Vibration Stability Studies of a Type III+ XFEL/FLASH Superconducting Accelerating Module Operating at 2 K

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Abstract

The European X-ray Free Electron Laser (XFEL) superconducting accelerating modules, containing a string of Niobium (Nb) cavities and a quadrupole, will operate at 2 K. In this paper, vibration stability studies of a high gradient XFEL/FLASH type-III+ superconducting accelerating module with its quadrupole operating at 2 K for the first time and with the latest design of the cryogenic inner layout is reported. These measurements are possible, using geophones, which operate at cryogenic temperatures in both horizontal and vertical directions. In addition, an investigation of vibration stability in relation with positioning of the quadrupole at the end or center of the module is presented.

M8 on the Cryo-Module Test Bench (CMTB) facility in DESY, photo 1 (front) & photo 2 (behind)

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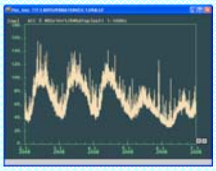
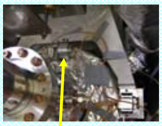


Vertical & horizontal geophones on the vacuum vessel top. Two identical geophones were placed on the tunnel floor for reference, photo 3. Typical day/night, weekday/weekend variations of ground vibrations at DESY site are shown in 4.

Instrumentation for 2 K Operation

M8 during its assembly in DESY

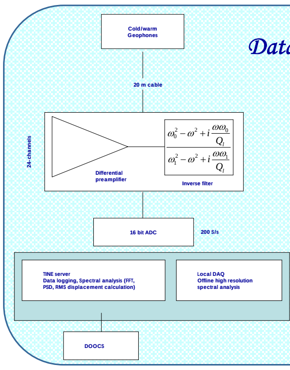
Vertical geophone GS-11D at the center of the cold mass on the bracket supporting cavity #4



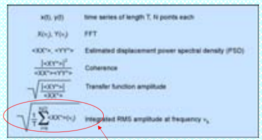
Geophones, vertical & horizontal, affixed to the front face of M8 quadrupole

The cold mass of Module 8 has been instrumented, during its assembly, with three seismic sensors. Two single axis geophones, one vertical GS-11D from Oyo Geospace and one horizontal (oriented in direction transverse to the beam pipe) SM6-HB from Sensor b.V, have been affixed to the front face of the quadrupole helium vessel; an additional vertical GS-11D has been installed at the center of the cold mass on the bracket supporting cavity #4

Data Acquisition & Analysis



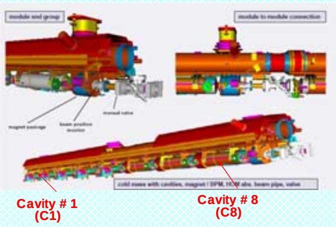
Definitions



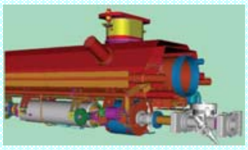
This is What is shown on the DOOCS display.

the root-mean-square (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

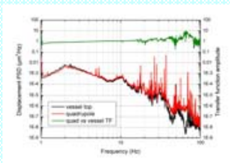


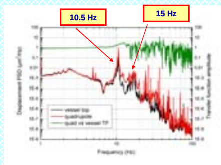
3-D model cut-away view of the Type-III+ cryomodule cold mass end group: from the left the last cavity of the string, the magnet/BPM package, the HOM absorber and the beam pipe valve.

the main modification in Type-III+, compared with Type-III, is the new support of the magnet package and its operation at 2 K, as compared with 4.5 K in FLASH. The magnet package is suspended from the 300 mm diameter Helium gas return pipe using a bearing system that allows axial movement during the cool-down. The axial position with respect to the cavity string is kept constant by connecting the magnet package to the same reference Invar rod. With the operation at 2 K the magnet cryostat is not anymore part of the 4.5 K highly pressurized circuit for the inner shield refrigeration, which, as experienced in FLASH, may produce large excess vibrations.

Vibration Measurements at Room Temperature Using Inertial Sensors (Geophones)

Dynamic mechanical stability of the updated magnet support design was investigated by measuring the transfer function (TF) between the vacuum vessel and the quadrupole. The DESY site ground motion, with rms amplitudes often exceeding 100 nm in the frequency band 1-100 Hz, has been used as broadband excitation source of vibration. In the horizontal transverse direction, the displacement power spectral densities (PSD) are characterized, at low frequency (1-20 Hz), by the large amplitude peaks at 10.5 Hz and 15 Hz, corresponding to rigid body modes of the vacuum vessel on its support system, and at higher frequencies by the number of lines produced by technical noise sources.

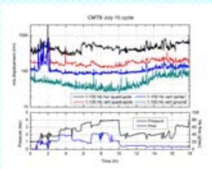


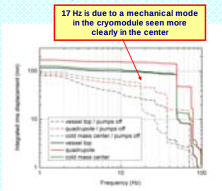


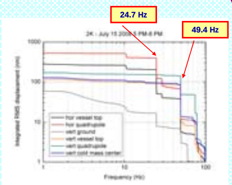
Power spectral densities, PSD (in μm^2/Hz), of quadrupole vs. vessel top in the vertical (left) and horizontal transverse (right) directions

The calculated TF do not show any evidence for mechanical resonances of the quadrupole support structure up to ~50 Hz in the horizontal and up to ~80 Hz in the vertical directions.

Vibration Measurements at 2 K







We have investigated the sensitivity of the vibration level measured on the cold mass to the parameters of the 4.5 K shield circuit, which were found to be rather strong in Type-II and Type-III design. The inlet pressure of the inner shield circuit has been regulated to establish two phases or single phase He; different flow rates have also been tested. No correlation between the parameter changes (even stopping the flow) and the vibration amplitude has been found; Noise spectra were shaped at low frequency (1-20 Hz) by the DESY site ground motion, with the two characteristic traffic induced bumps around 2 and 10 Hz.

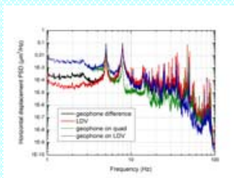
At higher frequencies (f > 20 Hz), technical noise sources are dominating with the two strong lines at 24.7 Hz and 49.4 Hz from the isolation vacuum pumps. In the horizontal transverse direction, the vibration amplitude (integrated from 1 to 100 Hz) was ranging from 400 to 600 nm as a function of the excitation level of the 10.5 Hz rocking mode of the vacuum vessel. In the vertical direction, levels lower than 200 nm, with a large contribution from the vacuum pumps, have been observed.

One of the major changes in the ILC cryomodule design (so-called Type-IV) with respect to FLASH/XFEL is the positioning of the magnet package at the center of the cold mass. Besides alignment issues, the other believed advantage is the reduction of magnet vibrations. Direct comparison between the two vertical geophones installed on the cold mass has shown systematically larger motion amplitude on the quadrupole. However, a detailed spectral analysis shows that the difference is due to impact of technical noise sources, such as vacuum pumps. This effect is discovered as soon as these pumps are switched off. This is expected since the center of the module is the farthest point from the vacuum vessel supports and from the end caps where external forces are applied and thus damping of the signals in the center is observed. The other feature discovered is that the module center is affected by a mechanical mode with a resonance around 17 Hz, which makes it slightly noisier than the quadrupole in the frequency band 1-20 Hz. This mode is also visible on the magnet side, both on top of the vessel and on the quadrupole, but with much lower amplitude.

Validation of Room Temperature Results via Optical Techniques

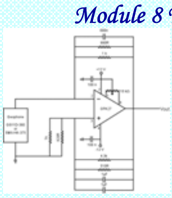
Module 8 is provided with two optical lines of sight from two viewports on the main vacuum vessel towards the quadrupole. Suitable cuts thru thermal shields allow a laser beam to hit diffusive retroreflecting targets to measure the relative motion between the quadrupole and the vacuum vessel along vertical and horizontal transverse directions, both at room and 2 K temperature, via optical interferometric techniques. This measurement was proposed to cross check and further validate the results obtained with the inertial sensors. A room temperature preliminary test was carried out by using a commercial laser Doppler velocimeter (LDV) OFV-505 from Polytec GmbH

Optical line of sight (horizontal)

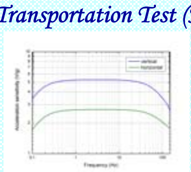


Results, for example, for the horizontal direction show a substantial agreement between the LDV and the geophone difference confirming the quality of the measurements done with inertial sensors.

Module 8 Transportation Test (Hamburg-Saclay-Hamburg)



Overdamping circuit diagram for adaptation the pre-installed geophones for vibration measurements during M8 transportation



Frequency response

The three geophones installed inside M8 (see above) will also be used to monitor the vibrations of the module during its transportation test (Hamburg-Saclay-Hamburg) scheduled by fall this year. For this application, the mechanical dynamic range of the geophones will be extended to few g's by means of a specifically designed overdamping amplifier

The single opamp feedback circuit transforms each geophone into an accelerometer and extend the low frequency (1-10 Hz) acceleration mechanical range from 0.15 to more than 4 g peak-to-peak

Summary

Data presented in this work confirm the results of the previous studies on Type-II and Type-III and the quality of the mechanical design of the FLASH/XFEL cryomodules in terms of vibration stability. The cryogenic tests have shown the vibration level measured on the cold mass substantially independent on the operational parameters of the inner thermal shield, suggesting benefits from the XFEL layout with respect to the FLASH one. The final word on this issue will be given next year when Module 8 will be installed in the FLASH linac. As an input for the ILC engineering design, the comparison between seismic sensors installed along the cold mass didn't show a clear advantage in term of vibration stability in moving the magnet package to the center of the cryomodule, once sufficient care in the vibration isolation of technical noise sources is taken .

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