C3Po1A-01: Cryogenic Testing of HL-LHC Q1/Q3 Cryo-Assemblies at Fermilab

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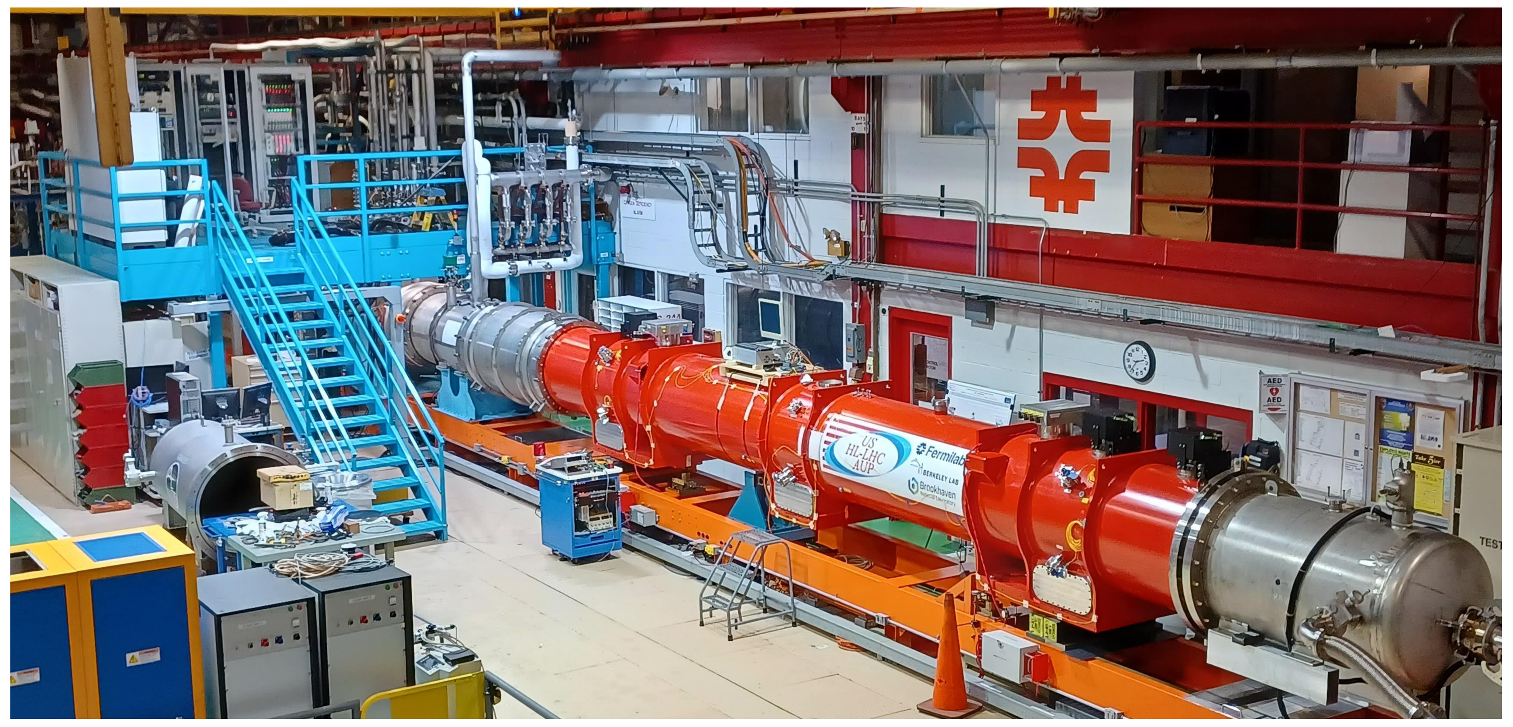
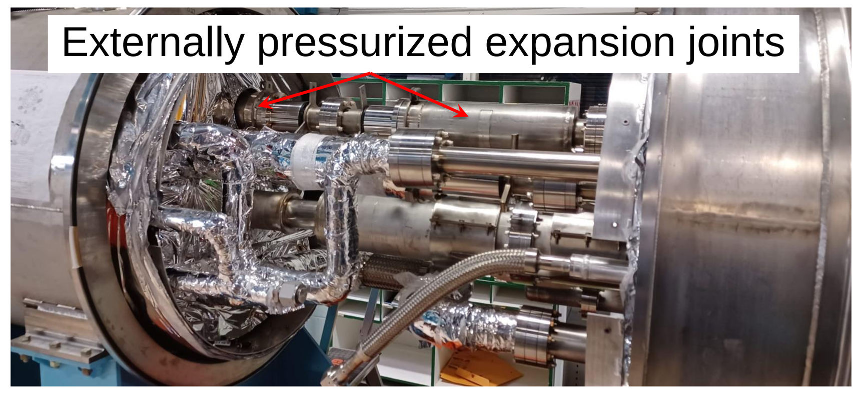
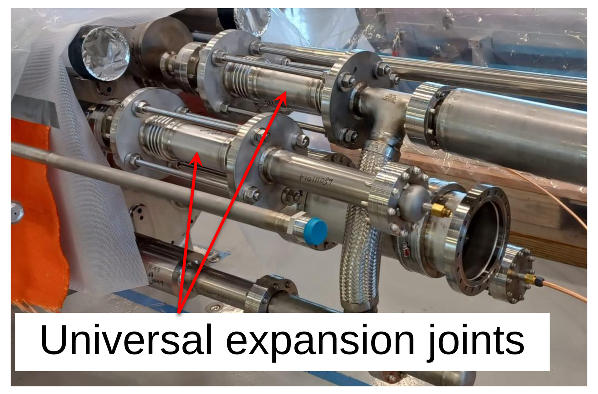
Abstract

Fermilab is conducting horizontal cryogenic testing of Q1/Q3 Cryo-Assemblies for the high-luminosity LHC upgrade (HL-LHC). Cryo-Assemblies are installed on the upgraded Fermilab horizontal test stand previously used for testing the LHC inner triplet quadrupoles. The cryogenic process requirements of these tests include controlled cool-down and warm-up with a 100 K maximum temperature differential between the two ends of the cold mass, operation of a 1.3 bar, 1.9 K bath of subcooled superfluid helium during power testing and magnetic measurements, and operation at pressures up to 18 bar with full helium recovery after a quench. This paper presents the operational experience gained from the first tests as well as improvements for subsequent tests.



Interconnect





The interconnect to the test stand uses flexible hose assemblies where possible to accommodate both longitudinal and lateral motions. Where this is not possible on the bus line and the two heat exchangers, externally pressurized expansion joints are used to handle longitudinal motion and universal expansion joints for lateral motion.

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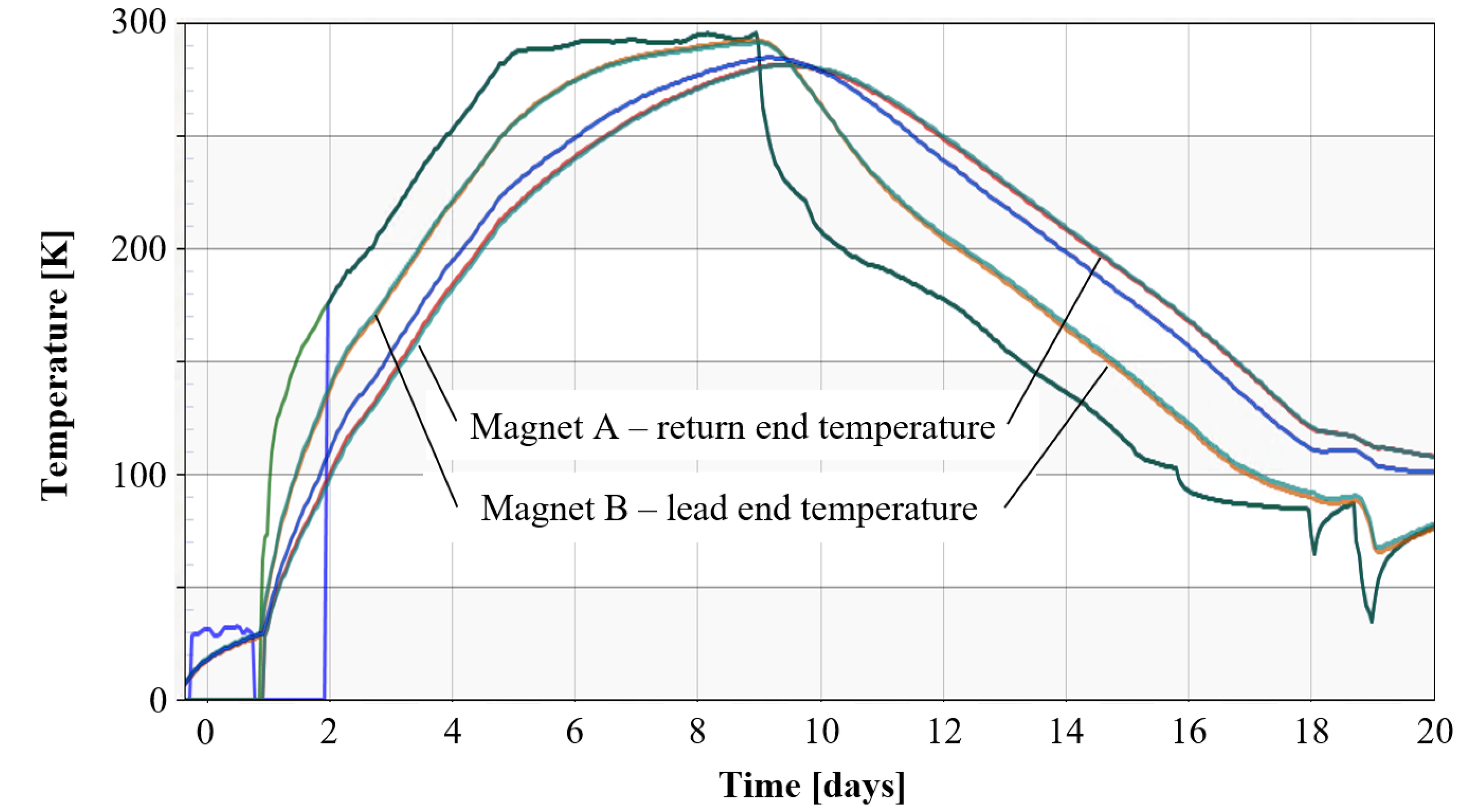
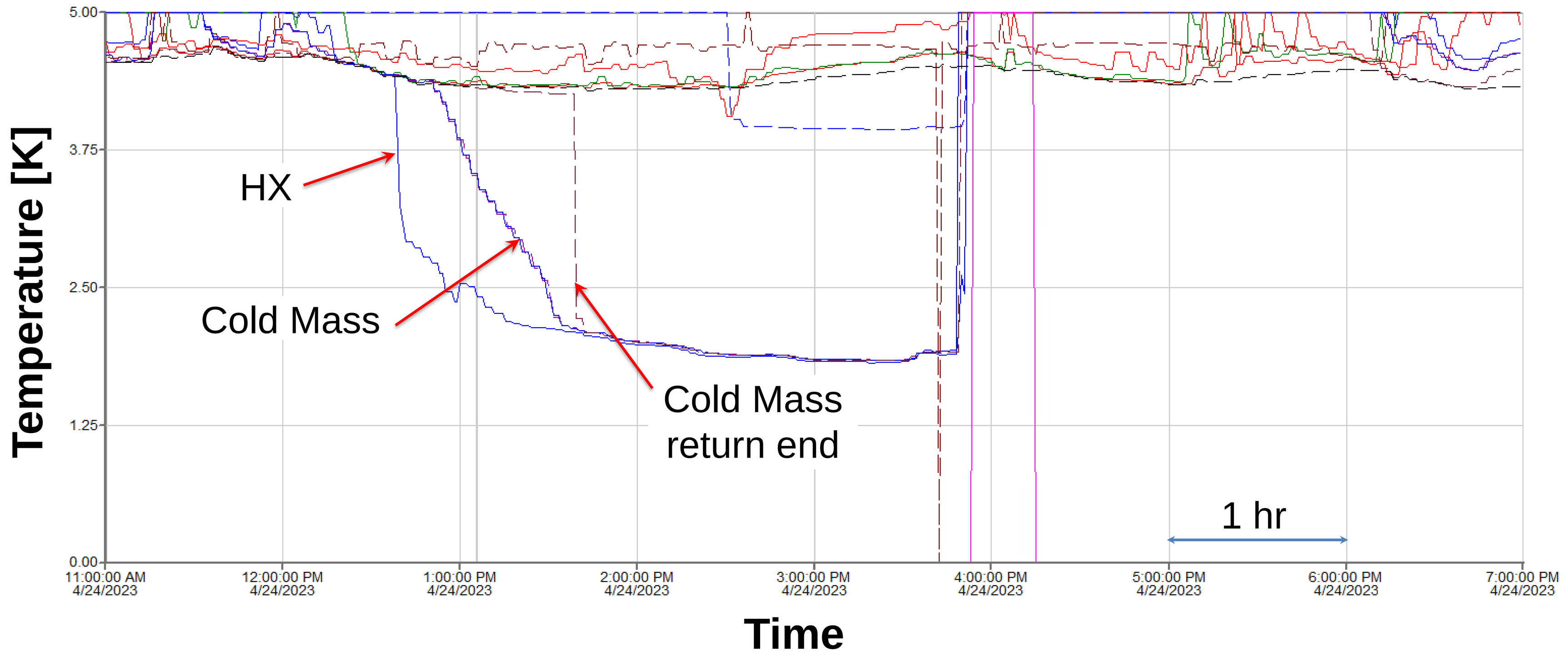
Cool-down & Warm-up: 300 K - 4.5 K

Controlled cool-downs and warm-ups are required to limit the temperature differential across the cold mass. Helium supply temperatures of 80 K and above are accomplished by mixing 300 K GHe and 80 K GHe. Helium supply temperatures below 80 K are accomplished by mixing 80 K GHe with 4.5 K LHe. 80 K GHe is obtained using an LN2 bath contained in a repurposed Fermilab Tevatron subcooler. A PLC script operates warm mass flow controllers and uses user-specified parameters (mass flow rate, temperature and temperature differential limits) to automatically control the temperature and the flow rate of the GHe supplied to the test stand. Cooldown time is ~2 weeks, and warm-up time is ~1 week.



Cool-down to 1.9 K

Cool-down from 4.5 K to 1.9 K (both at 1.3 bar) requires 3 hours. LHe is supplied to 2 bayonet heat exchangers running the 10.5 m length of the Cold Mass. Pumping is provided by 2 pumping skids, each with a Roots blower backed by a liquid ring pump.



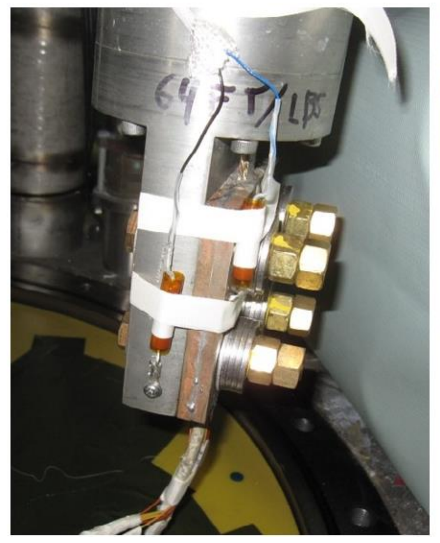
Heat Load to 1.9 K

Initial heat load measurements to 1.9 K are in good agreement with expectations after correcting CERN Cryo-Assembly analyses for the higher thermal shield temperature at the Fermilab test stand (85 K vs. 60 K). This provides a first measure of confidence that the Q1/Q3 Cryo-Assemblies will thermally perform as expected when installed in the HL LHC.

	1.9 K Heat Load [W]	Notes
Measured total	**53.5**	
Test stand component (expected)		
Warm bore	28.8	Fermilab analysis
Test stand Adapter Box spiders	5.1	Fermilab analysis
Quench line conduction	4.2	Fermilab analysis
Radiation	0.8	Fermilab analysis
Cryo-Assembly (calculated)	**14.6**	**Measured total heat load - Expected test stand heat load**
Cryo-Assembly component (expected)		
Support posts	5.0	CERN analysis, corrected for FNAL thermal shield temperature
Coupling Loss Induced Quench (CLIQ) capillary systems	3.3	CERN analysis
k-Modulation (KMOD) capillary system	2.4	CERN analysis
Radiation	2.3	CERN analysis, corrected for FNAL thermal shield temperature
Instrumentation Feedthrough System (IFS) capillary systems	1.8	CERN analysis
Frequency Scanning Interferometry (FSI) system	1.4	CERN analysis
Cryo-Assembly (expected)	**16.2**	**Sum of expected Cryo-Assembly heat loads**

Heat Load to 4.5 K - Improvement

The interface between one of the vapor-cooled current leads and the superconducting bus was redesigned, reducing the dynamic heat load to 4.5 K by 87 W.



Quench

The test stand includes capabilities for full helium recovery in the event of a magnet quench or a system trip. The helium is recovered into a 30,000 gallon (113.6 m³) gas storage tank. The helium flow rate being recovered is ~4 kg/s.

Conclusion

Horizontal cryogenic testing of HL-LHC Q1/Q3 Cryo-Assemblies is in progress at Fermilab. Details of the test stand interconnect are presented, as are early operating experiences and thermal performance.