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Thermomagnetic-instability-induced mechanical response in fully magnetized high-temperature superconducting bulk during pulse-field magnetization.

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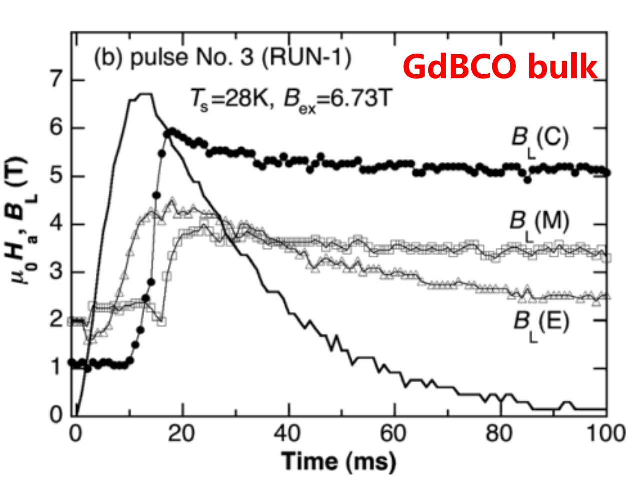
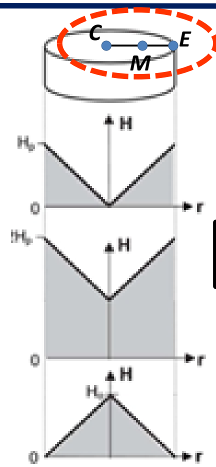
contents

content

introduction

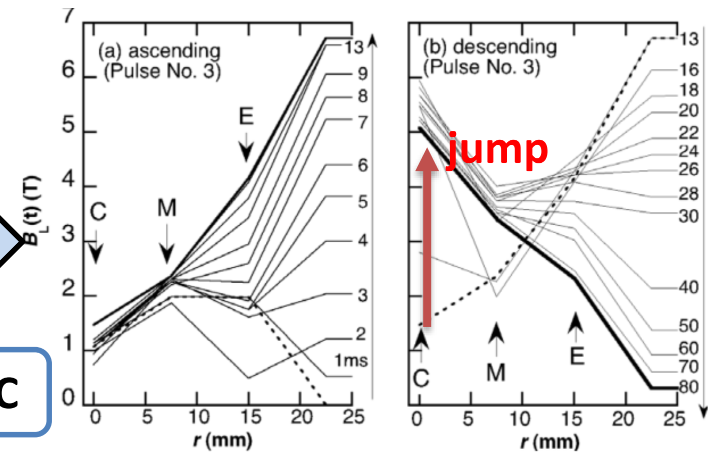
Flux jump in PFM technique





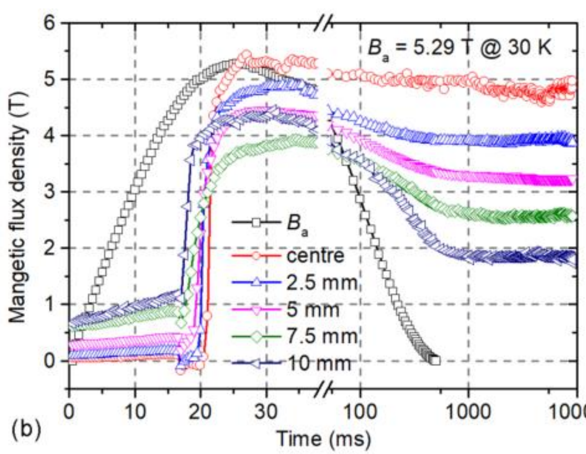
profile

MMPSC



The trapped field of >5 T achieved at 30 K

Magnetic distribution during flux jump



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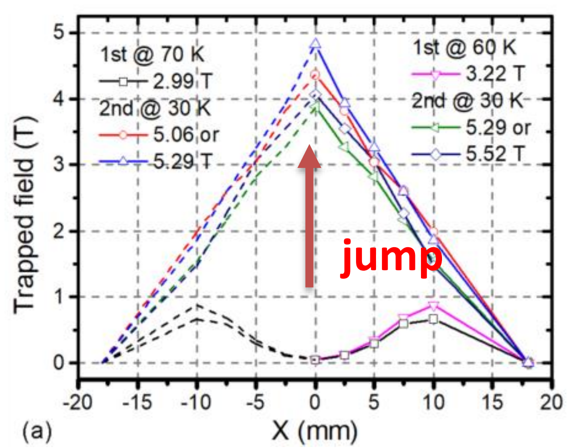

Flux jump is an essential condition for full magnetization

Variation of magnetic flux density on sample surface

Magnetic distribution during flux jump

Two-step PFM method

Research on the mechanical stability during PFM

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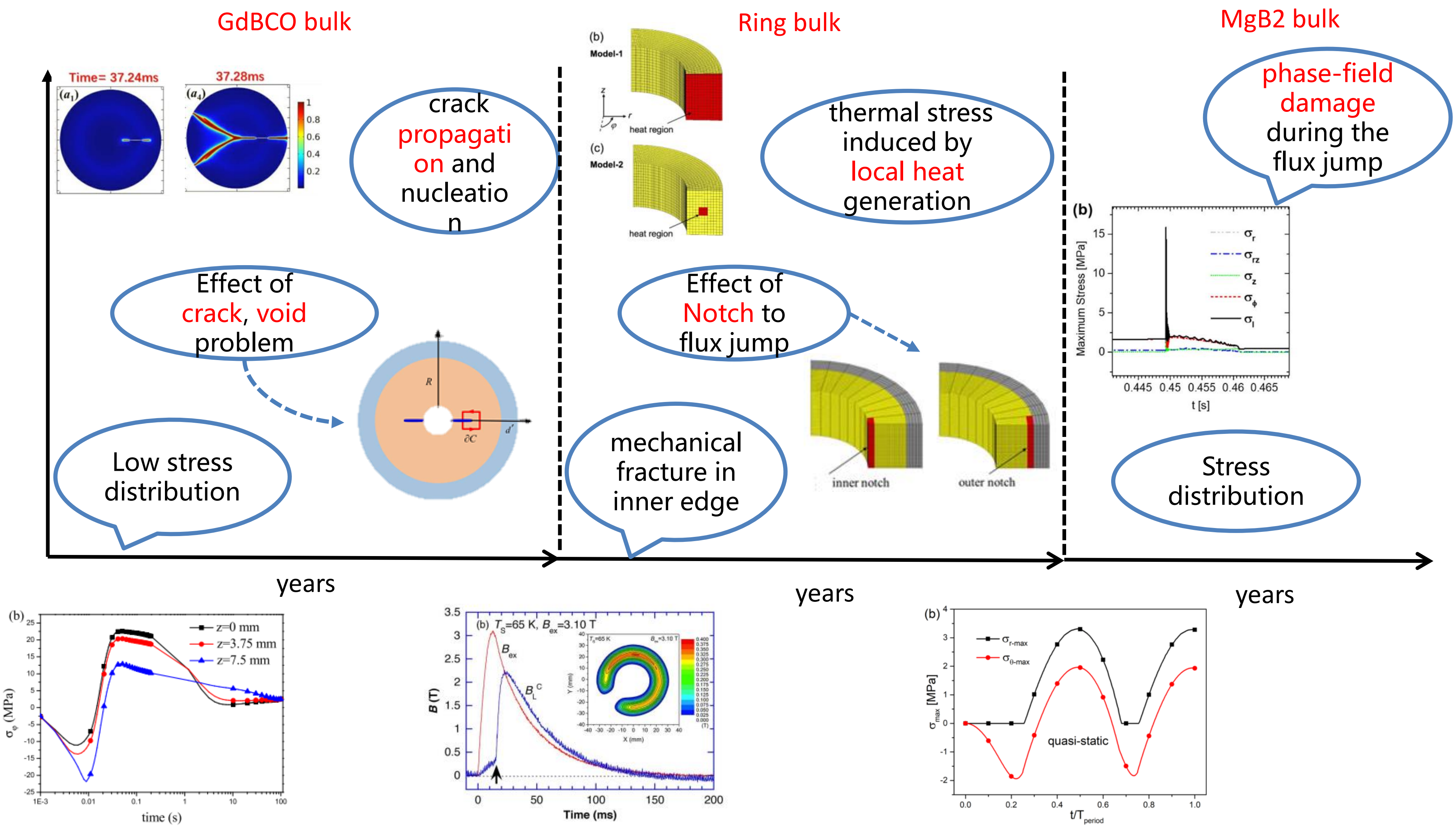

Research on the mechanical stability during PFM

Author	Sample	Method	Time	respect
Mochizuki	GdBCO bulk	2D Coupled H	2016	coupled thermomagnetic-mechanical instability behavior
Wu	GdBCO bulk	2D Coupled H	2018	
Zhang	MgB2 bulk	2D coupled H	2020	
Hirano	Ring bulks	2D Coupled H	2021	
Shinden	Ring bulks	3D Coupled H	2022	
Ru	GdBCO bulk	2D PD theory	2019	fracture/damage problem
Jing	GdBCO bulk	2D Phase-field theory	2020	
Jing	MgB2 bulk	2D Phase-field theory	2022	

the stronger flux pinning (Jc characteristic) is, the severer the mechanical stability is

⇦

the stronger flux pinning (Jc characteristic) is, the flux jump is prone to occur

Our work

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Analysis of electromagnetic characteristics of high performance HTS bulk during flux jump

Obtain the stress distribution of **fully magnetized** HTS bulk

Analysis of the **key failure factor** thermal stress in the magnetized process

- **Numerical model**

Model setting of magnetic field

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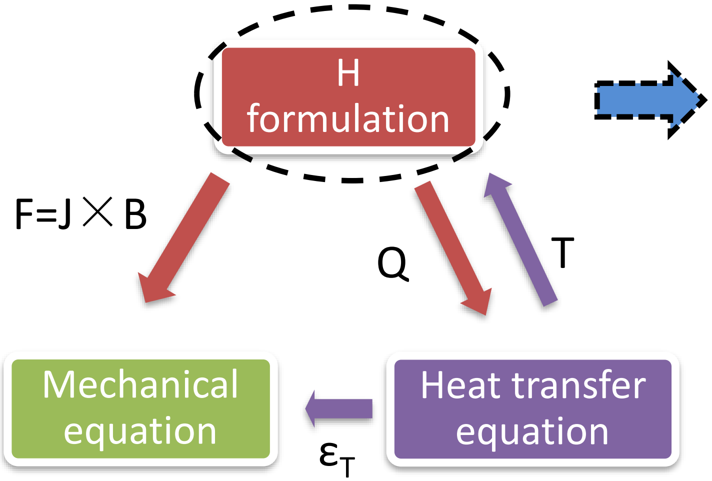
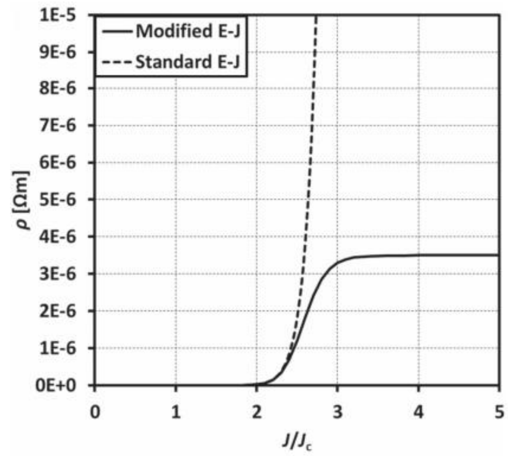
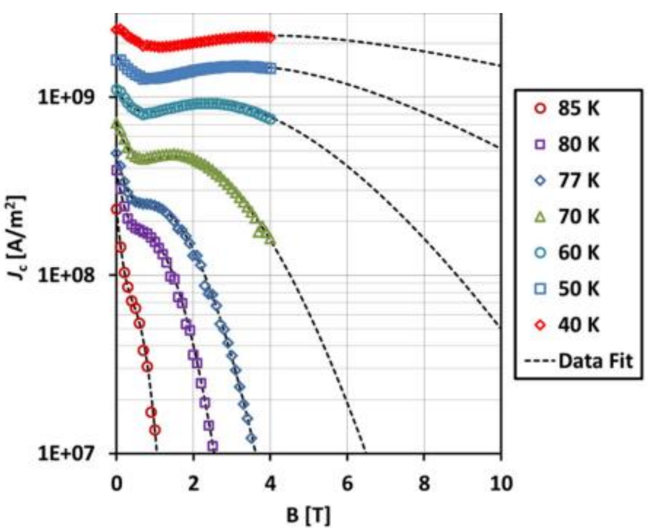




Modified E-J relationship

$$\rho_s = \frac{E_c}{J_c(\mathbf{B},\mathbf{T})}\left(\frac{|\mathbf{J}|}{J_c(\mathbf{B},\mathbf{T})}\right)^{n-1}$$

$$\rho = \begin{cases} \frac{\rho_s \rho_{norm}}{\rho_s + \rho_{norm}}, & T < T_c \\ \rho_{norm}, & T \geq T_c, \end{cases}$$

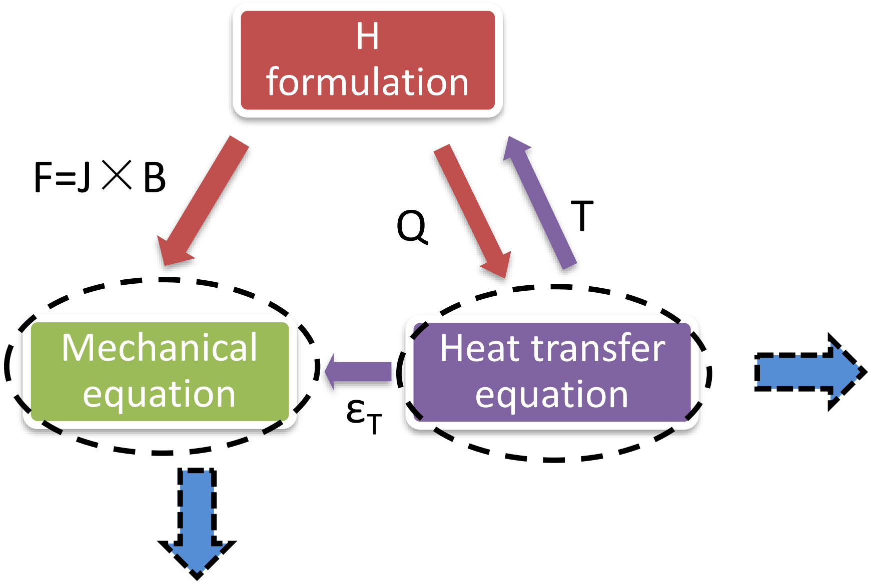


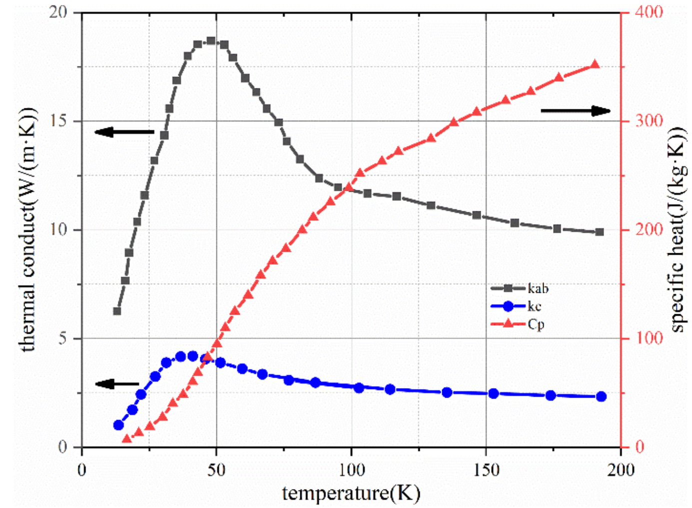
Two-variable interpolation Jc characteristic

Introduce ρ_{norm} to modify the E-J relationship during flux jump

Adopt high performance HTS bulk Jc expression

Model setting of Multiphysics





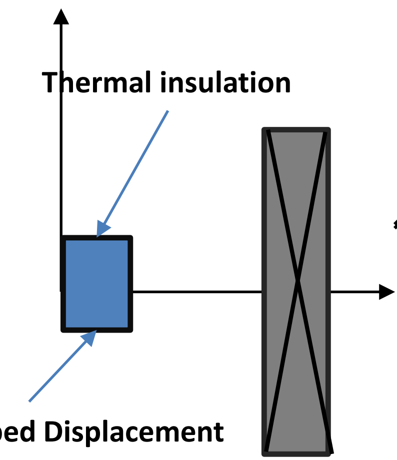
Key Thermal parameter

$$\nabla \cdot \boldsymbol{\sigma} + \mathbf{f} = 0$$

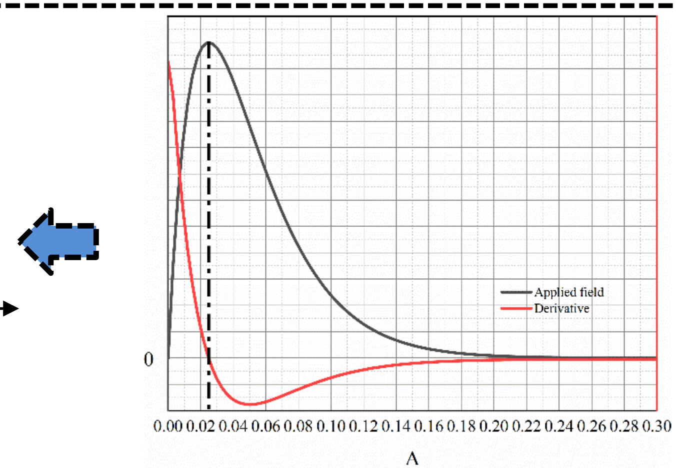
$$\boldsymbol{\varepsilon} = \frac{1}{2}[(\nabla \mathbf{u})^T + \nabla \mathbf{u}] + \alpha \cdot \Delta \mathbf{T}$$

$$\boldsymbol{\sigma} = \mathbf{D} : \boldsymbol{\varepsilon}$$

axial symmetry



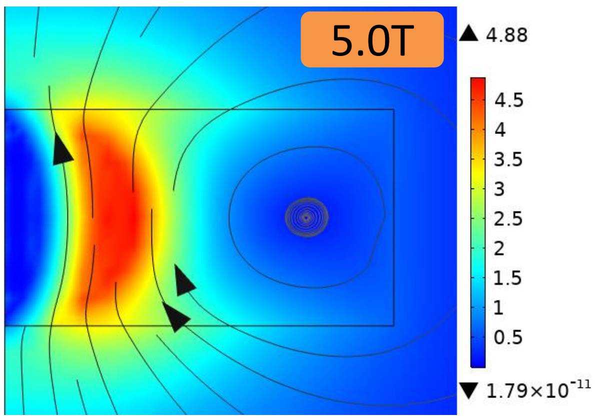
Axial symmetry model



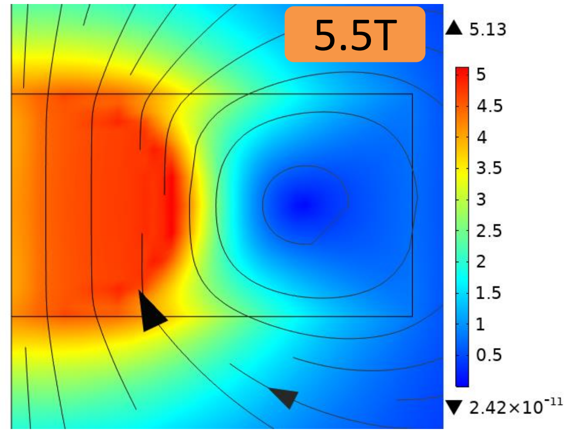
Wave form of applied field

- **Numerical result**

Magnetic distribution after fully magnetized

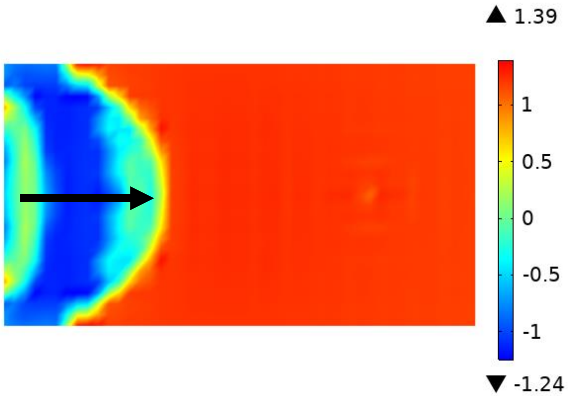


before flux jump

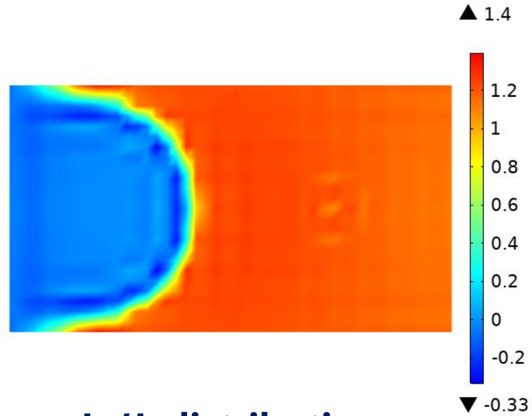


After flux jump

Only increasing 0.5T, the sample is fully magnetized



J_φ/J_c distribution



J_φ/J_c distribution

After flux jump, the current is redistributed, and there is no positive current at the center

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Temperature evolution and distribution

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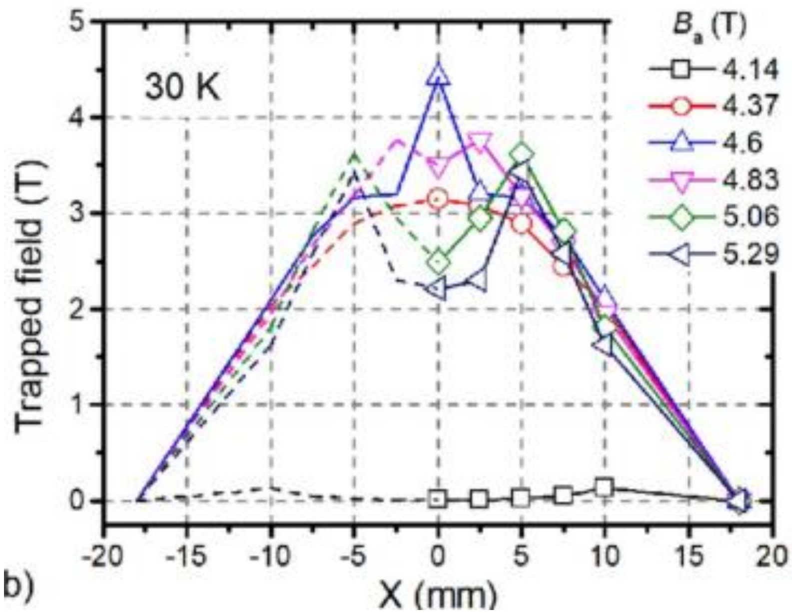
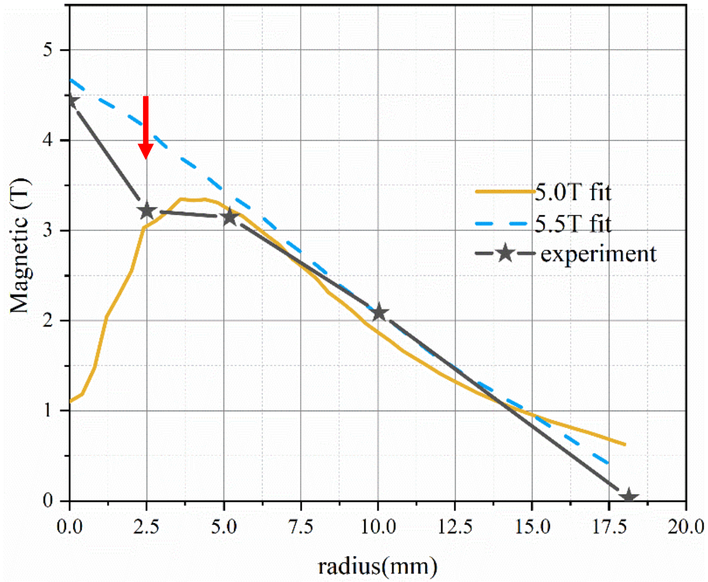


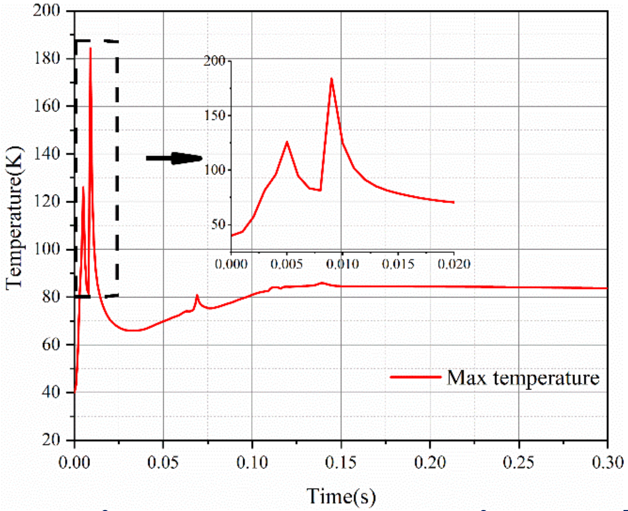
Magnetic distribution of Experiment



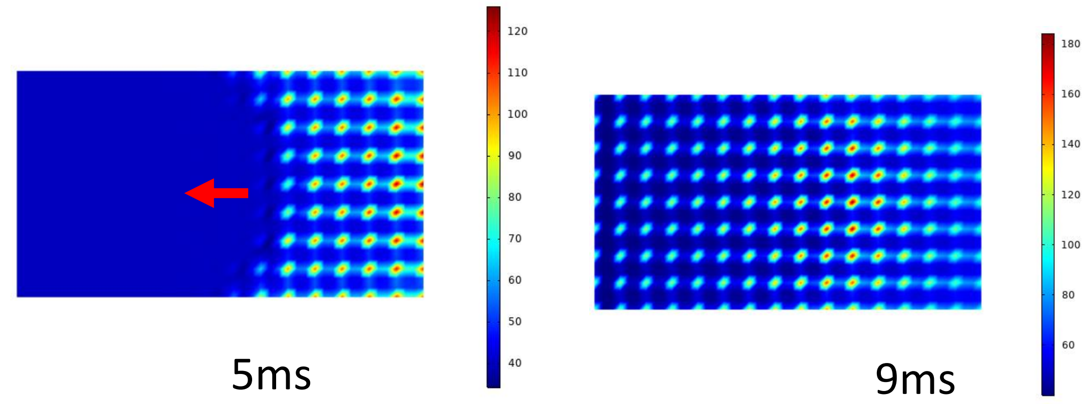
Simulation result

The final trapped field 4.6T has good agreement with the experiment 4.4T, but there is a concave in the position 2.5mm

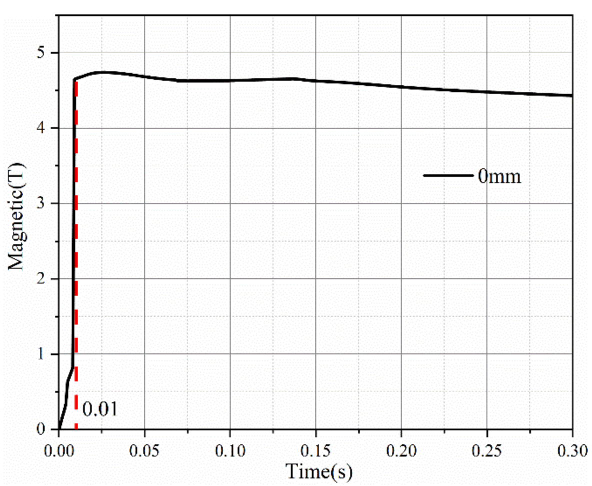
Temperature change during flux jump



Maximum temperature time evolution



temperature hot pot at peak position



0mm magnetic time evolution

with the temperature attach to the peak, the screen current induced by Jc reduced immediately, resulting in the flux jump

Lorentz force load

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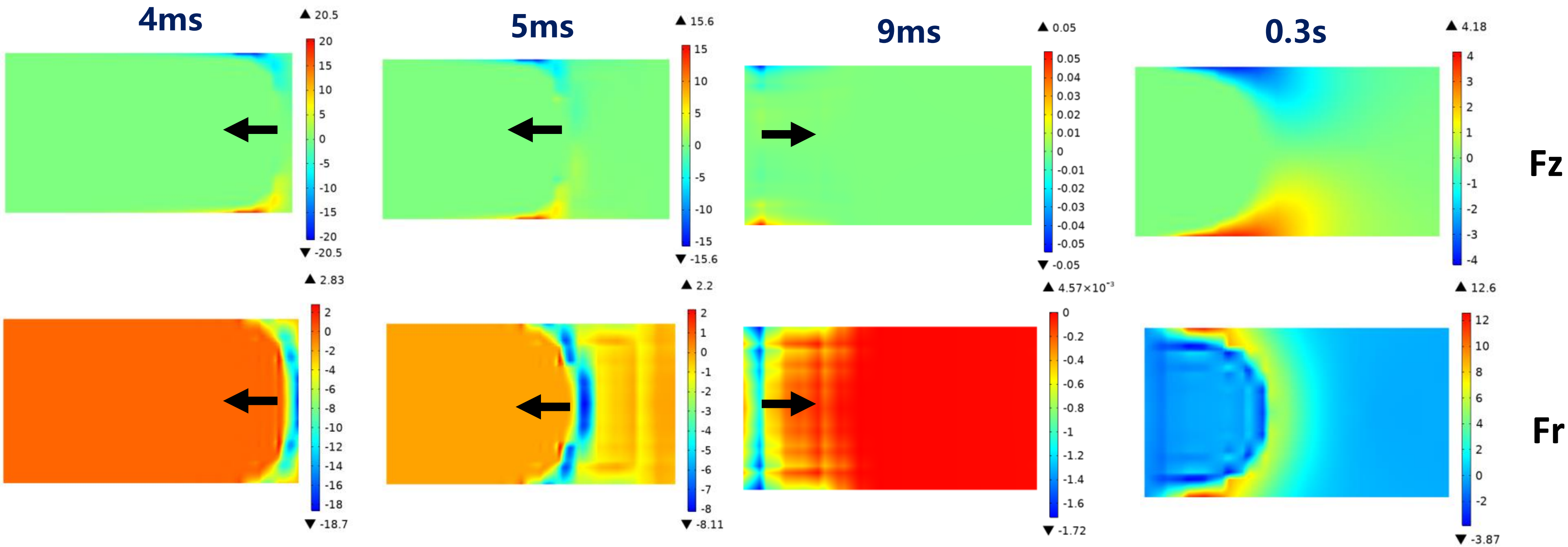

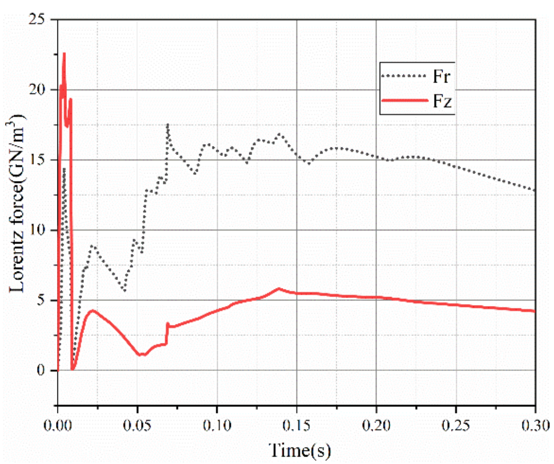

Maximum Lorentz force evolution

the Lorentz forces Move from edge to center and suddenly penetrate into the center, then Slowly return to the edge

Thermal Stress distribution after fully magnetized

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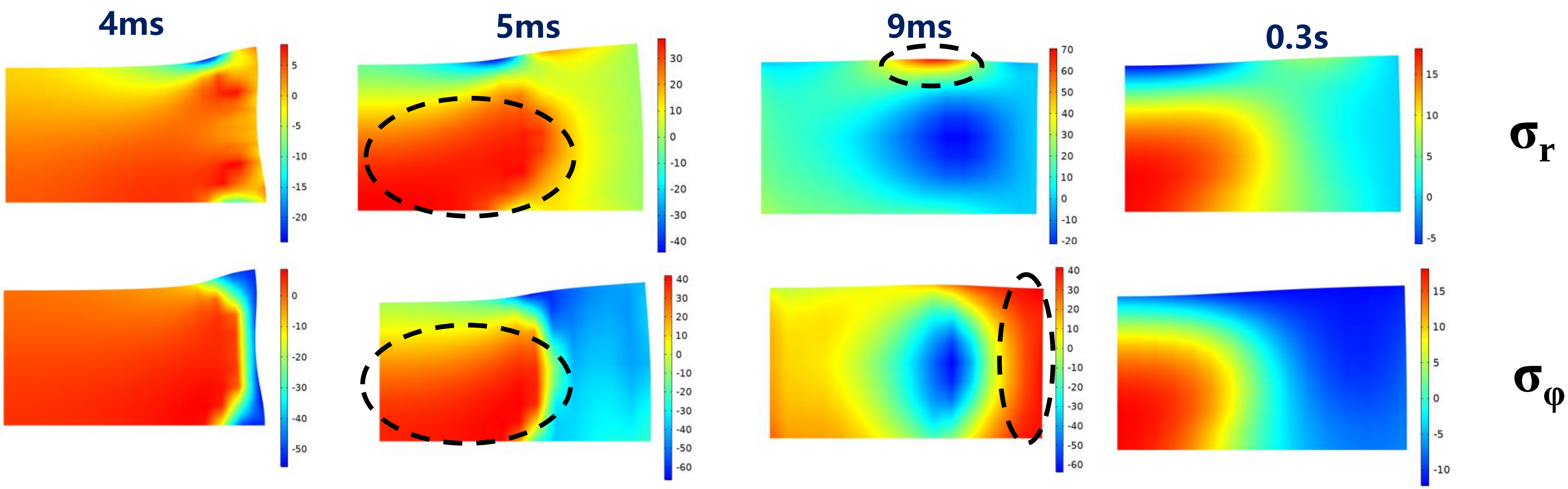
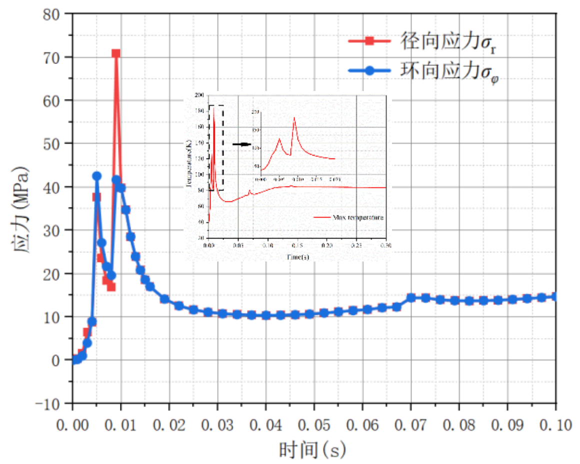


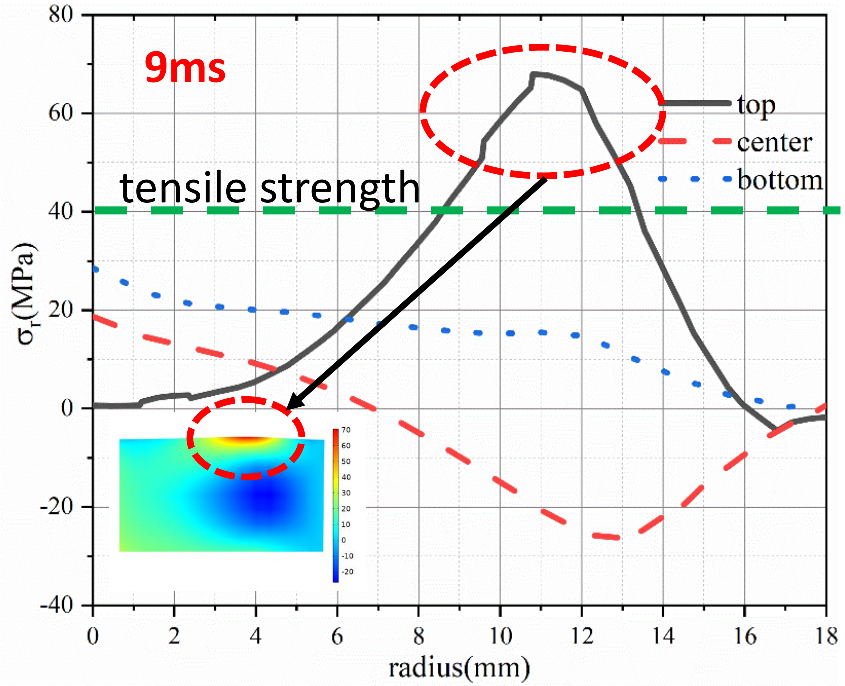


Maximum thermal stress time evolution

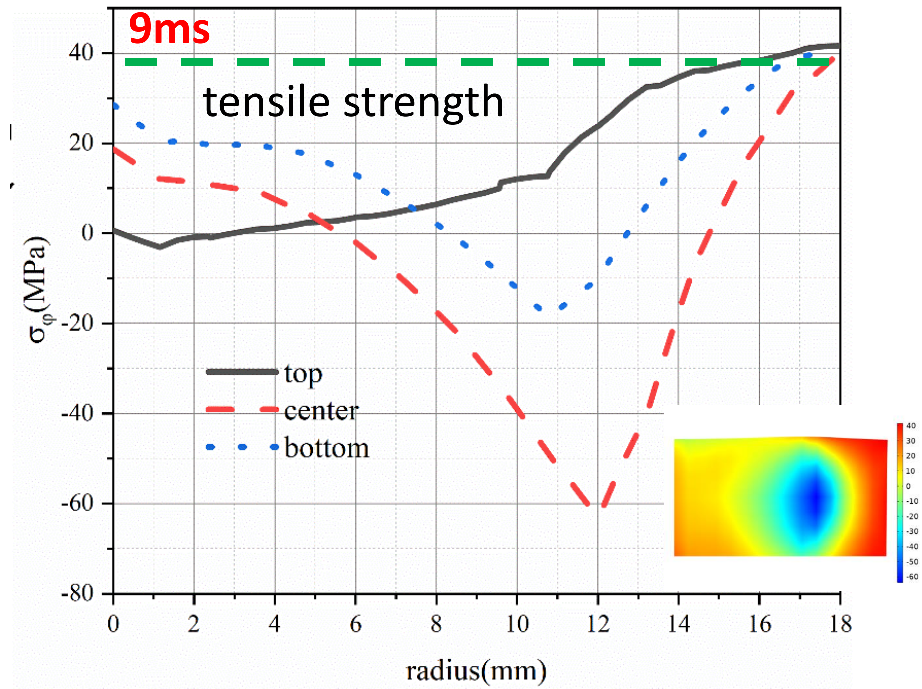
the change of maximum thermal stress is highly consistent with the temperature

after flux jump, the thermal stress redistributed, and the core stress released, result in local stress concentration

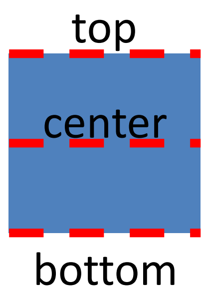
Spatial distribution of thermal stress during flux jump



thermal σ_r Spatial distribution

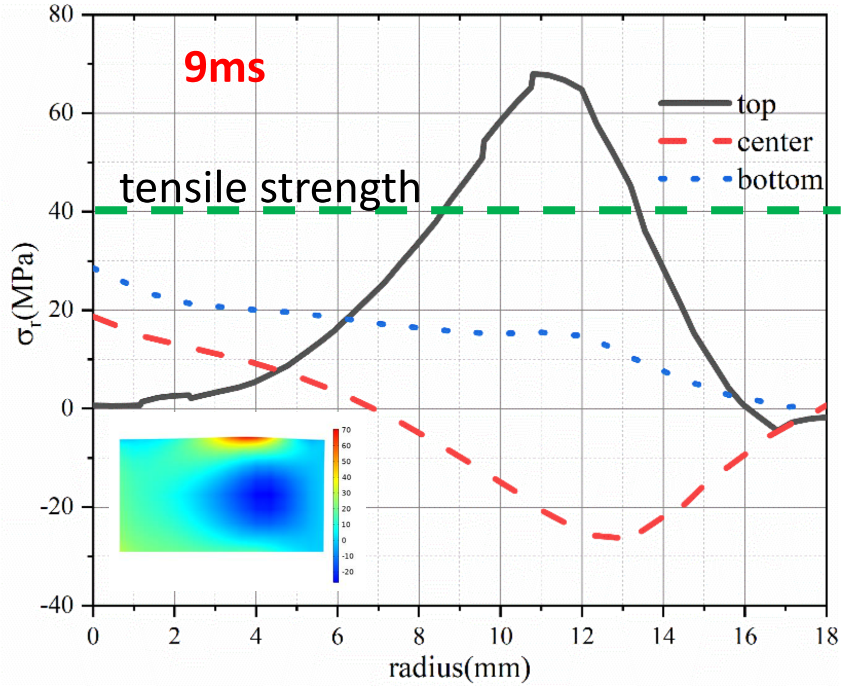


thermal σ_φ Spatial distribution

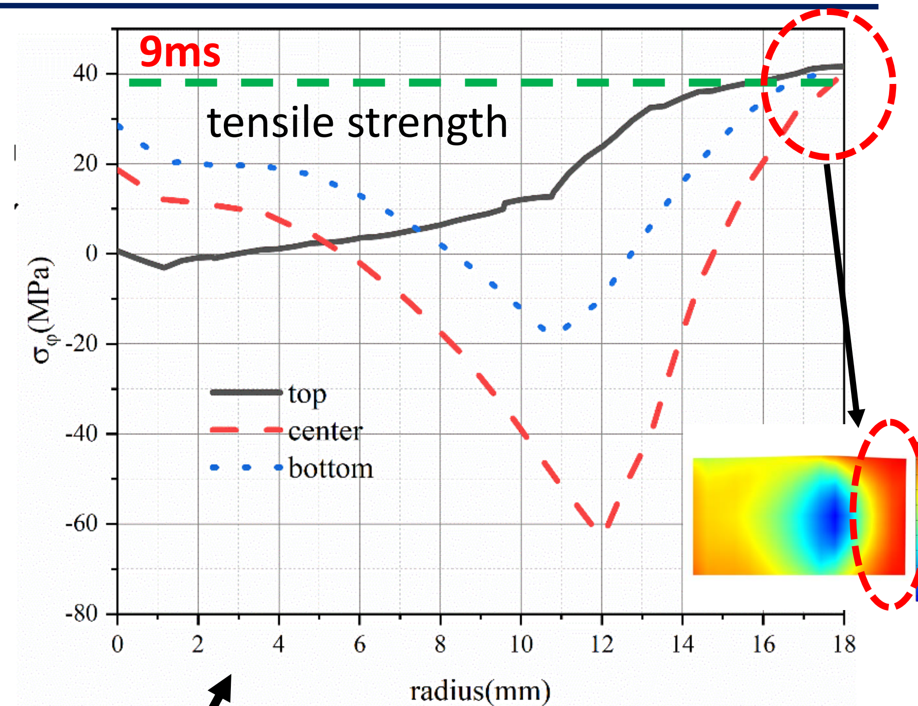


After stress redistribution, the thermal σ_r concentrated at the top surface, then the peak value hits 70MPa and exceeds tensile strength 40MPa , which is dangerous for HTS materials

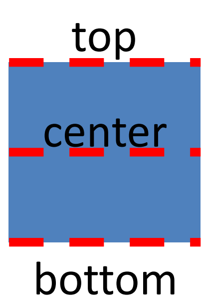
Spatial distribution of stress during flux jump



Thermal σ_r Spatial distribution

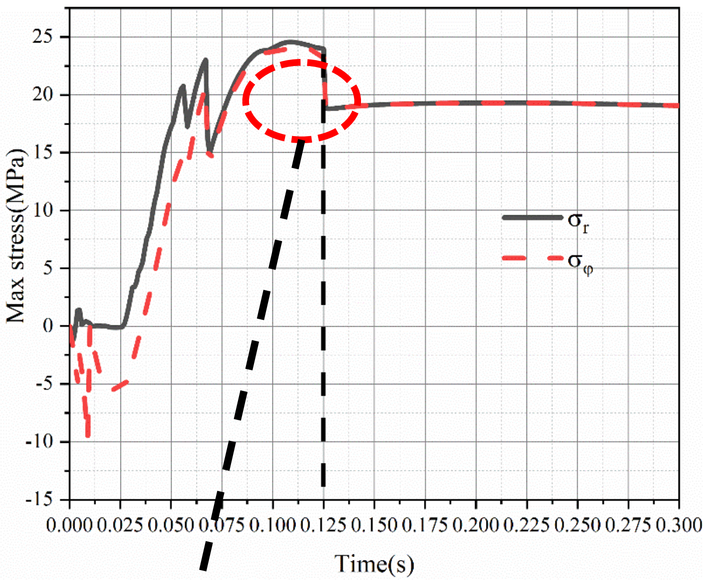


Thermal σ_φ Spatial distribution

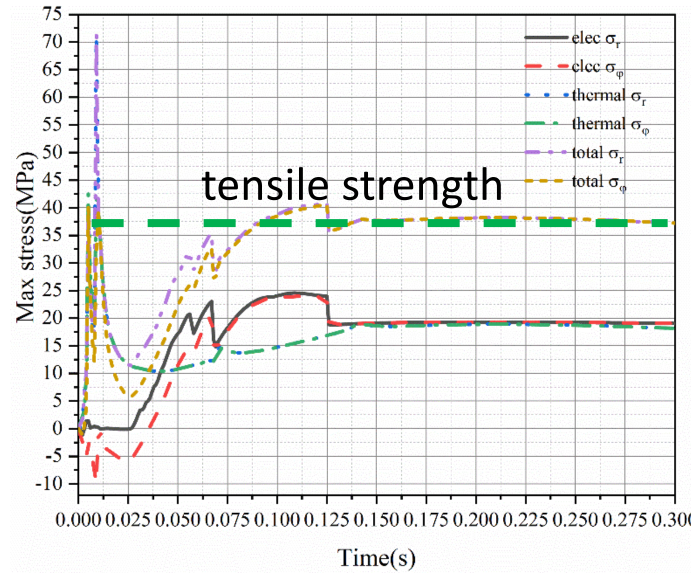


For the σ_φ, the stress is concentrated at the outer region of the bulk. the max value is close to the tensile strength 40MPa.

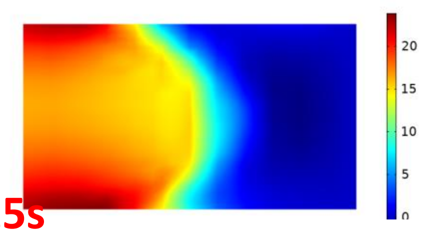
Spatial distribution of electromagnetic stress during flux jump



Max electromagnetic stress time evolution

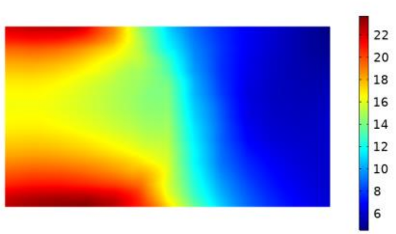


Max total stress time evolution



σ_r

0.125s



σ_φ

Electromagnetic stress is small compared against thermal stress at flux jump, but gradually increases with time goes by

The total stress hit the tensile strength at the end of PFM, which is the obstacle to further improve the trapped field

Conclusion

After flux jump, the electromagnetic and thermal parameters will change rapidly and help the bulk to be fully magnetized

After flux jump, the stress will redistribute to propagate outward, result in local stress concentration

The total stress in fully magnetized bulk trapped 4.8T is close to the mechanical strength, which is the obstacle to further improve the trapped field

Conclusion

THANK YOU