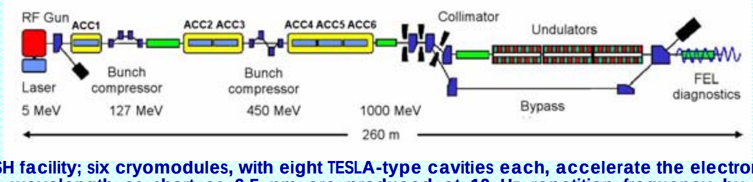
Effects of the Cryogenic Operational Conditions on the Mechanical Stability of the FLASH Linear Accelerator

Ramila Amirikas, Alessandro Bertolini, Jürgen Eschke, Mark Lomperski

Deutsches Elektronen-Synchrotron DESY, 22603 Hamburg, Germany

Motivation

The superconducting linear accelerator (linac) of the European X-ray Free Electron Laser (XFEL) will nominally operate with 0.65 ms long, widely spaced (~200 ns) electron bunch trains, at a pulse repetition rate of 10 Hz. Tight tolerances on energy and position jitter of the 20 GeV electron beam, 0.01% and 10% of the beam size respectively, are demanded for the operation of the photon beam section of the machine. Intra-train feedback systems are foreseen upstream of the undulators to keep these beam instabilities, generated during beam acceleration by a variety of sources, within the specifications. Mechanical vibrations of superconducting quadrupoles and cavities are the most relevant. In this work, we present results of a systematic investigation carried out during several months of normal operation of Free electron LASer in Hamburg (FLASH), using a network of moving coil seismometers (geophones). Results of a preliminary study on the impact of large levels of cavity microphonics on the beam energy are also reported.



Layout of the FLASH facility; six cryomodules, with eight TESLA-type cavities each, accelerate the electron beam up to 1 GeV. Laser pulses with wavelength as short as 6.5 nm are produced at 10 Hz repetition frequency by Self-Amplification of Spontaneous-Emission (SASE) radiation in the undulator section.

Instrumentation

FLASH user facility in DESY

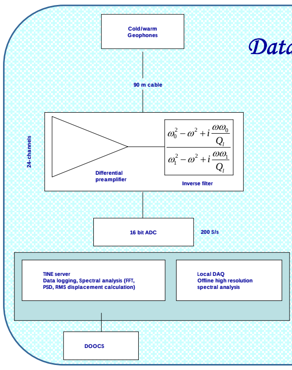
Triaxial sensors on the tunnel floor

Triaxial sensors on each cryomodule vessel top

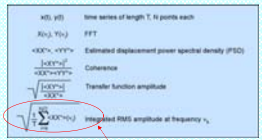
Geophones (H &V) affixed to the front face of each quadrupole

The quadrupoles of Type-II cryomodule ACC3 and of the string of three Type-III modules ACC4, ACC5, ACC6 have been equipped with single axis vertical geophones GS-11D type, with 4.5 Hz spring system and 4000-Ohm coil, from Oyo Geospace. Identical sensors in horizontal (oriented in direction transverse to the electron beam axis) and vertical configuration were installed on top of each vacuum vessel as room temperature reference channels. Two additional horizontal/vertical pairs were placed on the ground of the facility, underneath ACC3 and ACC5, as environmental channels providing amplitude and spectral information on the seismic activity of the site.

Data Acquisition & Analysis



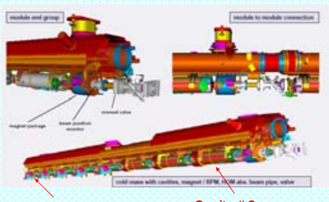
Definitions



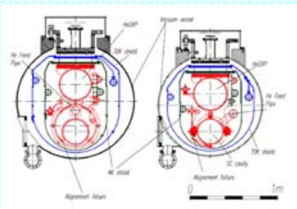
This is What is shown on the DOOCS display.

the RMS displacement, integrated over the 1-100 Hz and 20-40 Hz frequency bands, measured during the last 20.5 sec, updated every ~1 second

Cryomodule & Cavity String layout



XFEL cryomodule layout

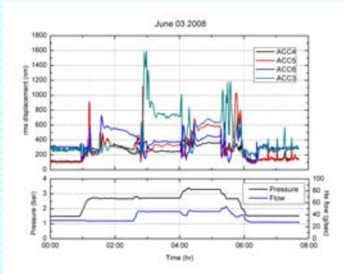


Design differences between type II (left) and type III (right) FLASH/XFEL cryomodules. The location of 4.5 K & 70 K shields are clearly marked (cross section view).

Survey of Cryogenic Plant Cycles in FLASH

The cryogenic plant of DESY went through the following pressure & He gas flow in the 4.5 K shield during three dedicated FLASH accelerator/FEL study shifts, two shifts with electron beam in the linac and one with electron beam and SASE in the undulator section:

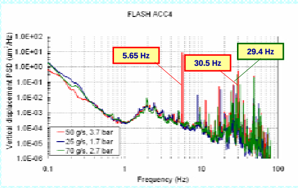
- **1.5 bar, 25 g/s to 2.7 bar, 30-50 g/s**
- **2.7 bar, 50 g/s to 3.3 bar, 50-80 g/s**
- **And back to 1.5 bar, 25 g/s**

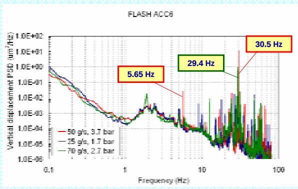


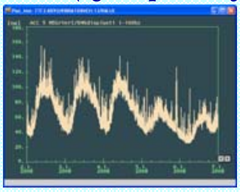
A clear correlation between the He pressure/flow settings of the 4.5 K shield with quadrupole vibration level in every cryomodule (in nm) is observed.

However, no effects from the 70 K shield up to a flow of 45 g/s were observed.

Vibration Survey in the FLASH Linac (Quadrupoles & Ground)

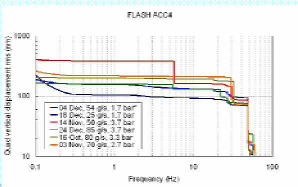


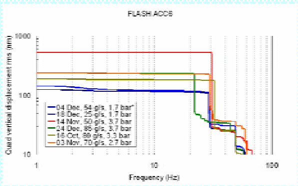


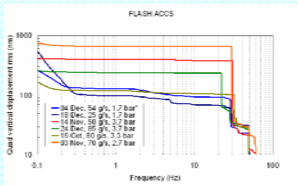


Typical weekly root mean square (rms) of vertical vibration amplitude history (immediate left snap shot) from the DOOCS server as measured on the ground of the FLASH tunnel. The strong influence of the traffic noise is clear from the day/night alternation and the quietness of the weekend days.

This is the lowest vibration amplitude `thinkable' for the quadrupoles in the FLASH linac.







Power Spectrum Densities, PSD (in μm^2/Hz) and rms of vertical vibration (in nm) of the ACC4 & ACC6 quadrupoles are shown, under various cryogenic settings, in the first two panels on the far left together with rms of ACC5 in the lower immediate left panel.

Three typical behaviors are observed as a function of the pressure:

- Low pressure (1.5-1.7 bar) -> low noise
- Intermediate pressure (2.7-3.3 bar) -> appearance of a strong line around 30 Hz
- High pressure (3.7 bar) -> ~30 Hz line plus a low frequency line around 6 Hz

No systematic dependence on the flow has been observed.

Disturbances have the same frequencies along the whole linac.

Vibration Survey in the FLASH Linac (Cavities)

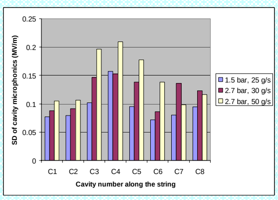


Diagram on the left shows the absolute value of spread (standard deviation) in the microphonics as experienced by the cavities during cycles of the cryogenic plant. It seems that the pressure/flow condition of 2.7 bar, 50 g/s affects the cavities most compared to two phase He condition at 1.5 bar, 25 g/s. As the 4.5 K shield is clamped to the cold mass in the middle of the string (e.g. C4), microphonics are felt most in the middle of the cavity string.

The energy of the electron beam, in the FLASH linac, was monitored during these changes to possibly establish a correlation between cavity microphonics and beam energy fluctuations. These fluctuations even though measurable, are at a 1% level and do not effect the stability of the beam in the linac. In these measurements, RF feedback and feedforward were turned off.

Summary

- **FLASH quadrupole vibration monitoring system has been commissioned successfully and is in full operation.**
- **It is proven to be a very useful tool for the optimization of the cryogenic system operation.**
- **Influence of the 4.5 K circuit settings on the level of microphonics both in cavities & quadrupoles was observed.**
- **For the cavities, the resultant microphonics amounted to measurable phase jitter and gradient change in a few per cent level. These measurements were done with RF feedback and feedforward turned off.**
- **Therefore, The change in the beam energy, although measurable, is in the level of a few per cent.**
- **No change in the level of SASE is observed as a direct result of microphonics in the cavity & quadrupoles along the linac (preliminary result).**

Acknowledgment

This work is supported by the Commission of the European Communities under the 6th Framework Programme "Structuring the European Research Area", contract number RIDS-011899.