Vibration stability studies of a superconducting accelerating module at room temperature and at 4.5 K

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In this work we present a collection of results from a systematic investigation carried out at DESY on the mechanical stability of the quadrupole of a third generation (Type-III) FLASH (Free electron LASer in Hamburg) cryomodule (named Module 6). The results are of interest for the International Linear Collider (ILC) [2] and the European X-ray Free Electron Laser (XFEL) [3] cryomodule design, planned in both cases as a further evolution of the FLASH Type III one. Vibration level and mechanical transfer functions (TF) have been measured covering a large variety of conditions: from room temperature to 4.5 K, starting from the installation of the quadrupole on the cold mass during the module assembly and ending with data taken with the cryomodule in fully operating conditions at the CryoModule Test Bench (CMTB) facility.

1 Introduction

FLASH Type-III Module 6 is equipped with a string of eight 9-cell superconducting cavities, capable to operate with an average gradient of ~27 MV/m, and with a superconducting quadrupole located at the end of the module. Cavities, operating at 2 K and the quadrupole, operating at 4.5 K, suspended from the Helium Gas Return Pipe (HeGRP), supported from above by three posts consisting of large diameter thermal insulating fiberglass pipes [4]. The mechanical stability of the quadrupole was investigated by measuring the TFs between the key components of the cryomodule (vacuum vessel, HeGRP, quadrupole) using inertial velocity sensors (geophones and broadband seismometers), and the DESY site ground motion as broadband excitation source of vibrations (The root mean square (rms) displacement in the 1-80 Hz band can exceed 100 nm during working days [5]). This approach allows to discriminate the effect of the internal mechanics of the module from the effects of the cryostat support/girder and from environmental vibration sources, providing a picture which is totally site independent, therefore, usable for the ILC and the XFEL module design and for beam dynamics simulations.

2 Room temperature measurements

2.1 Quadrupole versus vacuum vessel

The displacement PSD spectra are dominated at low frequencies (1-20 Hz) by the effects of the rigid body modes of the cryostat on it supports, and at higher frequencies by technical noise sources. The TF measurements (Figure 1) have shown no evidence for mechanical resonances up to ~ 40 Hz in the horizontal transverse direction and up to ~ 70 Hz in the vertical direction.

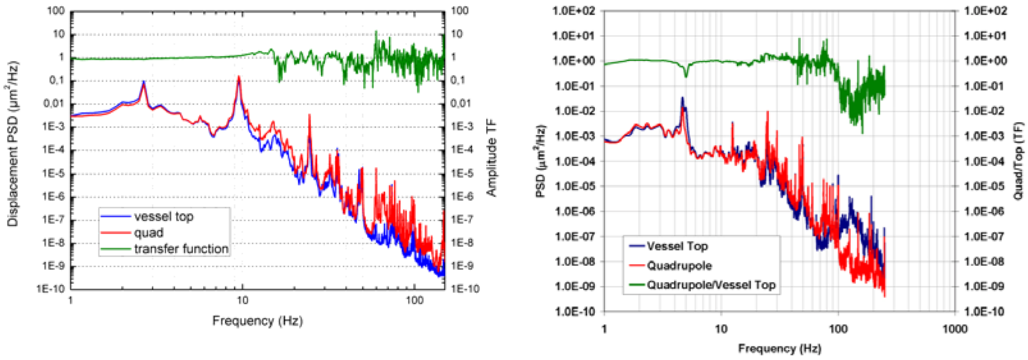

Figure 1: Quad vs.vessel top horizontal (left) and vertical (right) displacement PSDs and TFs.

2.2 Quadrupole versus HeGRP

The quality of the connection between the quadrupole and the HeGRP was tested first on the the Module 6 cold mass before the installation in the vacuum vessel (see Figure 2 left side).

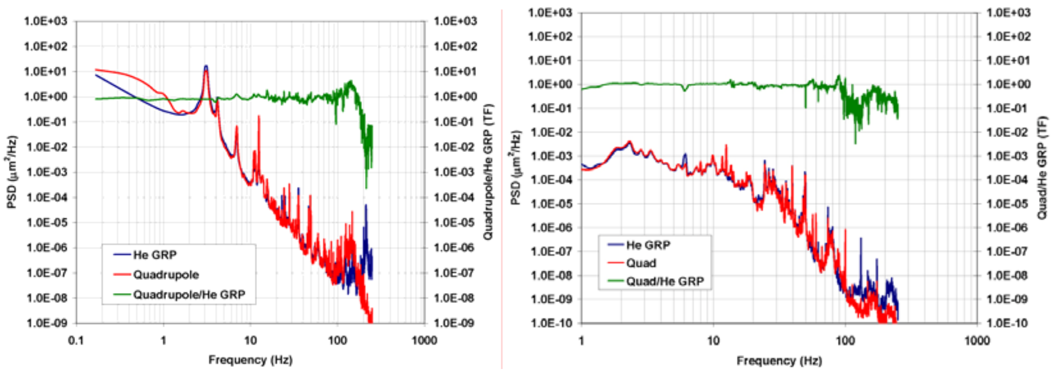

Figure 2: Quad vs. HeGRP: (left) horizontal displacement PSDs and TF measured during Module 6 assembly; the peaks below 10 Hz in the PSD are resonances of the assembly stand; (right) vertical displacement PSDs and TF measured with Module 6 on the CMTB.

The measurement was repeated on the module fully assembled and installed on the test bench to confirm the results (see Figure 2 right). Transfer functions show the absence of internal resonances up to 100 Hz in both vertical and horizontal transverse directions.

2.3 Stability along the module

The reduction of the vibration level is believed to be a reason for positioning of the quadrupole at the center of the cryostat. This is perhaps the major change in the ILC cryomodule design (Type-IV) with respect to the FLASH Type-III and future XFEL cryomodule prototype.

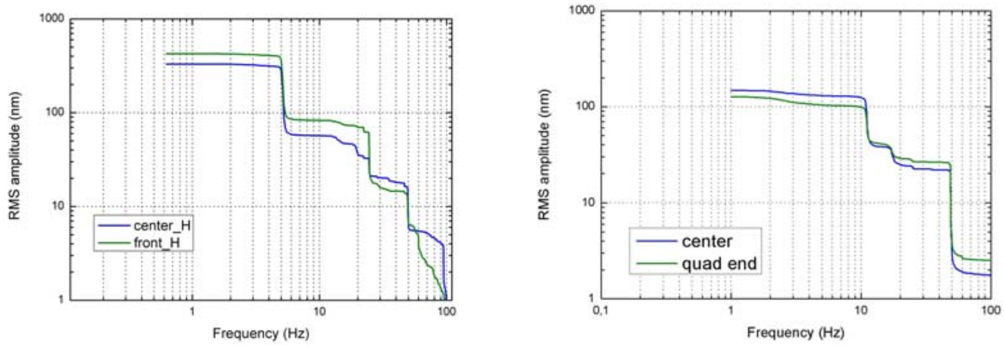

Figure 3: Quadrupole end vs. center horizontal rms comparison: inside the HeGRP with the module sitting on concrete blocks (left). On top of the vessel with Module 6 installed on the CMTB (right); in this configuration, a slightly larger amplitude was measured at the center.

To make a preliminary comparison between the two layouts, geophones have been positioned along the Module 6 length inside the HeGRP. In the horizontal axis the data show an integrated rms amplitude larger (up to ~ 30 % from 2 to 100 Hz) at the quadrupole end with respect to the center of the module (see Figure 3 left). Smaller differences (~ 10 %) were found in the vertical direction. Similar results were obtained by repeating the test on top of the vacuum vessel. Data taken at the CMTB (Figure 3 right) show a better matching and the clear influence of the cryostat supports (transverse rocking mode moved from 4.7 to 11 Hz, with a better girder-support interface and connection of the module to the endcaps).

3 Measurements at 4.5 K

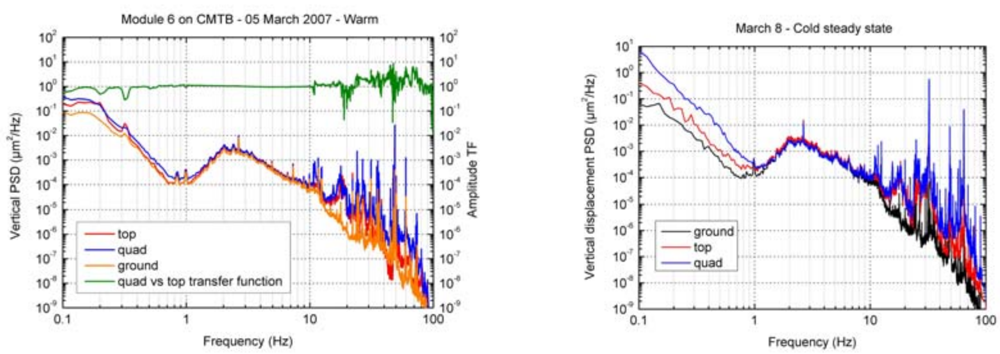

Figure 4: PSD spectra measured on the CMTB floor, on top of the vacuum vessel and on the quadrupole at room temperature (left), and in cold steady state with RF off (right).

Vertical vibrations of the quadrupole at 4.5 K have been measured using a commercial geophone [6]. The sensor could operate at cryogenic temperatures without loss of sensitivity, providing nanometer resolution even in the 1-10 Hz frequency band, region not covered by the existing data because of the lack of resolution of cooled piezo accelerometers [7]. No difference (Figure 4) between reference room temperature data and measurements done during cold operation was found up to 30 Hz: the quadrupole position simply tracks the ground motion, with some amplification due to the effects of the vessel supports (coupling with the rocking modes at 11 and 18 Hz, resonance at 27 Hz). At higher frequencies, besides the common lines from the technical systems (the insulation vacuum pump at 48.6 Hz the strongest one), the onset of a strong anharmonic vibration, with fundamental frequency ~30 Hz, detectable both inside and outside of the cryostat and on the hall floor, was observed. The effect, not related to the module design, has been identified as a thermal acoustic oscillation originated by a flow sensor, with direct transition to room temperature, installed outside of the cryomodule upstream of the inlet valve of the quadrupole 4.5 K feed line [8]. A clear correlation between the vibration amplitude (ranging from 200 nm up to one micron rms on the quadrupole) and the settings of the same valve was in fact discovered, and no similar phenomenon was observed afterwards during the tests of Module 5 Type-III cryomodule [9]. No effect from the high power RF was observed in this experiment (data not shown here).

4 Summary

This study has proven the reliability of the FLASH Type III mechanical design with the quadrupole at the end of the module. In the frequency range 1-10 Hz, vibration spectra of the quadrupole are shaped by the local seismic activity. Amplification of the ground motion, mostly in the horizontal axis, only occurs due to the rigid body modes of cryostat on its supports, perhaps the most relevant engineering issue to improve the quadrupole stability. At high frequencies (> 20 Hz) lines from technical noise sources are dominant. A continuous monitoring of the FLASH linac cryomodules, using cooled geophones, is planned to confirm during machine operation the promising results obtained at the CMTB.

5 Acknowledgements

The authors would like to thank the DESY MKS Division. 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.

6 References

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