PAUL SCHERRER INSTITUT

PSI

U. Flechsig :: PSI

X-ray optics and mechanical vibrations

vibration management and measurements @ PSI

PSI, DENIM meeting Sep 18, 2018

Outline

Beamline Optics Group - Who are we?

Uwe Flechsig
Head (1998)

Andreas Jaggi
Beamline (2005)

Sibylle Spielmann
Metrology (2007)

Juraj Krempaský
Controls (2007)

Vincent Thominet
Metrology (2011)

Rolf Follath
Optics (2012)

Marcus Knop
Beamline (2017)

Ulrich Wagner
Athos (2017)

Main Subjects - What do we do?

- optical beamline design – SLS, SwissFEL, SLS 2
- quality assurance of optical elements – metrology lab, optics beamline
- planning – installation, survey and alignment strategies
- beamline commissioning and maintenance
- performance measurements, wavefront metrology
- beamline setup and commissioning at SwissFEL
- vibration monitoring and measurements at SLS and SwissFEL

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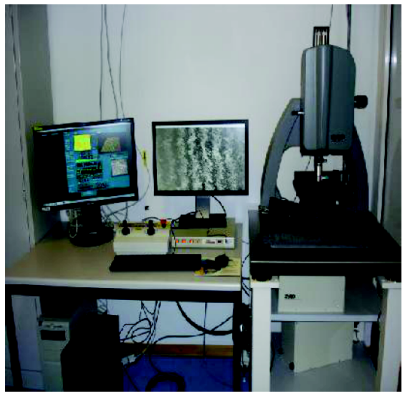
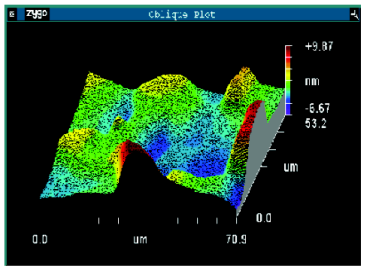
Outline

SLS Metrology Laboratory – Instruments

3d profiler Zygo NewView 5010



microscope setup

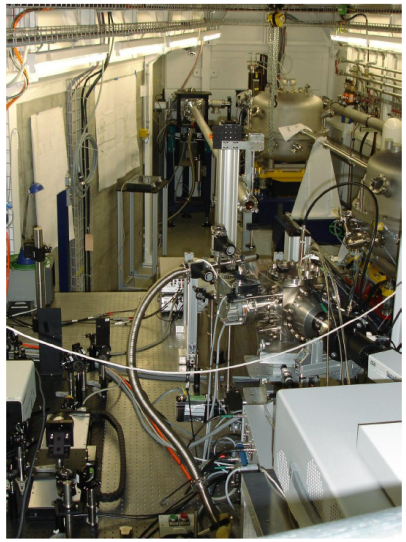


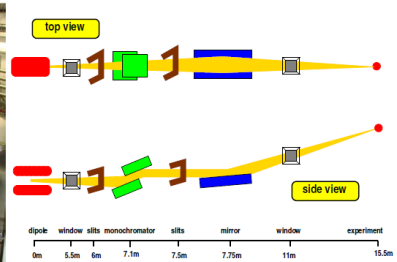
CVD diamond window, thickness: 100 μm

- various objectives
- FOV 0.1...2.5 mm
- max. lat. resolution: $0.6\,\mu m$

- 2011 upgrade
- motorized stage for stitching
- new computer, software upgrade

SLS optics beamline X05DA

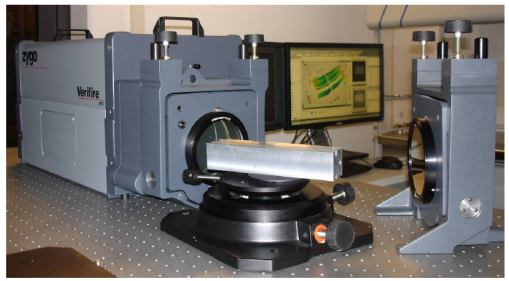




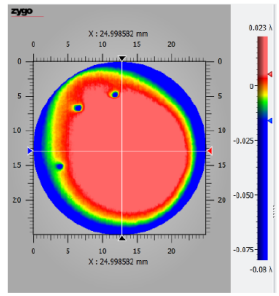
- photon energy: 5.5 ... 22.5 keV (with mono)
- different modes: monochromatic, pink beam, focused, unfocused

LTP-1400

Fizeau Interferometer Zygo Verifire ATZ



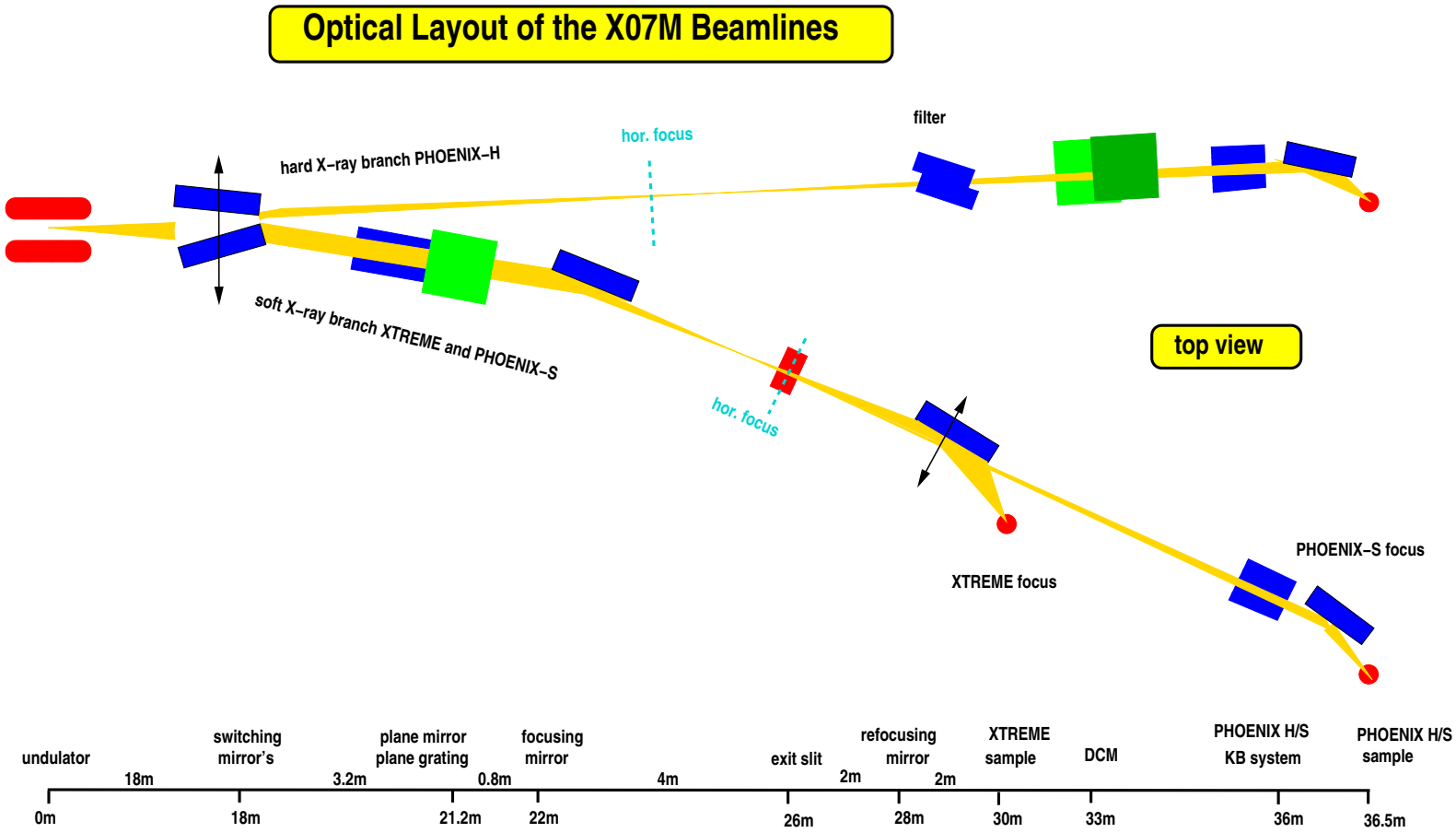
grazing incidence setup



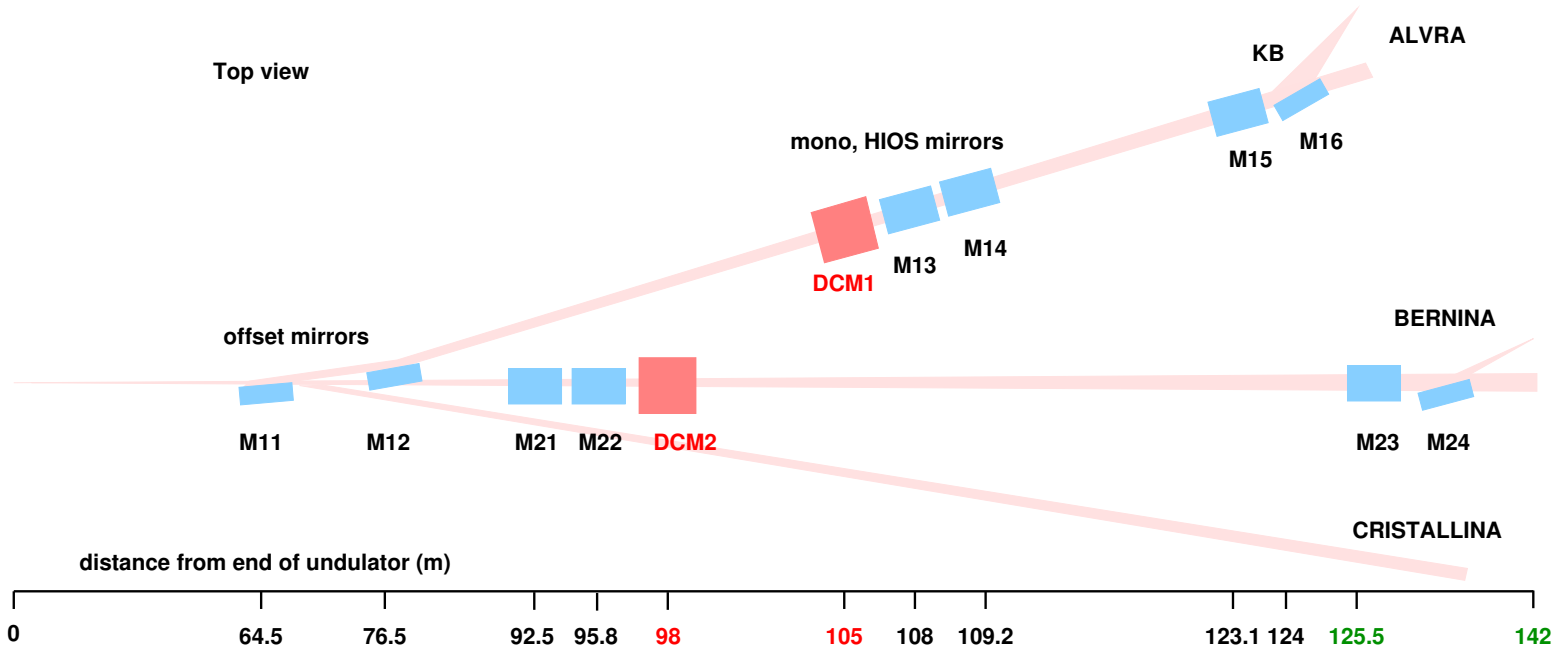
Si mirror for SwissFEL testcoatings

- aperture: 100 mm
- camera: (1000×1000) pixels, frame rate: 43 Hz
- PV wavefront error $< \lambda/36$
- RMS wavefront repeatability 0.35 nm or $< \lambda/1800$

SLS Beamline – example: X07M[AB]



SwissFEL Beamline – example: ARAMIS



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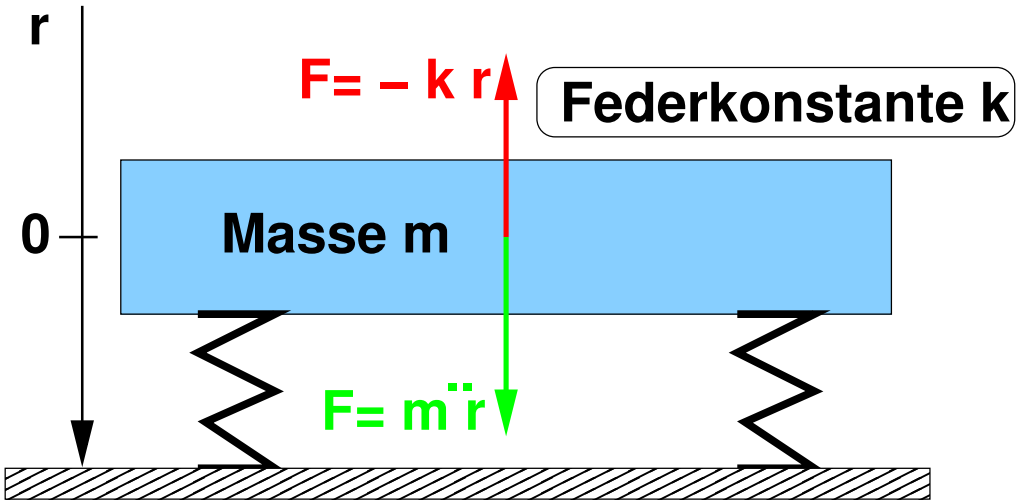
Outline

Vibrations – theoretical Approach

the harmonic oscillator



$$m\ddot{\vec{r}} = \vec{F} = -k\vec{r}$$

$$\ddot{\vec{r}} + \frac{k}{m}\vec{r} = 0$$

$$\ddot{\vec{r}} + \omega^2\vec{r} = 0$$

$$\vec{r}(t) = A\cos(\omega t - \varphi)$$

Note

a) The system needs energy (from outside) to excite vibrations!
b) The ratio k/m determines ω!

Basics of Spectral Analysis

http://numerical.recipes/
chapter 12 and 13

- The (fast) Fourier Transformation (FFT): $h(t) \Longleftrightarrow H(f)$
- Energy conservation, *Parseval's Theorem*

$$W \equiv \int_{-\infty}^{\infty} |h(t)|^2 \, dt = \int_{-\infty}^{\infty} |H(f)|^2 \, df$$

- *(one sided) power spectral density* PSD of a real function

$$P_h(f) = 2|H(f)|^2 \qquad 0 \leq f \leq \infty$$

Note

The integral of the PSD is equivalent to the mean square amplitude rms^2 !

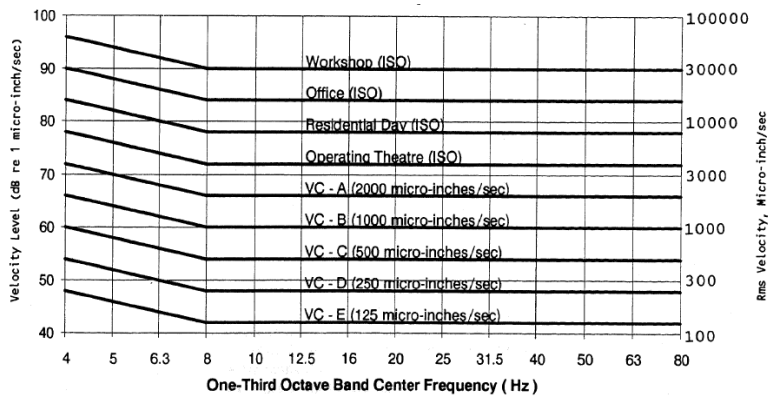
Typical Problems

- artifacts of the discrete Fourier Transformation – aliasing, leakage, windowing.
- The variance of one point of a 'raw' PSD (periodogram) is 100%. Faster sampling or longer time window does not help. solutions: FFT of the auto correlation (Blackman Tukey) or smoothing/ averaging/ rebinning of the periodogram.
- Normalizing of the PSD. Is the PSD a continues function or a discrete function defined just at discrete points? Solution: Plot the running PSD integral (the CSD). (it is usual to start at high frequencies towards the low frequencies).
- use correct units, sometimes we see dB without any reference, not clear if power or amplitude...

Vibration Levels, VC– Lines

Criterion Curve (see Figure 1)	Max Level (1) microinches/sec (dB)	Detail Size (2) microns	Description of Use
Workshop (ISO)	32,000 (90) 813	N/A	Distinctly feelable vibration. Appropriate to workshops and nonsensitive areas.
Office (ISO)	16,000 (84) 406	N/A	Feelable vibration. Appropriate to offices and nonsensitive areas.
Residential Day (ISO)	8,000 (78) 203	75	Barely feelable vibration. Appropriate to sleep areas in most instances. Probably adequate for computer equipment, probe test equipment and low-power (to 50X) microscopes.
Op. Theatre (ISO)	4,000 (72) 102	25	Vibration not feelable. Suitable for sensitive sleep areas. Suitable in most instances for microscopes to 100X and for other equipment of low sensitivity.
VC-A	2,000 (66) 51	8	Adequate in most instances for optical microscopes to 400X, microbalances, optical balances, proximity and projection aligners, etc.
VC-B	1,000 (60) 25	3	An appropriate standard for optical microscopes to 1000X, inspection and lithography equipment (including steppers) to 3 μ line widths.
VC-C	500 (52) 13	1	A good standard for most lithography and inspection equipment (including electron microscopes) to 1 μ detail size.
VC-D	250 (48) 6	0.3	Suitable in most instances for the most demanding equipment including electron microscopes (TEMs and SEMs) and E-Beam systems, operating to the limits of their capability.
VC-E rot: μ m/s	125 (42) 3	0.1	A difficult criterion to achieve in most instances. Assumed to be adequate for the most demanding of sensitive systems including long path, laser-based, small target systems and other systems requiring extraordinary dynamic stability.

- empirical levels for vibration velocity density
- terz (1/3 octave) $\Longrightarrow$ variable band width
- $\Longrightarrow$ log-log scale



C. G. Gordon, SPIE Vol. 1619, (1991), 71–85
VDI Richtlinie 2038 (VDI guideline), Düsseldorf, 2013.

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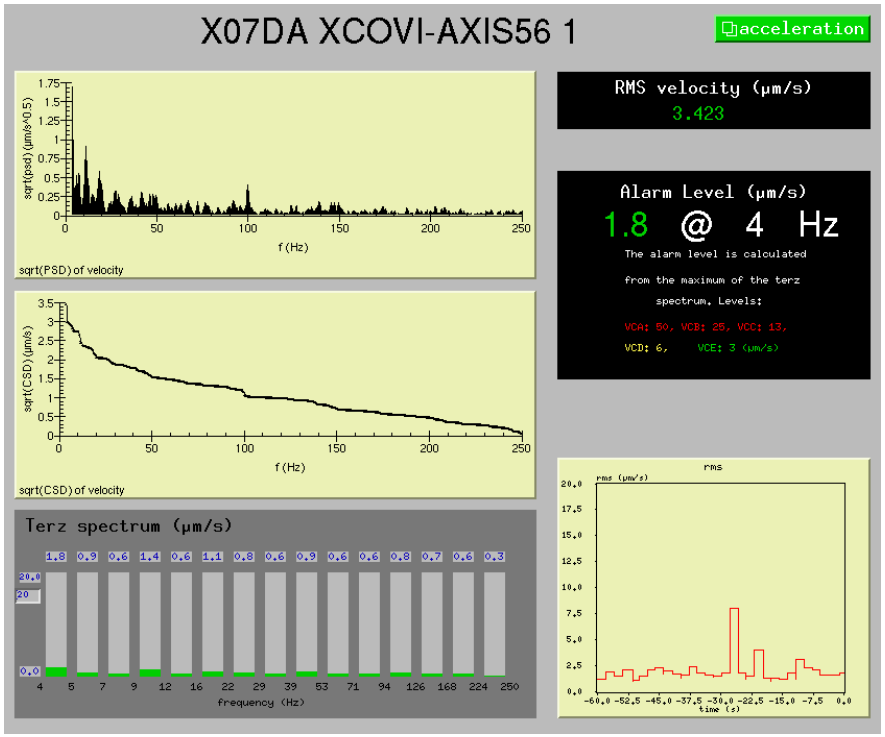
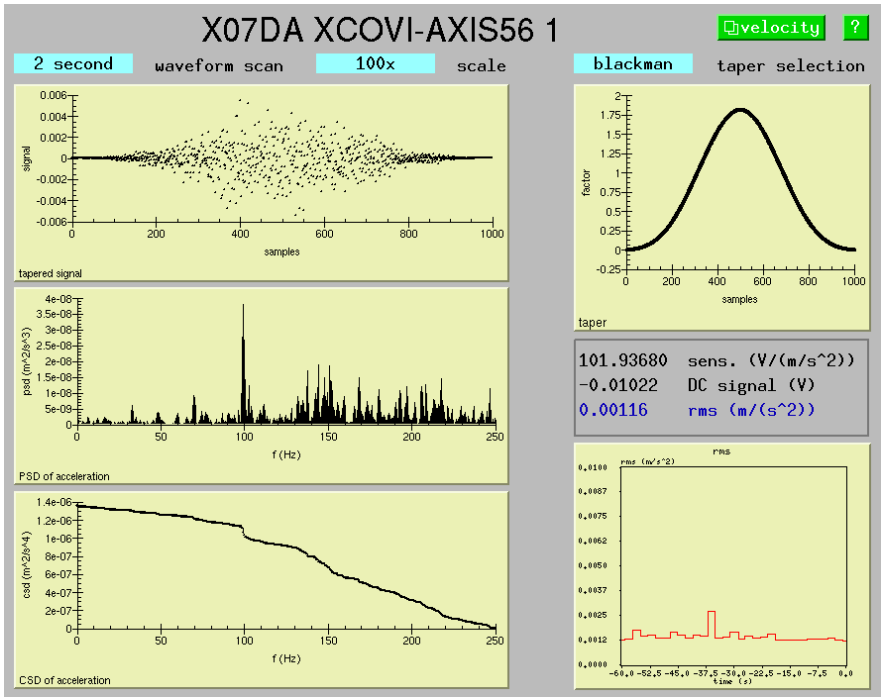
Outline

SLS Vibration Monitoring System

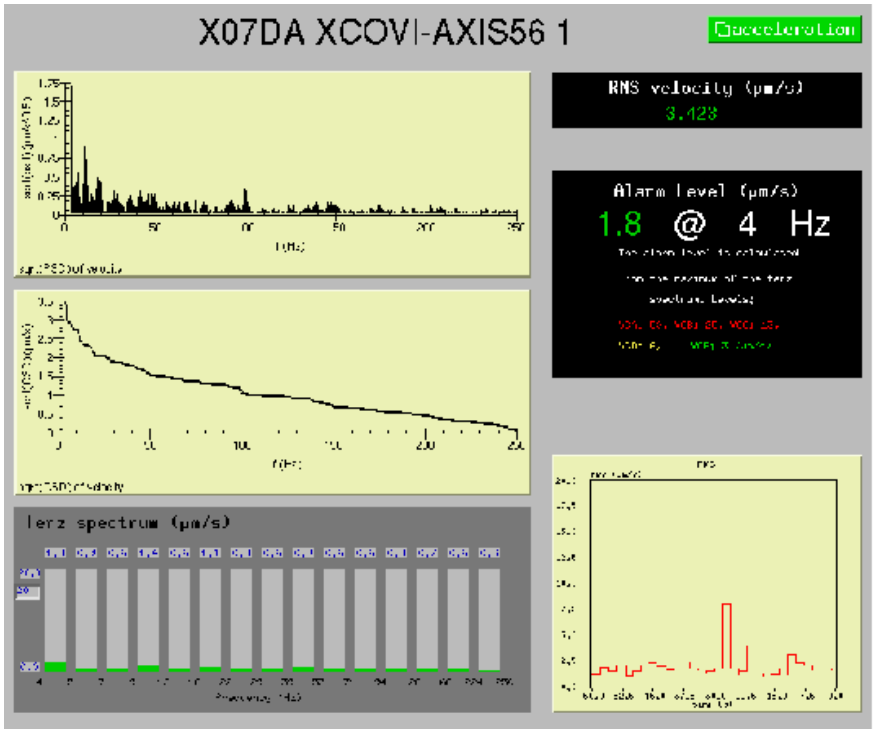
- 4 stations around SLS tunnel
- Sensor: PCB SN 7894, acceleration, 10 V/g, 0.1...200 Hz, (1d vertical)
- ADC 16 bit, VME, 500 Hz, 1 s, update rate 2 s
- "real time" evaluation in EPICS, alarm generation, archiving of statistics (short term and long term)

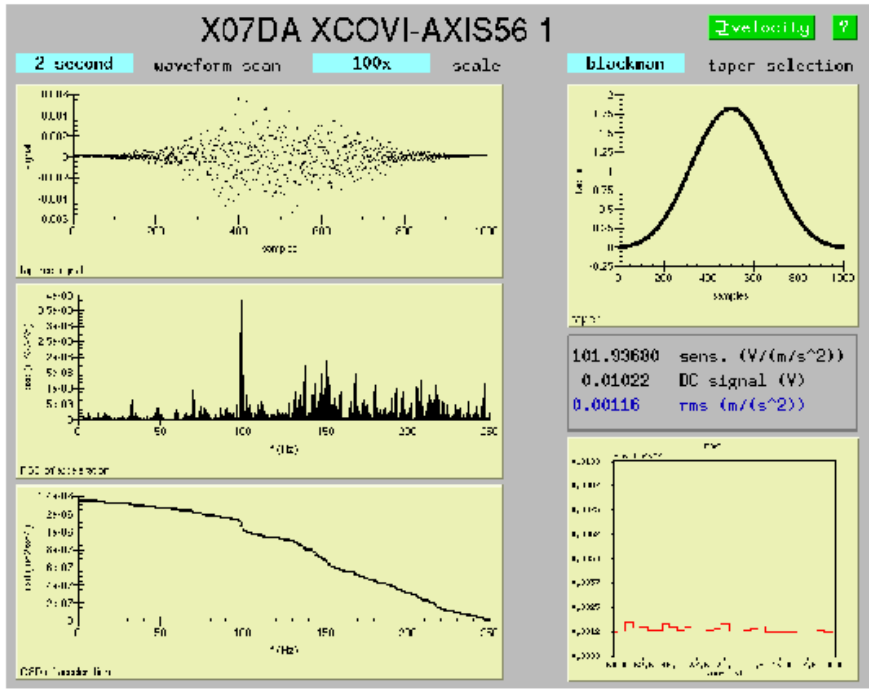
SLS Vibration Monitoring System GUI





SLS Vibration Monitoring System GUI Movie





SwissFEL Vibration Monitoring System

- 1 station with seismometer hooked up to a NAM server (Network Access Module)
- Sensor: Guralp CMG-6TD, velocity, 2400 V/(m/s), 3d, 24 bit ADC
- 200 Hz 3d streams recorded and permanently stored
- real time gcf streaming to Android apps or SCREAM clients (unicast and/or multicast), no EPICS so far
- default evaluation: 1 minute slices, once a month a monthly overview of rms and max and a detailed evaluation on every 15th, since 2013.

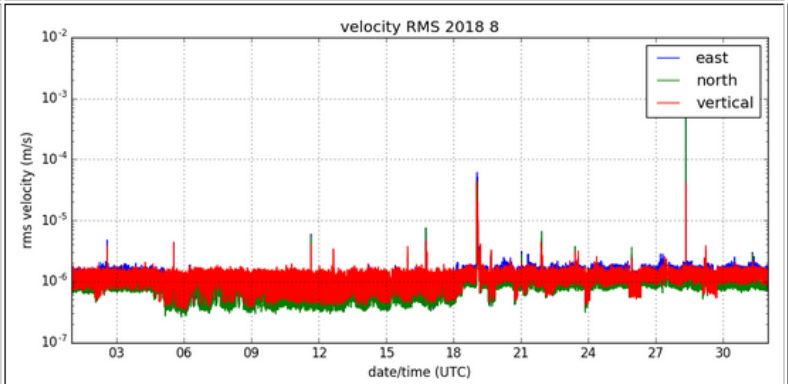
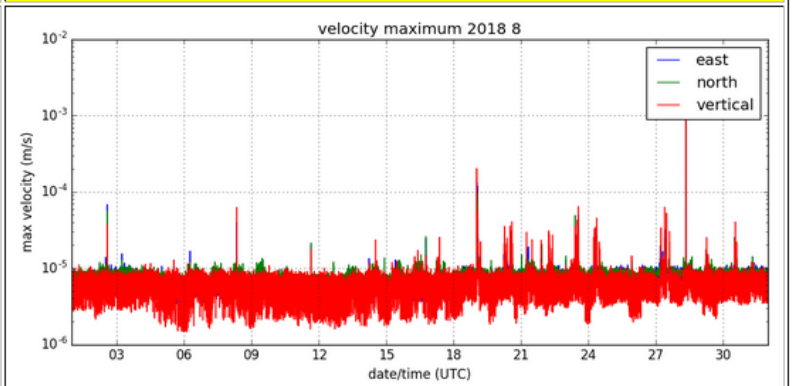
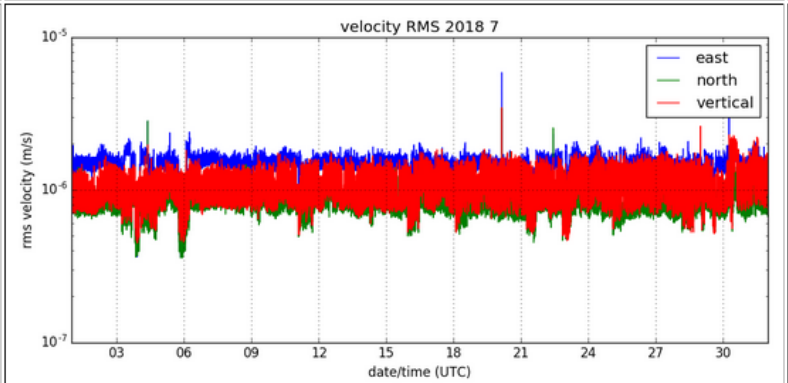
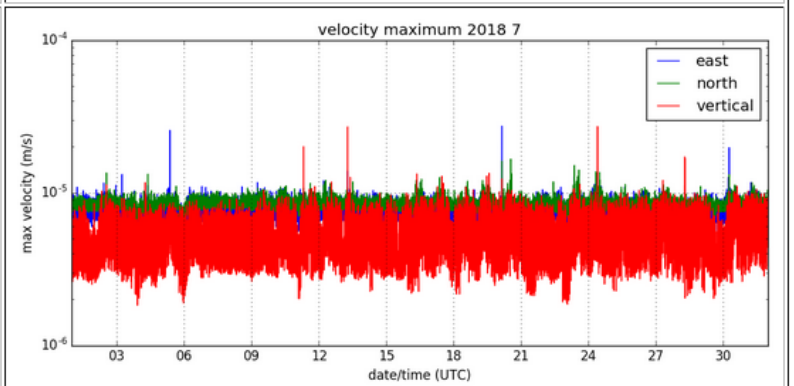
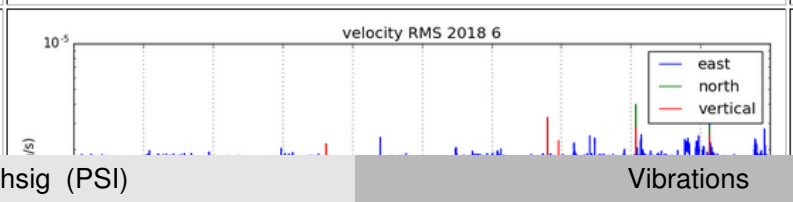
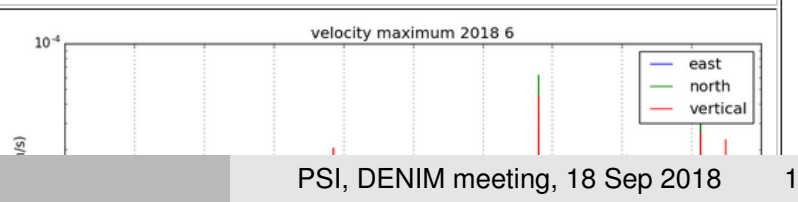
SwissFEL monthly overview

File Edit View History Bookmarks Tools Help

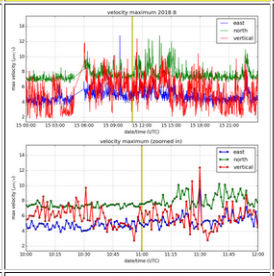
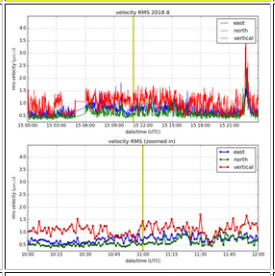
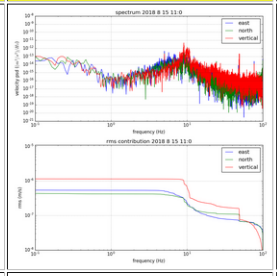
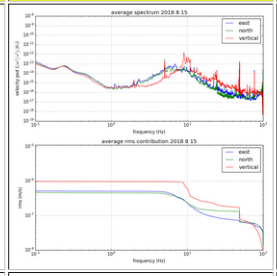
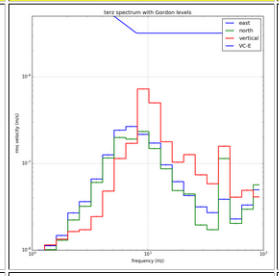
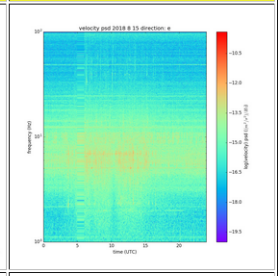
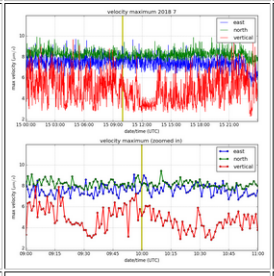
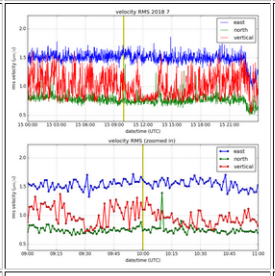
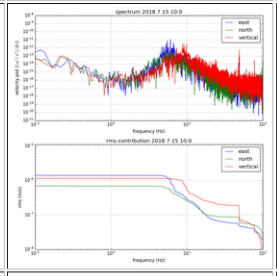
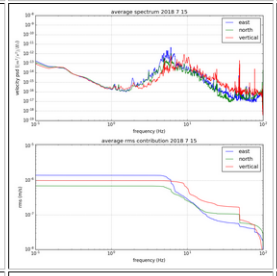
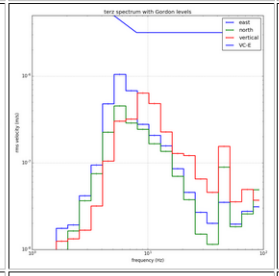
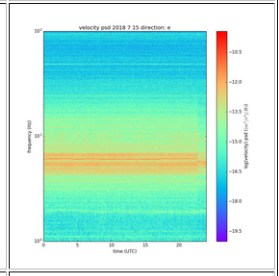
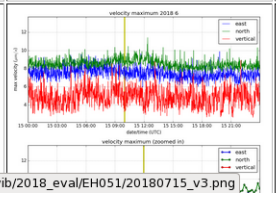
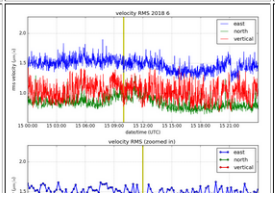
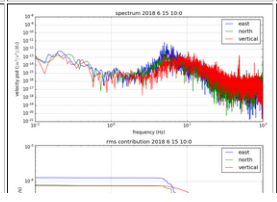
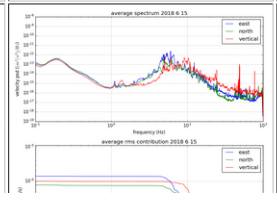
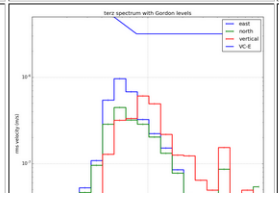
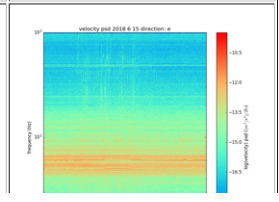
slsbl.web.psi.ch/perl-bin/show-vib.pl?loc=EH051 110% android file transfer li

Interflex group Interflex uwe SLS Optics g21800

SwissFEL EH051 vibration history

month	rms	max
201808		
201807		
		

SwissFEL EH051 vibration details

date&data	max(t)	rms(t)	spectrum 11am	average spectrum	average terz spectrum	psd(t) east
20180815						
20180715						
20180615						

Summary / Outlook

Note

- *avoid excitations, lower the excitation energy*
- *design goal: high k/m ratio i.e. high Young's modulus and low mass (for large scale facilities)*
- *vibration monitoring does not solve the vibration problem but helps to live with unavoidable vibrations*

future trends? noise/vibrations canceling techniques based on fast feedbacks, piezo tables...

The End Thank You PSI site: May 19, 2014