DE LA RECHERCHE À L'INDUSTRIE

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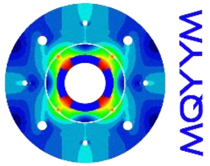
Vancouver, Canada | 2019

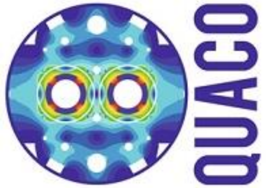
HiLumi HL-LHC PROJECT

Mechanical analysis and assembly of MQYYM: a 90 mm NbTi quadrupole magnet option for HL-LHC

D. SIMON, H. FELICE, S. PERRAUD, J. M. RIFFLET, E. ROCHEPAULT, M. SEGRETI, R. OLLIER, G. MINIER, P. GRAFFIN, R. CORREIA MACHADO, R. GODON **(CEA)**

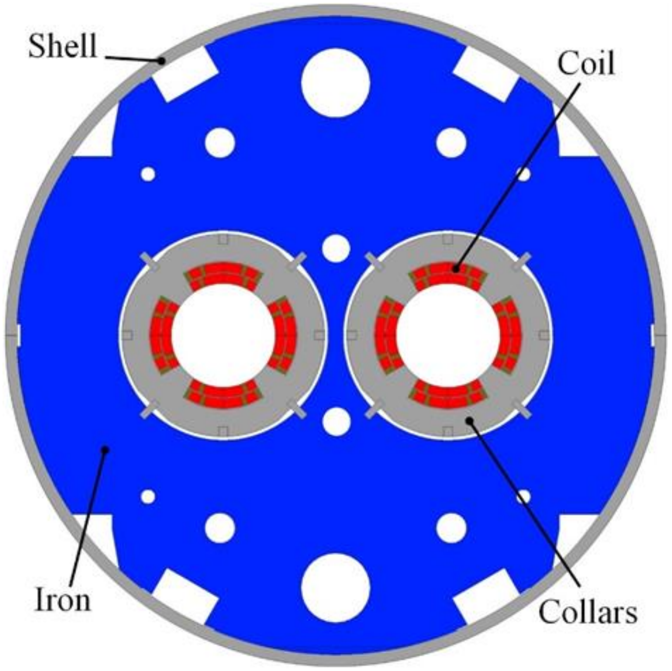
J. C. PEREZ, S. FERRADAS TROITIÑO, A. FOUSSAT, E. TODESCO, S. EMAMI NAINI, M. GUINCHARD **(CERN)**

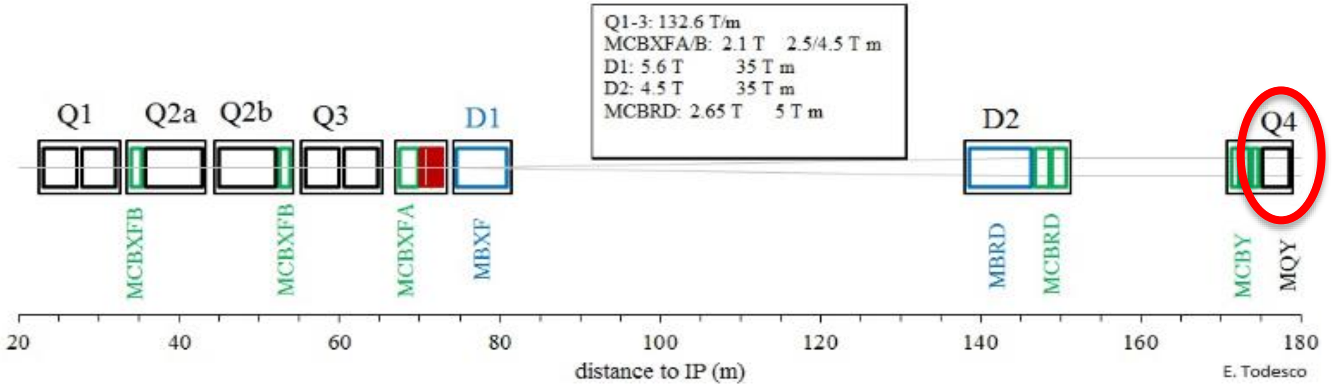




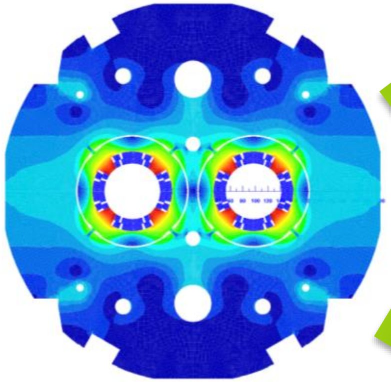
THE MQYY QUADRUPOLE OPTION IN HL-LHC

Characteristics	MQY	MQYY
Aperture diameter	70 mm	**90 mm**
Inter beam distance	194 mm	**194 mm**
Magnetic length	3,4 m	**3,67 m**
Gradient	160 T/m	**120 T/m**
Current	3610 A	**4590 A**
Peak field at nominal current	6,1 T	**6,4 T**
Load line margin	23%	**23%**
Temperature	4,5 K	**1,9 K**
Mechanical structure	**Self supported collars**	

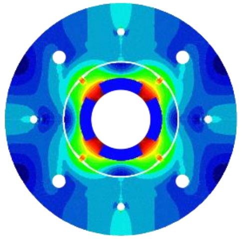




OVERVIEW OF MQYY ACTIVITY

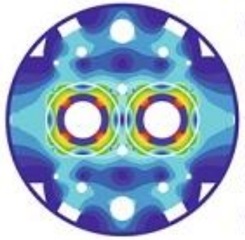


HL-LHC
MQYY magnet



MQYYM

- **Single aperture short model of 1.320 m long**
- Operating current : 4550 A (23% margin)
- NbTi cable with kapton insulation
- Yoke outer diameter 360 mm



QUACO

- 2 full length prototypes

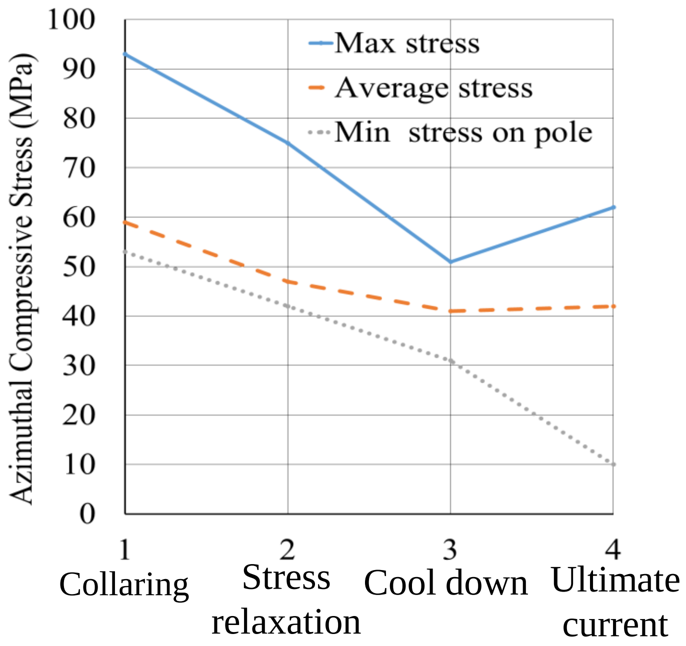
PHASE 1	PHASE 2	PHASE 3
Concept. design	Engineering design	**MQYYP** Manufacturing

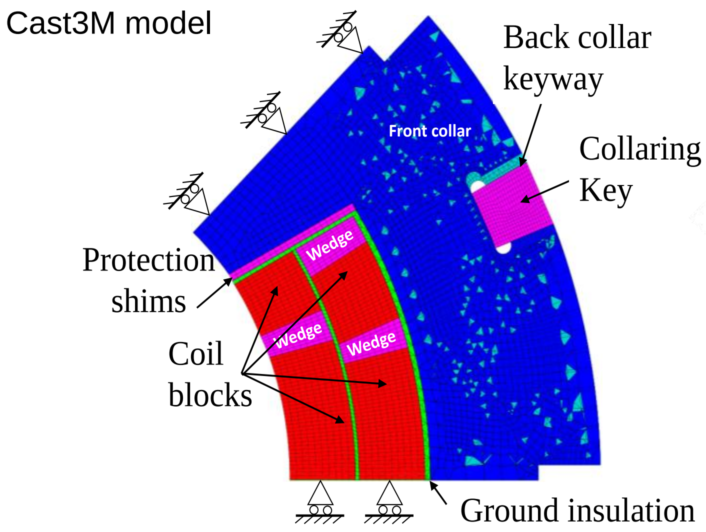
ELYTT ENERGY

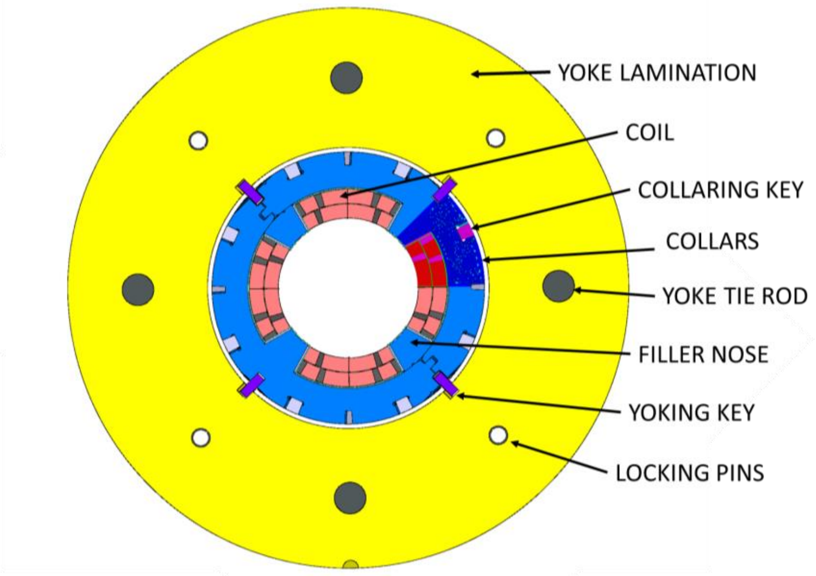
SIGMAPHI ACCELERATOR TECHNOLOGIES

HORIZON 2020

PRE-STRESS REQUIREMENTS







Design Material Properties	
Coils Young modulus at warm [1]	5,4 GPa
Coils Young modulus at cold	7,9 GPa
Coil thermal contraction	5 mm/m

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[2] H. Felice et al., “Development of MQYY : a 90 mm NbTi Double Aperture Quadrupole Magnet for HL-LHC”
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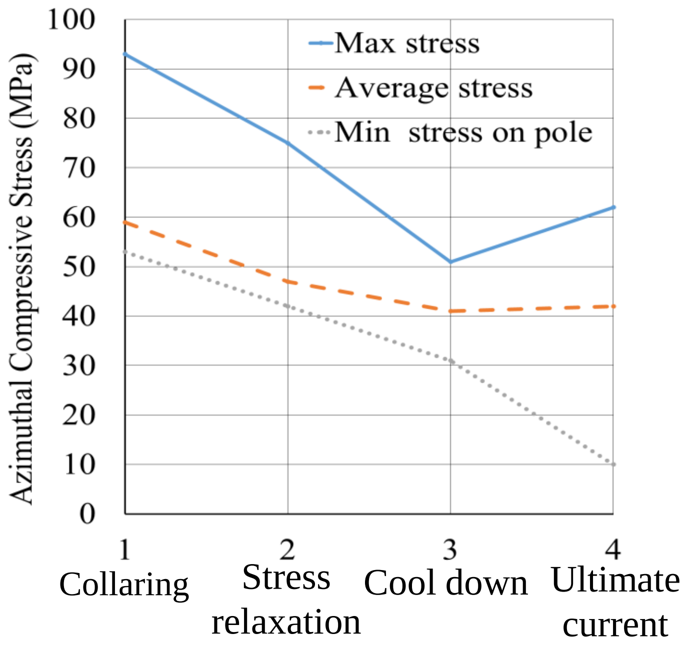
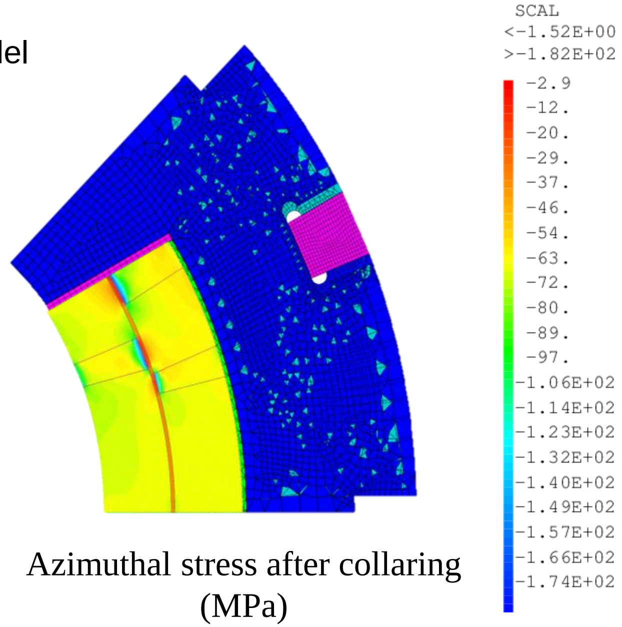
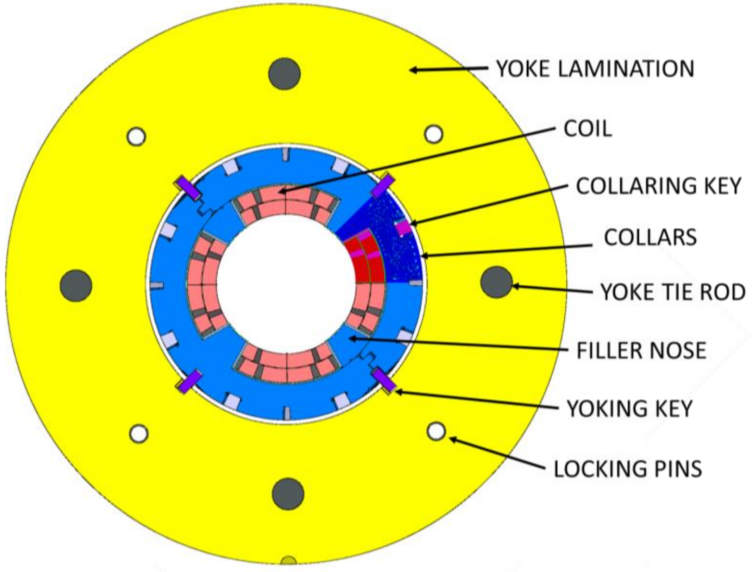


Cast3M model



Azimuthal stress after collaring (MPa)



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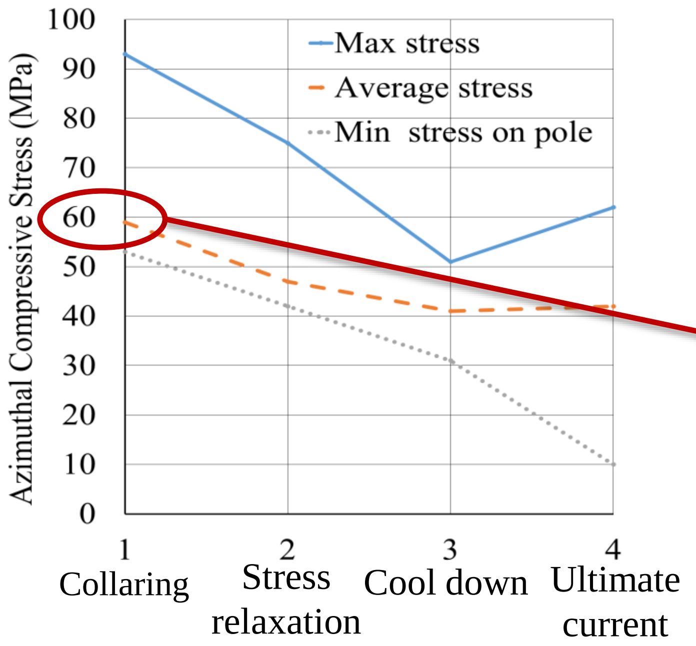

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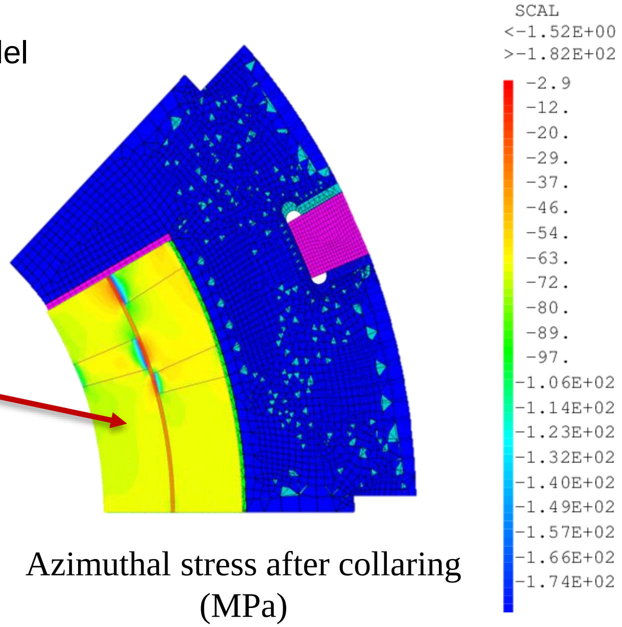

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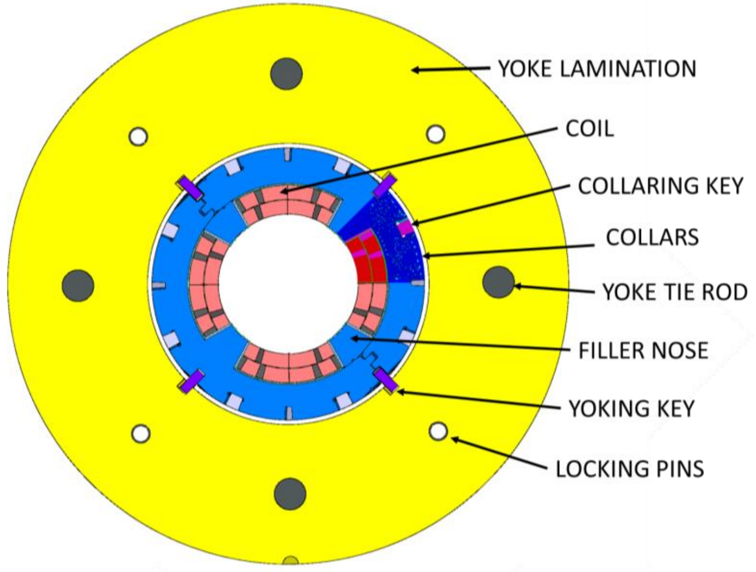

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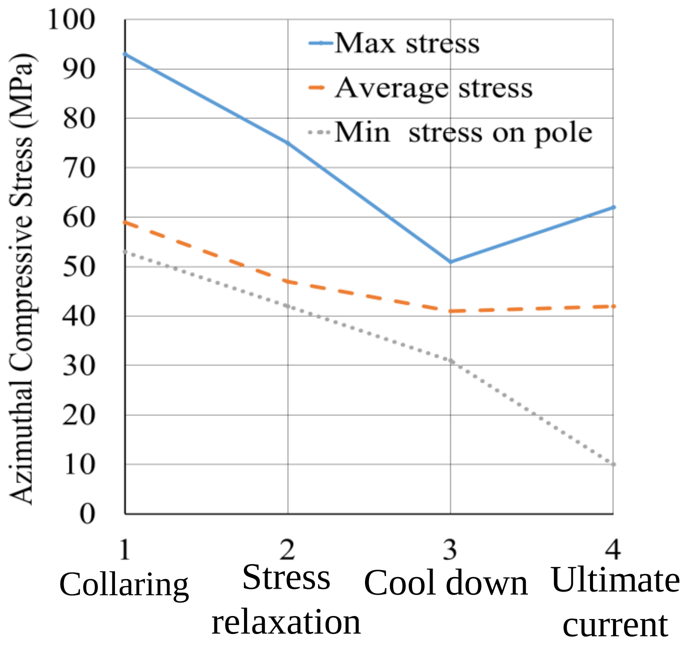

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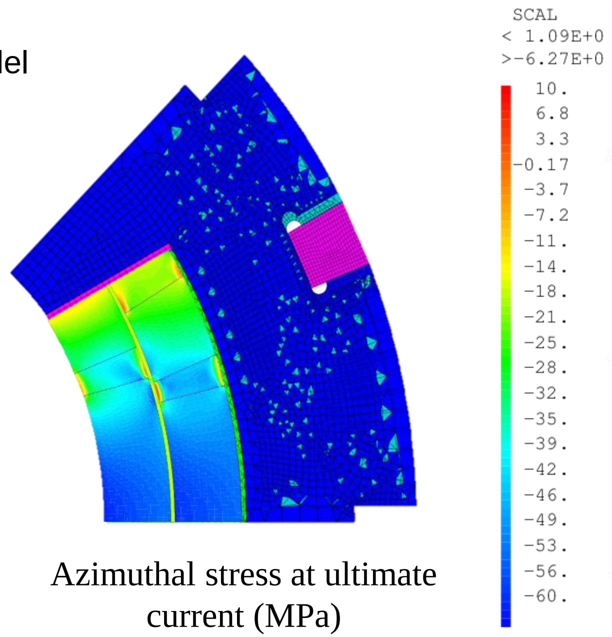
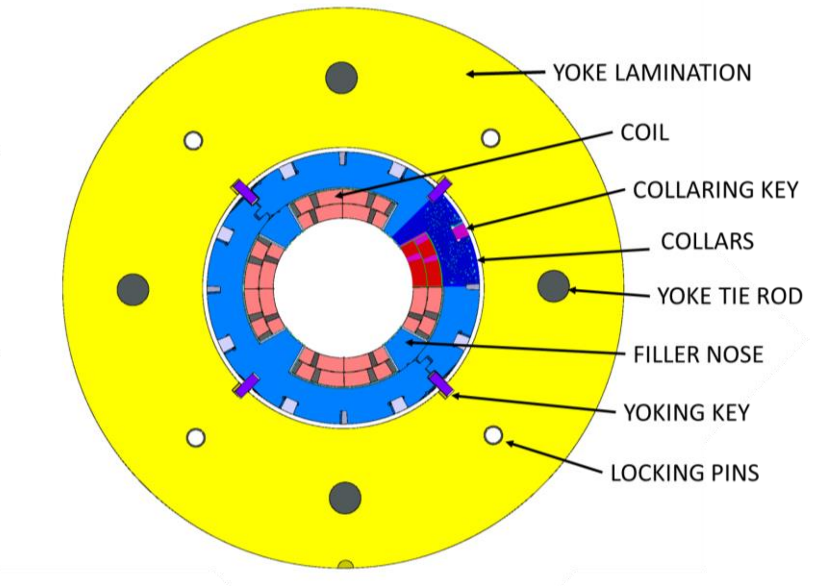


Azimuthal stress at ultimate current (MPa)



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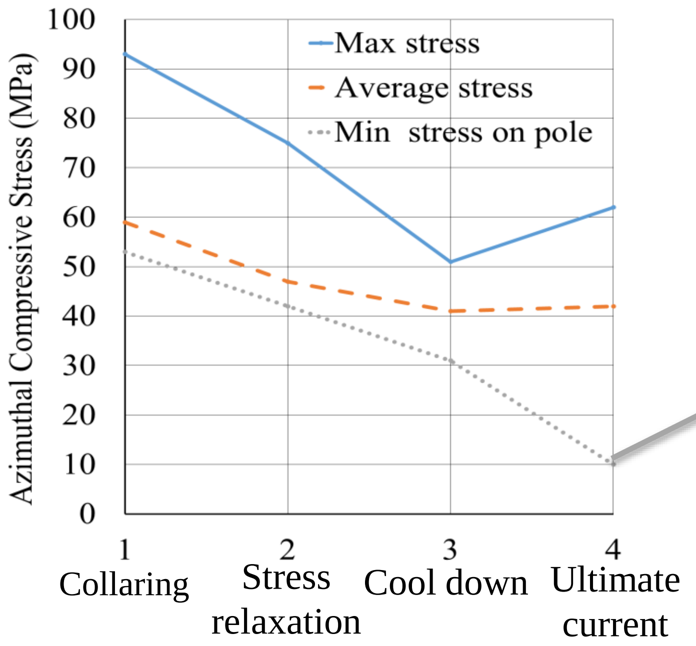

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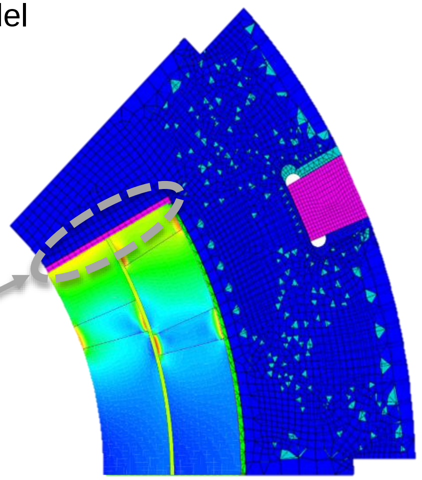

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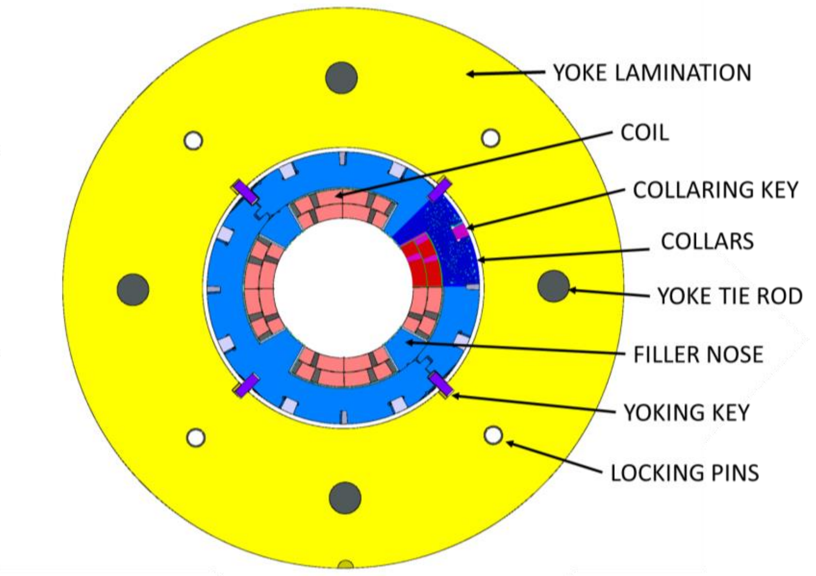

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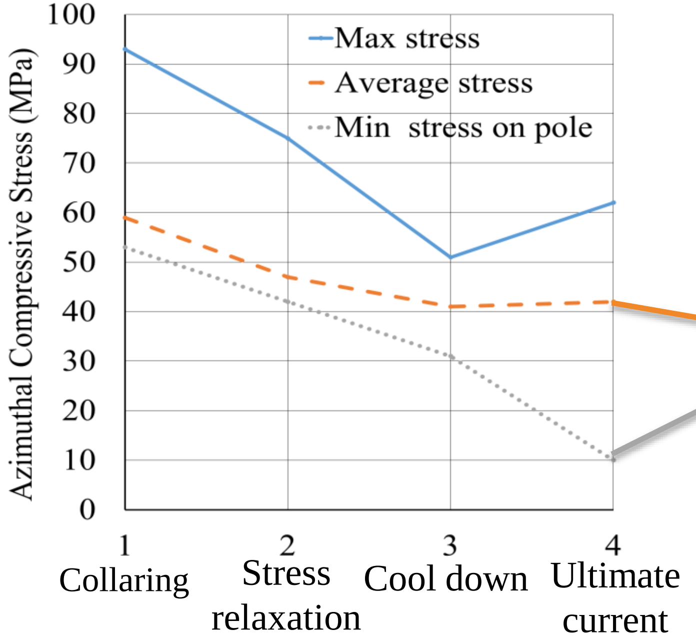

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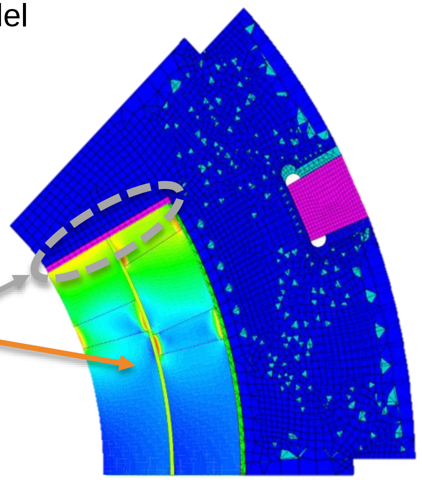

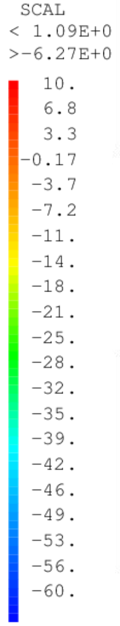

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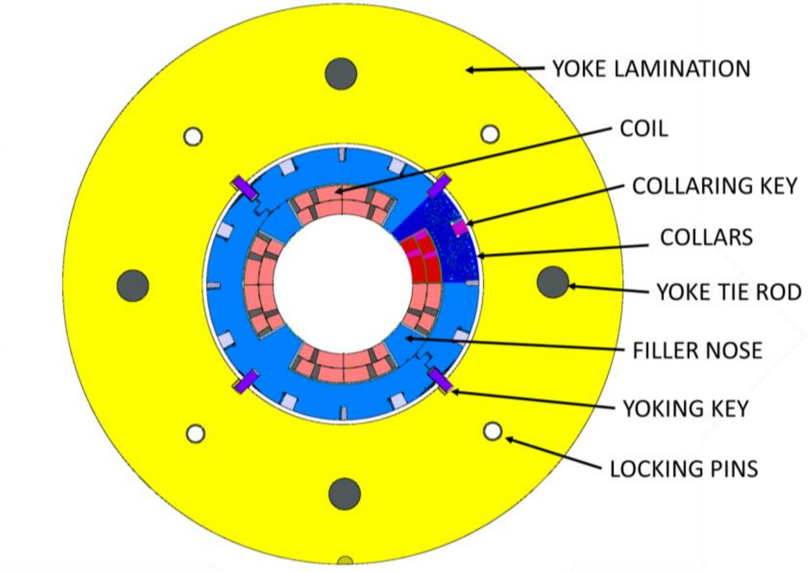

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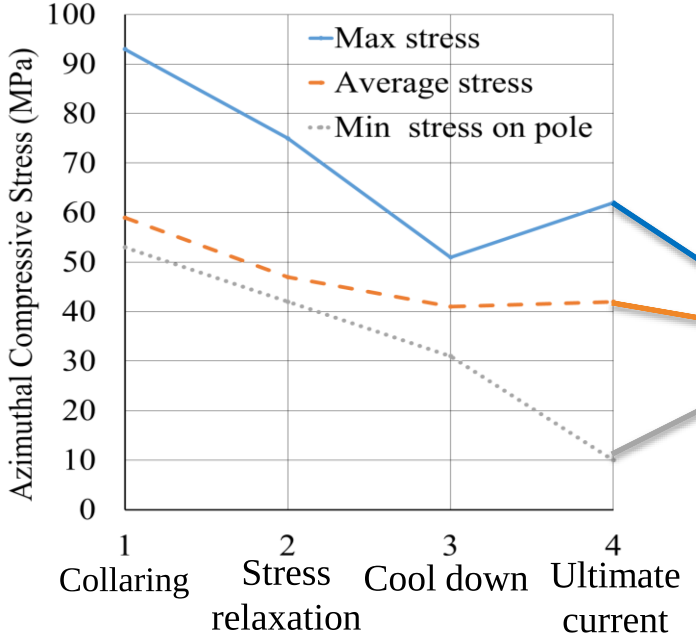

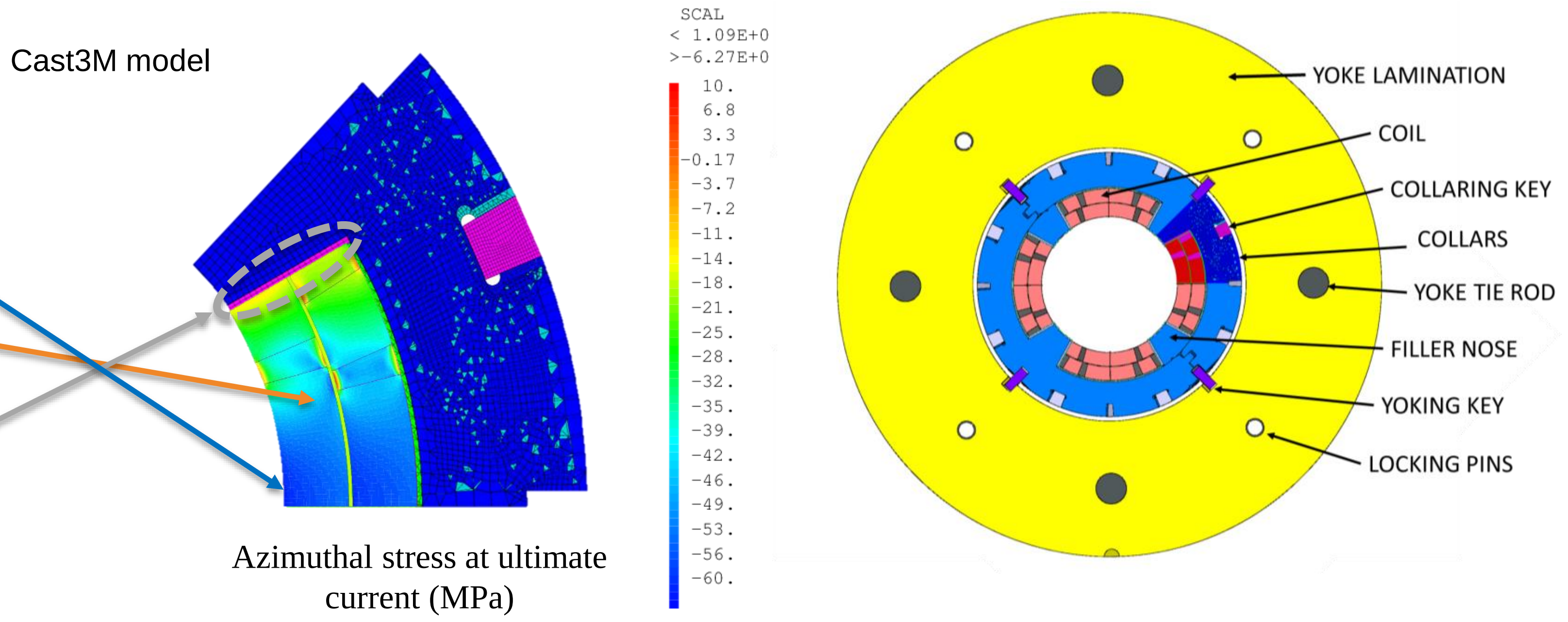

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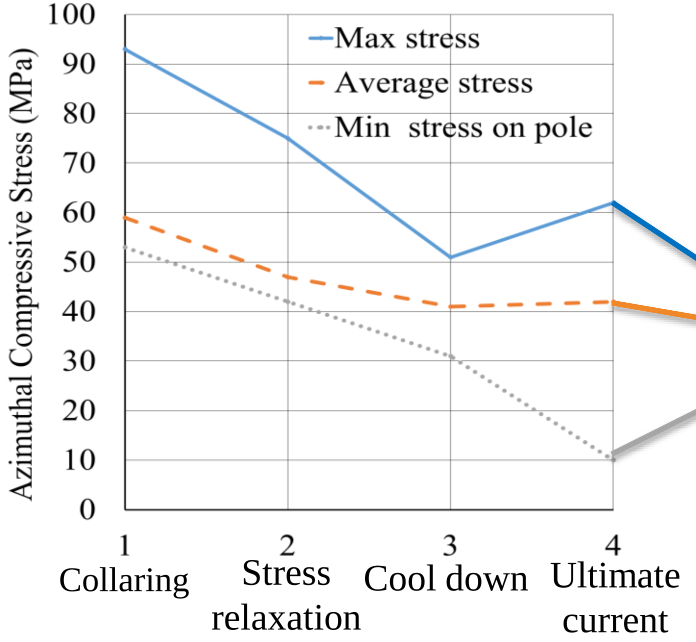

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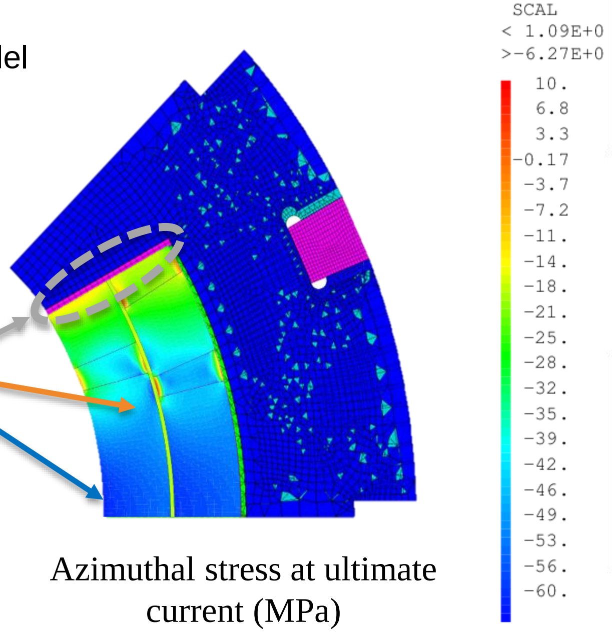
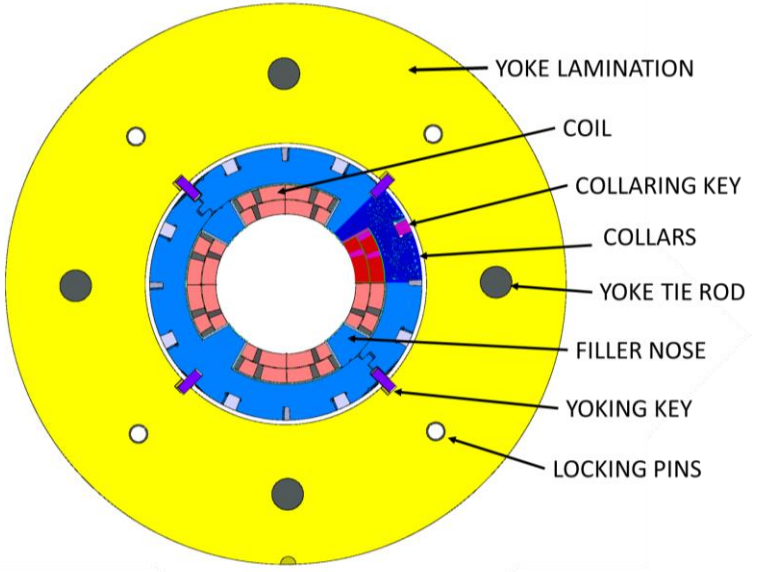


Azimuthal stress at ultimate current (MPa)



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Azimuthal stress after collaring:

60 MPa for a minimum compression of **10 MPa** on the pole during energization at ultimate current

Lower than **150 MPa** to not damage the insulation [3]

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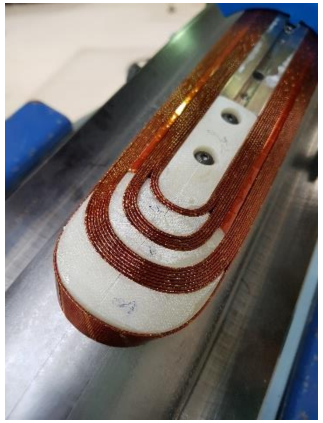
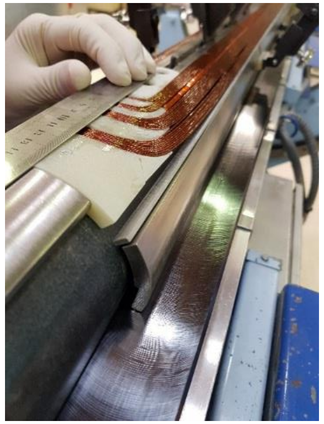
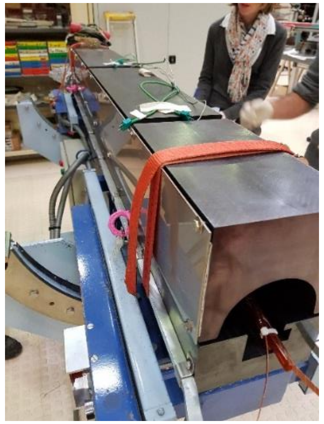
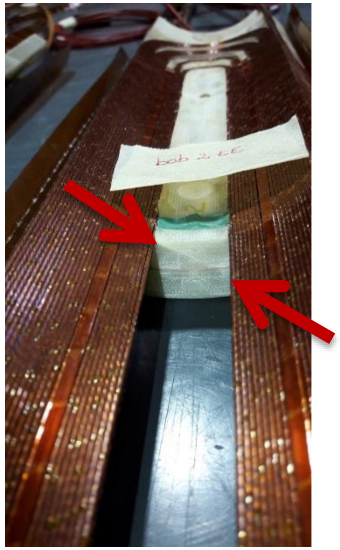
MQYYM WINDING

- 10 Coils have been wound at CEA
- 4 coils for magnet assembly and 2 spares have been identified after electrical tests

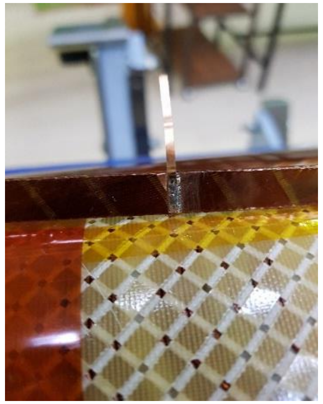
First layer winding and polymerisation

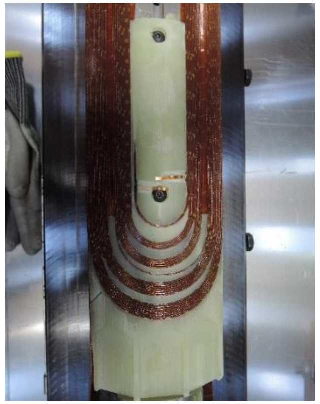





High pressure during polymerisation leading to the apparition of shear plane crack in G10



Second layer winding and polymerisation



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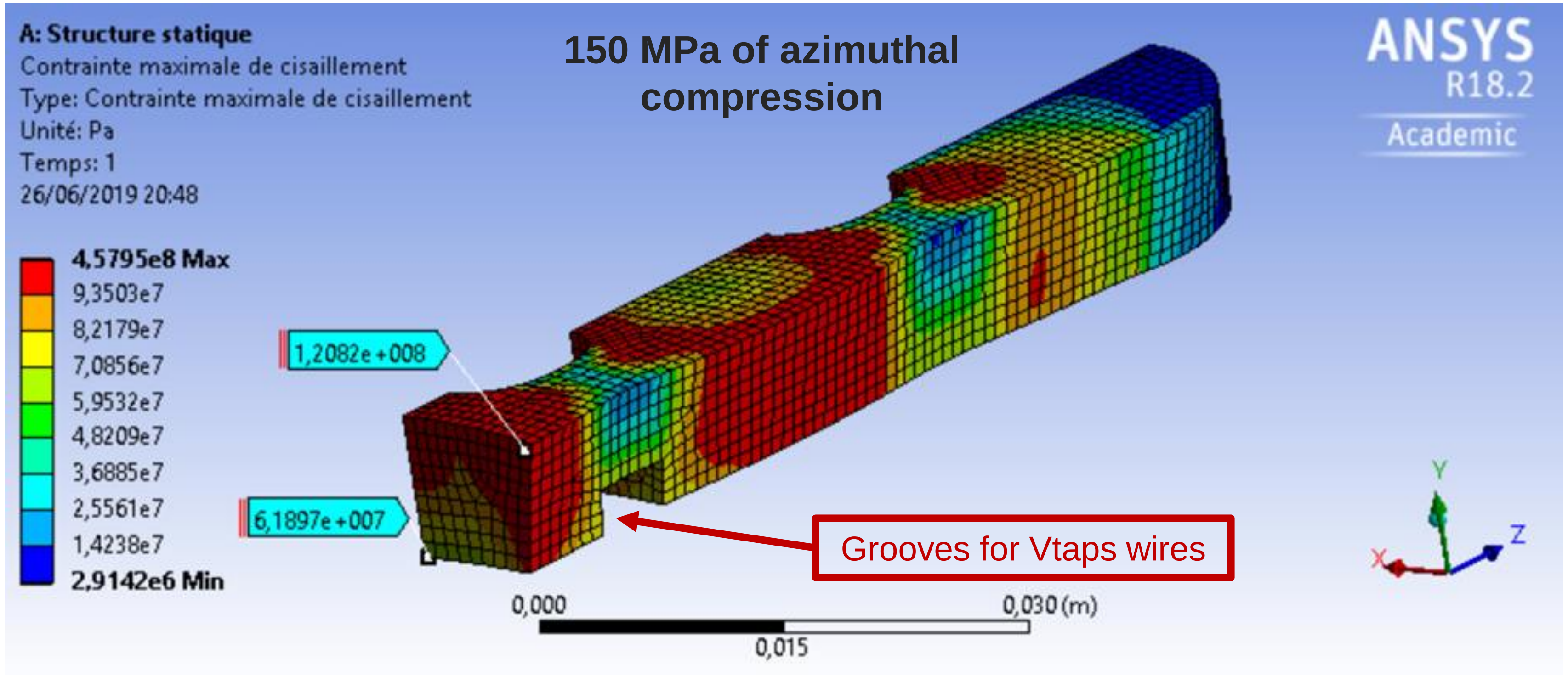

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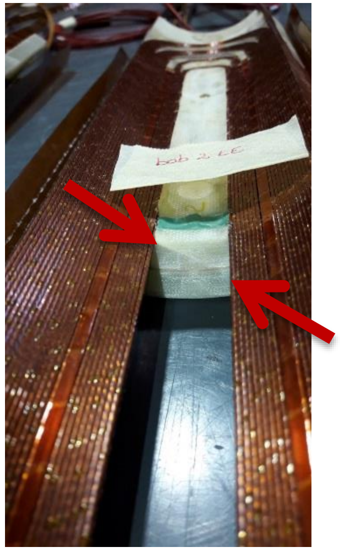
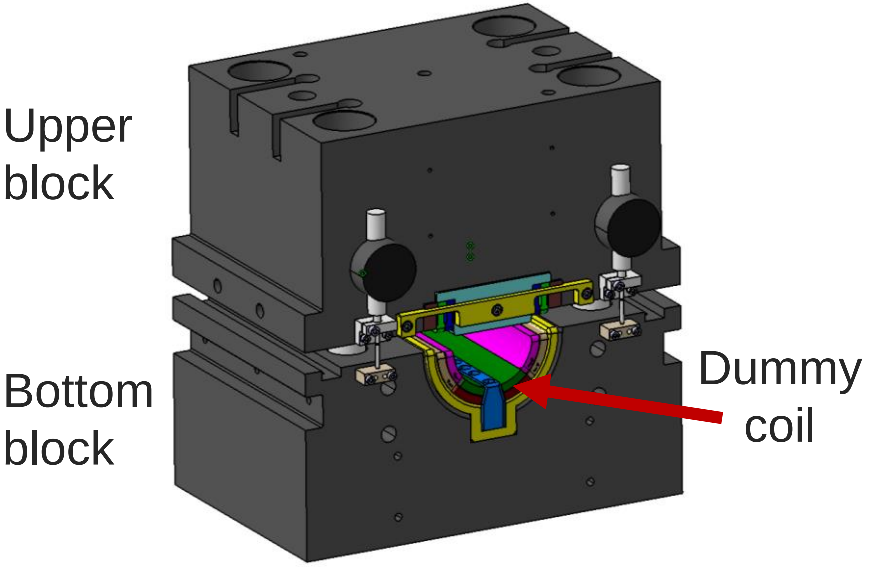
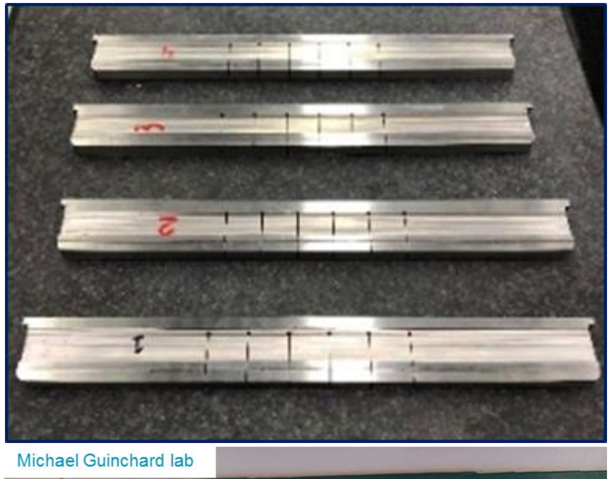
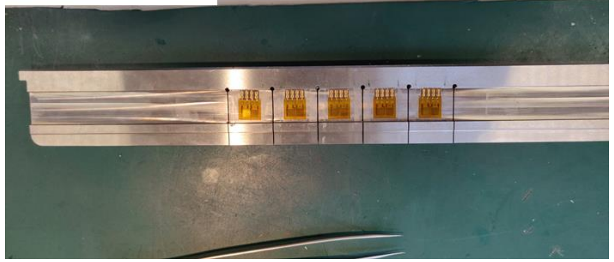


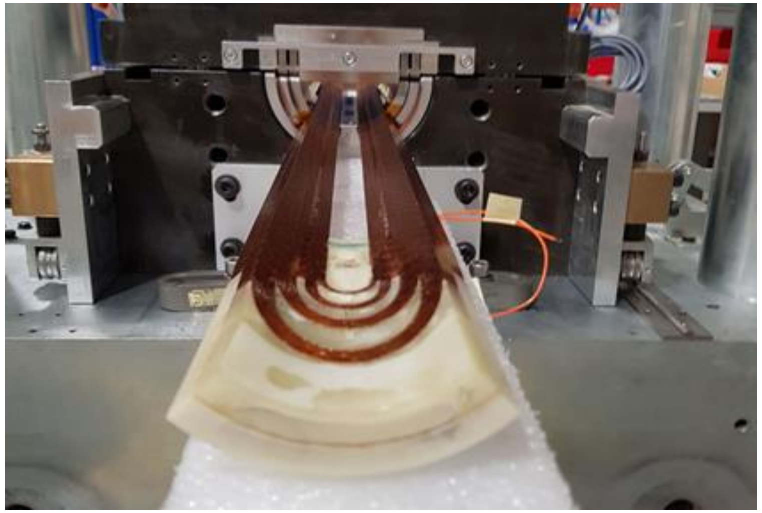
MQYYM MECHANICAL CHARACTERISATION OF THE COILS

- Check the coils size to adjust the coils preload after collaring (at CERN)
- General Procedure [6][7]:
  - Define the coil nominal size (using the stainless steel dummy coils)
  - Press the coil on the E modulus press until the nominal coil size









[6] G.A. Kirby et al, "Engineering design and manufacturing challenges for a wide-aperture superconducting quadrupole magnet"
[7] J.L Rudeiros et al, "Mechanical characterization of Nb3Sn impregnated coils – Compression properties"

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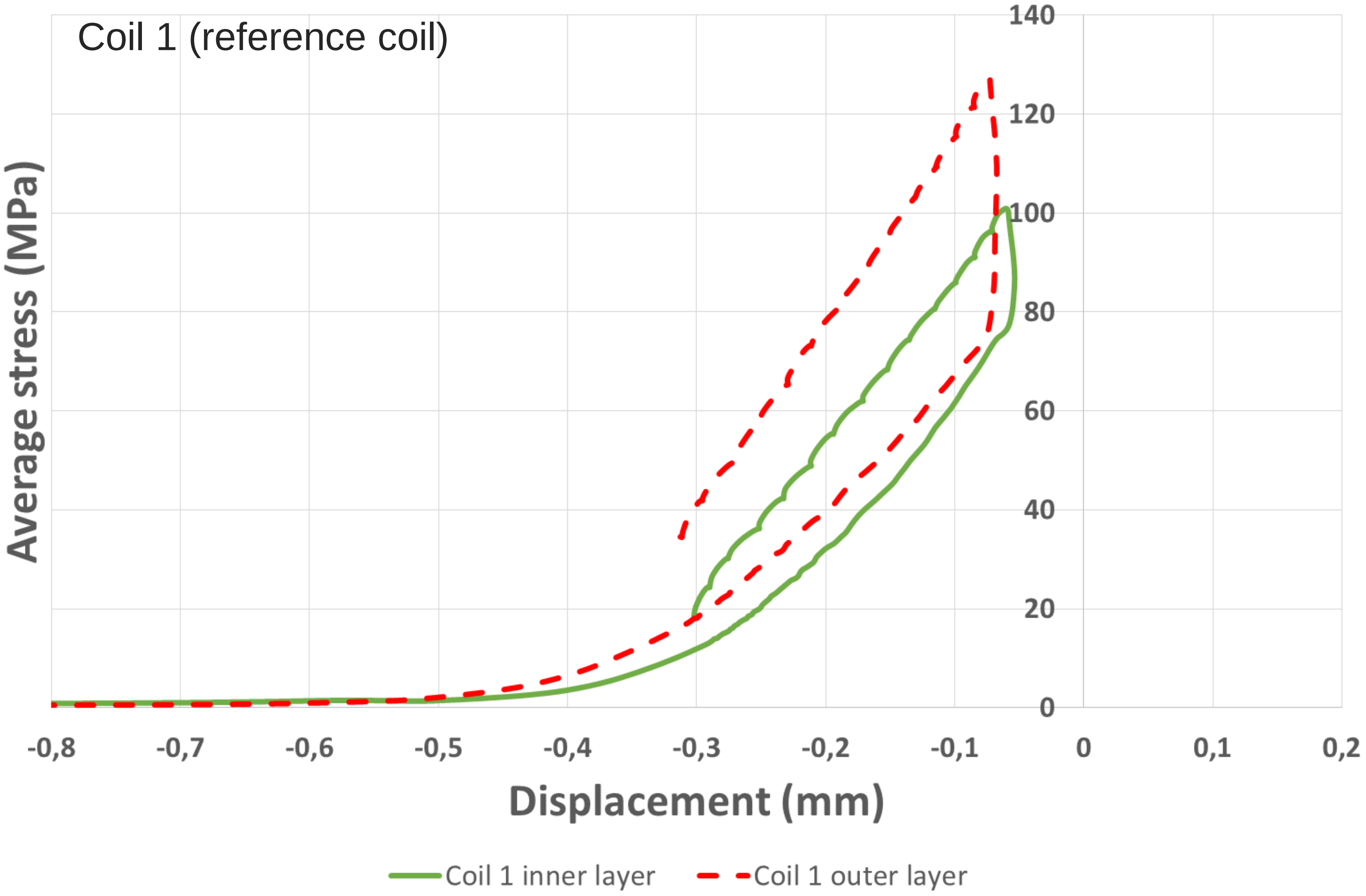

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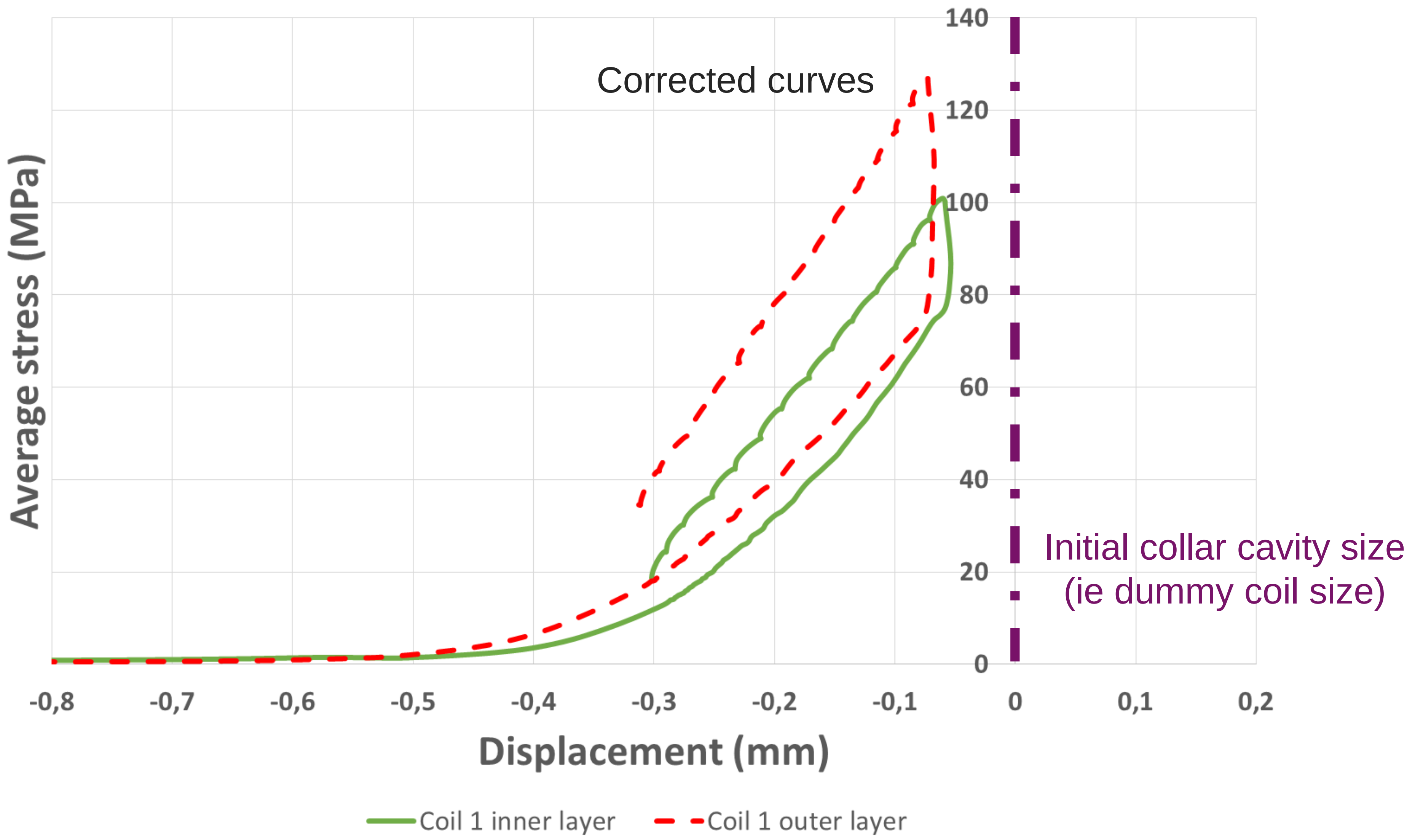

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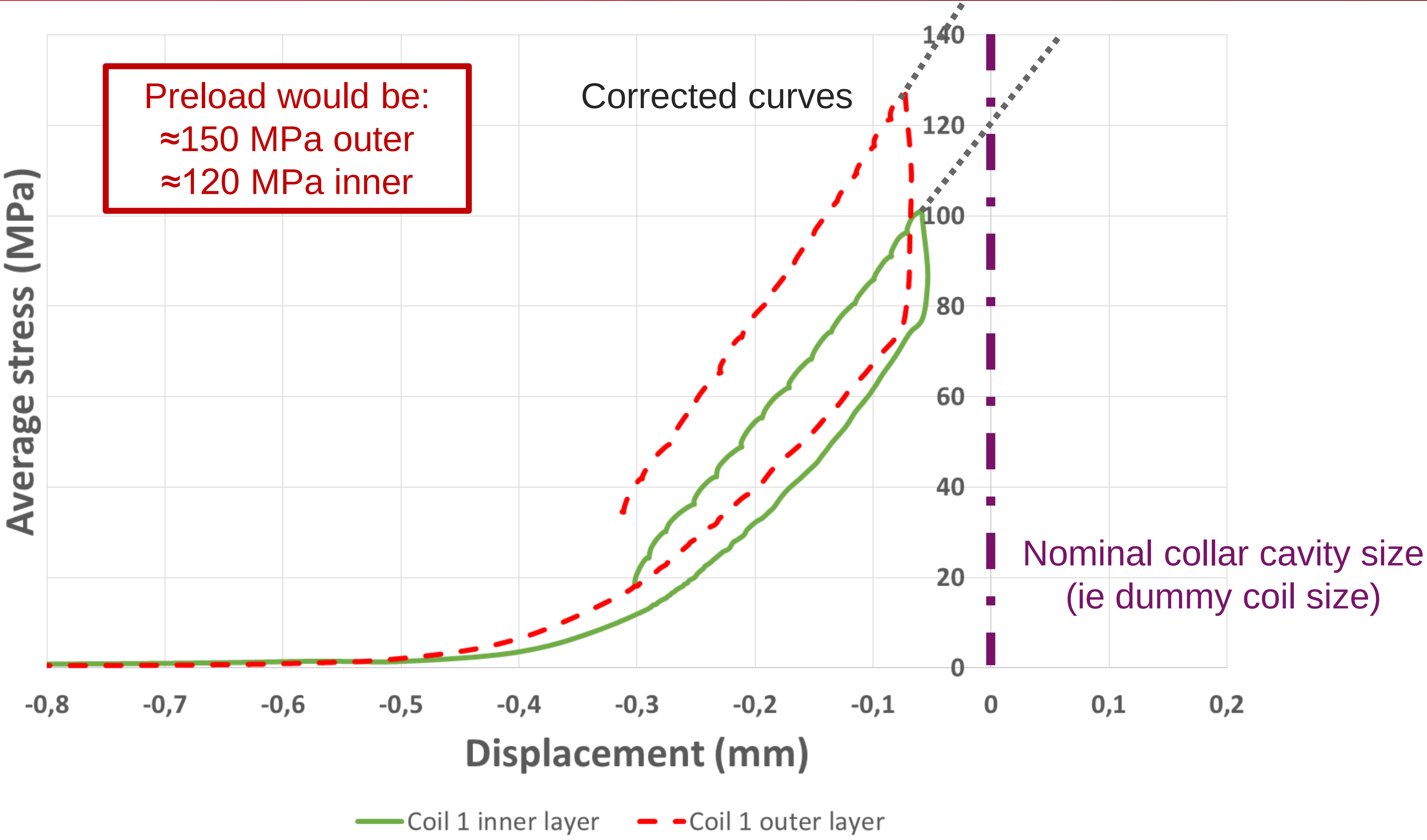

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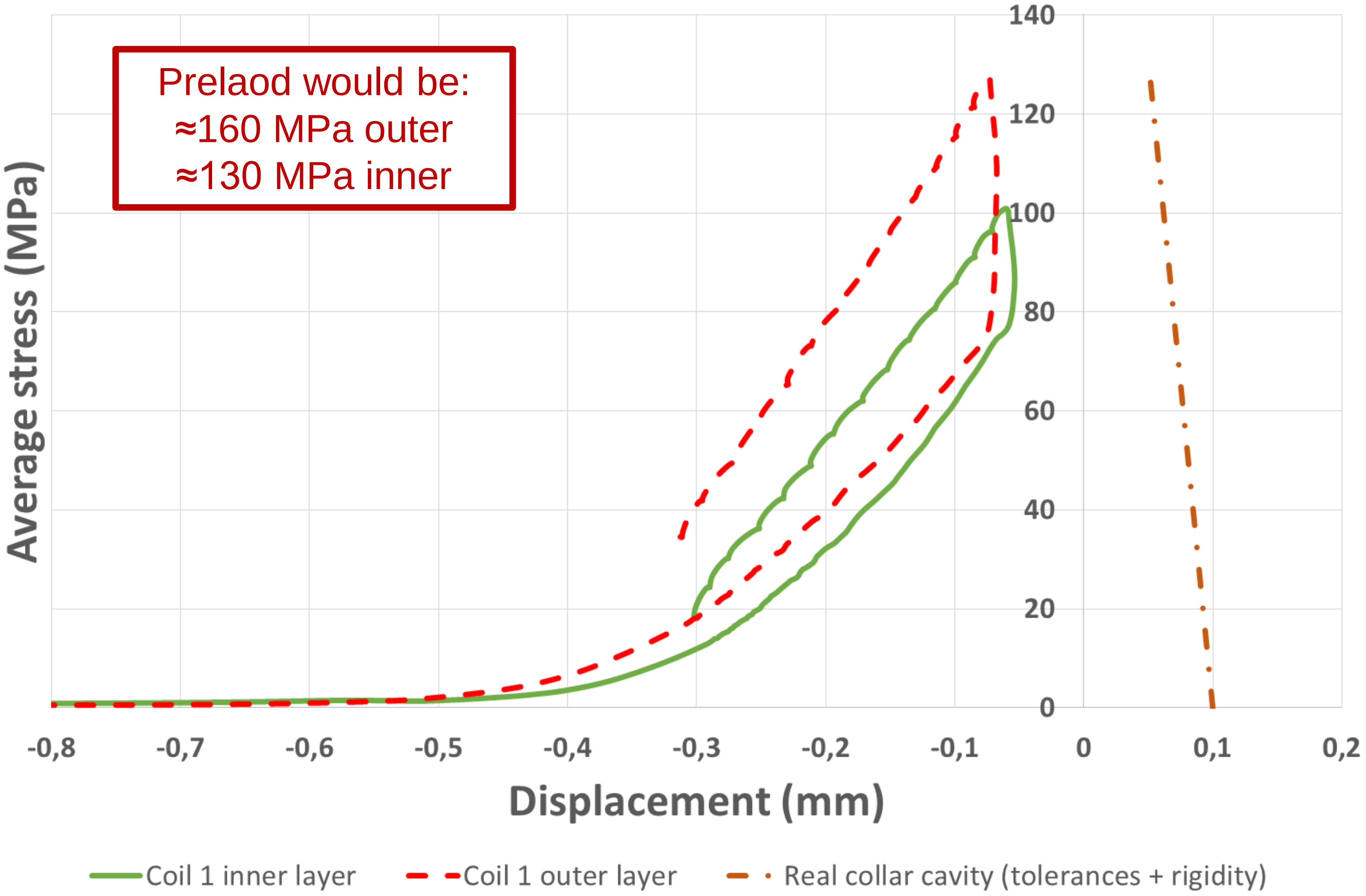

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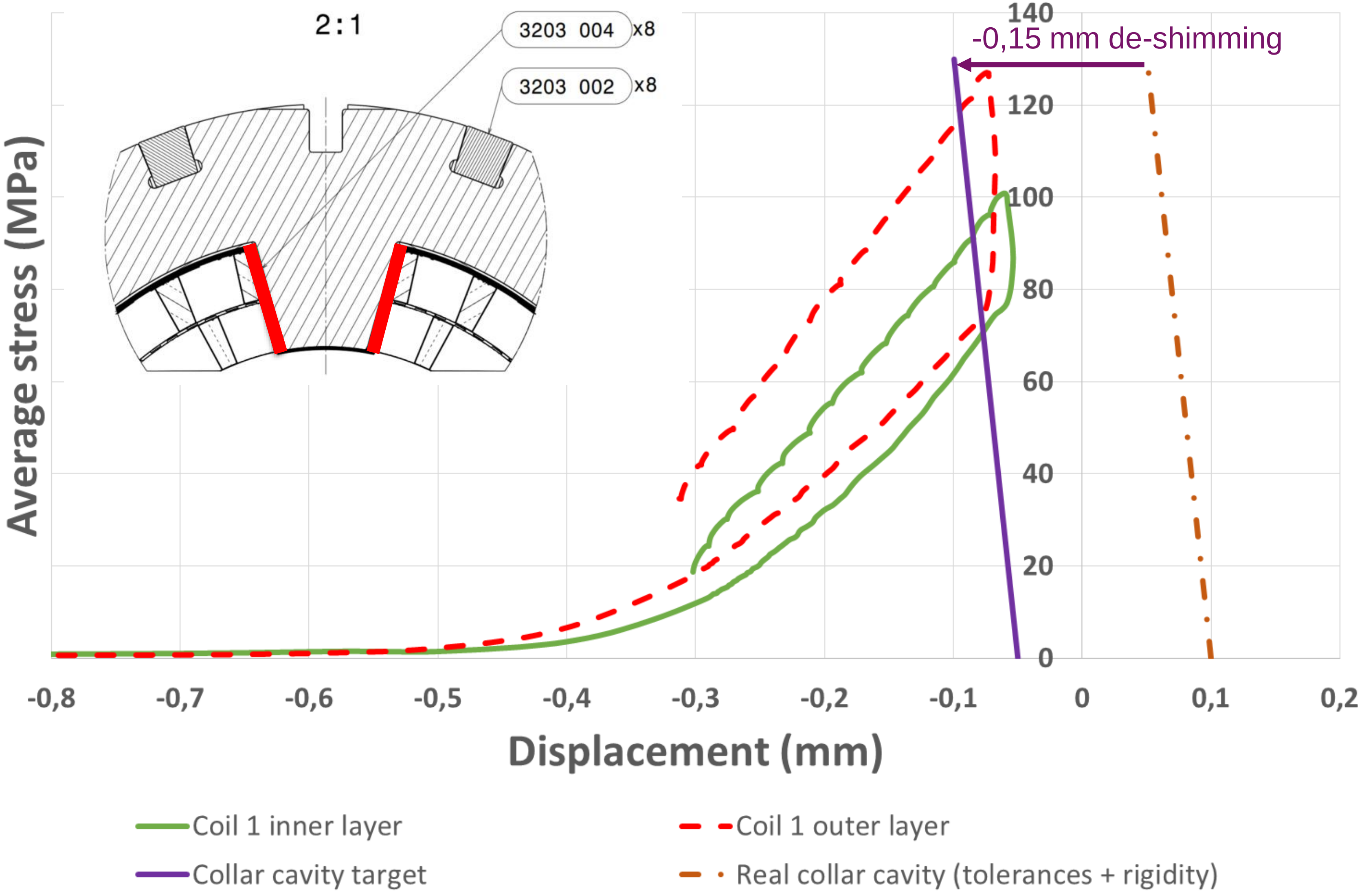

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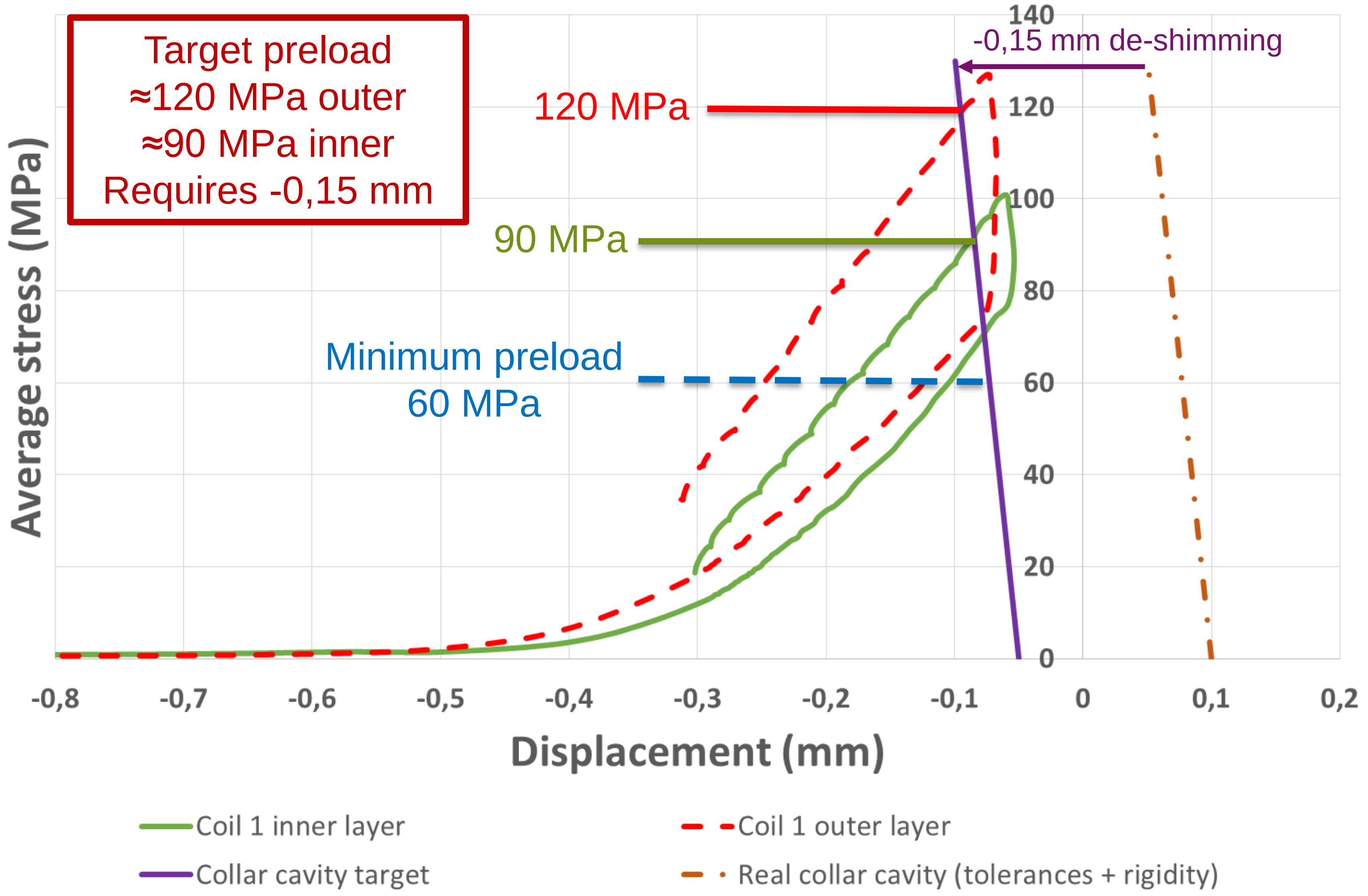

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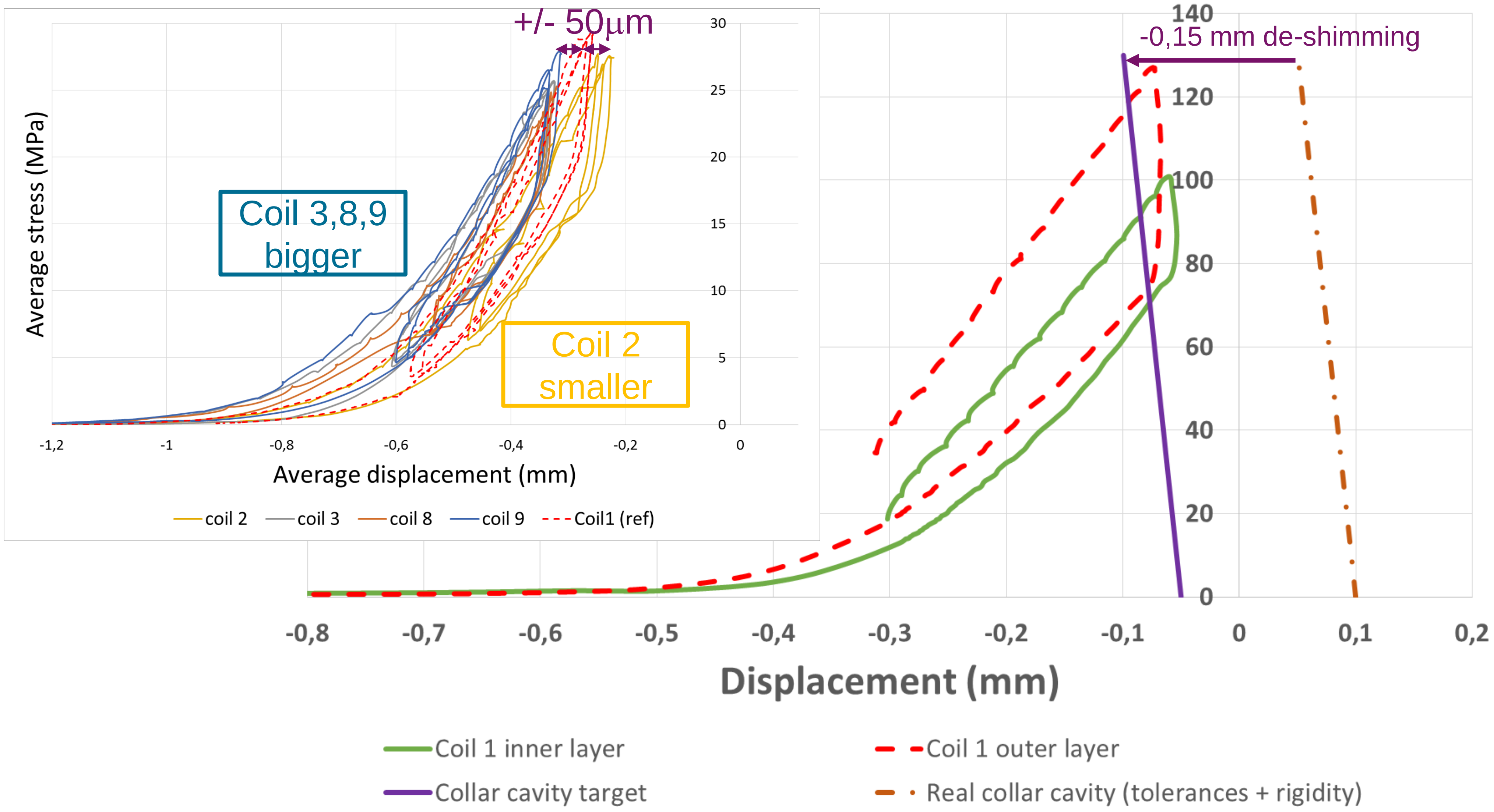

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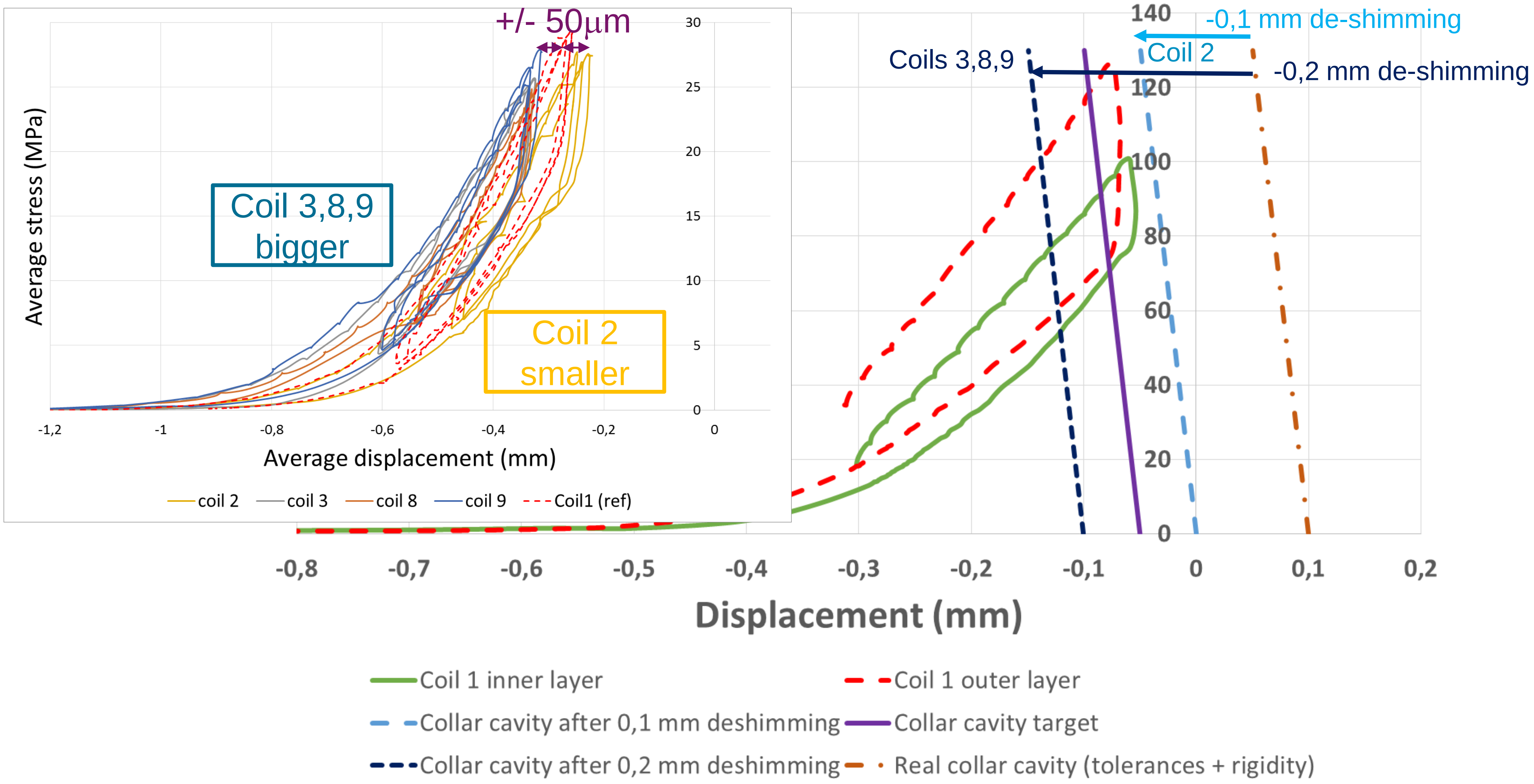

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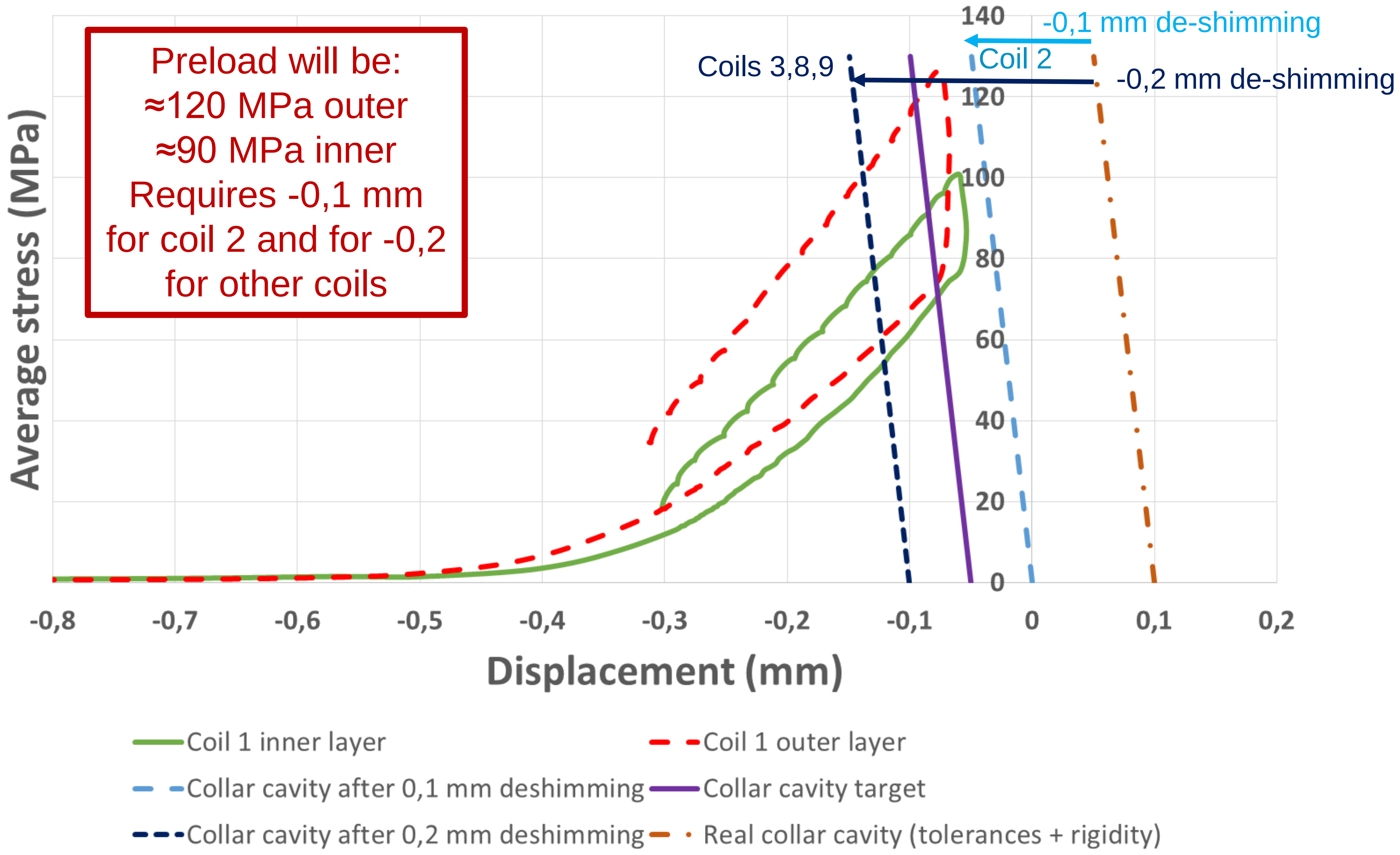
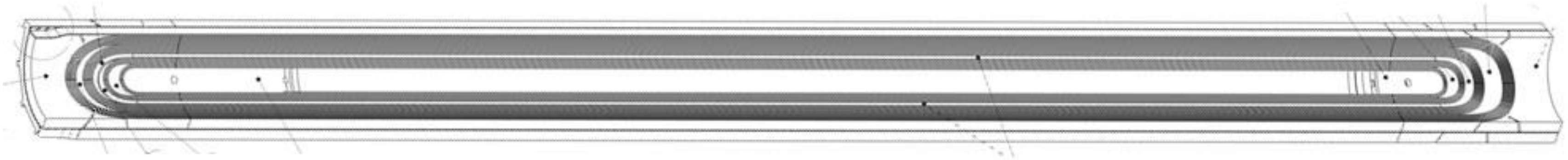
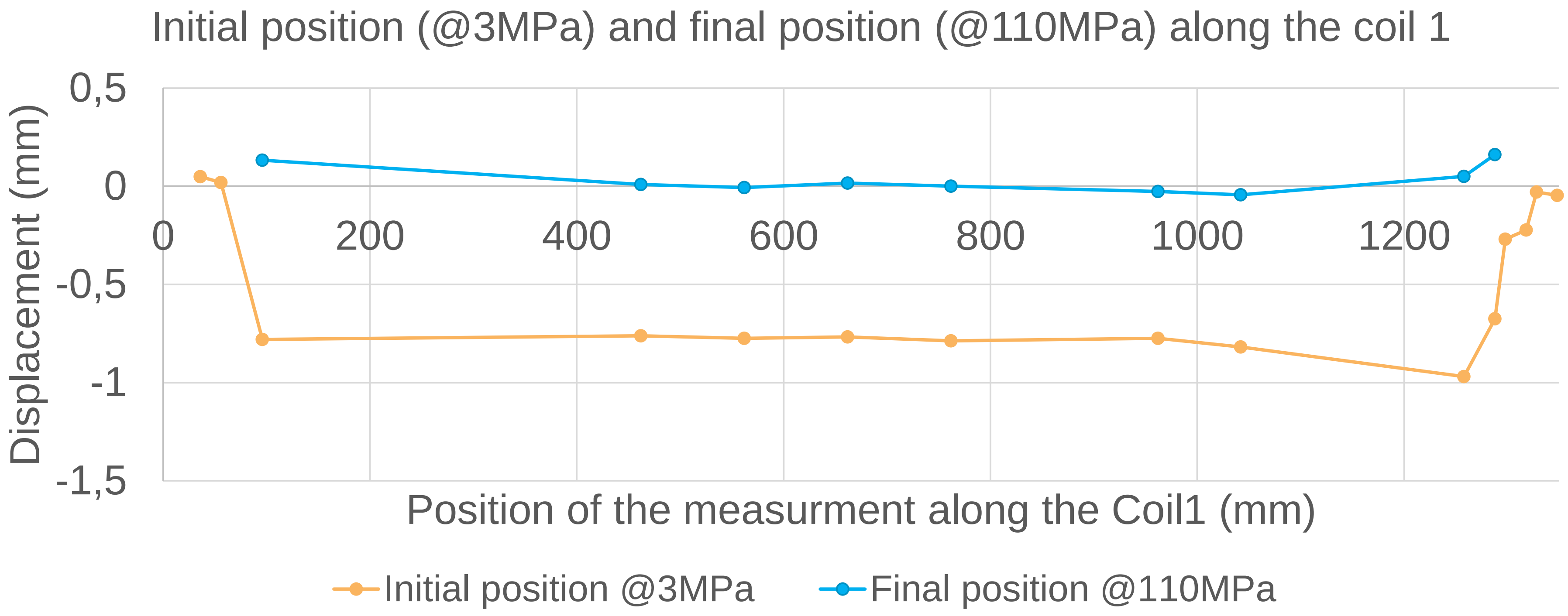


MQYYM MECHANICAL CHARACTERISATION OF THE COILS

No shimming in the ends



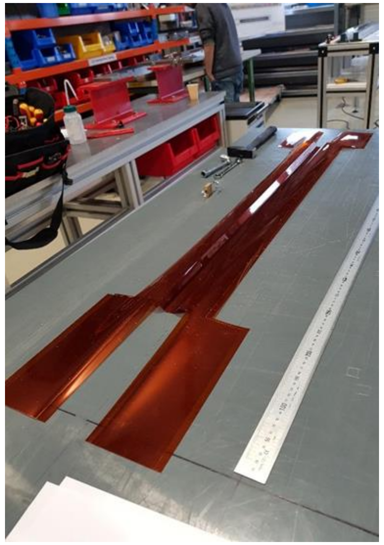


MQYYM ASSEMBLY

- Assemby made at CERN
- Positionning of the protection heaters and instrumentation of the trace

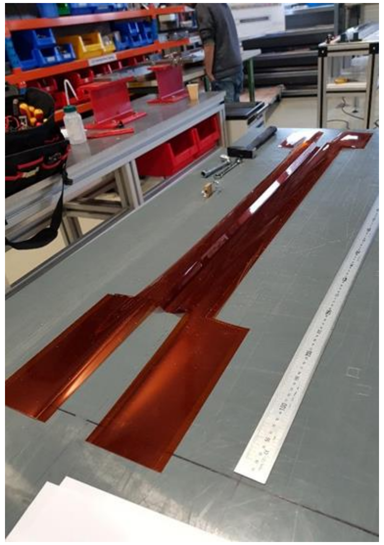
MQYYM ASSEMBLY

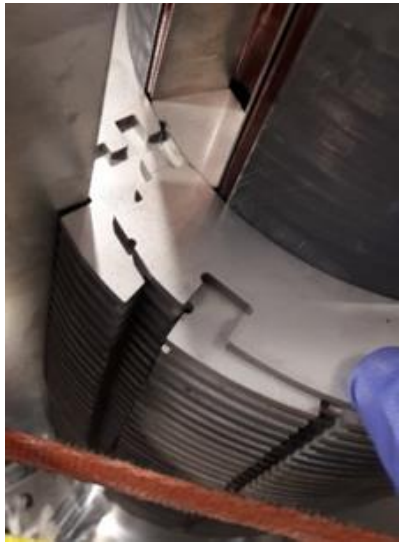
- Assemby made at CERN
- Positionning of the protection heaters and instrumentation of the trace
- Ground plane insulation forming and mounting



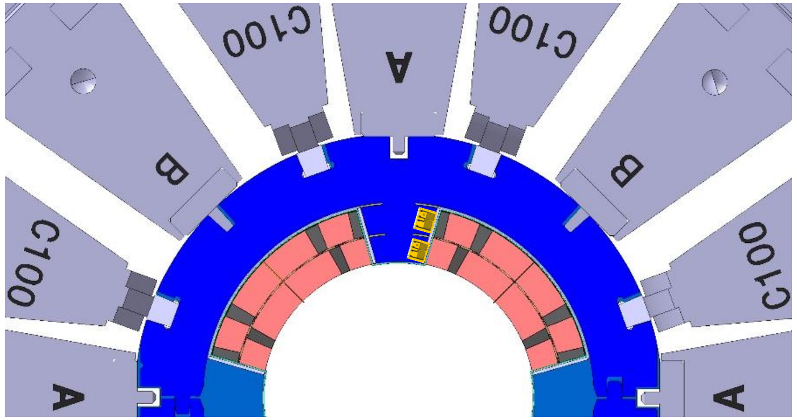
MQYYM ASSEMBLY

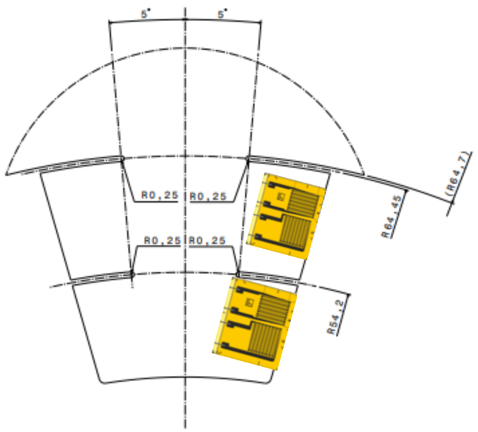
- Assemby made at CERN
- Positionning of the protection heaters and instrumentation of the trace
- Ground plane insulation forming and mounting
- Collaring shoe and protection shim positioning
- Mounting of the collars

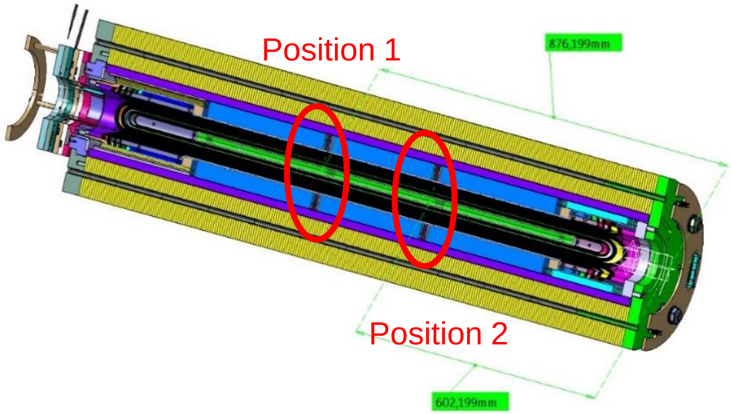



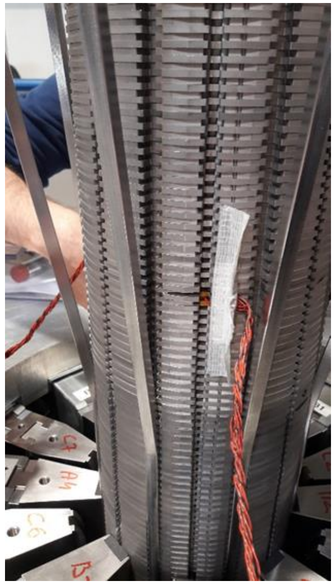



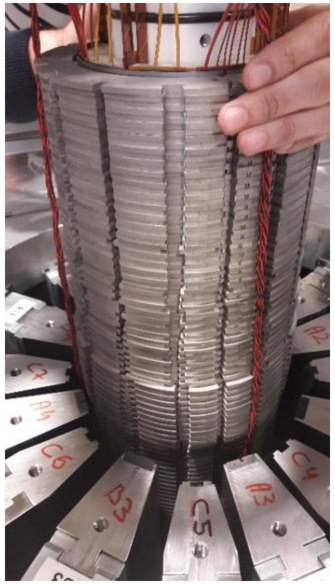

- **Bi-axial gauges** used at two locations
- **Cut out** in the instrumented collars to remove the σ_r
- Misalignment of the collars over the coil ends
- Bigger forces used on the jacks over the coil ends





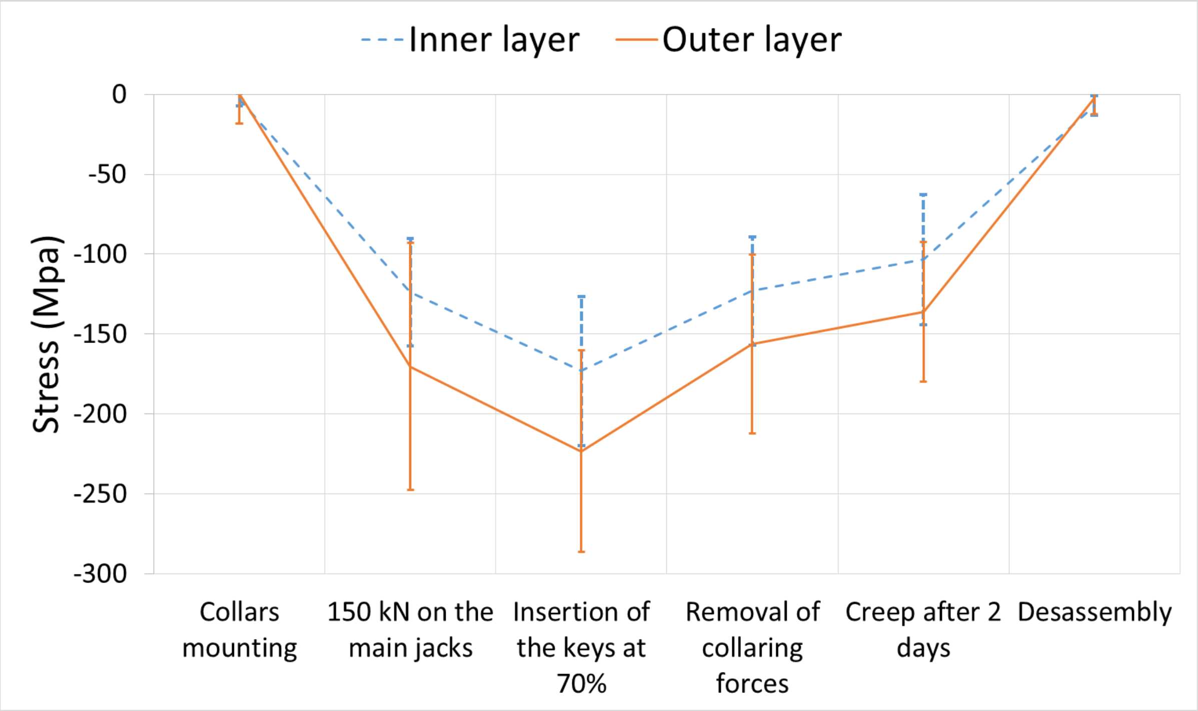




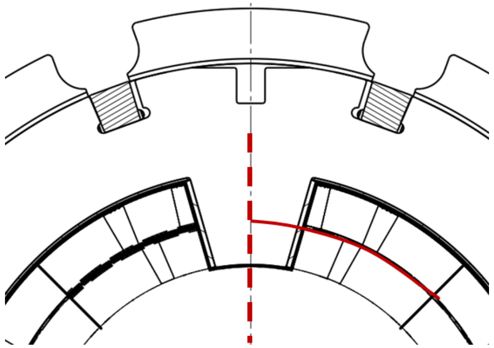


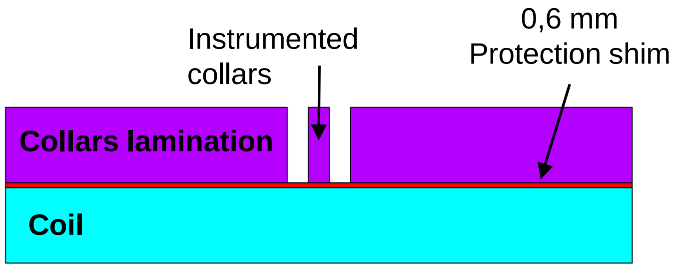
MQYYM COLLARING AND INSTRUMENTATION

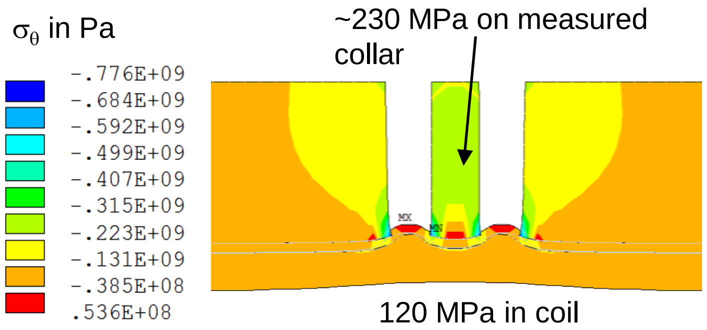
- Massaging + Insertion of the keys at 70%
- Factor 2 between the strain read in the collars and the one expected due to the lack of collar nose



Stress in the collars measured by the strain gages







MQYYM COLLARING AND INSTRUMENTATION

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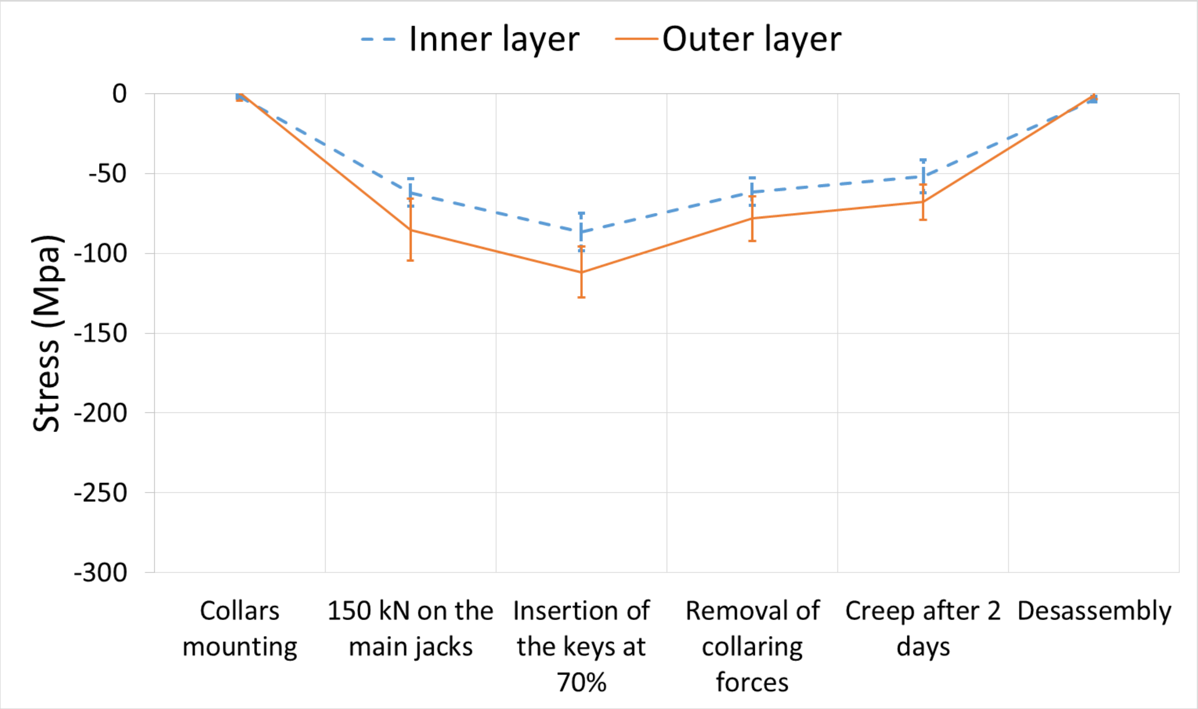
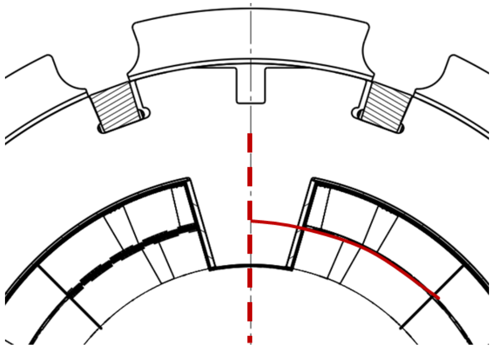
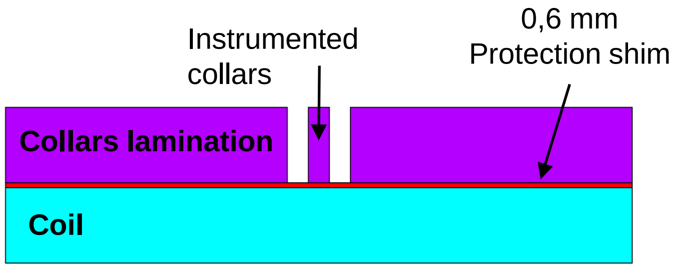
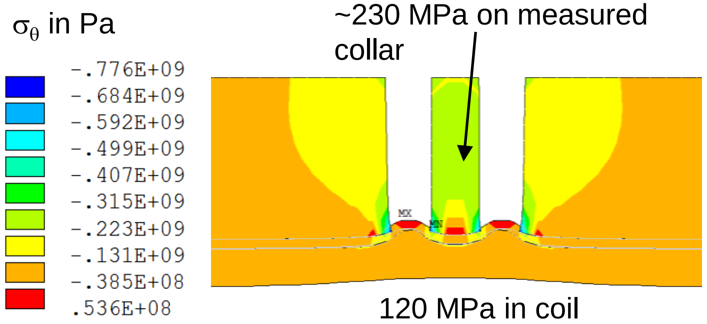


Stress in the coil (2 time less than the stress measured in the collar)

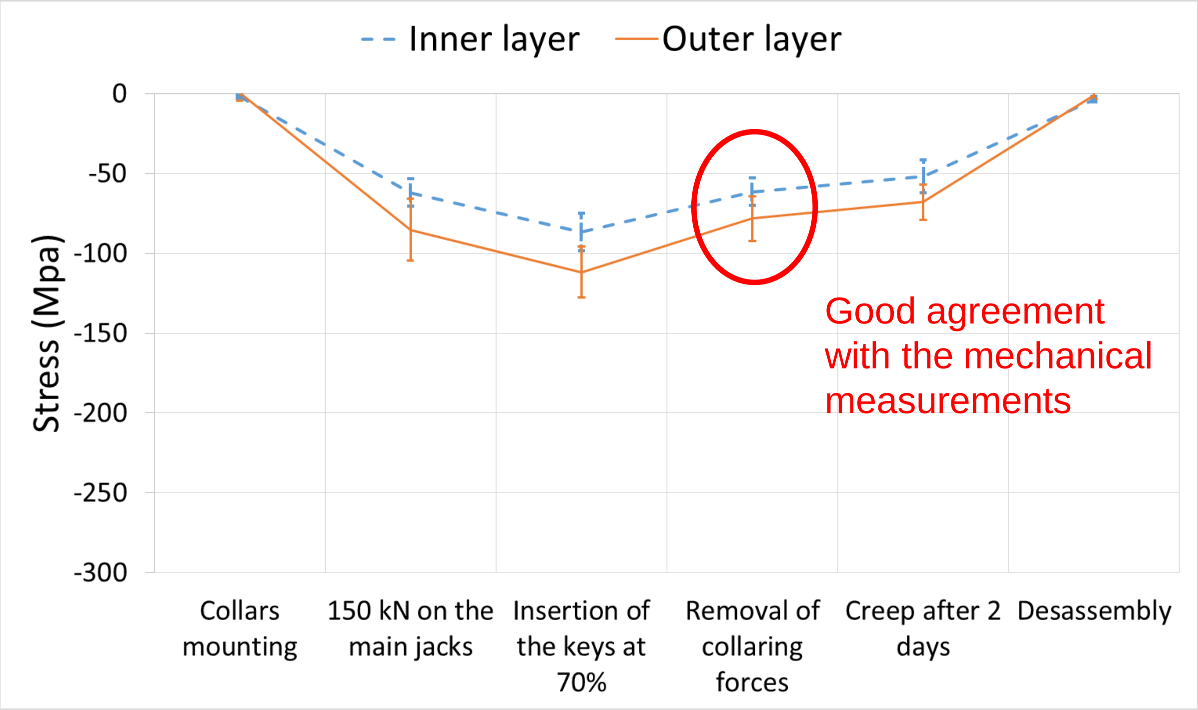




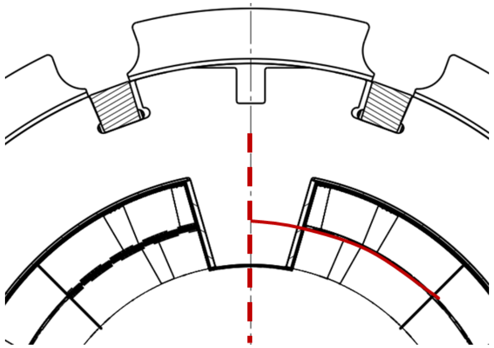


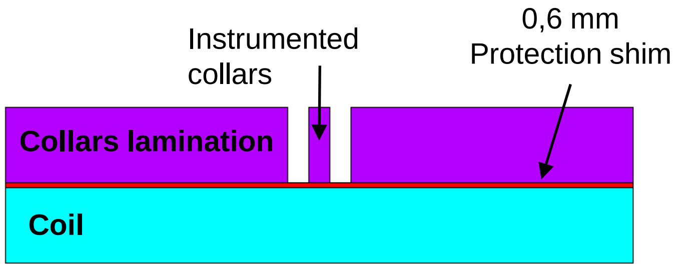
MQYYM COLLARING AND INSTRUMENTATION

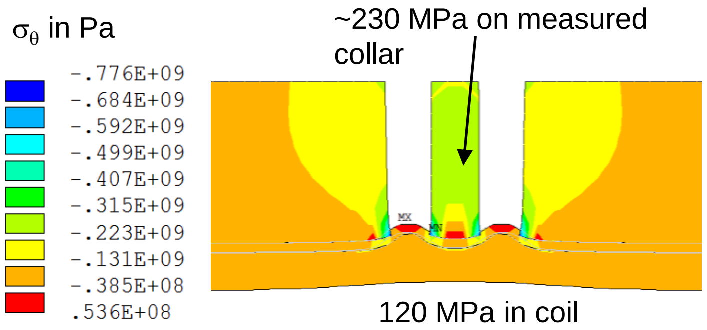
- Massaging + Insertion of the keys at 70%
- Factor 2 between the strain read in the collars and the one expected due to the lack of collar nose



Stress in the coil (2 time less than the stress measured in the collar)

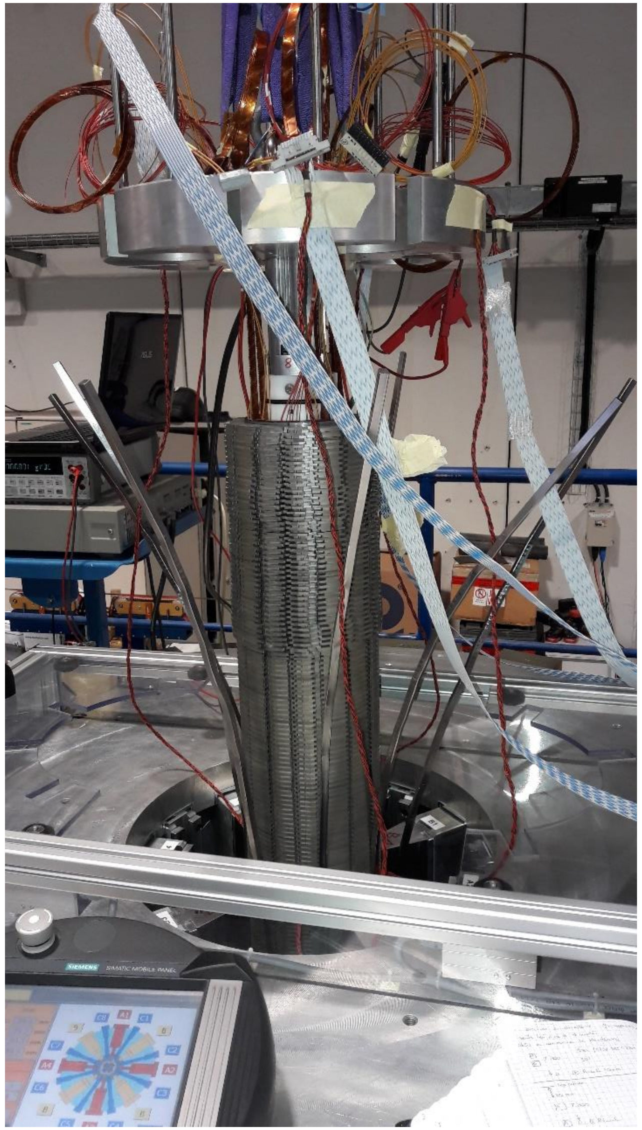




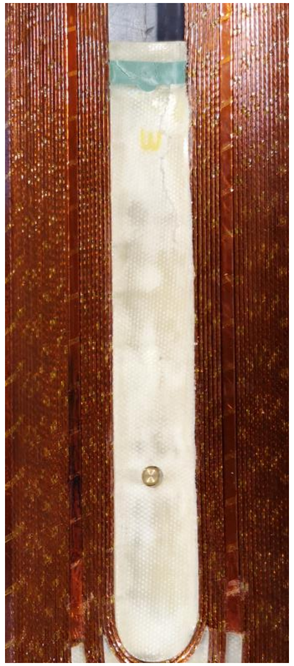


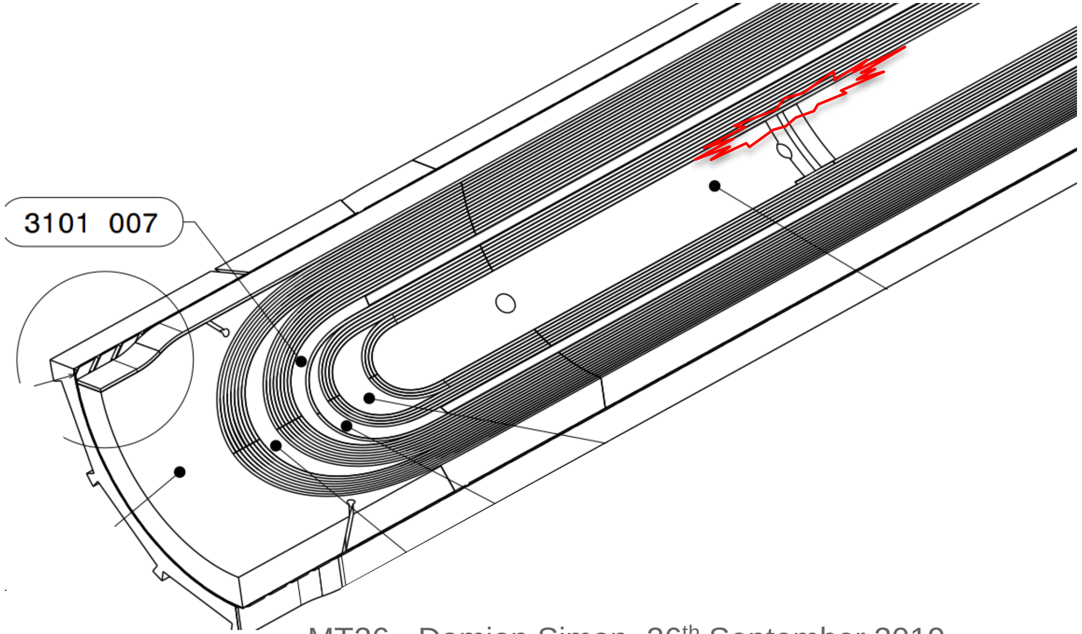
ELECTRICAL ISSUE & DECOLLARING

- Electrical tests after the collaring at 70%: **Turn to turn short circuit detected => decision to decollar**
- Short disappears after decollaring of the LE
- Location of the short circuit suspected to be between the pole turn and turn 2
- Crack starts observed in coils

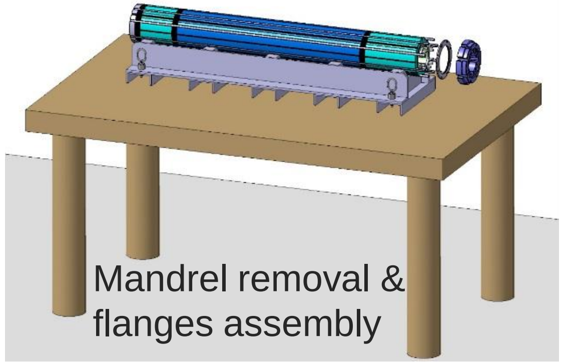


Coil 3 exhibits Reproduction of the short on the E modulus press Shear plane and cracks appear

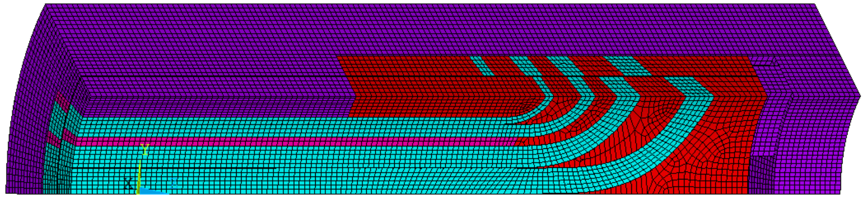




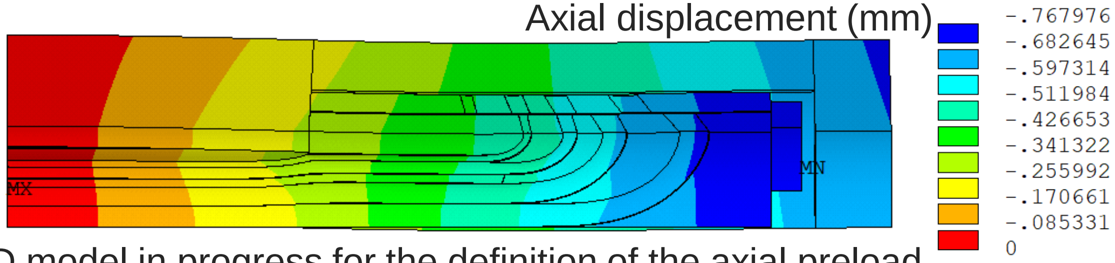
NEXT ASSEMBLY STEPS AND TEST



Longitudinal prelaod apply with instrumented bullets

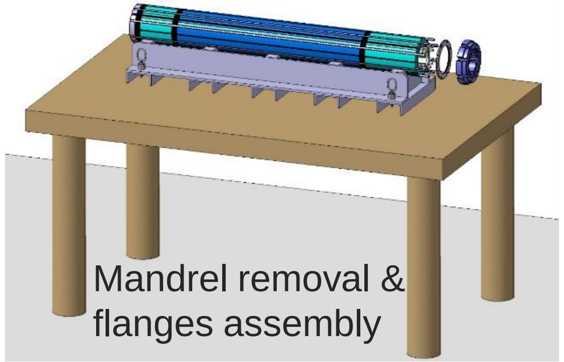


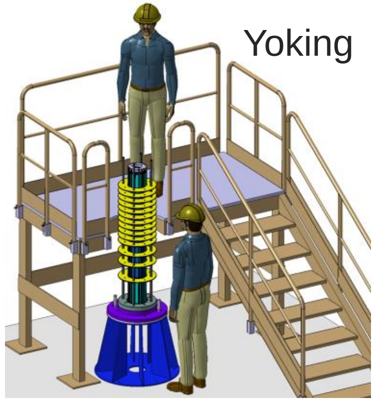
Axial displacement (mm)



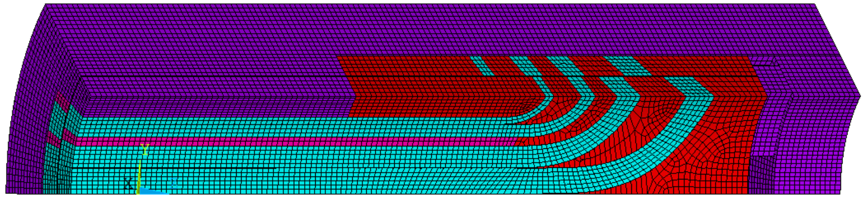
3D model in progress for the definition of the axial preload

NEXT ASSEMBLY STEPS AND TEST

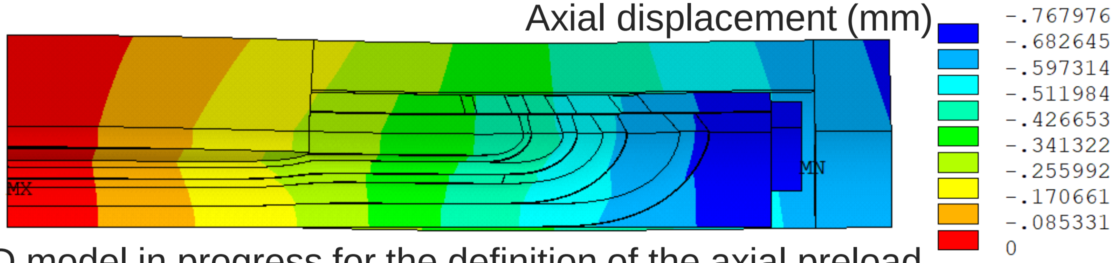




Longitudinal prelaod apply with instrumented bullets

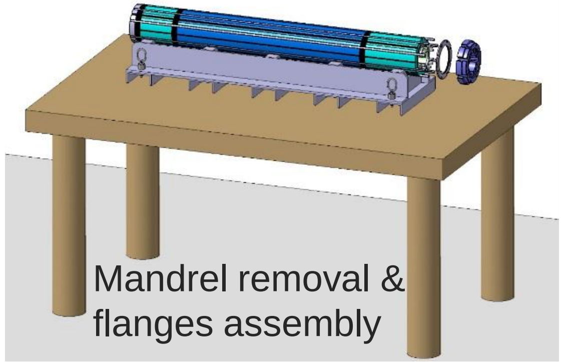


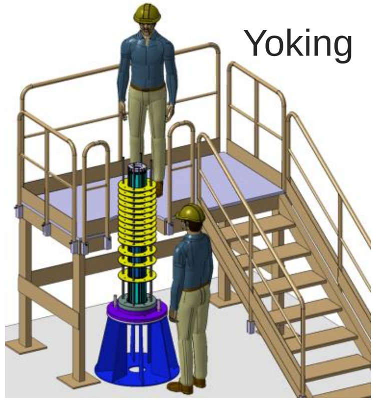
Axial displacement (mm)

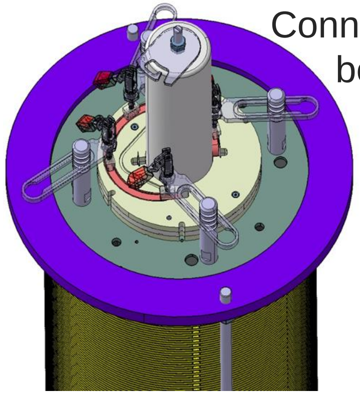


3D model in progress for the definition of the axial preload

NEXT ASSEMBLY STEPS AND TEST

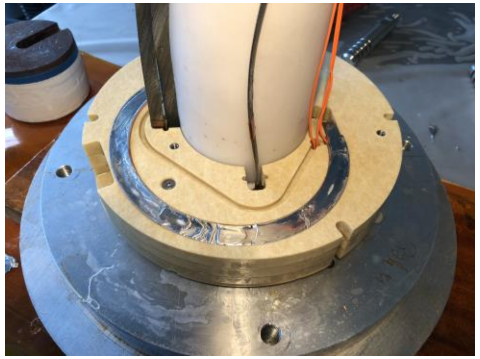


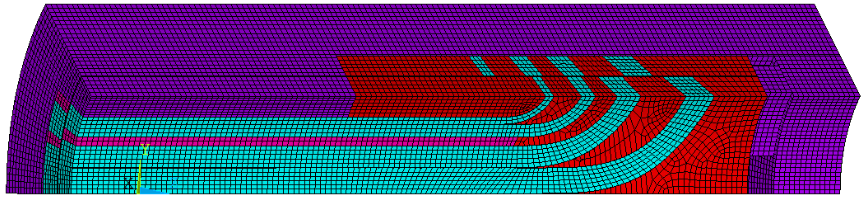




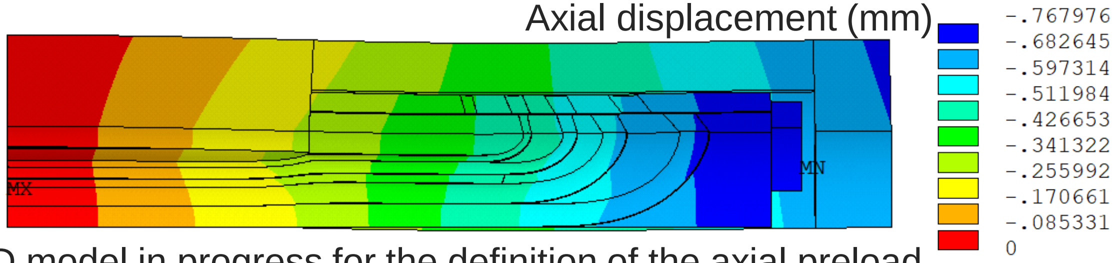
Longitudinal prelaod apply with instrumented bullets

Connection box mock-up made at CEA



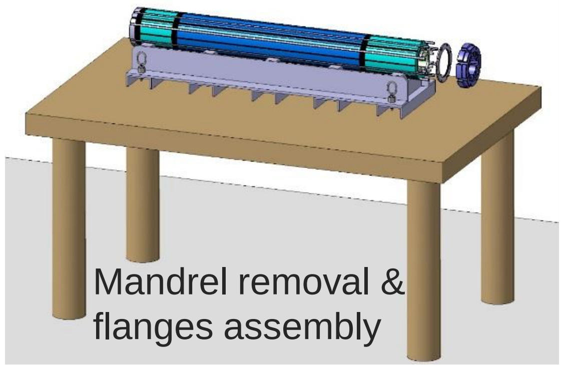


Axial displacement (mm)

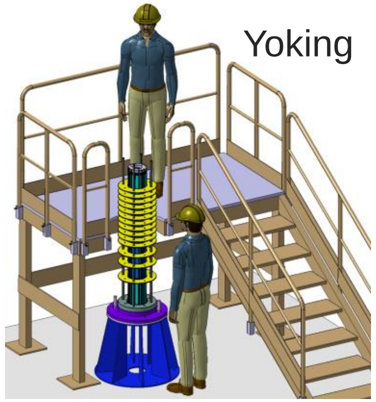


3D model in progress for the definition of the axial preload

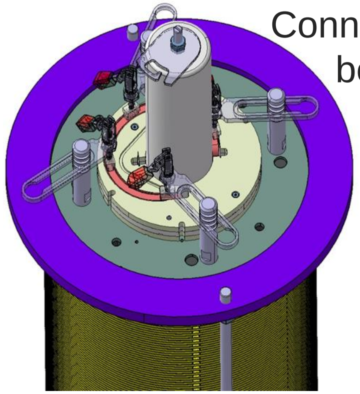
NEXT ASSEMBLY STEPS AND TEST



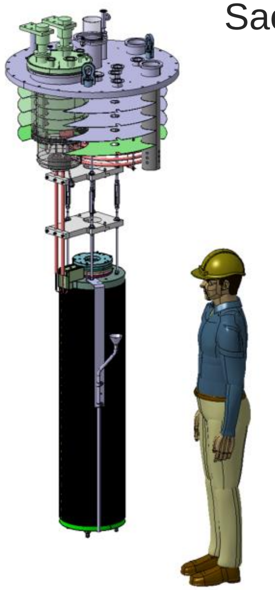
Yoking

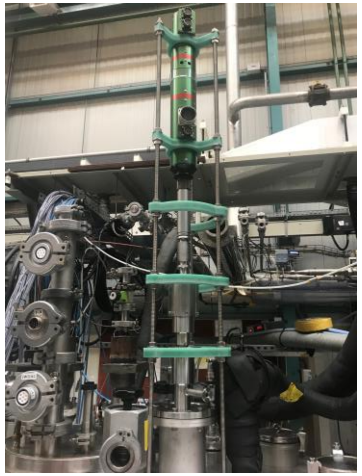


Connection box



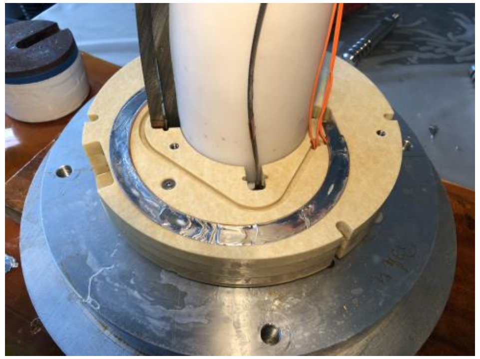
Test at CEA Saclay



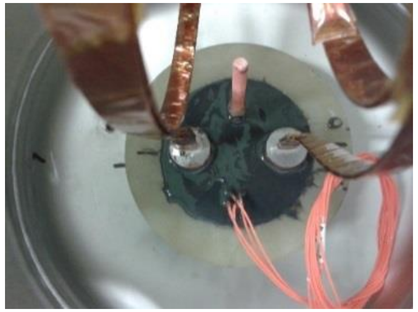


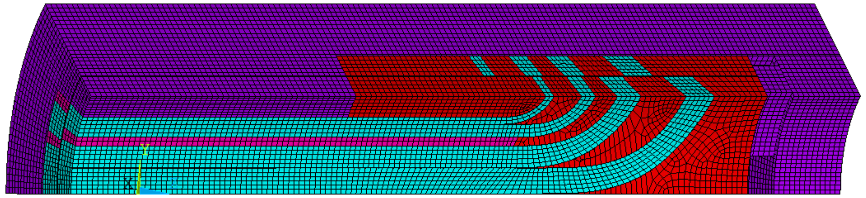
Longitudinal prelaod apply with instrumented bullets

Connection box mock-up made at CEA

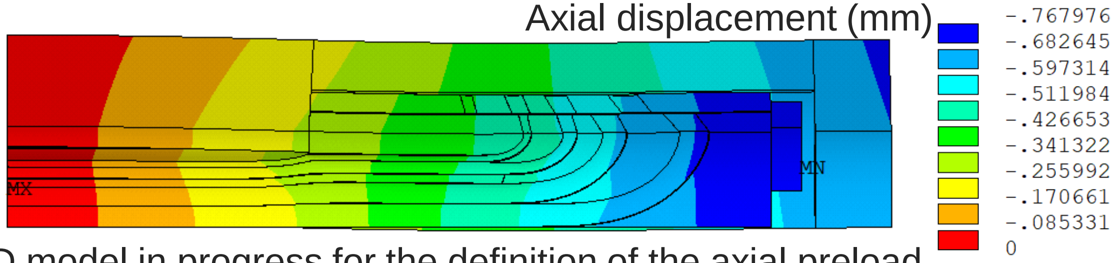


1.9K test in saturated bath





Axial displacement (mm)



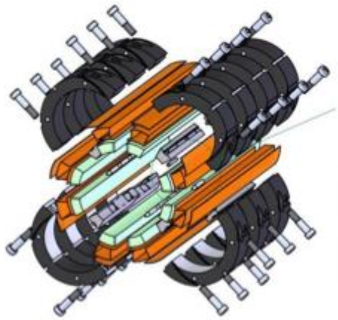
3D model in progress for the definition of the axial preload

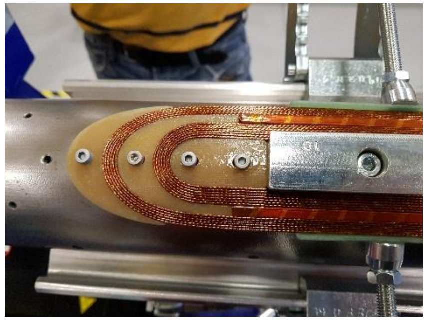
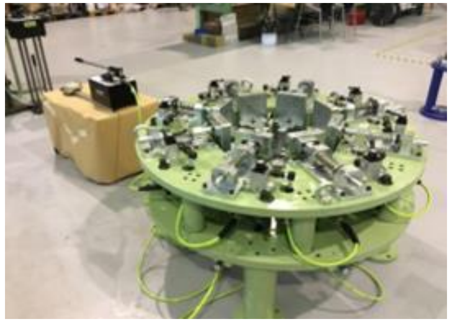
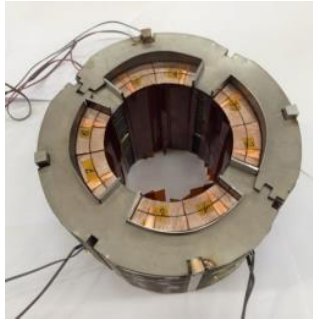
TOWARDS PROTOTYPES (QUACO)

- One 4 meter long practice coil has been wound by Sigmaphi and by Elytt Energy
- The mechanical structure mock-up program is in the final phase







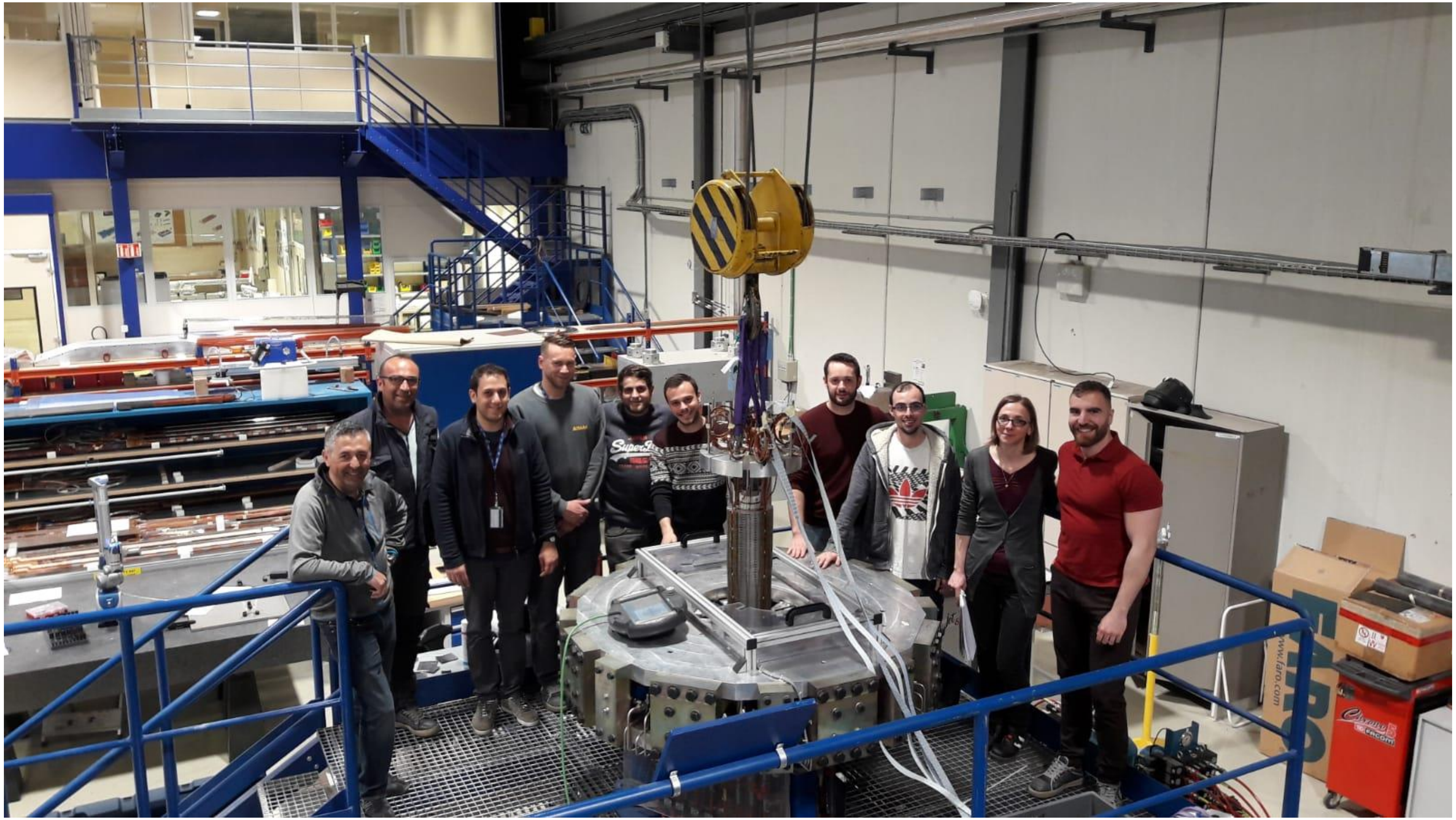
SIGMAPHI ACCELERATOR TECHNOLOGIES

ELYTT ENERGY

- Due to turn-to-turn short in the first MQYYM assembly a **new assembly is foreseen in october 2019**
- Based on coils mechanical measurement and strain gages measurement of the first MQYYM collaring, **target pre-load should be achieved**
- A cold test is scheduled this winter at CEA

- **Two 4 meter long practice coil** have been wound within QUACO: One by Sigmaphi and one by Elytt Energy
- **2 full length prototypes are expected** to be delivered in fall 2020 at CEA for cold tests

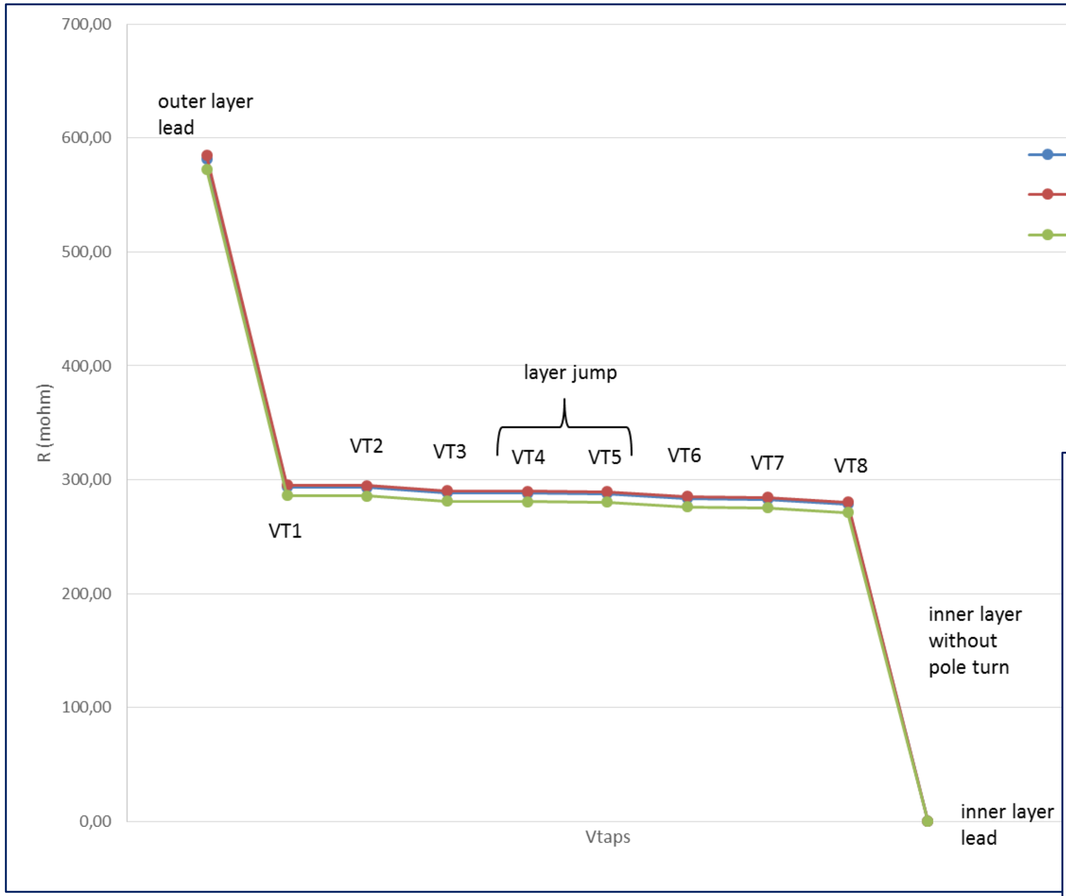
THANK FOR YOUR ATTENTION

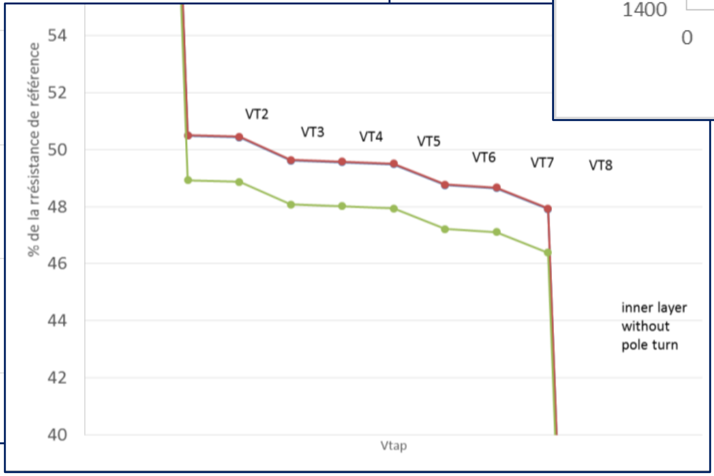


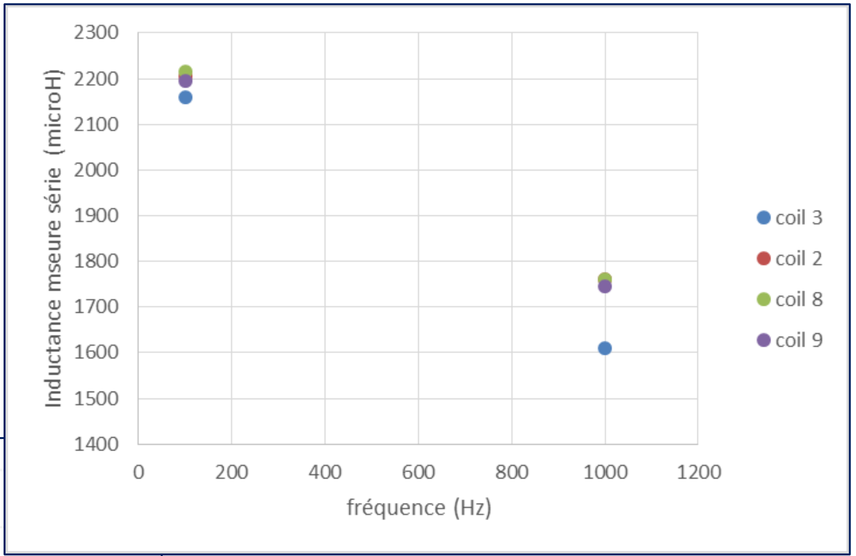
BACK UP

ELECTRICAL ISSUE

- Electrical tests after the collaring at 70% (Resistance and capacitance discharge)
- Turn to turn short circuit detected => decision to decollar







Coil 3 exhibits
- a change of R of about 9 mΩ in the inner layer (2%)
- a change of L of about 2/8 % at 100 Hz/1kHz wrt other coils

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Vancouver, Canada | 2019

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Centre de Saclay | 91191 Gif-sur-Yvette Cedex

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