Lessons we are Learning re MQXF – SS-shell Axial Interaction (Updated with new target)

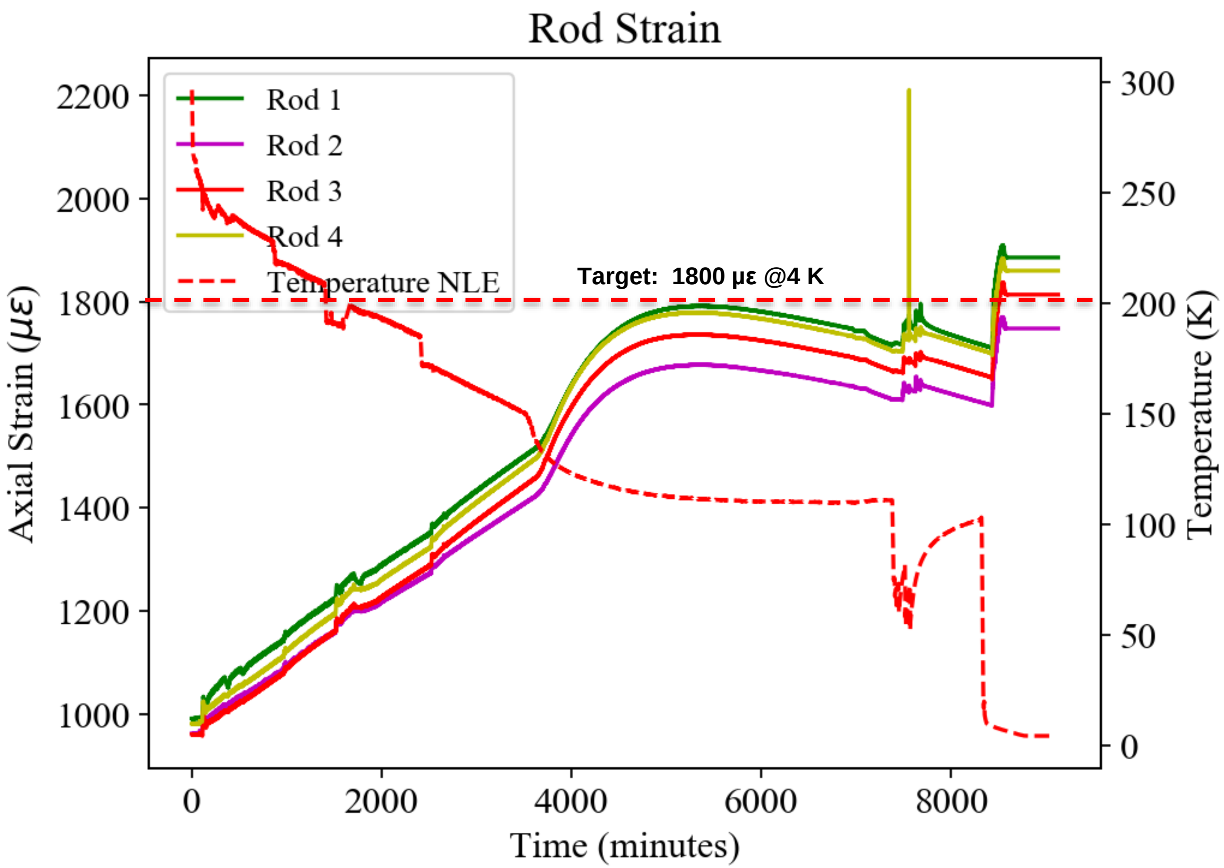
G. Ambrosio and P. Ferracin

Cold Mass Experience from CERN - #2; June 10, 2021

Outline

- Test data
- MQXFBP2 inspection
- Possible Mechanism
- FE analysis
- New target for SS-shell welding

MQXFA03 Rods



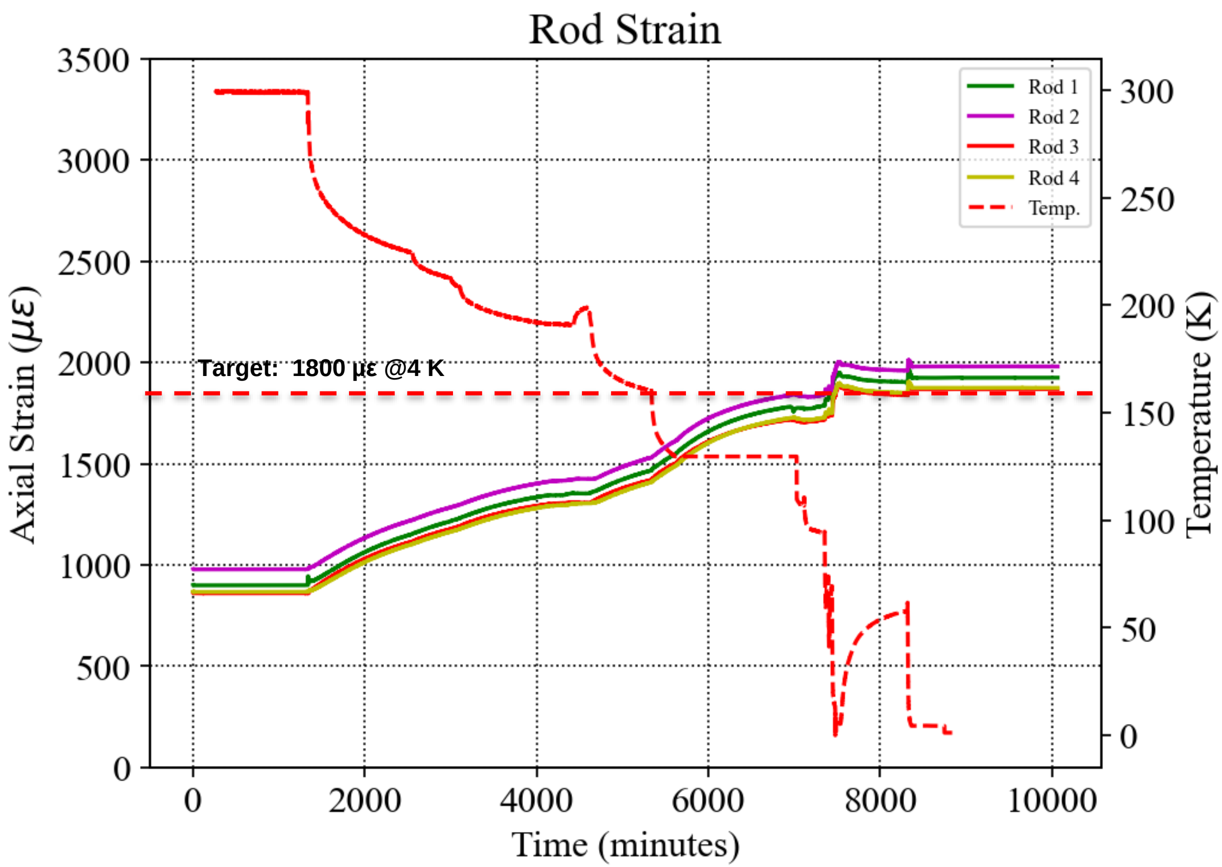
MQXFA04 Rod S.G. Readings

	Rod 1	Rod 2	Rod 3	Rod 4	Average
Preload	915	1075	1050	N/A	1013.3
Preload Elong.	*0.1395*	*0.1625*	*0.164*	*0.15*	*0.1553 in.*
Pre-shipping	875	1200	750	N/A	941.6
Post-Shipping	875	1200	750	N/A	941.6
Cooldown	1850	2150	1700	N/A	1900

Target R.T. Average: 950 µe

(*Values read from plots, not exact numbers)

MQXFA05 Rods



MQXFBP2- FEM analysis

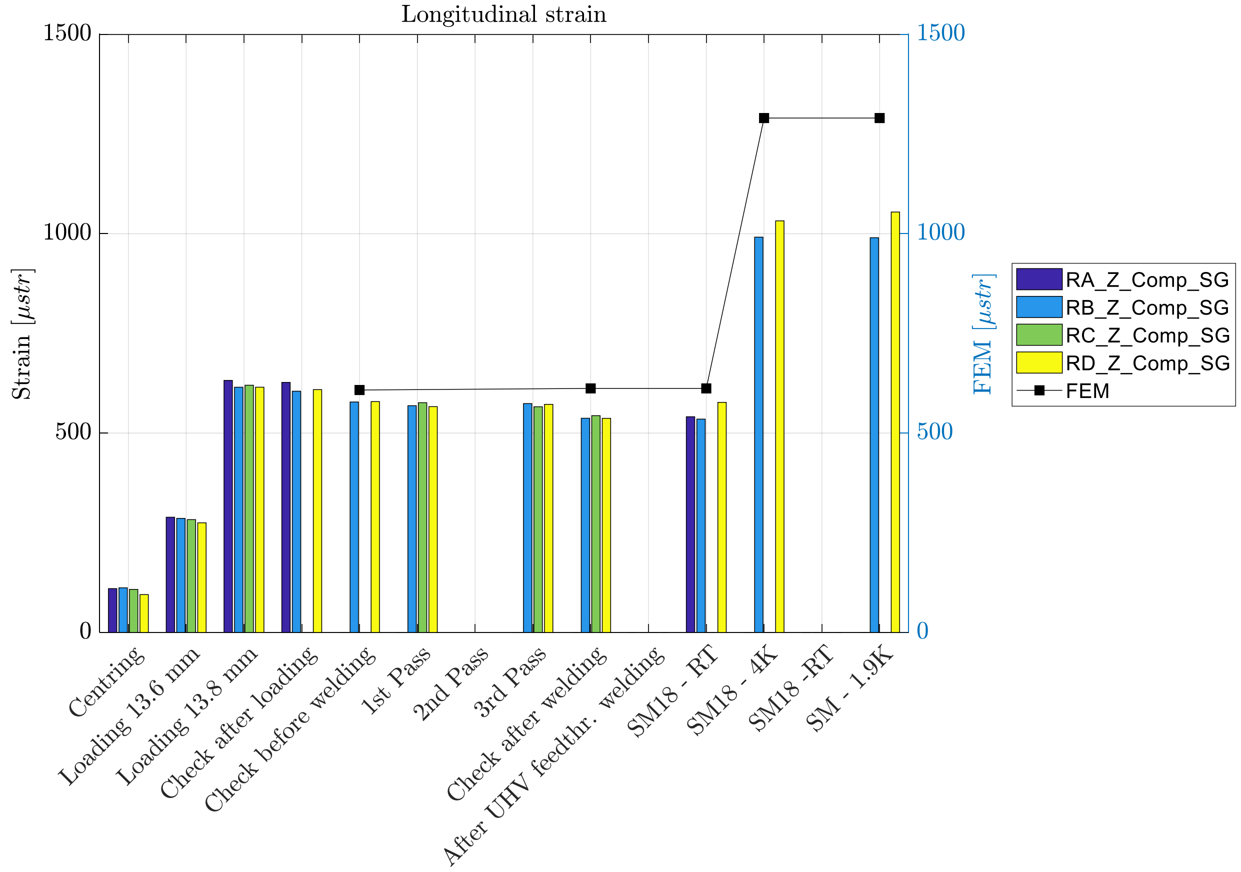
J. Ferradas Troitino, E. Takala, H. Pan, G. Vallone, P. Ferracin, S. Izquierdo Bermudez,

on behalf of the MQXF collaboration

Technical meeting on MQXF prototypes
April 28th, 2021

MQXFBP2

Stainless steel rods: Long. Strain



The model overestimates the delta due to cool-down:

Model ~ 680 µstr
Measured ~ 455 µstr

Investigations ongoing.

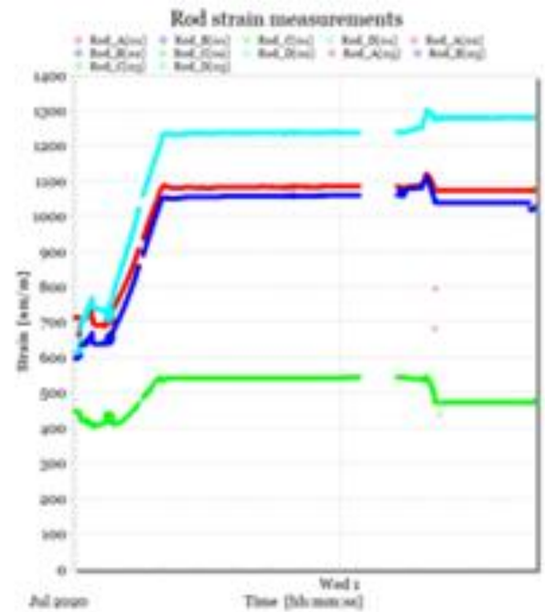
Delta determined by the longitudinal stiffness of the structure, friction and material properties.

MQXFBP1

Cool Down – Rods BP1

- We lost around 20 % of the longitudinal pre-load from magnet assembly to before cool down
- Lower slope on Rod C not understood

ustrain	Before CD	1.9 K	Delta
Target	900	1600	700
Rod A	618	1080	462
Rod B	588	1030	442
Rod C	455	550	95
Rod D	642	1300	658



		Rod Strain [με]		Rod Stress [MPa]		Rod Elongation [mm]		Total Force [MN]	
		RT	1.9 K	RT	1.9 K	RT	1.9 K	RT	1.9 K
Target	MQXFS	2450	3800	172	300	3.99	6.19	0.70	1.22
	MQXFA	950	1700	183	357	4.37	7.83	0.59	1.15
	MQXFB	900	1500	174	315	6.80	11.33	0.67	1.21

Outline

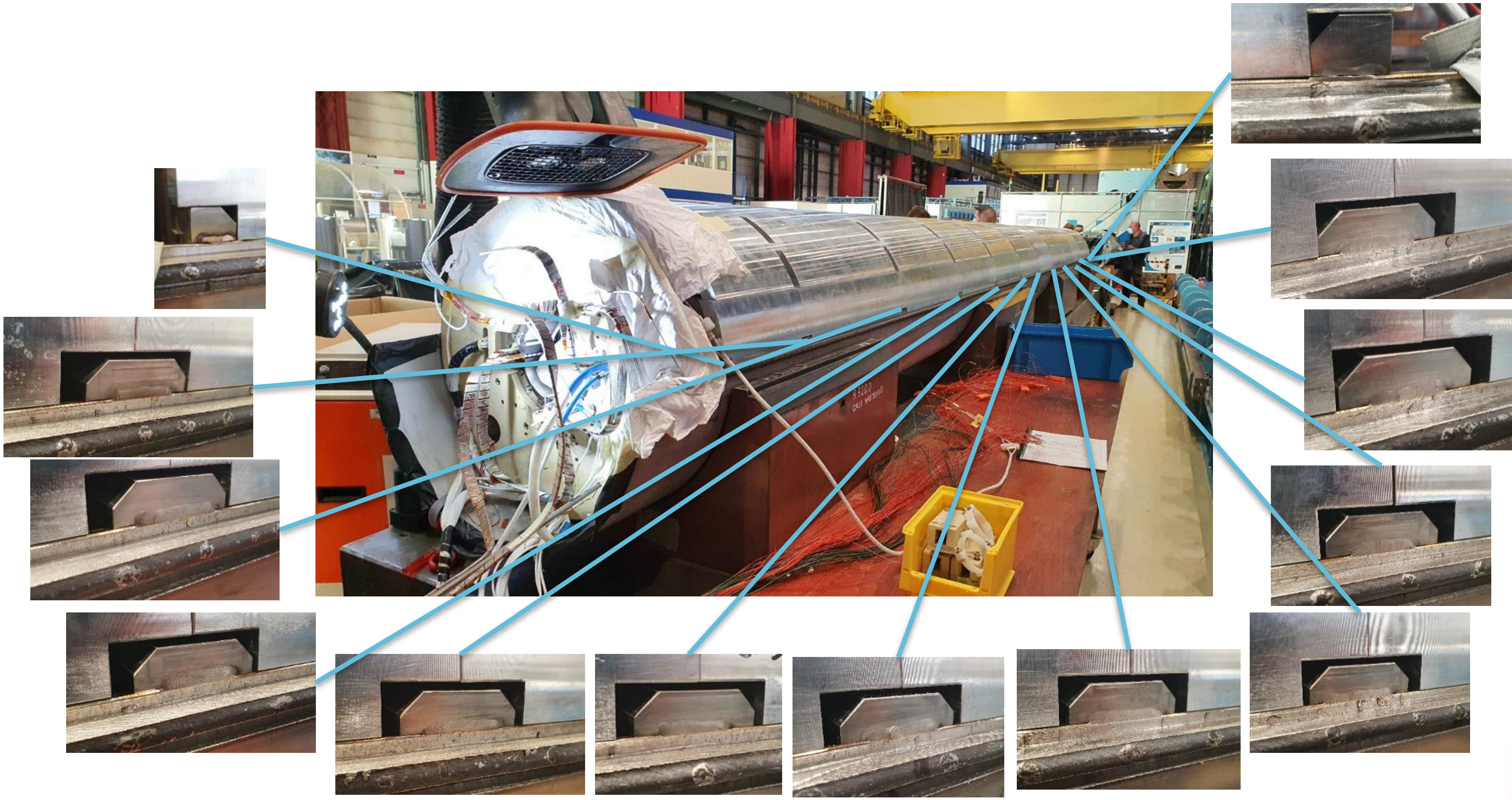
- Test data
- **MQXFBP2 inspection**
- Possible Mechanism
- MQXFA FE analysis

Integration of SS shell in LMQXFB cold masses

H. Prin

Technical meeting on SS shell integration in MQXFA and MQXFB ***May, the 6th 2021***
https://indico.cern.ch/event/1034536/

LMQXFBT001: Disassembly after cold tests
Tack blocks movements observed *October 2020*

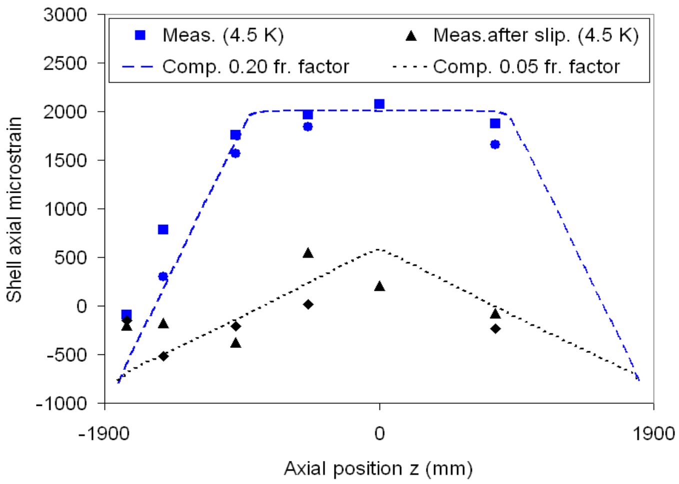


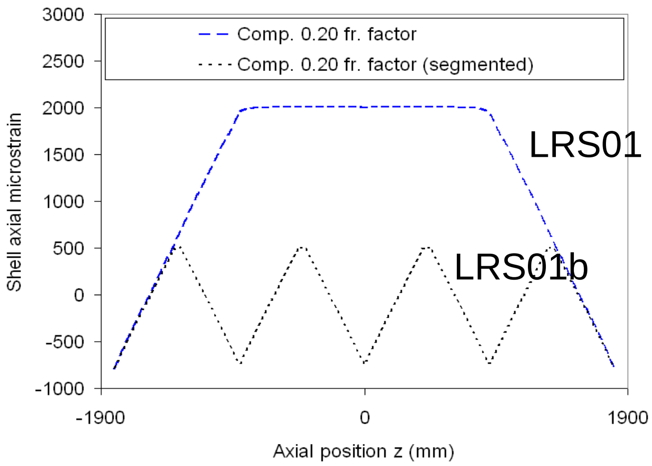
Outline

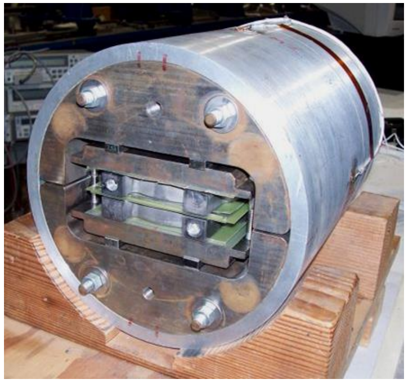
- Test data
- MQXFBP2 inspection
- **Possible Mechanism**
- MQXFA FE analysis

Scale-up to long coils and structures: LR

- Observation of shell-yoke slippage in LR01 led to <u>shell segmentation</u> in LR02
- Friction between Al-shell and yoke caused <u>stress increase</u> in magnet center after cooldown, and <u>stick-slip behavior during energization</u>



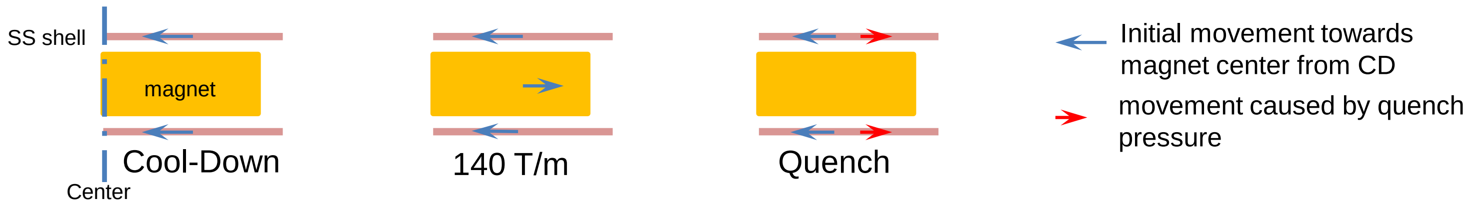




P. Ferracin, et al. "Assembly and Test of a Support Structure for 3.6 m Long Nb3Sn Racetrack Coils", IEEE Trans\. Applied Supercond., Vol. 18, No. 2, pp. 167-170, June 2008

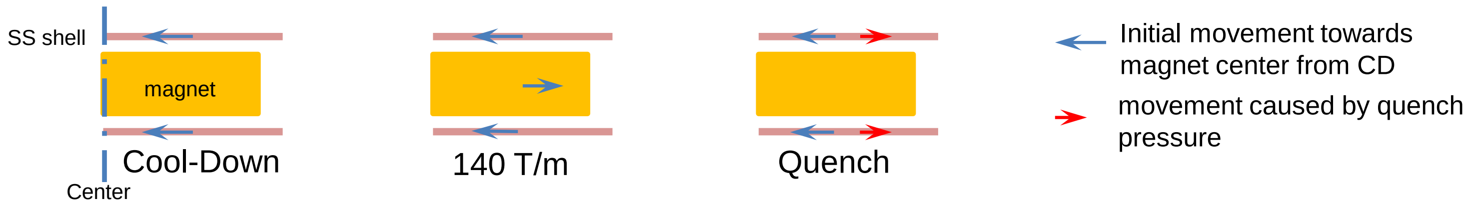
MQXFS vs MQXFA

- During cooldown two “forces” are acting in opposite direction:
- Differential thermal contraction would like to make SS-shell shorter than magnet (magnet behaves as iron because of the iron yoke)
  - Iron DL/L = 2 mm/m (300 – 4.2 K)
  - SS DL/L = 2.9 mm/m (300 – 4.2 K)
  - $DL/L_{differental}$ generates a force if there is no sliding
- Friction tries to avoid sliding btw SS-shell and magnet



MQXFS vs MQXFA

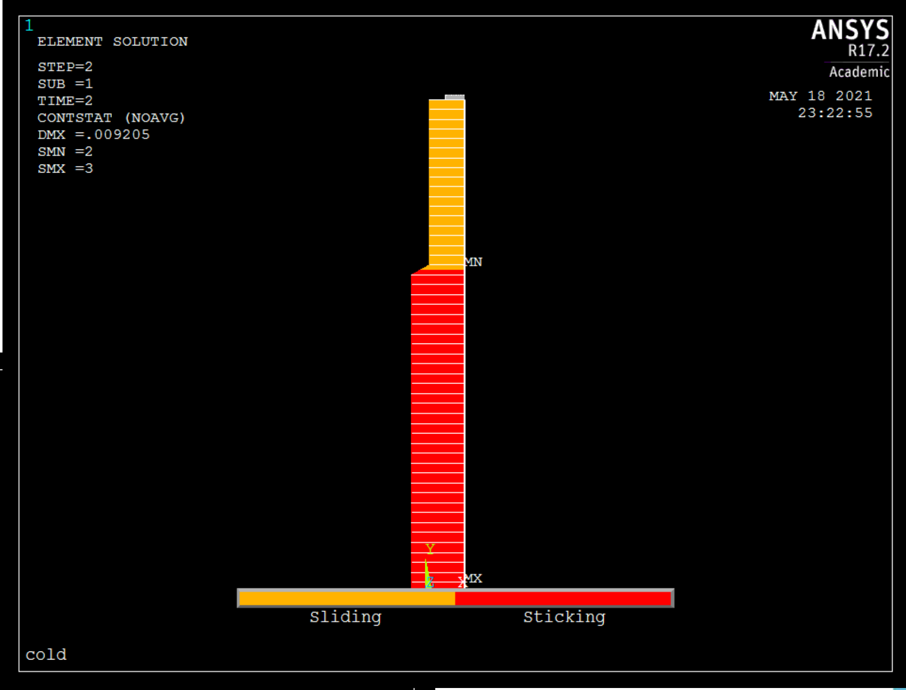
- Differential thermal contraction would like to make SS-shell shorter than magnet (that behaves as iron because of the iron yoke). If SS-shell cannot slide:
  - $F = \text{SS-shell}_{\text{x-section}} \times \text{Pressure} = \text{SS}_{\text{x-section}} \times E_{SS} \times DL/L_{\text{differential}}$
- Friction tries to avoid sliding btw SS-shell and magnet
  - $F = \mu \times$ Radial Pressure x Magnet surface
  - Magnet surface = SS-shell circumference x Length
- ➔ MQXFS1d is not representative of MQXFA



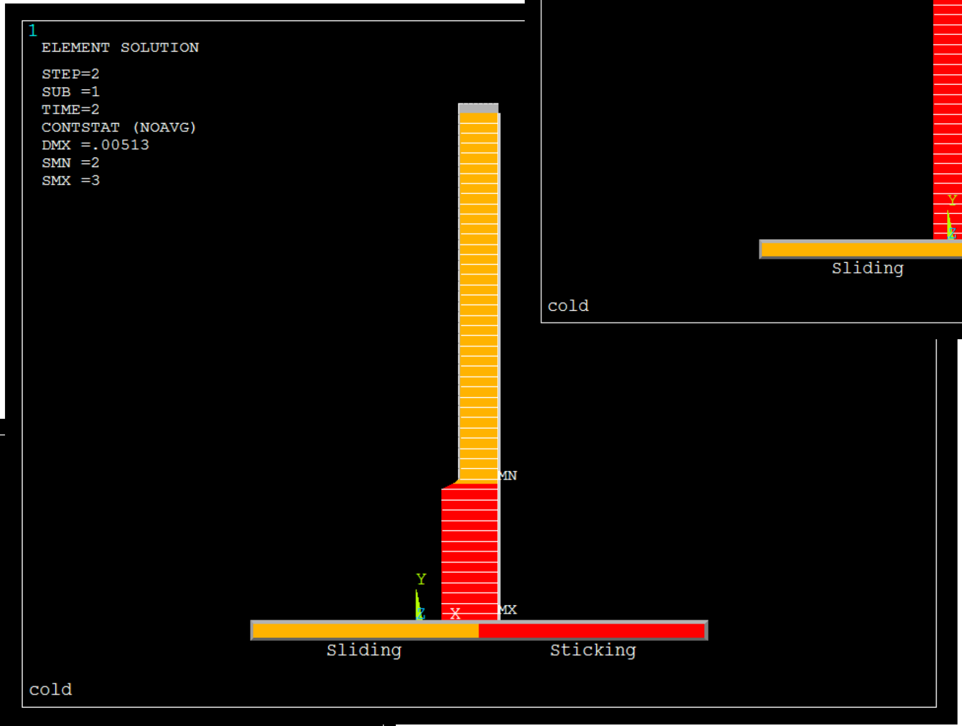
Outline

- Test data
- MQXFBP2 inspection
- Possible Mechanism
- **MQXFA FE analysis**

Very Simple FEM



4 m model



2 m model

1 m model

MQXFA FEM

BERKELEY LAB	Lawrence Berkeley National Laboratory	Cat Code SU3322	TECHNICAL NOTE	LBNL Technical Note # SU-1007-5656	Rev A	Pag 2 o

US-HiLumi-doc-4078

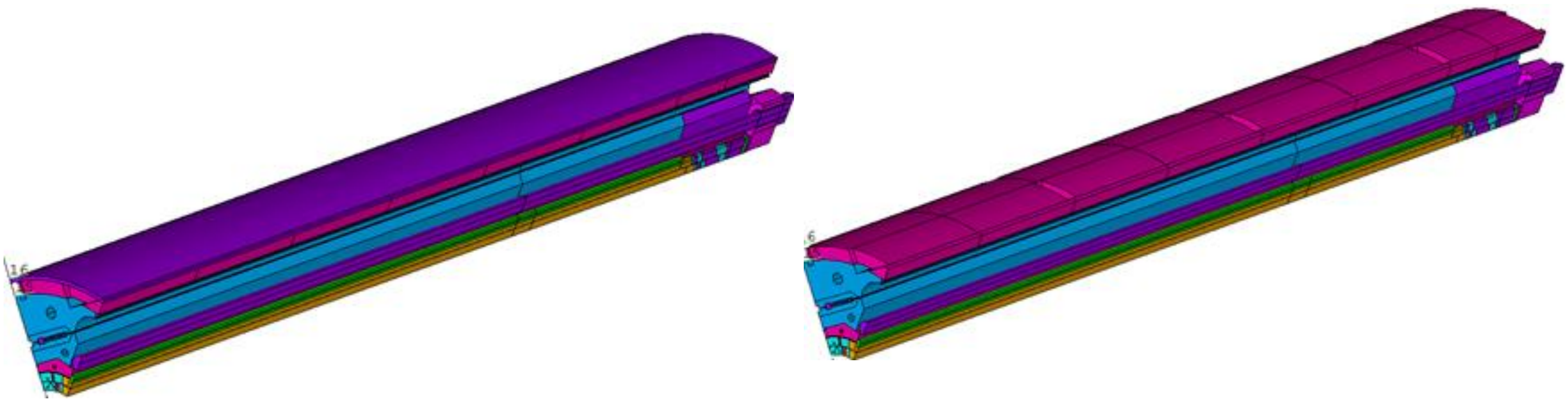


Fig. 2 3D models with (left) and without (right) SS LHe shell

An octant 3D model is built in ANSYS (Fig. 2). All of the structural components are modeled with contact elements. For the support structure elements, a <u>frictional coefficient of 0.2</u> is applied on contact interfaces. For coil blocks, the wedges, coil, and poles are bonded.

MQXFA FEM

Lawrence Berkeley National Laboratory	Cat Code SU3322	TECHNICAL NOTE	LBNL Technical Note # SU-1007-5656	Rev A	Pag 2 o

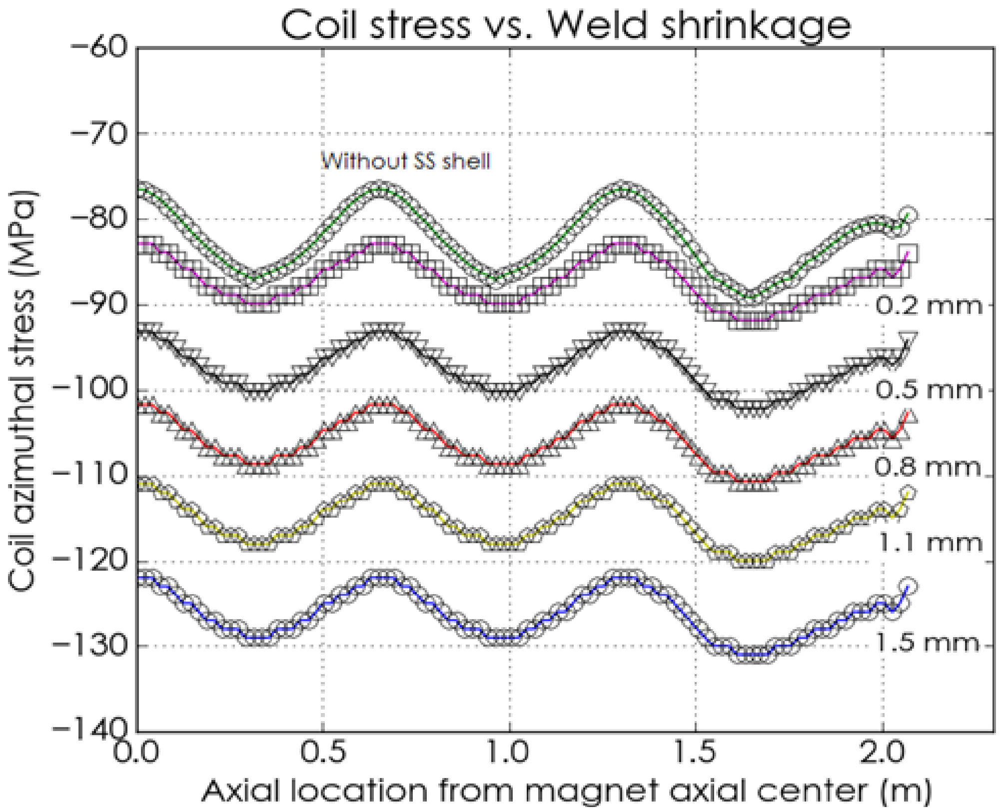


Fig. 6 Coil average azimuthal stress at layer 1 pole/turn interface with different weld shrinkages (MQXFAP1)

Lessons Learning

- If there is friction btw SS-shell and Magnet at 1.9 K, short and long magnets may behave differently
  - the test performed on MQXFS1d did NOT fully reproduce the expected behavior of MQXFA (and MQXFB) in coldmass
  - Magnet status may change from thermal cycle to thermal cycle
- Our 3D simulations do not fully capture the interaction btw SS-shell and magnet.

Outline

- Test data
- MQXFBP2 inspection
- Possible Mechanism
- FE analysis
- **New target for SS-shell welding**

Method

- We developed analytical model used to compare forces (gravity, friction, force due to diff. thermal contraction w/o sliding) in MQXF magnets of different length (MQXFS/A/B)
- Since MQXFS1d exceeded requirements (I > ultimate current before & after thermal cycle) we assumed that MQXFA/B magnets must have friction force* (btw magnet & SS-shell) ≤ friction force* in MQXFS1d
  - *<u>TOTAL friction force</u> (not force per unit length)

Result & Specs (w feedback from Sandor)

- 0.1 mm interference per weld gives friction force in MQXFB similar to MQXFS1d

- Proposed specification for the *circumferential interference* after welding:
  - Delta_C = Circumference (SS inner) – Circumference (Al outer)

- **Average: Delta_C ≥ - 0.2 mm**;

- For **short spots: Delta_C ≥ - 0.5 mm**.

Lawrence Berkeley National Laboratory	Cat Code SU3322	TECHNICAL NOTE	LBNL Technical Note # SU-1007-5656	Rev A
Author(s)			Released By	Relea

Title
LARP QXF
LQXF-MAGNET
MECHANICAL IMPACT OF THE SS LHE SHELL FOR MQXFA

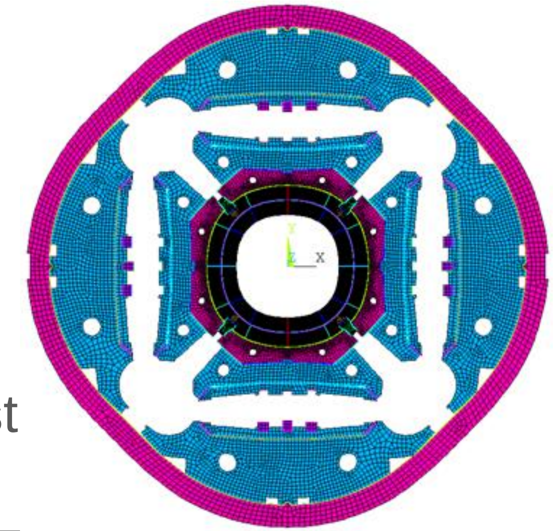
0.1 mm interference per weld ➔

~29 MPa hoop tension on SS-shell at warm

3.2 MPa coil pre-stress increase at warm

Fig. 5 SS shell tension induced by weld shrinkages of a half shell

MQXFBP2

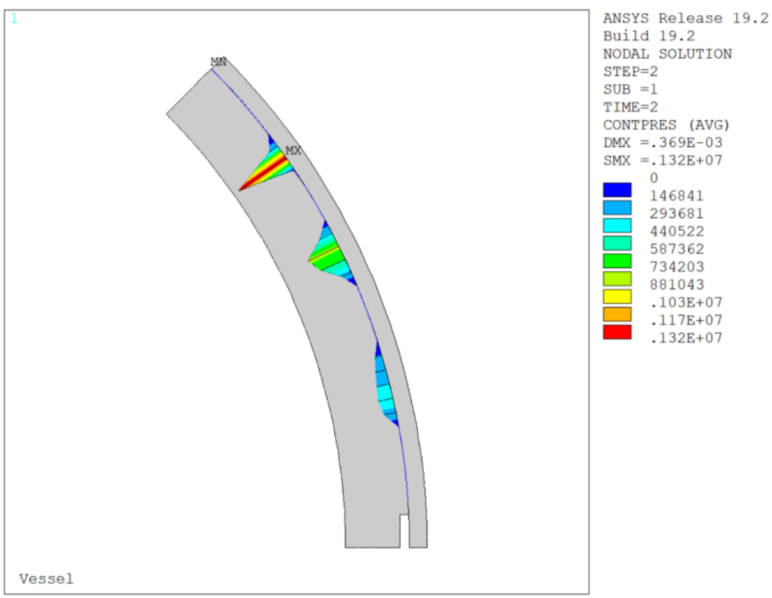


Vessel

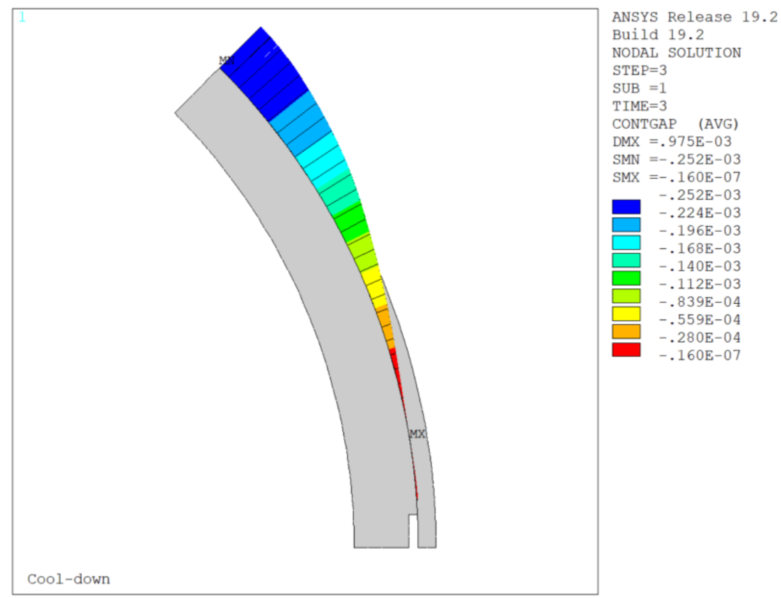
A last word on the SS vessel to Al shell interference.

Could we estimate the gap at cold, if the SS vessel just shell at warm?

Radial pressure after welding



Gap at cold



Barely touching at warm (less than1 MPa increase in the pole stress) corresponds to ~ 250 micron max. gap at cold. 2D model computation (preload dependent)

Note: this FE model does NOT include tack blocks

Back up Slides

Result & Target (original version)

- **0.1 mm interference per weld** gives friction force in MQXFB similar to MQXFS1d

- Assuming that 0.5 mm tolerance is needed along SS-shell length, the proposed target is:
  - To be finalized with input from CM team

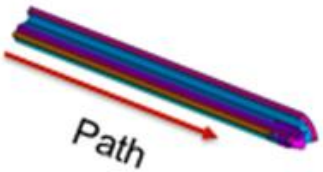
	Interference	less material (= interference)	additional material (= gap)
Any point	0	+0.25	-0.25
Average	**0**	**+0.1**	

All dimensions in mm

FEA: MQXFBP2 with 0.2 friction coeff.

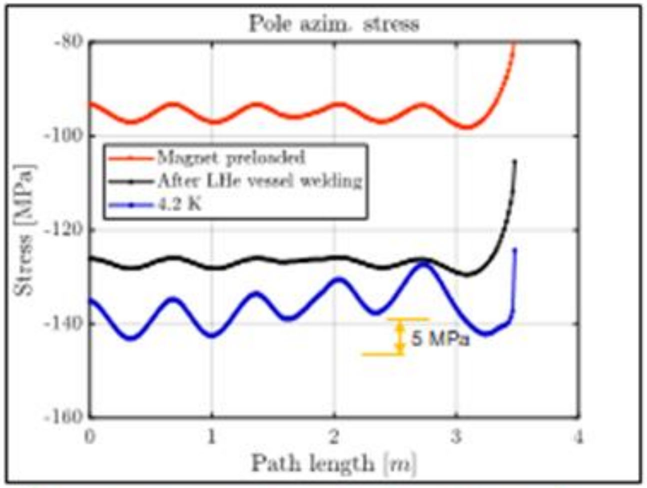
MQXFBP2

$$\sigma_\theta = \frac{E}{(1-\nu^2)}(\varepsilon_\theta + \nu\varepsilon_z)$$



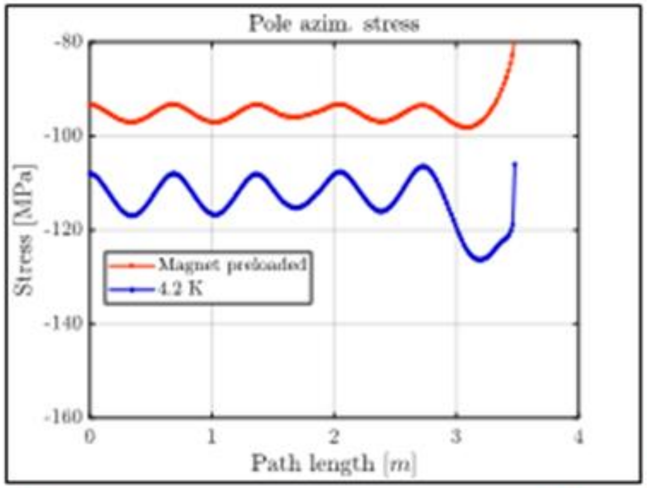
Pole: Azimuthal stress

Cold mass



Pole stress increases towards the magnet center (~ 5 MPa along 2 m). Effect of the SS vessel (see next).

Magnet



In absence of SS vessel, the expected delta during cool-down is approximately 20 MPa. In the cold mass configuration, the delta is reduced to 15 MPa (loss of stress in the SS vessel).