

## TRANSPORT OF DESY 1.3 GHZ CRYOMODULE AT FERMILAB\*

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### Abstract

In an exchange of technology agreement, Deutsches Elektron-Synchrotron (DESY) Laboratory in Hamburg Germany has provided a 1.3 GHz cryomodule “kit” to Fermilab. The cryomodule components (qualified dressed cavities, cold mass parts, vacuum vessel, etc.) sent from Germany in pieces were assembled at Fermilab’s Cryomodule Assembly Facility (CAF). The cavity string was assembled at CAF-MP9 Class 10 cleanroom and then transported to CAF-ICB cold mass assembly area via a flatbed air ride truck. Finite Element Analysis (FEA) studies were implemented to define location of instrumentation for initial coldmass transport, providing modal frequencies and shapes. Subsequently, the fully assembled cryomodule was transported to the SRF Accelerator Test Facility at New Muon Lab (NML). Internal geophones (velocity sensors) were attached during the coldmass assembly for transport (warm) and operational (cold) measurements. A description of the isolation system that maintained alignment during transport and protected fragile components is provided. Shock and vibration measurement results of each transport and modal analysis are discussed.

### INTRODUCTION

The cryomodule transport design acceleration criteria were initially established by considering the 805 km over-the-road Spallation Neutron Source (SNS) transport from Jefferson Lab in Newport News, Virginia to Oak Ridge, Tennessee [1]. A transport analysis completed by Babcock Noell regarding TTF style cryomodules found that the shock limits for the input coupler (IC), perpendicular to the antenna, must be less than 1.5 g [2]. During the Fermilab transport studies in 2007 and 2008 [3], an acceleration limit criteria for testing was established as 1.5 g (vertical), 5 g (transverse) and 1.5 g (longitudinal). The FEA work was initially completed to understand transport stresses, modal shapes and frequencies of the coldmass. Subsequently, the October 15<sup>th</sup>, 2007 cryomodule #1 (CM1) coldmass transport helped to validate the FE modeling.

A 1.3 GHz, type III+ European X-Ray Laser Project (XFEL) cryomodule consists of eight dressed 9-cell niobium superconducting radio frequency (RF) cavities. The cold mass hangs from three column support posts constructed from G-10 fiberglass composite, which are attached to the top of the vacuum vessel. The helium gas return pipe (HeGRP), supported by the three columns, acts as the coldmass spine, supporting the cavity string, quadrupole and ancillaries. Brackets with blocks on two

sides provide a connection between each cavity and the HeGRP. Two aluminum heat shields (80 K and 5 K) hang from the same two column supports. The coldmass consists of all components found within the 80 K shield shown in Figure 1. Relative longitudinal and transverse alignment (or position) of the cavity string and quadrupole is held by an Invar rod (a material with very low thermal expansion).

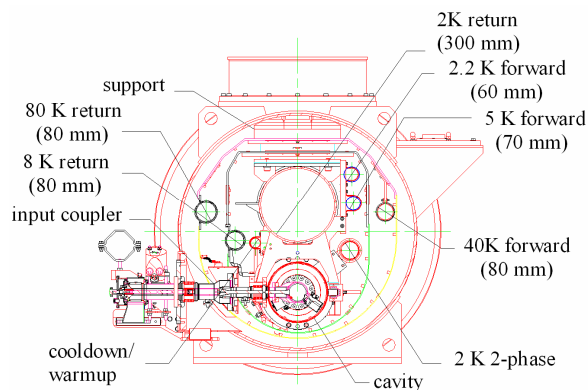


Figure 1: CM1 cryomodule section view.

### TRANSPORT ASSEMBLY DESIGN

The total CM1 transport assembly shown in Figure 2 consists of a cryomodule weighing 7,257 kg, a strong-back fixture weighing 3,175 kg and base frame weighing 1,270 kg; in total 10,430 kg. Ten Isolator Dynamic Corporation (IDC) helical coils in a compression-roll (45 degree) configuration attenuated shock by 80% between the base frame and isolation fixture [4].

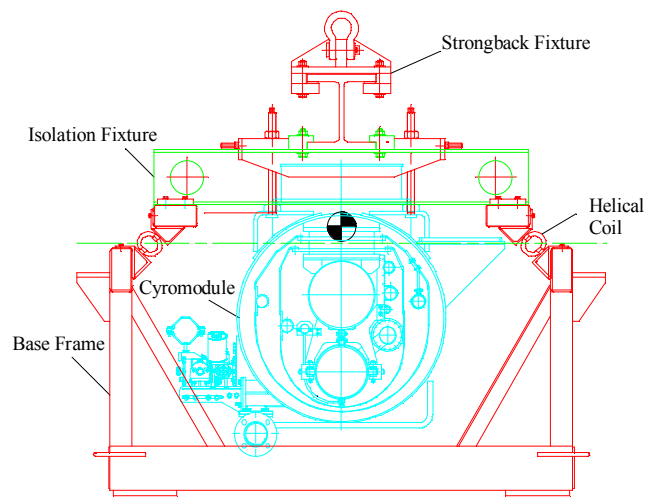


Figure 2: End view of cryomodule transport assembly.

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## Instrumentation

A total of (12) inertial velocity sensors Geospace HS-1 geophone [5] devices in tri-axial aluminum block sets were attached to the isolation fixture, cavity number 5 - IC port, base frame and trailer bed as shown in green, Figure 3. Geospace GS-14-L9 geophones were mounted on a supporting bracket above cavity number 3, 5 and 7 (one vertical and one horizontal) within CM1, shown in blue, Figure 3. Also in blue, Geospace GS-11-D geophones (one vertical and one horizontal) were mounted at the upstream (US) end on the beam-valve (BV). All geophones were connected to six National Instruments (NI) NI-9233 4-channel, 24-bit ADC modules sampled at 5K/s, and the data was recorded to a laptop hard-drive. Three SENSAR GP1 Programmable Accelerometer devices [6] shown in red, Figure 3 found at the cavity number 5 - IC, US beam-valve near quad and on the base frame were used in DAQ mode to record acceleration with an epoch of 1 sec.

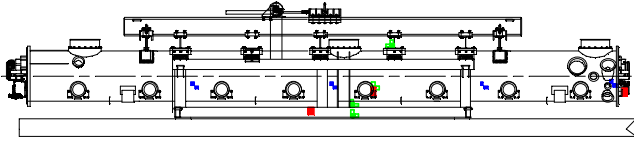


Figure 3: Elevation view of instrumentation locations.

## TRANSPORT

On August 6<sup>th</sup>, 2008 CM1 was transported 3.4 km at an average speed of 4.2 km/hr from CAF-ICB to NML within the Fermilab site. The transport duration of 4 hours, 11 minutes and 29 seconds was divided into three phases; loading at CAF-ICB using an overhead crane, over-the-road transport by air ride trailer to NML and unloading with a crane at NML.

### Acceleration Response

From the CM1 coldmass transport a benchmark maximum base frame acceleration of 2.43 g (vertical) and cavity acceleration of 0.25 g (vertical) was established. Table 1 provides a summary of maximum vertical (y), transverse (x) and longitudinal (z) accelerations experienced during transport. The maximum base frame acceleration was 2.40 g (transverse) and cavity acceleration, 0.40 g (vertical).

Table 1: Summary of maximum acceleration.

Device	Vertical Acceleration		Transverse Acceleration		Longitudinal Acceleration	
	Geo (g)	GP1 (g)	Geo (g)	GP1 (g)	Geo (g)	GP1 (g)
BV/Cav	0.40	0.2*	0.36	0.2	---	0.1
Base	1.90	1.7*	2.40	2.1	1.41	0.7
IC	0.51	0.1*	0.43	0.6	0.41	0.1

\* Data without inertial offset

Figure 4 shows the maximum acceleration vertical GP1 device data over all three phases. The highest loads were found during handling or in-transition between phases. These acceleration results were within the expected values, based on the coldmass transport benchmarks and beneath the acceleration limit criteria.

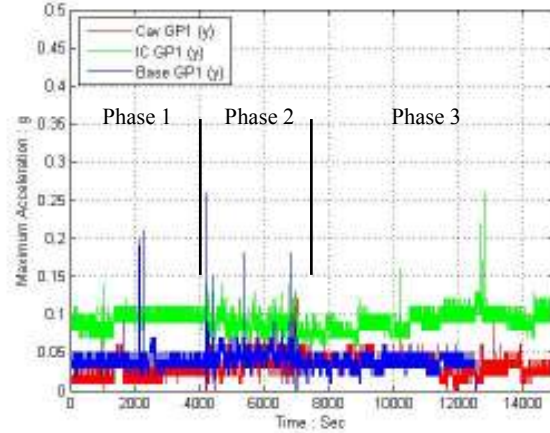


Figure 4: Vertical GP1 device data for entire transport.

### Frequency Response

The cryomodules share inherent modal properties which were investigated theoretically. Figures 5 and 6 provide a spectrogram for the quad during the CM1 transport as broken red lines indicate resonance free transport in vertical and transverse direction, respectively. A method for selecting relevant frequency considered smoothing data (to reduce spectral bias and variance) prior to plotting a periodogram, then evaluating the peaks in terms of Q-factor. A periodogram is an estimate of spectral density in terms of power (dB/Hz) of a signal. The periodograms were averaged (smoothed) and Q-factor estimated based on peak frequency divided by bandwidth (given a 3 dB height). Subsequently, these Q-factors were compared against possible mechanical values.

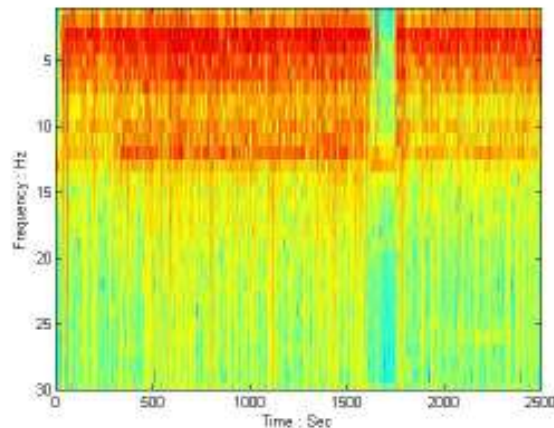


Figure 5: Vertical spectrogram for quad  $Q_y$ .

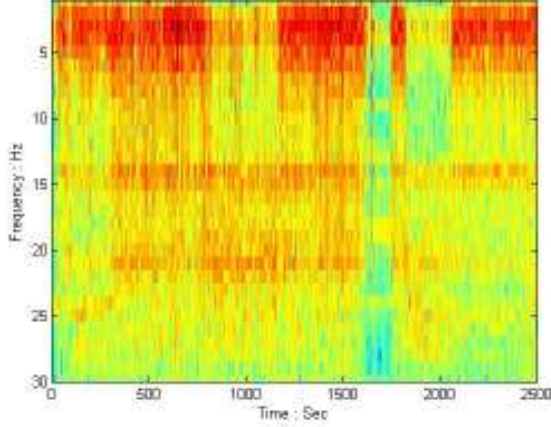


Figure 6: Transverse spectrogram for quad  $Q_x$ .

Table 2 compares the modal frequencies measured during the CM1 transport considering the spectral evaluation described above. The frequencies between 2 and 7 Hz were possibly from each truck's transmission and suspension (shock from potholes transmitted through the tires). Comparison with the modal ANSYS results was difficult due to coupling between the base frame, isolation fixture, vacuum vessel and coldmass. The transport assembly base frame, vacuum vessel and coldmass moved coherently (as one) at low frequency.

Table 2: Modal frequencies for CM1, base transverse  $B_x$ , base vertical  $B_y$ , vessel longitudinal  $V_z$ , center cavity vertical  $C_y$ , quadrupole transverse  $Q_x$  and vertical  $Q_y$ .

$B_x$ $f$ (Hz)	$B_y$ $f$ (Hz)	$V_z$ $f$ (Hz)	$C_y$ $f$ (Hz)	$Q_x$ $f$ (Hz)	$Q_y$ $f$ (Hz)
2	2	2	2	2	2
4-5	4-5	4-5	4-5	4-5	4-5
7	7	7	7	---	7
---	11.5	---	11	11.5	11
15	---	---	15	15	---
---	20	---	---	20	---

Differences shown in Table 3 regarding the spectral response between the CM1 transport and DESY module #8 (M8) transport from DESY to the Commission for Atomic Energy (CEA) at Saclay [7] involved the cryomodule assembly isolation system, vehicle suspension, road conditions and transport speed. One factor was the lower natural frequency of the CM1 transport isolation system. Agreement between the CM1 and M8 transport transverse quad measurement was observed at frequencies of 11.5 and 20 Hz. The quad installed within CM1 has a mass less than a typical cryomodule focusing quad, which may account for spectral differences.

Table 3: Comparison with M8 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	2
---	---	4-5	4-5
7	7	---	7
11.5	11	11.5	11
14	---	---	---
---	15	15	---
18	---	---	---
20	---	20	---

## CONCLUSIONS

Transition and handling of the transport assembly had the highest potential for peak acceleration. The maximum base frame acceleration was 2.40 g (transverse) and cavity acceleration, 0.40 g (vertical) which was beneath the acceleration limit criteria. These accelerations occurred while in transition.

Post transport RF and beamline vacuum evaluation confirm that the cryomodule arrived without damage to sensitive components, such as the input couplers. Good agreement between CM1 and M8 transport frequencies and over-the-road CM1 transport was resonance free.

## ACKNOWLEDGEMENTS

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