Status and performance of strand and cable for the FRESCA2 magnet

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Outline :

Main Characteristics of the FRESCA2 strand
Status of the strand order
Performances of the PIT strand
Stability measurements on virgin and on extracted strands

Main Characteristics of the cable
Status of the cable development work

Main characteristics of the FRESCA2 strand

		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	1.25 +/- 0.1	1.30 +/- 0.1
J_C(12 T, 4.2 K)	(A/mm^2)	2500	**2450**	**-**
J_C(15 T, 4.2 K)	(A/mm^2)	**1250**	**1350**	**1575**
n-value @15 T and 4.2 K	-	> 30	> 30	> 30 expected
RRR (after full reaction) *Pilot order* *Production order*	-	 > 150 > 150	 Accepted **-**	 **> 75** (target >100) **-**
Piece length *Pilot order* *Production order*	(m)	 > **150** **(target 400 m)** > 800 m	 Accepted ?	 Accepted ?

Nb_3Sn Strand Procurement Status 1/2

13 km of PIT strand ordered by CERN in March 2010.

used for the cable development work and for the fabrication of the SMC cable.

30 km of PIT strand ordered by CEA and CERN to Bruker-EAS.

delivered and available for the fabrication of the first unit lengths

25 km of RRP strand ordered by CEA and CERN to OST.

expected to be delivered before June 2012

Option for 10 km of RRP strand to be taken by CEA depending of the performances of the RRP strand under fabrication for CERN.

~ 25 km of strand to be ordered by CEA in April 2012.

offers to be received before end of March 2012

~ 45 km of strand to be ordered by CERN in November 2012.

Nb_3Sn Strand Procurement Status 2/2

PIT 0904 1600 m, 2260 m (round)
PIT 0905 4200 m (hexa)
PIT10402 1880 m + 2954 m (hexa)
Quantity delivered to CERN : 12894 m

PIT 10503 3162 m (round)
PIT 11201 2594 m, 2786 m (round)
PIT 11302 4903 m (round)
PIT 11403 1575 m (round)
Quantity delivered to CERN : 15020 m

PIT 23448 404 m, 564 m, 881 m
PIT 23258 1133 m, 1672 m, 547 m, 518 m
PIT 23728 2360 m, 3085 m
PIT 11403 4028 m
Quantity delivered to CERN : 15192 m

Performances of the 1.0 mm PIT strands

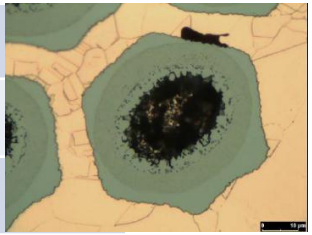
- Jc values given at 4.2 K for optimized heat treatments.
- Quite reproducible values obtained on the 7 billets produced these last 2 years.
- The Jc values in magenta were measured by Bruker.
- **Jc (15T, 4.2K) ~ 1350 to 1500 A/mm²** as measured by Bruker

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
	(Max – Min)/ Average	8 %	7 %	7 %	

RRR values for round and hexagonal filaments and for various heat treatments

The heat treatment was optimized for the billets with round filaments to have a RRR value greater than 150 while keeping a critical current density higher than 2400 A/mm^2 at 12 T and 4.2 K, but not successful for the billets with hexagonal filaments.

Heat treatment	HE10S0904 (round filaments)	HE10S0905 (hexagonal filaments)
250h/625C	254/309	67
120h/620C + 100h/650C	181/188/239	52/65/66
120h/620C + 90h/650C	260/287	74/97



A new heat treatment has been strongly recommended by Bruker for the billets produced in 2011: **100h**/620C + 120h/**640**C to optimize the Jc both at 12 T and at 15 T.

HE10S10503	HE10S11201	HE10S11302	HE10S11403
153/155	160/172/175/177	165	154/173/179/201

RRR values on extracted strands

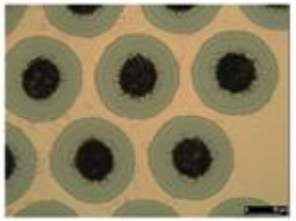
In the table, The RRR values measured on extracted strands from 2 types of cable (SMC and FRESCA2 cables) are presented.

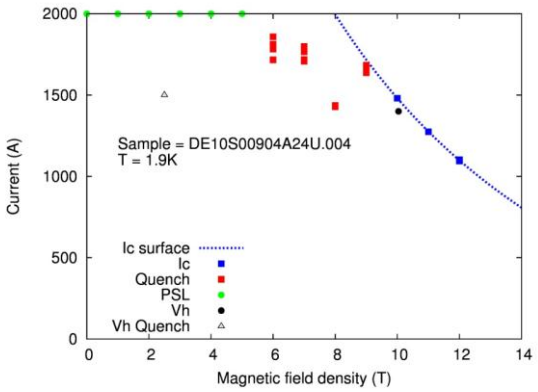
Standard heat treatment 120h/620C + 90h/650C	HE10S0904 (round filaments)	HE10S0905 (hexagonal filaments)	HE10S10402 (hexagonal filaments)
Average RRR value for virgin strand	~ 270	~ 85	~ 110
SMC cable : 18 strands	125 to 147	57 to 61	-
FRESCA2 cable : 40 strands	143 to 189	56 to 72	52 to 82

Conclusion : Initial RRR values of virgin strands are very important

Stability current Is determined by V-H measurements

PIT 0904 strand with round filaments



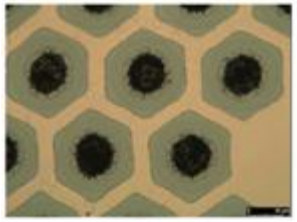


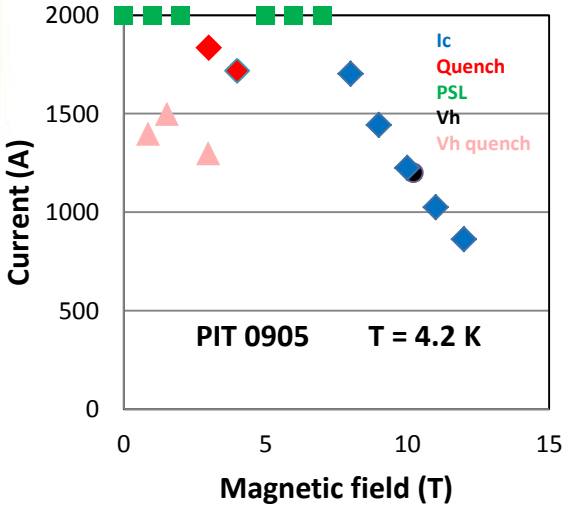
Is at 4.2 K on virgin strand > 2000 A (RRR > 235)

Is at 1.9 K on virgin strand > 1500 A

Is at 4.2 K on extracted strands > 1500 A (RRR > 135)

PIT 0905 strand with hexagonal filaments





Is at 4.2 K on virgin strand > 1300 A (RRR = 67)

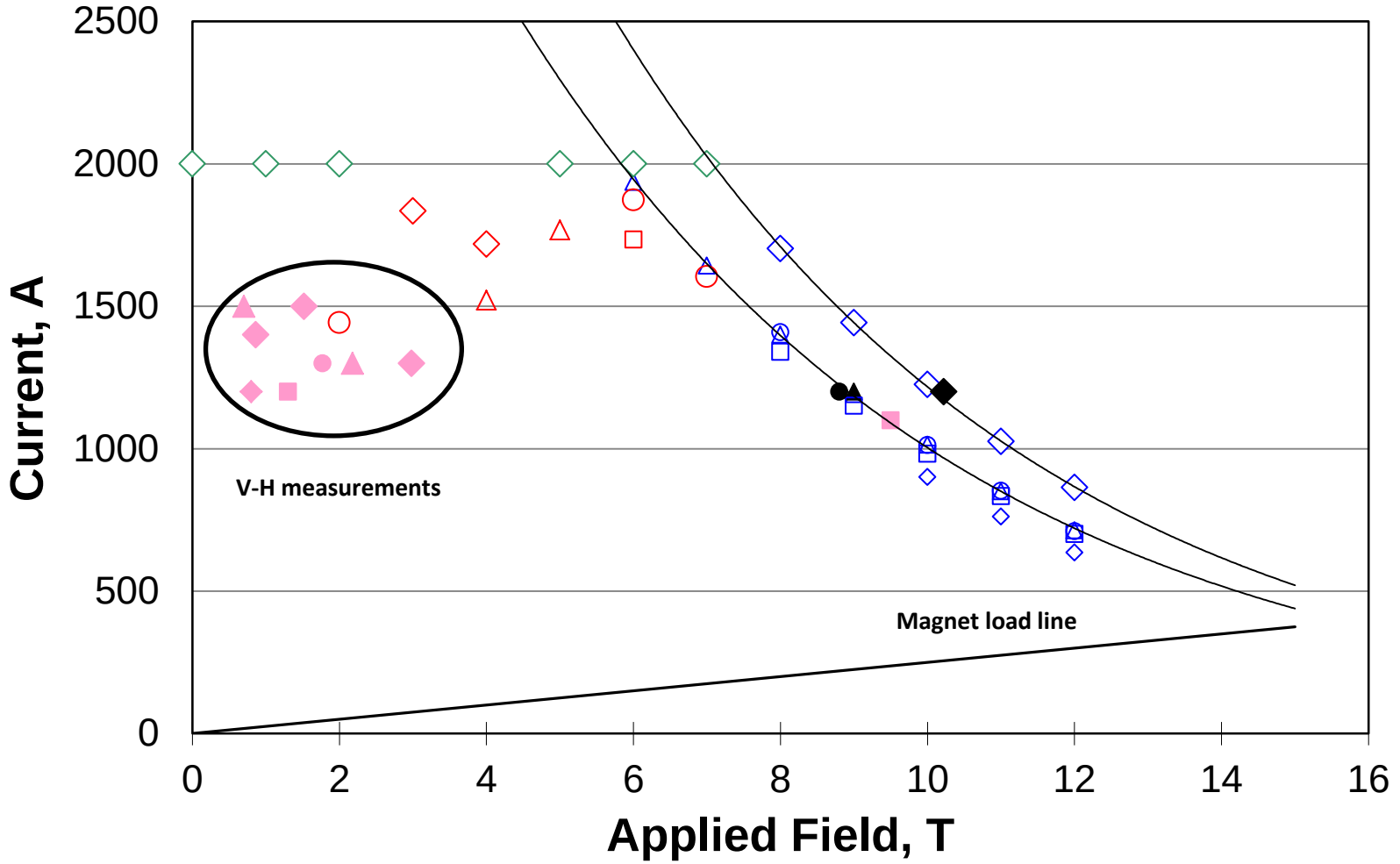
Is at 1.9 K on virgin strand not measured

Is at 4.2 K on extracted strands > 1100 A (RRR = 30)

Stability Current Is

PIT Strand from billet 0905 **extracted** from the FRESCA2 cable 46
T = 4.33 K, average degradation ~ 19%. RRR between 31 and 39

Ic
Quench
PSL
Vh
Vh quench



46AF03E
46AF03E
46AF04E
46AF04E
46AF04E
46AF04E
46AF06E
46AF06E
46AF06E
46AF05E
46AF05E
46AF05E
46AF05E
HE10S0905A72UX
HE10S0905A72UX
HE10S0905A72UX
HE10S0905A72UX
HE10S0905A72UX

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.

FRESCA2 cable development

- Work started in 2010 with hard Cu wires to fabricate a cable with the aim to optimize the tooling and the cabling parameters.
  Depending of the cable width, the transposition pitch of the cable has to be adapted to get a cable *mechanically* stable and having *no gaps* between the strands.
  Smaller is the width of the cable, larger could be the transposition pitch.

- **The best results in terms of mechanical stability were obtained with a cable width of 20.9 mm and 20.4 mm.**

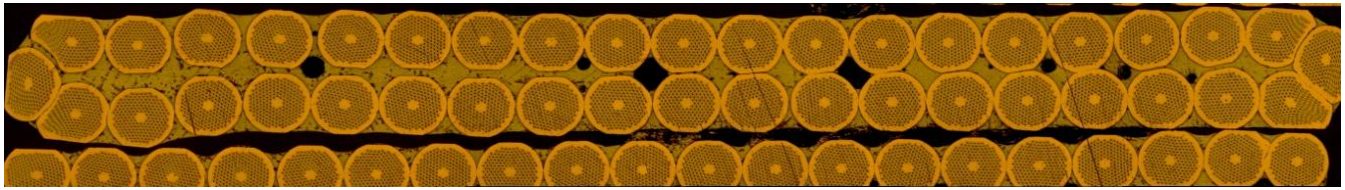
- Different values for the width, the mid-thickness and the transposition pitch of the cable were tried to minimize the degradation of the Ic during cabling.

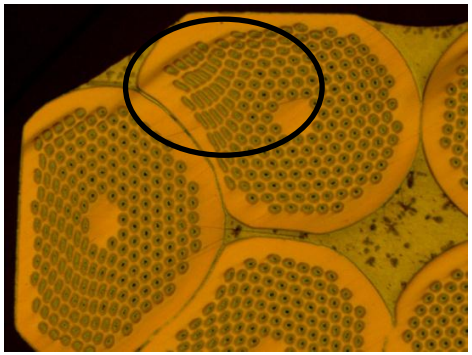
Summary of the work carried out to develop the FRESCA2 cable

9 km of PIT strands used for all the cabling tests performed to develop the cable

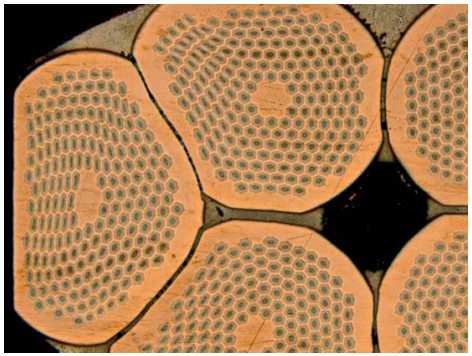
Billet number	Cable width	Transposition pitch / Mid-thickness	Ic / Degradation	Packing Factor
PIT 0905	**21.4 mm**	120 mm / 1.82 mm		85.6 %
		130 mm / 1.82 mm		84.9 %
PIT 0904		120 mm / 1.82 mm		85.6 %
		110 mm / 1.86 mm		84.7 %
PIT 10402	**20.9 mm**	120 mm / 1.82 mm		87.5 %
		140 mm / 1.82 mm		86.2 %
PIT 10402	**20.4 mm**	120 mm / 1.806 mm		89.9 %
		160 mm / 1.806 mm		88.0 %
		120 mm / 1.86 mm		87.3 %
		150 mm / 1.86 mm		85.8 %

Comparison of different cable cross-section for a mid-thickness of 1.82 mm

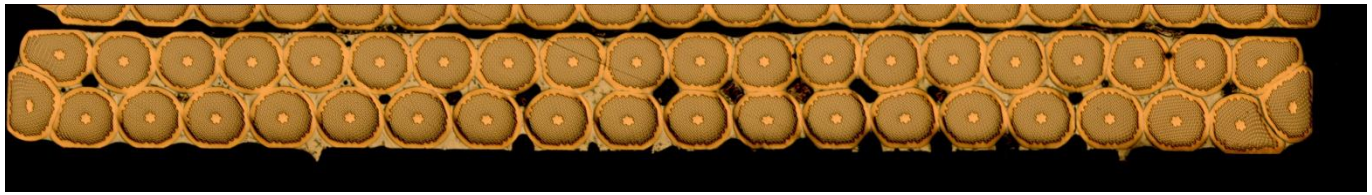


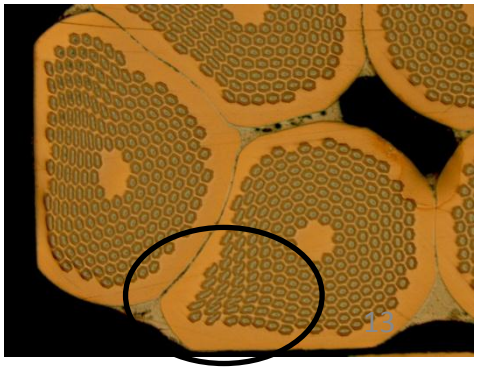


Width of 21.4 mm **Total compaction 85.6 %**



Width of 20.9 mm **Total compaction 87.5 %**





Width of 20.4 mm **Total compaction 89 %**

Conclusion on the cable development

With the results obtained up to now, we already have a cable meeting the required critical current at 15 T. Further decrease of the degradation below 10 % will give us more margin.

To decrease further the degradation below 10%, the best candidate is the cable with a width of 20.9 mm. A new cabling run was already carried out to fabricate a cable with a width of 20.9 mm using PIT strands and playing with the width of the mandrel.

(The results obtained recently with the fabrication of a cable with a width of 21.4 mm giving an average degradation of 10.7 %, indicates that such a degradation can also be achieved with a width of 20.9 mm.)

The development of the FRESCA2 cable will continue with the fabrication of a cable with the RRP strand.

Conclusion on the strand production

- Performances of the PIT strands are within the specification, production of the strand is well under control by Bruker.
- Stability is not an issue at 4.2 K with the PIT strand. Measurements have to be performed at 1.9 K on extracted strands.
- The production of the OST Strand 132/169 is well advanced with the first billet achieving more than 1575 A/mm^2 at 15 T and having given a long strand piece length of 3.3 km.