Non Conformity of the PIT cable: impact on the magnet margin

B. Bordini

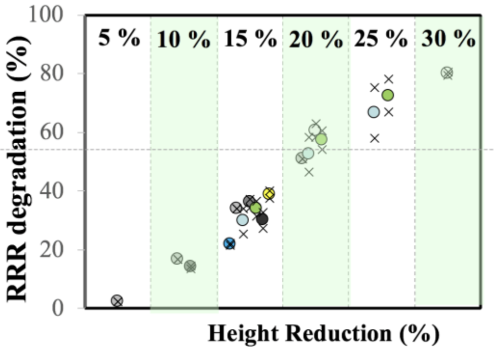
TCC Meeting
CERN – 30th August 2018

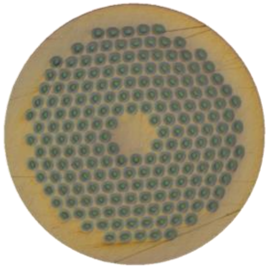
Outline

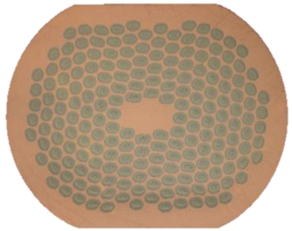
- Introduction
  - Characteristics of the Regular PIT wire
  - The bundle-barrier PIT wire for HL-LHC
- Degradation Due to Cabling
  - HL-LHC specifications
  - Performance of the PIT cable
- PIT MQXF magnet margin and Cabling Degradation
  - 5% critical current degradation
  - 10% critical current degradation
- Conclusions

INTRODUCTION
The 0.85 mm PIT wire for HL-LHC

- The **regular** PIT wire did not meet the HL-LHC MQXF specification
  - the RRR of the cabled strands was not acceptable for the magnet stability





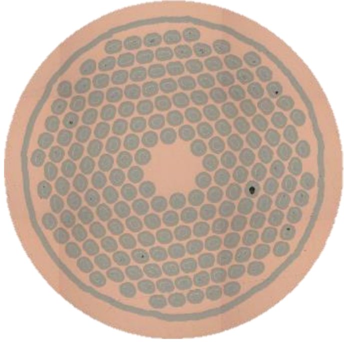


- The average performance of the regular PIT had small margin with respect to the specification → not a cost efficient production

I_c (12 T) [A]	I_c (15 T) [A]	RRR	J_c (12 T) [A/mm^2]	J_c (15 T) [A/mm^2]	B_{c2} [T]	
597 *(14)*	**333.1** *(11)*	**175** *(30)*	**2340** *(53)*	**1306** *(41)*	**25.8** *(0.3)*	← Average values (and RMS) for the wire received by CERN
590	**331**	**150**	-	-	-	← HL-LHC MQXF PIT wire Specification

- To meet HL-LHC specifications, CERN successfully developed, in collaboration with BRULER-EAS, a new version of PIT wire: the bundle barrier PIT

INTRODUCTION
The bundle barrier PIT wire 1/2



- The bundle barrier PIT mainly differs from the regular PIT for:
  - A common Nb diffusion barrier that separates the filaments from the outer copper
  - Having a larger % of Tin in the filaments
  - A more aggressive heat treatment

- These modifications allowed obtaining a conform wire that cost less than what proposed by Bruker-EAS for the regular PIT wire

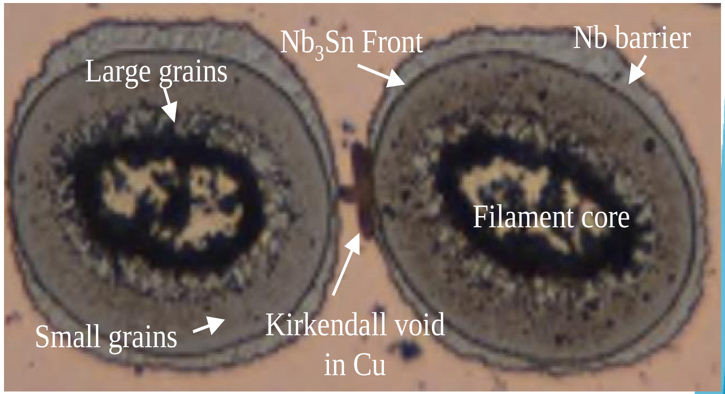
	Regular PIT	Bundle Barrier PIT
Minimal I_c (12 T, 4.22 K), A	585	590*
Minimal I_c (15 T, 4.22 K), A	320	331*
Minimal RRR, -	100	150*
Minimal RRR – 15% Rolled, -	50	100*
Price per meter, %	117	100

*HL-LHC specified values

INTRODUCTION
The bundle barrier PIT wire 2/2

- The only drawback of the bundle barrier PIT wire is a slightly larger degradation of its critical current when cabled

- During the development of the bundle barrier wire, we discovered that the PIT wire behaves as if the Nb_3Sn cannot form anymore in a filament as soon as its Nb_3Sn front has reached the copper stabilizer at any point.
  - At that moment, the remaining tin instead of forming additional Nb_3Sn, prefer to diffuse into the copper stabilizer
  - Where Nb_3Sn and Cu enter into contact, a Kirkendall void is often observed in the copper matrix



- The bundle barrier is more sensitive to cabling because, during the heat treatment, the Nb_3Sn front has more probabilities of reaching the copper stabilizer when the filament roundness is deformed (by cabling)

Degradation Due To Cabling
HL-LHC Specification

- At present for the HL-LHC project, a cable must have a critical current degradation lower than 5% and a RRR of the stabilizing copper larger than 100

- These parameters where established taking into account the magnet stability and performance + the behavior of the RRP wire when cabled
  - In particular the maximal critical current degradation value was set considering that the the RRP sub-elements are heavily sheared (and the local RRR is significantly lower than 100) when the I_c degradation is larger than 5%

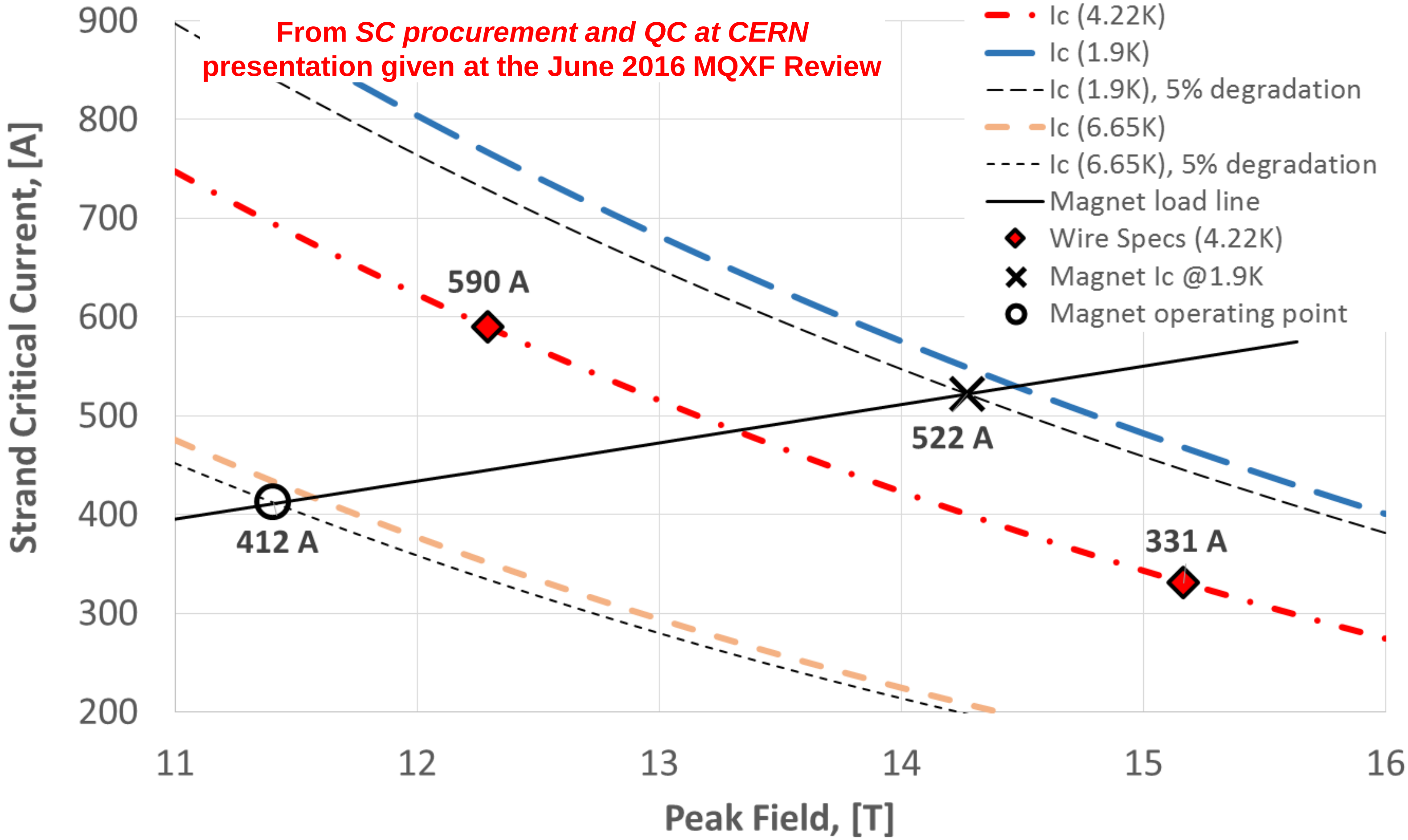
Degradation Due To Cabling
The HL-LHC PIT MQXF cable

- Three long cables were manufactured and measured by using the bundle barrier PIT bought for the prototype MQXF magnets

- The average critical current degradation is 7-8%
  - Cable H16EC0235A, 5 pairs of samples (Extracted and Virgin), average degradation was 8.3% (min 6.2%, max 10.8%)
  - Cable H16EC0236A, 4 pairs of samples, average degradation was 7.3% (min 5.8%, max 8.6%)
  - cable H16EC0248A, 4 pairs of samples, average degradation was 8.3% (min 5.4%, max 11.6%)

- The PIT cable is not conform to the present HL-LHC cable specification

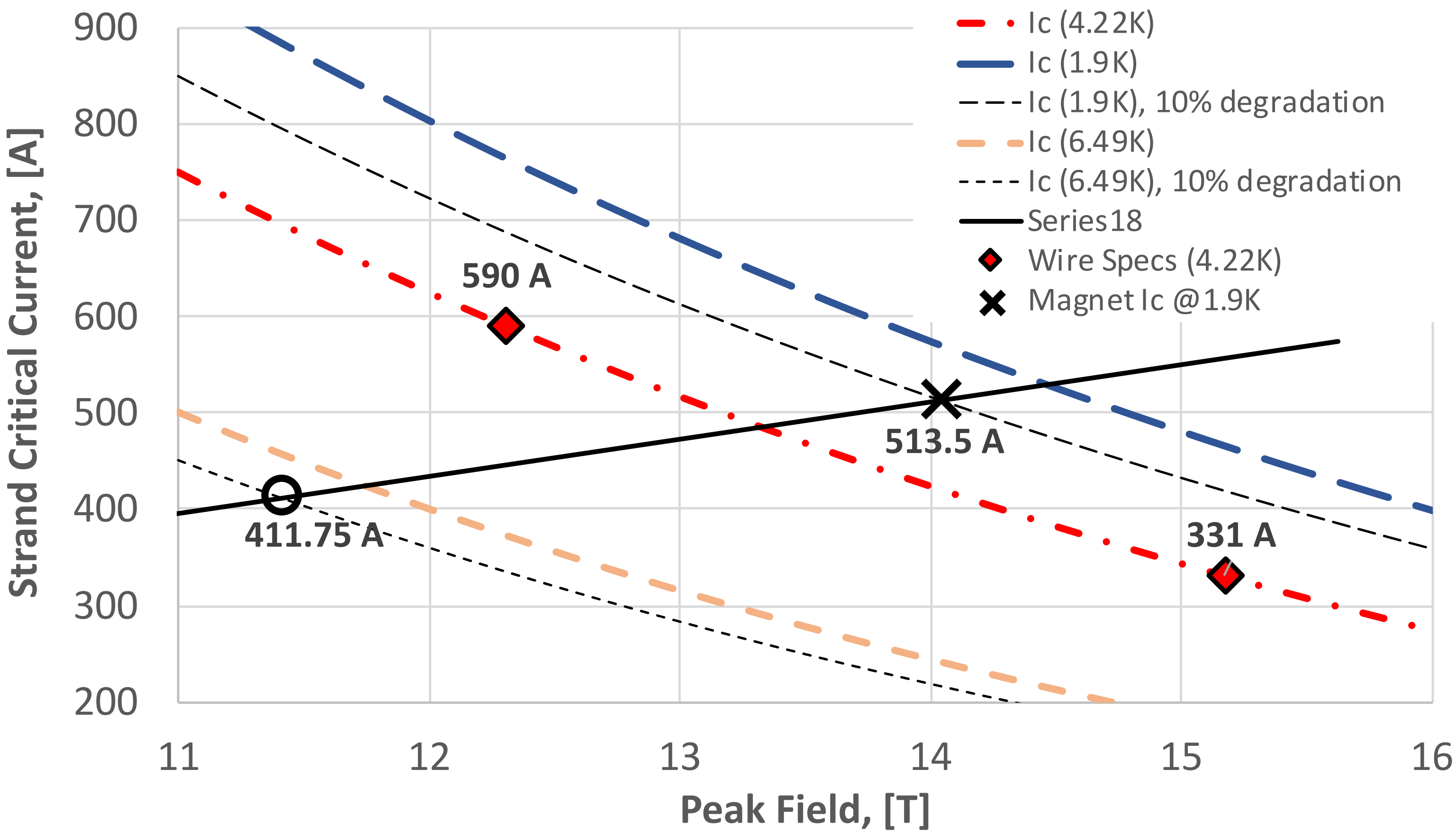
PIT MQXF Magnet Margin
5% Cabling Degradation



4.75 K Temperature Margin, Current Margin 104 %

21.1% Margin on the Load-Line

PIT MQXF Magnet Margin
10% Cabling Degradation



4.59 K Temperature Margin, Current Margin 93 %

19.8 % Margin on the Load-Line

Conclusions

- The first three long PIT MQXF cables showed an average critical current degradation (due to cabling) of about 7-8%
- An I_c degradation of 10 % (instead of 5 %) has a limited impact on the magnet margin (1.3 % on the load line)
- The cabling process has a limited impact on the RRR of the bundle barrier PIT (which is not the case for the RRP conductor)

It is proposed to increase the average degradation limit of the bundle barrier PIT cable to 10 % (maximum 12%) while keeping 5 % (maximum 6%) for the RRP cable