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# MONITORING THE FLASH CRYOMODULE TRANSPORTATION FROM DESY HAMBURG TO CEA SACLAY: COUPLER CONTACT, VACUUM, ACCELERATION AND VIBRATION ANALYSIS

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*Abstract*

With a view to the series production of one hundred, 12 m long XFEL 1.3 GHz cryomodules and their transportation from the assembly site at CEA Saclay (F) to the installation site at DESY Hamburg (D) a test transportation of a FLASH cryomodule has been performed, in the condition foreseen for the mass transportation. The present study examines the stresses induced on the module and verifies the damping capabilities of the transport frame in order to minimize risk of damage to the most critical components. During the transportation, acceleration and vibration have been monitored as well as coupler antenna contacts and vacuum performances. This paper describes the analysis performed and compares those results to the data of a similar transportation study at Fermilab for the CM1 cryomodule.

## INTRODUCTION

An industrialization study of the XFEL cryomodule production and installation was performed and the results highlighted a critical point in the cryomodule transport between the assembly site in CEA Saclay and the installation site at DESY Hamburg. The study reports a critical acceleration value of 1.5 g for the vertical and longitudinal directions (risks of coupler damages) and a limit value of 1 g in the transverse direction (corresponding to a 45° inclination of the cold mass).

A transportation tool has been therefore designed to keep the accelerations on the module below those limits.

A test transportation of an assembled cryomodule has been done and a set of measurements has been performed to verify the tooling and record the maximum accelerations. Thanks to the installed geophones existing inside the module, a vibration analysis has been performed, to study the cryomodule and cold mass vibrations induced during the transportation.

## SET UP AND INSTRUMENTATION

### *Module supporting frame and dampers*

The cryomodule is supported with a metallic frame consisting of two cages, one fixed to the truck and the other damped with helical coils in a compression-roll configuration connected to the cryomodule. The coils are designed to attenuate the shocks between the base frame and the module.

The supporting system includes two end-caps to lock the helium gas return pipe position at the end position and to avoid transversal movement of lateral supporting posts which can cause stresses in the epoxy glass pipes.

Figure 1: The damping frame, the coils and an end cap.

### *Instrumentation*

The module is equipped with the following instrumentation:

- 4 vacuum gauges: 2 monitoring the vacuum level in the coupler line (static vacuum), 2 for the beam line vacuum (cavities travel in static vacuum condition);
- a circuit to monitor coupler antenna shorts;
- 2 independent systems of accelerometers: Monilog and Sensr GP1 sensors (each system with a sensor on the fixed frame and one on the damped one);
- 4 geophones: 3 already installed inside the module (one on the center cavity, 2 on the magnet) and one on the damped frame. The geophones are equipped with a feedback circuit to extend the low frequency (1-10 Hz) acceleration mechanical range from 0.15 to more than 4 g peak-to-peak [1].

The data measured by the gauges, the coupler circuit outputs and the geophones were recorded through a stand alone data logger with a sampling rate of 180 sample/s, allowing a good quality Fourier analysis.

Figure 2: The installed instrumentation.

## SUMMARY OF THE TRAVEL

The truck left DESY Hamburg on the 3rd of November 2008 and reached CEA Saclay after ~24 hours. The cryomodule was uploaded from the truck and removed from the supporting frame to test the CEA ability to handle a cryomodule. Then the module was uploaded to the truck which left Saclay on the 5th of November. The truck had a technical incident 150 km north from Paris and needed to be towed away from the highway with the trailer. The truck change operations were smooth and did not produce critical impacts on the module, however they caused the memory of the data acquisition system to saturate before the end of the travel. The cryomodule arrived at DESY on the 7th of November.

## DATA ANALYSIS

### *Coupler antenna shorts and vacuum gauges*

No coupler antenna shorts were detected during the module uploading, transportation and unloading.

The gauges registered a stable value of vacuum in the coupler and beam lines.

### *Accelerometers*

Figure 3 shows an example of the time behaviour of the acceleration measured during the travel. The night stop and other shorter stops can easily be recognized. Moreover, no peak shocks where measured by the sensor, while continuous vibrations were recorded during the trip.

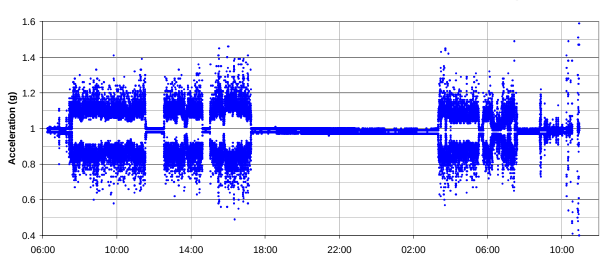


Figure 3: Data recoded by the accelerometer on the inner frame during the travel to Saclay on the vertical direction.

The following tables resume the data recorded by the two independent accelerometer systems positioned on the inner and outer frame. Slightly different values recorded by the two independent systems are related to different settings of the accelerometers (for example integration time and acceleration range).

Table 1: Accelerations measured on the inner frame

| **Inner Frame** | **to Saclay** | | | **to Hamburg** | | |
|---|---|---|---|---|---|---|
| *Maximum values* | *X [g]* | *Y [g]* | *Z [g]* | *X [g]* | *Y [g]* | *Z [g]* |
| MoniLog | 0.55 | 0.63 | 1.11 | 0.55 | 0.86 | 1.42 |
| GP1 | 0.62 | 0.77 | 0.49* | 0.39 | 0.47 | 0.46* |
| *Minimum values* | *X [g]* | *Y [g]* | *Z [g]* | *X [g]* | *Y [g]* | *Z [g]* |
| MoniLog | -0.59 | -0.58 | -1.18 | -0.47 | -0.87 | -1.30 |
| GP1 | -0.22 | -0.39 | -0.51* | -0.29 | -0.44 | -0.52* |

* Data without earth gravity offset

Table 2: Accelerations measured on the outer frame

| **Outer Frame** | **to Saclay** | | | **to Hamburg** | | |
|---|---|---|---|---|---|---|
| *Maximum values* | *X [g]* | *Y [g]* | *Z [g]* | *X [g]* | *Y [g]* | *Z [g]* |
| MoniLog | no data: threshold too high (2g) | | | 0.5 | 1.26 | 1.93 |
| GP1 | 1.32 | 0.86 | 1.19* | 0.55 | 0.78 | 1.33* |
| *Minimum values* | *X [g]* | *Y [g]* | *Z [g]* | *X [g]* | *Y [g]* | *Z [g]* |
| MoniLog | no data: threshold too high (2g) | | | -0,43 | -1,37 | -1,25 |
| GP1 | -0.54 | -0.75 | -1.21* | -0.66 | -0.63 | -0.96* |

* Data without earth gravity offset

In the inner frame, i.e. on the cryomodule, the maximum measured values are within the required limits of 1.5 g in the vertical and longitudinal direction (Z) and 1 g in the transverse (Y) direction.

### *Geophones for vibration monitoring*

The frequency analysis procedure has been the following:

- Divide the travel data in sub-periods (truck running, night stop, shorter stops).
- Perform a spectrogram for each geophone, for each sub-period. FFT length in the spectrogram set at 2 s.
- Select the most representative range and plot Power Spectrum Density (PSD) for each geophone. Chosen range: data recorded on the way to Saclay on the 3rd of November between 16:00 and 18:00.
- Define the frequency peaks and compare them with theoretical data and CM1 transport data.

Spectrogram analysis shows no strange behaviour during transportation (similar data even after truck change). Some frequencies around 50-60 Hz where observed while the trucks were stopped, but a postanalysis of the instrumentation showed there were no relationship with the vessel movement.

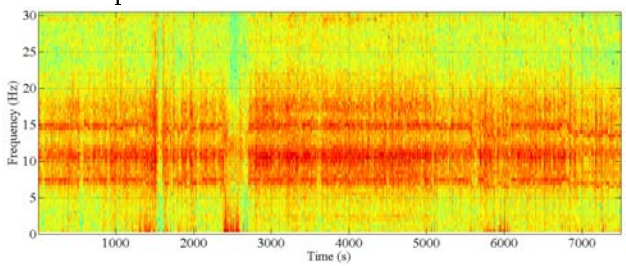


Figure 4: Spectrogram of the selected range, geophone 4 (vessel vertical movement). Frequency range: 0 – 30 Hz. Three frequencies can be recognized ~7, ~11 and ~15 Hz.

A comparison of the obtained spectrograms shows that frequencies repeat in the four graph and are presumptively frequencies due to an overall movement of the structure cryomodule and frame, rather then excited modes of a specific part. The frequencies are shown in table 3.

Table 3: PSD results for each geophone

| Vessel longitudinal *f (Hz)* | Cavity vertical *f (Hz)* | Quadrupole transverse *f (Hz)* | Quadrupole vertical *f (Hz)* |
|---|---|---|---|
| --- | 2 | 2 | --- |
| 7 | 7 | 7 | 7 |
| 11 | --- | 11.5 | 11 |
| --- | --- | 14 | --- |
| 15 | --- | --- | 15 |
| --- | --- | 18 | --- |
| --- | --- | 20 | --- |

### *Comparison with Fermilab CM1 transportation*

Table 4 compares the frequencies obtained with the Fourier analysis of the geophones positioned on the quadrupole during the module transportation to Saclay with the same data collected during cryomodule CM1 transportation in Fermilab [2].

Table 4: Comparison with CM1 transportation analysis, quadrupole transverse Q (x) and vertical Q (y) movement.

| **M8 Transport** | | **CM1 Transport** | |
|---|---|---|---|
| $Q_x$ - *f (Hz)* | $Q_y$ - *f (Hz)* | $Q_x$ - *f (Hz)* | $Q_y$ - *f (Hz)* |
| 2 | --- | 2 | 2 |
| --- | --- | 4-5 | 4-5 |
| 7 | 7 | --- | 7 |
| 11.5 | 11 | 11.5 | 11 |
| 14 | --- | --- | --- |
| --- | 15 | 15 | --- |
| 18 | --- | --- | --- |
| 20 | --- | 20 | --- |

The data shows a good agreement and strengthens the hypothesis that the observed frequencies arise from the external transporting system rather than are excited modes of the structure. Moreover an analysis of the truck working mechanisms shows that the two frequencies at 2 and 7 Hz are possibly from each truck's transmission.

## RF TESTS AT DESY CMTB

After the transportation the cavity performances have been tested (dashed red in fig. 5) on the Cryo_Module Test Bench (CMTB) at DESY and the results compared with the set of tests performed before the transportation (red in fig. 5).

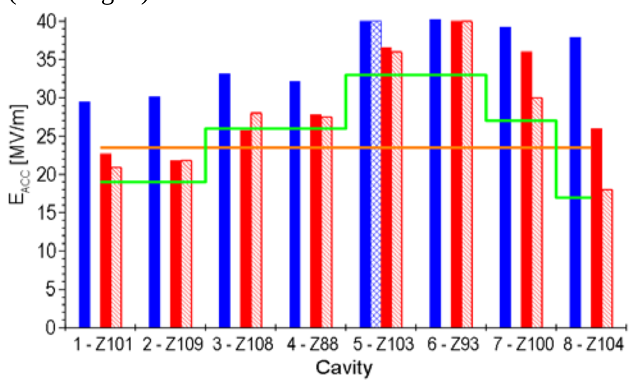


Figure 5: RF performances of the M8 cavities (blue: vertical test – dashed blue: horizontal test – red: test on CMTB before transportation – dashed red: test on CMTB after transportation) – green: FLASH, orange: XFEL goal

The data shows a lowering of the maximum accelerating gradient of the last 2 cavities in the string with respect to the data collected before the transportation. As a part of the degradation was already observed after the string assembly during the first test in CMTB, it could be that some contamination was transported during the procedures related to the module transport e.g. pumping and venting cycles related to installation from and to the test stand. A direct correlation to the transport itself can neither be established nor excluded.

## CONCLUSIONS

The module was successfully transported, uploaded and unloaded at Saclay and transported back to DESY.

The RF test performed after the transportation shows a lowering of the maximum accelerating gradient of the last 2 cavities, but a direct correlation to the transport itself can neither be established nor excluded.

During the transportation the required acceleration limits were satisfied with the designed frame and end caps and no relevant shocks were observed on the module.

Moreover, the vibration analysis shows a good agreement with a similar transportation test performed at Fermilab on the CM1 cryomodule.

## REFERENCES

[1] http://vibration.desy.de/documents/presentations/

[2] M.W. McGee, T. Arkan, E. Borissov, J. Leibfritz, W. Schappert, S. Barbanotti, "Transport of DESY 1.3 GHz Cryomodule at Fermilab," PAC'09, also in these proceedings, (May 2009).