Conductor and Cable
Summary and Comparison of MQXFB07 Witness Sample Results

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Cable and Coil Overview

Coil	Cable [1]	Cabling Report	HT	Witness Report	Cable NCRs	Strand Contract [2]	Billets
CR138	H16OC0410A	2772486	765	3012883		F663/Am4 (22) F663/Am5 (18)	AO08S00295 (6) AO08S00443 (8) AO08S00559 (8) AO08S00592 (7) AO08S00633 (11)
CR145	H16OC0454A	3058659	791	3101766		F663/Am4 (21) F663/Am5 (19)	AO08S00470 (11) AO08S00565 (10) AO08S00627 (10) AO08S00630 (9)
CR146	H16OC0417A	2822508	802	3132280		F663/Am3 (11) F663/Am4 (10) F663/Am5 (19)	AO08S00222 (11) AO08S00477 (10) AO08S00635 (9) AO08S00640 (10)
CR147	H16OC0452A	2963109	814	3132282	2957863	F663/Am4 (16) F663/Am5 (24)	AO08S00296 (9) AO08S00568 (7) AO08S00621 (8) AO08S00622 (9) AO08S00636 (7)

[1] MQXF cable specification, EDMS 1863790 [2] MQXF wire specification, LHC-MQXF-CI-0001, EDMS 1419924

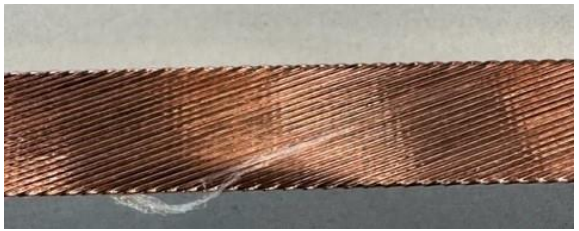
Nonconformities

- NCRs affecting the cable are summarised below and in the following slides
- Witness samples (coil heat treatments)
  - Any damage to witness sample test pieces did not impact testing for the present coils
  - For CR138, one extremity of the furnace reached 675 °C, resulting in reduced RRR on *CoC*
  - No indication of a significant performance impact from minor coil HT NCRs

Coil	HT	Cable NCRs	Coil NCRs Implicating Cable	Coil HT NCRs
CR138	765		2974448	2961736
CR145	791			3073728, 2884016
CR146	802		3083049	3088822
CR147	814	2957863		3101915, 2884016

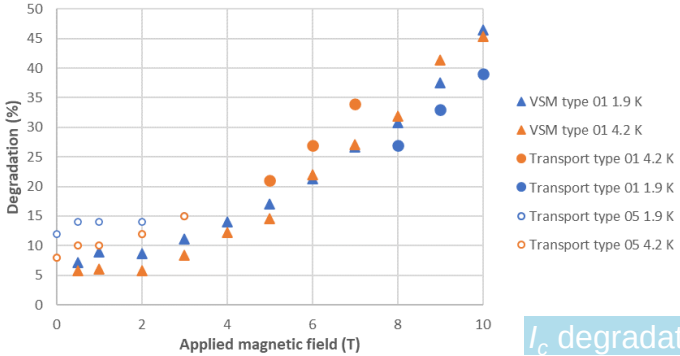
NCR: Plastic Entrapped in Cabling

- During production of cable **H16OC0452A** for **CR147**, the inspection system identified fragments of material at positions 686, 746 and 755 m:
  - Identified as polyethylene film (23 µm thick) used to wrap wire spools
  - Similar film applied by the manufacturer is removed for inspection and sampling, and replaced by CERN for storage
- The cable was thoroughly inspected and all plastic removed
- All standard tests were performed, and the cable geometry and extracted strand I_c and RRR were in specification: no impact on this cable expected
- Respooling procedures were revised to prevent recurrence:
  - Reduced speed and tension for removing plastic wrap
  - Heightened vigilance during unwrapping and respooling, with inspection by a second operator
- A blue coloured wrap will be used when wrapping future stock for storage, to increase visibility of any fragments



NCR: Overheating During Impregnation

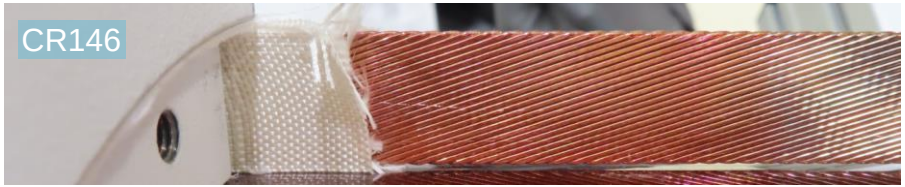
- During impregnation of reacted coil **CR138**, thermocouples were not connected and an uncontrolled temperature increase potentially up to 300 °C for 24 h occurred
- Transport I_c and VSM tests (see EDMS 3007813) following application of a simulated heat treatment to reacted samples suggested negligible impact on both Nb-Ti and Nb_3Sn performance
  - For Nb-Ti leads, I_c degradation increases with applied field, but is modest (~10 %) in operating conditions, and RRR increases
  - For Nb_3Sn, VSM data suggest no degradation of I_c

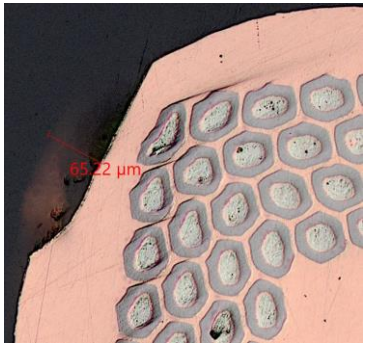


I_c degradation of Nb-Ti samples

NCR: Cable Mechanical Damage

- For **CR146**, the cable of the inner connection was lightly scratched with tooling during the removal of cable insulation
- The scratch does not appear to penetrate beyond the copper, with estimated depth 22 µm
- Not specifically evaluated at cable level, but a study is ongoing to simulate the effects of mechanical damage following a more severe case for coil CR141 (MQXFB06)
  - Initial findings showed no degradation of RRR even for severe simulated defects:
    - ~60 µm depth, applied compressively by a straight edge or rolling (indenting) with a 60 µm wire
  - I_c samples recently reacted: due for measurement in ~2 weeks

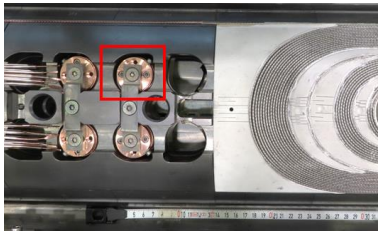


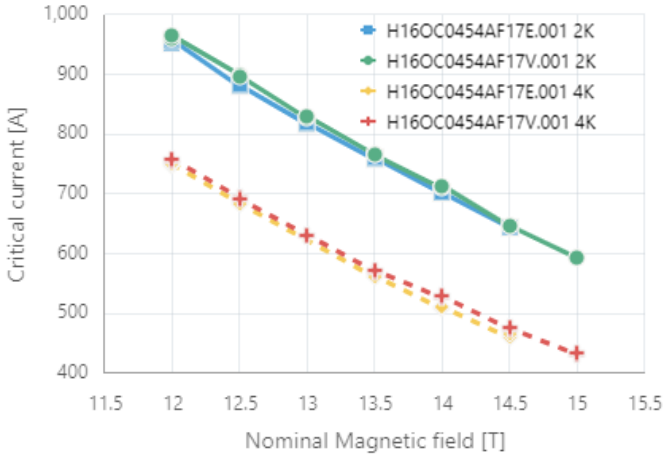


More severe simulated defect not causing RRR degradation

Witness Sample Damage

- Recap from MQXFB06:
  - For CR141, two virgin witness samples were found to be damaged after heat treatment
  - Modifications were made to the mica sheet in the mould assembly for CR144 onwards
- For **CR145**, an extracted witness sample from strand 17 appeared to be damaged
  - Not the same form as previous defects, and no apparent contact with mica sheet
- On testing, no degradation of I_c was found
  - No indication that further changes to reaction tooling are required

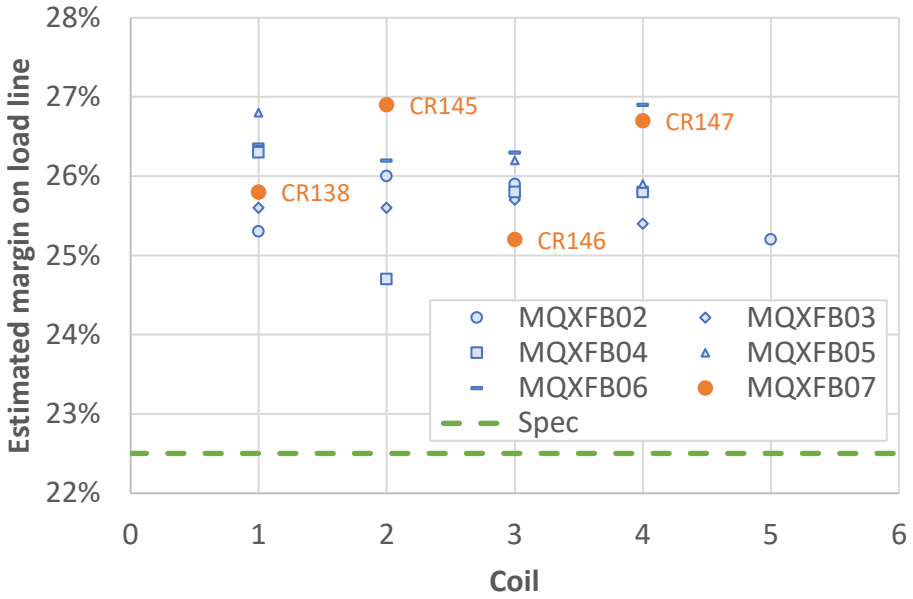




Testing Anomalies

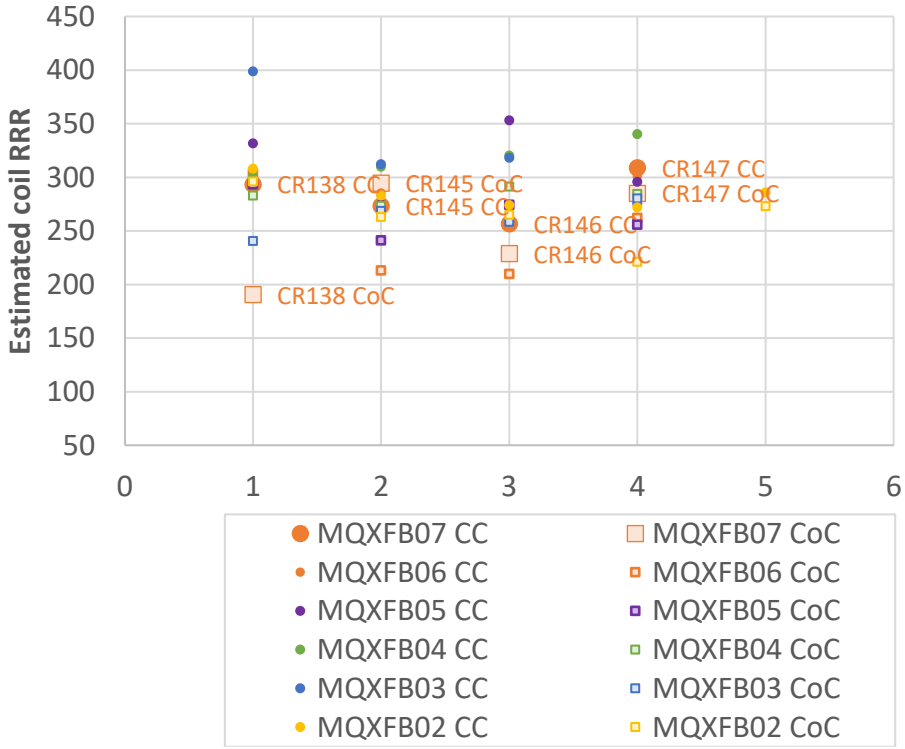
- For CR138, extracted sample WE13 was degraded, probably due to sample damage
  - Excluded from analysis
  - No correlation with furnace position, so not caused by heat treatment anomalies
- For CR146, the 60 cm voltage taps were not measurable for extracted strand WE15. Results for this sample were not included in the analysis
  - Values measured on the 90 cm voltage taps are consistent with the general behaviour and intermediate between other samples, so any effect on coil evaluation is negligible
- For CR145 and CR147, **cable qualification** samples were re-measured because of a concern with magnetic field calibration of a test station at the time of the original measurement
  - The cabling report was issued using only the **second** measurement to calculate cabling degradation
  - The witness reports plot results from the **first** measurement, but degradation values were confirmed with the **second** measurement
  - The heat treatment evaluation is not affected, as this is on the basis of virgin verification samples
  - The cause of the unexpected magnetic field behaviour has been identified and repaired

Load Line Margin



- Large margin on load line of ~26.2 %
  - Consistent in mean and spread with recent coils

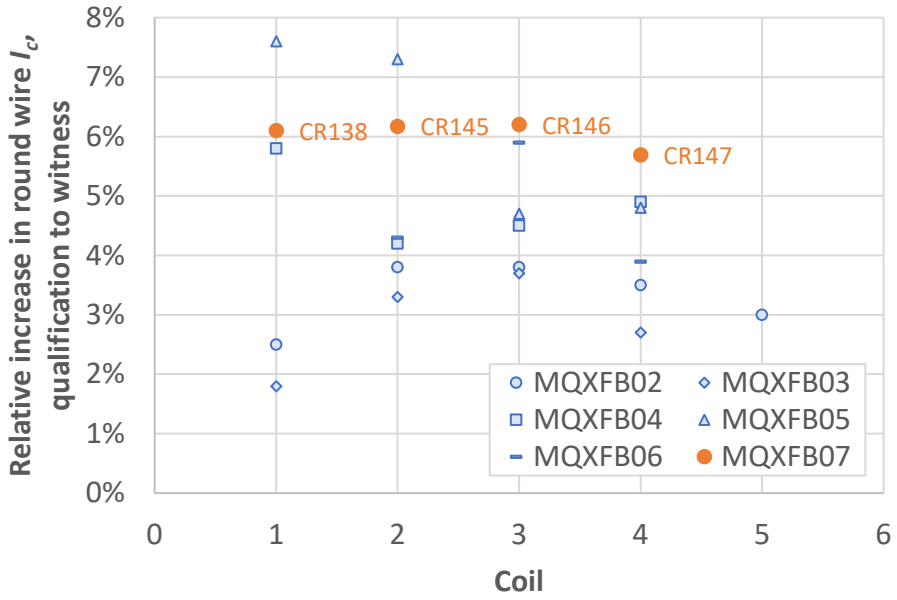
Estimated Coil RRR



- Large RRR margin
- Connection side (CC) generally has higher RRR
- Low RRR of CR138 CoC due to HT NCR, but still well above specification limit
- All other values within the range of other recent coils

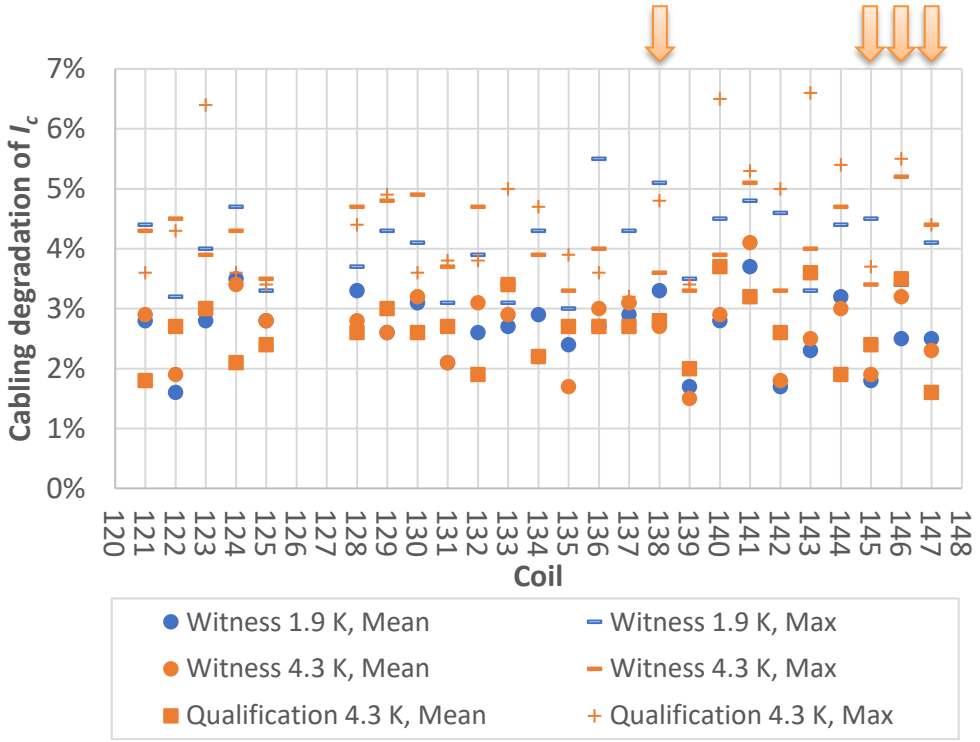
Effect of HT/Furnace on Round Wire I_c

- I_c of virgin **witness** samples (building 180) – I_c of virgin **qualification** samples (building 163)



- I_c consistently slightly higher for witness samples (HT in building 180) than qualification samples (HT in building 163)
- Very consistent for recent coils (despite HT NCRs)

Cabling Degradation of I_c



- Cabling degradation of I_c is within the 5 % specification for all coils
- Consistent and conforming degradation as assessed from witness samples across all recent production, both at 1.9 K and 4.3 K
- Mean cabling degradation ~3 %

Summary

- Cable data in specification for all coils
- Good consistency between recent coils, and data in a comparable range to MQXFB02-06
- Systematic differences remain between small (building 163) and large (building 180) HT furnaces, and in RRR between CC and CoC

Thank you for your attention!