Abstract
Cryo-assemblies with the low-beta Nb3Sn quadrupoles for the high luminosity LHC (HL-LHC) upgrade will be tested at Fermilab’s magnet test facility. Total of 10 cryo-assemblies will be delivered to CERN within the US LHC Accelerator Upgrade Project (AUP). The horizontal test stand at Fermilab already has been used for testing the existing LHC inner-triplet quadrupoles, but the stand and related electrical and cryogenic sub-systems were not operational more than a decade. In order to restore the test stand functions and meet the design and test requirements for the high luminosity LHC quadrupole magnets, the existing horizontal test facility at Fermilab underwent a significant refurbishment of the cryogenic and mechanical components. Most of the upgrades were completed during or shortly following the zero-magnet test by late 2020. These tests with the shorted superconducting conductor leads verified the major cryo-mechanical installations, as well as the basic test stand operations, including controlled cooldown, current ramps, process controls and magnet protection. Over four months were required to perform the zero-magnet test.

New Location of the lambda plug
The adapter box also serves as a separation between the 4.5K and 1.9K temperature levels. Lambda plug was moved from the lambda box to the Feed box-Adapter box interconnect. A new Lambda plug box was designed and built as an adapter box (see 3D model sketch on the right). The Lambda plug box was designed for a high level of dependability and long term continuous operation and is based on three tiers: Tier-1 is a primary FPGA based Digital Quench Detection (DQ) system, Tier-2 - secondary Analog QUAD system, Tier 3 - Quench controls and Data Management system.

Horizontal Test Stand Commissioning
The horizontal test stand was a success. After more than a decade of shutdown, the horizontal test stand is operating again. Functionality of the upgraded systems, including new piping, control systems and new pulseformers were successfully verified. The insulation vacuum of the stand reached ~10⁻¹⁰ mTorr. The return end piping was successfully pressurized up to 17 bar, demonstrating acceptable vacuum sealing of the lambda plug and interconnects. Controlled cooldown from room temperature to 5 K was successfully demonstrated. Without a cryo-assemble and its heat exchangers built into the cold mass, there was no way to achieve subcooled operation in the zero magnet test configuration. Therefore, 1.9 K operation was demonstrated only in the pumping system and a small return end reservoir vessel.

CONCLUSION
After more than a decade of shutdown, Fermilab’s horizontal test stand was a success. After more than a decade of shutdown, the horizontal test stand is operating again. Functionality of the upgraded systems, including new piping, control systems and new pulseformers were successfully verified. The insulation vacuum of the stand reached ~10⁻¹⁰ mTorr. The return end piping was successfully pressurized up to 17 bar, demonstrating acceptable vacuum sealing of the lambda plug and interconnects. Controlled cooldown from room temperature to 5 K was successfully demonstrated. Without a cryo-assemble and its heat exchangers built into the cold mass, there was no way to achieve subcooled operation in the zero magnet test configuration. Therefore, 1.9 K operation was demonstrated only in the pumping system and a small return end reservoir vessel.

Various improvements have been made to achieve high reliability of the cryo-plant, test facility and power systems operation at Fermilab. New liquefier will increase total liquid helium make rate to 600 liter/hour and total liquid storage volume to 14000 liters. New liquefier installation is in progress and will be fully functional in 2022. Full stream purification system helps to control contamination level. New helium compressor skids include four Kinney pumps providing sufficient pumping speed for Fermilab’s vertical and horizontal test stands. Process controls system was completely rebuilt and is based on Siemens ST PLC electronics. Existing 30 kA power system will be used for cryo-assemblies horizontal test. New 280A flexible power leads were installed for powering magnets at the horizontal test stand. All water hoses and fittings in the power system were replaced.

In order to prevent excessive stresses in the magnet structure during the cool-down and warm-up, we plan to set the maximum temperature difference of 5K between the ends of the cold mass. The temperature gradient during cool-down and warm-up in the tunnel is expected to be less than the upper limit. Controlled cooldown is accomplished in two stages: for temperatures above and below 80 K. For cool-down from 300K to 80K, helium gas is cooled in a liquid nitrogen bath and then mixed with the 300K helium to achieve the required cold mass supply temperature. For further cooldown to 80K, helium gas is mixed with the 4.5K liquid helium.

New Quench Protection and Monitoring system was successfully verified. CERN designed CLiQ units were manufactured by the same vendor both for CERN and Fermilab. Our goal was to provide magnet protection at Fermilab as close as possible to the operating conditions at CERN.

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