

Status and performances of strand and cable for the FRESCA2 magnet

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Outline :

Main characteristics of the strand

Status of the strand order

Performances obtained during the qualification phase

Main characteristics of the cable

Results of the cable development work

Stability measurements on extracted strands

Conclusion

Main characteristics of the FRESCA2 strand and performances obtained during the qualification phase

		FRESCA2 specification	PIT	RRP
Strand diameter	(mm)	1.00	1.00	1.00
Strand layout	-		192 filaments	132/169 stack
Sub-element diameter	(μm)	< 50	~ 48	~ 57
Copper to non-Copper volume ratio	-	1.25 +/- 0.1	1.28 ($\sigma = 0.02$)	1.28 ($\sigma = 0.02$)
J_C (12 T, 4.2 K)	(A/mm ²)	2500	2497	2842
J_C (15 T, 4.2 K)	(A/mm ²)	1250	1425	1623
n-value @15 T and 4.2 K	-	> 30	~ 44 ($\sigma = 8$)	~ 50 ($\sigma = 10$)
RRR (after full reaction)	-	> 150	192 (average)	260 (average)
ΔM at 3 T and 1.9 K	mT	-	173	323
Effective filament diameter	(μm)	-	44	64
Piece length	-		7% below 1 km	40 % below 1 km

Status of Nb₃Sn Strand Procurement

Order	Type of order	Delivery date	Length	Supplier	Remaining length
CERN	R&D	Aug. 2010	13 km	Bruker	1.1 km
CERN	Qualification	June 2011	15 km	Bruker	13.5 km
CEA	Pilot	April 2012	15 km	Bruker	6.5 km
CERN	Production	Aug. 2013	45 km	Bruker	-

Used for cable development

Used for a SMC cable

Total quantity to be available for cabling : 66 km

Order	Type of order	Delivery date	Length	Supplier	Remaining length
CERN	Qualification	Aug. 2010	10 km	OST	8 km
CEA	Pilot	June 2011	13 km	OST	13 km
CEA	Pilot	April 2012	12 km	OST	12 km
CERN	Production	Oct. 2013	40 km	OST	-

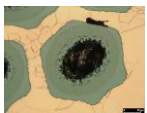
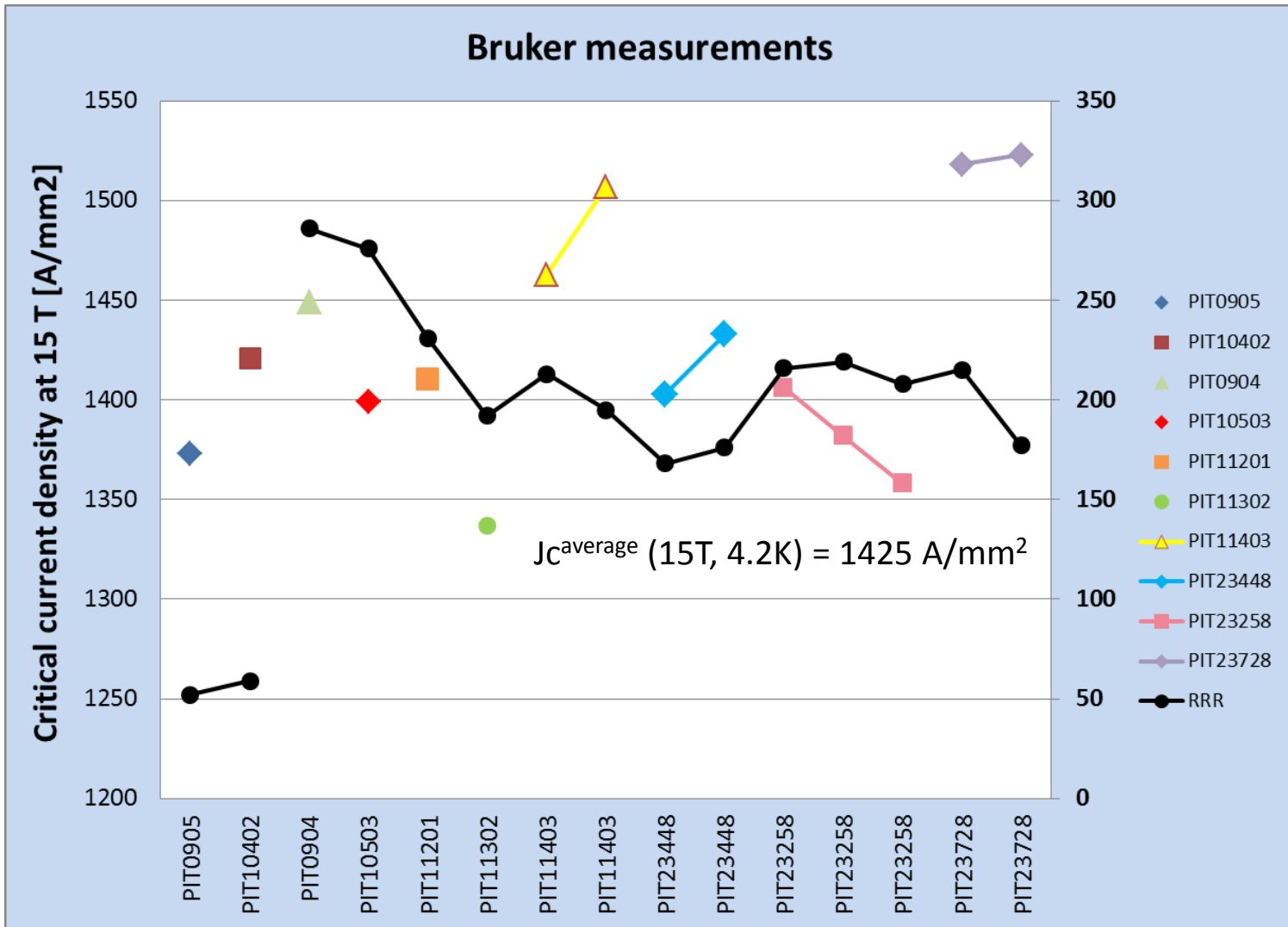
Used for cable development

Total quantity to be available for cabling : 73 km

Performances of the 1.0 mm PIT strands

- Jc values given at 4.2 K for optimized heat treatments.
- Quite reproducible values obtained on the 7 billets produced these last 2 years.
- The Jc values in magenta were measured by Bruker.
- **Jc (15T, 4.2K) ~ 1370 to 1520 A/mm²** as measured by Bruker

Sample ID	Heat treatment	Jc(12T, 4.2K)	Jc(11T, 4.2K)	Jc(10T,4.2K)	RRR
HE10S00904A24U	120h/620C + 100h/650C	2464 / 2539	2923	3476	235
HE10S00905A46U	120h/620C + 100h/650C	2451 / 2409	2937	3459	74/97
HE10S10402A15U	120h/620C + 90h/650C	2477 / 2452	2946	3481	96/103/105/135
HE10S10503A29U	100h/620C + 120h/640C	2528 / 2487	2997	3523	153/155
HE10S11201B01U	100h/620C + 120h/640C	2418 / 2468	2899	3442	177
HE10S11201A01U	100h/620C + 120h/640C	2616 / 2468	3120	3687	175
HE10S11302B01U	100h/620C + 120h/640C	2467 / 2418	2911	3456	165
HE10S11403A01U	100h/620C + 120h/640C	2510 / 2565	2965	3493	154/173
HE10S11403B01U	100h/620C + 120h/640C	2510 / 2637	2969	3500	179/201
HE10S23258B90U	100h/620C + 120h/640C	2480 / 2471	2959	3506	159/161
HE10S23448A82U	100h/620C + 120h/640C	2442 / 2502	2915	3457	86/85 168/178
HE10S23728B93U	100h/620C + 120h/640C	2606 / 2676	3080	3629	180/184
	(Max – Min)/ Average	11 %	7.5 %	7 %	

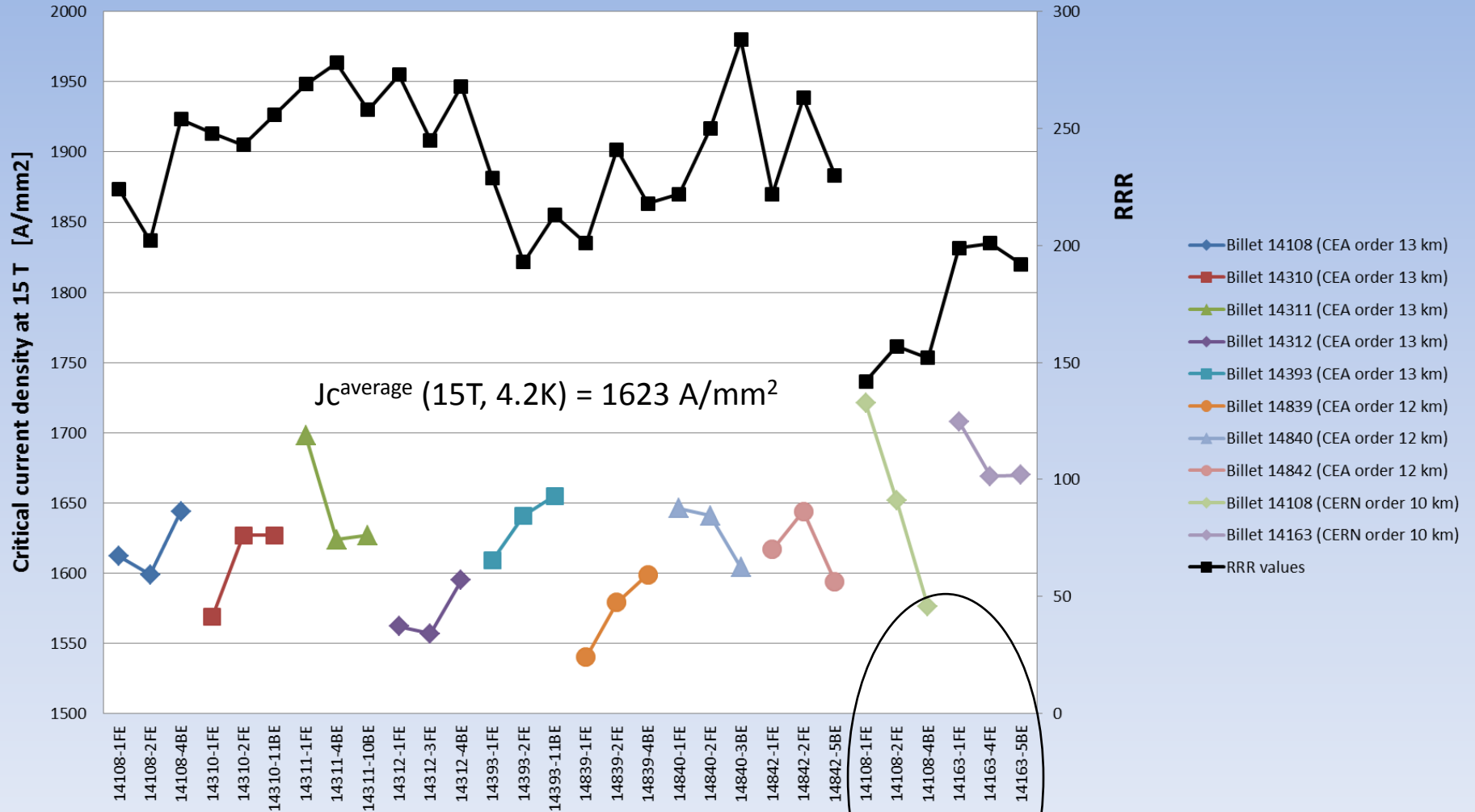


PIT 09Y05



PIT 09Y04

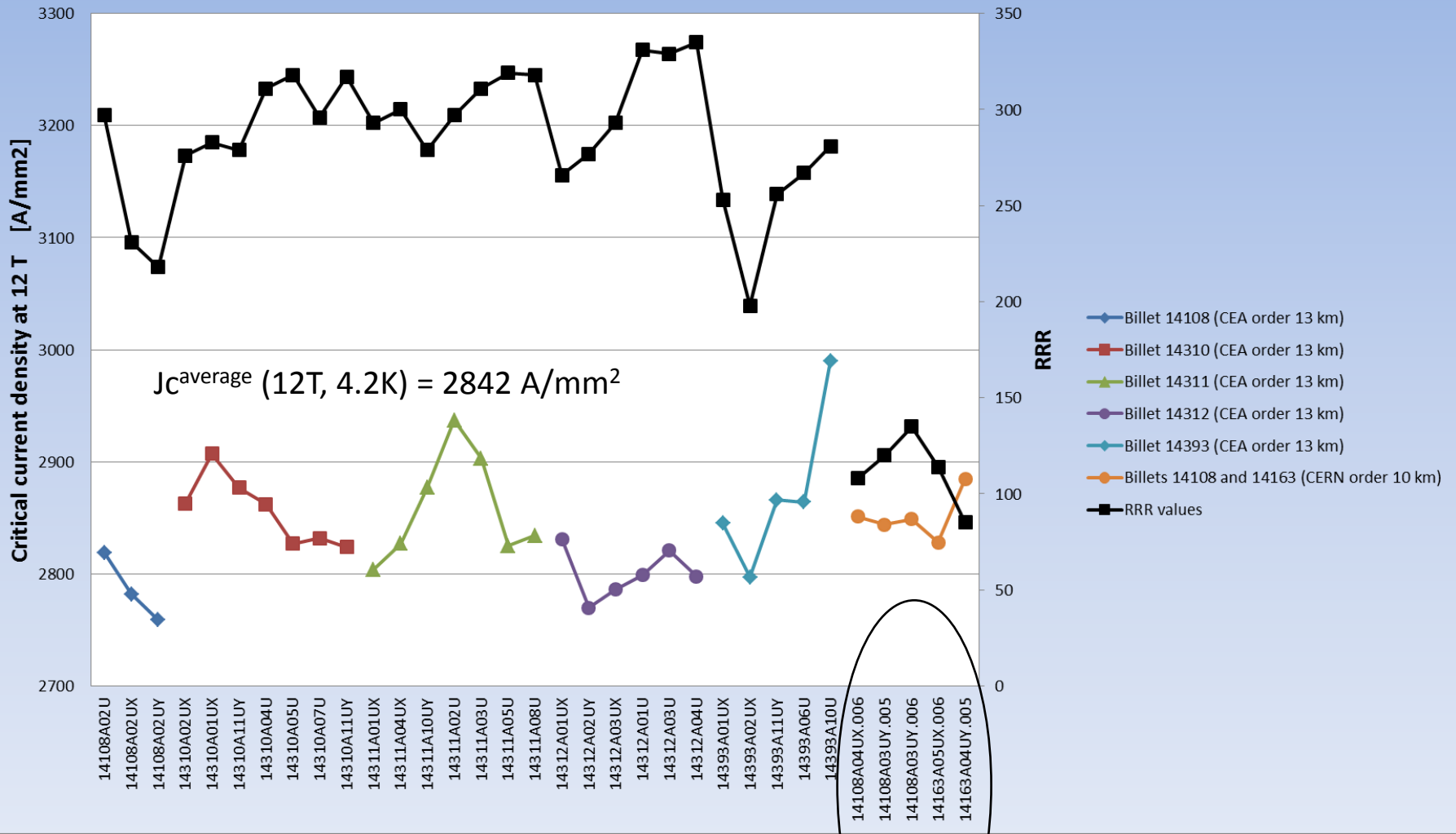
OST measurements



HT of Billets : 48h/210C + 48h/400C + 50h/650C

HT of Billets
 48h/210C +
 48h/400C +
 50h/665C

CERN measurements



HT of Billets : 48h/210C + 48h/400C + 50h/650C

HT of Billets
48h/210C +
48h/400C +
50h/665C

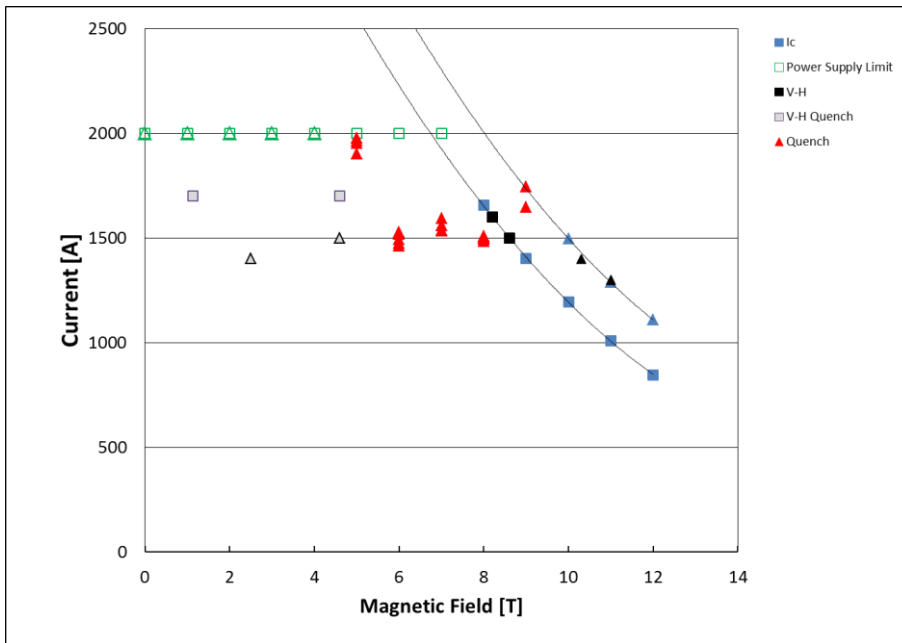
Stability measurements at 4.3 K and 2.0 K

PIT strands (billet 0904)

V-I and V-H measurements performed at 4.3 K (square marker) and at 2.0 K (triangle marker).

$I_s = 1600$ A at 4.3 K

$I_s = 1400$ A at 2.0 K

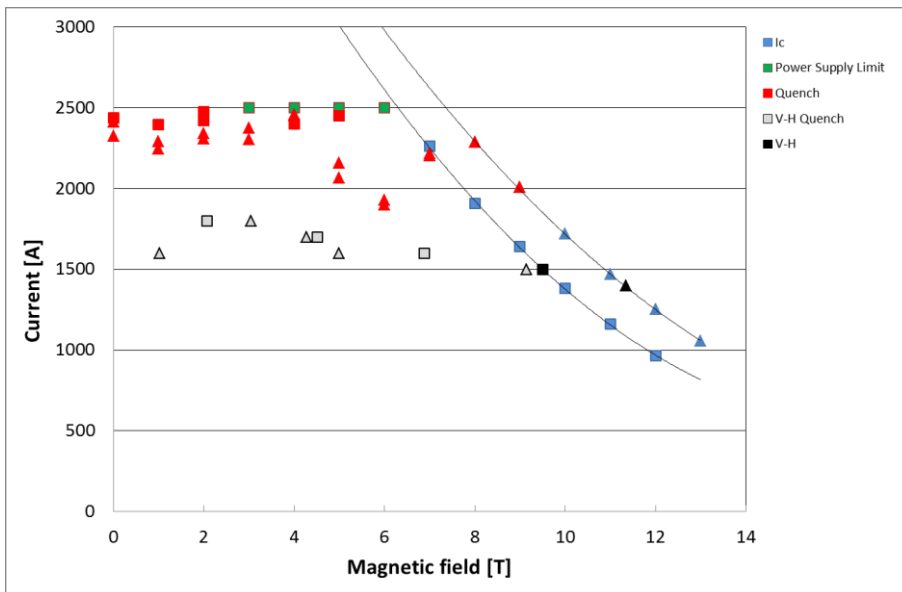


RRP strands (billet 14311)

V-I and V-H measurements performed at 4.3 K (square marker) and at 2.0 K (triangle marker).

$I_s = 1500$ A at 4.3 K

$I_s = 1400$ A at 2.0 K



Main characteristics of the FRESCA2 cable

Cable width	20.9 mm
Cable mid-thickness at 50 MPa	1.82 mm
Keystone angle	0 degree
Cable transposition pitch	120 mm
Number of strands	40
I_c (12 T, 4.2 K)	31420 A
I_c (15 T, 4.2 K)	15170 A
n-value @ 15 T and 4.2 K	> 20
RRR after HT	> 120
Minimum cable unit length	260 m

The critical current of the cable is calculated taking into account a degradation of 10 % due to cabling.

Following an extensive development program of the FRESCA2 cable, the objective to obtain a degradation smaller than 10 % was achieved with a cable width of 20.9 mm and a transposition pitch length of 120 mm.

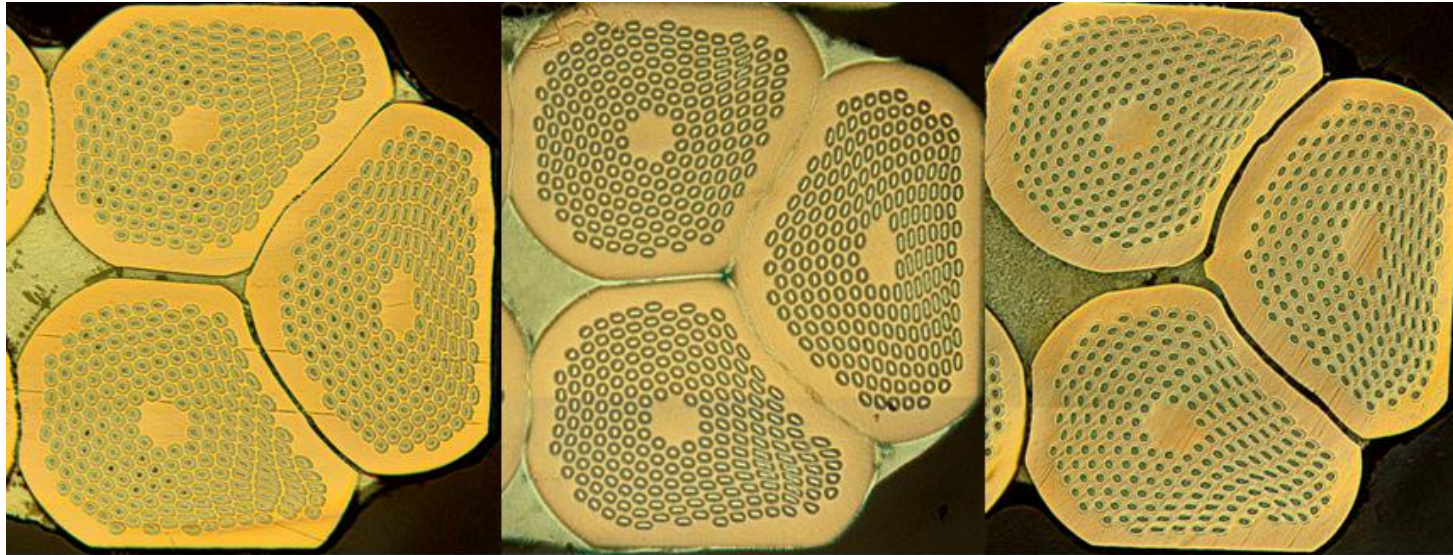


Summary of the work carried out to develop the FRESCA2 cable

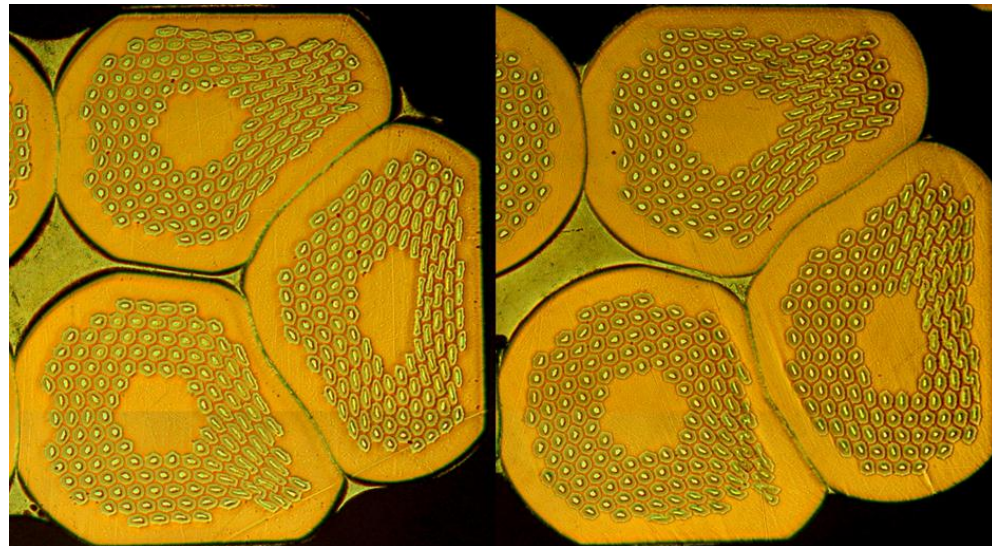
13 km of PIT strands and 2 km of RRP strands used for all the cabling tests performed to develop the cable

Billet number	Cable width	Transposition pitch Mid-thickness	Ic Degradation	RRR	Packing Factor
PIT 0905	21.4 mm	120 mm / 1.82 mm	19 %	62 to 69	85.6 %
PIT 0904		130 mm / 1.82 mm	18 %	60 to 65	84.9 %
		120 mm / 1.82 mm	10.7 %	170 to 189	85.6 %
		110 mm / 1.86 mm	18 %	135 to 180	84.7 %
PIT 10402	20.9 mm	120 mm / 1.82 mm	15 %	58 to 67	87.5 %
PIT 11403		140 mm / 1.82 mm	18.5 %	52 to 61	86.2 %
		120 mm / 1.82 mm	8.9 %	109 to 119	87.5 %
		120 mm / 1.86 mm	11.4 %	121 to 137	85.6 %
		120 mm / 1.82 mm	5.5 % (oil)	113 to 128	87.5 %
RRP 132/169	20.9 mm	120 mm / 1.82 mm	4.2 % (buthanol)	88 to 109	87.5 %
		120 mm / 1.82 mm	3.9 % (oil)	84 to 115	87.5 %

Cross-sectional photographs of the **20.9 mm** wide cable fabricated with **PIT** strands using either ethanol (left), oil (middle) or buthanol (right) as lubricant.



Cross-sectional photographs of the cable fabricated with **RRP** strands using either oil (left) or buthanol (right) as lubricant.

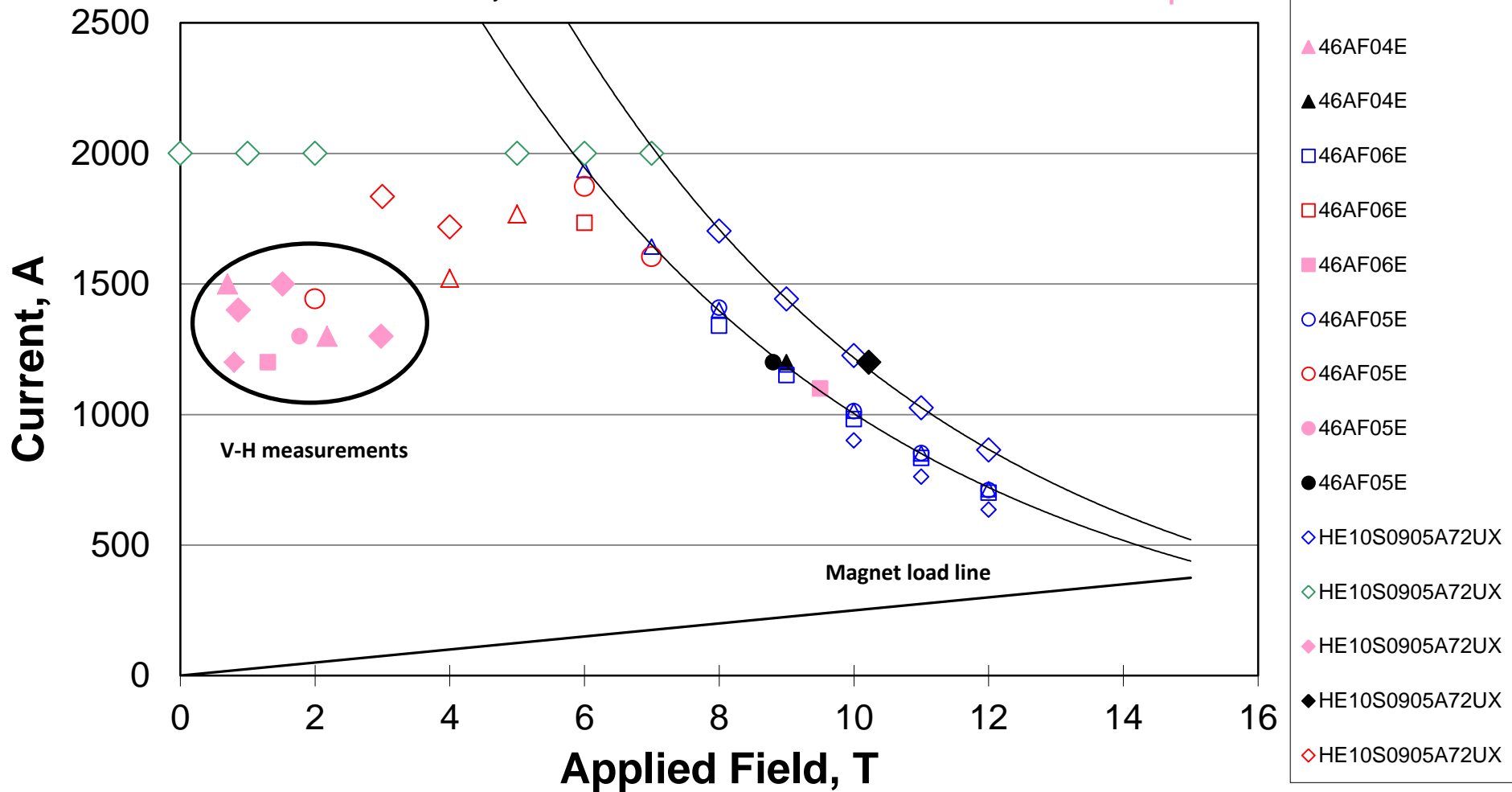


Stability Current I_s measured by V_H tests

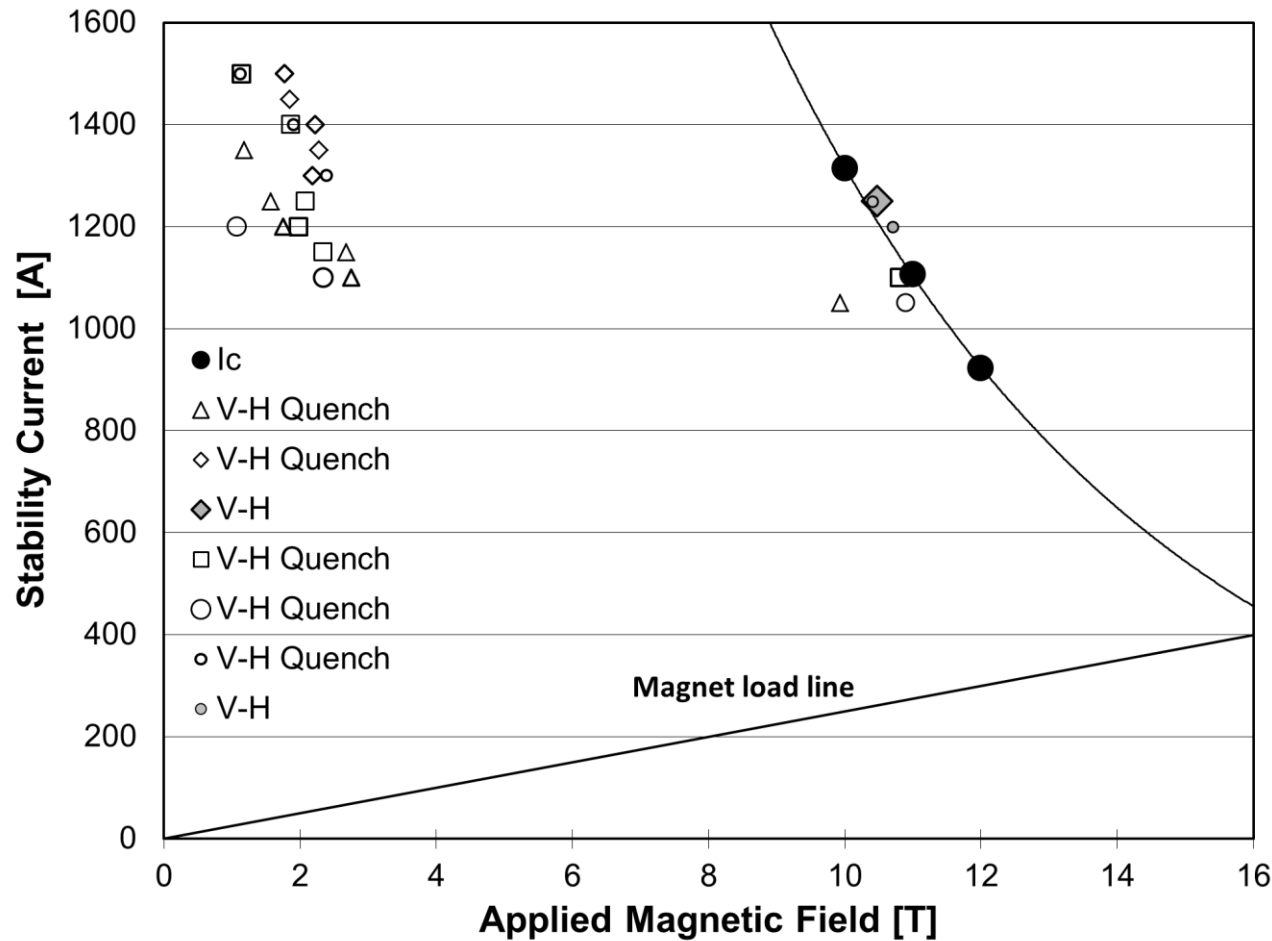
PIT Strand from billet 0905 extracted from a 21.4 mm wide cable
T = 4.33 K, average degradation ~ 19%. RRR between 31 and 39

I_c
Quench
PSL
V_h
V_h quench

Stability current = 1100 A



Characterization of the 20.9 mm wide cable fabricated with RRP 132/169 strands by V-H tests performed at 4.3 K on extracted strands



$I_s = 1050 \text{ A}$

a value more than 2 times higher than the value of the current defined by the intersection of the magnet load line with the critical current curve

Conclusion

- The two suppliers Bruker and OST were qualified for the strand production after a successful development.
- Following an extensive development program of the FRESCA2 cable, a degradation of the critical current due to cabling of 4-5 % was achieved for a 20.9 mm wide cable fabricated either with PIT or RRP strands using oil as lubricant.
- The stability current measured on PIT or RRP extracted strands is quite high => low magnetic field instabilities should not be an issue for the FRESCA2 dipole.