OPTIMIZATION OF MAGNET STABILITY AND ALIGNMENT FOR NSLS-II

Sushil Sharma
NSLS-II (BNL)

Acknowledgments

Coauthors: L. Doom, A. Jain, P. Joshi, F. Lincoln, V. Ravindranath

C. Channing, T. Dilgen, R. Hubbard, W. Guo, F. Karl, B. Kosciuk, S. Kramer, S. Krinsky, O. Singh, S. Ozaki,, W. Themann, C. Yu, F. Willeke

J-R Chen (NSRRC), J. Galayda (SLAC), R. Putnam (APS), E. Swetin (APS), L. Yin (SSRF)

NSLS-II at BNL

BNL Campus

NSLS-II

Storage Ring

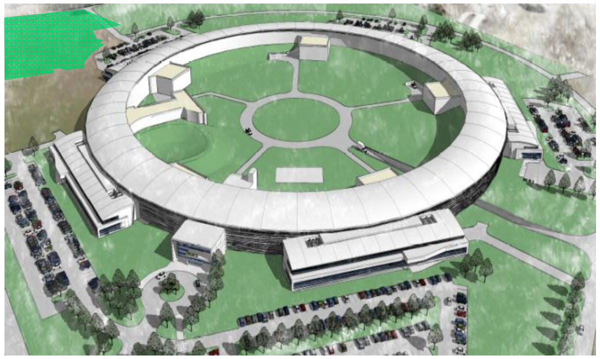
Experimental Hall

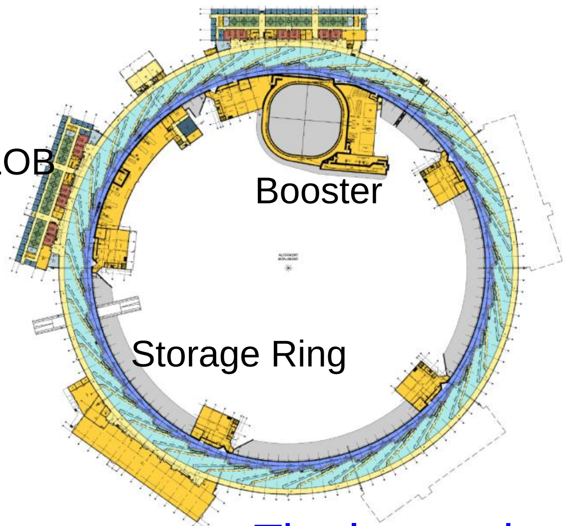
1st Girder Assembly

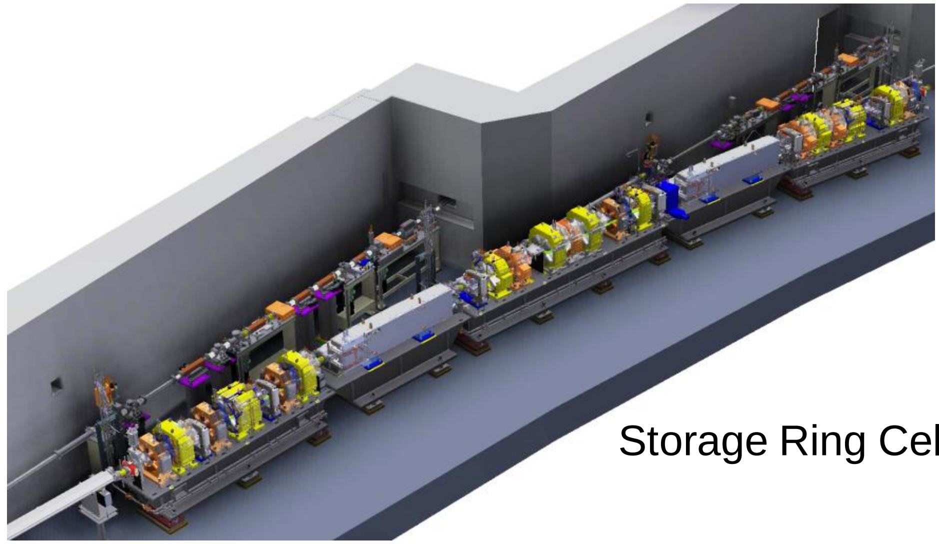
Outline

- Introduction
- NSLS-II magnet support system design
- Alignment
- Stability (vibration and thermal)
- Conclusions

Introduction







- **Energy: 3 GeV**
- **Circumference: 792 m**
- **Lattice: 30 DBA Cells (15 Super periods)**
- **Low Emittance: 2 nm-rad without damping wigglers**
- **0.6 nm-rad with damping wigglers (56 m)**

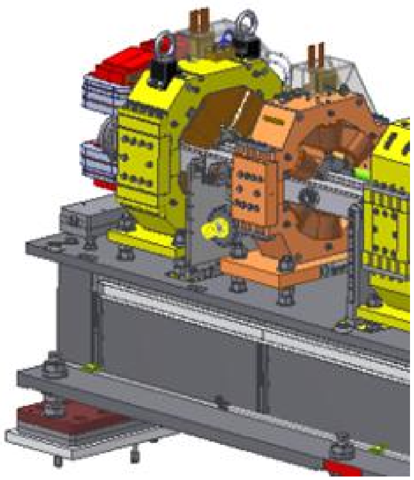
The low-emittance lattice has stringent alignment and stability requirements. An optimum support design requires a compromise between different design features.

Support System Alignment Requirements

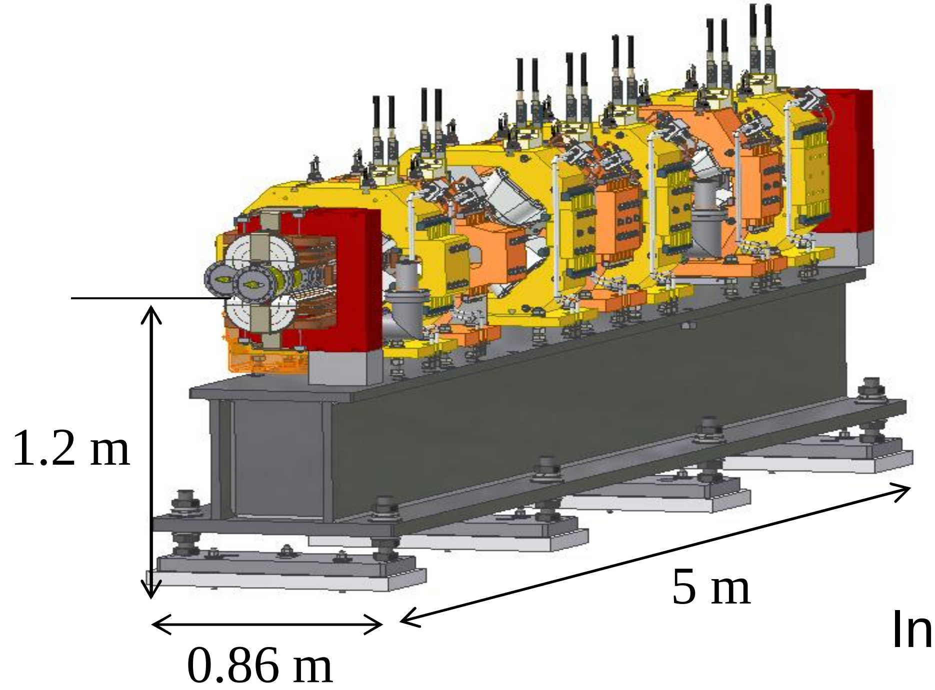
Alignment Requirements	ΔX RMS (μm)	ΔY RMS (μm)	Roll (mrad)
Magnet-to-Magnet Alignment	< 30	< 30	< 0.2
Girder-to-Girder Alignment	< 100	< 100	< 0.2

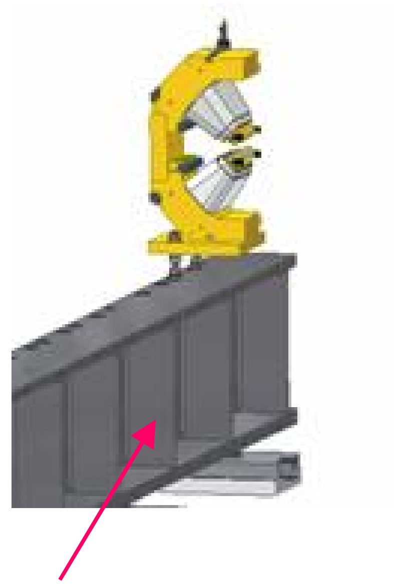
The transverse alignment requirements are difficult to meet due to:

- Stack-up of measurement and mechanical tolerances.
- Alignment needs to performed in a temperature controlled environment.
- Gravity deflection (~ 120 εm) of the girder has a scatter of ~ 15 εm.

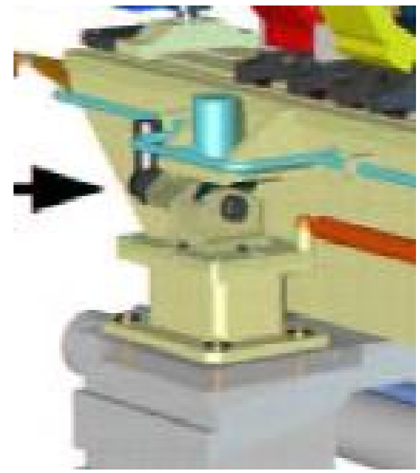


Design Considerations





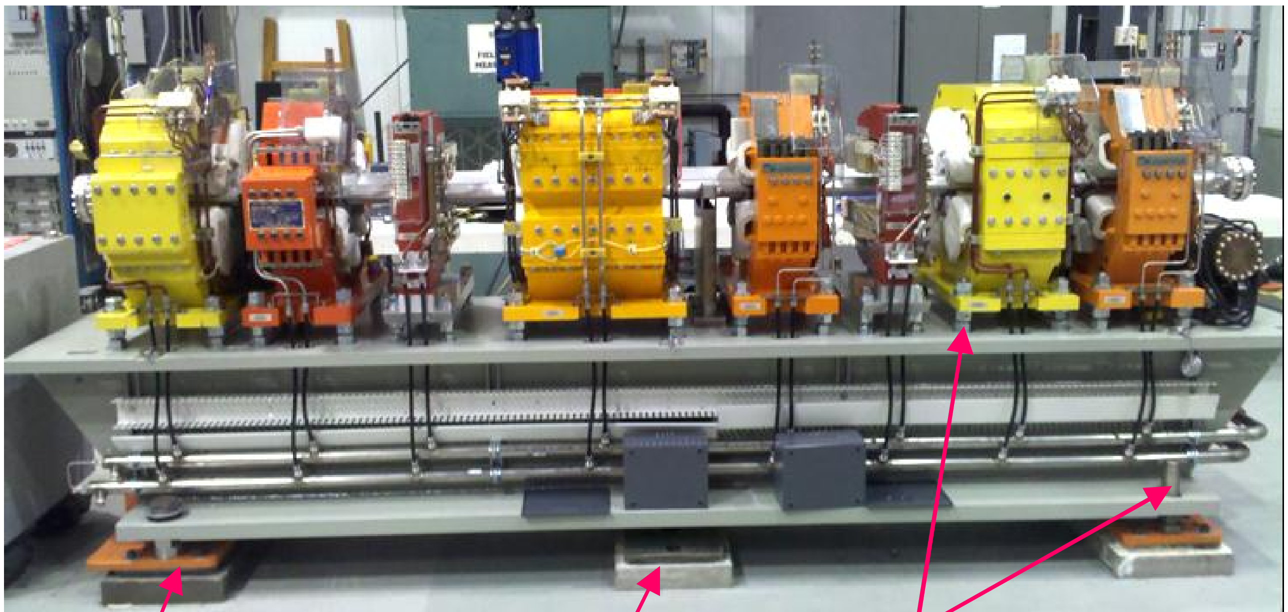
Internal Ribs



Cam Movers

- Stiff welded structures ï weld distortions and stress relaxation.
- Machined top surface for alignment ï gravity deflection, stress relaxation.
- Cam movers for alignmentï unpredictable vibration and thermal stability.
- Multiple supports for vibration stability ï thermal stability is compromised.

NSLS-II Support System Design

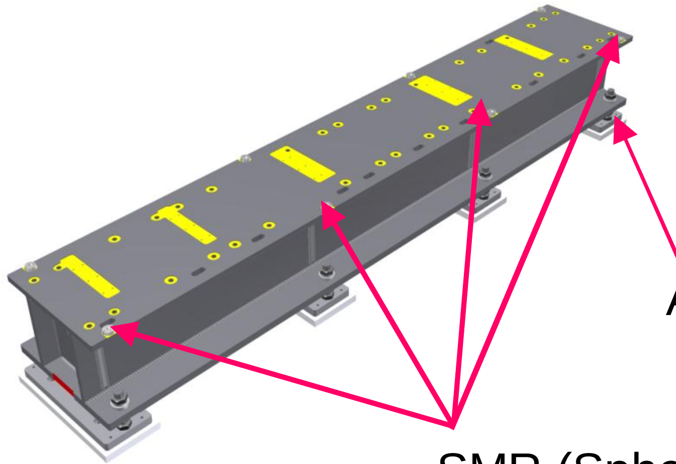


Viscoelastic Pad   Fixed Support   Alignment Studs

Unique Features:

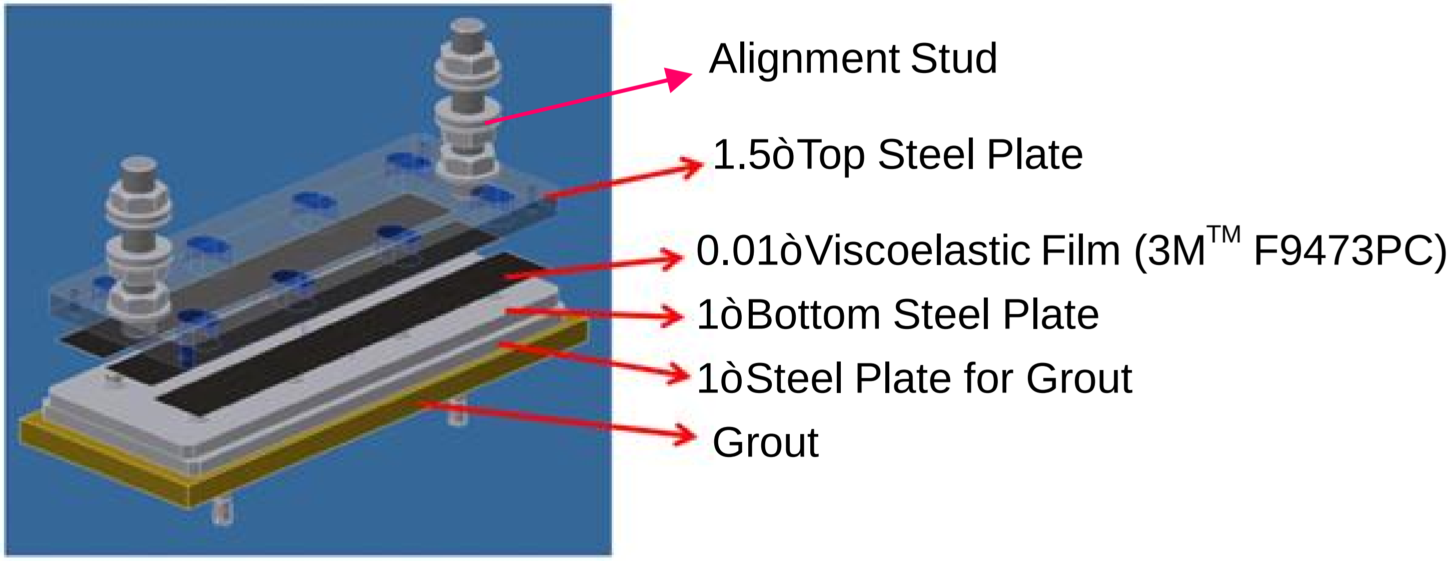
1. Girder profiling for alignment
2. Viscoelastic pads for thermal stability

Girder Profiling



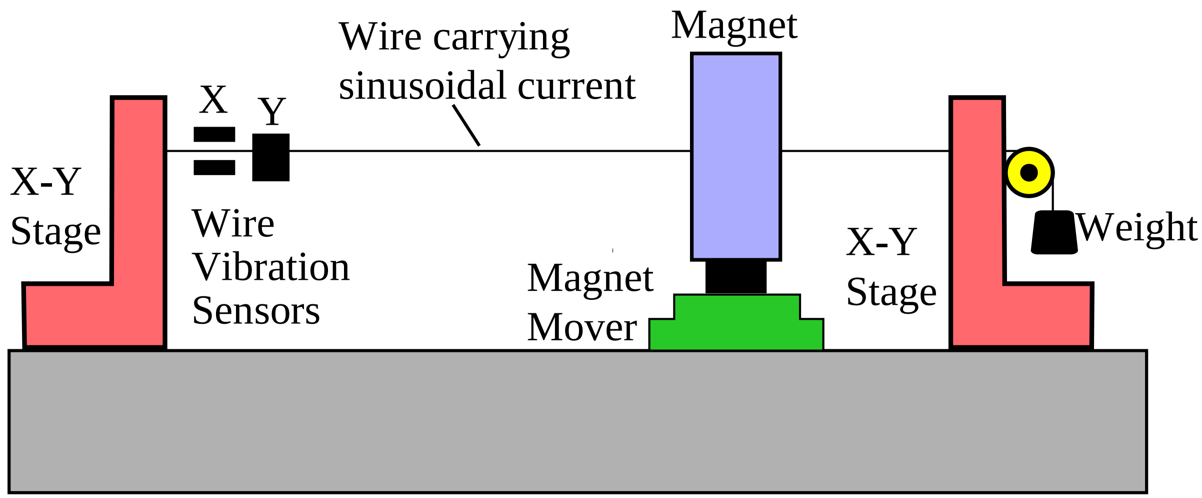
- Girder profiling assumes that the girder would sag and deform during transportation and storage.
- SMR cups are welded on the top surface of the girder.
- The girder is surveyed (profiled) with laser trackers.
- After transportation to the tunnel the girder profile is re-established using alignment studs.

Viscoelastic Pads



The viscoelastic film allows top plate to move relative to the bottom plate freely at slow cycles (< 0.1 Hz). The girder can expand or contract without bending.

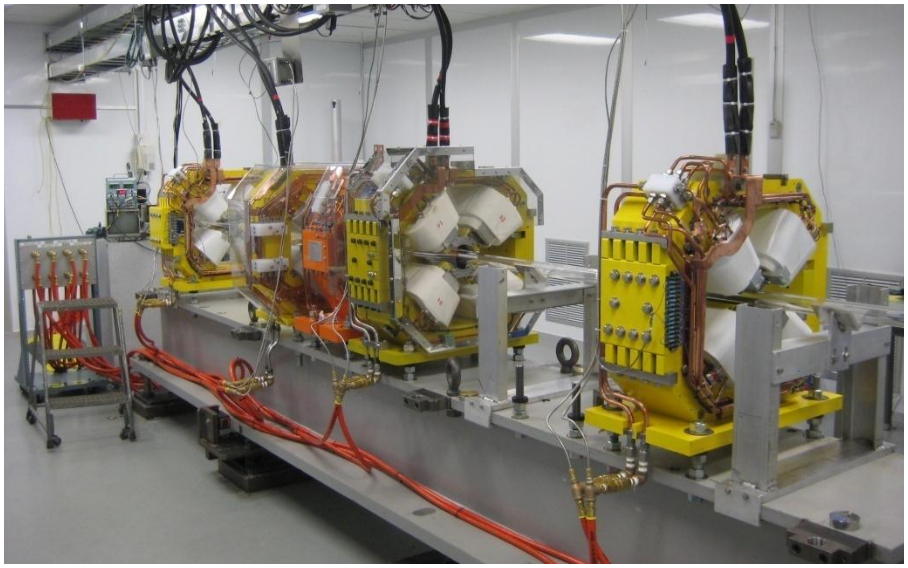
The Vibrating Wire Technique



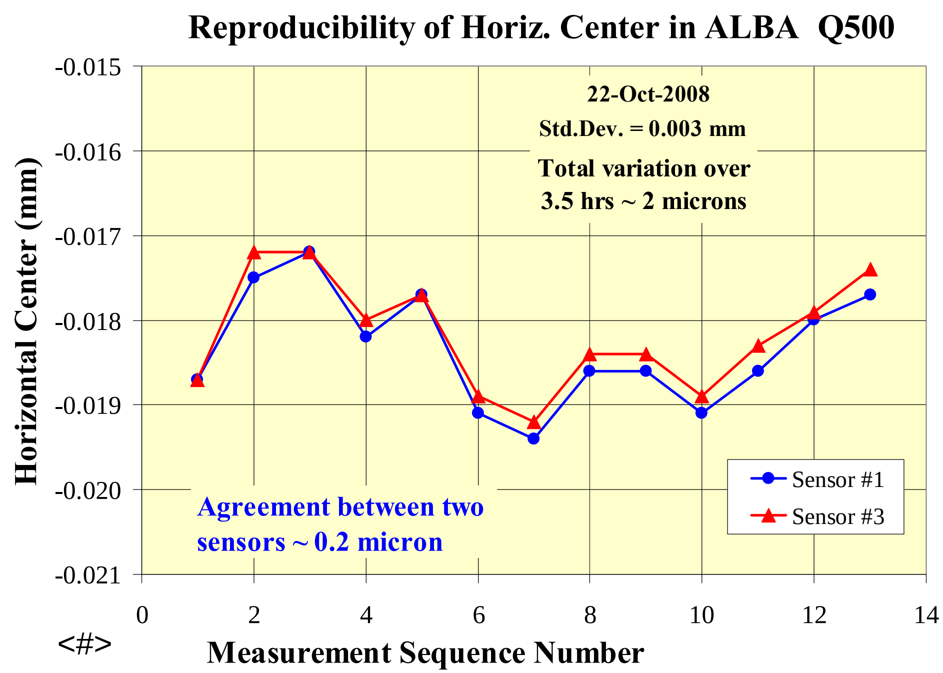
A. Jain
LER2010

- An AC current is passed through a wire stretched axially in the magnet.
- Any transverse field at the wire location exerts a periodic force on the wire, thus exciting vibrations.
- The vibrations are enhanced if the driving frequency is close to one of the resonant frequencies, giving high sensitivity.
- The vibration amplitudes are studied as a function of wire offset to determine the transverse field profile, from which the magnetic axis can be derived.

Magnet Alignment



Temperature-Controlled Alignment Room (± 0.05 °C)



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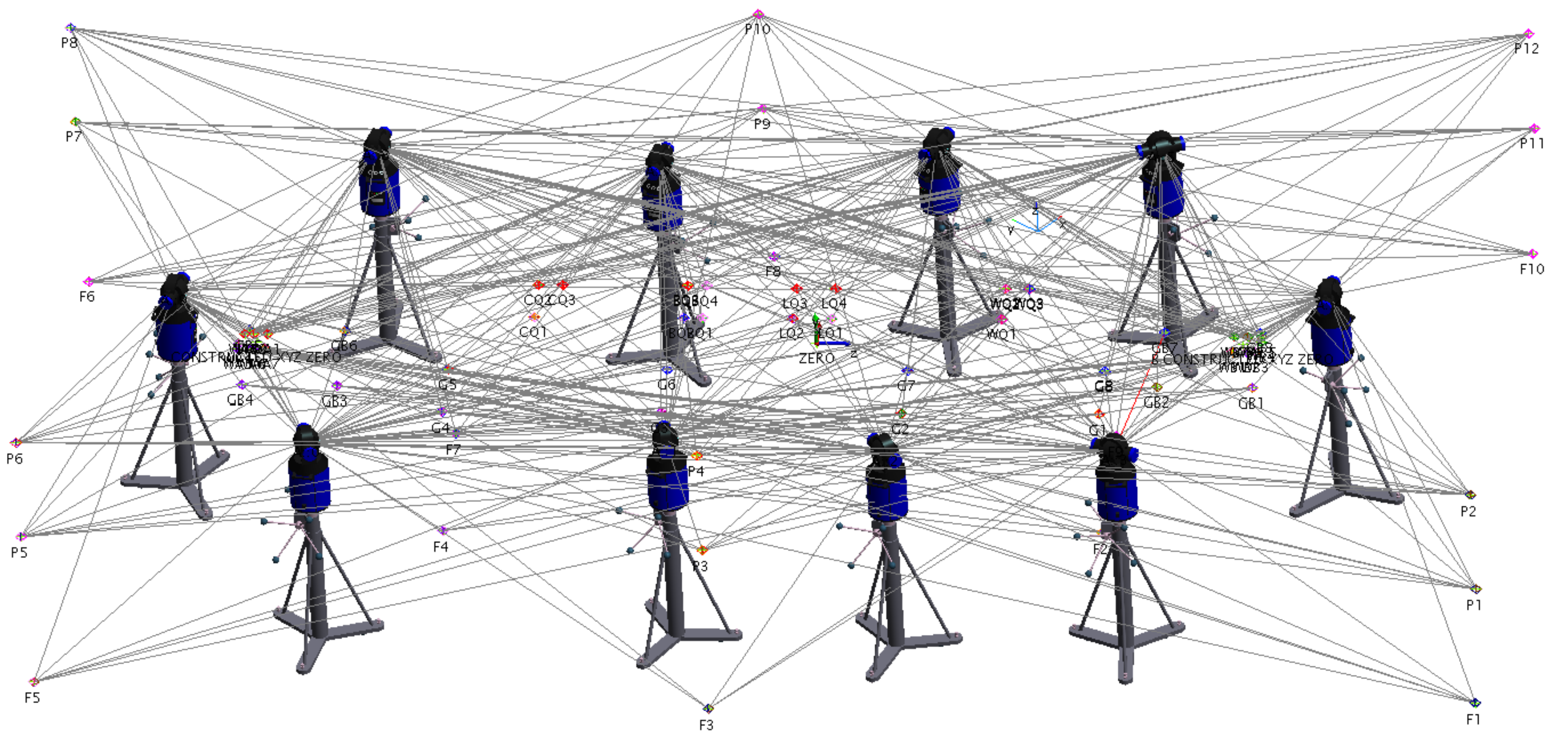
Å Multipoles on a girder can be aligned to within 5 εm.

S. Sharma
March 31, 2011

Aligned Reference File

10 Laser Tracker positions record all girder and magnet fiducials.



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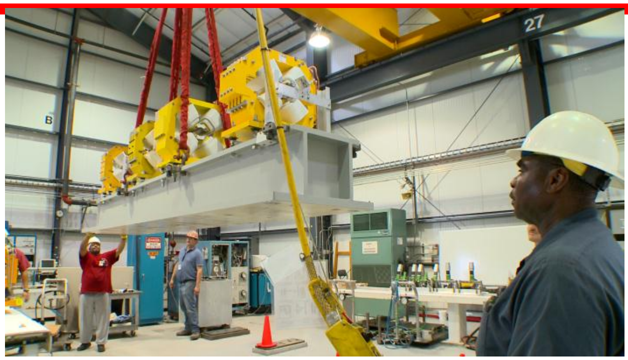
March 31, 2011

Girder Transport Test



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March 31, 2011

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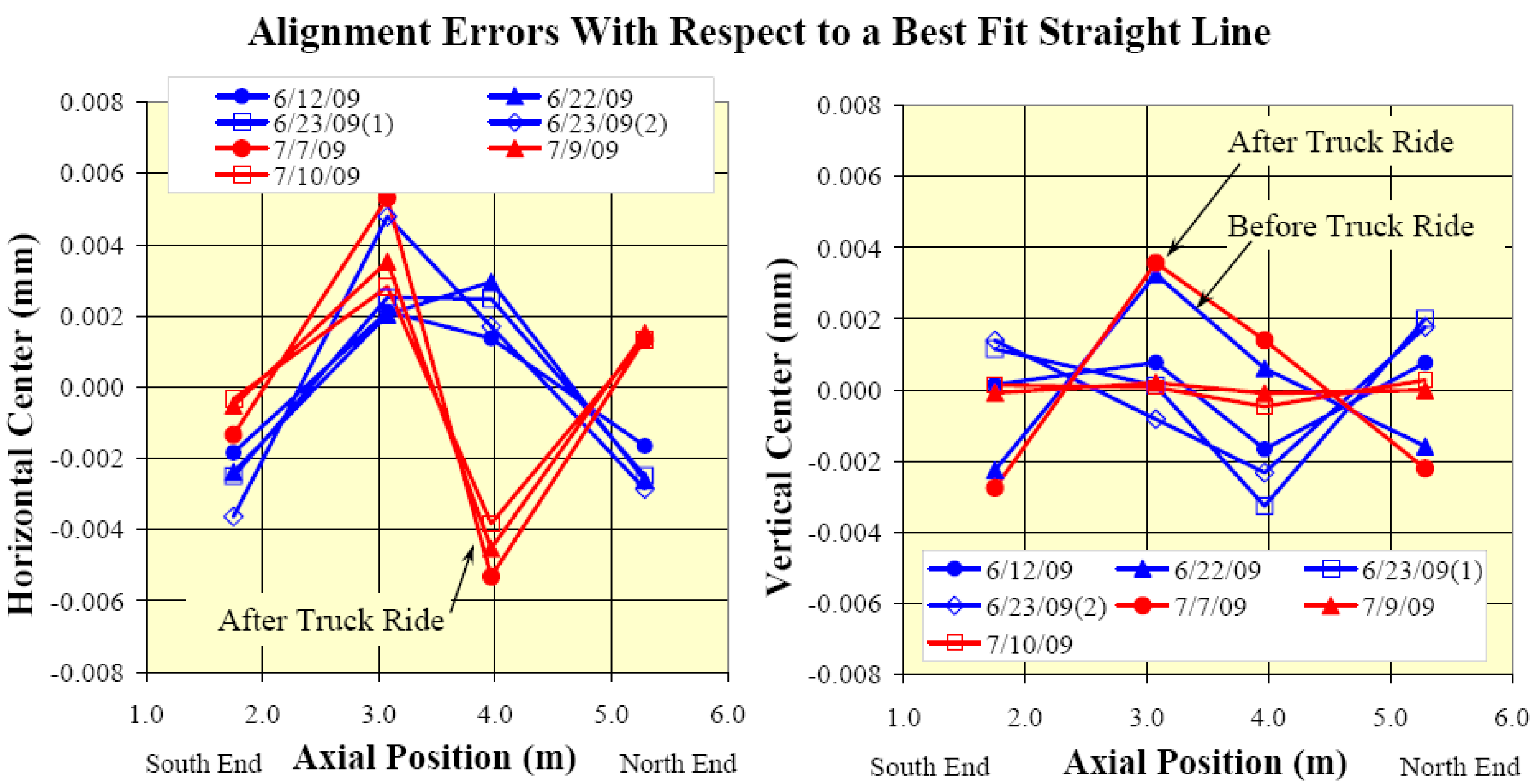
Verification of the Alignment and Profiling Techniques

- Truck Test (Summer 2009)
  - Prototype magnets mounted on a girder and measured, then the girder assembly was removed, driven around, and finally placed back, reprofiled and remeasured.



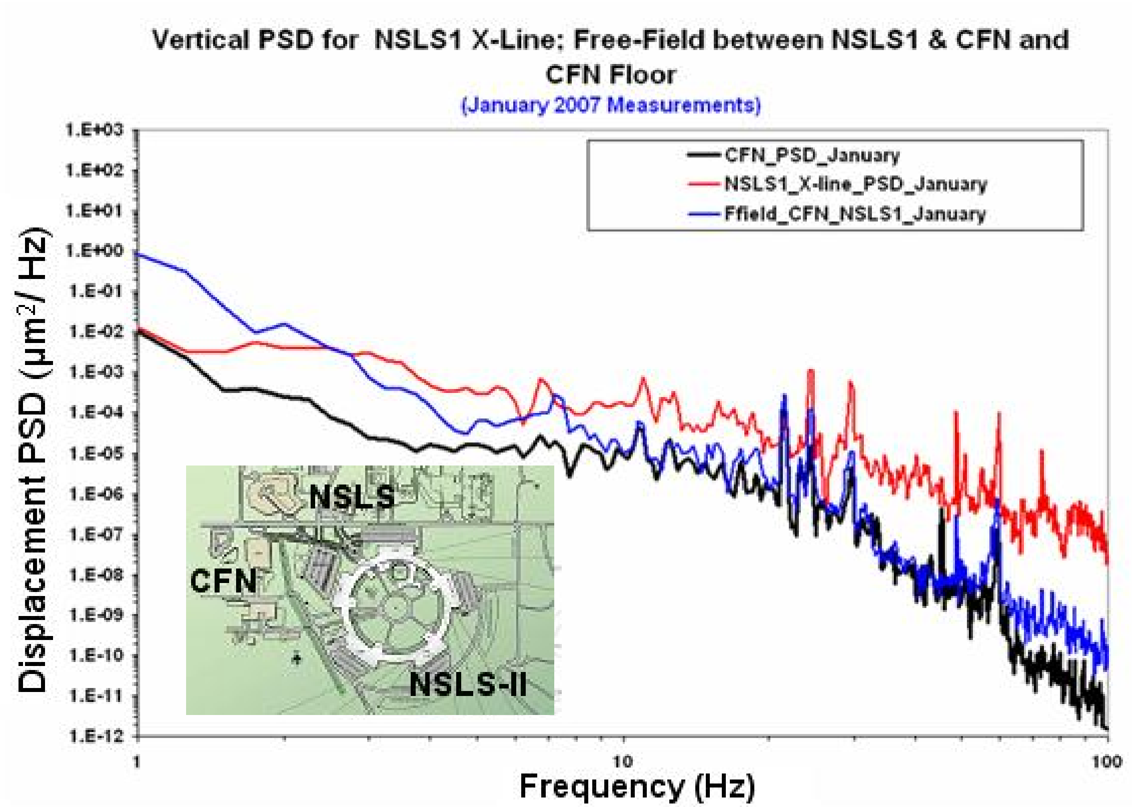
Jain, A. Dec. 1, 2009. Survey and Alignment Review, "Magnet Alignment on a Girder"

Stability Requirements

Stability Requirements (Vibration and Thermal)

Requirements	ΔX RMS (nm)	ΔY RMS (nm)
Magnets (uncorrelated)	< 150	< 25
Girders (uncorrelated)	< 600	< 70

Ambient Ground Motion



RMS Displacements at CFN *(N. Simos)*

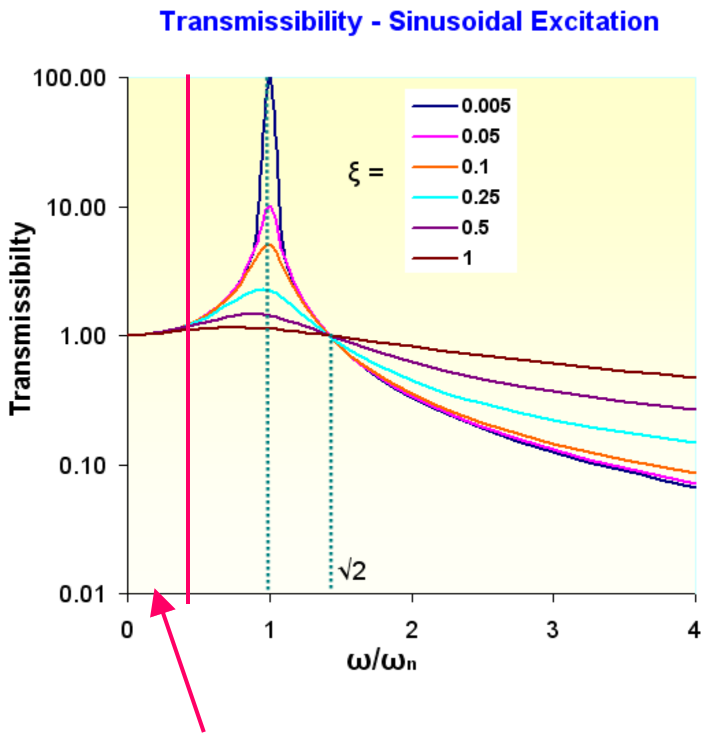
(0.5 - 4) Hz : 145 nm (correlated)

(4 - 30) Hz : 14 nm

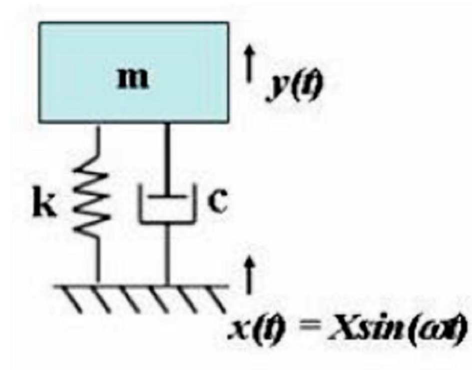
(30 - 100) Hz : 1 nm

The ambient floor motion below 4 Hz far exceeds 25 nm (rms). However, this motion is expected to be correlated due to long wavelengths of the shear waves at low frequencies.

Support System Design Approach



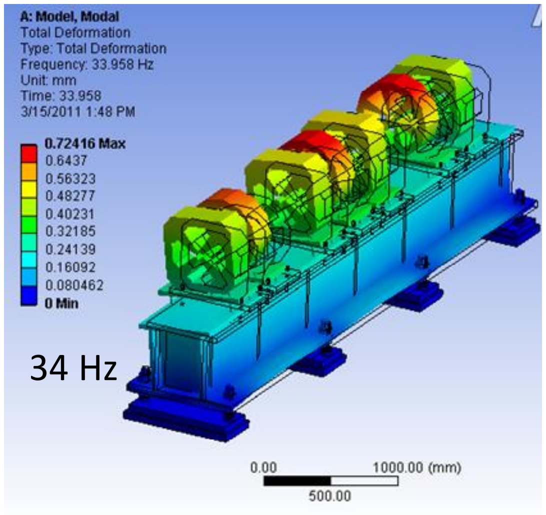
Stiff System

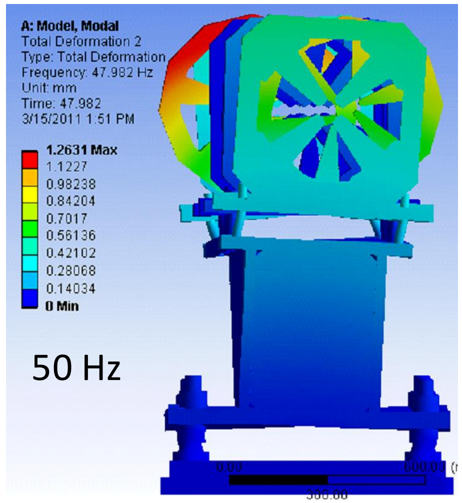


$$\omega_n = \sqrt{k/m}$$

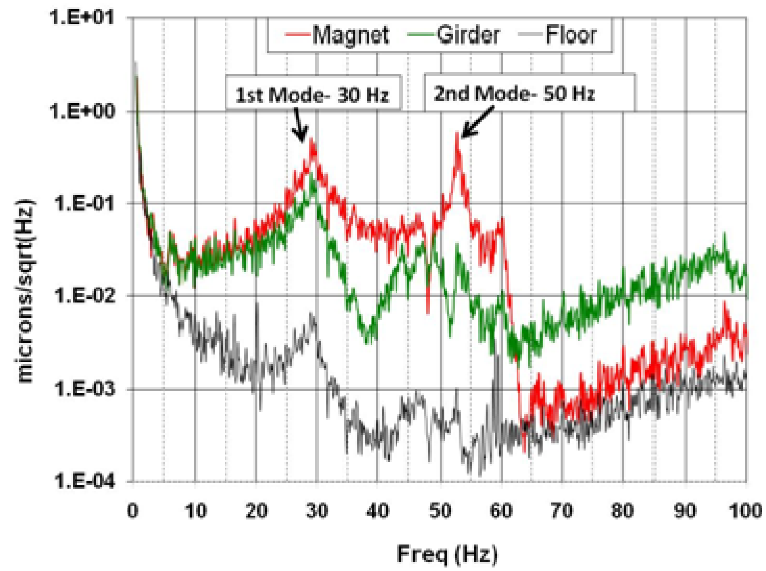
Support System Design Approach: resonant frequency >> 30 Hz → the rms motion that will be amplified by the girder-magnet assembly is only ~ 1 nm.

Natural Frequencies and Mode Shapes





Modal Analysis

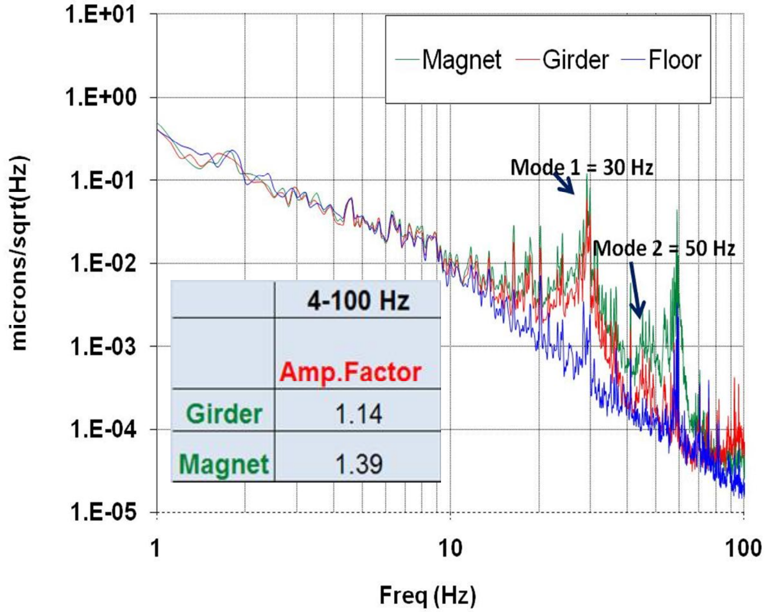


Test Data

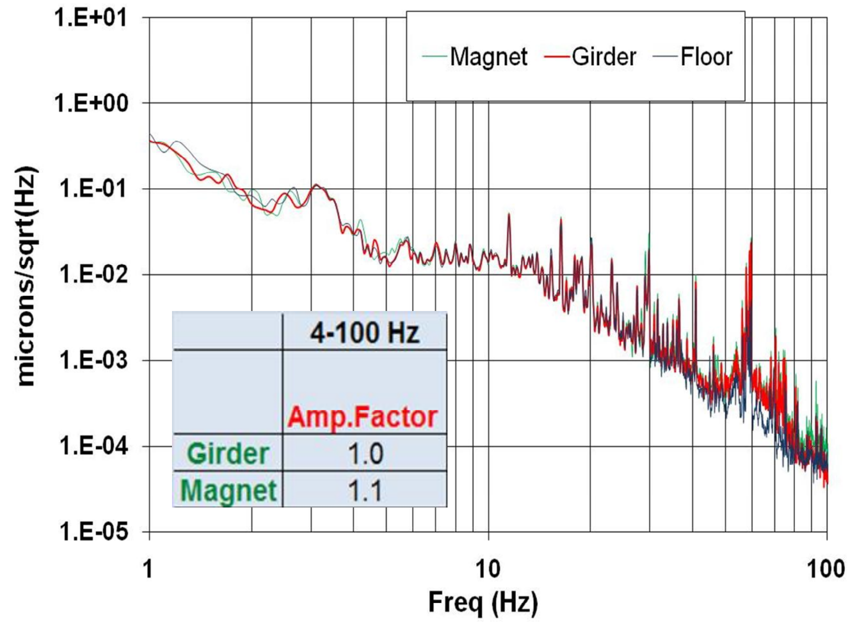
- 1st natural frequency, ~ 30 Hz, corresponds to a rocking mode (magnets move in phase).

- 2nd natural frequency, ~ 50 Hz, is a torsional mode that causes magnets' misalignment.

Vibration Amplification



Horizontal Motion

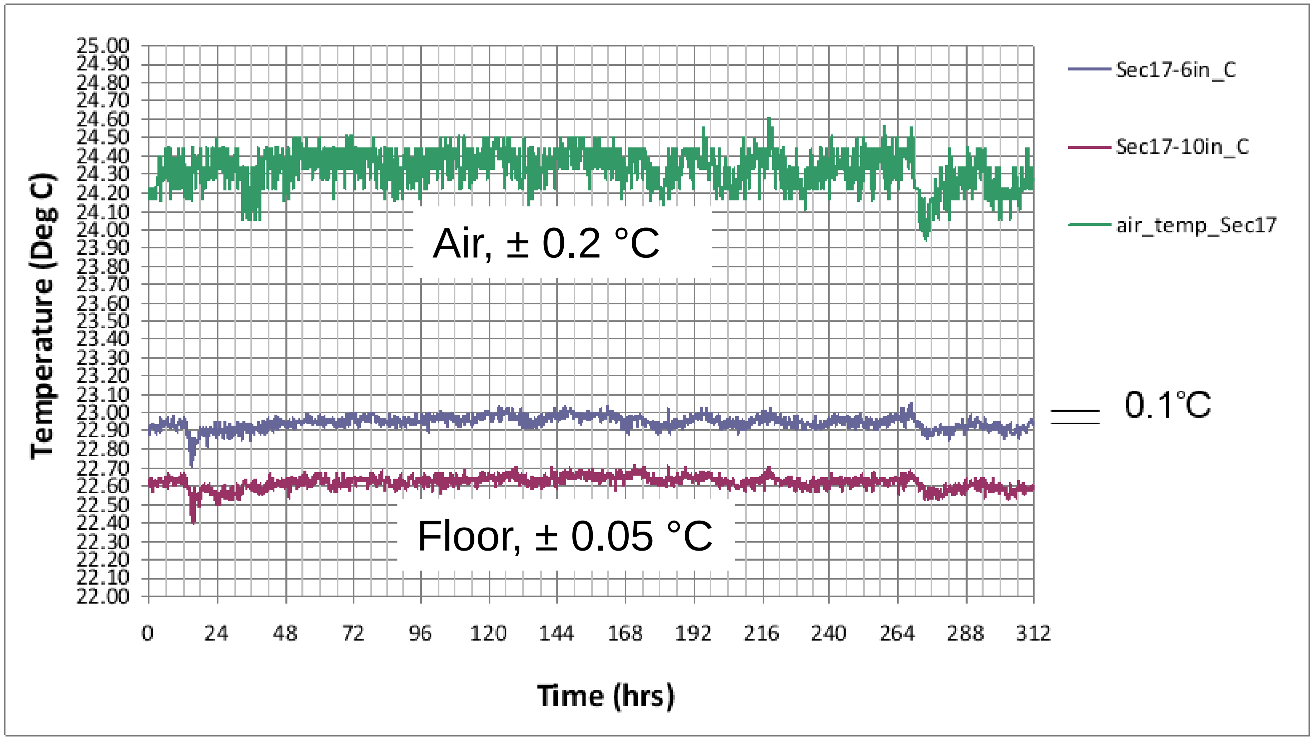


Vertical Motion

- The amplification factor in the horizontal direction is 1.4 → magnet motion of about 20 nm (rms) << 150 nm (specification).

- In the vertical direction the amplification is only 1.1 → magnet motion of ~16 nm < 25 nm (specification).

Thermal Stability

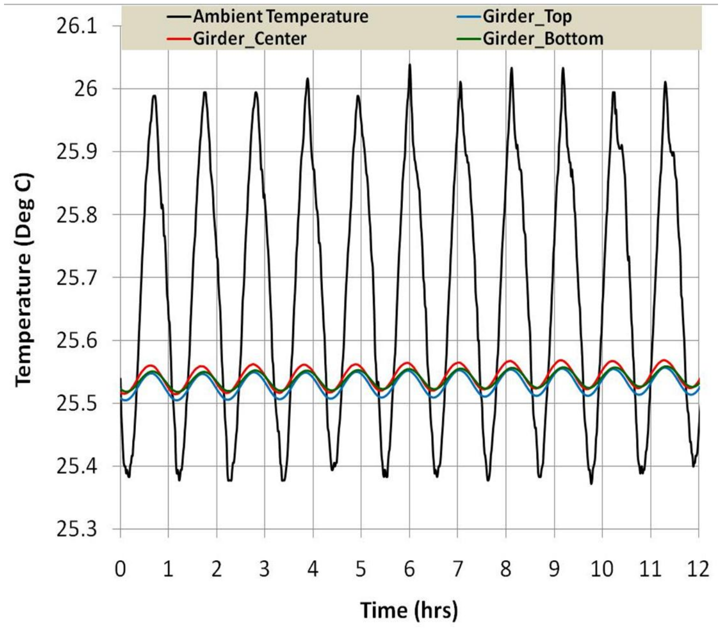


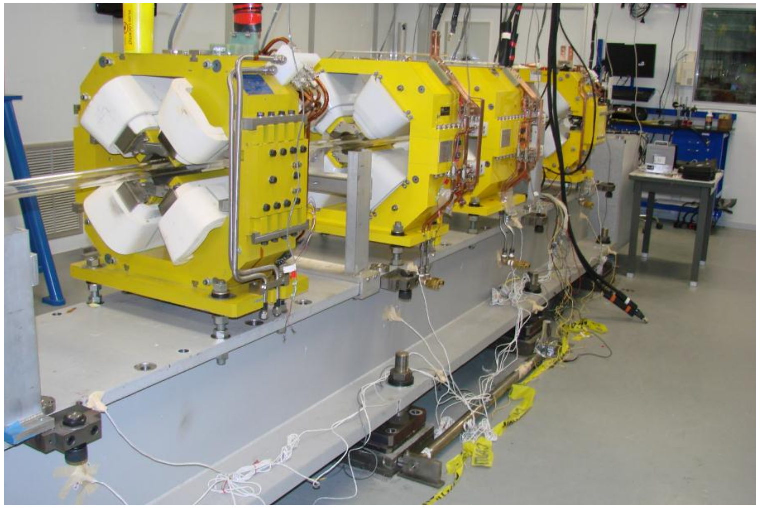
APS, Sector 17
August 2009

Thermal stability of the support system is impacted by:

- Tunnel air temperature change (± 0.1 °C, specification).
- Floor expansion and contraction.

Tunnel Air Temperature Fluctuations

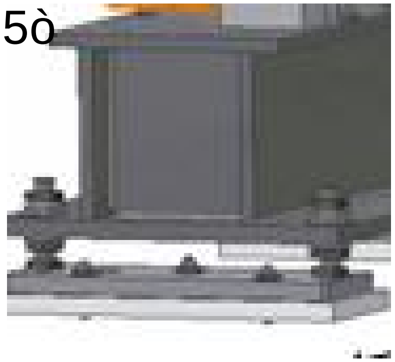




Temperature-Controlled Experiments

- The tunnel air temperature specification is ± 0.1 °C with 1 hour cycle.
- Because of thermal inertia, the girder experiences only ± 0.01 °C temperature cycles.
- The temperature-gradient fluctuations are negligible.

1.5ò



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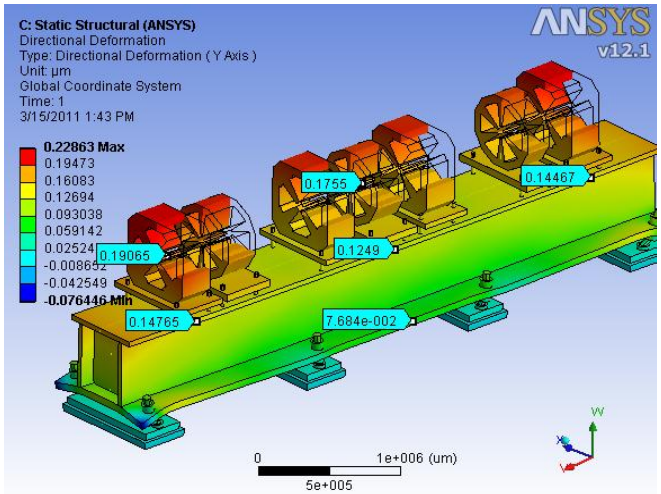
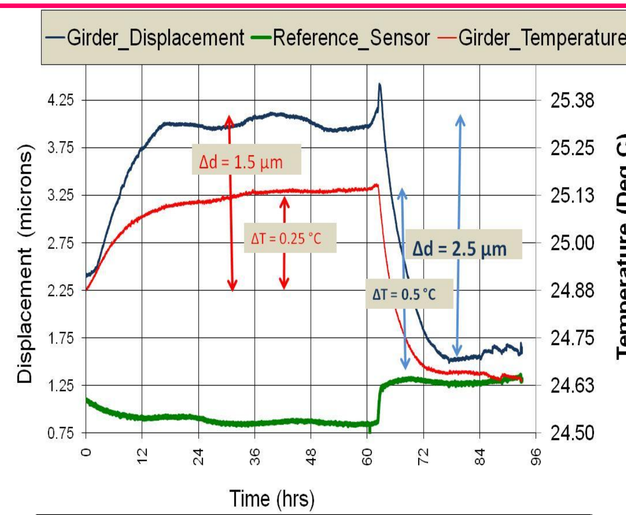
Experimental Verification of FEA Model- Fixed Supports

FEA Results Showing Vertical Displacement	Measured Girder Vertical Displacement on the Bottom Plate



- Absolute vertical displacement on the bottom plate = 77 nm

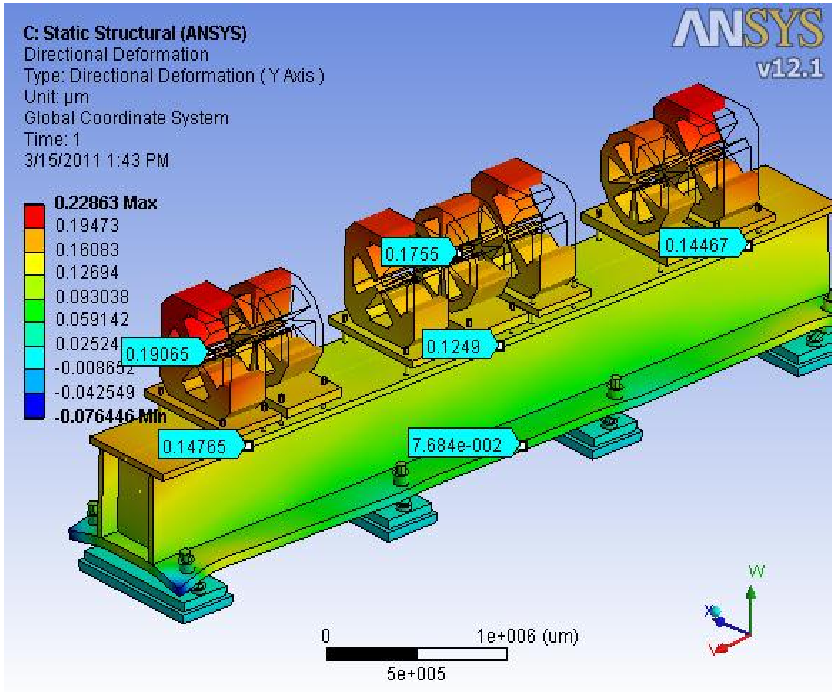


1. Girder motion: ~6 µm/°C
2. Sensor holder motion: ~ 1 µm/°C
3. Total absolute displacement: 7 µm/°C

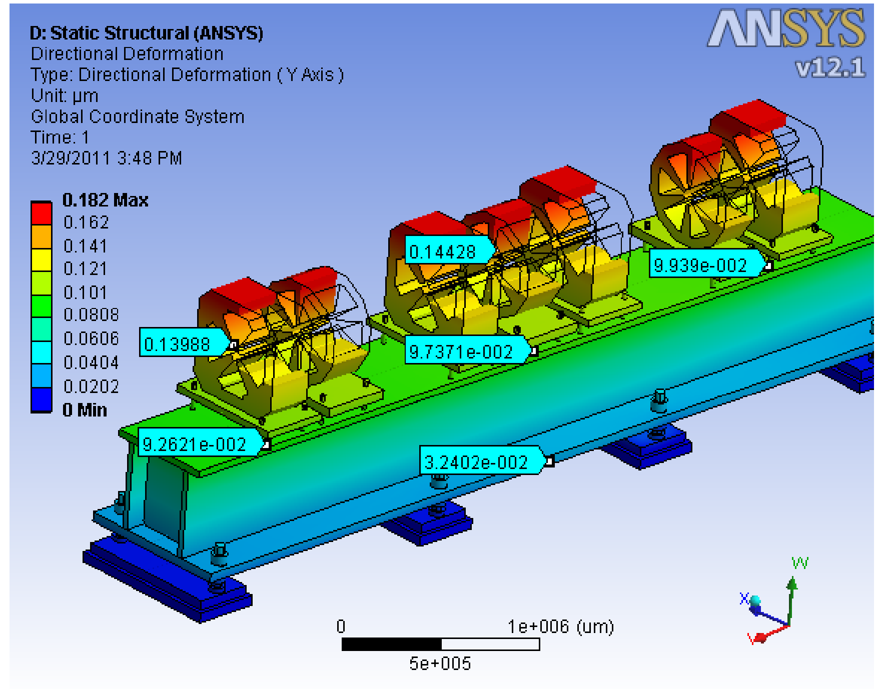
For a ΔT_{Girder} ~ 0.01 °C, absolute displacement = 70 nm

- The measured absolute vertical displacement of 60-70 nm for a girder temperature change of 0.01 °C is consistent with the FEA results.
- Magnet misalignment is 15 nm with fixed supports.

Air Temperature Fluctuations ï Fixed Supports versus Viscoelastic Pads



Fixed Supports

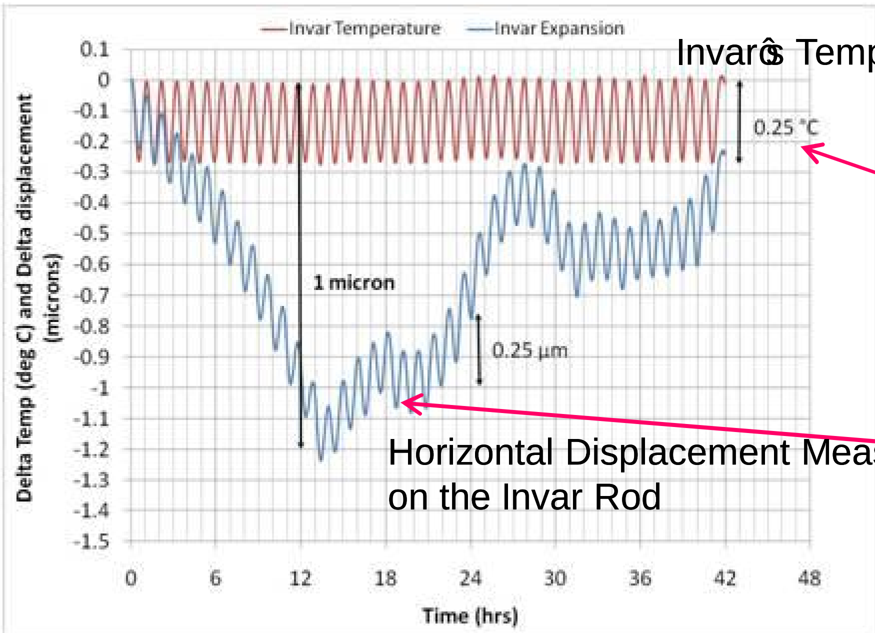


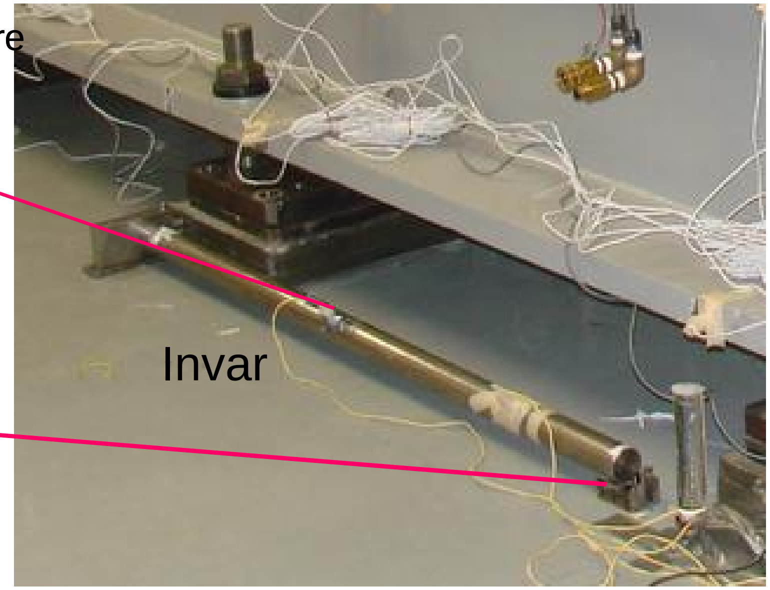
Viscoelastic Pads

Å Thermal bending of the girder is reduced substantially with the viscoelastic pads.

Å Magnetsômisalignment is reduced from 15 nm to 4 nm.

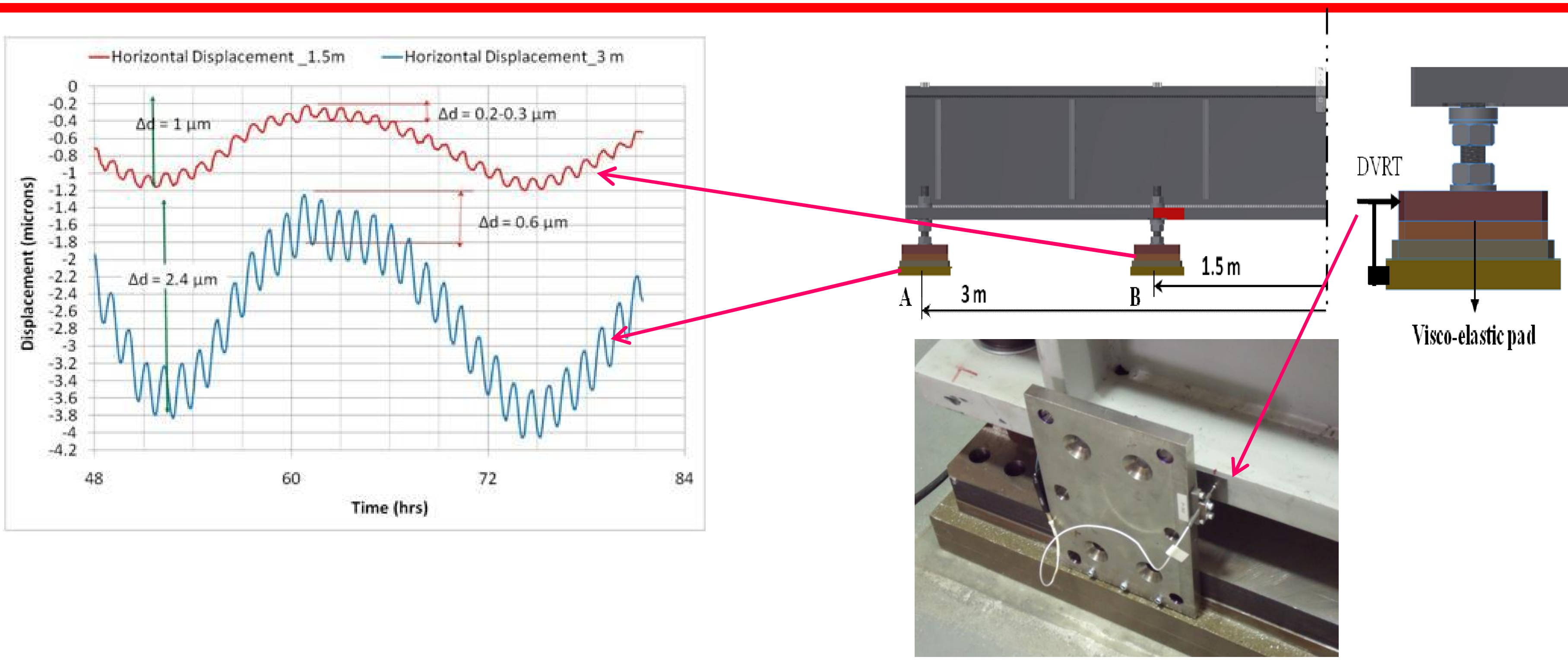
Floor Expansion and Contraction





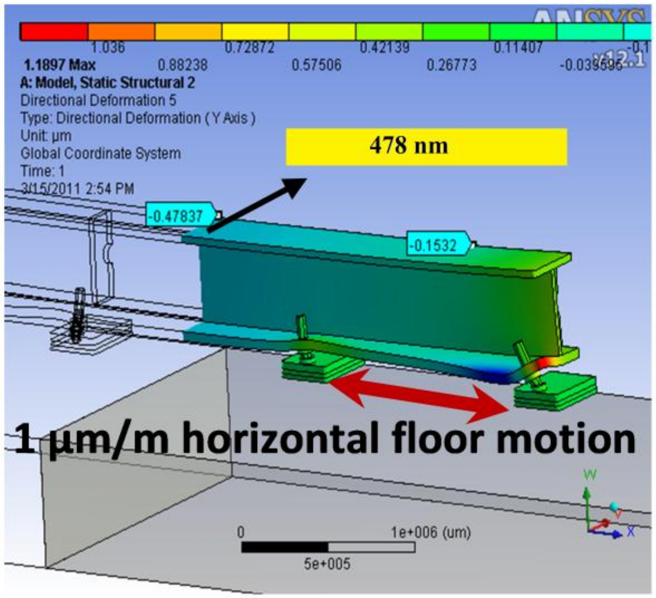
- Floor expansion is tracked by a Microstrain™ displacement sensor attached to an Invar rod.
- Floor expands/contracts about ~1 εm/m over 24 hour (diurnal).

Girder Expansion

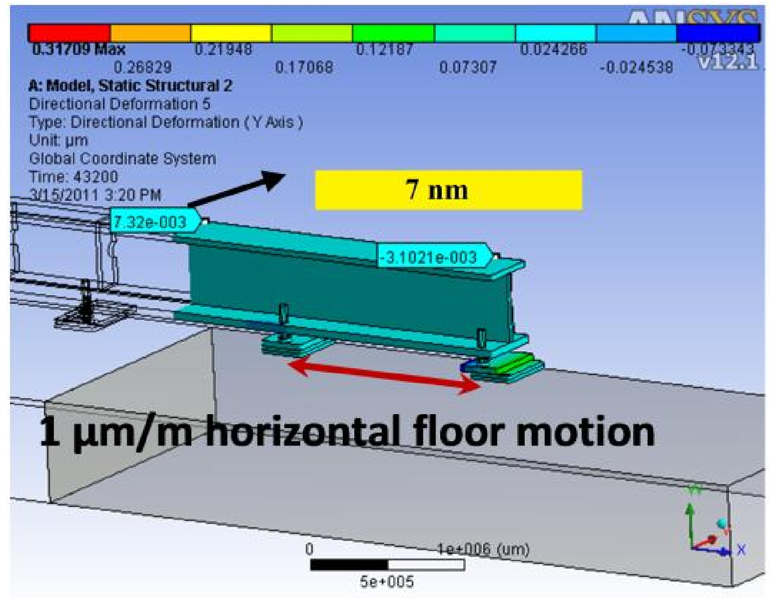


- The girder horizontal expansion is measured relative to the grouted plate for a temperature change of 0.25 ºC with 1 hr time cycle.
- The viscoelastic pads allow relative motion between the girder and the floor.

Floor Expansion ï Fixed Supports versus Viscoelastic Pads



Fixed Supports



Viscoelastic Pads

Å In some light-source facilities, diurnal floor expansion/contraction of ~ 1εm/m has been observed.

Å Bending deformations in the girder are up to 478 nm with the fixed supports, but only 7 nm with the viscoelastic pads.

Conclusions

- The NSLS-II support system was optimized to meet the diverse requirements of magnet alignment (± 30 ε) and magnet stability (25 nm).

- The important features of the support system designs are: girder profiling, multiple support points, viscoelastic pads and vibrating wire alignment technique.

- Extensive analyses and tests were performed to verify the performance of the support system.

Thank You