Impact of the cryomodule support design on the beam jitter of ILC and XFEL main linacs

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2nd EUROTeV Annual Meeting, January 8th 2007

Overview

Introduction

• effect of uncorrelated vibrations of quads on the beam position jitter at the end of the linac: comparison between ILC and XFEL.

• vibration sources for the quadrupoles: with a reliable proven inner mechanical design, cryomodule supports and support foundations appear the major causes of dynamical instability.

Measurements on some presently available support designs

• TTF linac at DESY: classic design with module sitting on a girder

• LHC dipoles at CERN: use only alignment jacks on floor, being proposed for ILC linacs

• XFEL: hanging from the tunnel ceiling

Conclusions and future investigations

Introduction

Beam position jitter due to uncorrelated quad vibration

Beam position RMS at the end of the linac:

$$\langle y_f^2 \rangle \approx a^2 N_q \beta_f \bar{\beta} k^2 / 4$$

*Regular FODO lattice with N_q quadrupoles with strength k.

XFEL vs ILC

- similar tolerances for the vertical RMS because of the stronger focusing in the XFEL main linac
- the XFEL round beam requires the same tolerance for the horizontal RMS (more challenging)
- with shorter quad spacing higher frequency onset for the uncorrelated motion

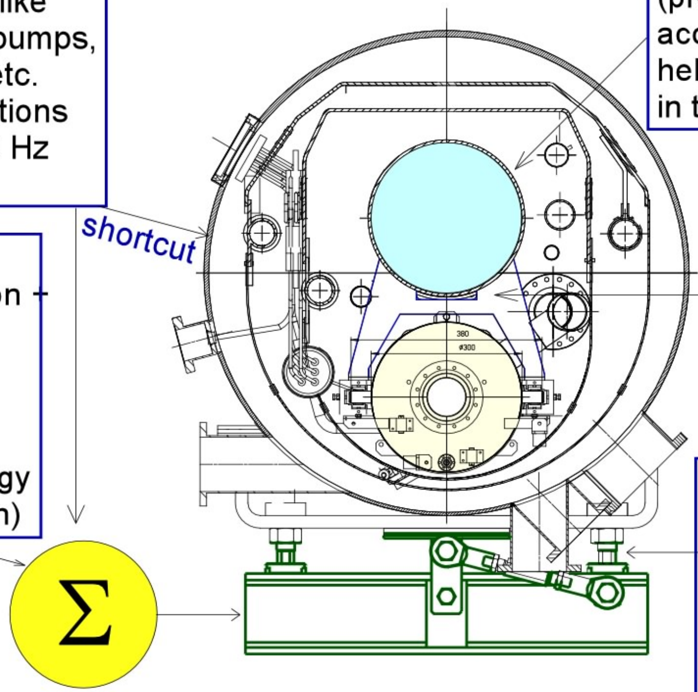
ILC and XFEL comparison

	ILC	XFEL
Linac length	10.6 Km	1.4 Km
Initial energy	15 GeV	2.5 GeV
Final energy	250 GeV	20 GeV
Repetition rate	5 Hz	10 Hz
No.of quads	~ 300	~100
Betatron wavelength	~ 90 m	~ 25 m
End σ_x	70 μm	30 μm
End σ_y	3 μm	30 μm
Beam jitter tolerance	1σ	0.1σ
Tolerable uncorrelated quad rms offset	a_y~70 nm a_x not critical	a_y, a_x~70 nm

Quad motion ingredients

Facility noise
(near-field sources like insulating vacuum pumps, fans,compressors,etc. produce huge vibrations with peaks in 10-50 Hz band)

Ground motion
(broadband excitation + microseismic peak around 0.15 Hz + cultural noise>1Hz; correlation length dependent on geology and civil construction)



End-section of a Type III+ cryomodule

Cryogenic system
(presently unknown effect;broadband acoustic noise induced by the 2K helium gas flow+pressure oscillations in the liquid helium feed lines)

Quad support
(in present cryo's the quad+cavity string is supported by the big He gas return pipe (GRP); already reliable design as shown in this work

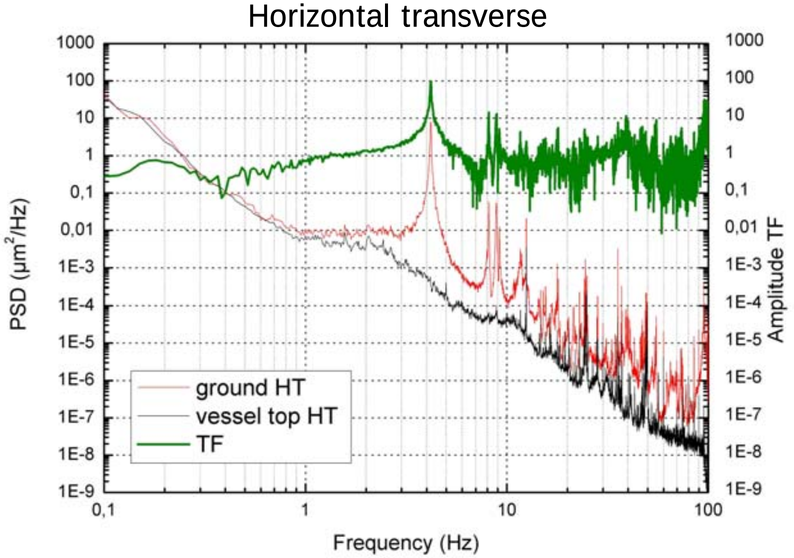
Cryomodule 'normal modes'
(the module on its supports/floor behaves like a compound pendulum; resonant frequencies depend on the stiffness of the support, on the module mass and on the interface between the support and the tunnel floor/ceiling. Easier design in vertical with modes >50Hz)

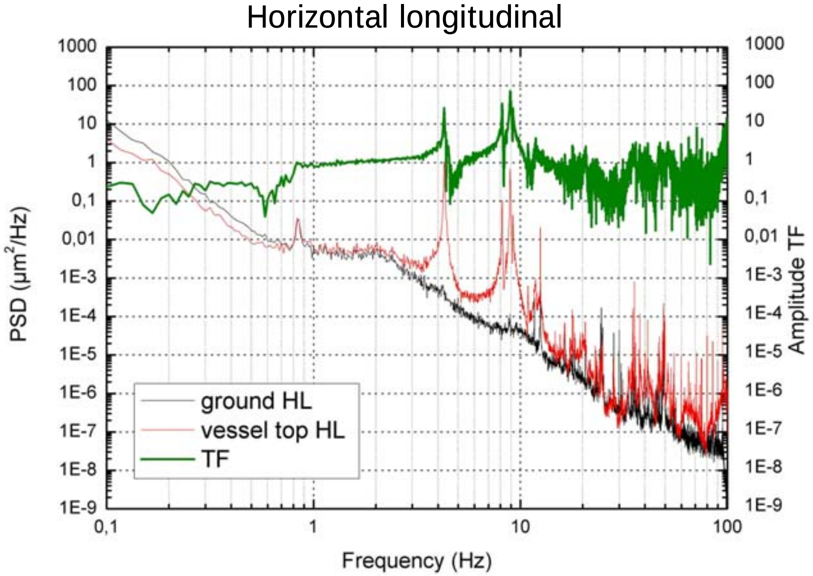
Studies on TTF type-II CM

Vessel top vs ground transfer function

TTF Type-II cryomodule in DESY Hall I

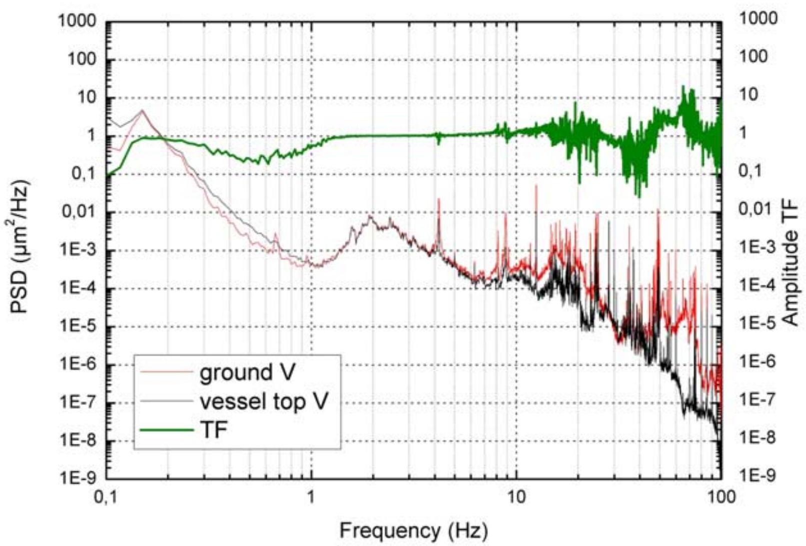
The horizontal motion was dominated by three large amplitude mechanical resonances at 4.3, 8.3 and 9 Hz.



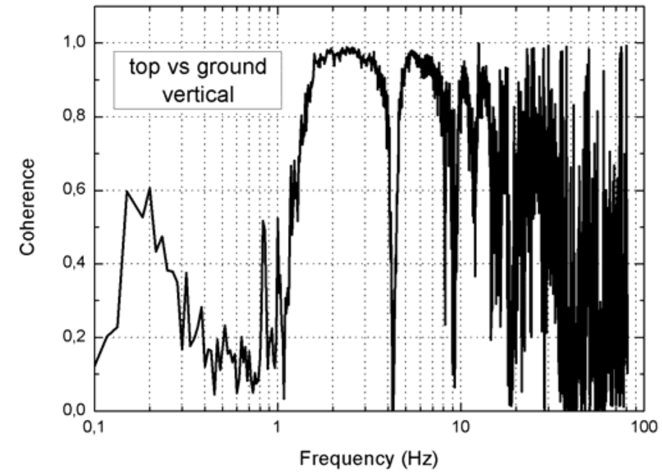


Studies on TTF type-II CM

Vertical transfer function

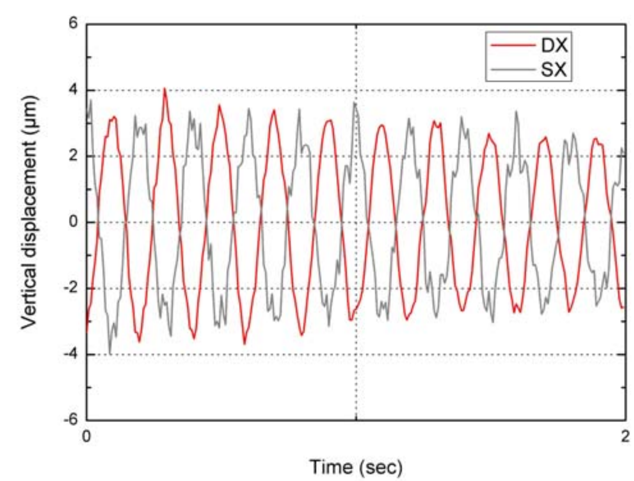


Coherence



- **Rigid vertical coupling with no resonances in the transfer function.**
- **Strong coupling between horizontal and vertical also confirmed by the notches in the coherence plot.**
- **Test with two vertical geophones confirms that we are dealing with rocking modes of the module on its support**

Horizontal to vertical coupling at the 4.3 Hz mode measured with two vertical geophones along the cryomodule transverse cross section

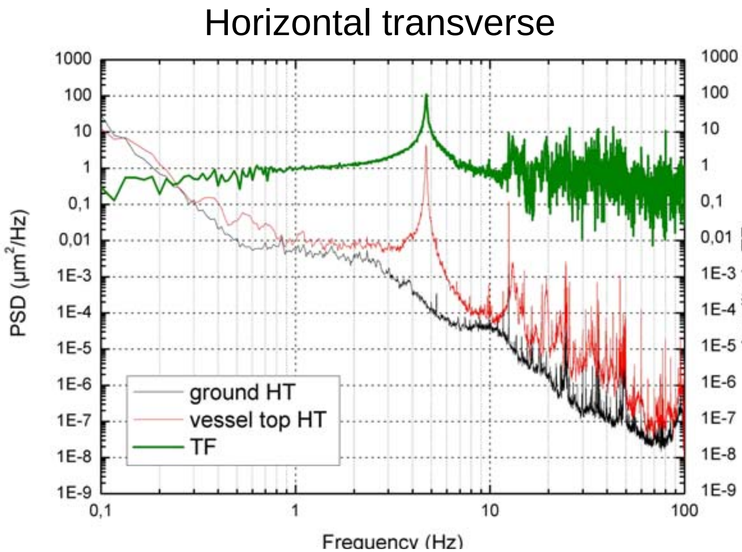


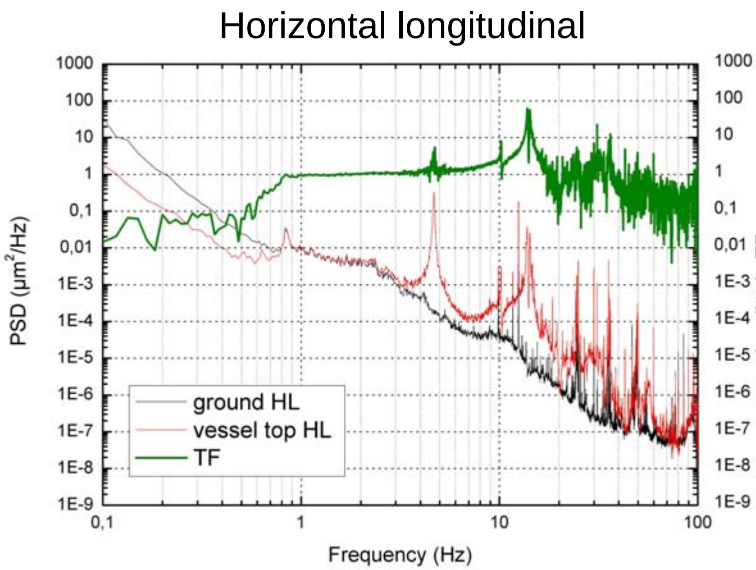
Module 6 – setup I

Vessel top vs ground transfer function

Same primitive support with leveling bolts on steel pads

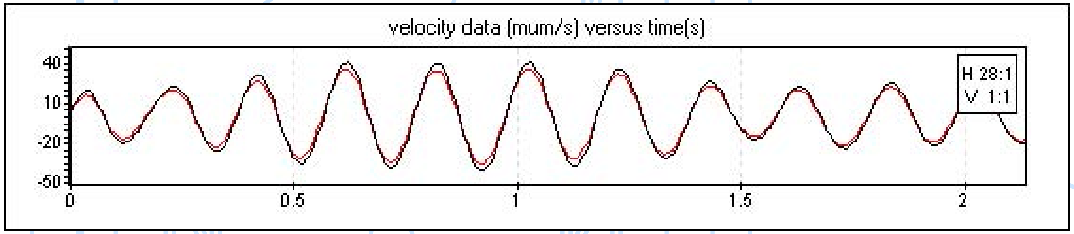
Similar behaviour with lowest frequency mode in the horizontal transverse direction at 4.7 Hz. Resonance in the longitudinal direction at 13 Hz.

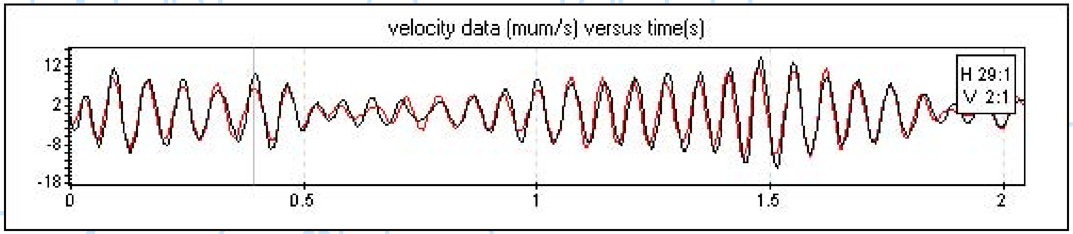




Module 6 – setup I

Rigid body modes with no amplitude and phase change along the module length



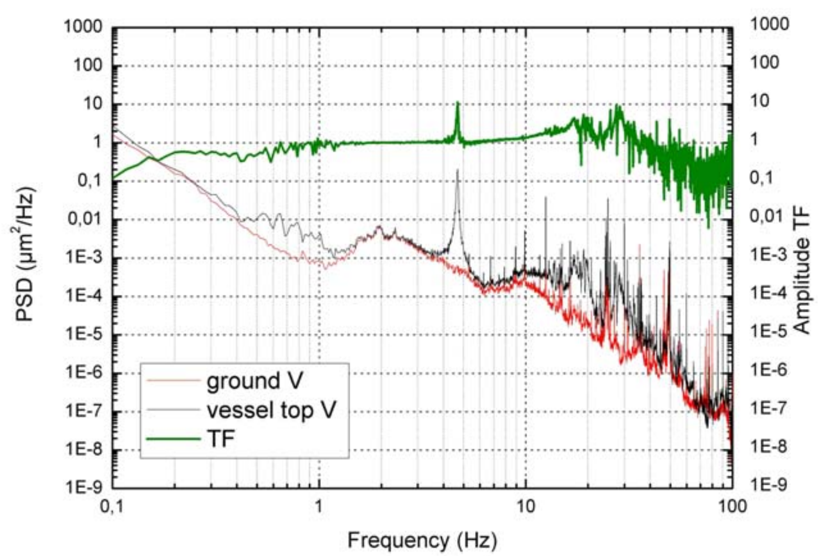


Mode at 4.7 Hz measured simultaneously on top of the module at the center and at the quad end.

Mode at 13 Hz measured simultaneously on top of the module at the center and at the quad end.

- **Rigid vertical coupling with no resonances in the vertical transfer function.**
- **Strong horizontal-vertical coupling.**

Vertical transfer function

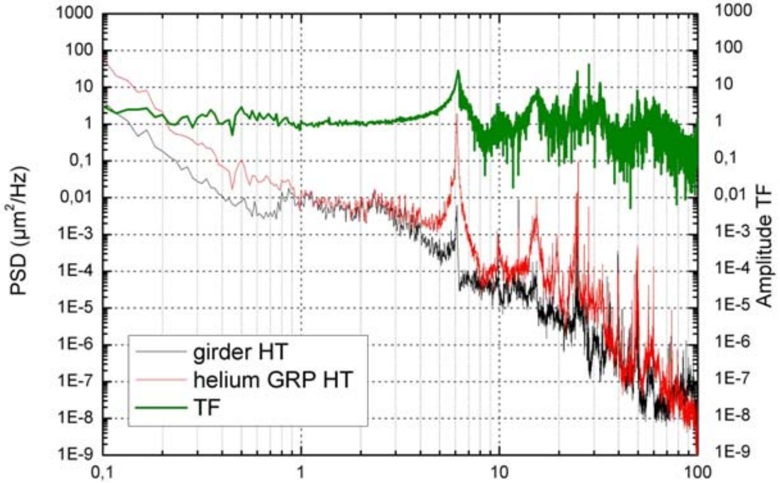


Module 6 – setup II

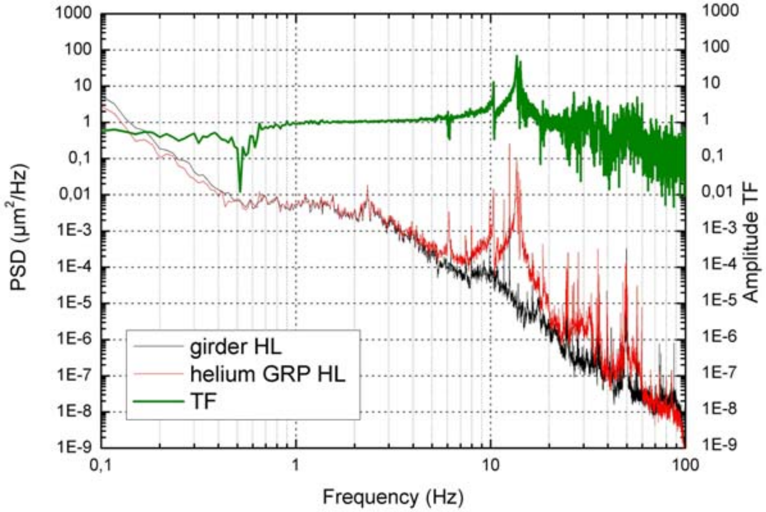
Stand-alone with crossbeams on a steel girder

Module 6 in DESY cryomodule test stand

Horizontal transverse



Horizontal longitudinal



Again similar peak structure in the horizontal plan. Lowest mode at 6 Hz, but we got similar results with the same layout on concrete. No effect on the 13 Hz mode.

LHC alignment jacks

- a standard alignment jack has been designed for 3-axis precise positioning of LHC cryomagnets
- rumors claim it as the baseline solution for ILC cryomodules which will be supported from the floor
- affordable long term static stability and easy installation (no girder)
- motorized version available for IP quadrupoles
- dynamic performances untested so far

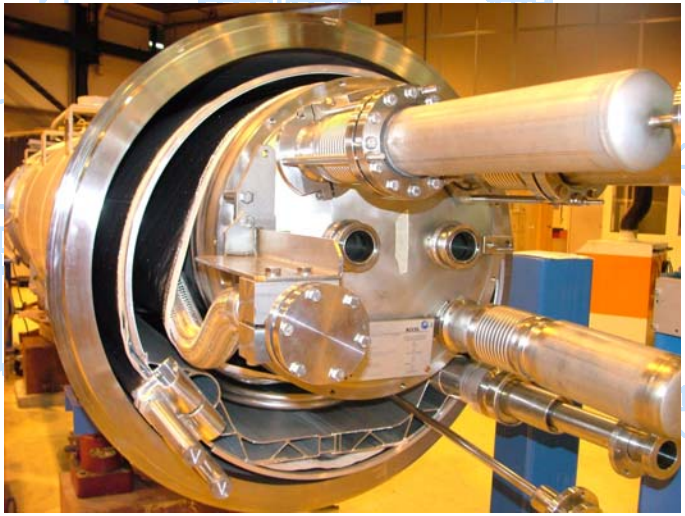
LHC Cryodipoles

LHC standard cryodipole installed in the 3-4 arc section

Fiberglass cold mass supports

Length	17 m
Weight	32 tons
Cryostat diameter	~ 1 m
No.of jacks	3+1 at center for sagitta compensation
Cold mass support	3 fiberglass posts on the bottom

Characteristics of LHC standard dipoles



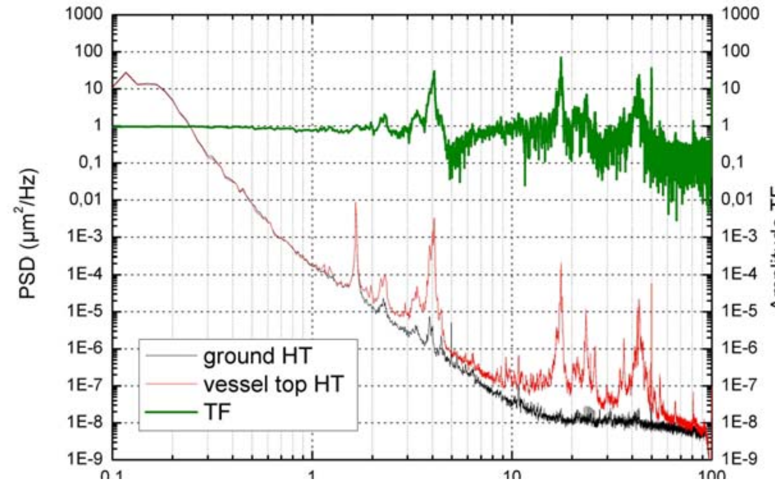
Cold mass view

LHC Cryodipoles

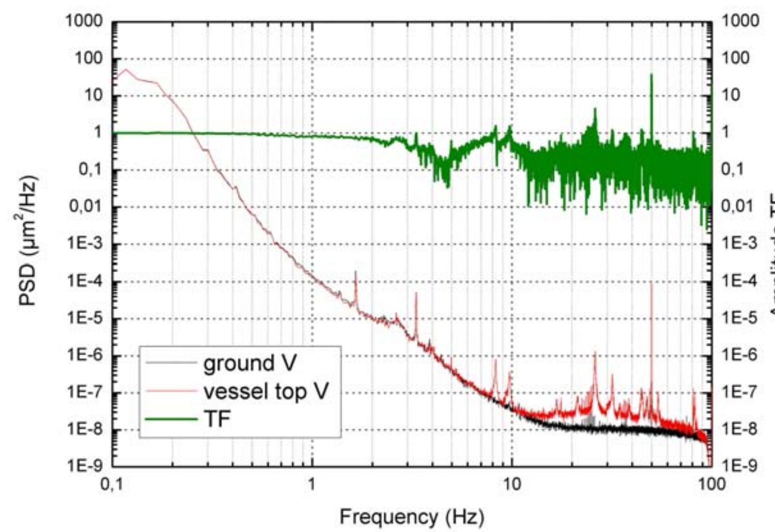
Stand-alone configuration

- **Low frequency resonance at 4 Hz (Q~30) in the horizontal transverse direction. Other large amplitude modes at 17 and 42 Hz.**
- **Very rigid in vertical.**

Horizontal transverse

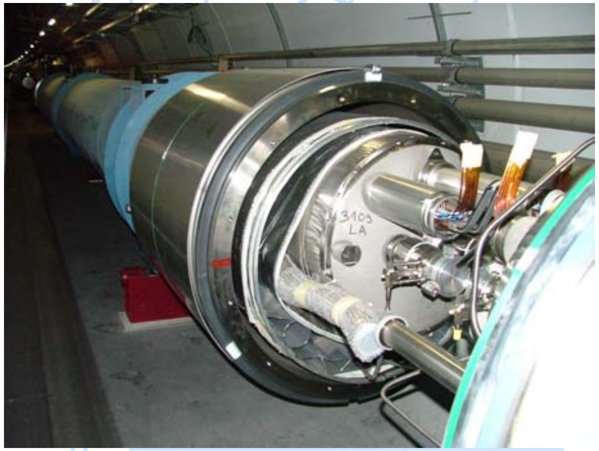


Vertical

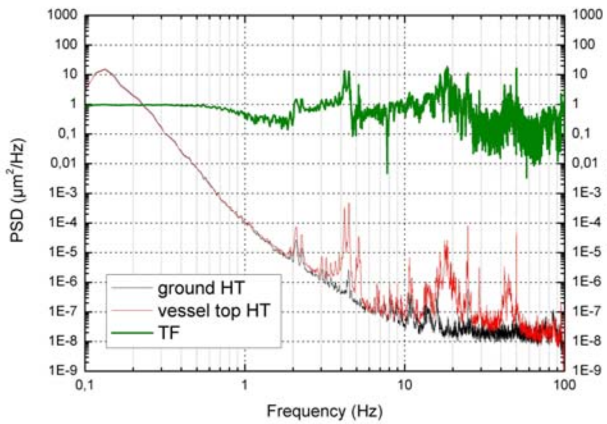


LHC Cryodipoles

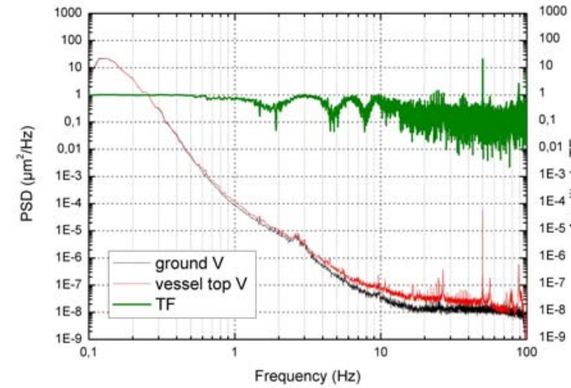
Connected configuration



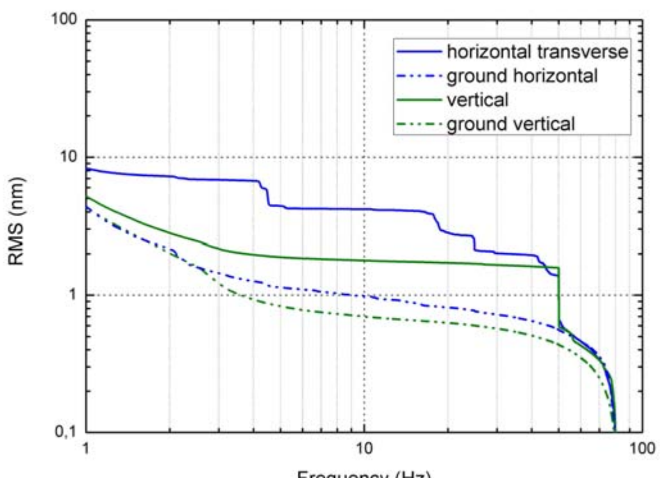
Horizontal transverse



Vertical



RMS summary



- **Frequency response almost identical to the stand alone case but with some damping of the resonances**
- **large amplification of the ground motion from the support, but taking advantage of the CERN site, the resulting RMS motion amplitude is absolutely safe for the LHC operation**

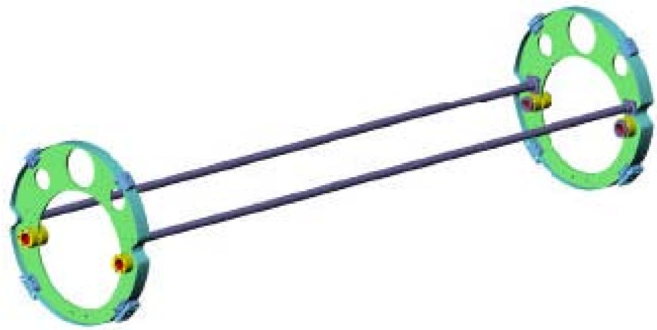
LHC Low ß Quadrupole

LHC low beta quadrupole next to ALICE Interaction region

View of the alignment jacks. Note the enlarged contact section and the extra layer of concrete.

Length	~ 9 m
Weight	17 tons
Cryostat diameter	~ 1 m
No.of jacks	3 with enlarged footing section
Cold mass support	Full cross section collars

Characteristics of LHC low beta quadrupoles

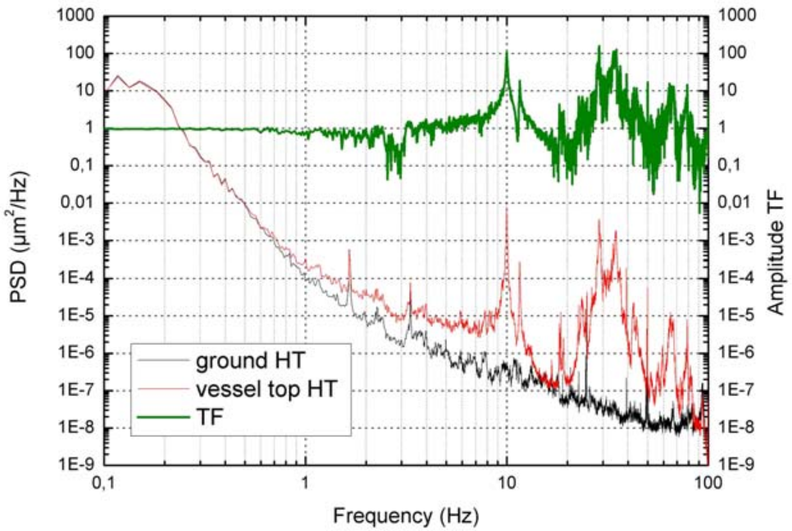


Composite spider-like cold mass support, designed for better rigidity.

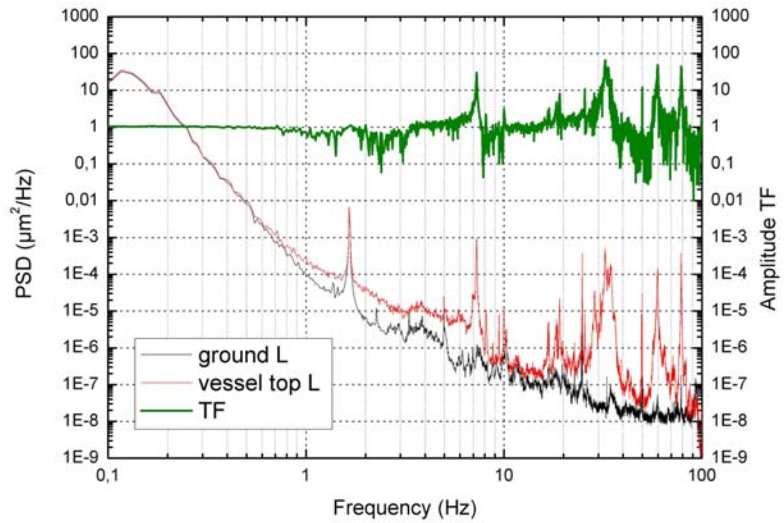
LHC Low ß Quadrupole

Ground to vessel top transfer function

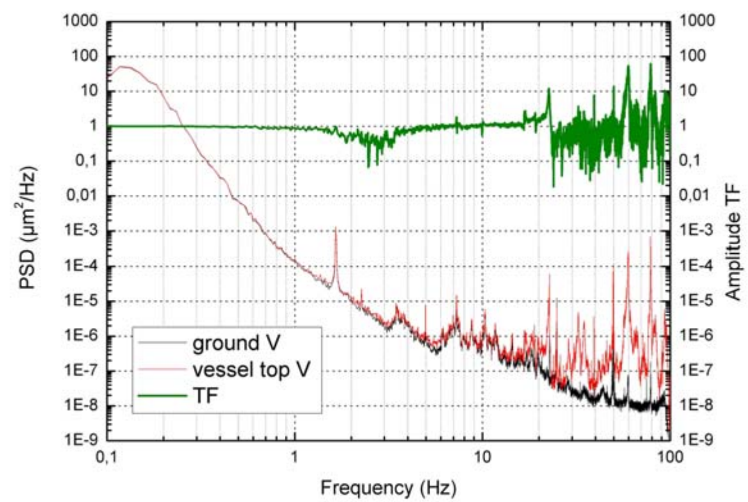
Horizontal transverse



Horizontal longitudinal



Vertical

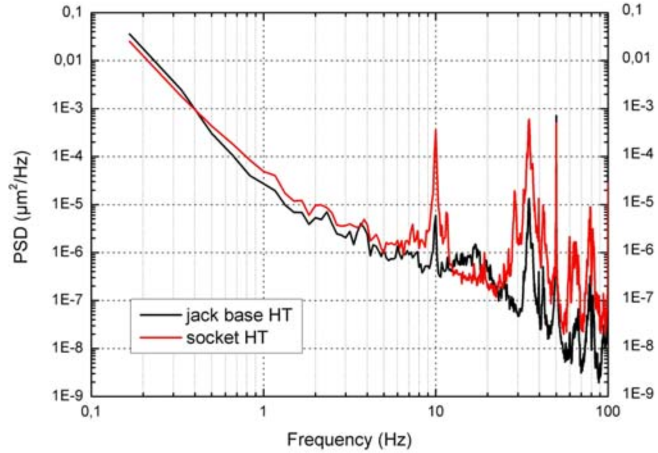


- **stiffer than dipoles along the transverse direction with the first mode at 10 Hz, but larger Q**
- **soft in the longitudinal axis with a 7.3 Hz mode**
- **rigid along the vertical direction**

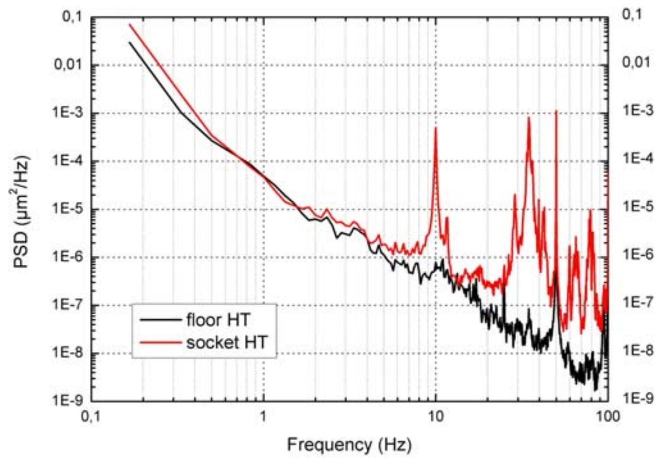
LHC Low ß Quadrupole

Effect of the support foundation

Vessel socket vs jack base



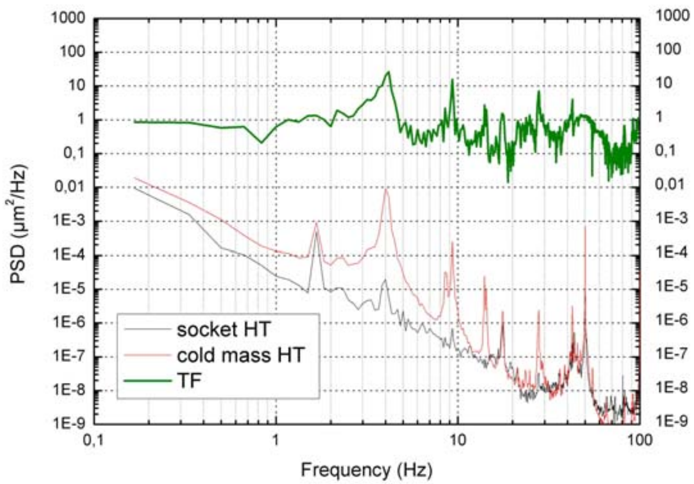
Vessel socket vs floor



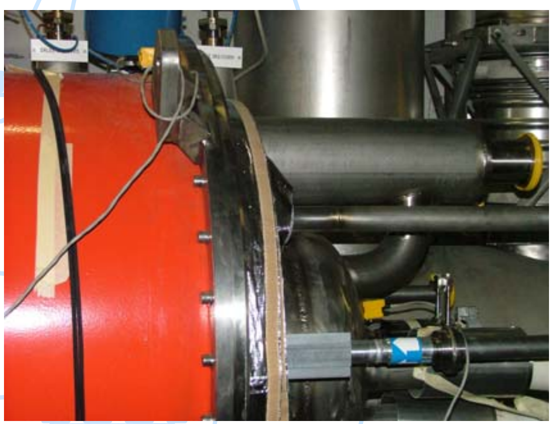
- **the transverse mode structure already visible at the interface between the jack and the concrete pad, but not in the floor**
- **the enlarged contact surface produces significant benefits on the dynamic stability of the module**

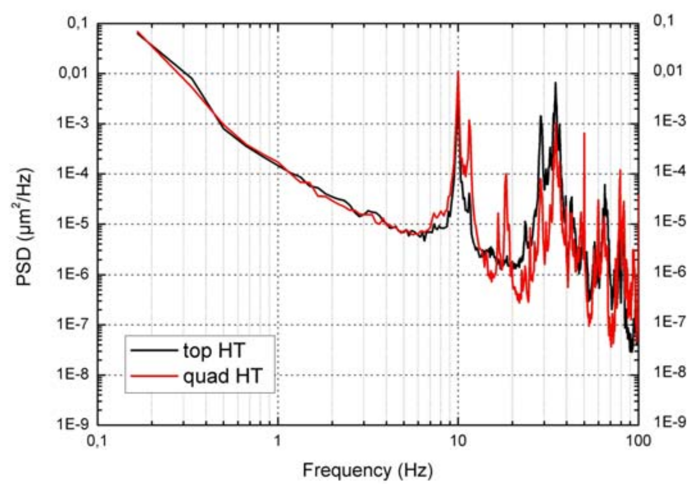
LHC Magnets-cold mass

Measurement on the standing alone dipole and quadrupole



the cold mass motion is dominated by the large amplitude module rocking modes. In dipoles seems not very rigidly supported internally: three modes at 8.6, 9 and 14 Hz are visible in the cold mass PSD only. Stiffer as expected the quadrupole with a lowest mode at 17 Hz. No modal shape investigation done yet.





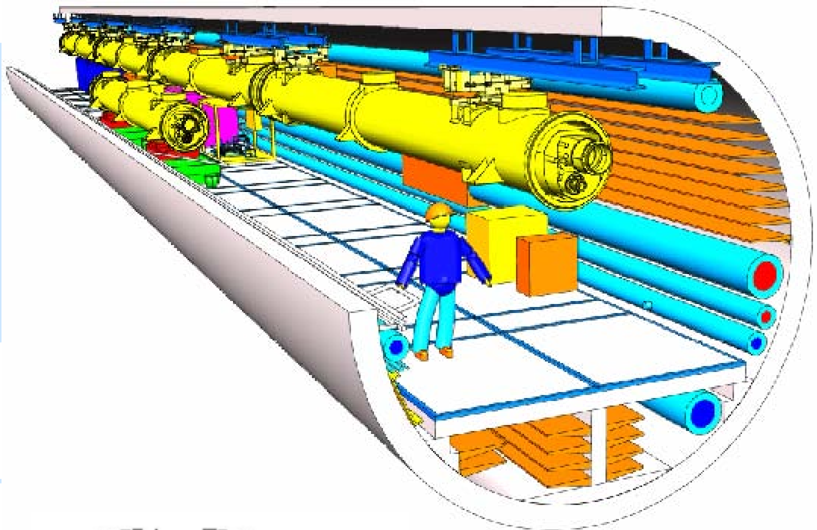
LHC Magnets- Summary

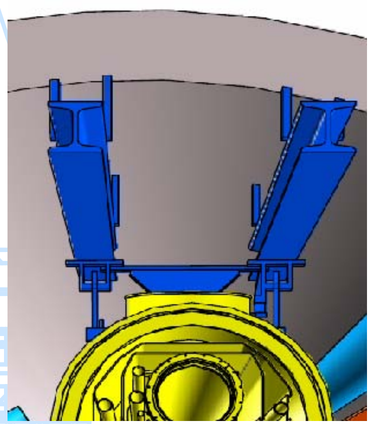
- we have investigated the dynamic stability of standard LHC arc section dipoles in both stand-alone and connected to the beam-line configurations
- the support design with no girder and short leveling jacks has been evaluated
- found low frequency mechanical resonances (4 Hz the lowest one) that largely amplifies the floor motion in the horizontal transverse direction
- anyway no effect on LHC operation is expected because of the outstanding ground motion level in the tunnel
- the alignment jacks look ‘undersized’ to guarantee proper vibrational stability to the 32 tons dipoles
- the results of the measurements on the short low beta quadrupole cryostat look promising for the use of the alignment jacks for the ILC linacs, after suitable modifications (properly sized footing)

Thanks to: Claude Hauviller, Helene Mainaud-Durand, Jean-Pierre Quenelle, Kurt Artoos (CERN)

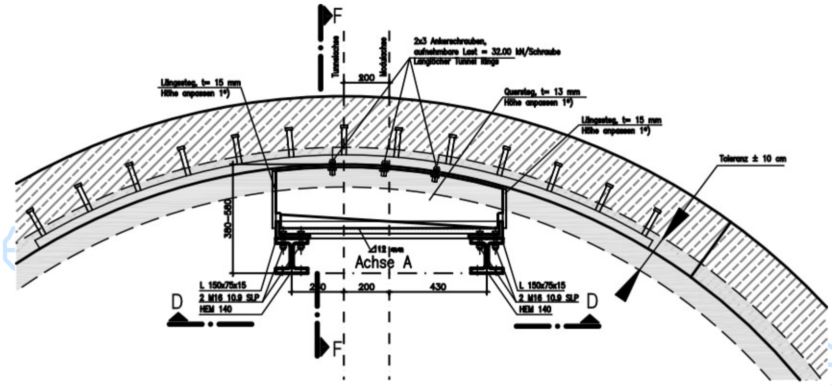
XFEL-hanging modules

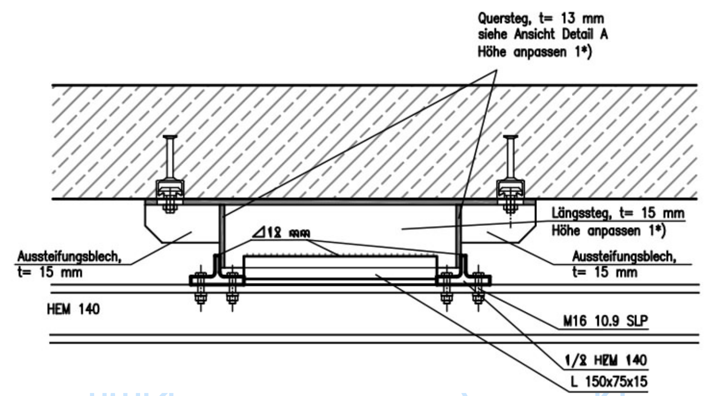
XFEL Tunnel layout





Alignment/support jigs clamped to the rails





*Courtesy of Amberg Engineering

Connection boxes + continuous rails as interface between the ceiling and the module string.

XFEL -jigs design

Two alternative design proposed and tested for vibrations by our group

Pull Rod Version

Bolt Version

Concept
The module is suspended by four M24 rods; three adjustment rods provide knobs for alignment in the horizontal

Advantages
Cheap, quick installation and alignment

Drawbacks
Horizontal and vertical adjustment coupled; Internal resonances at low frequency

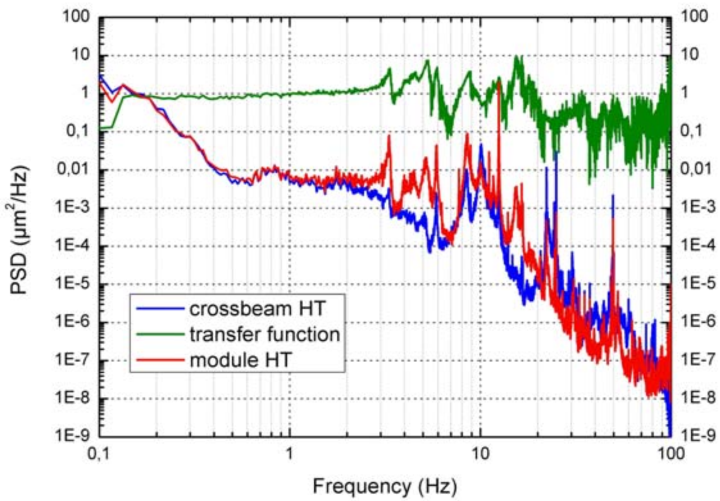
Concept
The module is standing on three leveling bolts; the weight is supported by the two large cross section crossbars.

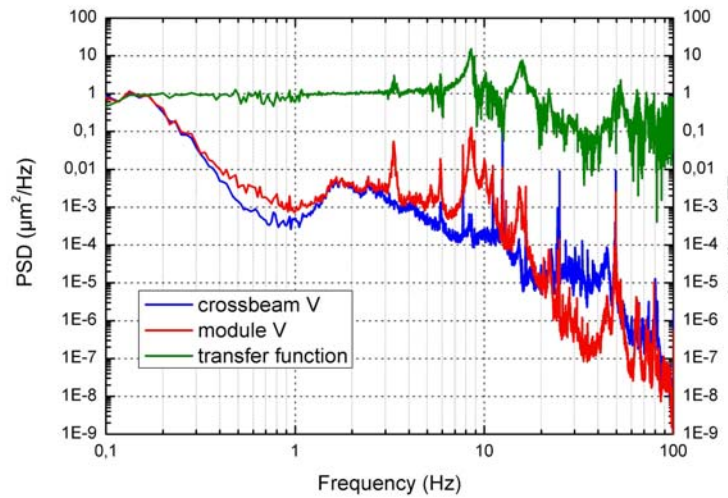
Advantages
Very rigid, the machine is just standing in place, no static shear stresses, horizontal and vertical adjustment well decoupled

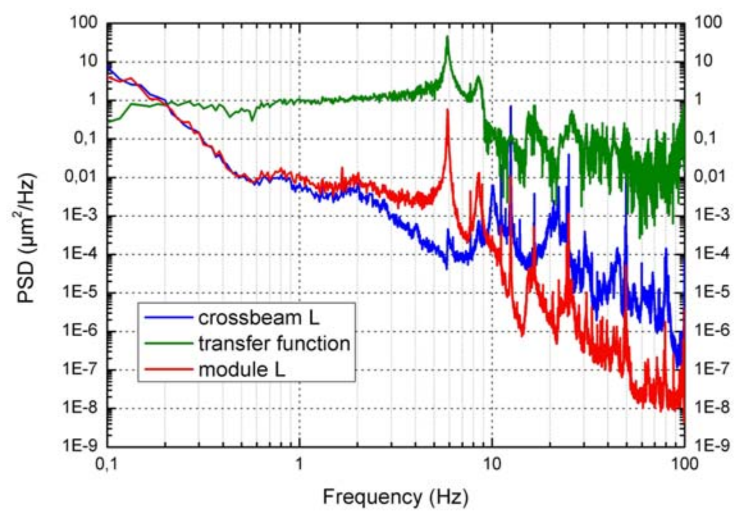
Drawbacks
Manufacturing costs, installation time

XFEL-Pull rod support

Quad end vessel top vs crossbeam







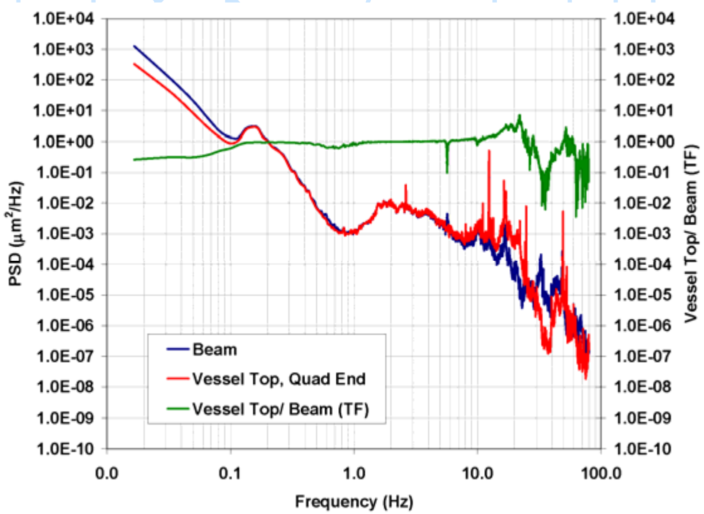
General comment

Rather complex transfer function due to the lack of stability of the test stand; all of the peaks at low frequency belong due to the elasticity of the crossbeams and to their poor interface with the concrete stands

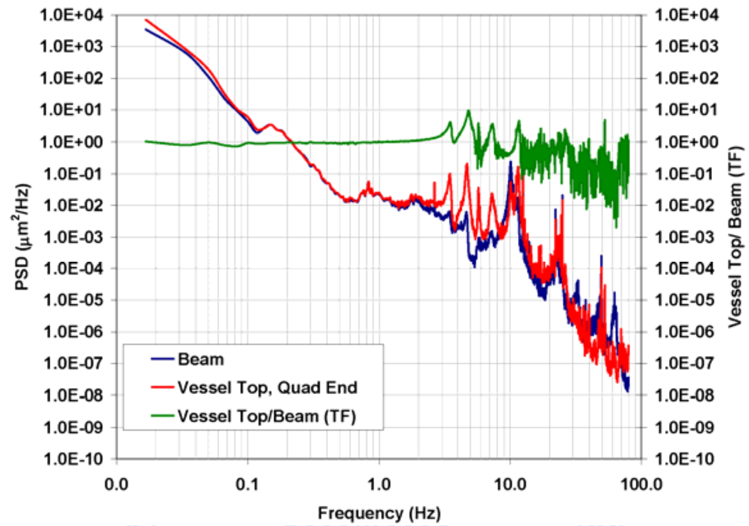
Horizontal transverse / Vertical: coupled internal mode at 15.5 Hz. The low frequency of the mode and the coupling prove the suspected limitations of this design

XFEL-Bolt support

Quad end vessel top vs crossbeam



Horizontal Transverse

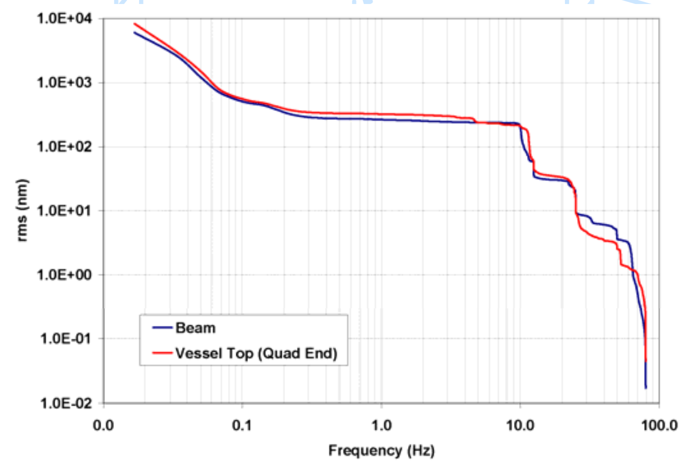


General comment

Same effect from the test stand but no evidence for low frequency internal resonances. The rigidity of this design is confirmed by the integrated RMS, with around 20% matching in both horizontal and vertical at 1Hz.

Horizontal transverse/Vertical: very well decoupled. Benefit from the standing-like design

Horizontal Transverse RMS



Conclusions

- the dynamic stability of the quadrupoles is a crucial parameter for beam jitter at the output of the ILC and XFEL linacs; more critical for the XFEL with 0.1σ tolerance at the input of the undulator

- the dynamics of the quadrupoles is dominated by the low frequency modes of the cryomodule on ist support system. A careful design should be implemented to avoid resonances below 10 Hz, at least.

- which support design choose for the ILC? TTF style looks inadequate. We have investigated on the stability of LHC cryomagnets: not as good as claimed, but a viable way for the ILC with some changes in the design.

- a vibrationally stable support/alignment jig for the XFEL cryomodules has been tested; a machine hanging from the ceiling and hosted in a single tunnel looks feasible.

Thanks to:

R. Lange, K. Jensch, W. Maschmann, H. Hintz (DESY-MKS)
H. Hirsemann, N. Meyners, M. Schlösser, B. Sparr (DESY-MEA)
D. Samberg (HASYLAB)
S. Wendt (Technische Universität Hamburg- Harburg)

*Financial support from EuroTeV: Work supported by the Commission of the European Communities under the 6th Framework Program ‘Structuring the European Research Area’, contract number RIDS-011899.