



Coupled electro-magnetic, thermal, mechanical analysis of a quench in the high luminosity LHC Nb₃Sn quadrupole magnet

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→ Goal: Simulate qualitatively and quantitatively the peak stresses/strains reached in the conductor during and after a quench

The strain/stress will be a combination of

- Pre-stress (collar, key & bladder) and stress due to differential thermal contraction (Al shell)
- Lorentz forces
- Thermal expansion during quench

Today's presentation

- → Modeling approach (LEDET + ANSYS)
- → Simulation of the stress/strain during a training quench
- → First attempt at validating the model against strain gauges measurements





Case study – MQXF quadrupole magnet



→ High Luminosity LHC inner triplets

 \rightarrow 132.6 T/m gradient, 150 mm aperture

- \rightarrow 16.5 kA, ~12 T in the conductor
- $\rightarrow Nb_3Sn$ superconductor

 \rightarrow 4.2/7.1 m magnets, 1.2 m model magnets











LEDET: Lumped-Element Dynamic Electro-Thermal model

- Approach based on lumped elements representing parts of the magnet
- Written in Matlab
- Typically runs a complete case in ~5 minutes
- Available as an executable (new!)



More info about LEDET → <u>ERavaioli@lbl.gov</u> ←





ANSYS mechanical model

- Baseline MQXF ANSYS model
- Frictional contact pairs used for structure interfaces.
- No axial loading in the 2D model.
- No symmetry boundary conditions:
 Only constraint on the shell nodes UY=0 at Y=0 and UX=0 at X=0
- 475 μm (825 μm) interference applied as the preload shims for MQXFS1a (b).
- Coil properties have been updated to lower modulus.







Training quench at 17.8 kA -1

MQXFS1a, Quench #16: 17.766 kA, quench started in 104a7_a8 (pole turn) Protection by means of 30 m Ω EE and outer+inner QH



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Training quench at 17.8 kA -2

MQXFS1a, Quench #16: 17.766 kA, quench started in 104a7_a8 (pole turn) Protection by means of 30 m Ω EE and outer+inner QH



Simulations performed with LEDET

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Qualitative pole strain (ɛ) transient





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Simulated pole strain





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Simulated pole strain – zoom





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Simulated pole strain – zoom2





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MQXFS1a -Pole strain -Measurement cpr Simulation



Δε thermal during training quenches



Peak stress in the conductor -1







Peak stress in the conductor -2

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Conclusion

<u>Goal</u>: Attempt at qualitative and quantitative analysis of the peak temperature and stress/strain during a quench.

<u>Simulation strategy</u>: coupled electrical/magnetic/thermal LEDET model with electrical/mechanical ANSYS model

<u>Results</u>: Comparison with strain gauge measurements → First results promising

Lot of work ahead!

- Model validation in more stressing conditions (no EE, ultimate current, failure cases, etc...)
- More detailed ANSYS sub-model for cable elements (insulation, strands, epoxy)
- Sensitivity of thermal stress on strand/cable parameters
- 3D model?
- Assess realistic stress/strain limits on the conductor via dedicated experimental activities (collaboration with University of Geneva)





QUESTIONS?

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LEDET (Lumped-Element Dynamic Electro-Thermal)



US HL-LHC AUP

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LEDET model

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The **interaction** between the superconducting magnet and the local coupling currents is modeled with an array of **RL dissipative loops mutually coupled** with the magnet self-inductance





MQXF powering and protection strategy



- → 132.6 T/m gradient, 4.2/7.1 m long
- \rightarrow 16.5 kA, 12 T in the conductor
- $\rightarrow Nb_3Sn$ superconductor

→ Quench protection is challenging





Quench protection system includes heaters and CLIQ to improve effectiveness and redundancy



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