Girder Design and Site Vibration Studies for SPEAR-3

Domenico Dell'Orco
SLAC/SSRL

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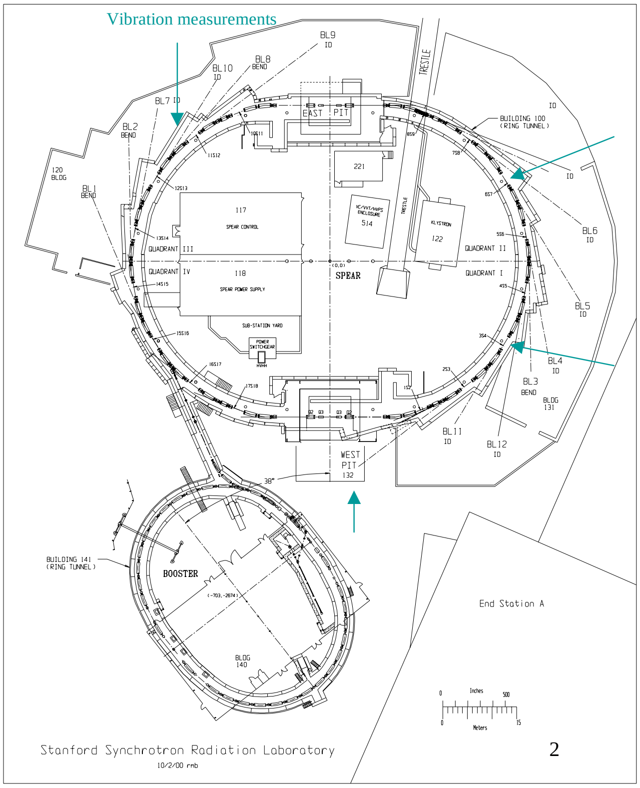
22nd Advanced ICFA Beam Dynamics Workshop on Ground Motion in Future Accelerators

November 6-9, 2000

SPEAR 3 Upgrade

- Project Goals
  - Decrease beam emittance from 160 to 18 nm-rad
  - Increase max. stored beam current from 100 to 500 mA
  - Increase injection energy from 2.3 to 3 GeV
  - Maintain long beam lifetimes (> 20 hours)
- Requirements
  - New lattice with new magnets, power supplies, vacuum system, RF system, cabling, instrumentation and controls, and shielding modifications

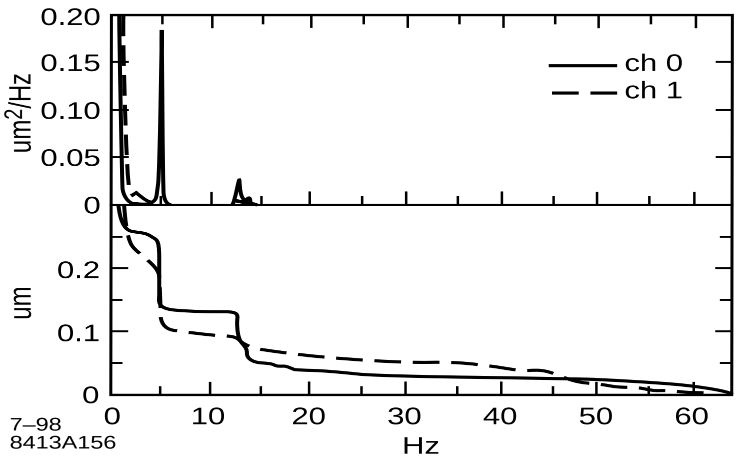


from T. Elioff - Lehman Review- June 13, 2000

SPEAR 2 Girders

- Vibration Modes in SPEAR2 girders
  - Ground vibrations amplified by girder = 0.04 µm rms
  - Vertical motion at dipoles = .25 µm rms (6X)
  - Horizontal motion at dipoles = .75 µm rms (19X)
- Goal: increase natural frequency to ~20 Hz

Global amplification



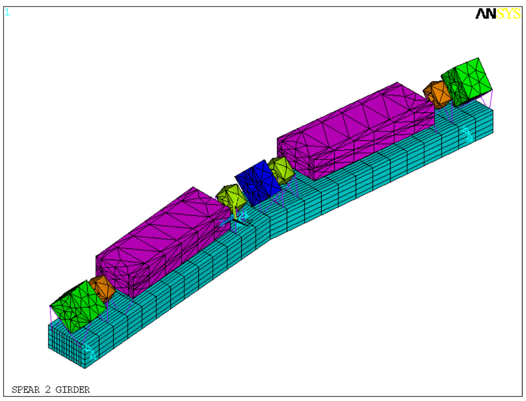
G. Bowden at Spear2

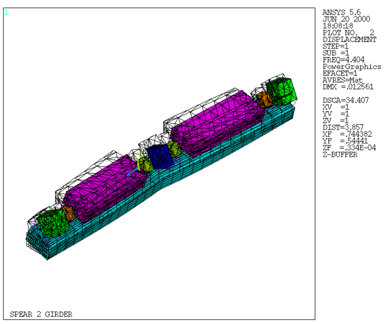
3

SPEAR 2 Girder vibration modes

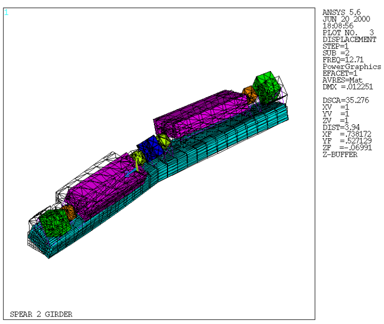
with flexible supports, computed with ANSYS

Rebars + stirrups+
concrete + magnets

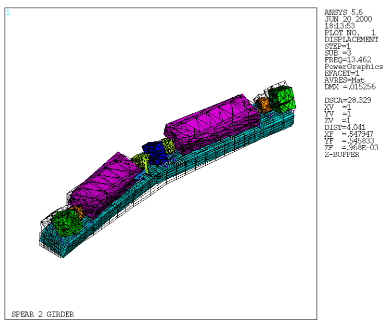




Mode 1: 4.4 Hz



Mode 2: 12.7 Hz



Mode 3: 13.46 Hz

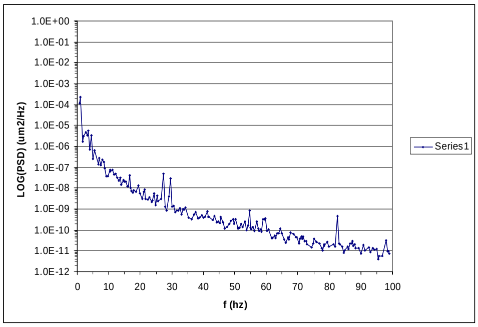
4

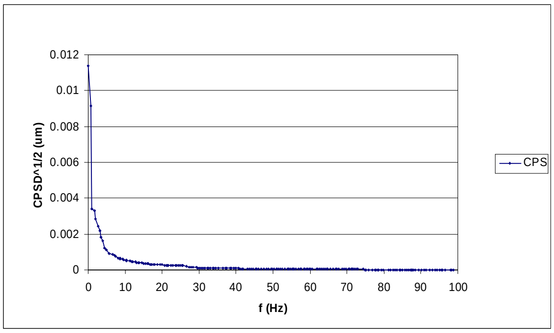
Ground motion spectrum and girder natural frequency

Design guideline: increase natural frequency to ~20 Hz   Why?

f_{ground}	5	5	5	5	5
f_{girder}	5	12	20	30	35
f_{ground}/f_{gird}	1	0.42	0.25	0.17	0.14
ξ/ξ_c	0.02	0.02	0.02	0.02	0.02
A	25.02	1.21	1.07	1.03	1.02

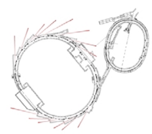
f_{ground}	12	12	12	12	12
f_{girder}	5	12	20	30	35
f_{ground}/f_{gird}	2.4	1	0.6	0.40	0.34
ξ/ξ_c	0.02	0.02	0.02	0.02	0.02
A	0.21	25.02	1.56	1.19	1.13



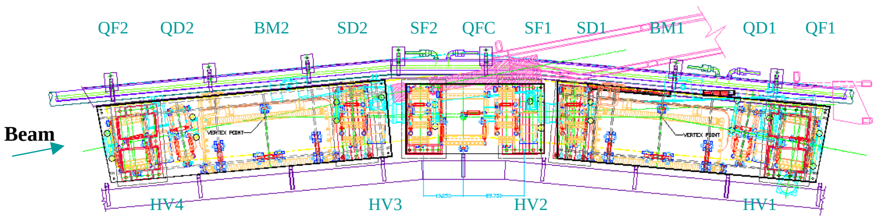


Measured at SPEAR in 1982 by Jendrzejczyk, Smith, Wambsganss, Zhu

SPEAR 3 Magnet supports

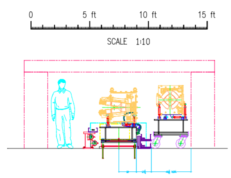


14 Standard cell girders (BM1, BM2, QFC)

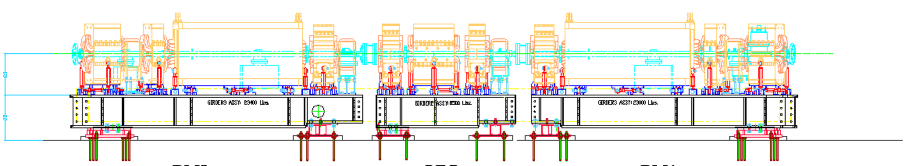


STANDARD CELL PLAN VIEW
LCW PIPING & CABLE TRAYS

6/6/00
SCALE 1:10



ILLUSTRATIVE SECTION
LCW PIPING & CABLE TRAYS



STANDARD CELL WALKWAY ELEVATION

All magnets are mounted on struts

SPEAR 3 steel girders with beam at 0.508 m (20") from top surface. Concrete floor.

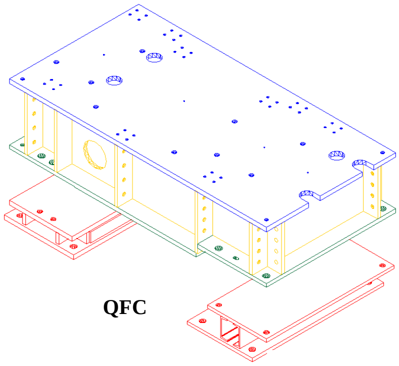
SPEAR 3 Magnet supports

Thermal expansion at flexible joint:
12. µm/m/C * 3m * 30 C = 1mm

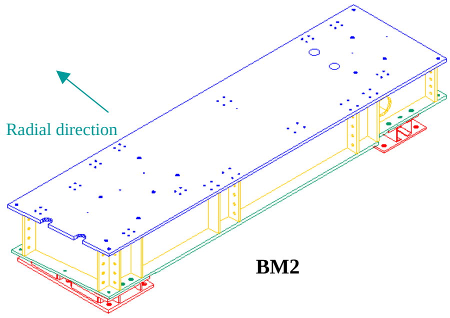
1" thick top/bottom plates
3/4 thick all other plates

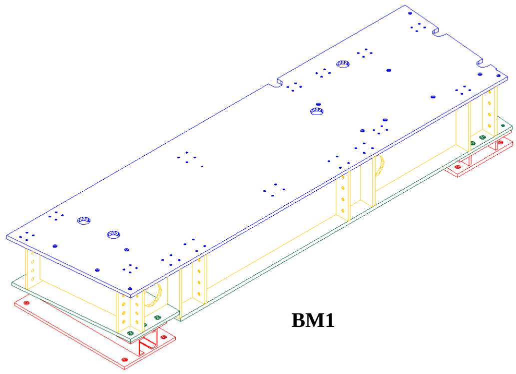
Welded and stress relieved structure

Concrete floor
fixed girders
adjustable magnets



Stiffeners to redistribute static loads and stiffen the girder in the radial direction (the welds can act like hinges especially for small deflections).

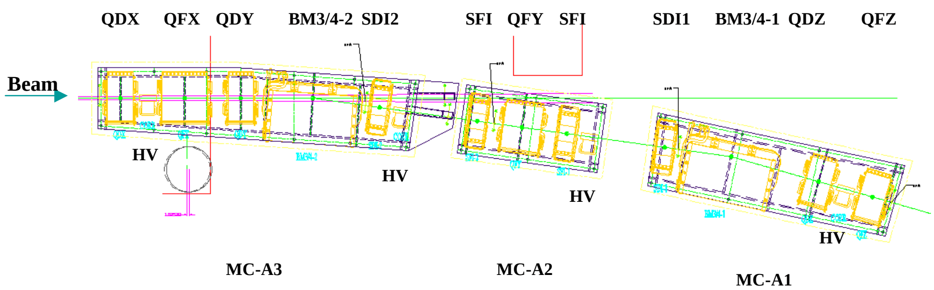




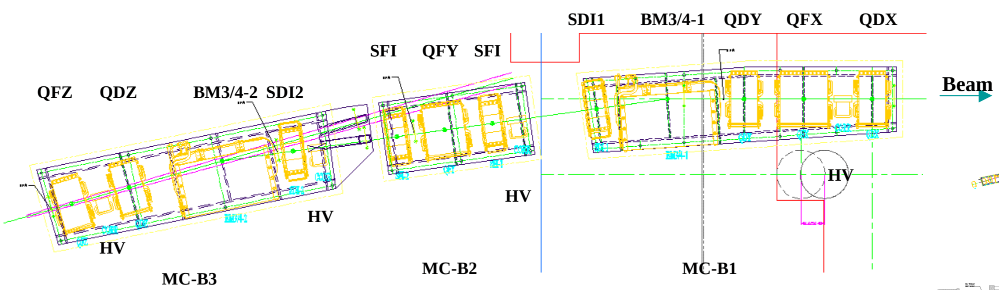
SPEAR 3 Magnet supports

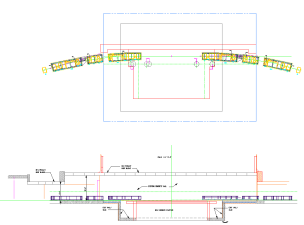
2 Matching cells A + 2 Matching cells B

Matching cell A



Matching cell B





SPEAR 3 Girders

	Qty	109D	145D	15Q	34Q	50Q	60Q	21S	25S	HV
BM1	14		1	1	1				1	1
QFC	14					1		2		1
BM2	14		1	1	1				1	2
MC-A1	2	1			2			1		1
MC-A2	2					1		2		1
MC-A3	2	1			2		1	1		2
MC-B1	2	1			2		1	1		1
MC-B2	2					1		2		1
MC-B3	2	1			2			1		2
Total		8	28	28	44	18	4	44	28	72
Mag. Weight (lb)		10581	13773	1003	2191	3193	3818	1041	1232	400

Girder	Length (in)	Width (in)	Height (in)	Girder weight (lb)	Magnet weight (lb)	Chamber weight (lb)	Total weight (lb)
BM1	133.5	38	16	4290	18600	1490	24400
QFC	67	34	16	2153	5700	750	8600
BM2	141	38	16	4531	19000	1570	25100
MC-A1	134	38.5	15	4306	16400	1500	22200
MC-A2	74	36	15	2378	5700	830	8900
MC-A3	190	37	15	6106	20600	2120	**28800**
MC-B1	155	37	15	4981	20200	1730	26900
MC-B2	73	36	15	2346	5700	810	8900
MC-B3	167	38.5	15	5367	16800	1860	24000

Matching cell A3 is longer and heavier than all the other girders => highest forces in the earthquake analysis and lowest vibration frequency

SPECIFICATION FOR SEISMIC DESIGN OF BUILDINGS, STRUCTURES, EQUIPMENT and SYSTEMS AT THE STANFORD LINEAR ACCELERATOR CENTER, August 5, 1999

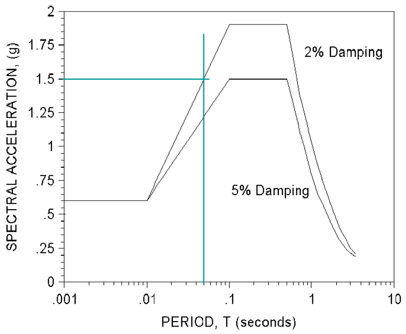


Figure 1. Response Spectra for Mechanical Systems
Horizontal Motions

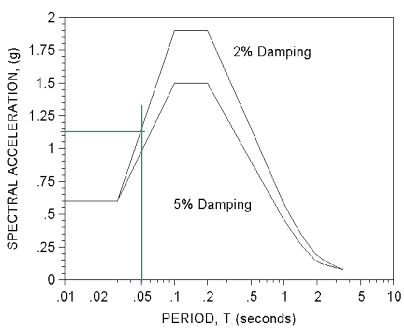


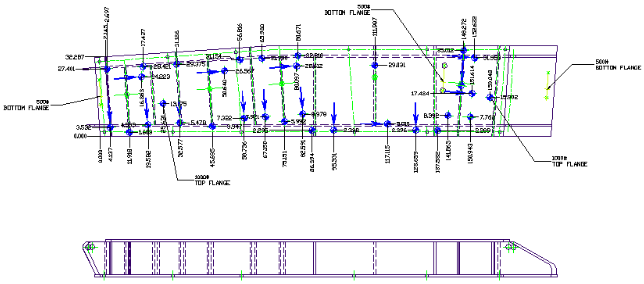
Figure 1. Response Spectra for Mechanical Systems
Vertical Motion

Horizontal acceleration: 1.5 g

Vertical acceleration: 1.15 g

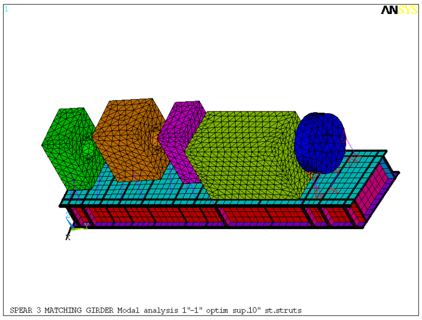
Assumption of 20 Hz natural frequency for girder/magnets system (verified later)

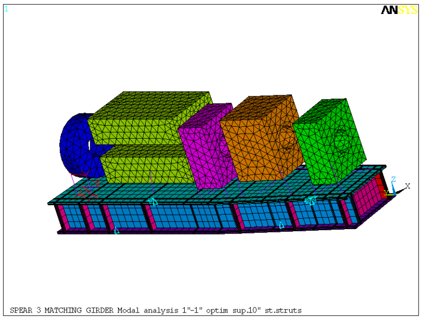
ANSYS model of MC-A3



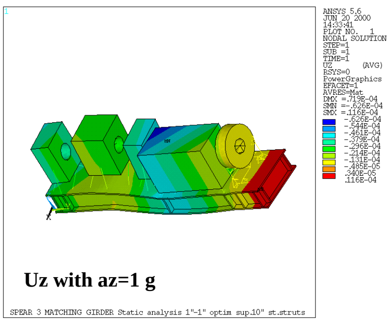
OLD version of MC-A3 used for the ANSYS model

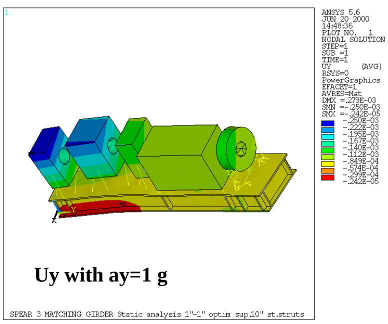
4 girder support points, realistic magnets, rigid struts

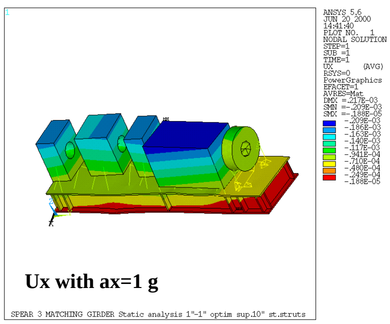




ANSYS static analysis of MC-A3







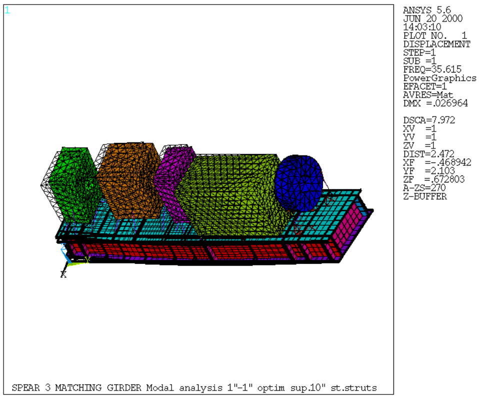
Dead weight only: Uz_{max}=0.07 mm
Dead weight + az=1.15 g: Uz_{max}=0.15 mm

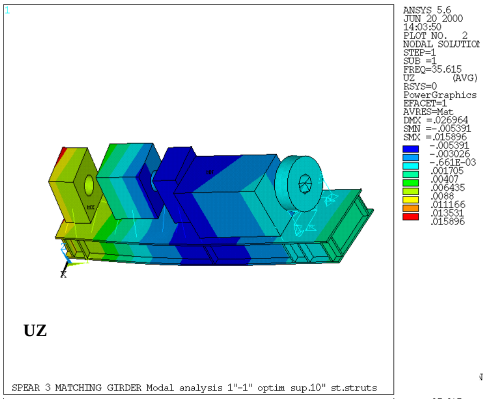
ay=1.55 g: Uy_{max}=0.43 mm

ax=1.55 g: Ux_{max}=0.34 mm

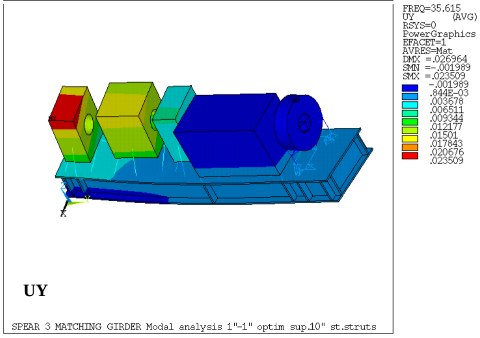
These deflection are computed <u>assuming that the strut stiffness is very high</u>

ANSYS modal analysis of MC-A3 - Mode 1



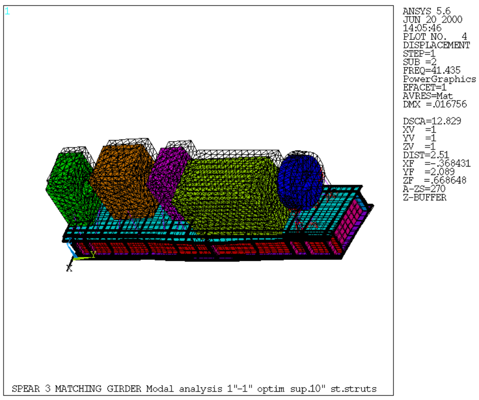


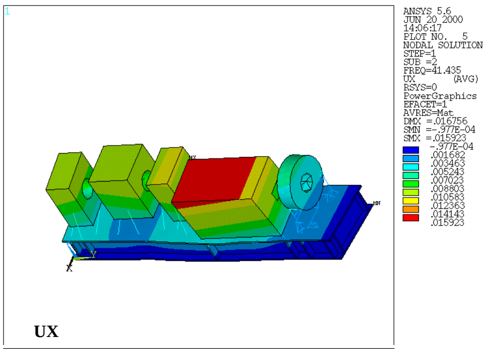
MODE	FREQUENCY (Hz)
1	35.615
2	41.435
3	49.304
4	56.092
5	57.594



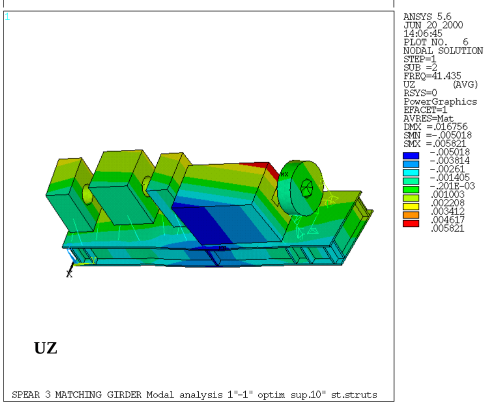
Mode 1 is a bending mode.
f1=35.6 Hz
RIGID STRUTS

ANSYS modal analysis of MC-A3 - Mode 2





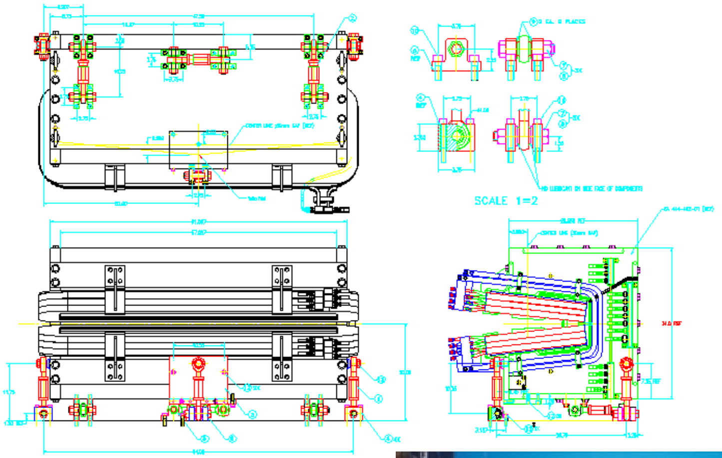
MODE	FREQUENCY (Hz)
1	35.615
2	41.435
3	49.304
4	56.092
5	57.594



Mode 2 is a torsional mode.
f1=41.4 Hz
RIGID STRUTS

SPEAR 3 Gradient dipole

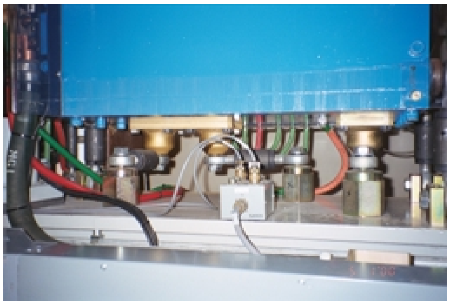
Dipoles, quadrupoles and sextupoles are supported with 6 struts



ALS

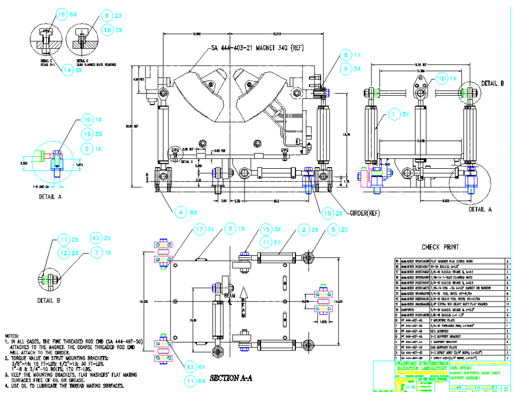
max load: 22000 lb - 10000 kg
during design earthquake

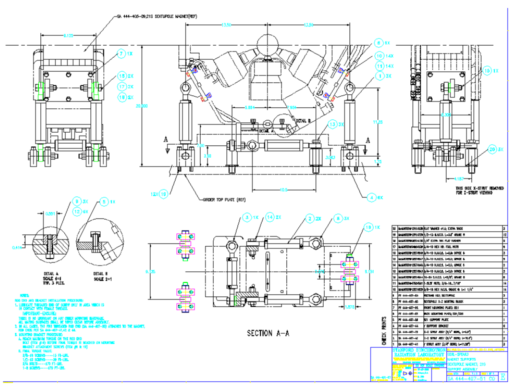
breakaway torque
collars
deflection: 0.0005-0.002 in/4000 lb
13-51 µm/1800 kg
unloaded horizontal struts



SPEAR 3 Quadrupole and Sextupoles

Dipoles, quadrupoles and sextupoles are supported with 6 struts





Magnet supports

Magnets with struts on rigid floor

Magnets with rigid struts on girder

Magnets with real struts on girder

DD- 8/23/00 - BM1 girder			**Strut stiffness**			Strut stiffness	
			2mils/4000Lb			0.5mil/4000lb	
25S only	**Mode**	**ANSYS**	**MathCad**	**Diff %**			
	1	24.614	24.826	-0.85	4th	35.2	
	2	60.169	60.433	-0.44		85.7	
	3	63.336	63.437	-0.16		89.4	
	4	113.862	114.573	-0.62		162.9	
	5	167.499	170.802	-1.93		240.3	
	6	221.441	223.177	-0.78		315.6	
145D only	**Mode**	**ANSYS**	**MathCad**	**Diff %**			
	1	19.381	19.543	-0.83	1st	29.1	
	2	20.138	20.31	-0.85	2nd	30.2	
	3	38.881	39.215	-0.85	6th	58.4	
	4	40.503	40.848	-0.84		60.8	
	5	56.464	57.893	-2.47		86.2	
	6	69.079	69.483	-0.58		103.5	
15Q only	**Mode**	**ANSYS**	**MathCad**	**Diff %**			
	1	23.716	24.024	-1.28	3rd	33.8	
	2	52.304	52.367	-0.12		73.7	
	3	67.958	69.01	-1.52		97.0	
	4	137.643	139.275	-1.17		195.8	
	5	179.626	184.099	-2.43		261.7	
	6	245.385	247.676	-0.92		348.4	
34Q only	**Mode**	**ANSYS**	**MathCad**	**Diff %**			
	1	26.670	27.019	-1.29	5th	38.0	Rigid mounts are assumed to be 50 times stiffer than struts
	2	45.225	45.837	-1.34		64.5	
	3	65.598	65.902	-0.46		92.7	
	4	91.471	92.508	-1.12		130.1	
	5	123.504	124.33	-0.66		174.9	
	6	164.120	164.509	-0.24		231.4	
Fixed girder							
BM1 with stiff struts	**Mode**	**ANSYS**					
	1	33.87					
	2	44.60					
	3	47.03					
	4	55.64					
	5	69.46					
	6	71.39					
Bm1 with real struts	**Mode**	**ANSYS**					
25mm/mm max	1	17.17					
52mrad/mm max	2	18.64					
	3	22.67					
	4	22.88					
	5	24.75					
	6	32.88					

What about amplitudes?

Requirements - Acceptable values

Magnet-to-orbit amplification Factors for SPEAR3 (J. Corbett 10/21/2000, SLAC)

- Uncorrelated motion of magnet on girders:
  - Lattice-to-beam Vertical amplification = ~30
  - Lattice-to-beam Horizontal amplification = ~40

  Uncorrelated motion of magnet on girders
- Magnet motion of ganged to motion of full cell:
  - Lattice-to-beam Vertical amplification = ~5
  - Lattice-to-beam Horizontal amplification = ~10

Before feedback

- Allowable uncorrelated magnet motion (10% of beam size /Amplification Factor):
  - Vertical motion = 1 μm / 30 = 33 nm
  - Horizontal motion = 10 μm / 40 = 250 nm

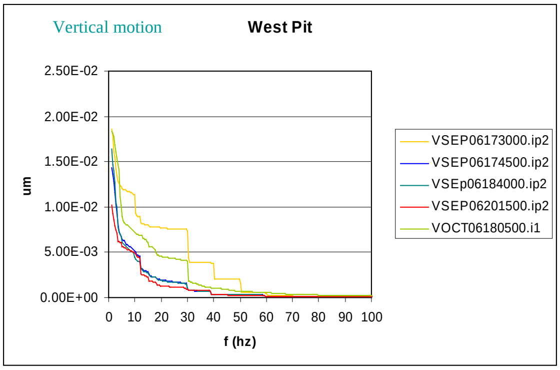
Which frequency range?

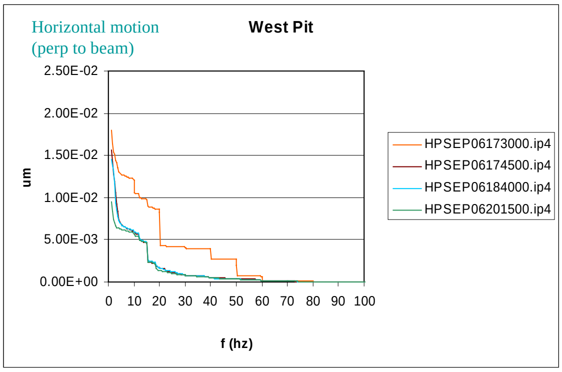
- These are allowable movements of individual magnets supported with struts on a girder.

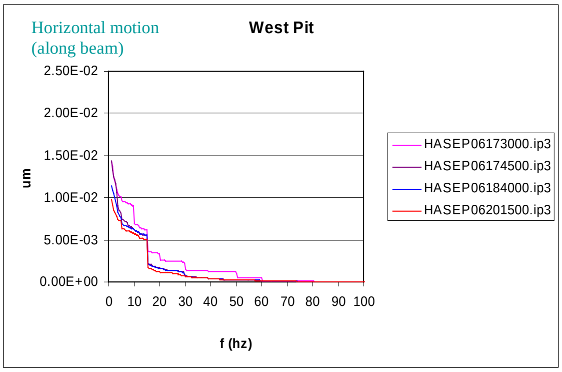
Integrated rms motion of Spear2 quadrupoles: vert. 70 nm, horiz. 700 nm

Ground motion measurement at the West Pit

Cumulative rms displacement vs. Frequency with Mark L-4 1Hz   Measured by Andrei Seryi







15 Hz present with Booster, LCW and HVAC off
10, 20, 30, 40, 50 Hz caused mainly by the booster
12 Hz Spear2 girder ?

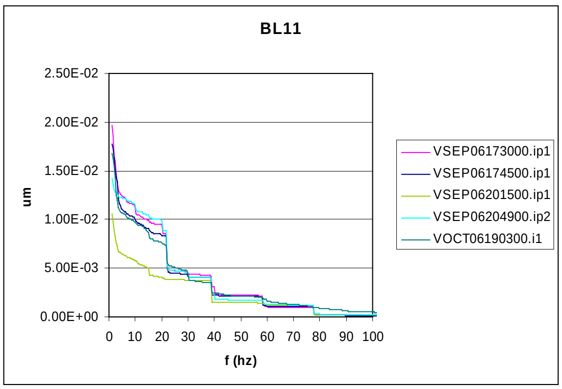
Cultural noise?
Locate and isolate booster components generating this noise

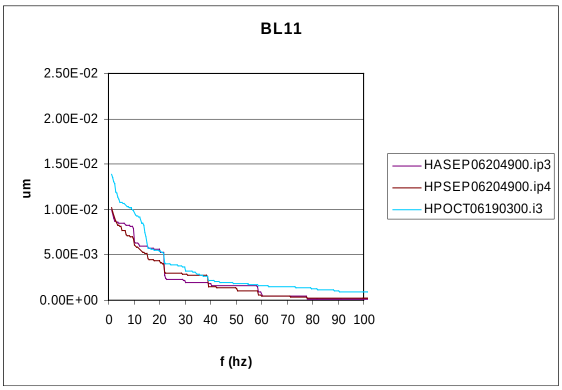
Sep16, LCW OFF:
17:30 Booster at 3 GeV
17:45 Booster off
18:40 Booster off, Linac off
20:15 (**not 2AM**) Booster off, Linac off, HVAC off
Oct 16 LCW ON
18:05 Booster at 2.25 GeV
V=Vertical
HA= Horizontal along beam
HP= Horizontal perp. to beam

Vertical motion
ground: 12 nm = 6 + 3 (at 30 Hz) +2 (at 40 Hz)
amplification: 68 nm = 6+ 3*20+2

Ground motion measurement at BL11 (concrete pad)

Cumulative rms displacement vs. Frequency   Measured by Andrei Seryi





Sep16, LCW OFF:
17:30 Booster at 3 GeV
17:45 Booster off
18:40 Booster off, Linac off
20:15 Booster off, Linac off, HVAC off
20:49 Booster on, Linac on, HVAC on

Oct 16 LCW ON
19:03 Booster at 2.25 GeV

V=Vertical
HA= Horizontal along beam
HP= Horizontal perp. to beam

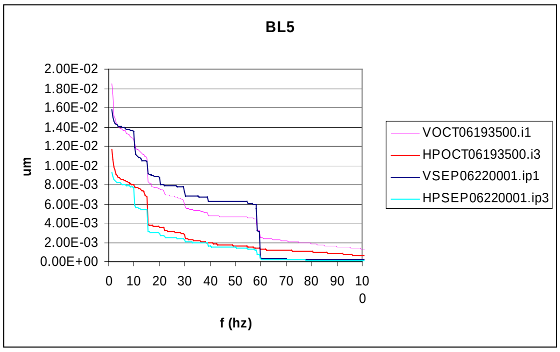
15, 40 Hz present with Booster, LCW and HVAC off
22 Hz caused by HVAC
10, 20, 30, 40, 50 Hz cause mainly by the booster

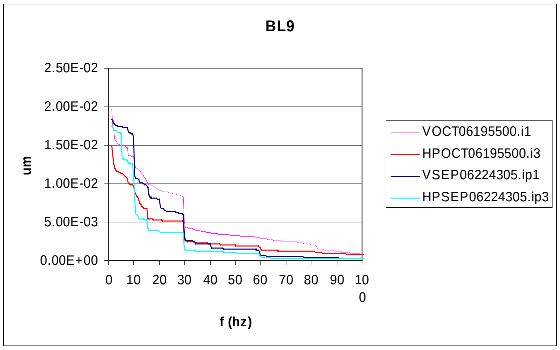
LCW, horiz. 15 Hz and less?
LCW, vert., almost no effect?

Ground motion measurement at BL5 & BL9(concrete pad)

Cumulative rms displacement vs. Frequency

Measured by Andrei Seryi



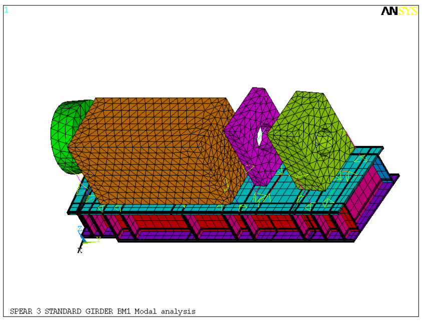


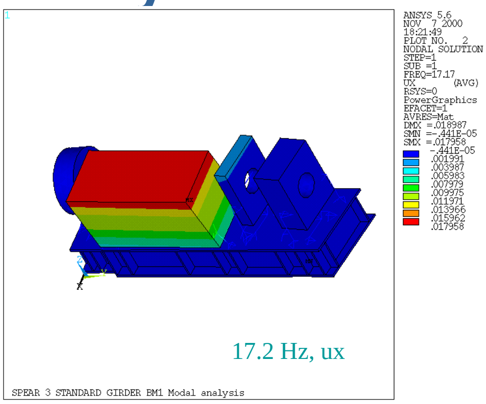
15 Hz present with Booster, LCW and HVAC off ??

Sep16, LCW OFF, Booster at 3GeV:
Oct 16 LCW ON, Booster at 2.25 GeV

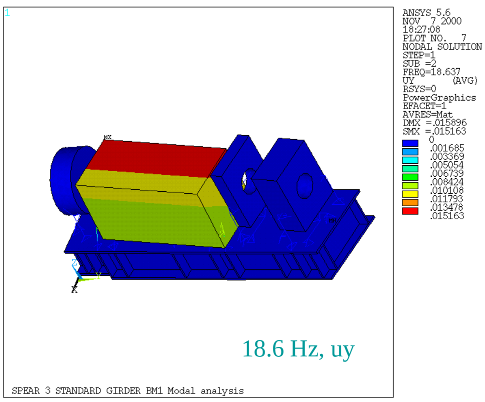
V=Vertical
HA= Horizontal along beam
HP= Horizontal perp. to beam

Girder Bm1 modal Analysis

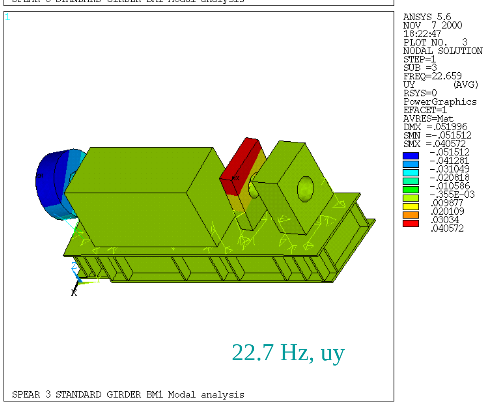




17.2 Hz, ux

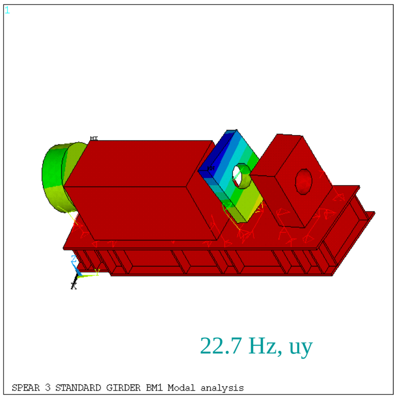


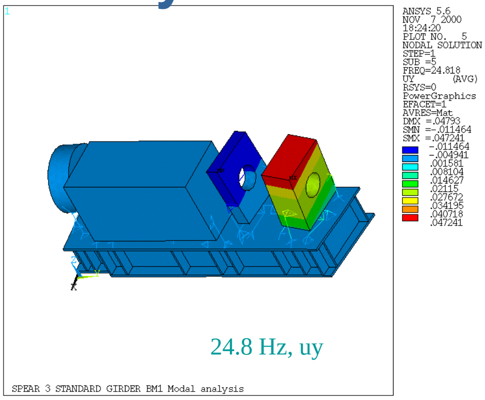
18.6 Hz, uy

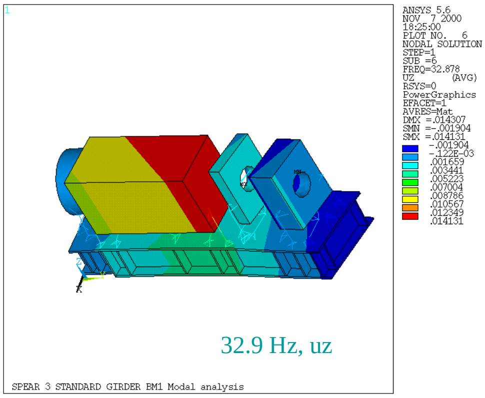


22.7 Hz, uy

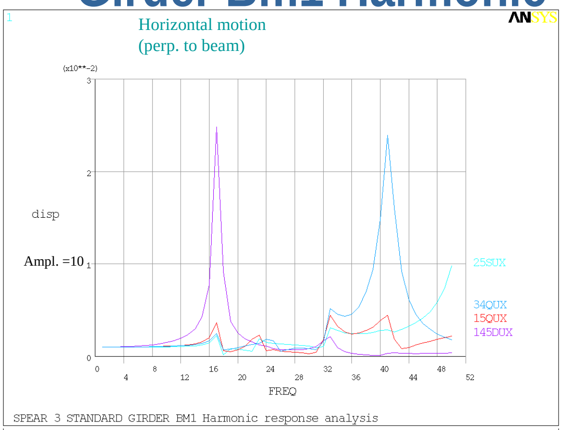
Girder Bm1 modal Analysis

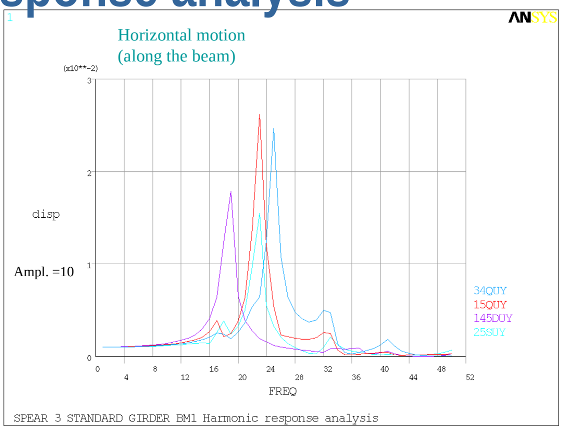


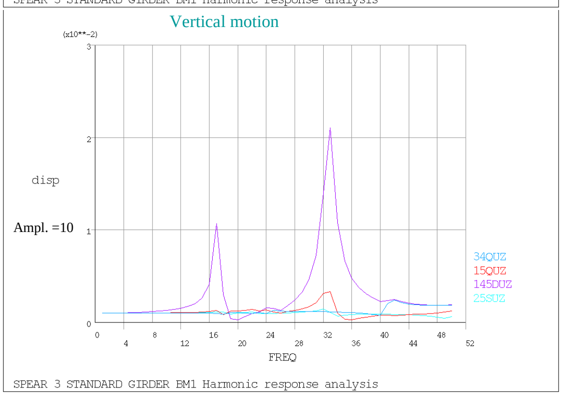




Girder Bm1 Harmonic response analysis

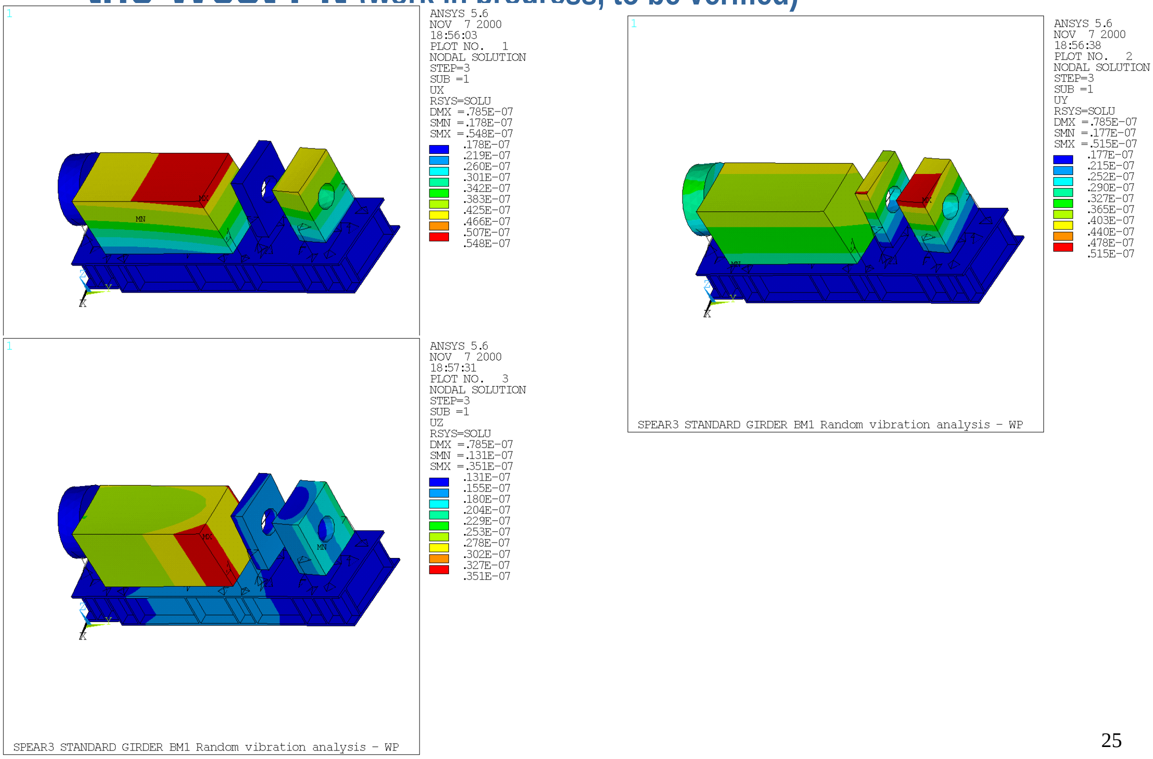






<u>Displacement of magnet (in m) at beam position with ground motion of 1 mm (x, y, z) @ f (Hz)</u>
SI units, linear problem.
disp=1.E-2 -> Amplification=10

Girder Bm1 Random vibration analysis at the West Pit (work in progress, to be verified)



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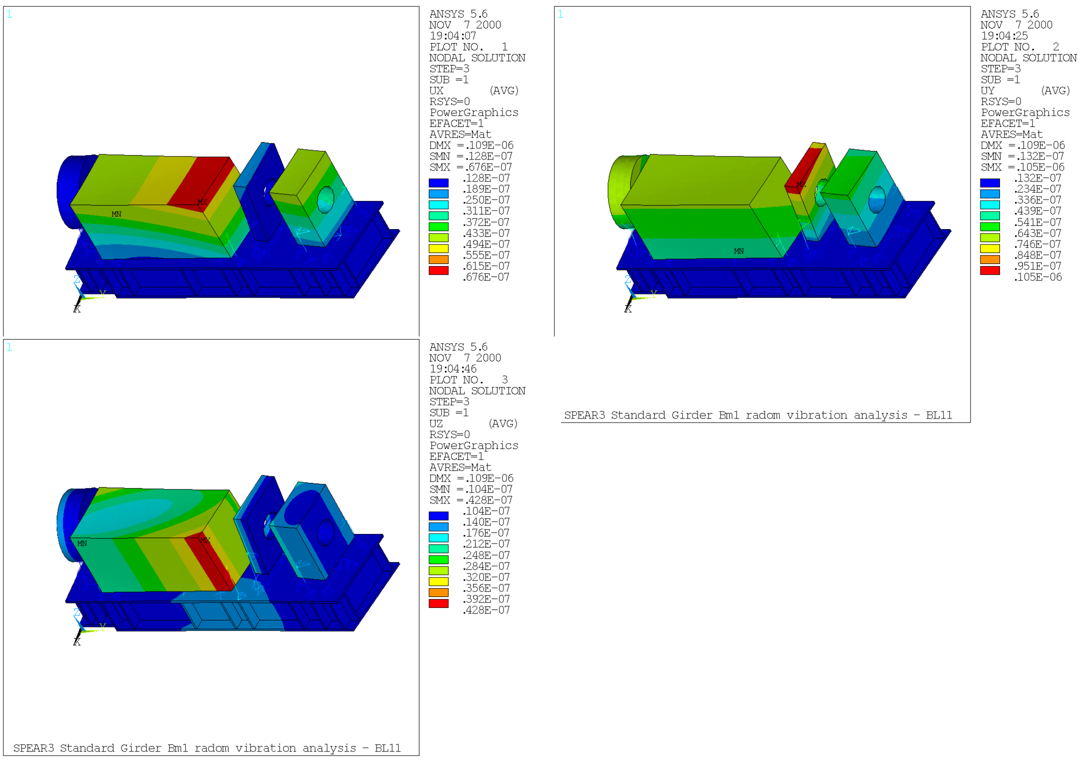
Girder Bm1 Random vibration analysis at BL11 (work in progress, to be verified)



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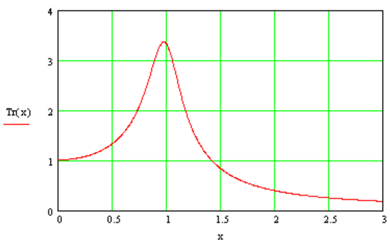
Simplified analysis of vertical damper

$A := 50\cdot 10^{-9}\cdot m$		Amplitude
$f := 20\ Hz$		Frequency
$\omega := 2\cdot\pi\cdot f$	$\omega = 125.664\ Hz$	
$ms := 6350\ kg$		mass
$v := A\cdot 2\cdot\pi\cdot f$	$v = 6.283\cdot 10^{-6}\ \frac{m}{s}$	max speed
$Em := \frac{ms\cdot v^2}{2}$	$Em = 1.253\cdot 10^{-7}\ J$	magnet stored energy energy
$Lf := 0.7$		loss factor
$G := 30\cdot\frac{1}{145}\cdot 10^6\ N\cdot m^{-2}$	$G = 2.069\cdot 10^5\ Pa$	Shear modulus
$Ar := 0.05\cdot 0.20\ m^2$		Area
$th := 0.002\cdot 25.4\cdot 10^{-3}\ m$		Thickness
$nd := 4$		Number of dampers
$Ed := \frac{G\cdot\left(\frac{A}{th}\right)^2\cdot 2\cdot Ar\cdot th\cdot Lf\cdot nd}{2}$	$Ed = 2.851\cdot 10^{-7}\ J$	Energy dissipated by shear in half cycle
$ratio := \frac{Ed}{Em}$	$ratio = 2.274$	
$Sf := G\cdot Ar\cdot\frac{A\cdot 2\cdot nd}{th}$	$Sf = 16.291\ N$	Shear force
$k := \frac{4000\cdot 3}{2.2}\cdot\frac{9.81\ \frac{N}{m}}{2\cdot 0.002\cdot 0.0254}$	$k = 5.267\cdot 10^8\ \frac{kg}{s^2}$	Strut stiffness
$Ccr := 2\cdot\sqrt{k\cdot ms}$	$Ccr = 3.657\cdot 10^6\ \frac{kg}{s}$	Critical damping
$C := \frac{Ed\cdot 2}{A^2\cdot\omega\cdot\pi}$	$C = 5.777\cdot 10^5\ \frac{kg}{s}$	
$\zeta := \frac{C}{Ccr}$	$\zeta = 0.158$	Damping ratio
$Tr(x) := \frac{\sqrt{1+(2\cdot\zeta\cdot x)^2}}{\sqrt{(1-x^2)^2+(2\cdot\zeta\cdot x)^2}}$	$Tr(1) = 3.32$	$\frac{Y}{yo}$



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