On the relation of simulations and experiments in the context of HTS AC losses

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28.6.2018

HTS 2018 MODELLING
6th International Workshop on Numerical Modelling of High Temperature Superconductors
26 - 29 June 2018
Caparica - Portugal

Outline

- Formulating physics: infinitesimal vs. macroscopic "models of measurement"
- Compatibility
  - Continuum vs. discrete
  - Modelling vs. measurement
- "Model validation"
- Concluding remarks

Formulating physics

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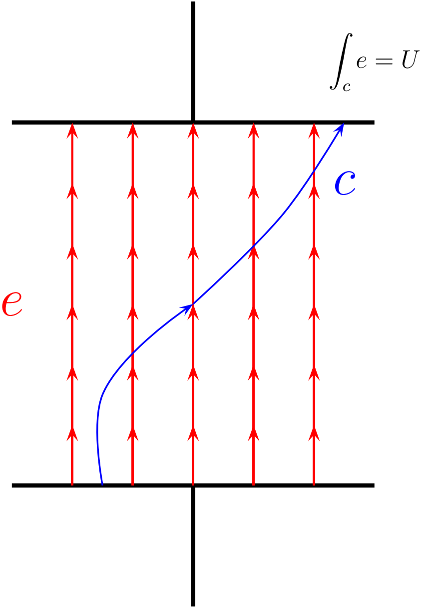
Formulating physics



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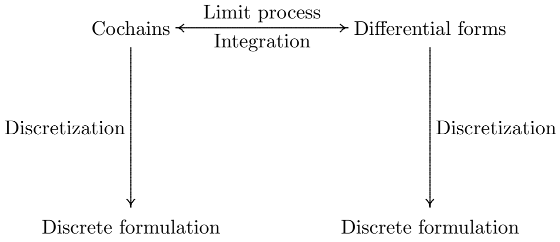
- A finite, *discrete description* is required for computer simulations of physical phenomena: *A numerical model*.



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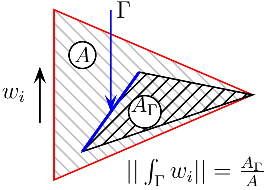

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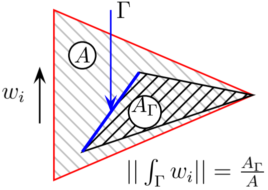

- In the *H*-formulation we interpret the solution as measurements of magnetomotive force along the mesh edges.

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- $RW\sigma = \sigma$, $WR\eta$ tends to η with the refinement of the mesh.
- Many essential properties are inherited by the discrete setting from the continuum: Continuity properties of the fields, properties of differential operators, ...

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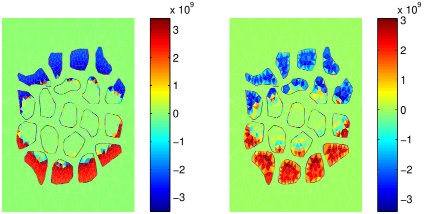
- This leads to tangentially continuous current density.



[Ste] A. Stenvall, T. Tarhasaari, *S*upercond. Sci. Technol. **23** 125013 (2010).

[Lah] V. Lahtinen *et al.* *S*upercond. Sci. Technol. **25** 115001 (2012).

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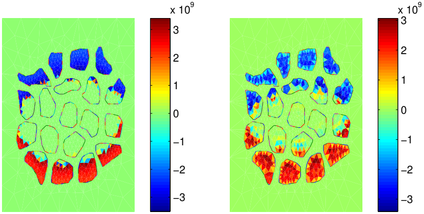

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- Antonio Morandi solved the problem for the community by introducing doubled nodal elements on the material interface [Mor].

[Mor] A. Morandi, *S*upercond. Sci. Technol. **25** 104003 (2012).

Compatibility

- The compatibility of the discrete description with the continuum one is crucial for the consistency of the numerical model *internally*.
- Even though there is a measurement-like interpretation of discrete formulations, this says nothing about compatibility with actual measurements.
- How do we compare a model with measurements?
- This is where we discuss *model validation*.

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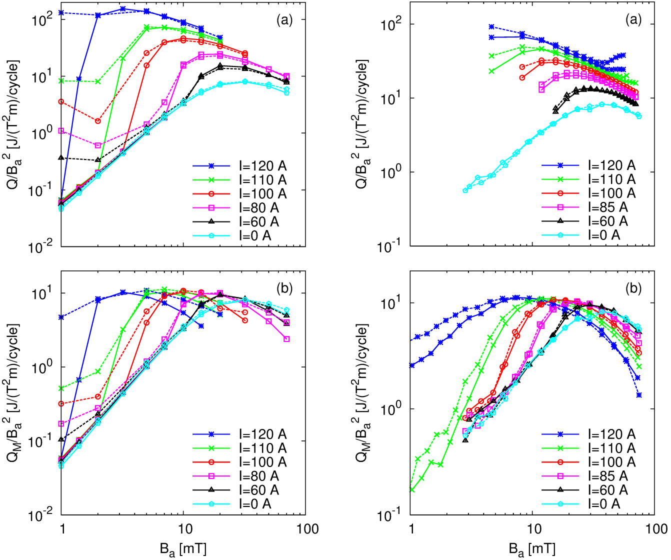
Model validation: Demonstrating the applicability of the whole modelling methodology in some particular cases via comparison with **measured data** (or analytical formulae).

Model validation: A literature example

AC Losses in REBCO: PL vs. CSM vs. Measurements



V. Lahtinen, E. Pardo, J. Šouc, M Solovyov, A. Stenvall, *J. Appl. Phys.* **115** 113907 (2014).

Model validation: A literature example

What was inferred?

- Qualitative and quantitative agreement between the predictions of PL and CSM was good in a wide range.
- Qualitative and quantitative agreement with measurements was good in a wide range.
- Discrepancies at low AC fields with significant DC. (†)
- Discrepancies in terms of magnetization loss (esp. for high DC). (‡)
- One model reflects measurements better in some range of situations (CSM †) while one in another (PL ‡).

Model validation: A literature example

Uncertainty

- Noise in measurements at low fields.
- Possible J_c degradation close to the tape edges.
- Possible under-estimation of J_c at low fields.
- Current-sharing with stabilization layer?
- Different discretization methods – compatibility?

Model validation

Conclusion

In many ways, "model validation" **does not validate** a model. Benchmarking against measurements has little to do with one model being more valid than another.

There is a lot of **uncertainty** associated to model validation.

Importance of model validation and **usefulness** of a model is, however, another story.

Concluding remarks

- Modelling has an interpretation in terms of "measurements".
- The consistency of a recursive model-theory system is independent of "model validation".
- The compatibility of a discrete formulation with the continuum formulation is independent of "model validation".
- "Model validation" is important, but in many senses it does not validate a model.

Cheers!