FERMILAB-CONF-09-081-AD-TD

TRANSATLANTIC TRANSPORT OF FERMILAB 3.9 GHZ CRYOMODULE TO DESY*

M.W. McGee†, C. Grimm, D. Olis, Warren Schappert,
Fermi National Accelerator Laboratory, Batavia, IL 60510, USA

Abstract

In an exchange of technology agreement, Fermilab has built and delivered a 3.9 GHz (3rd harmonic) cryomodule to Deutsches Elektron-Synchrotron (DESY) Laboratory to be installed in the TTF/FLASH beamline. Transport to Hamburg, Germany was completed via a combination of flatbed air ride truck and commercial aircraft, while minimizing transition or handling points. Initially, destructive testing of fragile components, transport and corresponding alignment stability studies were performed in order to assess the risk associated with transatlantic travel of a fully assembled cryomodule. Data logged tri-axial acceleration results of the transport with a comparison to the transport study predicted values are presented.

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 acceleration 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, an acceleration limit criteria for testing was established as 1.5 g (vertical), 5 g (transverse) and 1.5 g (longitudinal). A finite element (FE) analysis was initially completed to understand transport stresses, modal shapes and frequencies of the coldmass. Subsequently, over-the-road transport studies [3] were completed using a 3.9 GHz cryomodule mockup as instrumentation locations defined by previous FE modeling had been confirmed.

CRYOMODULE DESIGN

The 3.9 GHz cryomodule shown in Figure 1 consists of four dressed 9-cell niobium superconducting radio frequency (RF) cavities. This coldmass hangs from two 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 two columns, acts as the coldmass spine, supporting the cavity string and ancillaries. Support brackets with adjusting blocks using needle bearings on each side provide a connection between each cavity and the HeGRP. Two aluminum heat shields (80 K and 5 K) hang from the HeGRP column supports [4].

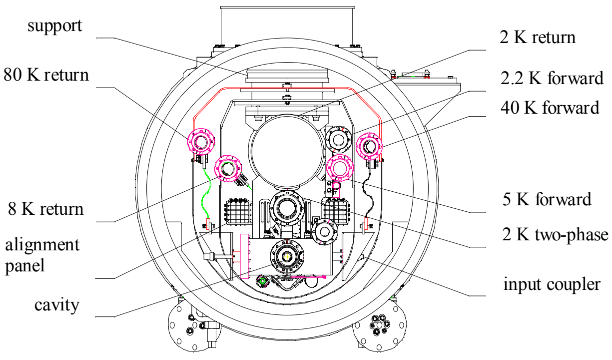


Figure 1: End view of 3.9 GHz cryomodule.

TRANSPORT ASSEMBLY DESIGN

The total cryomodule transport assembly shown in Figure 2 weighed 7,536 kg. The isolated components (cryomodule and isolation fixture) weighing 3,846 kg was relatively stiff and slightly under-damped with isolation which reduced shock by 80%. Helical coils (or cables) loaded in tension and rotated at 45 degrees, separate the isolation fixture from the base frame [5].

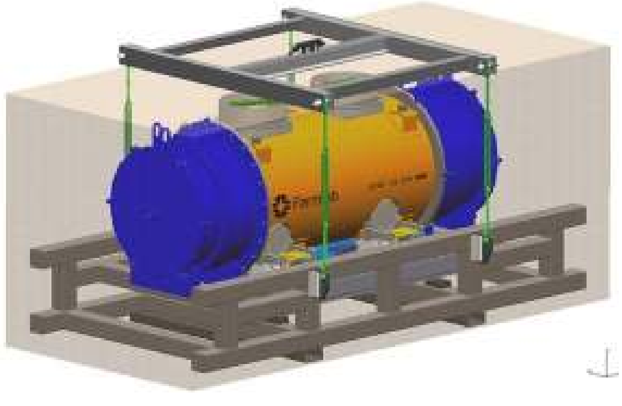


Figure 2: Solid model of cryomodule transport assembly.

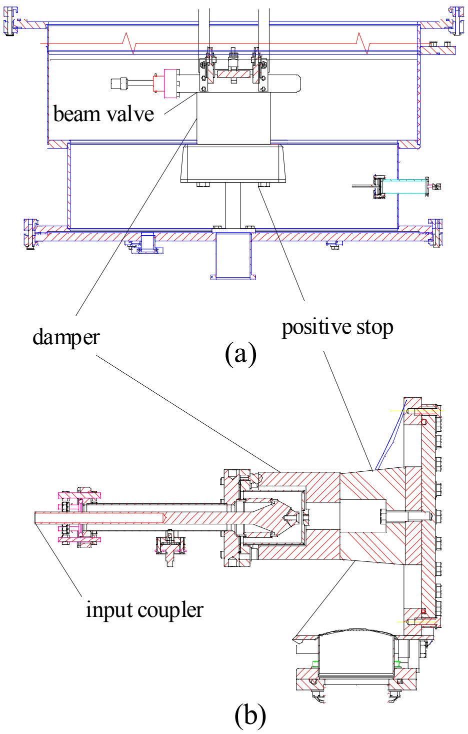
Special transport design features emerged from the FE analysis and transport studies; vertical constraints that secure the two column supports, composite dampers with positive stops prevent motion at the beamline level. Prior to final packaging, locking constraints were applied at each column support, rigidly connecting the coldmass to the vacuum vessel from above. Initial sources of un-damped internal motion include longitudinal rocking and

---

* Operated by Fermi Research Alliance, LLC, under Contract No. DE-AC02-07CH11359 with the U.S. Department of Energy.

† mcgee@fnal.gov

transverse pendulum modes of the coldmass. The composite design to limit longitudinal and transverse motion considered a stiff rubber section (or positive stop) in series with white 1.8 – 2.7 kg polyethylene foam as shown in Figures 3(a) and 3(b). A compressive longitudinal force of 44.5 N and transverse force 63.6 N was applied to the coldmass using a compensating load in this design. Similarly, the same density foam captured each heat shield against the outer vacuum vessel.



Figures 3(a): Plan view of longitudinal damper system. 3(b): Section view of input coupler damper system.

TRANSPORT

The transport in April of 2009 was divided into three phases; 56.3 km over-the-road transport from Fermilab to O'Hare Airport (ORD), 6,670 km (8 hour) flight from ORD to Charles de Gaulle Airport (CDG) and 744.6 km over-the-road transport from CDG to DESY in Hamburg, Germany. Both over-the-road transport routes were well known in terms of past studies; 3.9 GHz transport studies between Fermilab and O'Hare Airport [3] and 1.3 GHz M8 cryomodule transport between CEA Saclay, France and DESY, Hamburg [6]. The transport was monitored using commercially available accelerometer DAQ packages; SENSR GP1 [7] and ShockWatch "Shocklog" [8] with internal and external cryomodule range defined below 10 g. Beamline vacuum was also monitored by Fermilab personnel escorting the transport. This escort also served as supervision at points of transition. Beamline vacuum integrity was confirmed after arriving at DESY.

Modes of Transport

The effects of shock and vibration are important from both a perspective of protection and maintaining alignment. Handling operations such as transfers, loading and unloading were preplanned and closely monitored, as accidents and miss-handling can cause significant load levels (reaching between 35 to 40 g, such as with forklift operation) [9]. Special handling systems (e.g. roll-on and roll-off designs) in conjunction with an air ride trailer was specified which led to very low load levels. The use of forklifts was prohibited. Typical crane and cable systems have a maximum vertical acceleration of 0.6 g. Even when loads are dropped suddenly with a crane, inherent design properties limit the vertical acceleration to 0.94 g [10]. Over-the-road transport speeds was limited to 90 km/hr both in the US and Europe.

During flight, sources of excitation are random in nature. Spatially distributed over the surface of the aircraft, these sources include; aerodynamic forces applied to the structure by surrounding air, such as gusts, aerodynamic (flutter and buffering) and acoustic excitation [9]. At low frequencies, beneath 15 Hz air cargo does not respond dynamically as the aircraft frame experiences steady inertial loads (or accelerations) when excited by gusts, maneuvers and landing impact [11].

Alignment

Special alignment panels were developed during the transport study phase to consider both the effects of misalignment from this study and post transport alignment assessment. Overall alignment tolerance requirement for a cold cryomodule within the TTF/FLASH accelerator at DESY is 0.5 mm. The maximum tolerance for alignment and cavity movement during shipment was 0.25 mm, considering referencing of cavities centerline, thermal cycling, cavity string alignment and referencing to the vessel [12].

Results

Table 1 provides the GP1 and Shocklog device results of the transport in terms of accelerations experienced at the base frame, isolation fixture and coldmass. The highest acceleration experienced at the base was 2.4 g (vertical) while unloading at DESY. Figures 4 and 5 give the maximum and minimum accelerations during transport on the base and isolation fixture, respectively.

Table 1: Summary of maximum acceleration.

Device	**Vertical Acceleration**		**Transverse Acceleration**		**Longitudinal Acceleration**	
	SL (g)	**GP1 (g)**	**SL (g)**	**GP1 (g)**	**SL (g)**	**GP1 (g)**
BV	---	1.1*	---	1.2	---	0.7
Base	2.4	1.9*	1.1	1.2	1.3	1.2
Iso	0.8	1.2*	0.8	0.9	1.0	0.6

* Data without inertial offset

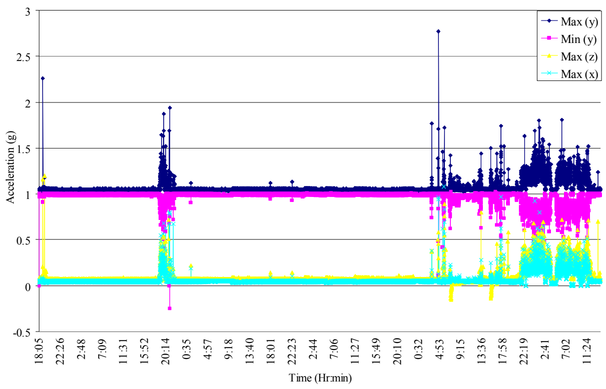


Figure 4: Vertical, transverse and longitudinal temporal variation of base frame acceleration during transport based on Greenwich Mean Time (GMT) from April 23rd through April 28th, 2009.

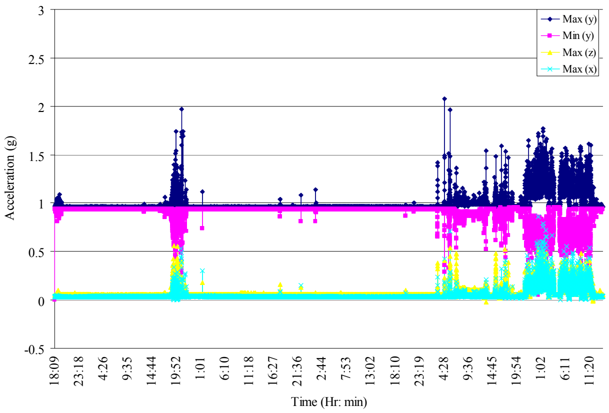


Figure 5: Vertical, transverse and longitudinal temporal variation of isolation fixture acceleration during transport based on GMT.

The epoch time for the base frame and isolation fixture was 30 and 20 seconds, respectively. Data taking was meant to be synchronous, however slight differences in the GP1 device models, caused variations of 10 seconds. As a result, the isolation fixture acceleration plot shown in Figure 5 appears more substantial or dense than the base frame case in Figure 4.

CONCLUSIONS

Precautions were implemented through supervision of the shipment, especially at points of transition. Acceleration results from the transport were as predicted with maximum coldmass acceleration in the transverse direction of 1.2 g while over-the-road in Belgium and 1.1 g in the vertical direction, remaining beneath the established acceleration limit criteria of 5 g and 1.5 g, respectively.

Alignment analyses of each transport study indicate that the cavities maintain their relative alignment of 0.1 mm with respect to a straight line within the cavity string; however, the alignment with respect to the vacuum vessel is only marginal to the allowable tolerance and may need adjustment at DESY.

Beamline vacuum integrity was conserved during the transport, considering the initial pressure of 5.4 e-4 Torr and final reading of 7.4 e-4 Torr.

ACKNOWLEDGEMENTS

Thanks to 3.9 GHz Cryomodule Project Managers; Helen Edwards and Elvin Harms. Also, thanks to Don Mitchell and Tug Arkan and technical staff consisting of Mark Chlebek, Jim Rife, Glen Smith and Jeff Wittenkeller. Special thanks to Fermilab Procurement and Shipping Staff: Al Elste, Bob Cibic, Marsha Schmidt and John Zweibohmer.

REFERENCES

[1] T. Whitlatch et al., “Shipping and Alignment for the SNS Cryomodule,” PAC’01, (June 2001).
[2] G. Sikler, “Transport of Cryomodules,” Babcock Noell, Wurzburg Germany, DESY EV 010-94-S1 Draft version, p. 48 (September 2007).
[3] M.W. McGee, V. Bocean, C. Grimm and W. Schappert, “Transatlantic Transport of Fermilab 3.9 GHz Cryomodule for TTF/FLASH to DESY,” EPAC’08, (June 2008).
[4] H. Edwards et al., “Construction of a 3.9 GHz Superconducting RF Cavity Module at Fermilab,” PAC’09, also in these proceedings, (May 2009).
[5] http://www.isolator.com
[6] S. Barbanotti et al., “Monitoring the FLASH Cryomodule Transportation from DESY Hamburg to CEA Saclay: Coupler Contact, Vacuum, Acceleration and Vibration Analysis,” PAC’09, also in these proceedings, (May 2009).
[7] http://www.sensr.com
[8] http://www.instronics.com
[9] F. Ostrem, “Transportation and Handling Loads,” NASA SP-8077, p. 19 (1971).
[10] U. Carlsson, “Noise and vibration aspects on railway goods transportation,” Marcus Wallenberg Laboratories, Report 050E, (2003).
[11] U.S. Department of Defense, “MIL-STD-810F Method 516.5 SHOCK,” p. 5-3 (January 2000).
[12] V. Bocean and M.W. McGee, “Referencing and Stability Studies of the Fermilab 3.9 GHz (3rd Harmonic) Cryomodule for DESY TTF/FLASH,” IWAA’08, (February 2008).