VIBRATION STABILITY STUDIES OF A SUPERCONDUCTING ACCELERATING MODULE AT ROOM TEMPERATURE

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Abstract

Both the European X-ray Free Electron Laser (XFEL) [1] and the proposed International Linear Collider (ILC) [2] will rely on superconducting accelerating modules (cryomodules) for their linear accelerator (linac) section/s. In this paper, vibration stability studies of a type III cryomodule with relation to its mechanical design, at room temperature, have been presented. Results of this study are relevant for the design of both the XFEL and the ILC module prototypes.

INTRODUCTION

The cryomodule studied is of type III [3] and is equipped with eight 9-cell Niobium cavities, six of which are capable to operate at a nominal gradient of 31.5 MV/m, and a quadrupole package at the end of the module, supported by a Helium gas Return Pipe (HeGRP) from above. For ease of reference, it is named 'Module 6' as it is the 6^{th} cryomodule in a series built and installed in the Free electron LASer in Hamburg, (FLASH) tunnel at DESY. Type III is a further design evolution of type II cryomodules which were first developed for the proposed Tera-Electronvolt Superconducting Linear Accelerator (TESLA) in the 1990s. The major differences of Type III cryomodules with respect to Type II are a reduced diameter of the vacuum vessel and therefore, the use an off-axis Helium feed pipe instead of placing it below the HeGRP, sliding supports for the cavity string in order to keep the cavity string fixed in the transverse position, but at the same time keeping its longitudinal motion independent of the supporting HeGRP during cooldown and changing the position of the support posts on the vacuum vessel tank to match the position of the quadrupole package at the end of the module. Vibration stability measurements of a Type II cryomodule were reported earlier [4, 5]. This paper is divided into three sections: first, vibration stability within 'Module6' is presented. Afterwards, the effect of the external module support system is discussed. Finally, data of vibration stability along the module are shown.

METHODOLOGY

Even though the XFEL/ILC linacs will operate at 2 K, before studying possible quadrupole vibrations at cryogenic temperatures, it is imperative to gain an understanding of a cryomodule mechanical stability at room temperature to facilitate comparison. More than one cryomodule at any one time and repeated measurements over a longer span of time should be attempted to check reproducibility of the results. Moving the module to different locations and repeating the measurements can disentangle ambiguities of external sources of vibration such as facility noise.

In this study, mechanical stability of 'Module 6' was studied from its inception, when it was a string of cavities and a quadrupole connected to HeGRP from above, until it was fully assembled in the vacuum vessel tank. Ground motion at DESY can be > 100 nm during day time [6] and hence it was used as broadband excitation source of vibrations.

The equipment and data analysis tools employed in this study were the same as [4], i.e., two Güralp CMG-6TD broadband tri-axial digital output seismometers (frequency response: 60 s-80 Hz) and 4 single axis vertical/horizontal geophones, Model SM-6 of Sensor. The seismometers could be placed inside the HeGRP and on the vessel top. However, due to space constraints on the quadrupole package, geophones were utilized. Measurements of the floor and/or the support stand were also undertaken as a reference measurement. Velocity signals taken at a sampling rate of 200 Hz were Fast Fourier Transformed (FFT) and displacement Power Spectrum Density (PSD) and integrated root mean square (rms) of these spectra, in the frequency range f > 1 Hz, were calculated. The techniques of analysis are described in [6]. If $X(f_i)$ and $Y(f_i)$ are two FFT signals in the frequency (f_i) domain, then the estimated displacement PSDs of the two signals are, $<XX^*>$ and $<YY^*>$ respectively and their transfer function (TF) is defined as:

$$TF = \sqrt{\frac{|<XY^*>|}{<XX^*>}} \qquad (1)$$

MECHANICAL STABILITY OF TYPE III CRYOMODULES

Helium Gas Return Pipe versus the Quadrupole

Fig. 1 is the displacement PSD of the quadrupole versus HeGRP, in the horizontal transverse direction to the beam pipe, in its initial assembly phase as a string of cavities and the quadrupole package, supported by the HeGRP, from above. The low frequency resonances at ~3, 4 and 7 Hz are due to the assembly stand. Frequencies ~ 12, 24, 35, 39, 49 and 74 Hz are due to technical noise and are depicted everywhere at the DESY site. TF as shown in Fig. 1 is ~1 up to a frequency of 100 Hz. No internal resonances within the quadrupole and HeGRP acting as its support are visible. The ratio of the integrated rms of the quadrupole versus HeGRP in the horizontal transverse direction is ~20% at f > 1 Hz. These measurements were repeated once the module was fully assembled in the vacuum vessel tank. Fig. 2 shows a

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displacement PSD, in the vertical direction. The ratio of the integrated rms of the quadrupole versus HeGRP is better than 10% in the vertical direction at f > 1 Hz. For example, at f ~ 2 Hz, the rms displacements of both the quadrupole and the HeGRP are ~65 nm. Therefore, this system exhibits similar behavior in both directions and before and after assembly inside the vacuum vessel tank.

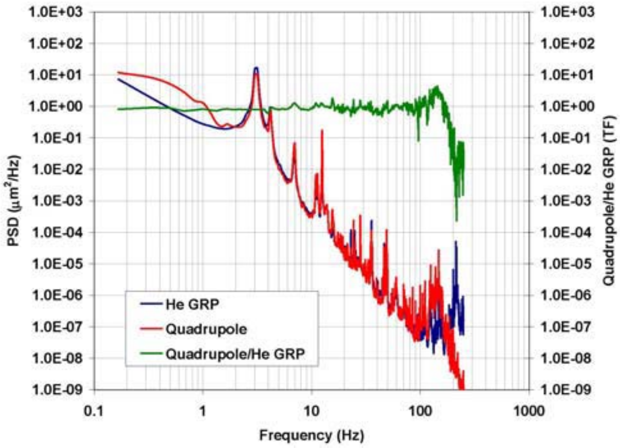

Figure 1: Displacement PSD of HeGRP versus the quadrupole of 'Module 6', in the horizontal transverse direction, before its assembly in the vacuum vessel tank and the corresponding transfer function between the two signals; measured on 1 June 2006 at DESY Hall III.

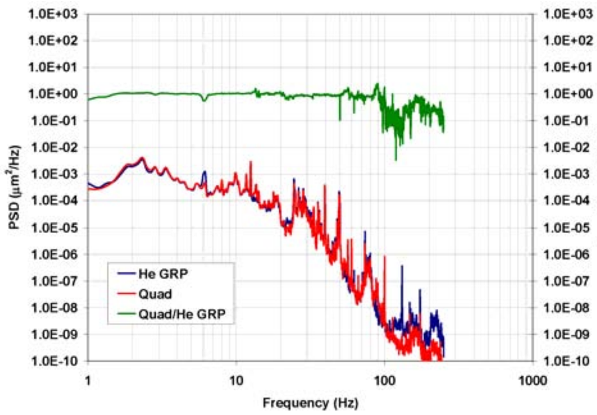

Figure 2: Displacement PSD of HeGRP versus the quadrupole, in the vertical direction, after the cold mass assembly in the vacuum vessel tank. The module was placed on the Cryo Module Test Bench (CMTB) at DESY; measured on 25 August 2006.

Quadrupole versus Vacuum Vessel Tank

PSD spectra were also measured between the quadrupole and the vacuum vessel top. Fig. 3 is a measurement, in the horizontal transverse direction, on the CMTB. No internal resonances, in going from the quadrupole to the vacuum vessel top, are evident in the TF. The ratio of the integrated rms of the quadrupole versus vessel top is ~20% at f > 1Hz. Similar results are also obtained in the vertical direction.

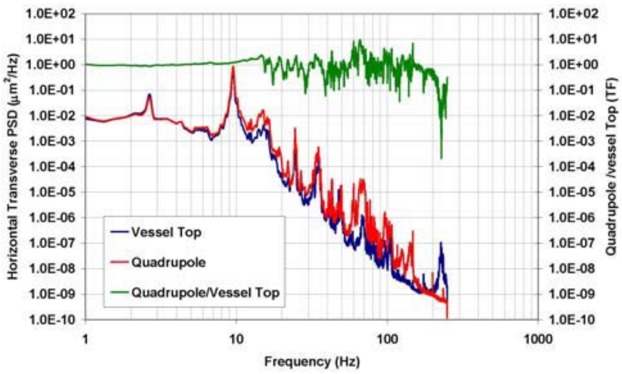

Figure 3: Displacement PSD of the vacuum vessel top versus the quadrupole in the horizontal transverse direction and its corresponding transfer function, on the CMTB; measured on 12 February 2007.

THE EFFECT OF EXTERNAL MODULE SUPPORT SYSTEM

In the previous section, it was demonstrated that the internal structure of 'Module 6' is rigid with respect to vibration stability. However, the way a module is supported externally, whether suspended from the ceiling of a tunnel, as will be in the case of the XFEL, or on the tunnel floor, in the case of the ILC, has profound influence on the vibration stability of the whole system. A combination of the cryomodule mass and a 'soft' support system can produce low frequency resonances in the whole system. In addition, a good support/girder design aims at pushing the internal resonances of the structure to as high frequency values as possible. Fig. 4 shows the PSD of the vessel top versus the floor of Hall III in DESY, in the horizontal transverse direction. Here, the module was placed on concrete blocks on its two ends.

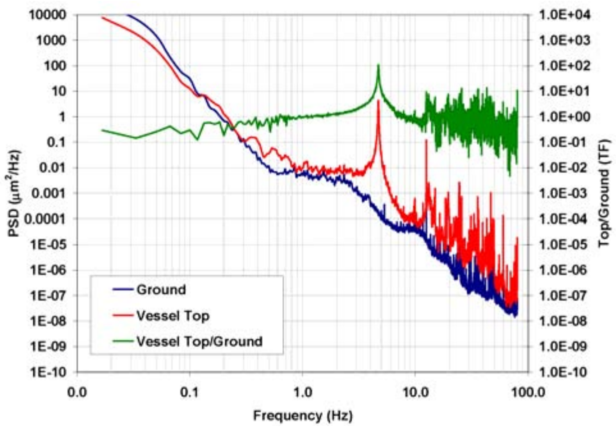

Figure 4: Displacement PSD of vessel top versus the ground in the horizontal transverse direction. The resonance of the cryomodule support at 4.7 Hz is clearly visible in the corresponding TF; measured on 23 June 2006.

The origin of the 4.7 Hz resonance seen on the vessel top stems from rocking modes of the module moving as a

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whole on its support system and the TF in Fig. 4 supports this conclusion. This is also seen in Fig. 3, albeit at a frequency of 11 Hz since the bellows and endcaps of the module were closed for the cool down cycles. In this case, as the module became 'stiffer' due to these connections, these low frequency modes were pushed to higher values.

VIBRATION STABILITY STUDIES ALONG THE CRYOMODULE

In Type III cryomodule design, the quadrupole has been placed at the end. Vibration stability along the 12 meter long module was investigated to compare the center of the module with the end by placing sensors on the vessel top and inside the HeGRP at both the quadrupole side end and the middle of the module. Fig. 5 shows a comparison of the vibration measurements taken inside the HeGRP in the quadrupole side and the center of the module. The difference between the rms spectra of these two positions is ~30%. This picture improves by having stiffer support system and in general, the difference between center and either end of the module is even less in the vertical direction. Fig. 6 shows rms spectra, in the vertical direction, when the module was placed on the CMTB (better support system) and the encap bellows were closed. At low frequency, e.g. f = 2 Hz, the rms value of the vessel top in the center position is 71 nm and on the quad side, 65 nm.

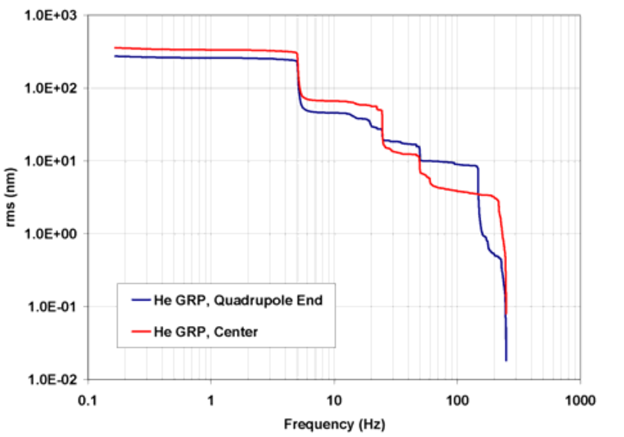

Figure 5: Integrated displacement PSD spectra inside He GRP in two positions along the module, quadrupole end and center in the horizontal transverse direction; measured on 24 July 2006.

CONCLUSIONS

The internal design of the type III cryomodules is shown to be reliable with respect to vibration stability issues. No internal resonances are seen between the vessel top, HeGRP and the quadrupole up to a frequency of at least 50 Hz in both directions. This conclusion is independent of the level of the ground motion in a particular site. However, stability of the module support system, whether a module is suspended or is positioned on the tunnel floor, is imperative in total vibration stability of the system. Low frequency resonances of the girder/module support system can push the rms to high values and hence mask the real stability features of the system. Vibration measurements along the module indicate the rms difference between the center and one end of the module is ~30% in the worst case. With improved support system, this figure improves considerably.

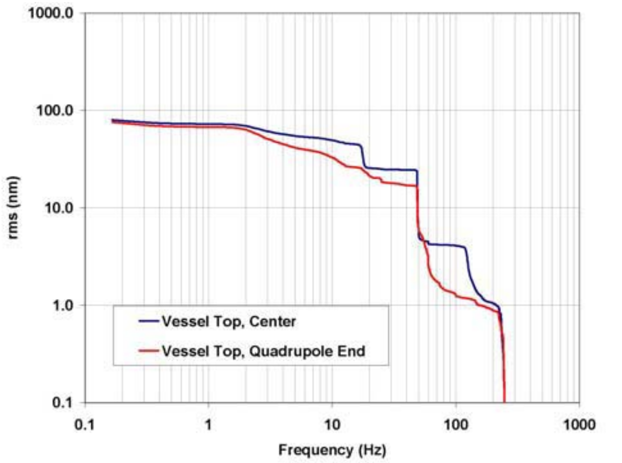

Figure 6: rms measured in two positions along the module on the vacuum vessel top, at quadrupole end and center in the vertical direction; measured on 23 January 2007.

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