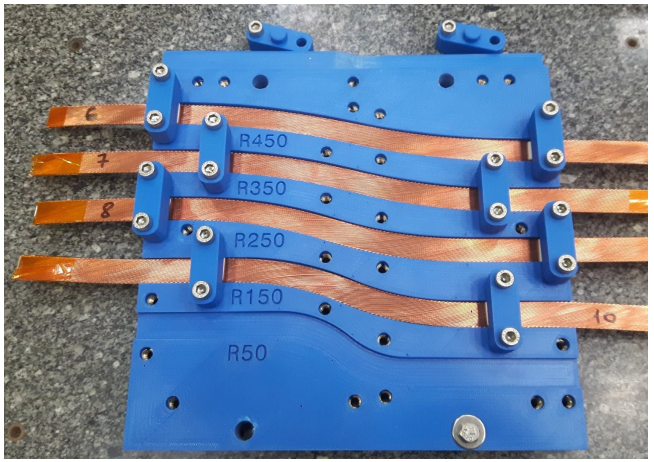
DE LA RECHERCHE À L'INDUSTRIE

Conceptual Design Review of R2D2
5
- Coil R&D -

https://indico.cern.ch/event/1003865/



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CERN: S. Izquierdo Bermudez, J.C. Perez, D. Tommasini, J. Fleiter, H. Felice

09/03/2021

OPEN QUESTIONS REQUIRING R&D

a. What are the **safe bending parameters** for coil winding?
b. How to handle the different cables in **graded coils** ? Winding R&D

c. How to deal with longitudinal contraction during **heat treatment**?
Heat treated winding R&D

d. How to guide and secure the **exits** to the outside of the coils?
e. How to provide **margins** (geometric, magnetic, mechanical…) to the exit path?
f. How to perform all the **joints** in a compact area? Splices R&D
g. How to apply **longitudinal pre-stress** without damaging the joint area?

h. What will be the **mechanical behavior** of the coils?
i. What level of **transverse pre-stress** to apply?
j. How to guarantee the **pre-stress** is controlled and reproducible?
Structure R&D

COIL R&D AND TESTS

- Bending tests
- Winding mock up

} Winding R&D

- Heat treated cable stacks
- Heat treated short coils

} Heat treated winding R&D

- Splice tests
- **Splice mock up**

} Splices R&D

- Cable and winding characterization :
  - Jc measurements on strands
  - Jc measurements on cable under pressure
  - Thermomechanical measurements on impregnated cable stacks

CABLE FOR TESTS

R2D2 Cable (bare)	# of strands	strand Ø [mm]	Thickness [mm]	Width [mm]	Tp [mm]	Core	Insulation thickness [mm]
R2D2 HF	21	1.1	1.97	12.58	85	non	0.15
R2D2 LF	34	0.7	1.25				

- **F2D2/R2D2 cables not available today**
- No existing cable with 1.1 mm diameter strand
- FRESCA2 experience has shown that **SC conductor** is necessary for bending tests
- For **first bending test campaign** we looked for superconducting cable with dimensions as near as possible to final ones

Available cables	Cable (bare)					
	Strand (N x Ø) [mm]	Width [mm]	Thickness [mm]	Keystone [°]	tp	Core
DS 11 T SC	40 x 0.7	14.7	1.25	0.791	100	25µm
SMC 11T	40 x 0.7	14.7	1.25	0	100	non
QXF	40 x 0.85	18.15	1.525 *	0.55		non
FRESCA2	40 x 1	20.9	1.82	0	120	non

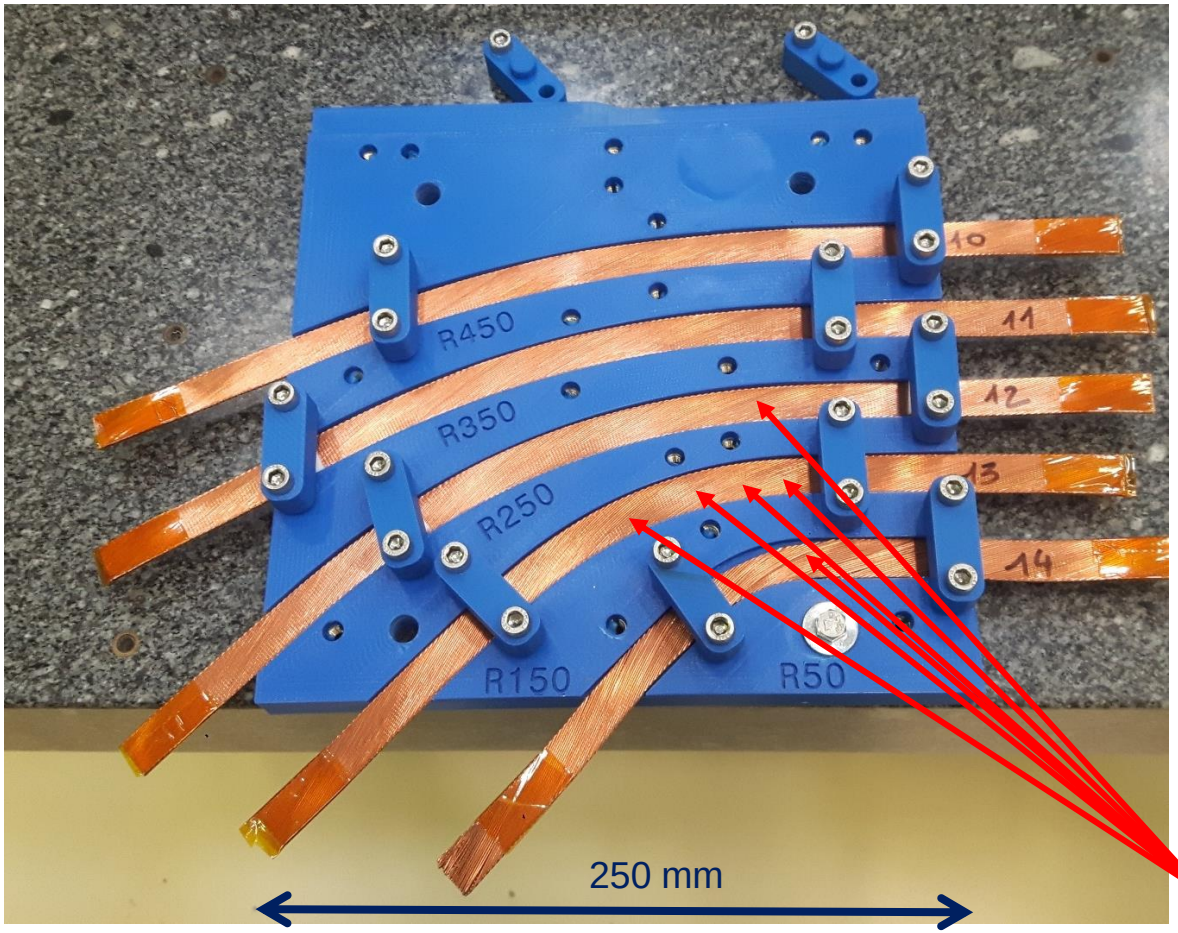
Hard-way bending tests

Easy-way bending tests

Splice tests

BENDING TESTS

- **Hardway bending tests – SMC 11T bare cable - C shape**
- Without winding tension



OK

OK

OK

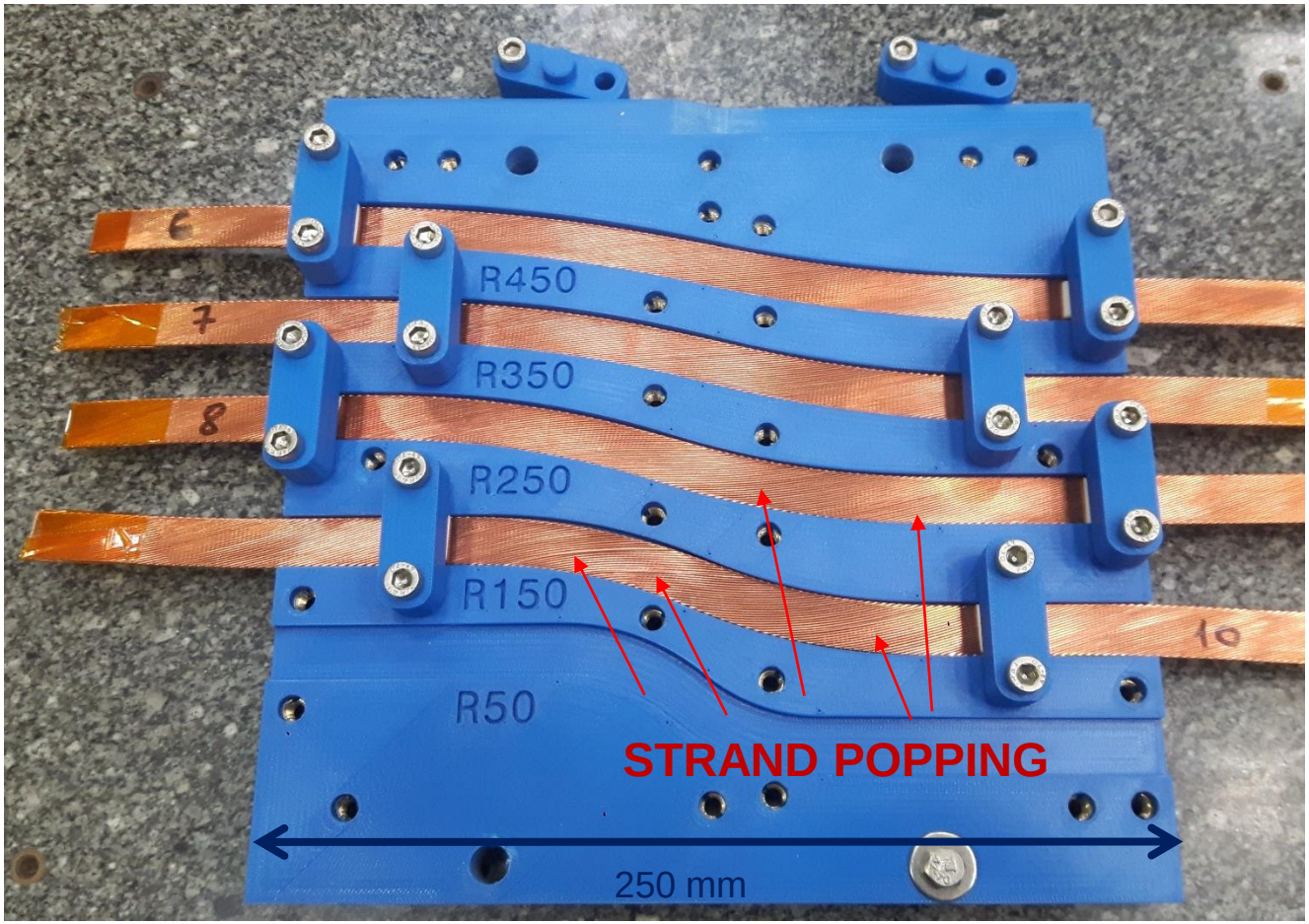
Too many strand popping

Cable collapsing

STRAND POPPING

BENDING TESTS

- **Hardway bending tests – SMC 11T bare cable – layer jump S shape**
- Without winding tension



OK

OK

OK

Many strand popping

BENDING TESTS

- The **minimum hard-way bending radius** has been fixed to **450 mm**
- Even if bending radius over 300 mm is considered as acceptable (for instance in order to reduce coil end length)

→ Coil Layer jumps or exit jumps

- **To be confirmed with final R2D2 cables**

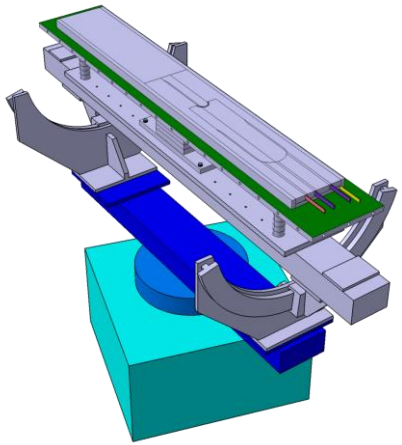
BENDING TESTS

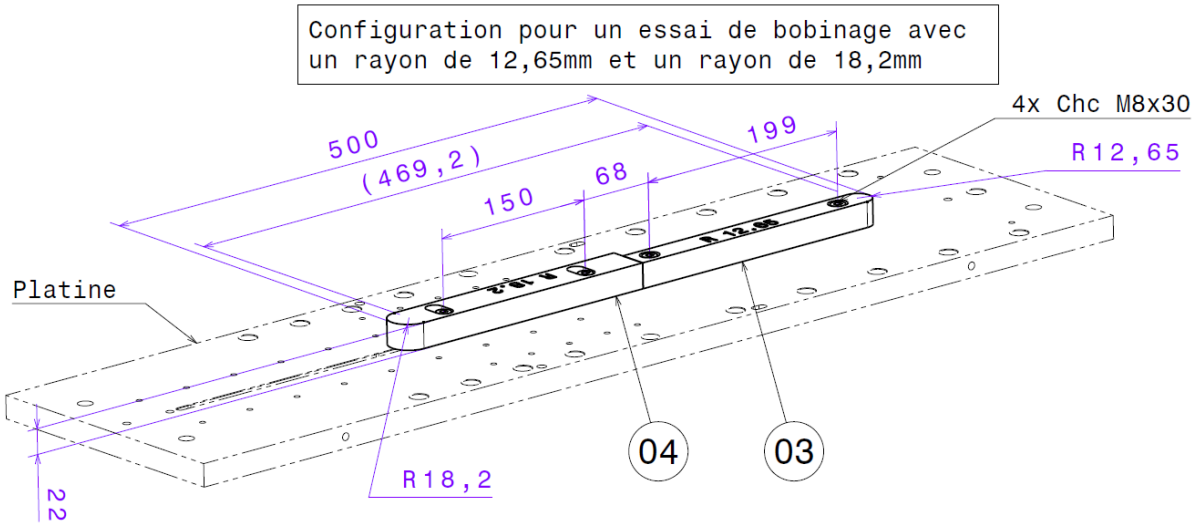
Easy way bending tests realised with FRESCA2 cable, on winding machine

Winding tension applied

Mandrel radius adapted to FRESCA2 cable thickness in order to have:

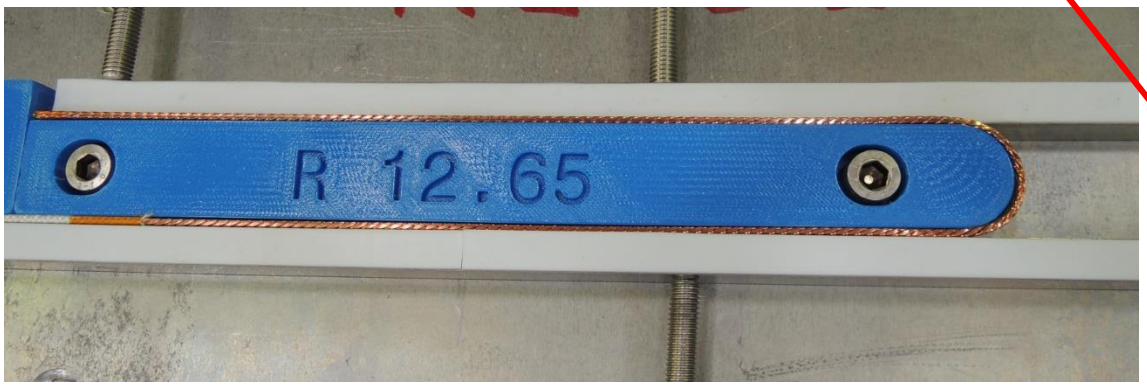
1. The same easy-way bending factor (6.95) than for F2D2 cable in F2D2 → **R 12.65 mm**
1. A conservative easy-way bending factor of 10 → **R = 18.2 mm**

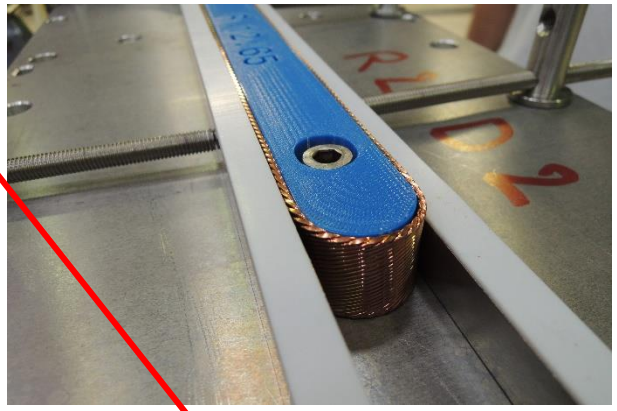


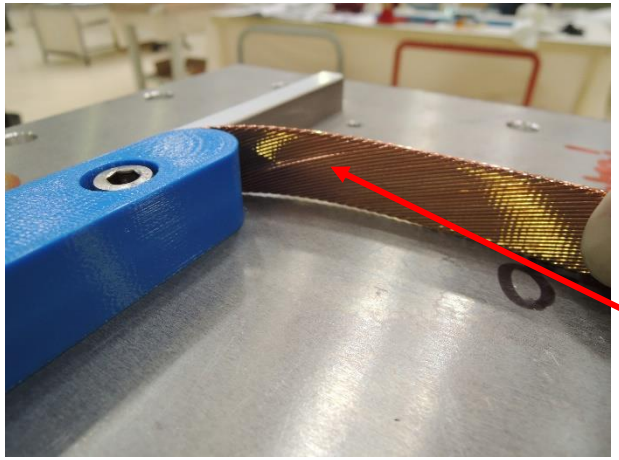


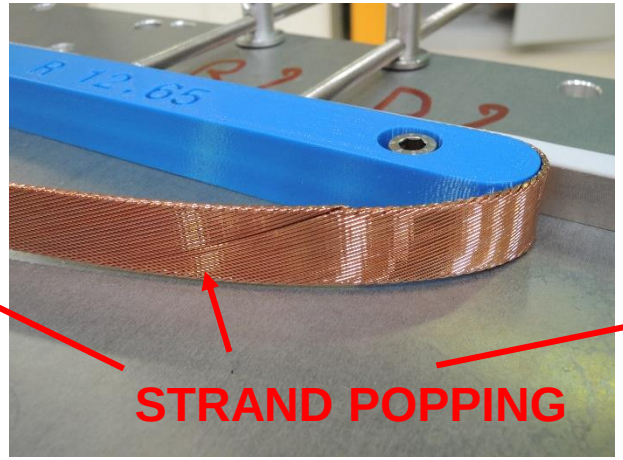
BENDING TESTS

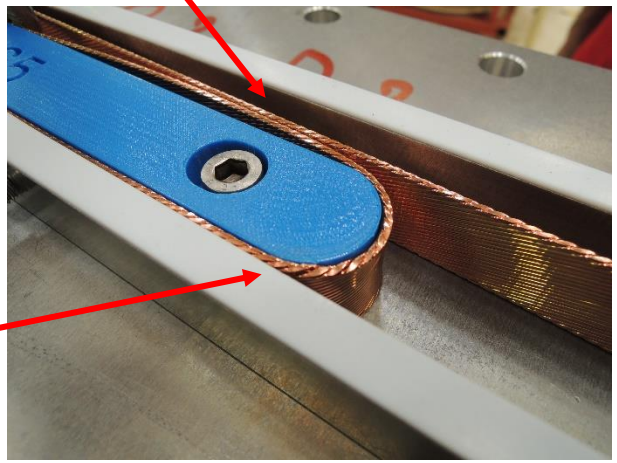
- **EWBF 6.95, FRESCA2 bare cable** **Winding tension 10kg**
- Strand popping, inside and outside the bending
- Cable difficult to fix against the mandrel, tend to relax as soon as the lateral pression is over
- Dishing, deformation of the cable, top and bottom





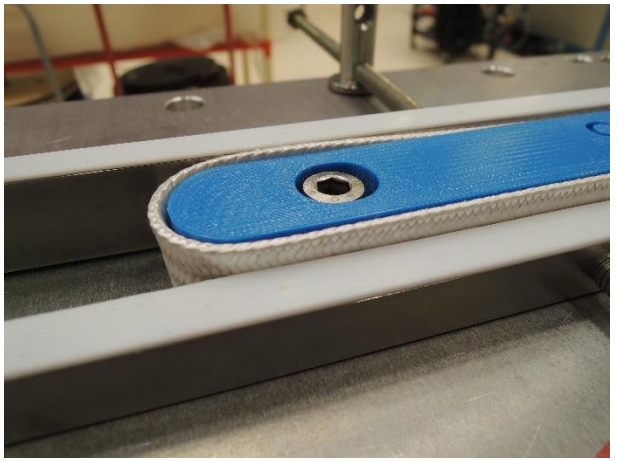


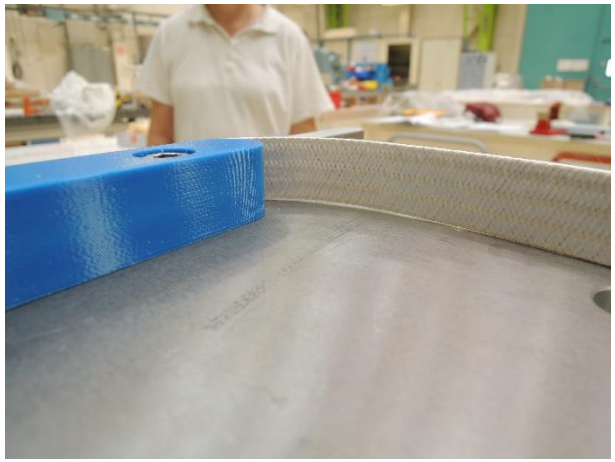


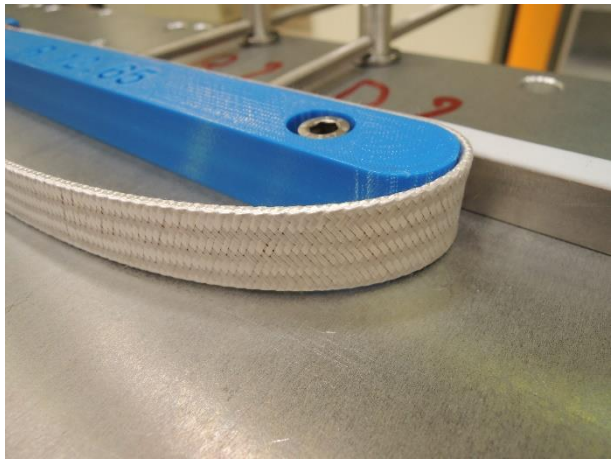


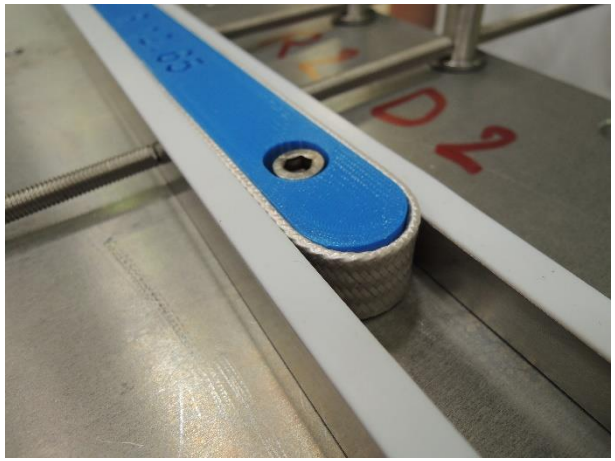
BENDING TESTS

- **EWBF 6.95, FRESCA2 insulated cable** **Winding tension 10kg**
- Strand popping, inside the bending
- Cable difficult to fix against the mandrel, tend to relax as soon as the lateral pression is over
- Dishing, deformation of the cable, top and bottom





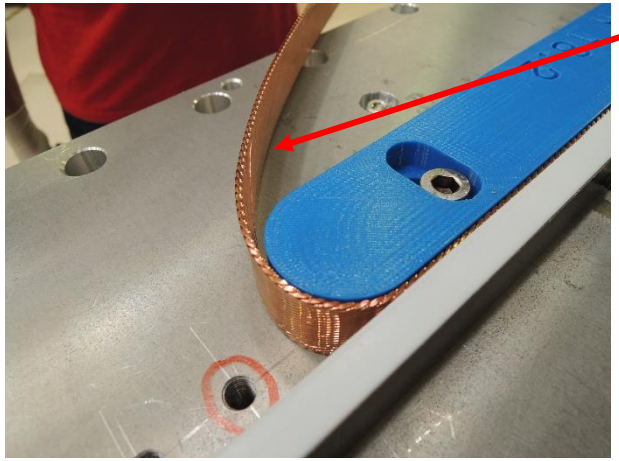


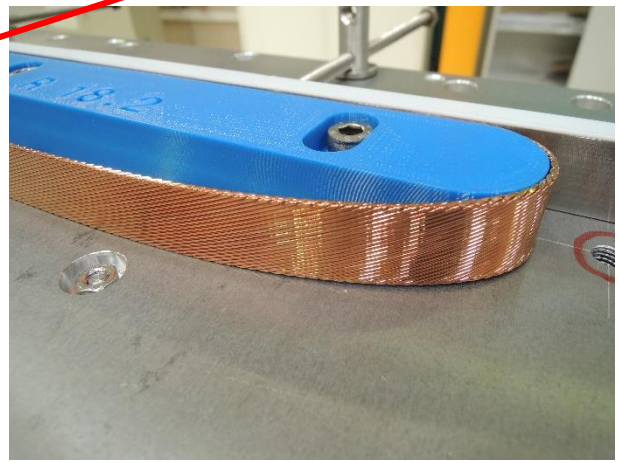


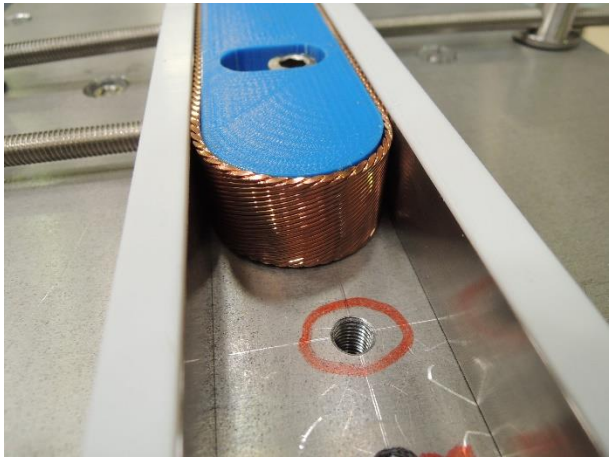
BENDING TESTS

- **EWBF 10, FRESCA2 bare cable** **Winding tension 10kg**
- Strand popping inside the bending, not continuing outside, easy to be replaced

STRAND POPPING INSIDE

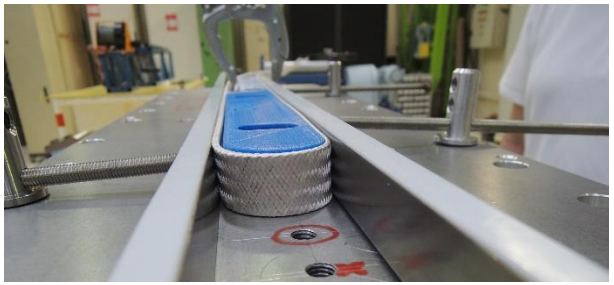


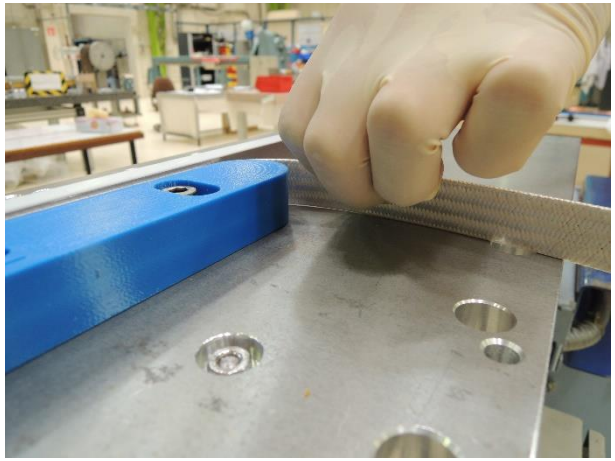


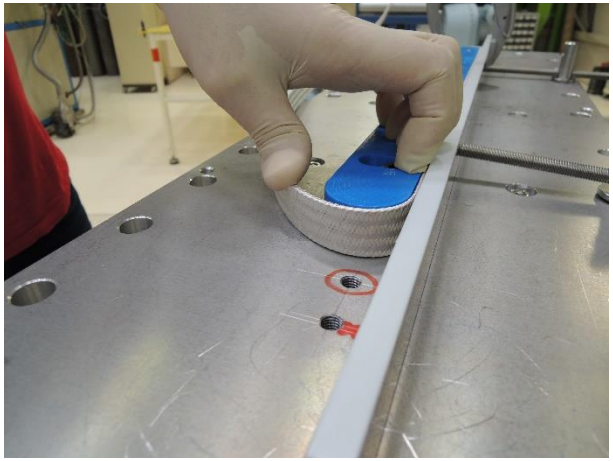


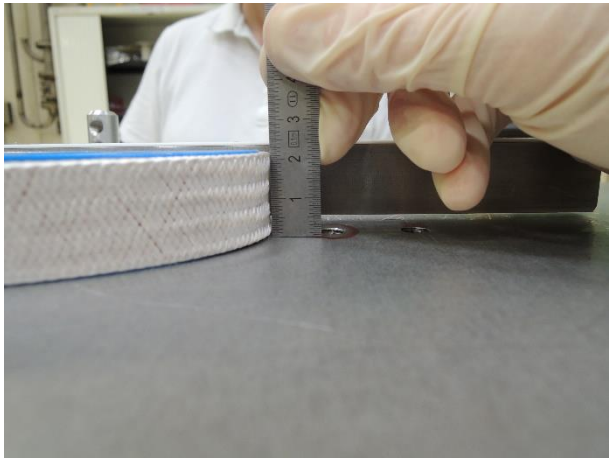
BENDING TESTS

- **EWBF 10, FRESCA2 insulated cable** **Winding tension 10kg → 15 kg**
- No strand popping
- Dishing









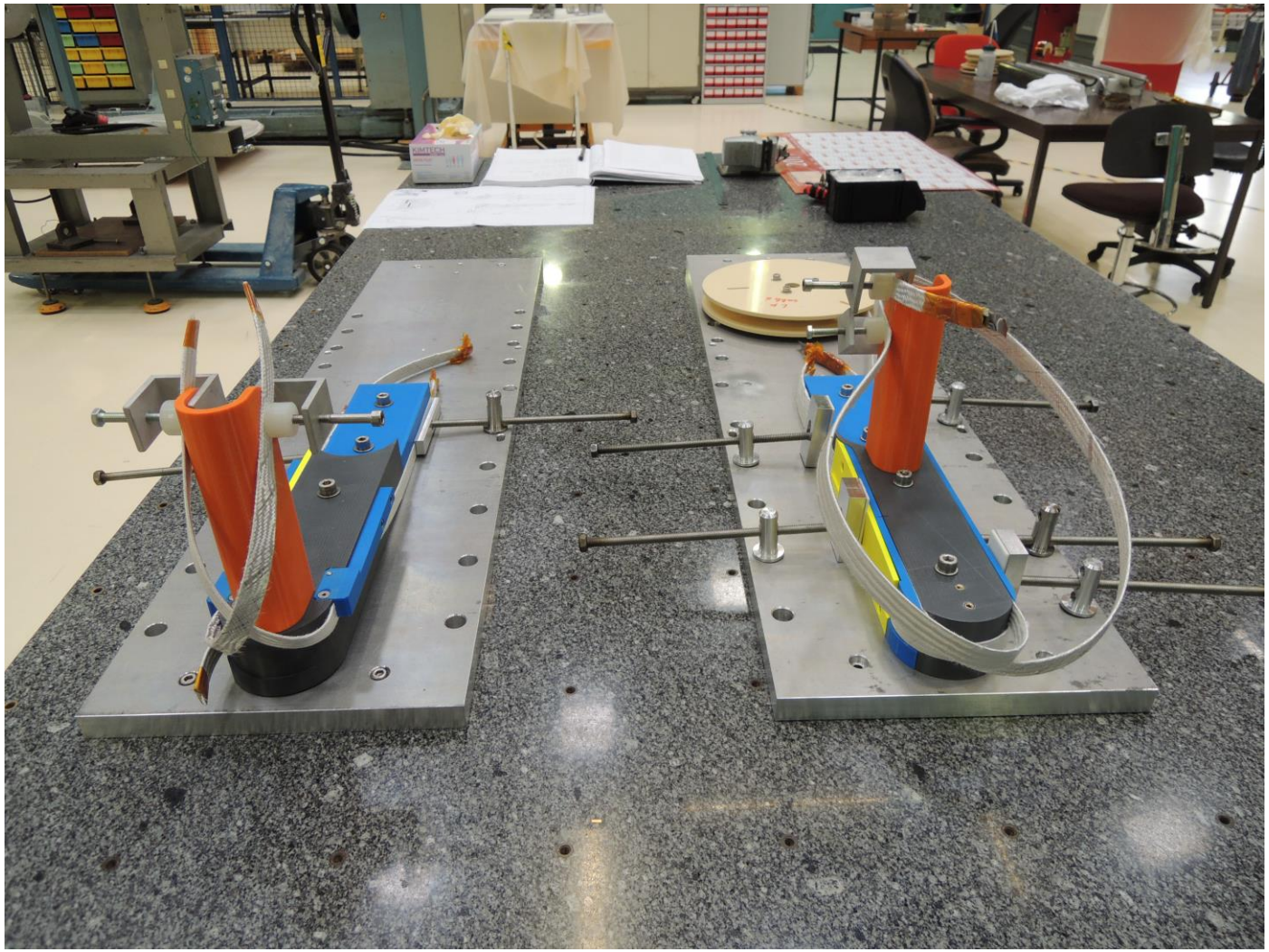
BENDING TESTS

- An **easy-way bending factor of 10** seems acceptable

  → **Minimum EW bending radius in the coil of 19.7 mm**

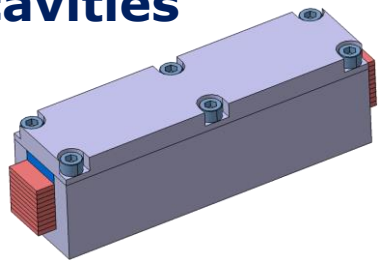
- **To be confirmed with final R2D2 cables**

WINDING TESTS (REALIZED FOR F2D2)

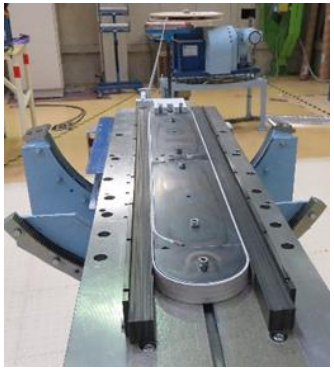


HEAT TREATED COILS AND STACKS

Height measurement campaign on **cable stacks** made from final superconducting cables, **heat treated in free and fixed cavities**



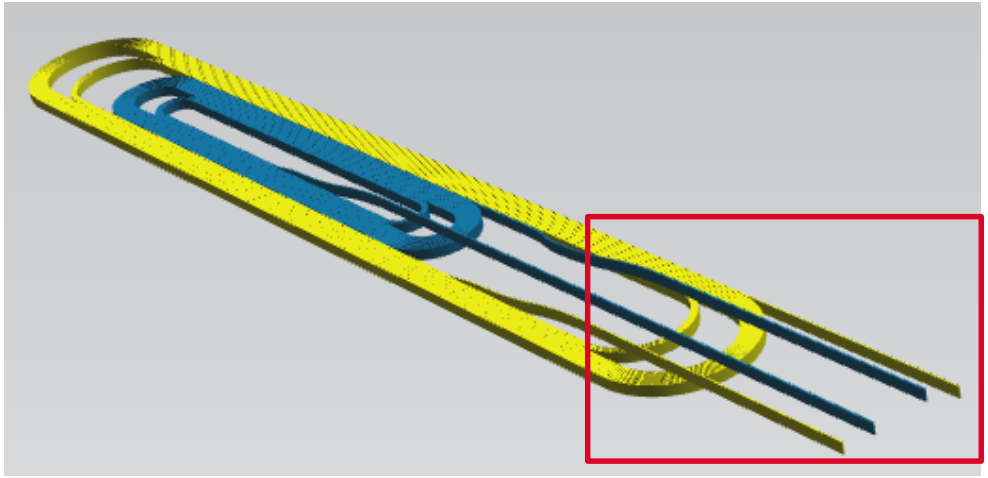
Short coils made from R2D2 **final** superconducting cables



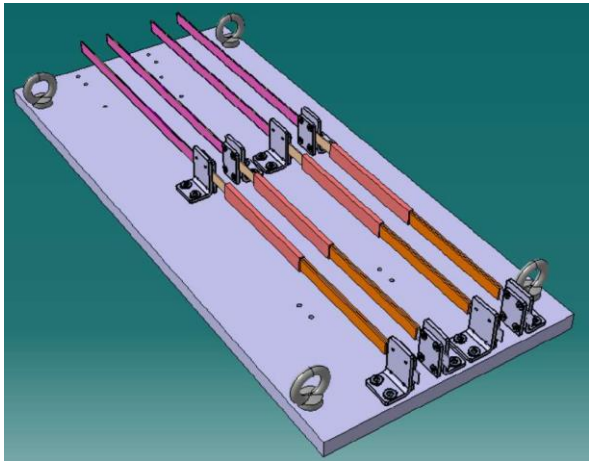
In parallel thesis by Mahmoud ABDEL HAFIZ on cable dimensional changes during heat treatement

SPLICES R&D

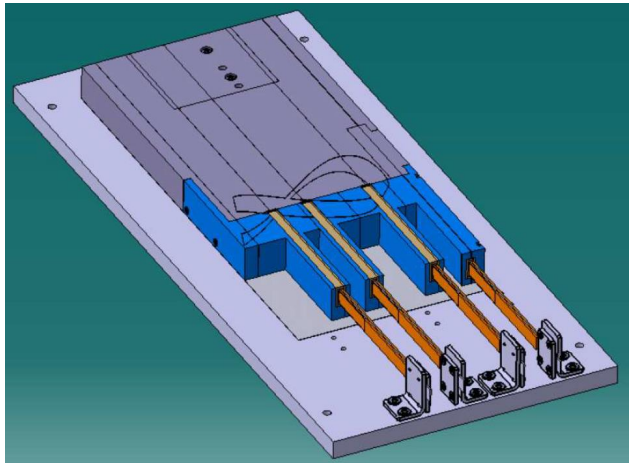
Coil ends handling and splice realisation in a quite crowded region



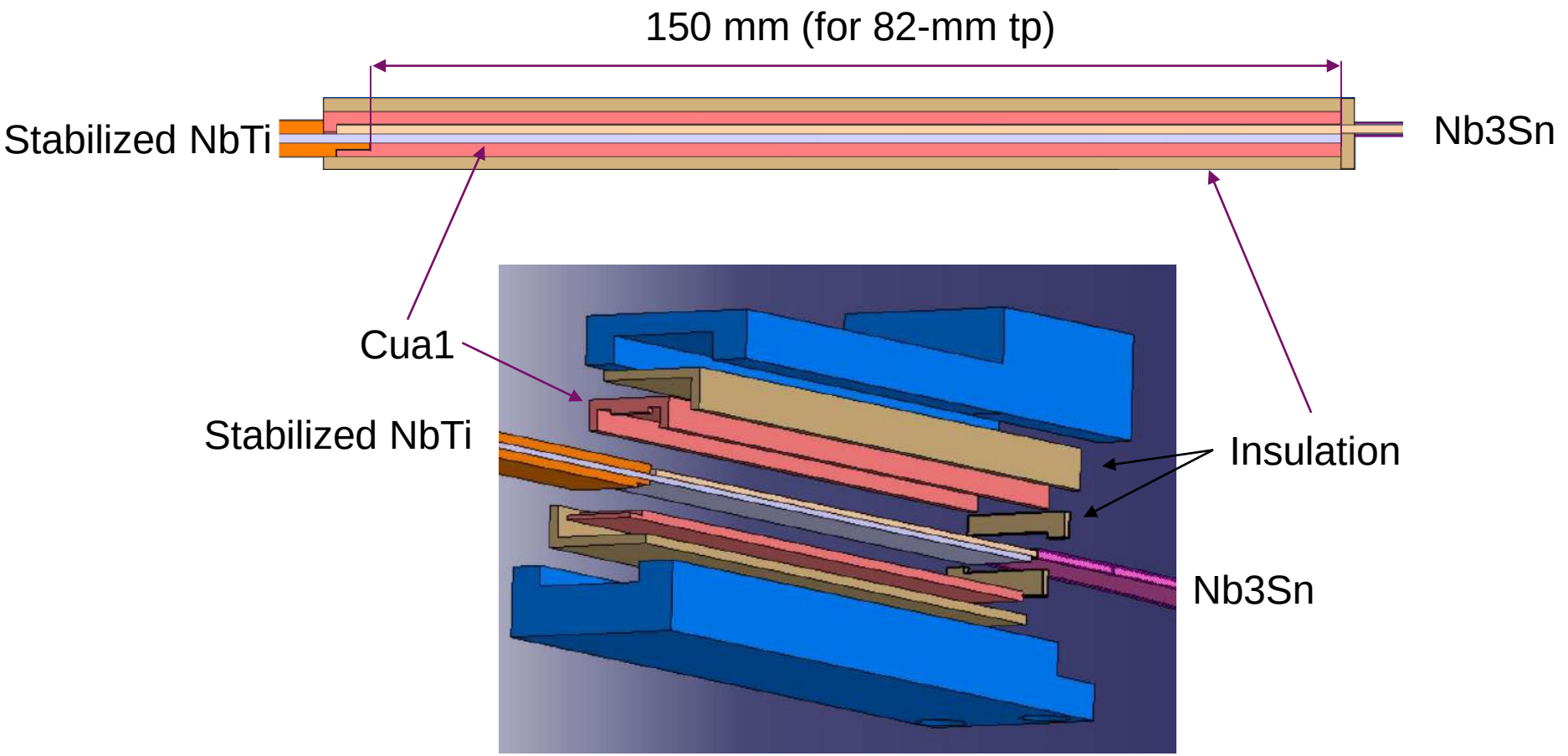
a. Splices tests



b. Coil Splices Mockup

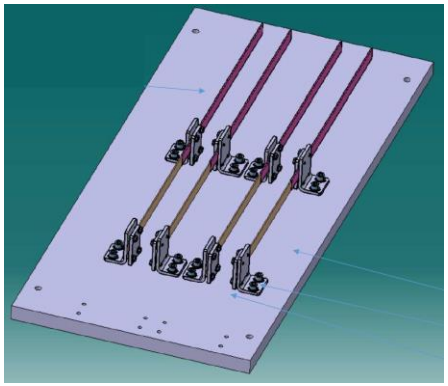


SPLICES R&D – SPLICE LAYOUT

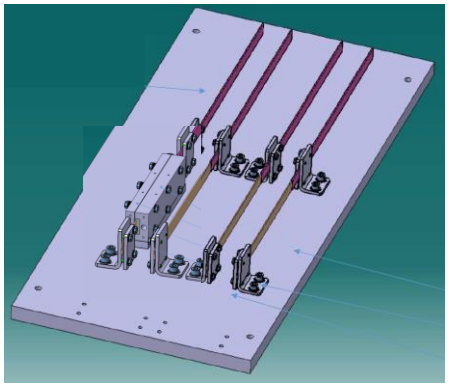


SPLICES R&D – SPLICES TESTS

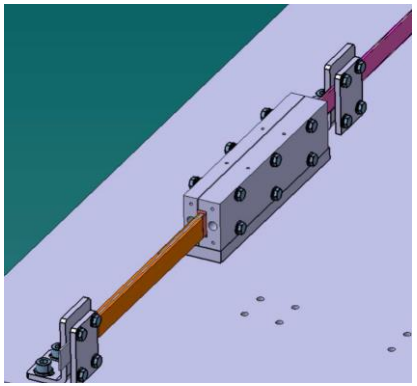
Target : Validate splices design, components and splicing procedure



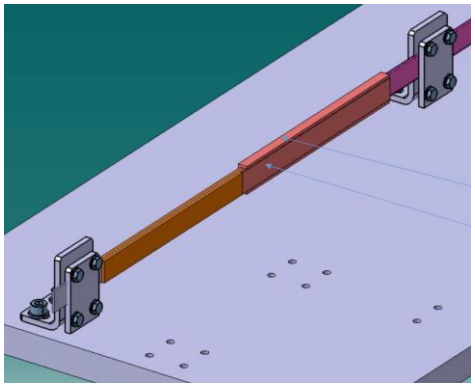
Cable exits



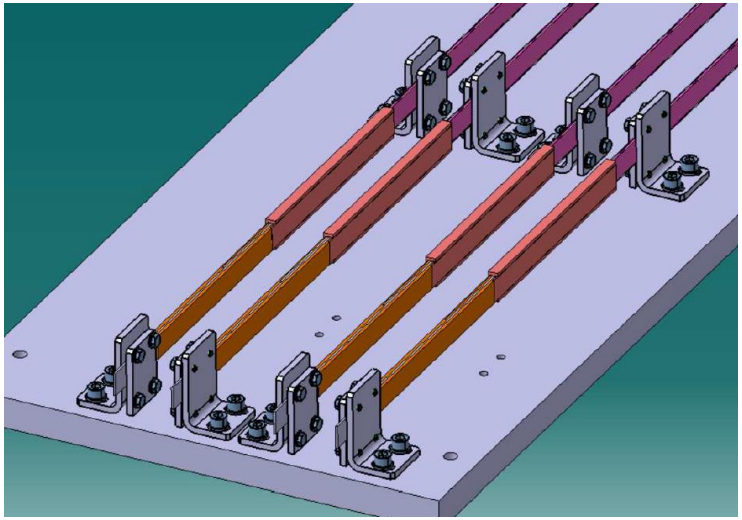
Cable Tinning



Splice soldering

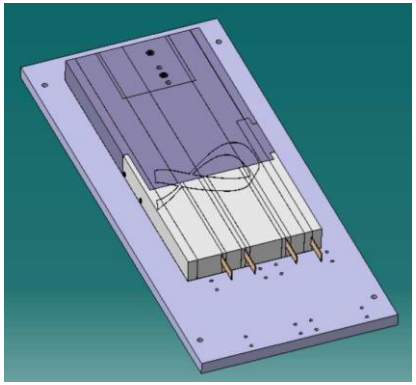


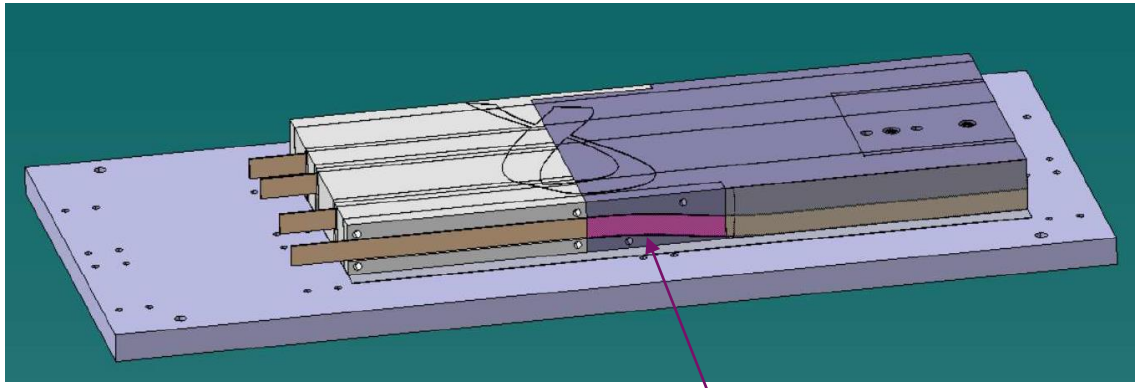
Splice



SPLICES R&D – COIL SPLICES MOCKUP

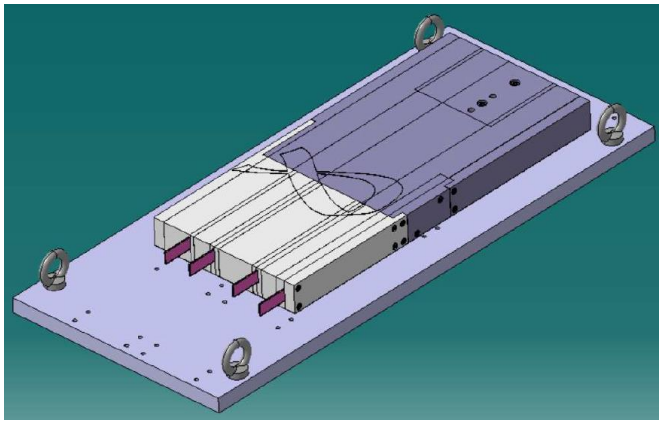
Mockup of the coil end cables in the reaction mold parts, as they will be at the end of the heat treatment



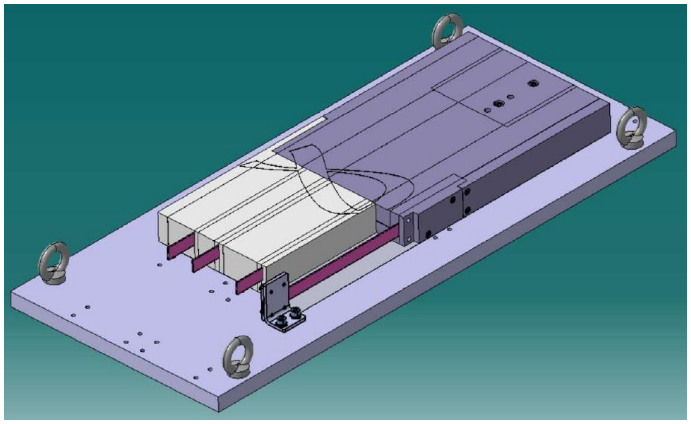


LF exit modified to allow splice soldering

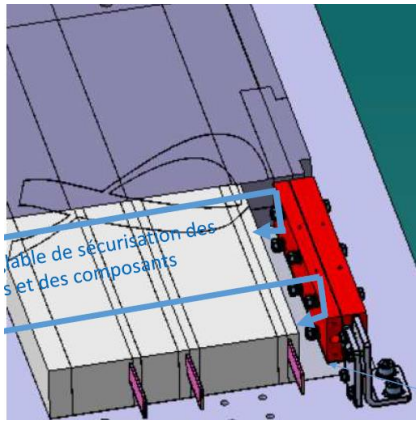
First LF Splice



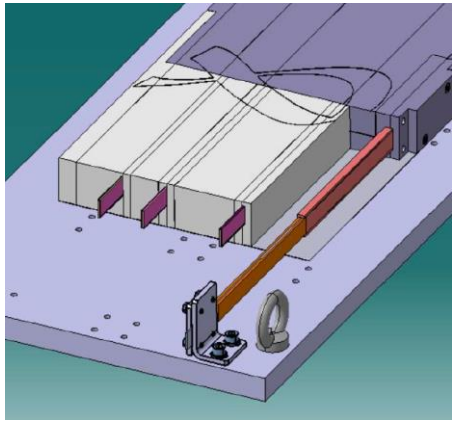
Cable exits



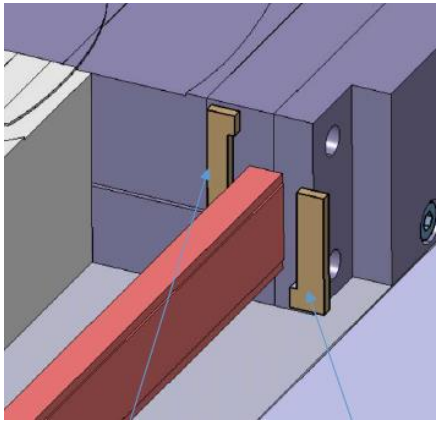
Cable preparation



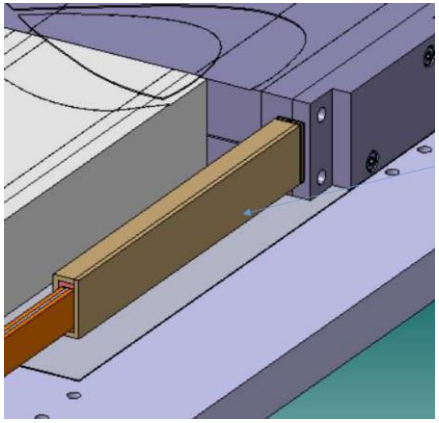
Splice soldering



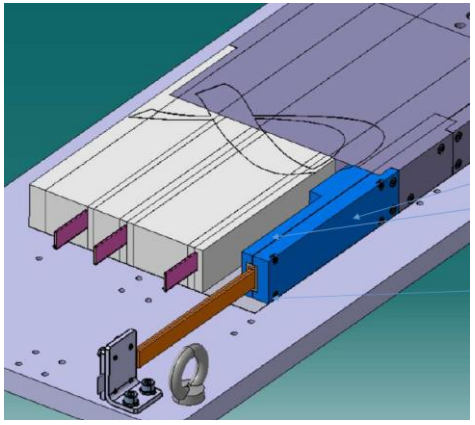
Splice



Splice insulation



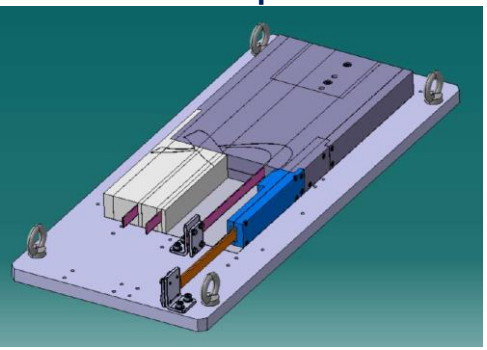
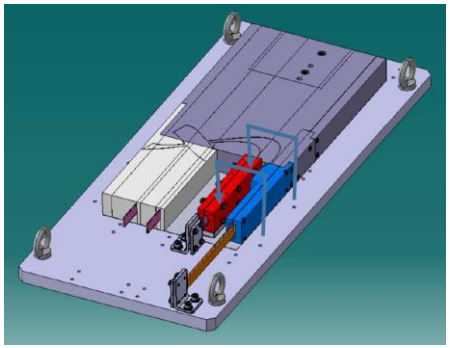
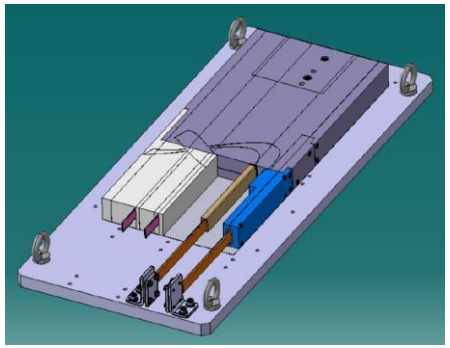
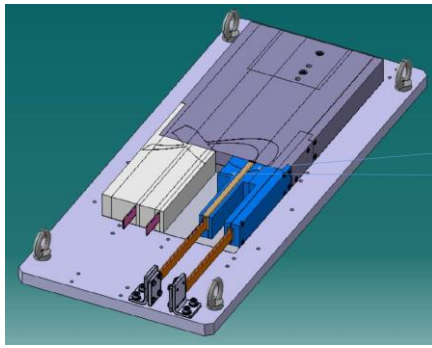
Insulated splice



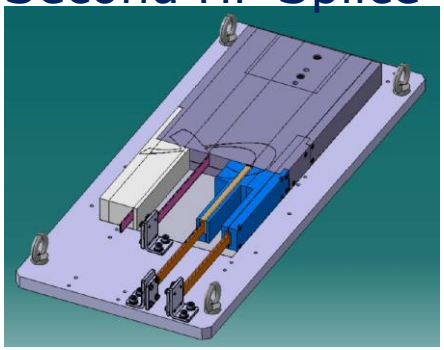
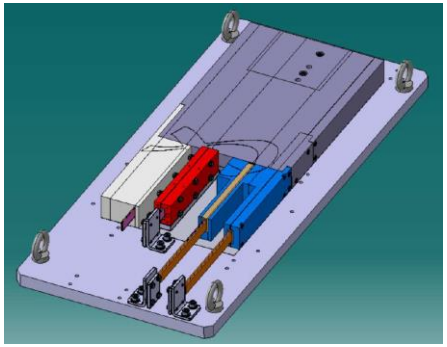
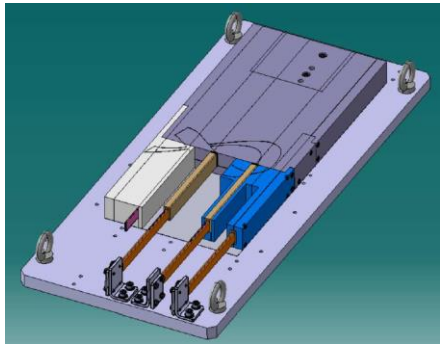
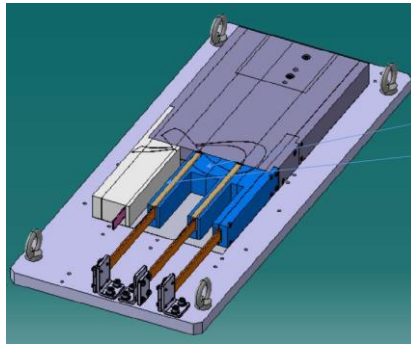
Splice final support

SPLICES R&D – COIL SPLICES MOCKUP

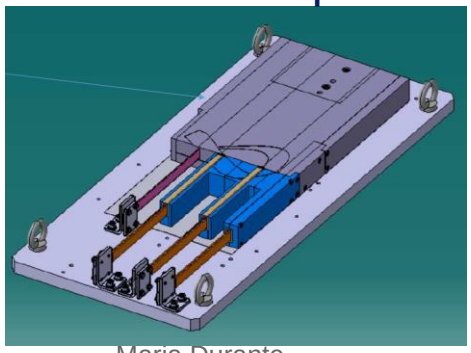
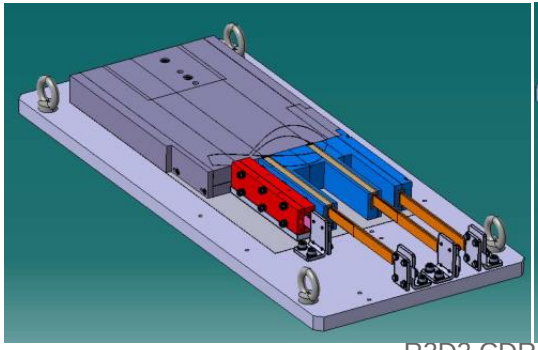
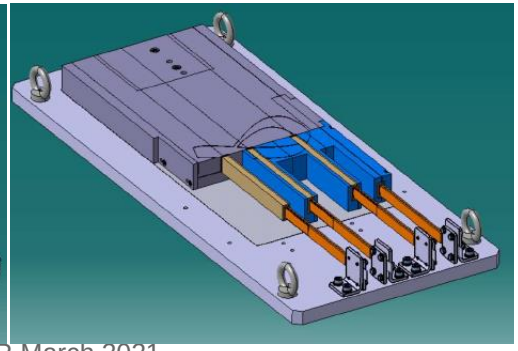
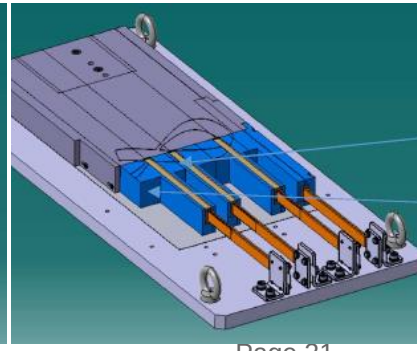
First HF Splice

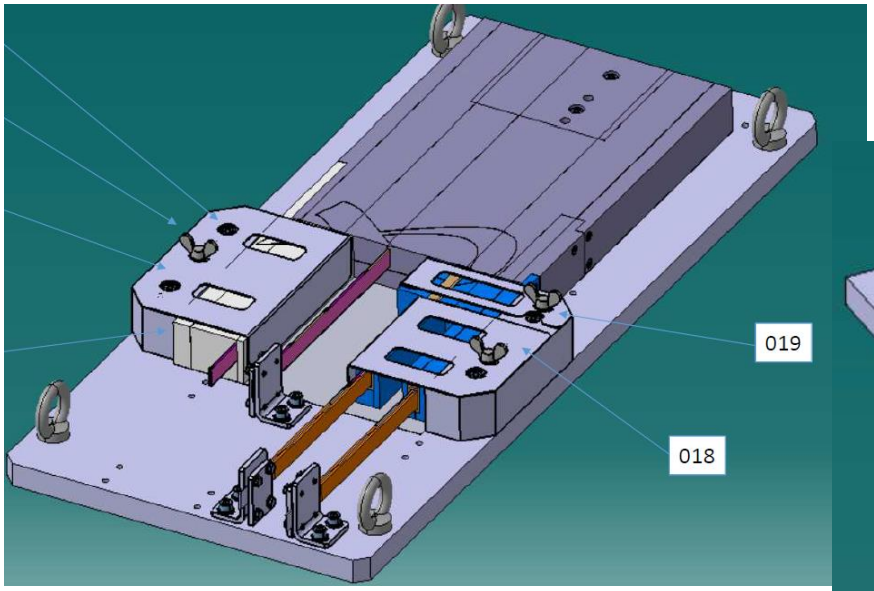
Second HF Splice

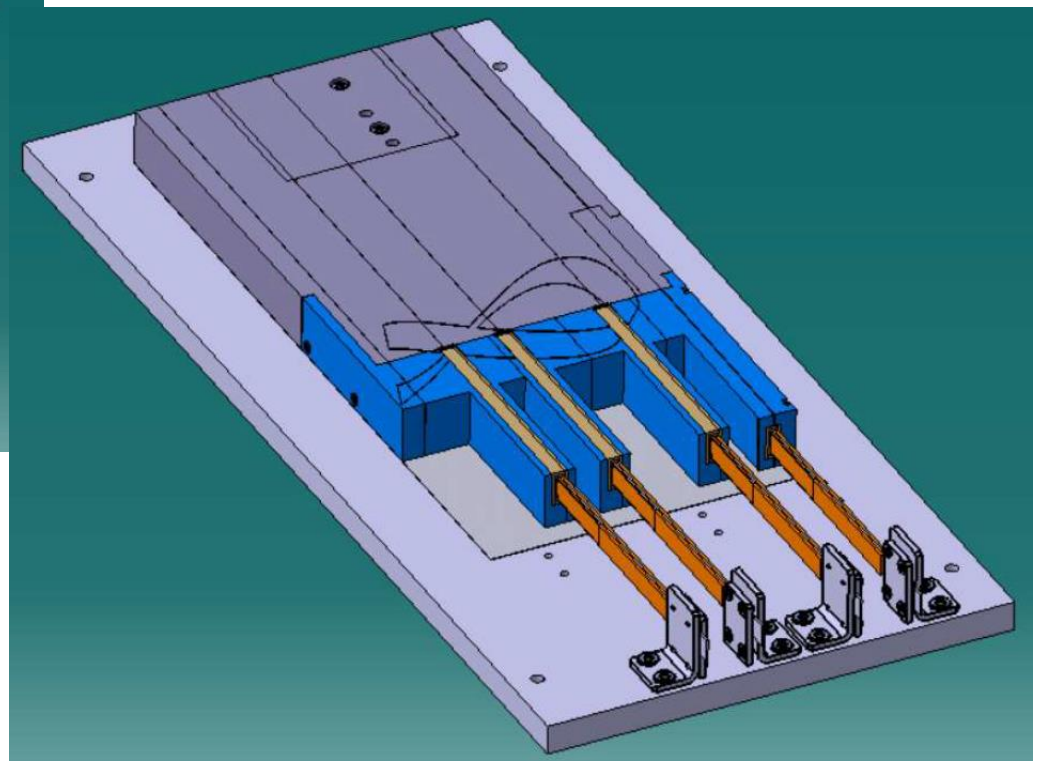
Second LF Splice

SPLICES R&D – COIL SPLICES MOCKUP



Protection tools of the other cables during splice operation



Coil ends studies
Space available for Longitudal prestress (tested elsewhere) ?

COIL R&D AND TESTS - STATUS

- Bending tests
- Winding mock up

Done with SMC and FRESCA2 cable – waiting for final cables

- Heat treated cable stacks
- Heat treated short coils

Test campaign program to be defined - waiting for final cables

- Splice tests
- Splice mock up

Tools under realization – delivery foreseen by the end of March – waiting for SMC cable short lengths for tests

- Cable and winding characterization :

Test campaign program to be defined - waiting for final cables

  - Jc measurements on strands
  - Jc measurements on cable under pressure
  - Thermomechanical measurements on impregnated cable stacks

DE LA RECHERCHE À L'INDUSTRIE

cea

Spares

BIBLIOGRAPHY ON MINIMUM BENDING RADIUS

Magnet	status	Cable (bare)				Easy-way min R (EWBF) [mm (/)]	Hard-way min R (HWBF) [mm (/)]
		Strand N x Ø [mm]	Width [mm]	Thickness [mm]	Keystone [°]		
HQ	Tested	35 x 0.8	15.15	1.437 *	0.75		645 (42.57)
11 T	Tested	40 x 0.7	14.95	1.253	0	8 (6.4)	
QXF	Tested	40 x 0.85	18.15	1.525 *	0.55		793 (43.7)
FRESCA2	In use	40 x 1	20.9	1.82	0	44.7 (24.6)	700 (33.5)
HD2	Tested	51 x 0.8	21.86	1.40	0	11.8 (8.4)	380 (17)
RMM	In fab.	40 x 1	20.9	1.82	0	14 (7.7)	
F2D2 HF	Design	21 x 1.1	12.58	1.97	0	13.69 (6.95)**	450 (36)
R2D2 HF	Design					19.7 (10)	
F2D2 LF	Design	34 x 0.7		1.25	0	20 (16)**	
R2D2 LF	Design						

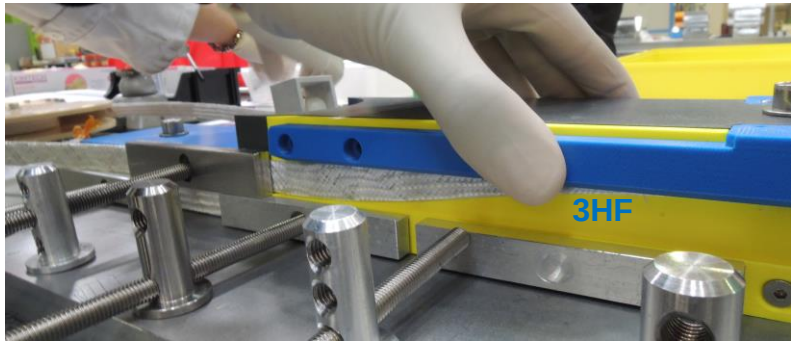
easy-way bending factor, **EWBF** = R_{EW}/t_{cbl}
hard-way bending factor, **HWBF** = R_{HW}/w_{cbl}

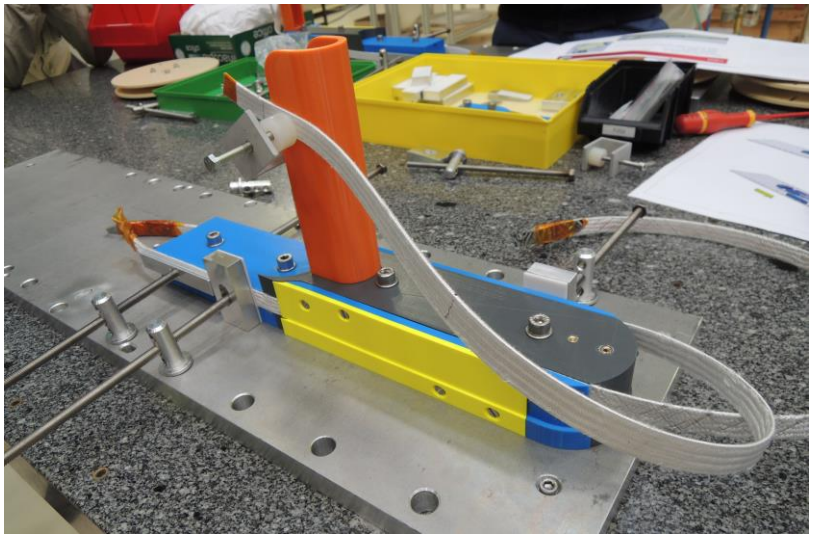
*mid-thickness

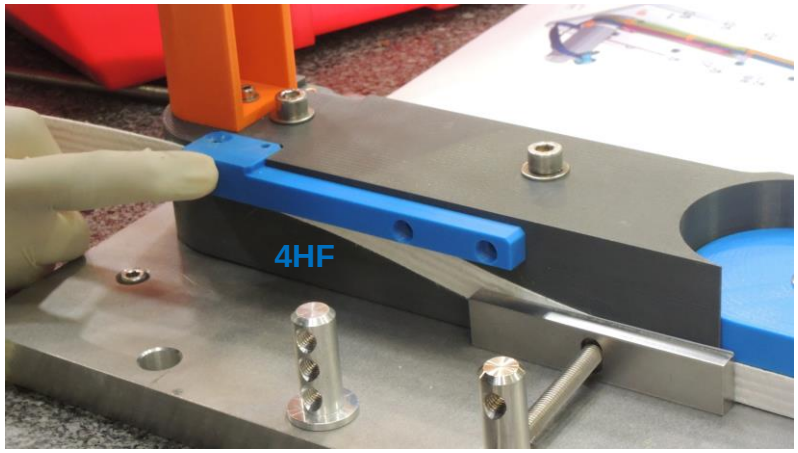
**from ECC magnetic design

WINDING TESTS (FOR F2D2) – HF CABLE EXITS

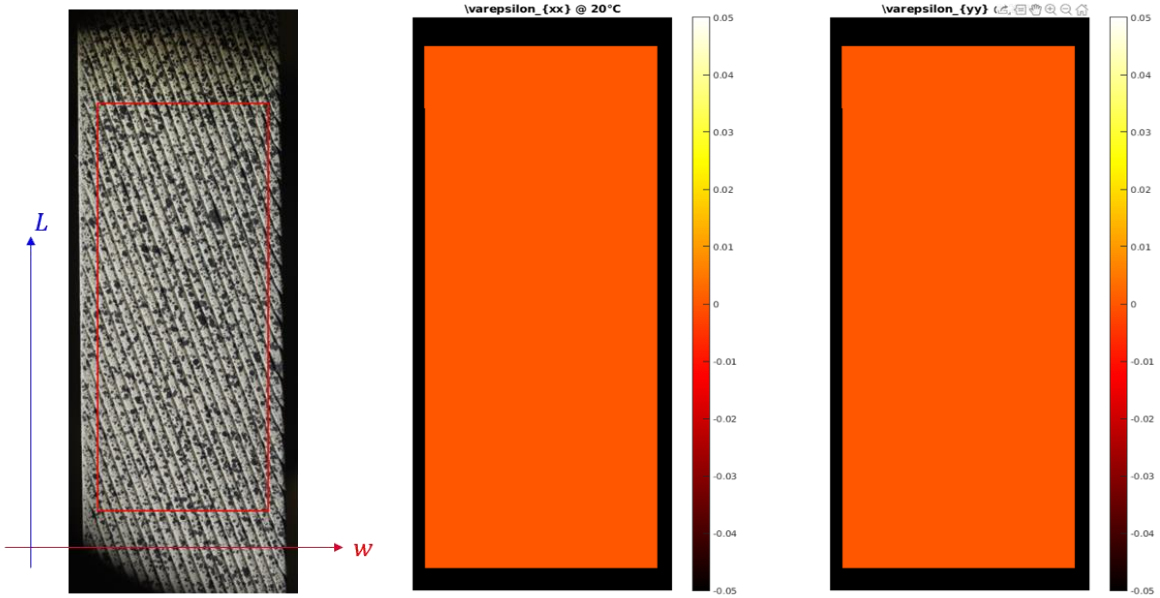
F2D2 Options A and B for HF end cable fixing tools and procedure

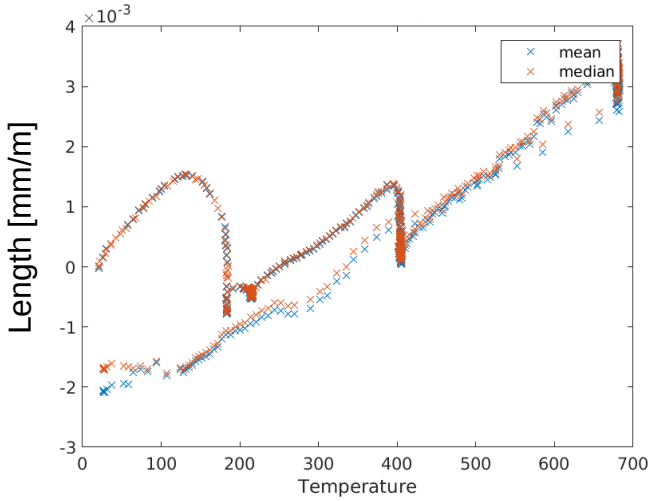


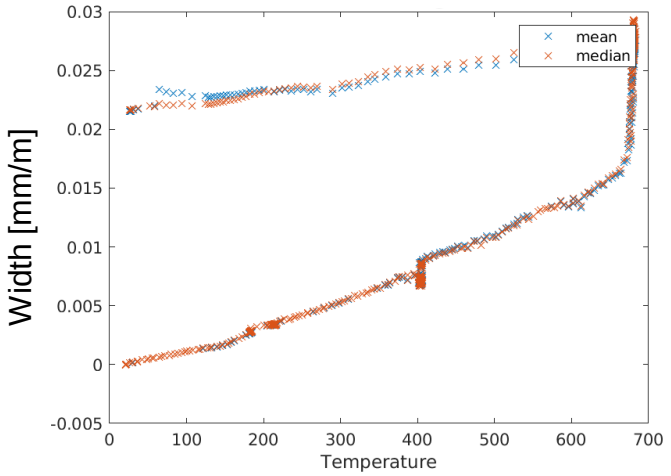




MESURE À ÉCHELLE DU BRIN (DÉFORMATIONS)







Digital Image Correlation (PhD thesis Mahmoud ABDEL HAFIZ):

→ displacement field of cables as a function of temperature

→ Fundamental approach

→ Not applicable to large coils (for the moment)