Applied Metrology for the Assembly of the Nb_3Sn MQXFA Quadrupole Magnets for the HL-LHC AUP

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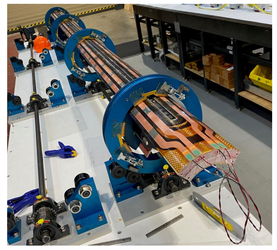
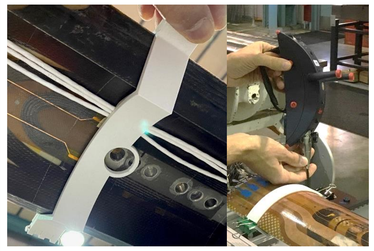
Abstract

The US HL-LHC Accelerator Upgrade Project (AUP) is building Nb_3Sn quadrupole magnets, called MQXFA, with plans to install 16 of them in the HL-LHC Interaction Regions. Variability in coil size must be dealt with at the assembly level, which requires timely and repeatable measurement of each coil. In this paper we will present the methodology used for coil measurements and the geometrical size data for the coils that have been measured thus far. We will also show the coil measurements of 8 coils before and after cold test. The Leica AT960-MR laser tracker with Spatial Analyzer software acquired to achieve these measurements has been used elsewhere in the project to great effect.

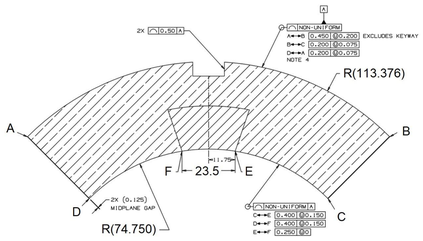
Coil Measurement Methods



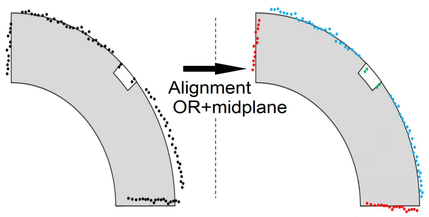
Method of supporting the coils during measurement. The coil rests on four supports.



(Left) Fixture for guiding the T-probe with a circle around the pole inner diameter to acquire more points (Right) T-probe guided by fixture



Coil Cross-section

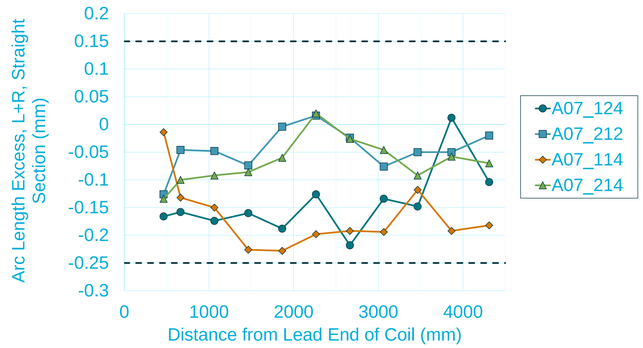


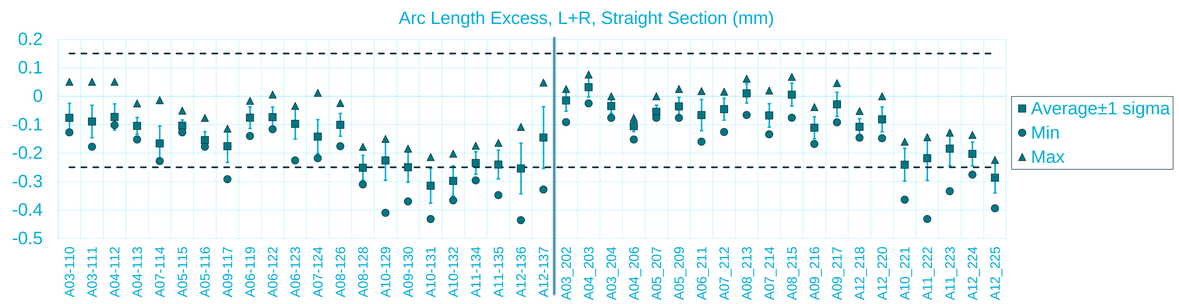
The outer radius and midplane points are used to fit the points to the nominal CAD model

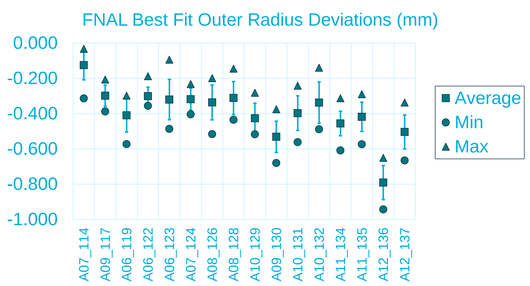
Coil Measurements for Magnets MQXFA03-MQXFA12

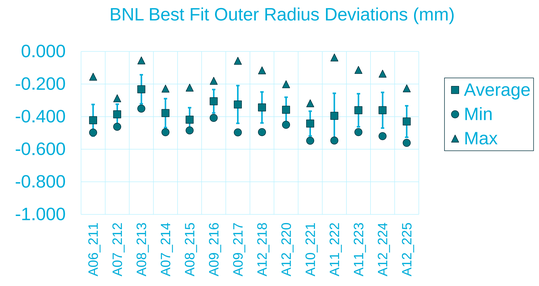
Coil Section	Upper Tolerance (mm)	Lower Tolerance (mm)
Outer Diameter	+0.200	-0.250
Arc Length Excess	+0.150	-0.250
Inner Diameter	+0.150	-0.250
Pole Inner Diameter	+0.000	-0.250
Keyway	+0.250	-0.250

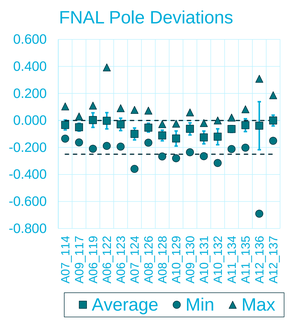
11-12 cross-sections are measured in the straight section and 3 cross-sections at the ends. The data presented here are from the straight section only.

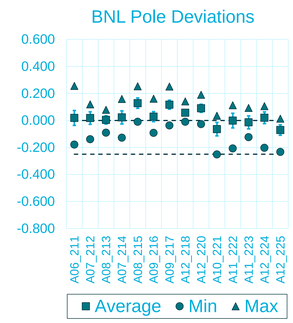


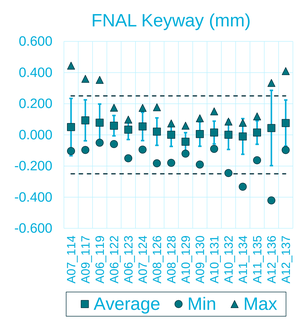


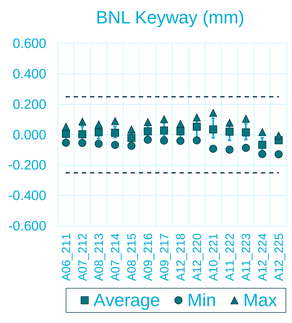












Difference After Preload/Cold Testing

Magnet MQXFA07 and MQXFA08 were disassembled after going through cold testing. Magnet MQXFA09 was disassembled after going through pre-loading. The amount that the best fit outer radius and arc length excess were reduced for each of these coils is presented in the table below.

Magnet, Quadrant, and Coil Number	Difference in Best Fit Outer Radius (mm)	Difference in Arc Length Excess (mm)
A07, Q1, 212	0.149	0.068
A07, Q2, 124	0.283	0.074
A07, Q3, 214	0.157	0.045
A07, Q4, 114	0.309	0.102
A08, Q1, 215	0.384	0.135
A08, Q2, 126	0.493	0.132
A08, Q3, 213	0.350	0.093
A08, Q4, 128	0.470	0.096
A09, Q2, 216	0.183	0.098
A09, Q3, 130	0.059	0.051

Other Uses of the Leica AT960-MR

The Leica AT960-MR was acquired to perform coil measurements as discussed in the bulk of this paper. Having this tool and the operators trained to use it dedicated to this project has come in handy on several occasions.

Firstly, when the coils are assembled into the first level of support structure, called the coil pack, we measure the height and width and squareness of the coil pack. Prior to the COVID-19 epidemic, we did this with a standard micrometer based measurement fixture that required 2 technicians to stand less than 2 meters apart while taking 26 measurements. We replaced this measurement fixture with the laser tracker during the pandemic.

Secondly, when we determined that the coil pack squareness was more critical, we added additional width and height measurements after each torqueing pass to allow us to make adjustments in coil pack squareness. The laser tracker allows us to get these measurements in a shorter amount of time than with the standard measurement fixture at 30 minutes between the start of measurements and having a data visualization to make decisions with.

Thirdly, we found that MQXFA10 had a 0.500 mm bend over the 5000 mm length, which is not something that can be caught by eye or conventional measurement fixtures. We added a step to measure the straightness of the outer support structure prior to inserting the coil pack, which is done with the laser tracker

Acknowledgments

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The magnet assembly process would not be possible without the skill and dedication of Jonathan Hekmat, Joshua Herrera, Robert Memmo, Ahmet Pekedis, Matt Reynolds, and Juan Rodriguez

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