

中国科学院高能物理研究所
Institute of High Energy Physics, CAS



中科院高能所超导磁体组
Superconducting Magnet Group, IHEP

Mechanical analysis and pre-load steps of LPF3

Superconducting Magnet Group, Accelerator Division

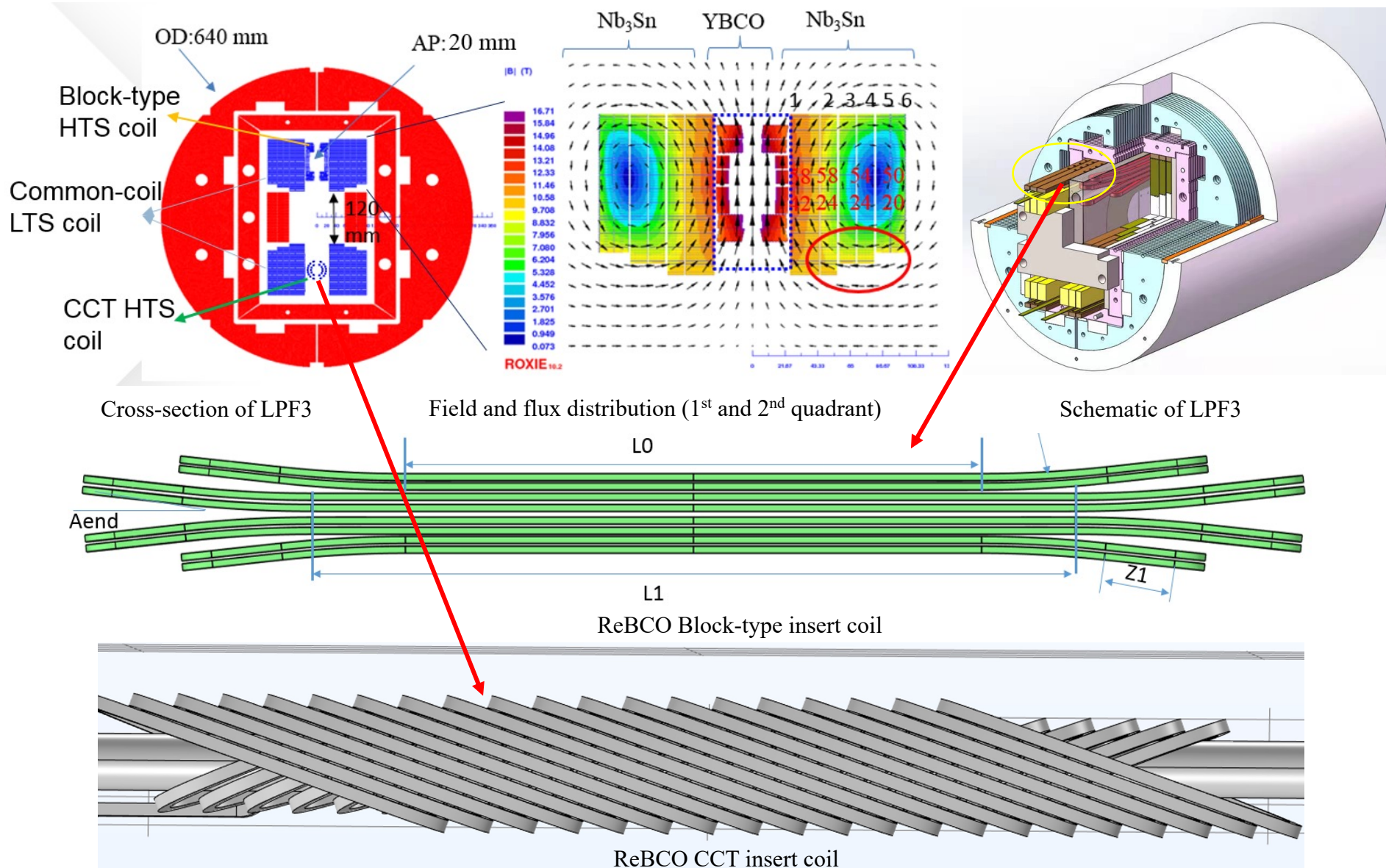
Institute of High Energy Physics, Chinese Academy of Sciences (IHEP, CAS)

2024.5.10

Development of LPF3 magnet

➤ Aiming at 16 T : 13 T (LTS) + 3 T (HTS)

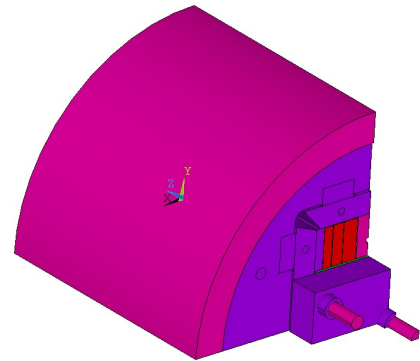
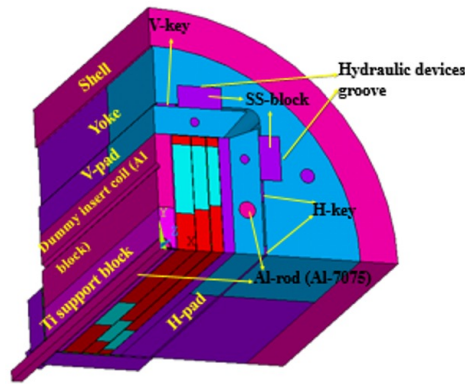
To be 16 T



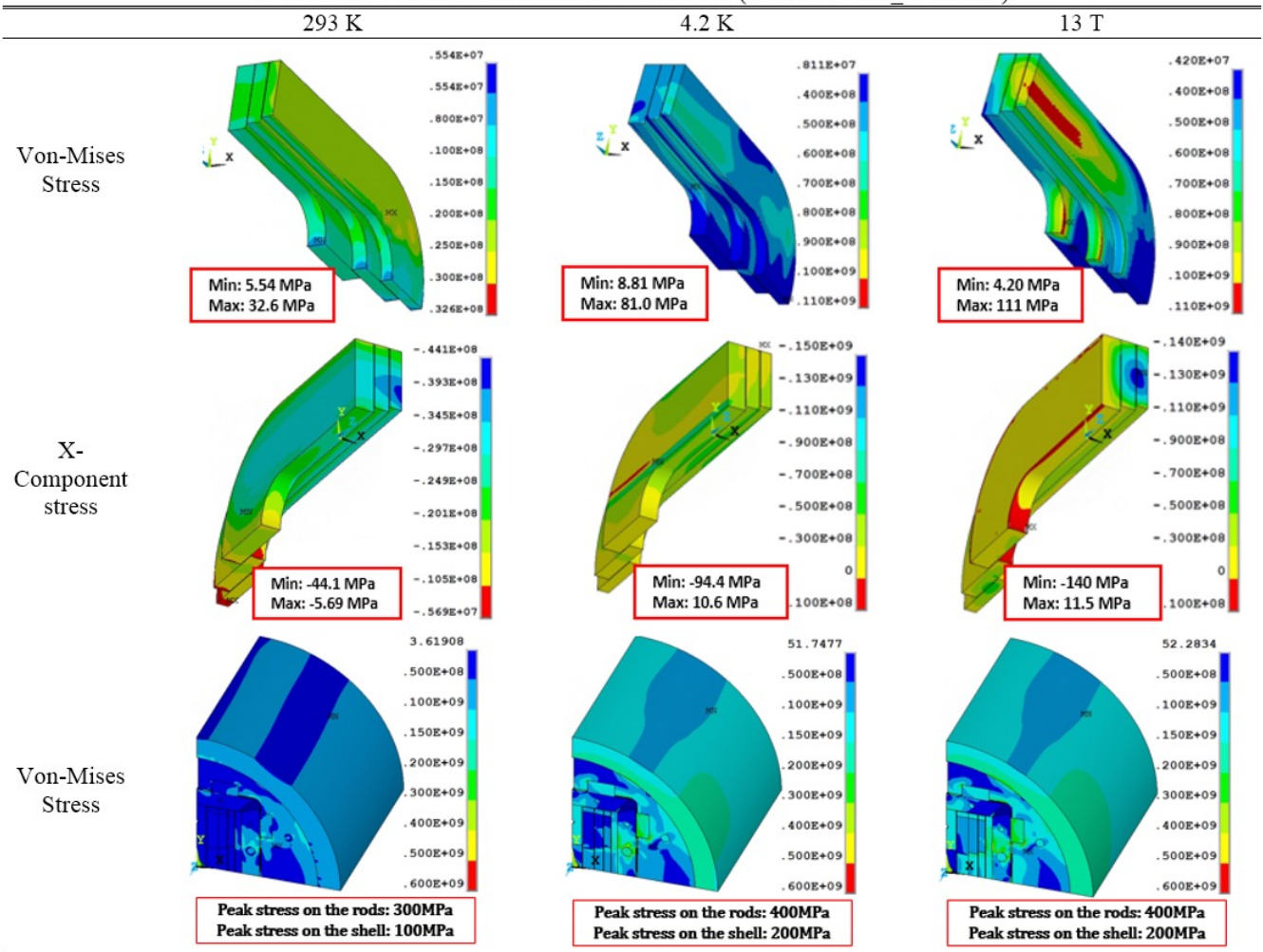
Mechanical analysis of LPF3-LTS

$f=0.2$; interference=-0.8 mm

STRESS DISTRIBUTION ON SC COILS AND MAGNET (INTERFERENCE $x=0.8$ MM)



- Superconducting coils
- Stainless steel
- Aluminum bronze
- Iron
- Aluminum
- Titanium



1/8 mechanical FEA model

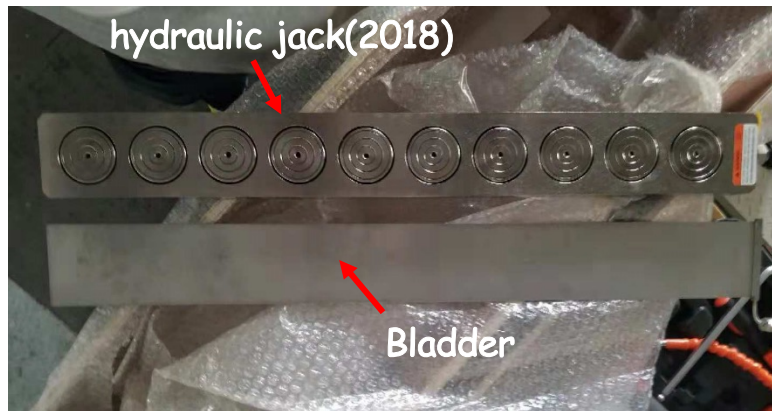
Stress variation during the three loading steps

Required maximum pre-stress for pre-load: 80 Mpa. Peak stress in coils during the three loading steps: 140 Mpa.

Preload with hydraulic jack instead of Bladder

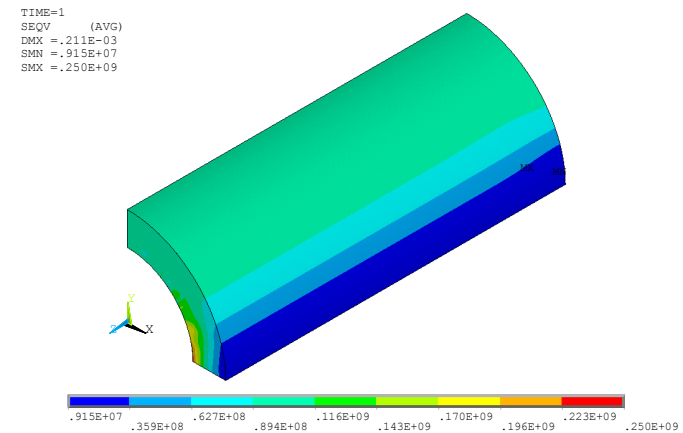
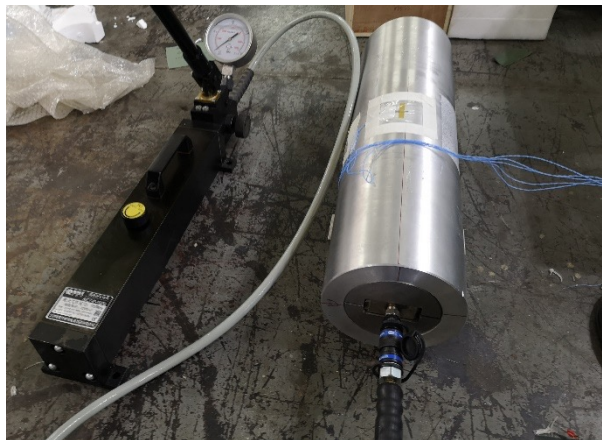


Leaking bladder during the assembly of LPF1



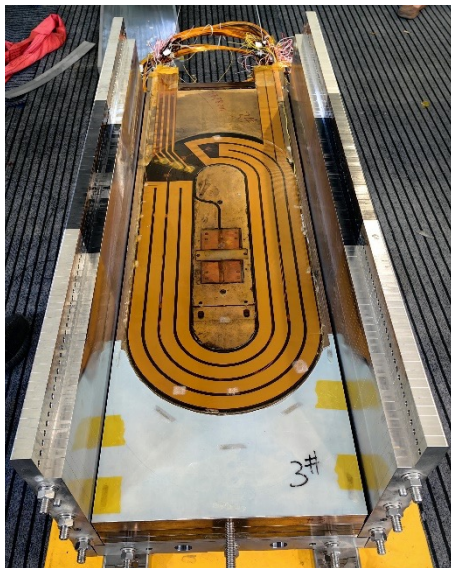
$$P_h = \frac{10 \times 3.14 \times \left(\frac{0.045}{2}\right)^2}{0.620 \times 0.067} \times 160 = 61.23 \text{ MPa}$$

simulation		Jacks(measurement results)	
Pressure (Mpa)	Hoop strain(μϵ)	Pressure (Mpa)	Hoop strain(μϵ)
30.44	394.9064	50	402.59
60.99	790.7798	159	834.67



After increasing the pistons area ratio, the hydraulic jack can provide 80Mpa pressure for the pre-stress, which can be used in most occasions.

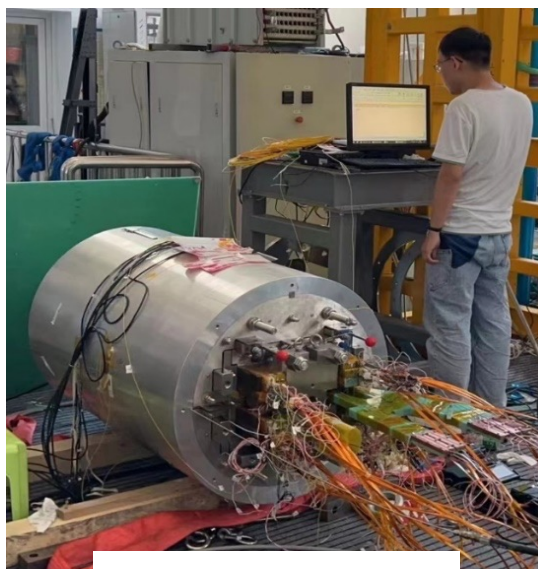
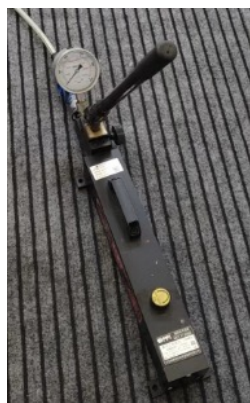
First assemble of LPF3



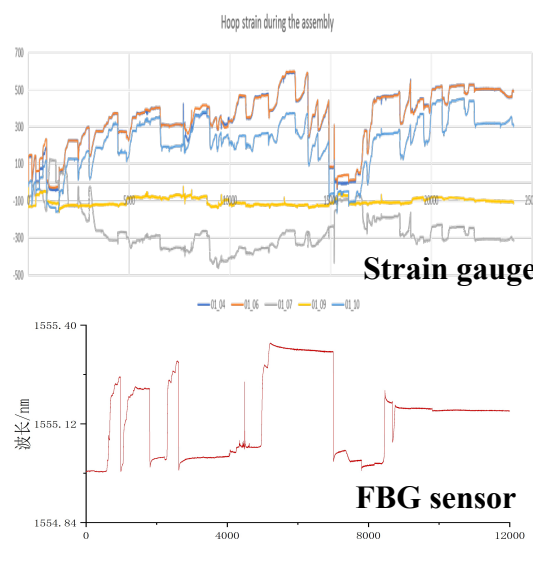
coils assembled with the H-pad & V-pad



Vertically assemble the Coil & Pad and yoke & shell



Pre-loading of LPF3



Strain gauges

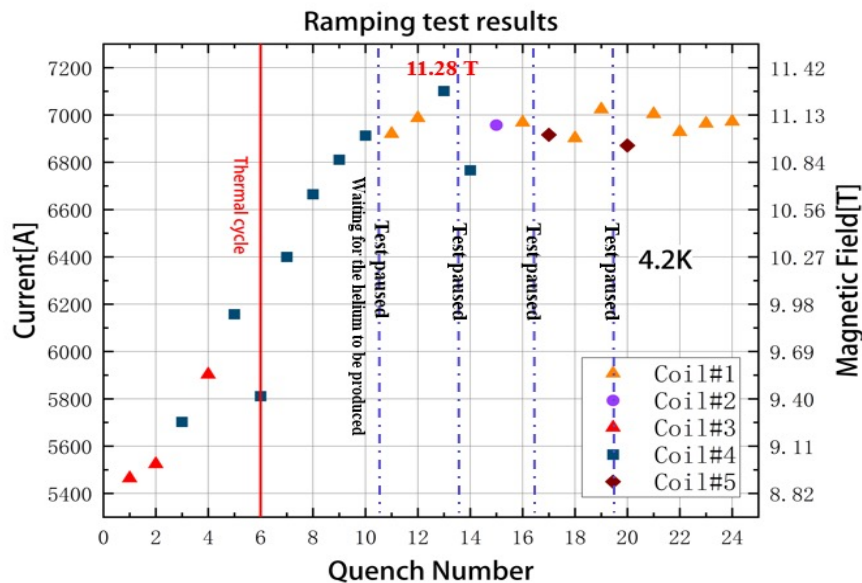
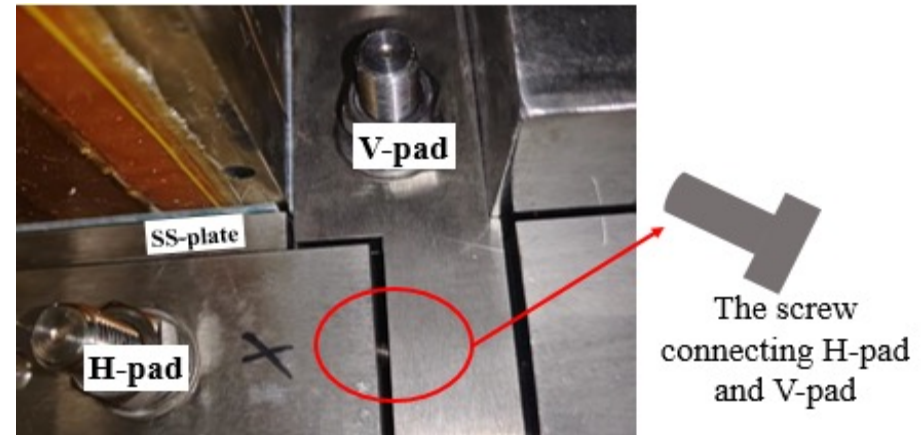
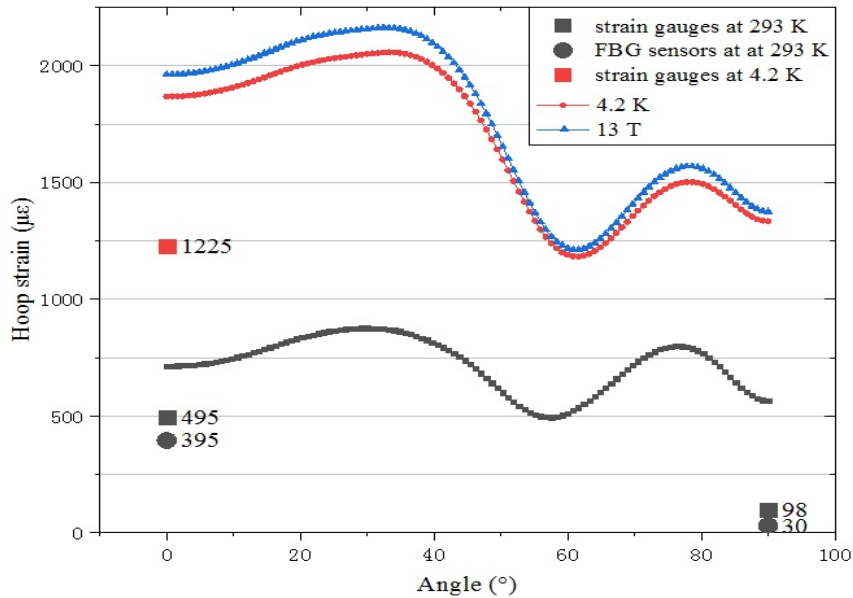
FBG sensor

Strain measurement results



Hydraulic pre-loading system

Performance of LPF3-LTS (first assemble)



- The first assembly of LPF3 failed to attain the desired pre-stress level during this assembly due to the underestimation of the gaps among the SC coils. The screws connecting H-Pad and V-pad stopped the pre-stress force transferred from the hydraulic devices to the coils.
- A maximum field of 11.28 T (7101 A) has been reached within two apertures.

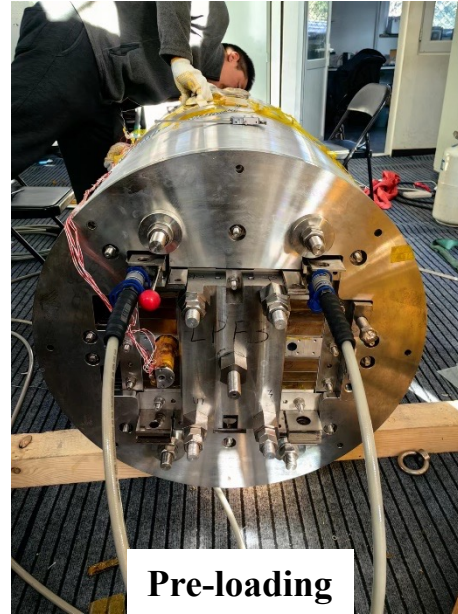
Re-assemble of LPF3



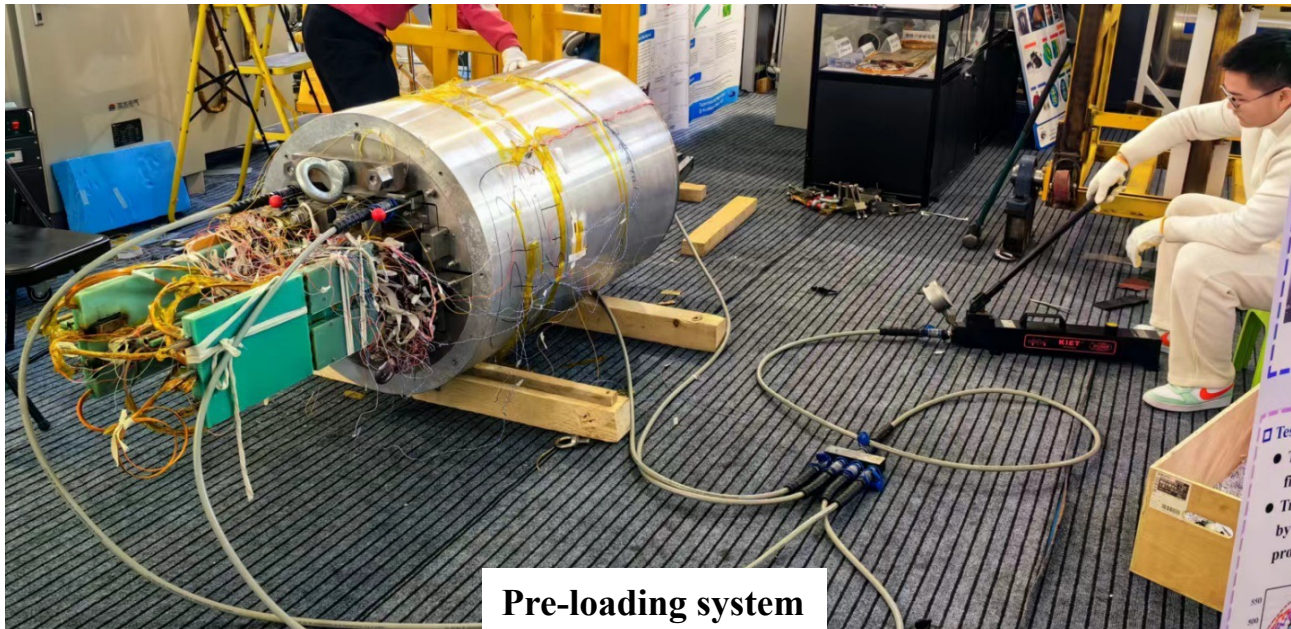
disassemble



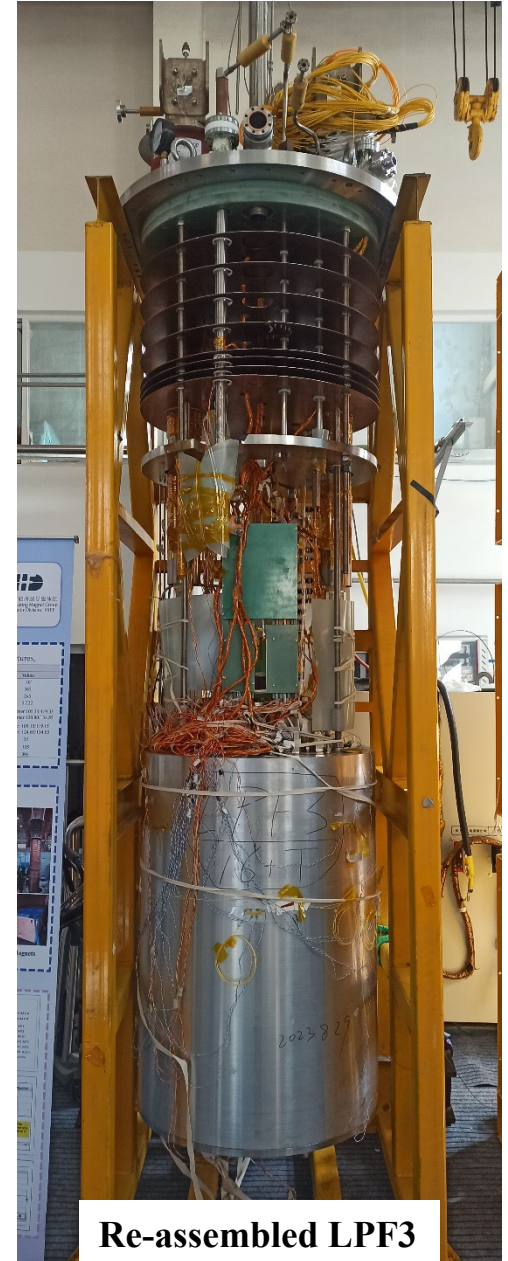
Modified V-pad



Pre-loading

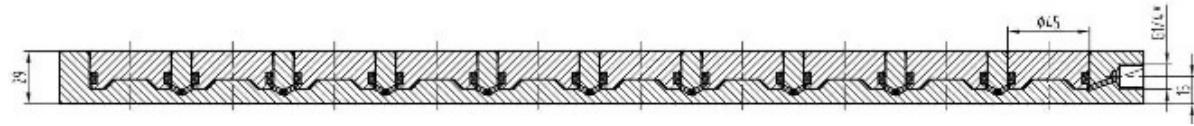


Pre-loading system



Re-assembled LPF3

Re-assemble of LPF3



Assemble steps:

- when the pistons reached the limit, pressurizing stopped. The thickness of the original key is 4mm

① 1&2 =less than 5MPa, 1&2+2mm: ⑦ 1&2=50 Mpa, 1&2+4mm: ⑩ 1=140MPa, 2=100MPa, 1&2+5mm

- a1&a2&a3:+2mm

- a1&a2&a3:+0.5mm

- a1+0.5, a2+0.2, a3+0.5

② 3&4 =less than 5Mpa, 3&4+2mm : ⑧ 3=150MPa, 4=90MPa, 3&4+4mm: ⑫ 3&4=160MPa, 1&2+5.5mm

- b1&b2&b3:+2mm

- b1+1.2, b2+0.4,b3+1.2

- Cannot insert one whole slice, fill the gap as tight as possible

③ 5&6 =less than 5Mpa, 5&6+4mm : ⑤ 5=15MPa; 6=20 MPa, 5&6+5mm:

- c1&c2&c3:+1mm

- c1&c2:+1mm

④ 7&8 =less than 5Mpa, 7&8+4mm: ⑥ 7=55MPa; 8=30MPa, 7&8+5mm:

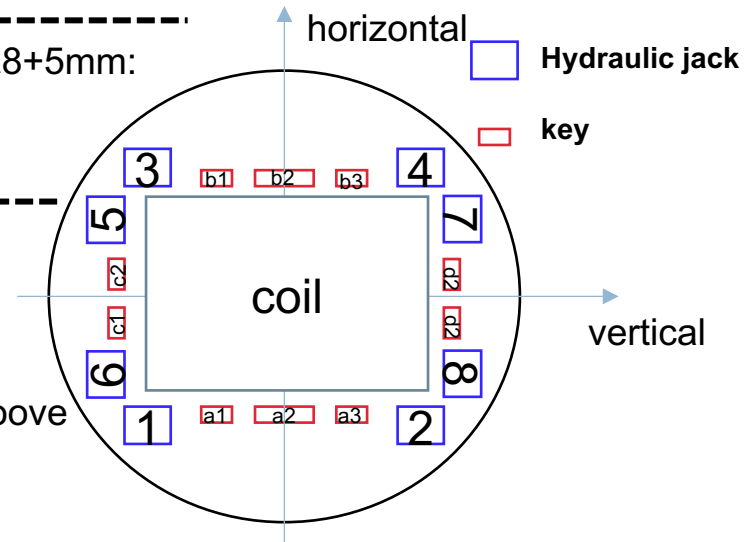
- d1&d2&d3+1mm

- d1&d2:+1mm

⑨ Put the SS block into 5,6,7,8 groove.

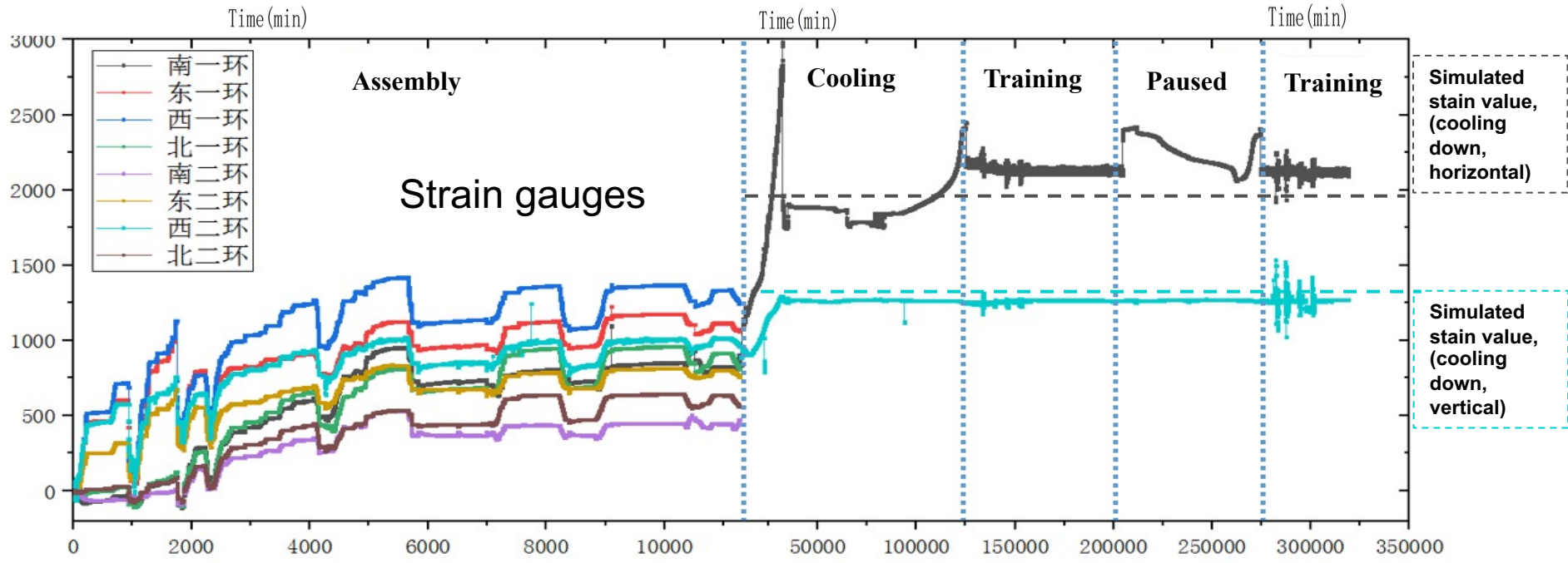
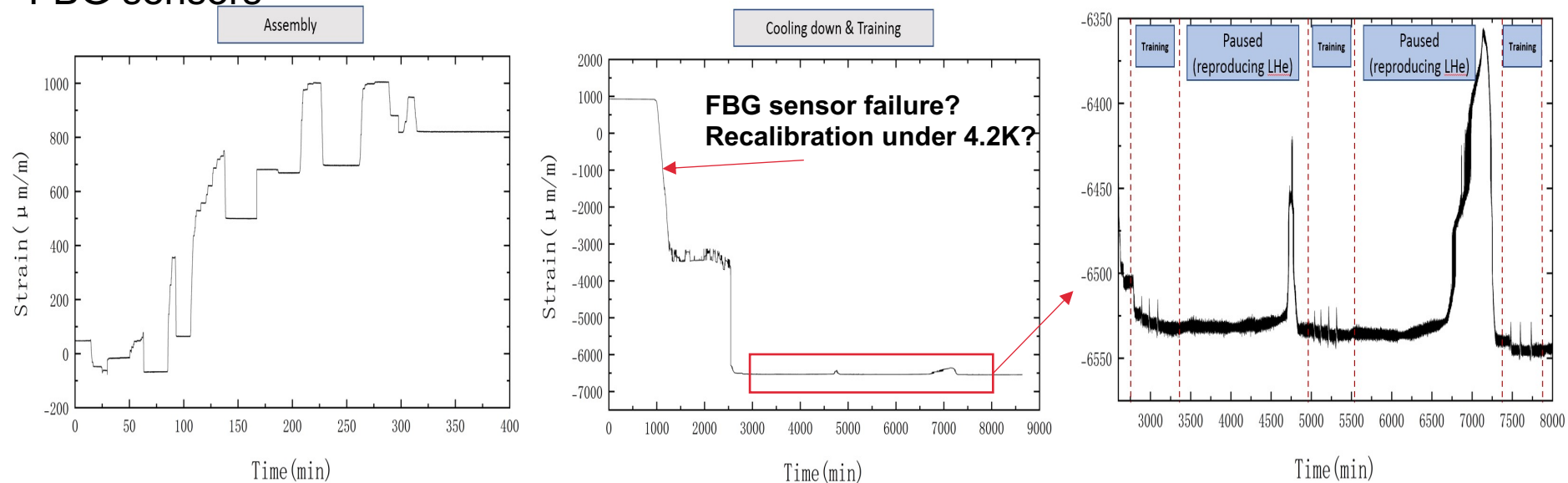
⑪ Put the SS block into 1,2 groove.

⑬ Put the SS block into 3,4 groove, use the SS slices to fill the groove as tight as possible.



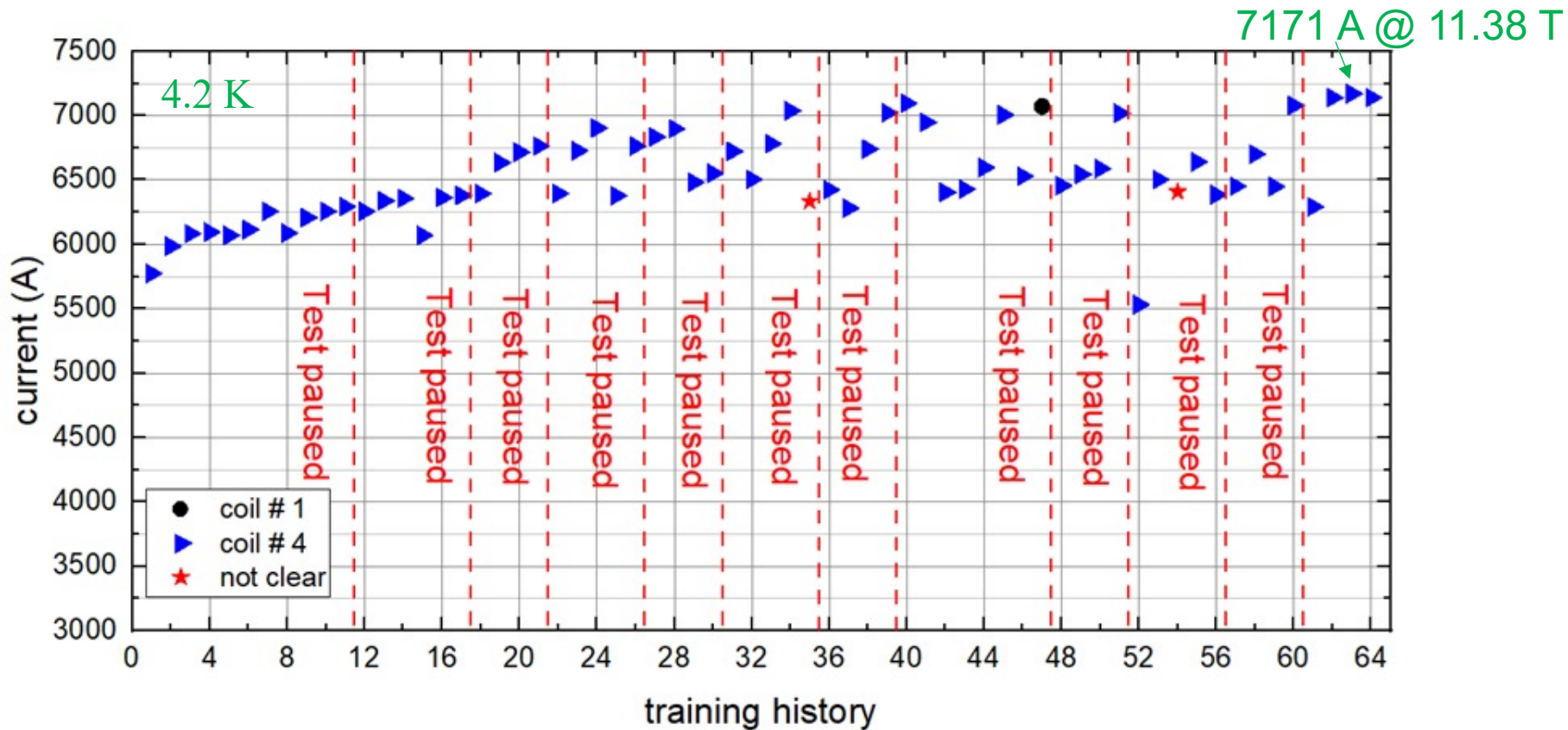
Re-assemble of LPF3 (Strain measurement results, FBG & Strain Gauge)

FBG sensors

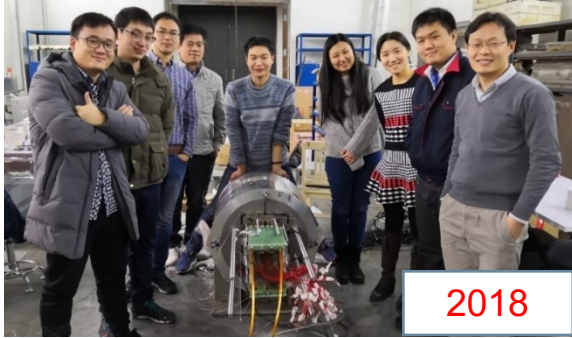


Test results of LPF3-LTS after reassembly

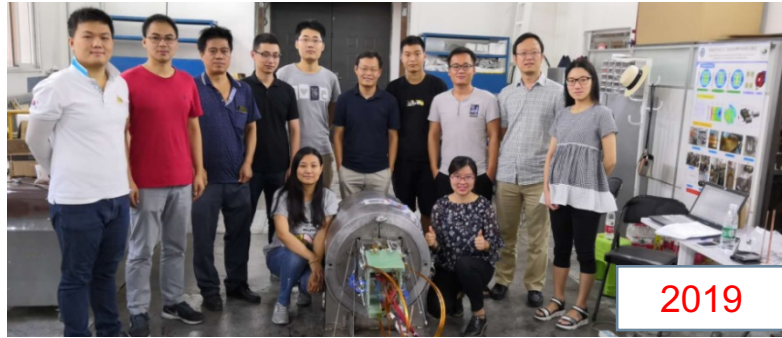
- ◆ The vast majority of quench events occurred in coil 4#. Reassembly of the magnet with sufficient preload effectively reduced quench events in coil 1#.
- ◆ Despite experiencing many quenches, the overall performance of the magnet is still on an upward trend.



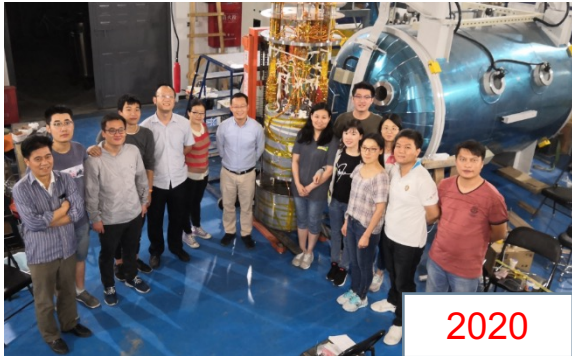
Training history of Nb₃Sn coils after reassembly



2018



2019



2020



2021



2023



Welcome to visit Qingjin's lab!



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Thanks !