Precision Support and Motion System (SMS) for the Undulators and Quadrupoles of the Linac Coherent Light Source (LCLS)

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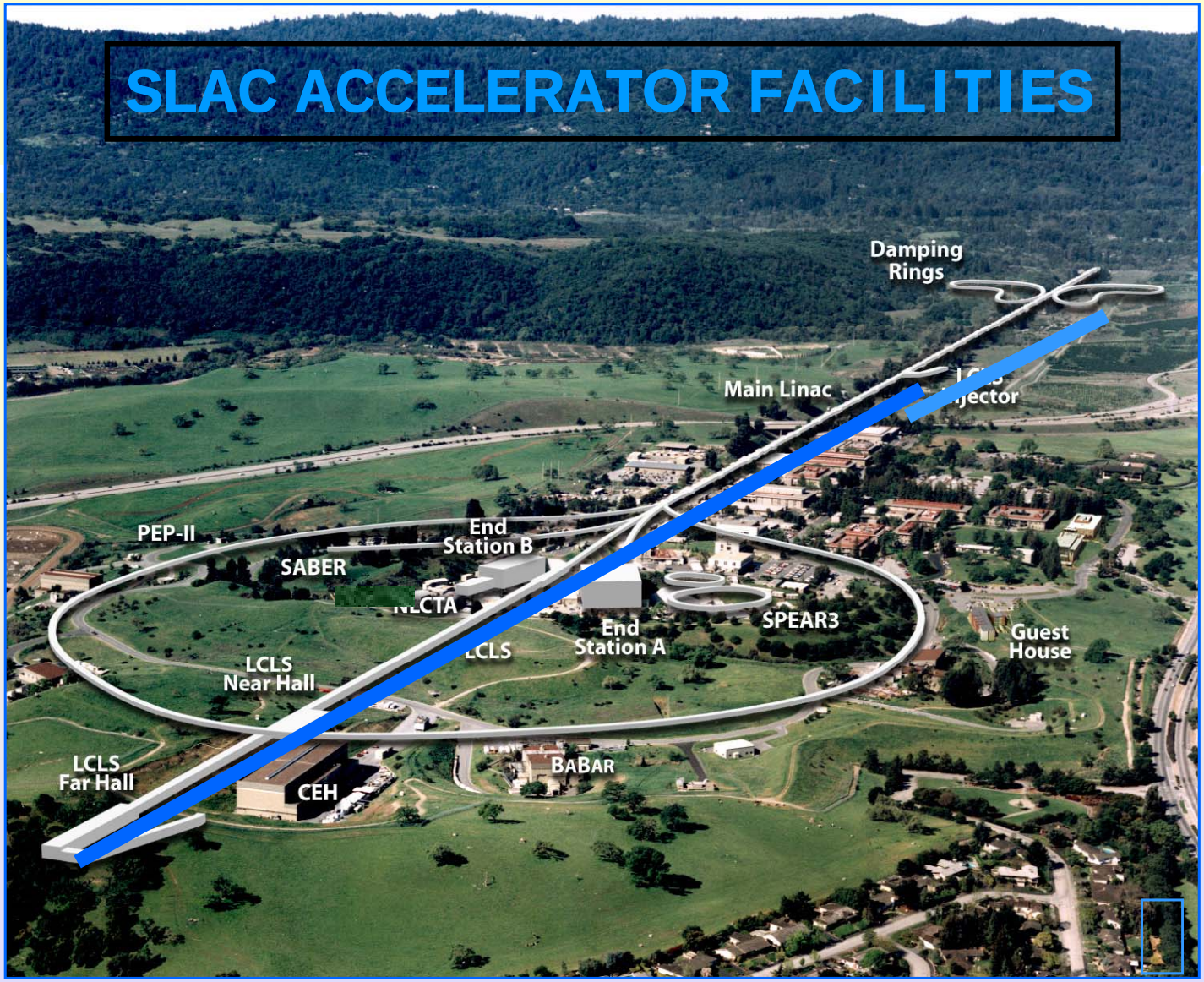
AES/MED



Roger A. Erickson, SLAC

Stability and motion precision for the LCLS Rf-BPM and Quads is crucial for the project success

Simulation show that for LCLS running at wave length 1.5 Angstroms if the electron beams develops a 2 microns rms deviation from the straight line over a distance above 10 m, the FEL saturation length will increase by one gain length (!)

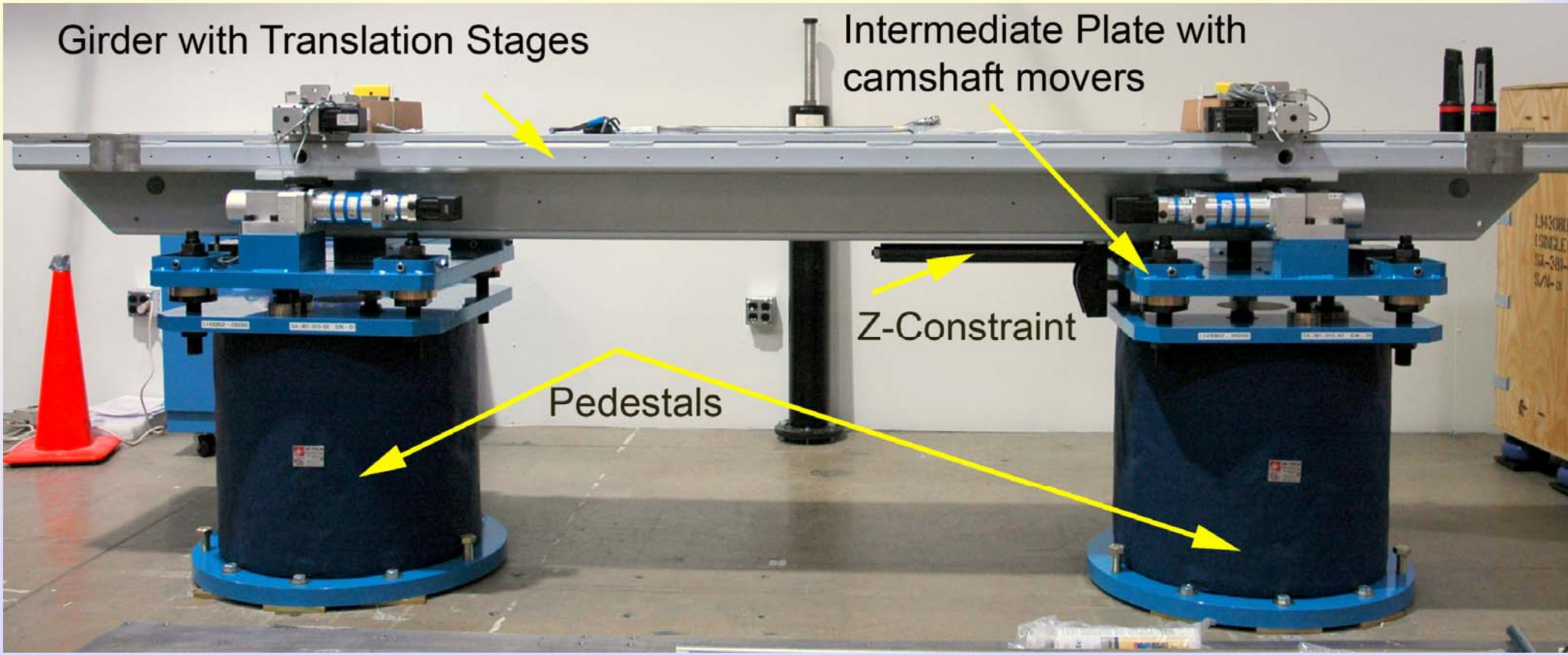
Major challenges to design Support and Mover System (SMS) for LCLS undulator segment

- Quad motion repeatability and precision ±2 μ
- RF-BPM motion repeatability and precision ±2 μ
- Short-term (1 h) BPM and Quad stability ±2 μ
- Long-term (24 h) BPM and Quad stability ±5μm
- Total weight of the girder with all components ~2300 Kg
- Total length of the girder 3800 mm

Critical requirements to determine the design of SMS for LCLS undulator segment

▪ Minimum Quad motion range radius	1.0 mm
▪ Maximum duration of full Quad motion	100 sec
▪ Quad center position manual adjustment range	±2 mm
▪ Quad center position manual adjustment resolution	2 µm
▪ Quad transverse position change in roll-out condition	±25 µm
▪ Quad position reproducibility after roll-away cycle	±2 µm
▪ BPM transverse position change in roll-out condition	±25 µm
▪ BPM position reproducibility after roll-away cycle	±2 µm
▪ Horizontal undulator position repeatability in roll-away cycle	±10 µm
▪ Vertical undulator position repeatability in roll-away cycle	±5µm

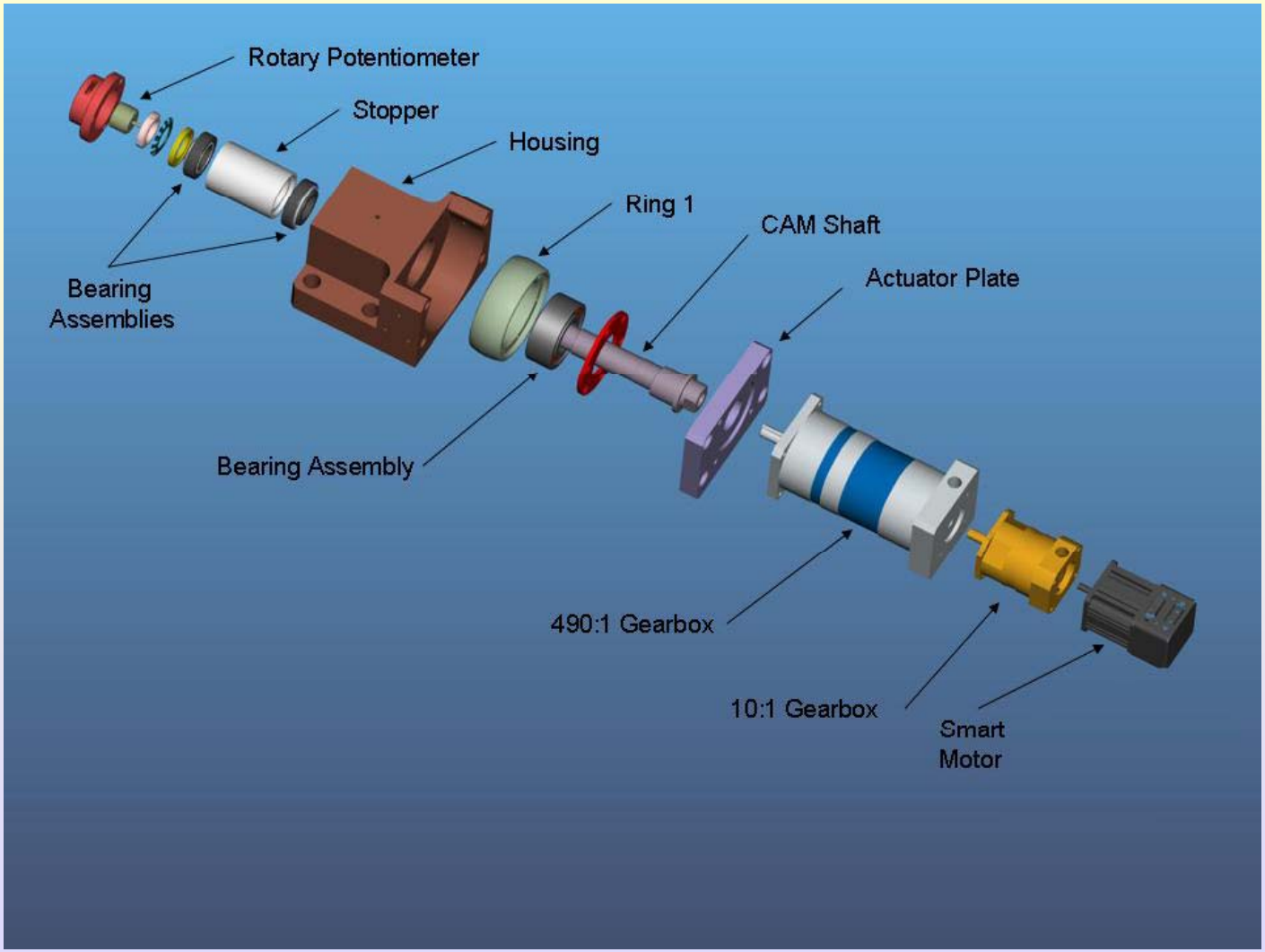
General view of the Support and Mover System



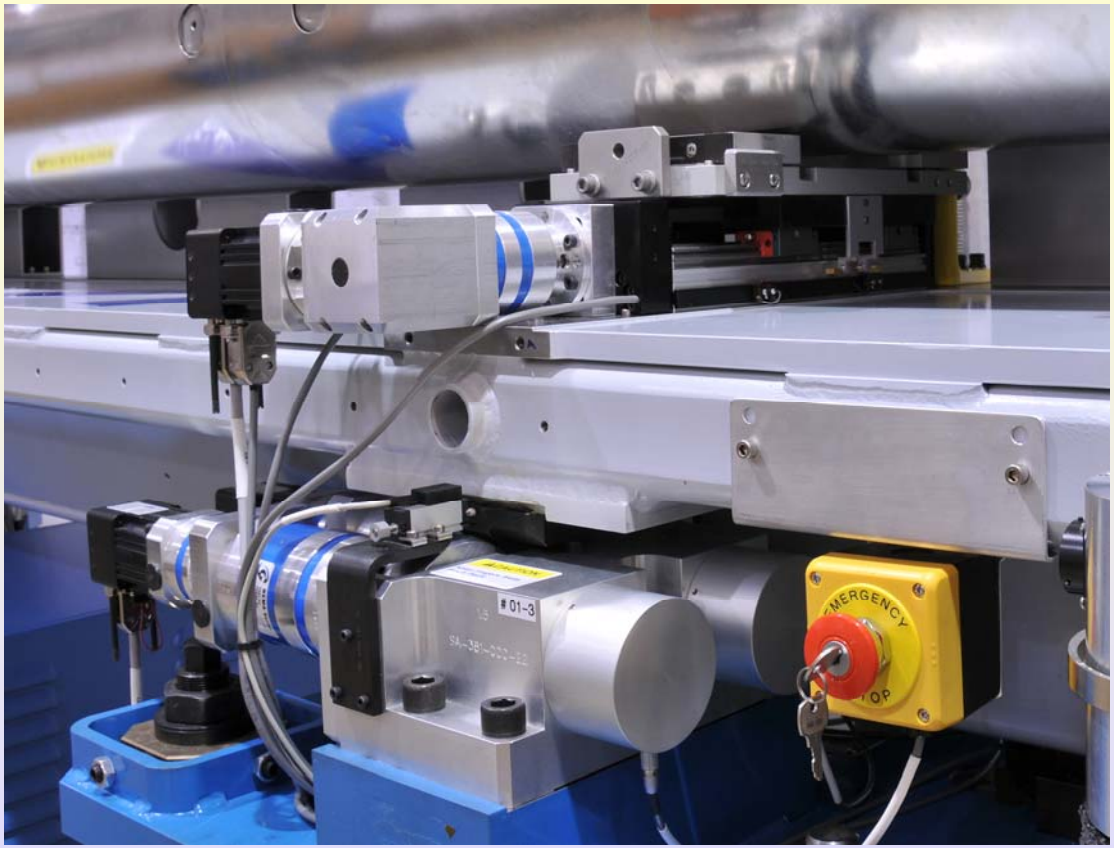
Weight transfer inside the LCLS SMS

- Weight of LCLS undulator through the translation stage going to the Cam-Shaft Mover and the through adjustable screws directly to the top plate of the pedestal.
- Girder itself has no undulator weight load.
- Rods for the girder height adjustment are unloaded and deflection of the pedestal top plate decreases.

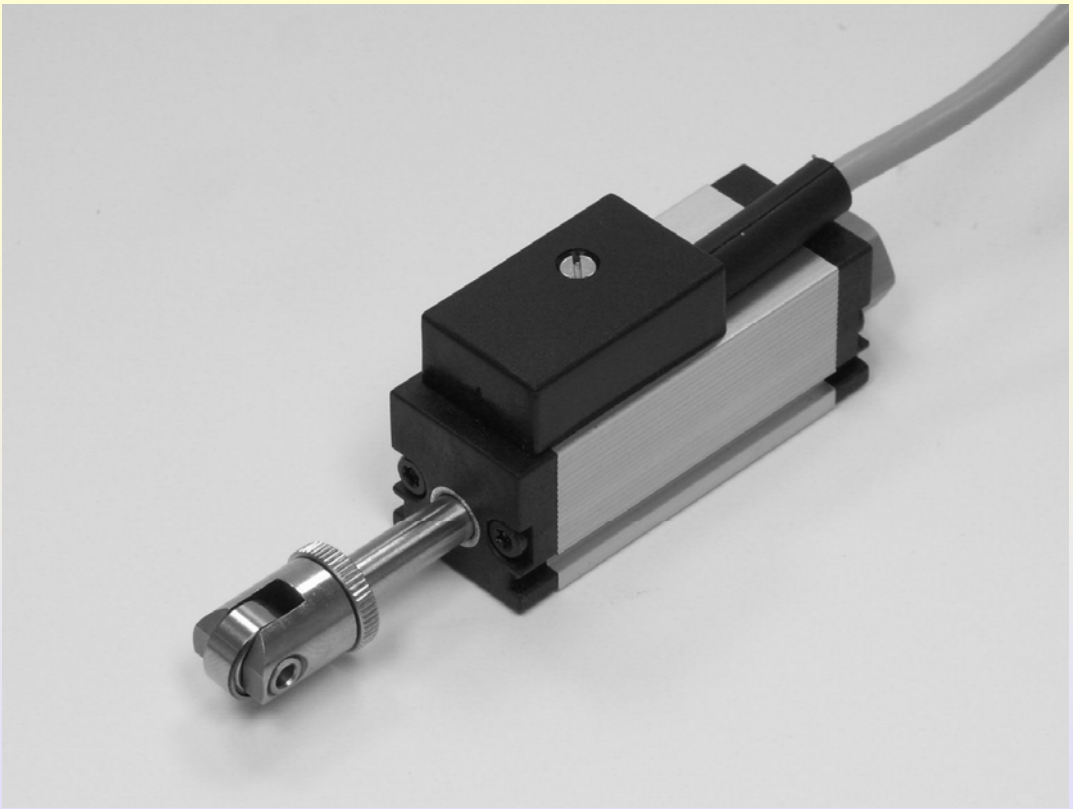
Single Cam-Shaft Mover (exploded view)



Double Cam-Shaft Mover



Linear potentiometer, manufactured by “Novotechnik”,



Travel range – 12.7 mm, precision 2μ

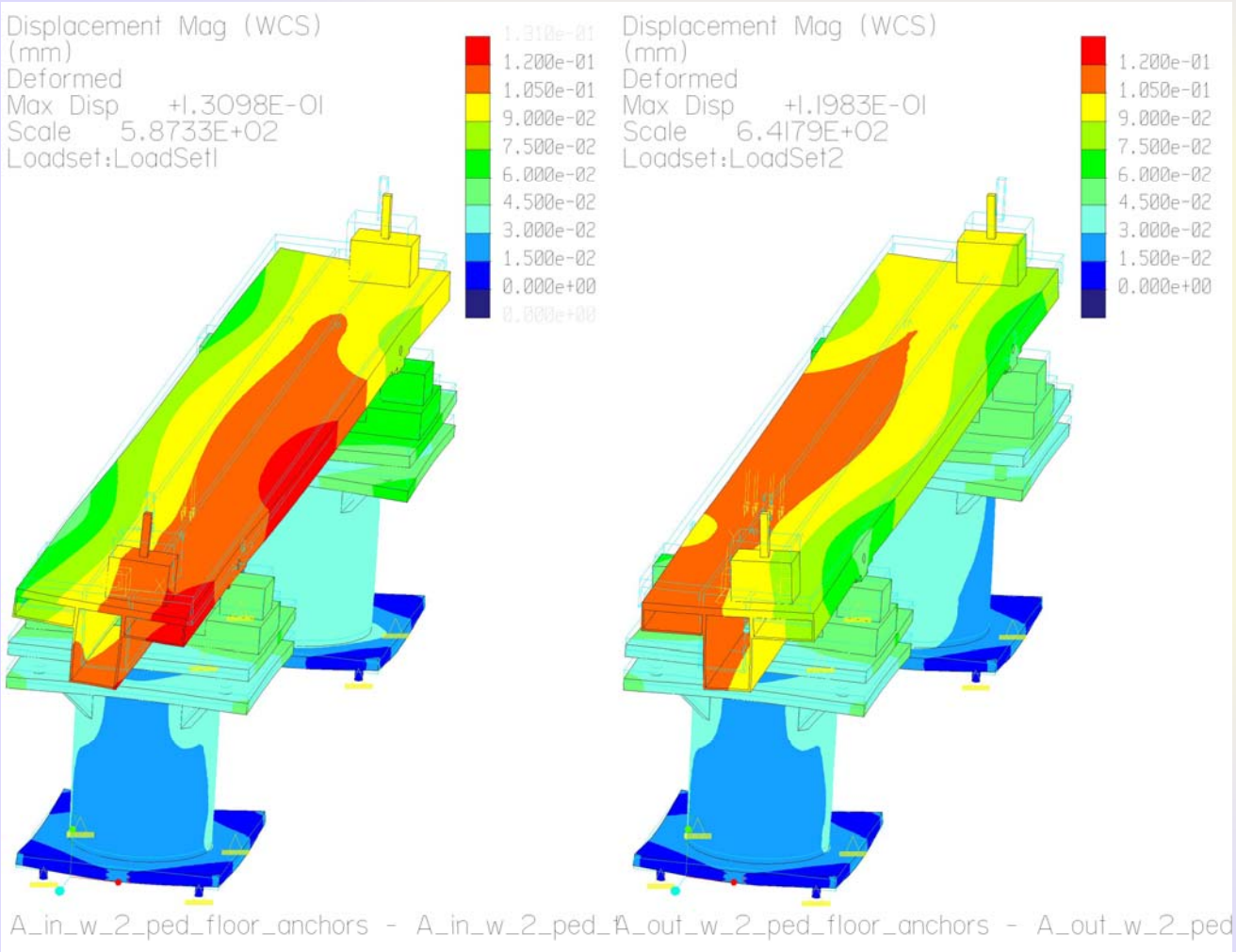
Location of the Cam-Shaft Movers at LCLS Support and Mover System

Upstream end

Downstream end

SMS girder cross-section

Numerical simulation of SMS girder twist and rocking during roll-off cycle

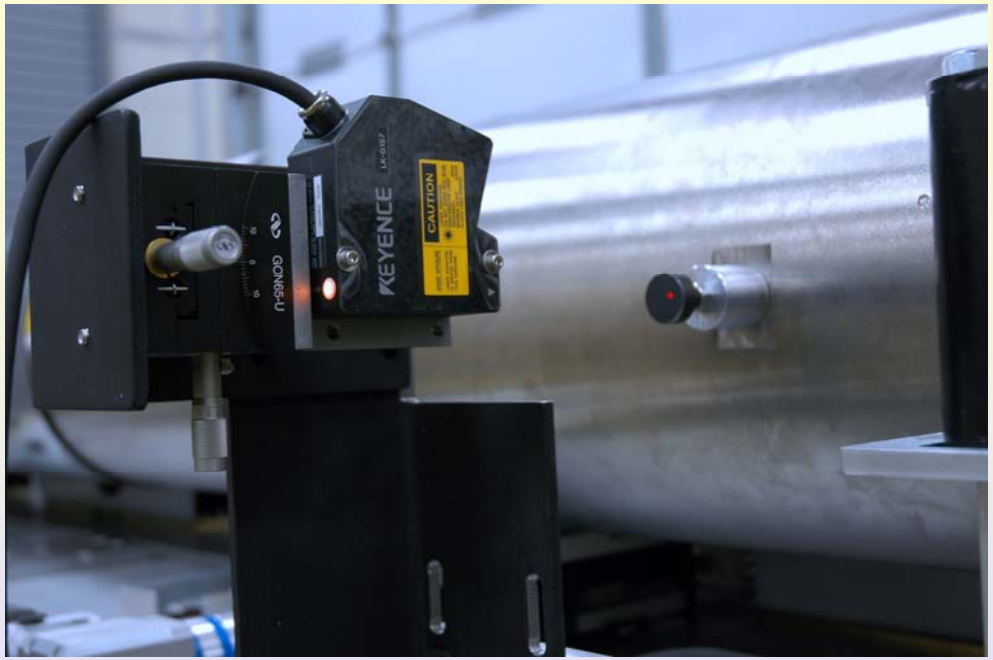


Displacement of the quad center during roll-off cycle is ~100 microns.

Wedge angles were changed from 45° to 42.8° and 25.6° to secure the rocking of the girder around quad center.

Test Set-Up for LCLS Support and Mover System

LCLS Support and Mover System equipped with the "KEYENCE" sensors for the prototype tests



"KEYENCE" sensor – one can see a laser light spot on the LCLS undulator target. Motion resolution 0.05μ

Some results for the Tests of Cam Shaft Mover System-I

Keyence Sensors	Motion Repeatability	System Backlash
$X_{Upstream}$	1.5 μm	5.0 μm
$Y_{Upstream}$	1.5 μm	5.0 μm
$X_{Downstream}$	1.5 μm	2.0 μm
$Y_{Downstream}$	1.5 μm	2.0 μm
$Y_{Midstream}$	1.5 μm	4.0 μm

Uncorrected Short-Term Stability = 2 μm
Uncorrected Long-Term Stability = 5 μm

Linear Potentiometers	Motion Repeatability	System Backlash
$X_{Pot\ Upstream}$	0.5 μm	2.5 μm
$X_{Pot\ Downstream}$	1.0 μm	2.0 μm
$Y_{Pot\ Upstream\ Inboard}$	0.5 μm	2.0 μm
$Y_{Pot\ Upstream\ Outboard}$	0.5 μm	3.0 μm
$Y_{Pot\ Downstream\ Inboard}$	0.5 μm	2.0 μm
$Y_{Pot\ Downstream\ Outboard}$	1.0 μm	3.5 μm

500 Cycle X-Translation Tests with 2000 micron Travel Range

September 2006

Some results for the Tests of Cam Shaft Mover System-II

Keyence Sensors	Motion Repeatability	System Backlash
$X_{Upstream}$	1.0 µm	1.0 µm
$Y_{Upstream}$	1.0 µm	1.0 µm
$X_{Downstream}$	1.0 µm	1.0 µm
$Y_{Downstream}$	1.0 µm	1.0 µm
$Y_{Midstream}$	1.0 µm	1.0 µm

Uncorrected Short-Term Stability = 0.4 µm
Uncorrected Long-Term Stability = 1.2 µm

Linear Potentiometers	Motion Repeatability	System Backlash
$X_{Pot\ Upstream}$	0.2 µm	0.5 µm
$X_{Pot\ Downstream}$	0.2 µm	0.3 µm
$Y_{Pot\ Upstream\ Inboard}$	0.1 µm	0.2 µm
$Y_{Pot\ Upstream\ Outboard}$	0.1 µm	0.2 µm
$Y_{Pot\ Downstream\ Inboard}$	0.1 µm	0.2 µm
$Y_{Pot\ Downstream\ Outboard}$	0.1 µm	0.5 µm

500 Cycle X-Translation Tests with 10 micron Travel Range

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Some results for the Tests of Cam Shaft Mover System-III

Keyence Sensors	Motion Repeatability	System Backlash
$X_{Upstream}$	1.5 μm	5.0 μm
$Y_{Upstream}$	1.0 μm	3.0 μm
$X_{Downstream}$	1.5 μm	5.0 μm
$Y_{Downstream}$	1.0 μm	4.0 μm
$Y_{Midstream}$	1.5 μm	3.0 μm

Uncorrected Short-Term Stability = 2 μm
Uncorrected Long-Term Stability = 4 μm

Linear Potentiometers	Motion Repeatability	System Backlash
$X_{Pot\ Upstream}$	0.5 μm	2.5 μm
$X_{Pot\ Downstream}$	0.5 μm	5.0 μm
$Y_{Pot\ Upstream\ Inboard}$	0.5 μm	1.0 μm
$Y_{Pot\ Upstream\ Outboard}$	0.5 μm	1.0 μm
$Y_{Pot\ Downstream\ Inboard}$	0.5 μm	2.5 μm
$Y_{Pot\ Downstream\ Outboard}$	0.5 μm	5.0 μm

500 Cycle Y-Translation Tests with 500 micron Vertical Travel Range

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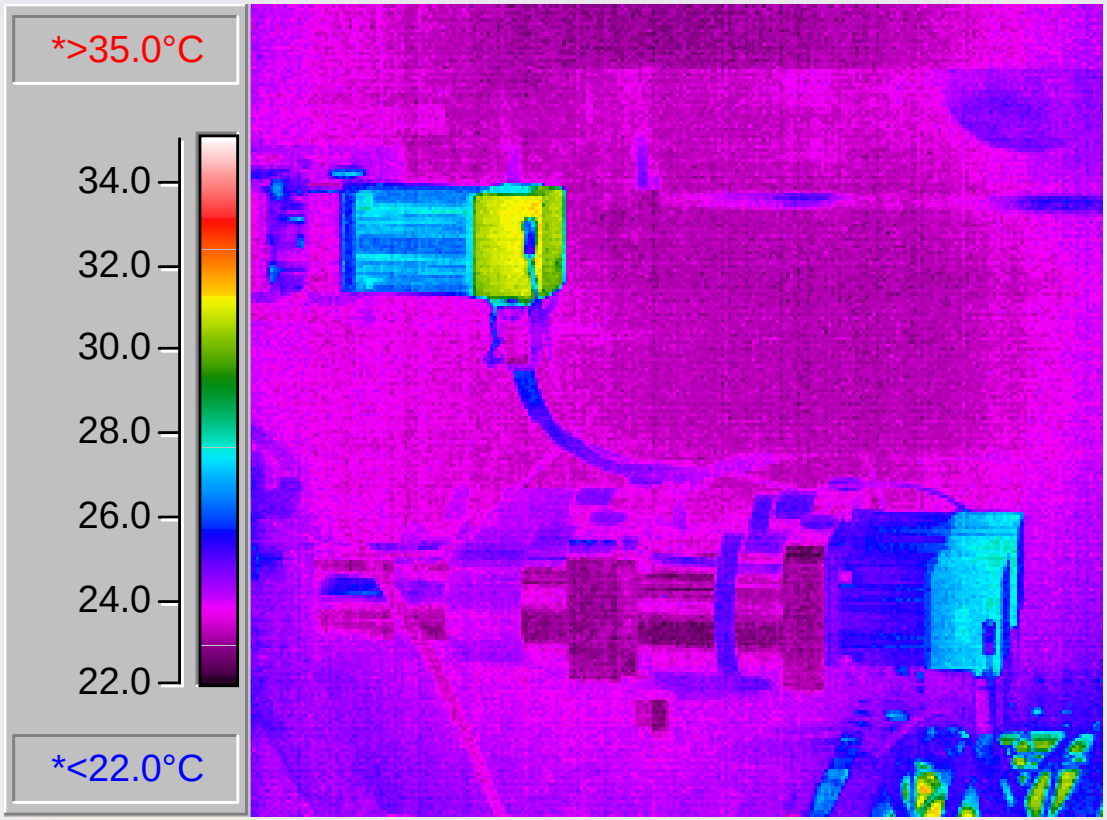
LCLS Undulator System Tests – Heating Effects with Motors Idle



- The Lower Two Motors Drive the Double Cam Mover and are Powered On But Idle
- The Maximum Steady-State Temperature of the Motors is Tmax = 28°C
- There is No Heating Effect on the Girder from the Motors

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Support/Mover System Test Conditions

- All Cyclic Motion Tests are Conducted without Feedback from Any of the Sensors
- Motions are Purely Driven by Motor Commands with No Positioning Iterations
- All Tests are Conducted Overnight for Typically a 6-12 hr. Period
- All Tests are Conducted Using the Entire Motion System Operating as a Synchronized System
- All Sources of Error such as Cam Calibration Errors, Sensor Misalignments, Temperature Effects, etc. are Included in All of the Measurements
- The CAM's Presently have 2500:1 Gear Reduction, the Actual System will have 4900:1 Gear Reduction

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Support/Mover System Test Conclusion

- The Cam-Mover System Resolution and Backlash Test Results for all Degrees of Motion are Well Within Specifications
- With Feedback Added, The Cam-Mover System Should Be Able to Achieve Any Move Within the Command Space to Within 2 µm with No More Than One Iteration
- The Roll-Away System Backlash and Resolution Results are Good and Within Specifications. Shorter Stroke Pots can be Added for Tighter Control at the "Home" Position
- All Motions for Both Motion Systems are Extremely Repeatable
- With the New System Design Motor Heating Effects are Non-Existent
- Engineering Solutions to Make the System Even Better are Underway

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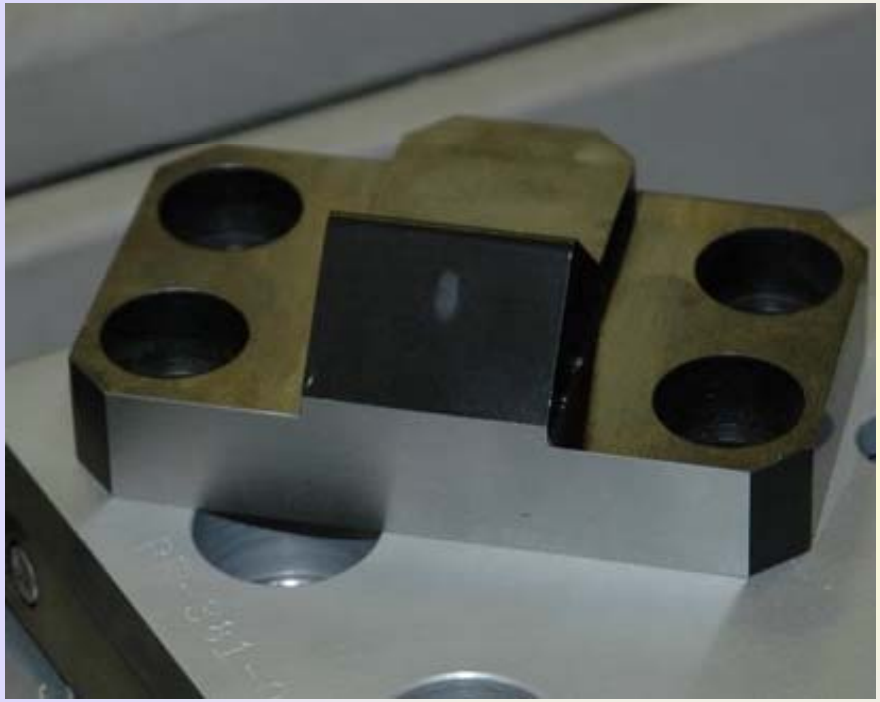
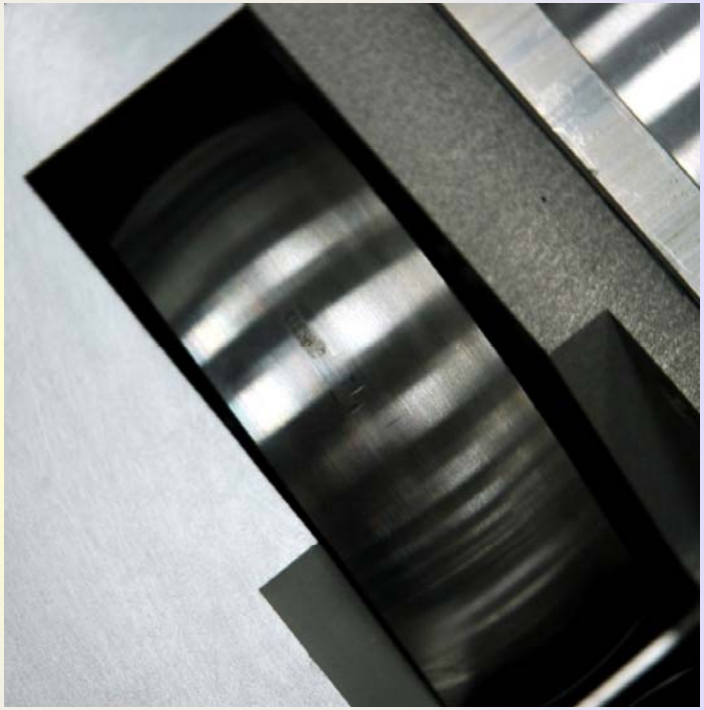
Wear of the SMS components after 100 hours of motion

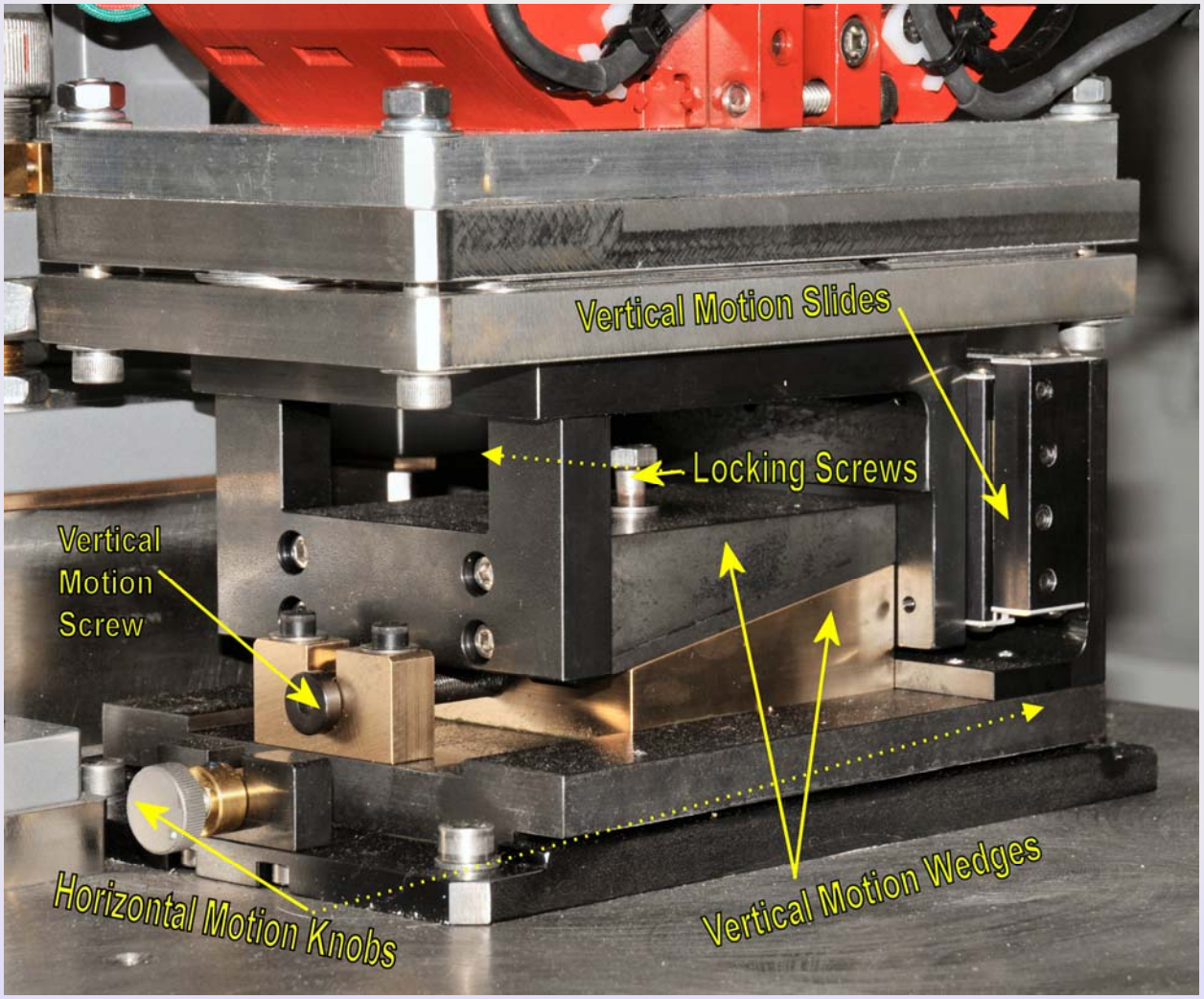


Wedge block

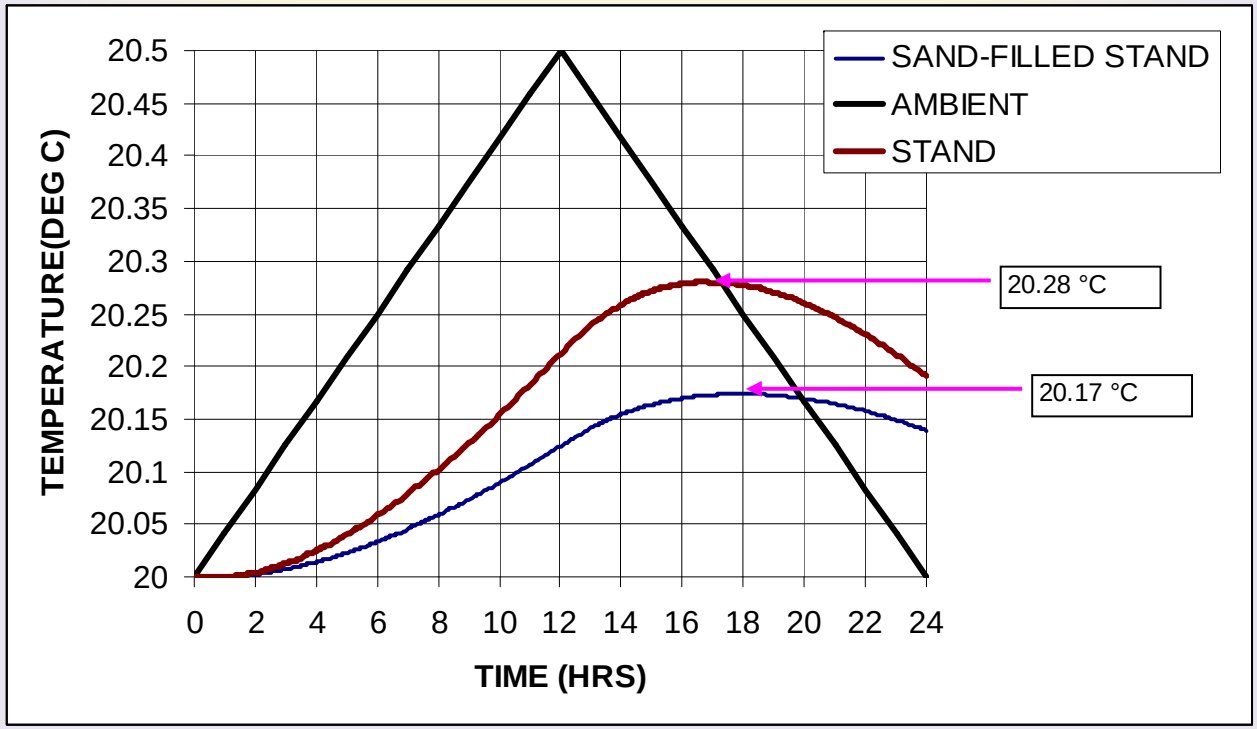


Ball-bearing crown

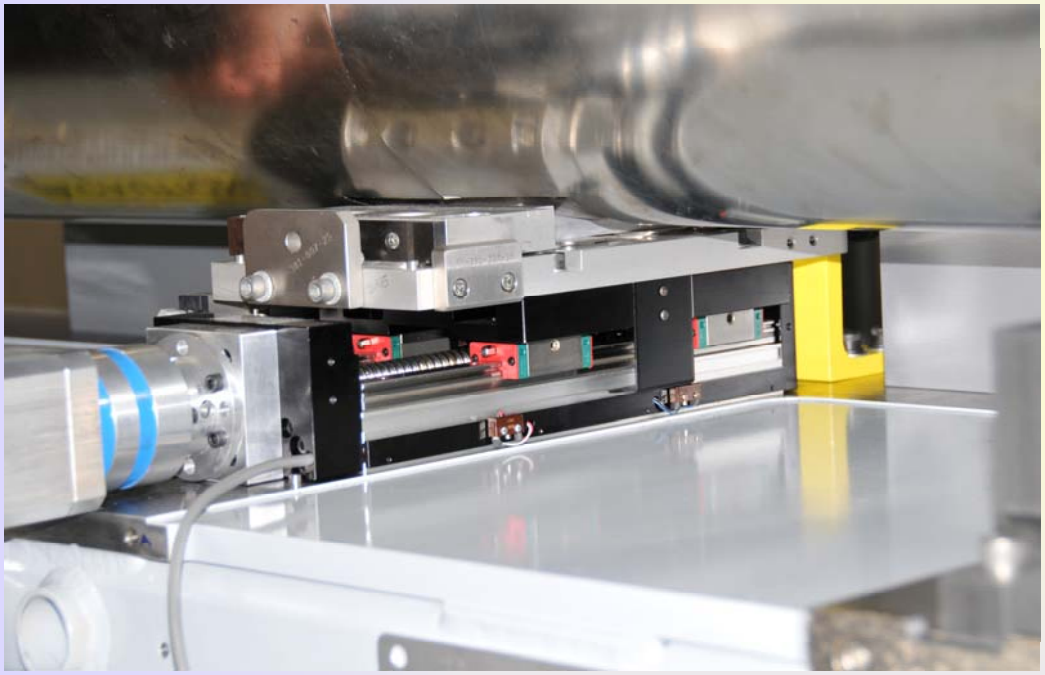
Quadrupole support stand



Impact of the sand filling on the pedestal temperature



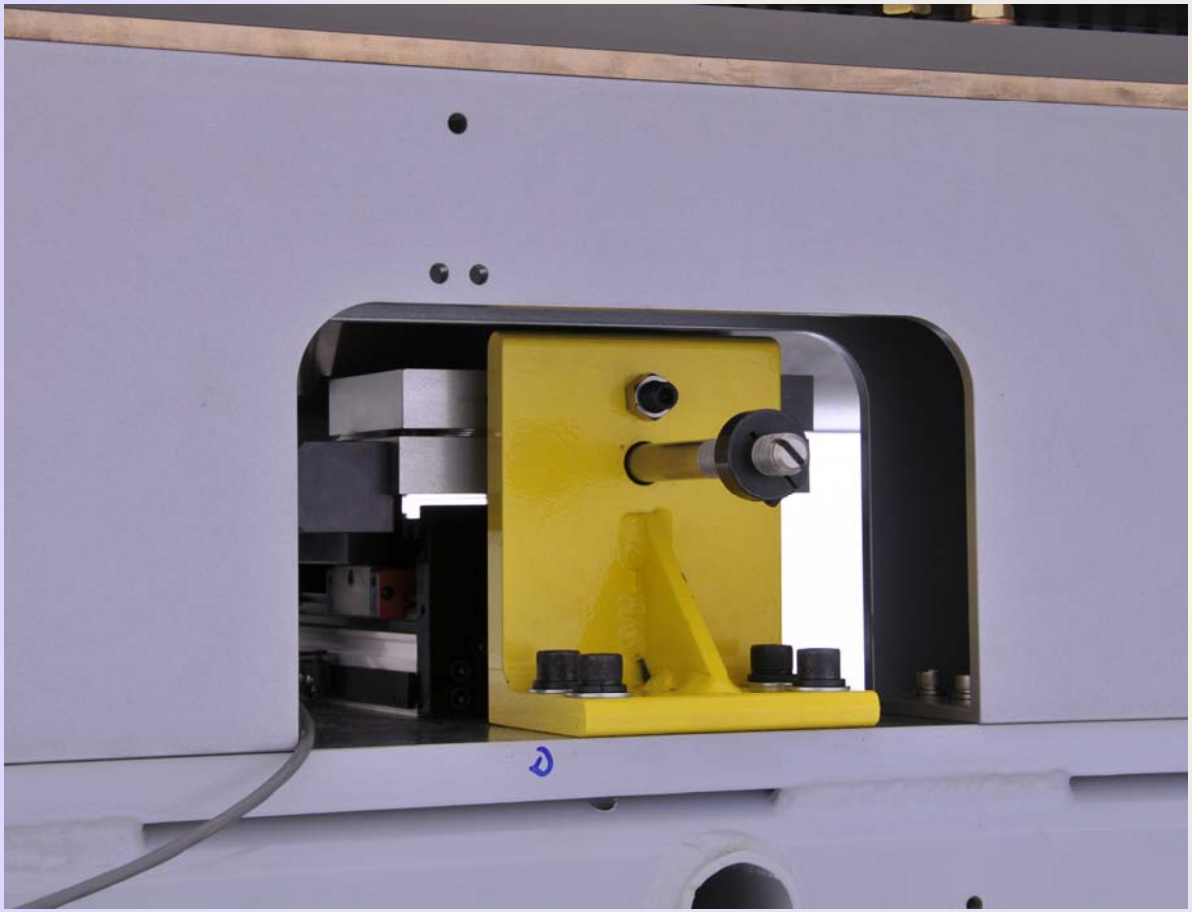
Modification of the limit switch actuator on translation stages



Before

After

Roll-off motion hard stop



Two hard stops, located in line with the translation stages, secure roll-off and roll-in motion of LCLS undulators

CONCLUSION

- Manufacturing and inspection of 38 sets of the Support and Mover System is complete.
- 37 sets were delivered to SLAC in time.
- One set is temporary at APS for the long term tests.
- Installation of the pedestals in LCLS tunnel started

Installation of the SMS pedestals in the LCLS tunnel

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