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LBNL Development: User-Defined Elements in ANSYS for Quench Simulation

L. Brouwer, B. Auchmann, 22.09.2017

UDEs in ANSYS, Motivation

- Some Fortran functions of user-programmable features are documented.
- An example of a 1-D mechanical link element is given.
- All element matrices and vectors need to be programmed from scratch.
- ANSYS can output matrices, which can be used for comparison to the UDE.
- Local field values can be obtained inside the UDE routines.
- Complex material data, therefore, does not have to be updated in a loop between solve commands.
- ANSYS adaptive time stepping can be used.

Electrodynamic Element

- Provide an ANSYS element type with key-options and real constants for SC magnets:
  - current- and voltage-driven thin-wire coils implemented in 2D.
  - IFCC magnetization model is implemented in 2D.
  - persistent-currents can be implemented, potentially even with hysteresis.
  - for ISCCs HdG’s current-redistribution zones could be applied as eddy-current term.
- Need to write ANSYS model-generator model and bench-mark the formulation against COMSOL.

2D Electrodynamic Element Matrices

$$\mathrm{curl}\,\frac{1}{\mu}\mathrm{curl}\,\vec{A} + \mathrm{curl}\,\frac{\tau}{\mu}\mathrm{curl}\,\partial_t\vec{A} - \vec{\chi}I = 0$$

$$\partial_t\Phi + RI - E = 0$$

As currently implemented, thin-wire coils with IFCC term without eddy-current term (3D version).

$$\begin{bmatrix} [\mathrm{C}^{AA}] & [0] & [0] \\ [\mathrm{C}^{IA}] & [0] & [0] \\ [0] & [0] & [0] \end{bmatrix} \begin{Bmatrix} \{\partial_t A_z\} \\ \{0\} \\ \{0\} \end{Bmatrix} + \begin{bmatrix} [\mathrm{K}^{AA}] & [\mathrm{K}^{AI}] & [0] \\ [0] & [\mathrm{K}^{II}] & [\mathrm{K}^{IE}] \\ [0] & [0] & [0] \end{bmatrix} \begin{Bmatrix} \{A_z\} \\ \{I\} \\ \{E\} \end{Bmatrix} = \begin{Bmatrix} \{0\} \\ \{0\} \\ \{0\} \end{Bmatrix}$$

All ANSYS DOFs are node based!

$$\begin{bmatrix} [\mathrm{Id}] & \{0\} & \{0\} \\ [0] & \{1\} & \{0\} \\ [0] & \{0\} & \{1\} \end{bmatrix}^T \begin{bmatrix} [\mathrm{K}^{AA}] & [\mathrm{K}^{AI}] & [0] \\ [0] & [\mathrm{K}^{II}] & [\mathrm{K}^{IE}] \\ [0] & [0] & [0] \end{bmatrix} \begin{bmatrix} [\mathrm{Id}] & \{0\} & \{0\} \\ [0] & \{1\} & \{0\} \\ [0] & \{0\} & \{1\} \end{bmatrix} \begin{Bmatrix} \{A_z\} \\ I \\ E \end{Bmatrix}$$

User-defined constraint must set all *I* and *E* DOFs in a given coil (electrical part) equal.

$$[\mathrm{K}_e^{AA}]^{ij} = \int_e \mathrm{grad}\,N_j \frac{1}{\mu}\mathrm{grad}\,N_i\,\mathrm{d}a,$$

$$[\mathrm{C}_e^{AA}]^{ij} = \int_e \mathrm{grad}\,N_j \frac{\tau}{\mu}\mathrm{grad}\,N_i\,\mathrm{d}a,$$

$$[\mathrm{K}_e^{AI}]^{ij} = \frac{N_\mathrm{c}}{S_\mathrm{c}} t \int_e N_j\,N_i\,\mathrm{d}a,$$

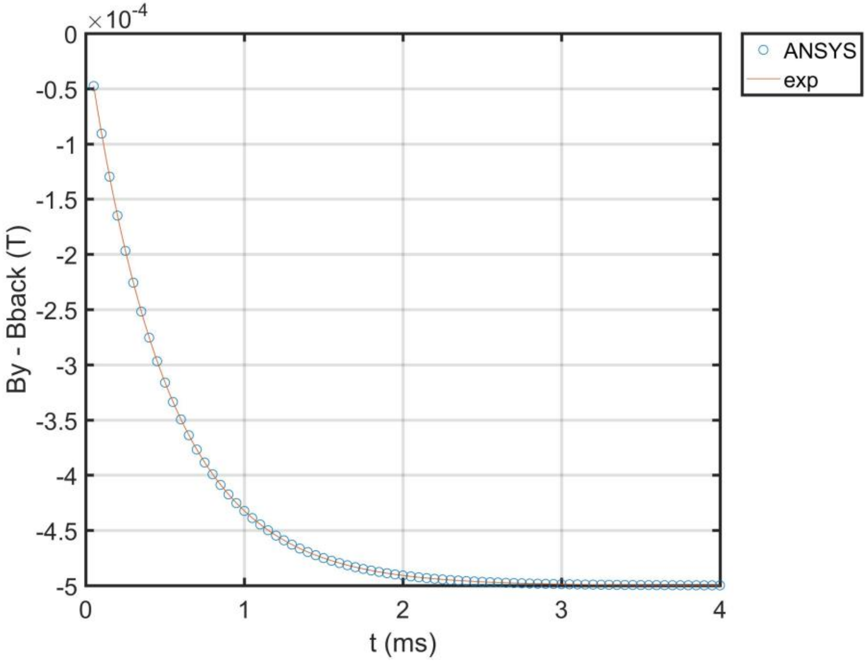
$$[\mathrm{C}_e^{IA}]^{ij} = \frac{sN_\mathrm{c}}{S_\mathrm{c}} t \int_e N_j\,N_i\,\mathrm{d}a,$$

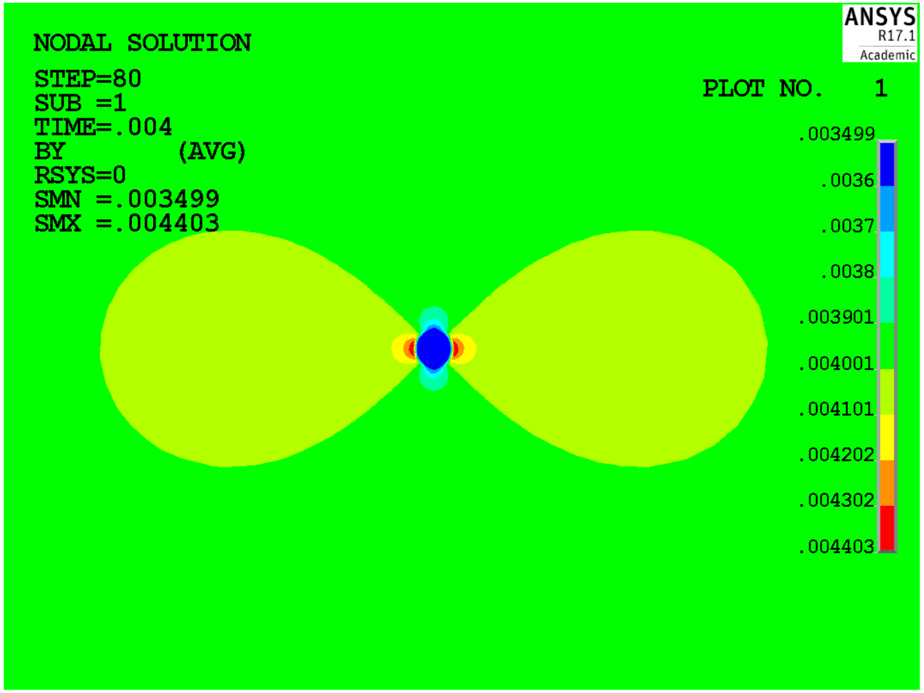
$$[\mathrm{K}_e^{II}]^{ij} = \frac{R}{\ell}\frac{1}{S_\mathrm{t}} \int_e N_j\,N_i\,\mathrm{d}a, \\ = s\left(\frac{N_\mathrm{c}}{S_\mathrm{c}}\right)^2 \int_e \rho\,N_j\,N_i\,\mathrm{d}a,$$

$$[\mathrm{K}_e^{IE}]^{ij} = -\frac{1}{\ell}\frac{1}{S_\mathrm{t}} \int_e N_j\,N_i\,\mathrm{d}a,$$

2D Element matrices trick ($\sum_j N_j = 1$) for scalar equation.

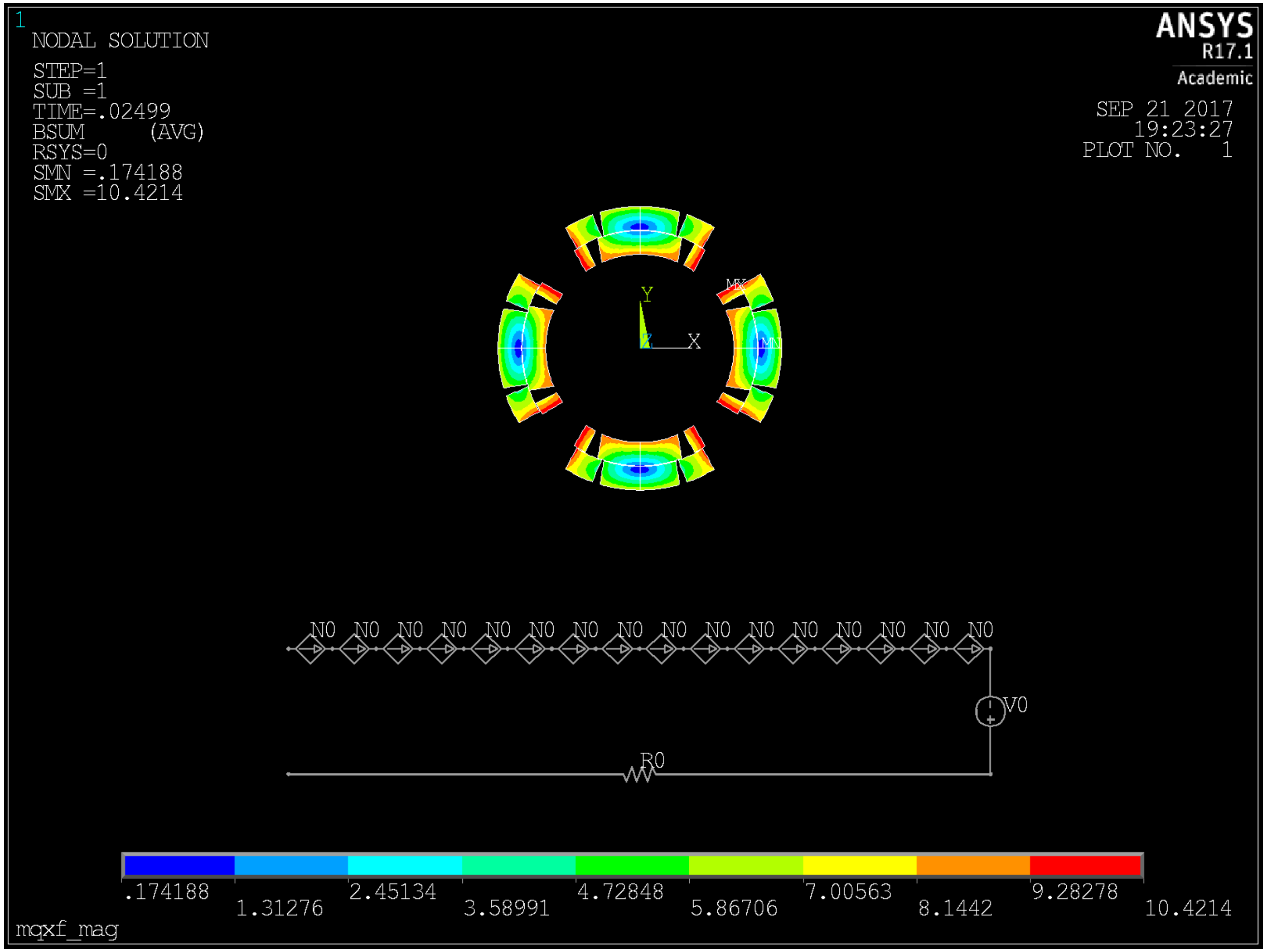
Example





courtesy: L. Brouwer

Benchmark Case MQXF



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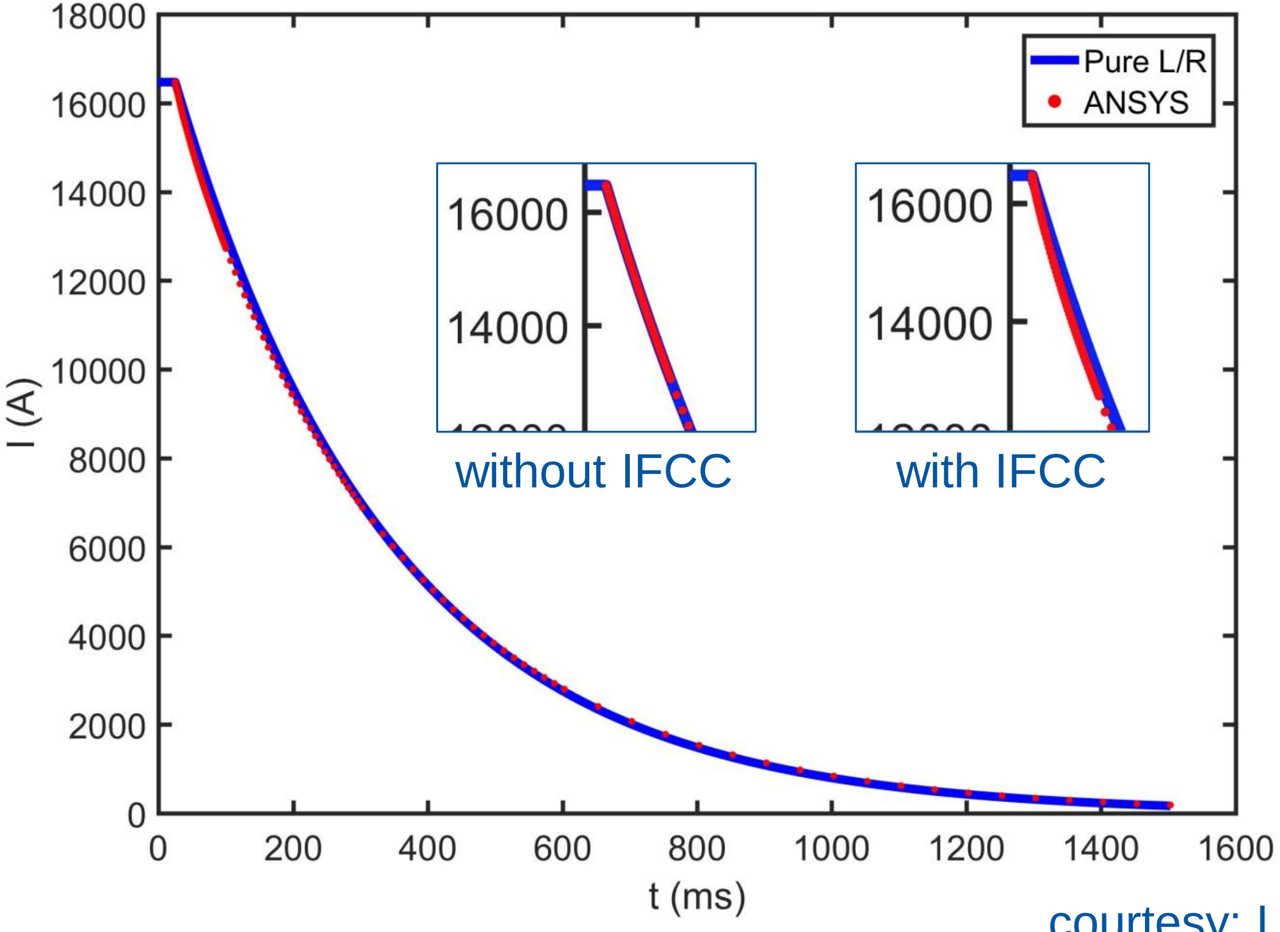

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Next Step: Thermal Element

- Provide an ANSYS element-type with material functions required for SC magnets:
  - Fortran material routines from ROXIE are readily available.
  - MatPro (INFN) routines require INFN approval.

Next Steps

- Finish 2D electrodynamic element type.
  - add ISCCs via current-redistribution zones.
  - possibly add ROXIE hysteresis model for persistent currents.
  - finish UI via key options, real constants, documentation.
- Create 2D thermal element type.
  - simple diffusion equation.
  - add ROXIE material properties.
- Create 3D tetrahedral electrodynamic elements. (ANSYS classic with mixed elements usually fails due to pyramid elements that are just collapsed hexahedra.)
- Create 3D thermal elements.
- Create thermal contact elements with transverse conductivity and heat capacity.
- Test / implement HPC capability.

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