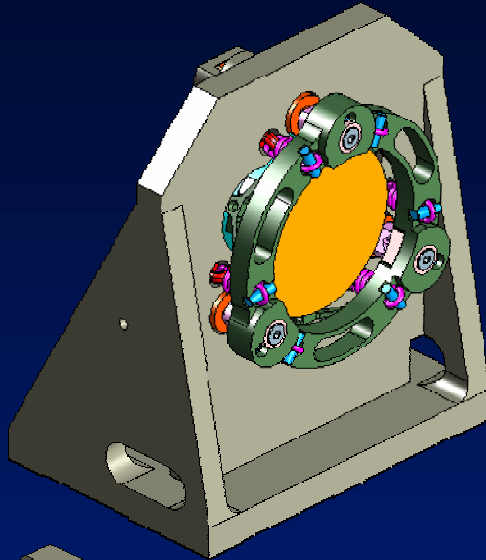


- The FSM is the optical path-length adjustment mirror in a Michelson interferometer setup.

Requirements

- **DOF** tip, tilt, piston
- **Steady state piston error** 0.1 nm
- **Steady state tip/tilt error** 4 e-9 rad
- **Settling time** ~1 ms
- **Maximum range** 10 micron
- **Optic diameter** 50.8 mm
- **Closed-loop bandwidth** ~1 kHz
- **Surface distortion** < 1 nm
- **Ambient pressure** 760 Torr
- **Ambient temperature** 25°C

Design features



- Mirror size: 50.8mm O.D., 12.7mm THK.
- Mirror CA: 25.4mm
- Mirror surface quality: $\lambda/100$
- Mirror mount: monolithic, stress free bonding
- Manual coarse adjustment
- Closed-loop fine adjustment: PZT actuators
- Gimbaled tip/tilt motion about the mirror surface center
- Kinematic mount of the moving mass
- Moving mass CG on the gimbal point
- Moving mass preloading: helical extension springs
- Adjustable preloading
- Sturdy mounting structure

Moving parts



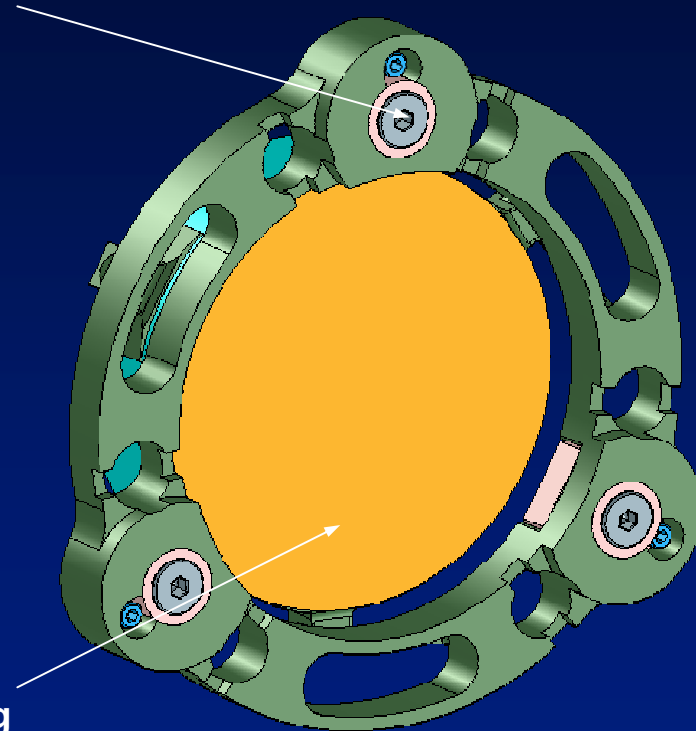
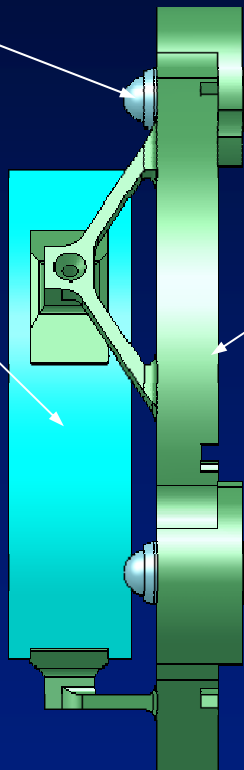
Manual adjuster tip

Manual adjuster

Mirror

Mirror mount

Mirror reflecting surface



Monolithic mirror mount

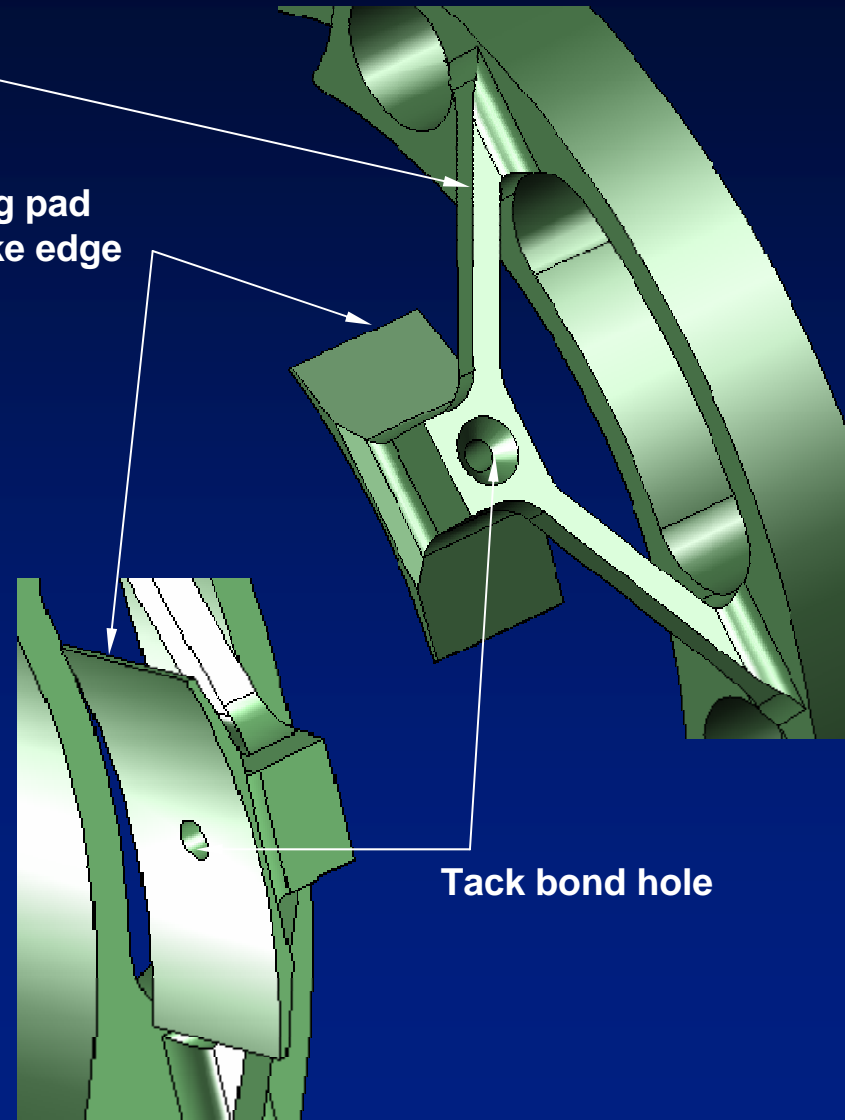
Ring shaped mount body

Bipods

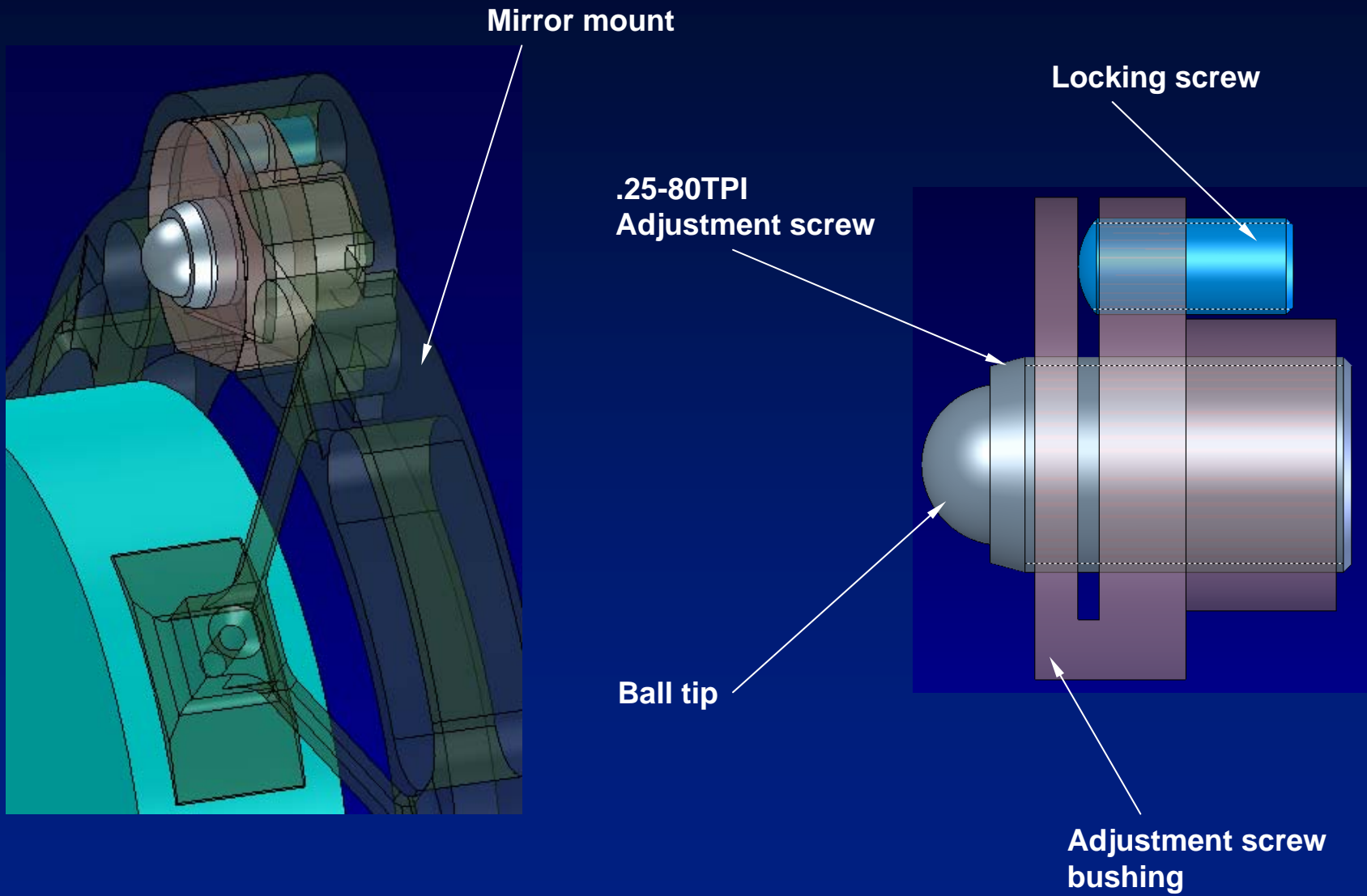
Bonding pad
knife-like edge

Manual adjuster
bushing inset

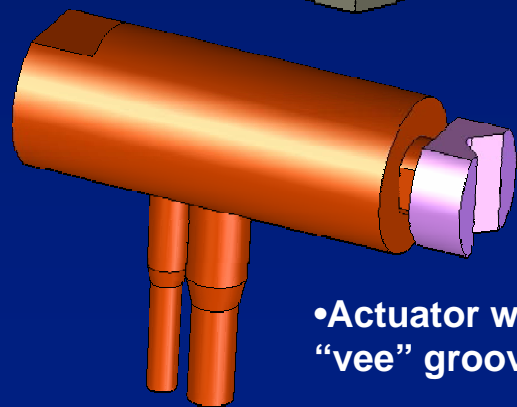
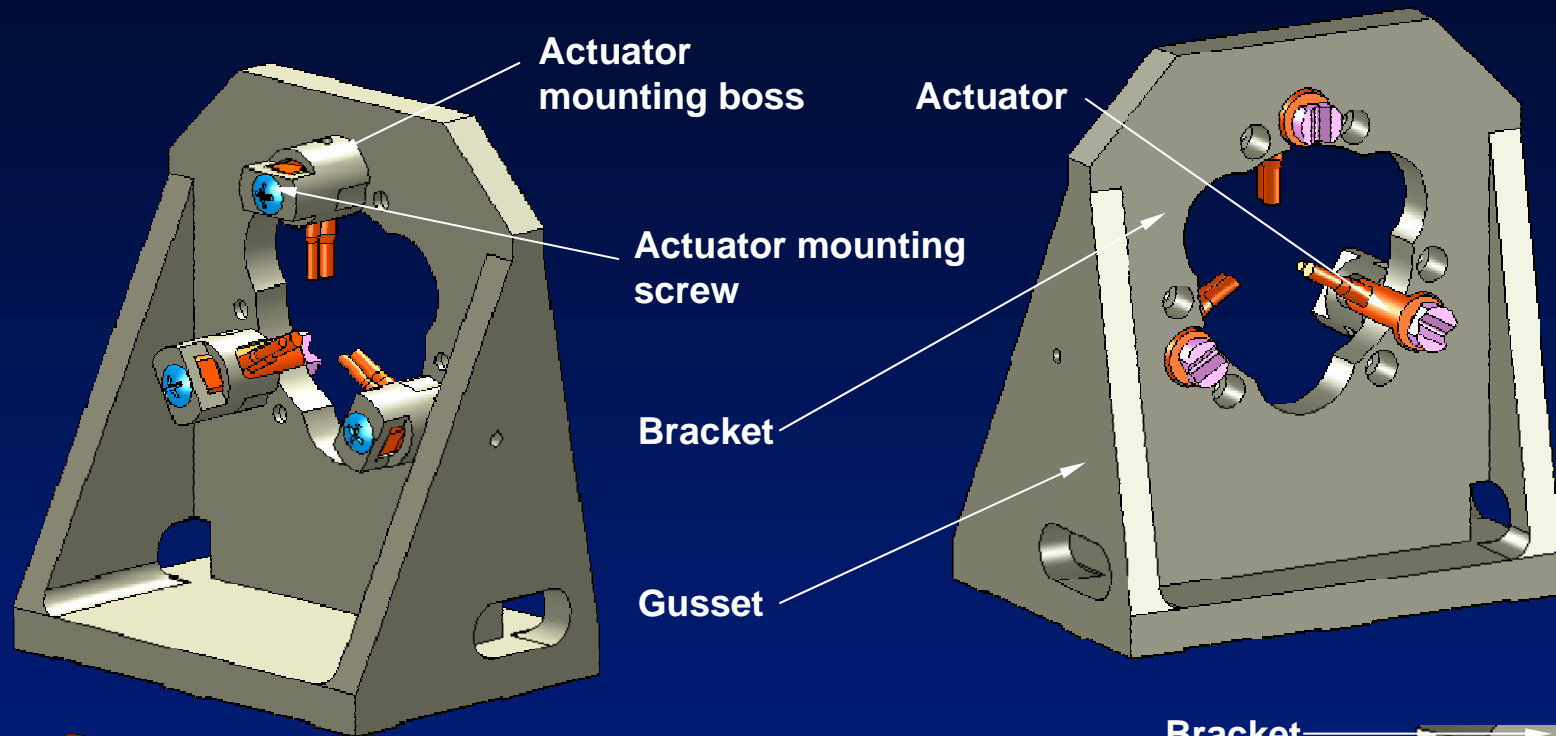
Tack bond hole



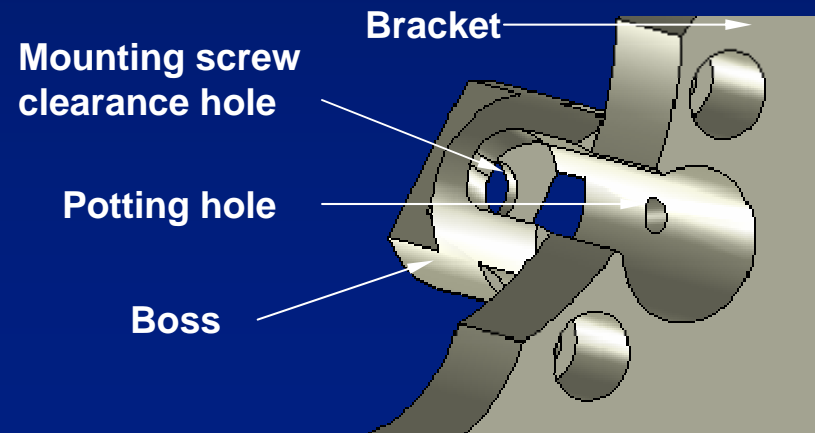
Manual coarse adjuster



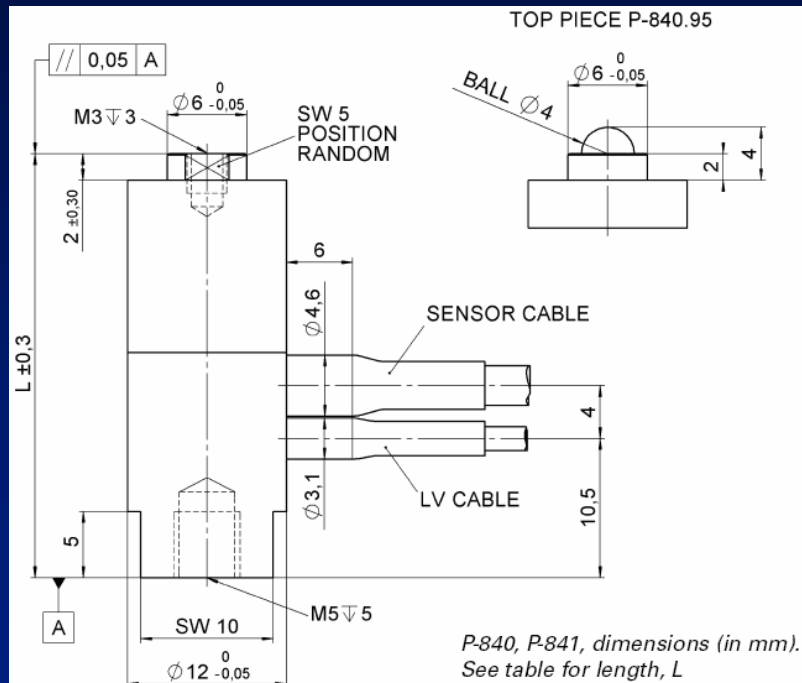
Fixed parts



•Actuator with custom "vee" groove attachment



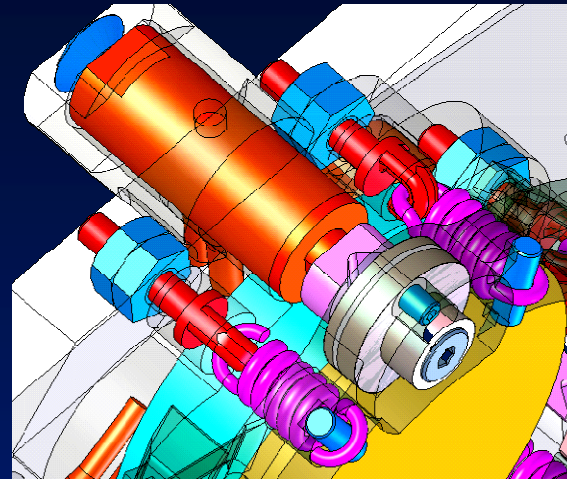
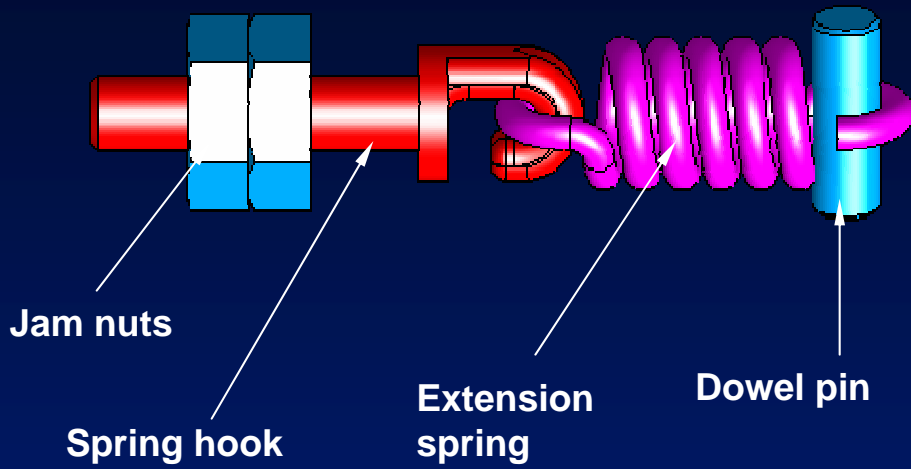
Off the shelf actuator specifications



	Closed-Loop P-841.10	Units
Open-loop travel @ 0 to 100V	15	$\mu\text{m} \pm 20\%$
Closed-loop travel \geq	15	μm
* Integrated feedback sensor	SGS	
Closed-loop / open-loop ** resolution <	0.3 / 0.15	nm
** Static Large-signal stiffness*	57	$\text{N}/\mu\text{m} \pm 20\%$
Push/pull force capacity	1000 / 50	N
Torque limit (at tip)	.035	Nm
Electrical capacitance	1.8	$\mu\text{F} \pm 20\%$
Dynamic operating current coefficient (DOCC)	15	$\mu\text{A}/(\text{Hz} \times \mu\text{m})$
Unloaded resonant frequency (f_0)	18	$\text{kHz} \pm 20\%$
Standard operating temperature range	-20 to +80	$^{\circ}\text{C}$
Voltage connection	VL	
Sensor connection	L	
Weight without cables	20	$\text{G} \pm 5\%$
Material case / end pieces	N-S	
Length L	32	$\text{Mm} \pm 0.3$
Recommended Amplifier/Controller (codes explained p.6-46)	C, D, G, H	

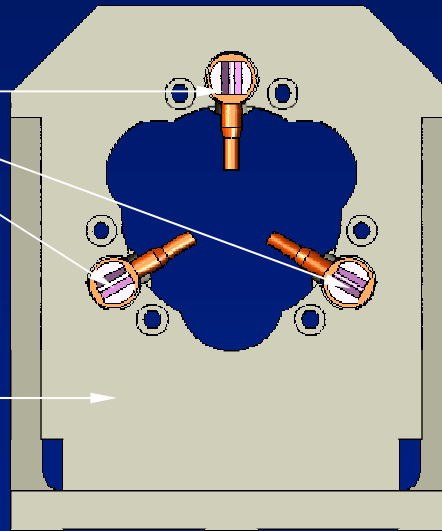
* Closed-loop models are supplied with calibration data sheets;
 **Resolution of PZT actuators is not limited by friction or stiction.
 Noise equivalent motion with E-503 amplifier;
 ***Dynamic small-signal stiffness 30% higher

Interface parts



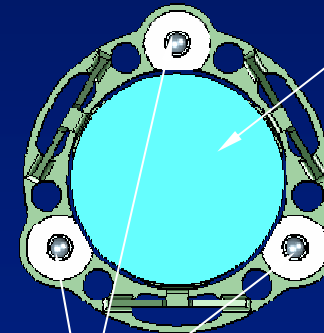
"Vee" grooves
(actuators)

Bracket
assembly



Mirror
assembly

Balls
(adjusters)

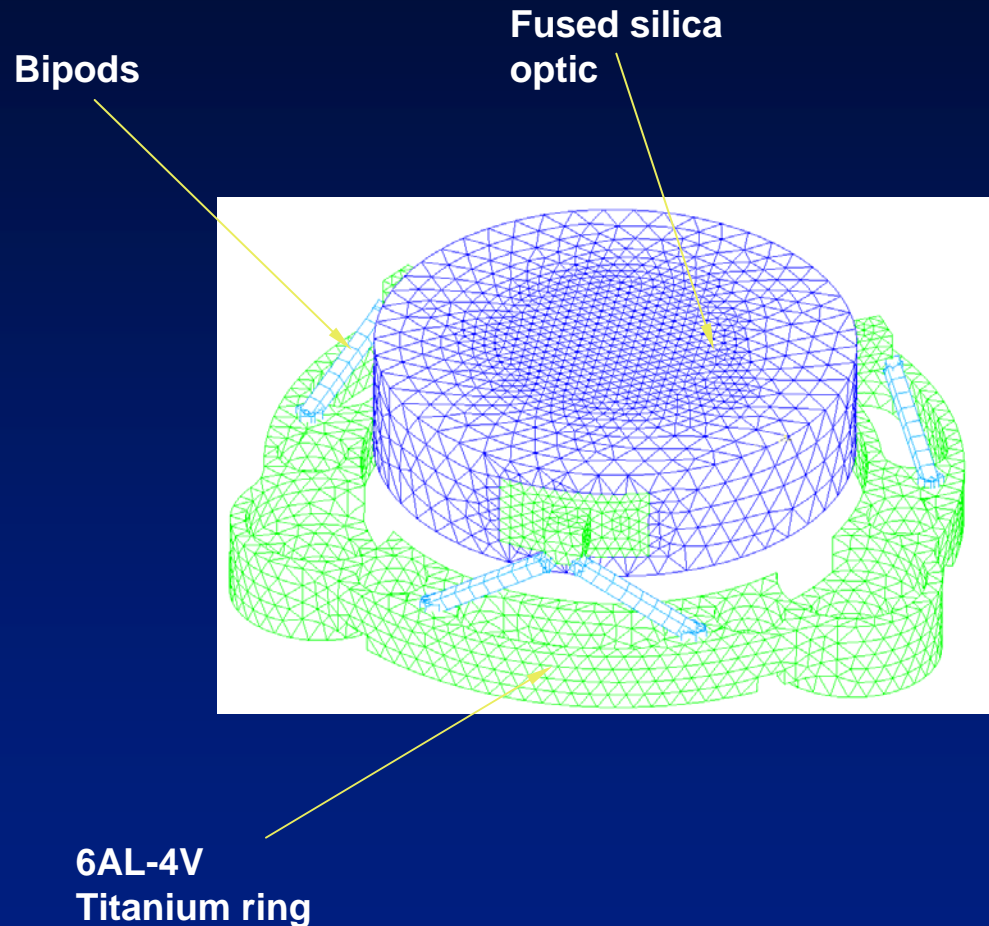


Analysis Requirements



- 100g static design load (should conservatively envelope loads from random vibration).
- Minimum 1000 Hz piston and tip/tilt modes required.
- Minimum 2000 Hz piston and tip/tilt modes goal.
- Mirror surface distortions should be much less than 0.84 nm RMS.
- 38 lb preload per spring required to prevent gapping.
- +/- 5 F temperature variation.
- Safety factor of 2.0 for qualification by analysis.

Finite Element Model

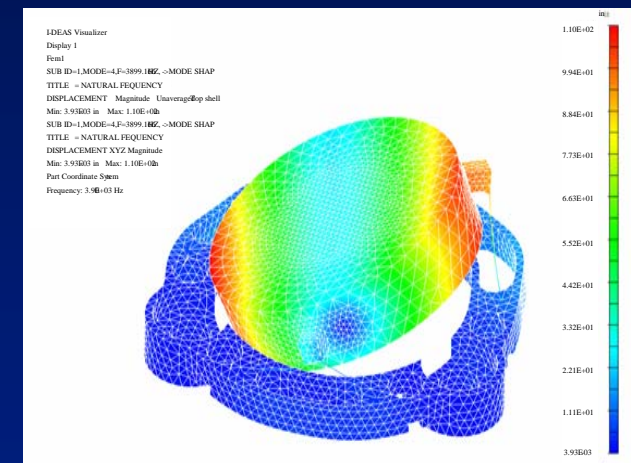
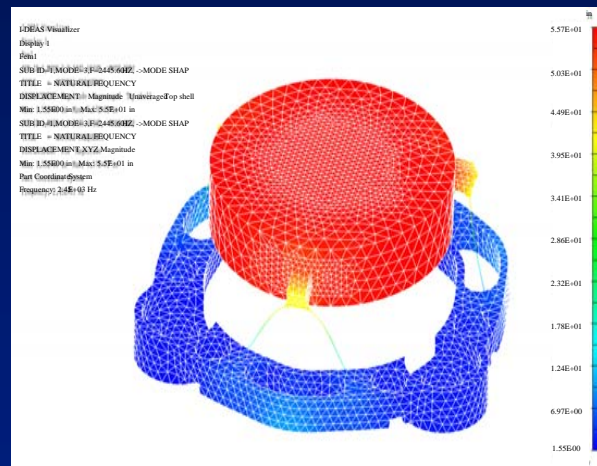
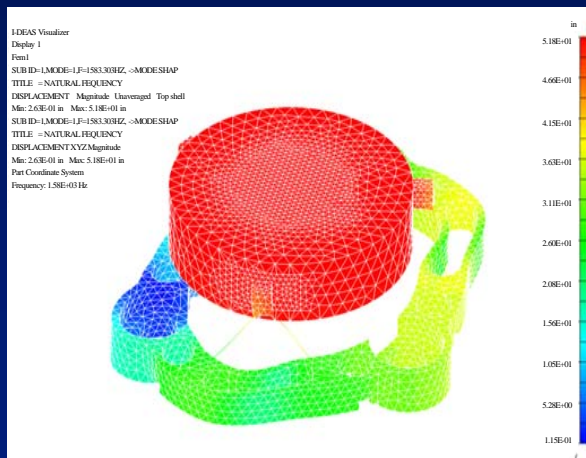


- Pre and Post Processed in I-DEAS 9
- Solved in NX/NASTRAN 2.0
- 29747 Total Elastic Elements:
 - 99 Beam Elements (for bipods)
 - 1279 Shell Elements (for bipod pads and data recovery on mirror surface)
 - 28369 Solid Elements
- 47738 Nodes

Modal analysis

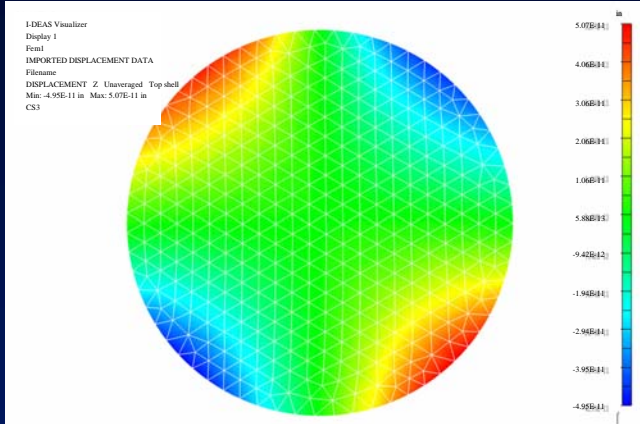


Mode	Frequency (Hz)	Effective Mass						Description
		ux	uy	uz	rx	ry	rz	
1	1583	5%	71%	0%	5%	0%	0%	Decenter
2	1585	71%	5%	0%	0%	5%	0%	Decenter
3	2446	0%	0%	64%	0%	0%	0%	Piston
4	3899	0%	0%	0%	14%	13%	0%	Tip/Tilt

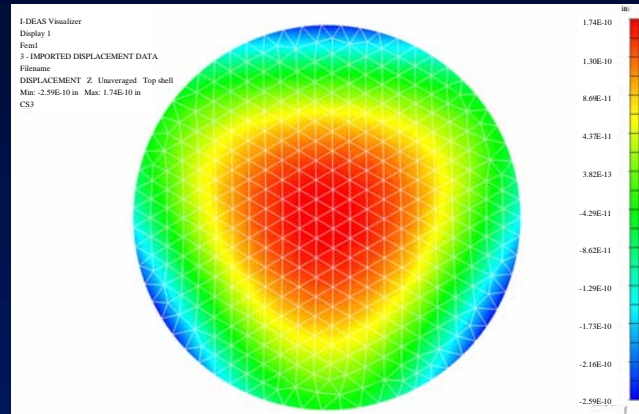


- Mode 1 (1580 Hz) - Decenter
- Mode 3 (2450 Hz) - Piston
- Mode 4 (3900 Hz) – Tip/Tilt

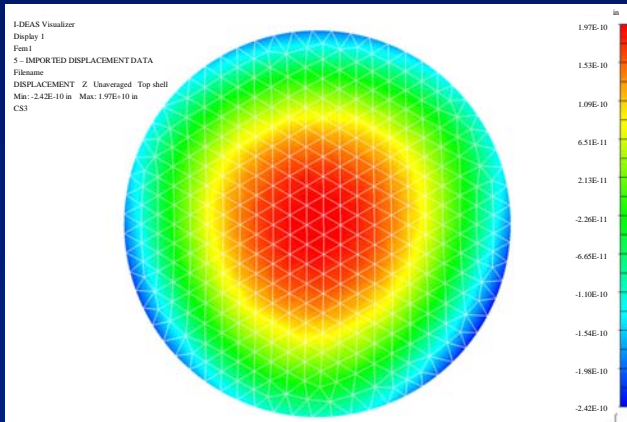
Surface distortion



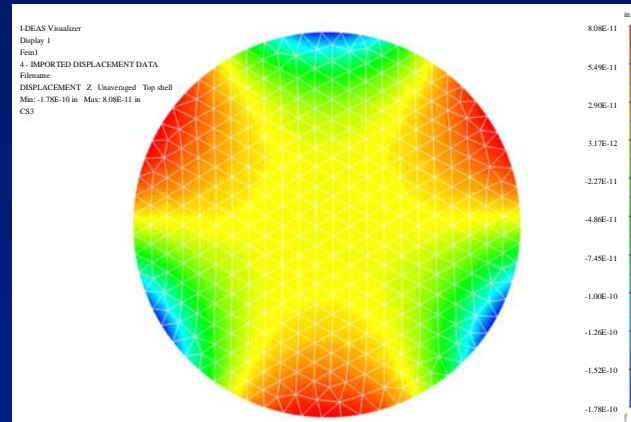
• Clear Aperture Surface Distortion (nm) – 1g X



• Clear Aperture Surface Distortion (nm) 1g Y



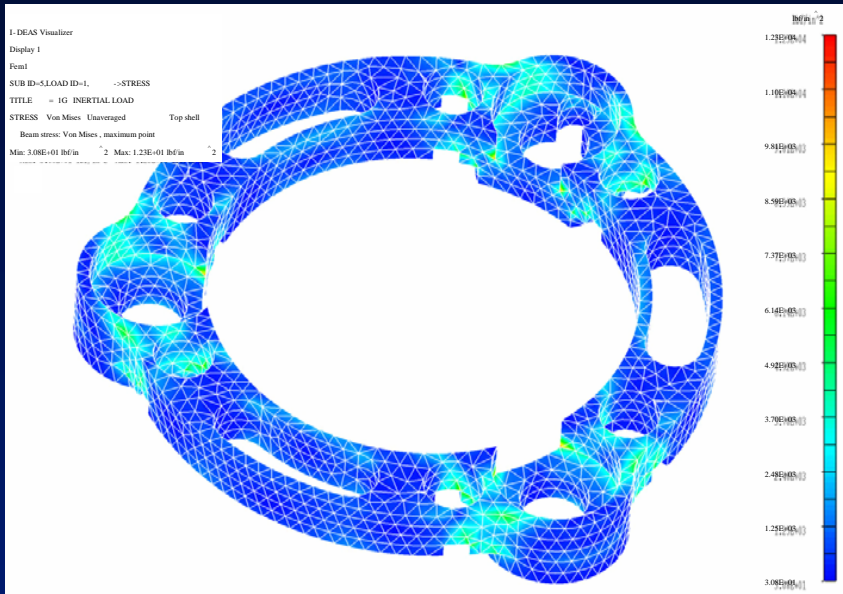
• Clear Aperture Surface Distortion (nm) - 38 lb Preload



• Clear Aperture Surface Distortion (nm) 5 deg F Temperature Delta

Load Case	Surface Distortion (nm RMS)
1g sag in X	0.02
1g sag in Y	0.02
1g sag in Z	0.11
38 lb preload at each spring	0.11
5F temperature delta	0.05

Stress Analysis



- Margin of Safety = [Allowable Load / (Safety Factor x Working Load)] – 1
- Margin of safety > 0 required.
- Margin of safety summary:

Component	Material	Failure Mode	Allowable	Working Load	Safety Factor	Margin of Safety
Bipod	6-AL-4V Titanium	Compression	120 ksi	2 ksi	2	33.78
Bipod	6-AL-4V Titanium	Buckling	483 lbf	6 lb	2	37.61
Bond Pad	Epoxy Adhesive	Shear	2 ksi	0.3 ksi	2	2.50
Mirror	Fused Silica	Tensile Fracture	7800 ksi	TBD	10	TBD
Ring	6-AL-4V Titanium	Tension	120 ksi	55 ksi	2	0.09

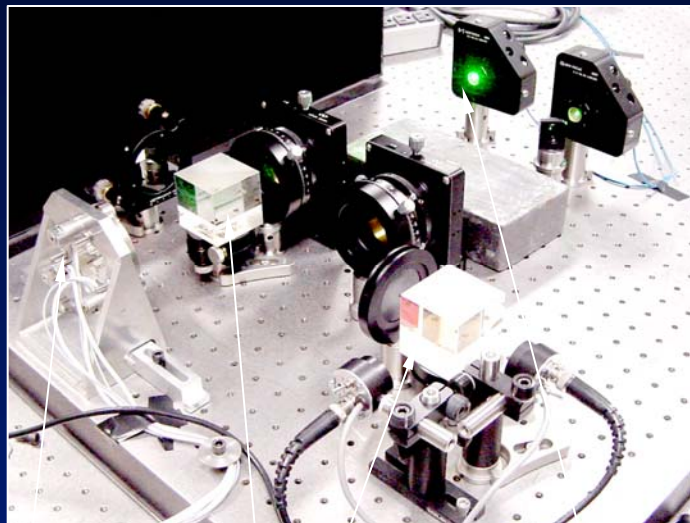
Manufacturing and assembly



FSM Assembled and Mounted in the Test Setup

- Bracket: stainless steel
- Mirror mount: titanium 6-AL-4V
- Mirror: fused silica
- Spring hook: stainless steel
- “Vee” groove attachment: stainless steel
- Adjuster bushing: brass

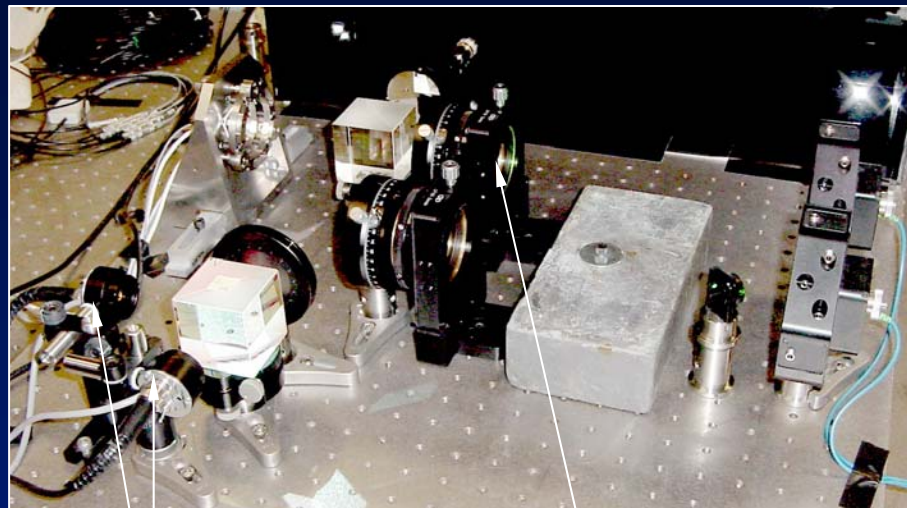
Testing setup



FSM

Beamsplitter

Source



Detectors

Polarizer

Summary



- The design features implemented made possible to meet all requirements
- Successfully manufactured all necessary parts and built the FSM
- Good results in partial testing
- Testing in progress