Vector Fields Software

COBHAM

PAC09 – Magnet Workshop

The most important thing we build is trust

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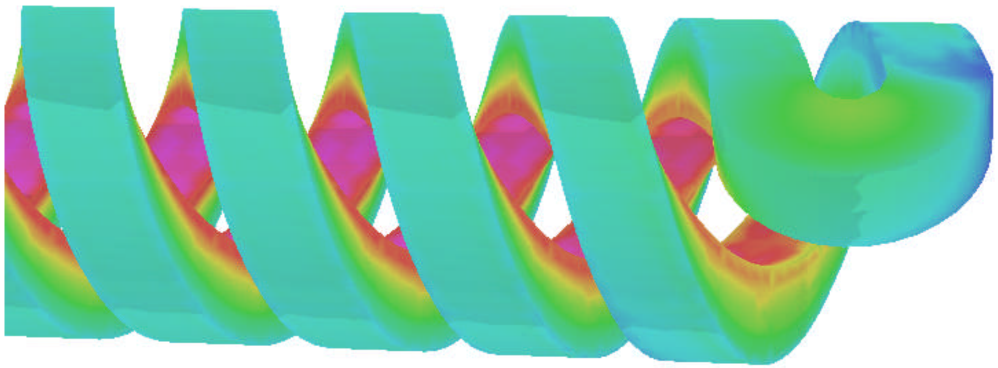
Opera - 13

Review of new and updated features



Status of Opera 13

- Many small changes to improve the programs, eg.
  - Script language updates, User defined dialog extensions
  - Removal of restrictions in Opera-2d circuits

- New features
  - Multiple moving parts in 2D Rotating Machines analysis (and there really are applications for this in accelerators)
  - Hysteresis models in Opera-2d
  - Hysteresis models in Opera-3d

- New features (that we don't tell people about)
  - Opera-3d Modeller supports Hexahedra, tetrahedra, pyramids & prisms (underlying software completed, but not easy to control it *yet*)
  - Circuit Schematic layout tool

- Release date & beyond

Opera version 13
Many small improvements

To extend the software's links to other programs

- Extensions to Opera's Windows COM interface
  - The Opera software can be started and controlled by other applications which have a COM interface (Excel, Matlab, Simulink, etc.)
  - The interface has been extended to the Opera Manager, so that:
    - interactive programs can be started (Opera-2d/PP, Opera-3d/Modeller etc.)
    - set or get the values of user variables and string variables;
    - send a command to an interactive program;
    - start an analysis program;
    - control a transient analysis (instead of using a command input file).

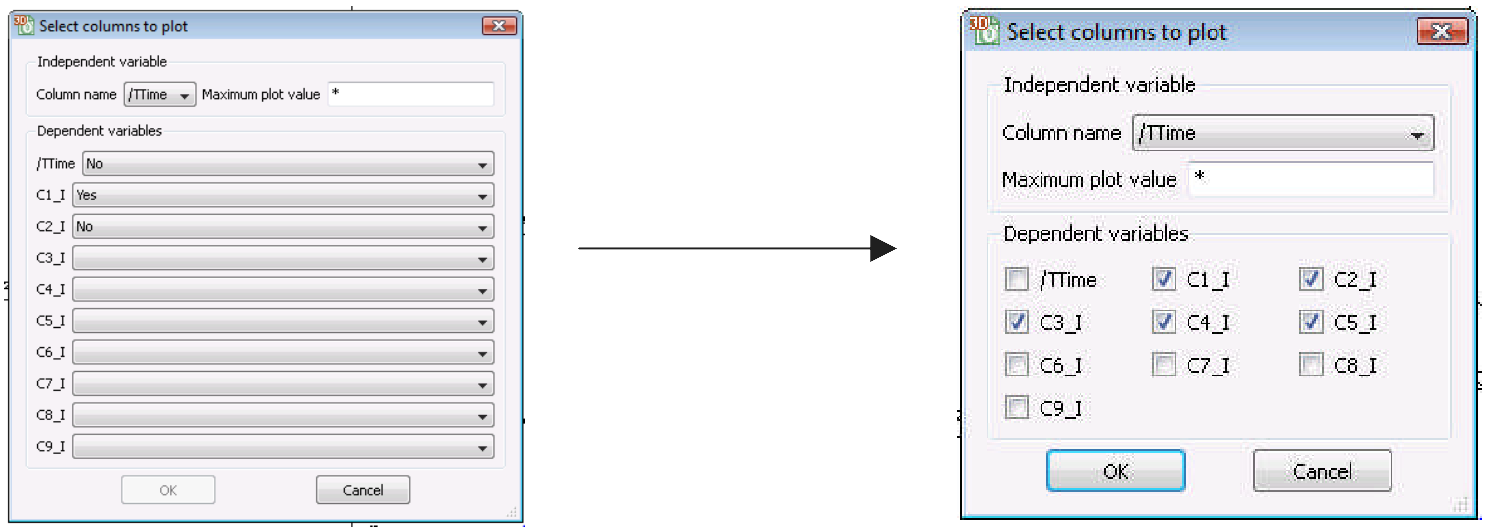
- A Matlab block is now available for both Opera-2d and 3d
  - Providing standard Matlab functions to control Opera
    - Opera transient simulators can run coupled to Simulink

- The full set of Spatial Technology CAD import tools can now be supplied (eg. Catia4, Catia5, Step, ProE)

Opera version 13
Many small improvements…

To Make the software easier to use

- Extensions to Opera’s Scripting language, for example
  - – Logical operators can now be used in arithmetic expressions
    - Example : PARAMETER #SCALE (T<0.5)*1+(T>=0.5)*2
      T<0.5 evaluates to 1 if T is less than 0.5, otherwise it evaluates to 0
    - Greatly simplifies construction of things like state machines
- New facilities for improved user defined dialog boxes (eg. checkboxes)



Opera-2d Rotating Machines Module

– The program was designed to analyse machines with one air gap ie. a rotor surrounded by a stator, separated by an air gap

– Three independently moving parts can now be specified

– Applications :
  - Magnetic reduction gearbox

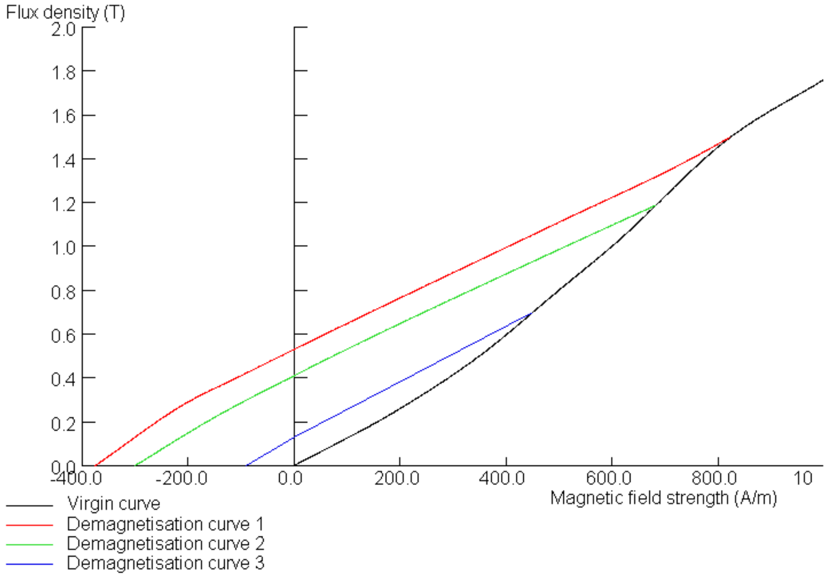
Hysteresis Modelling in Opera

- The original (de-)Magnetisation solver (Opera-2d):
  - Simulated magnetisation process in hard materials, incl. transients and eddy current effects
  - Transfer of magnetisation to ‘application device’
  - Included temperature effects (uniform over the device)
- 2nd Phase of development
  - Extended De-magnetisation in operation
    - Operation on a recoil permeability line
  - Temperature distribution over the device
    - coupled electromagnetic/thermal simulations

Opera version 13
Hysteresis modelling - history

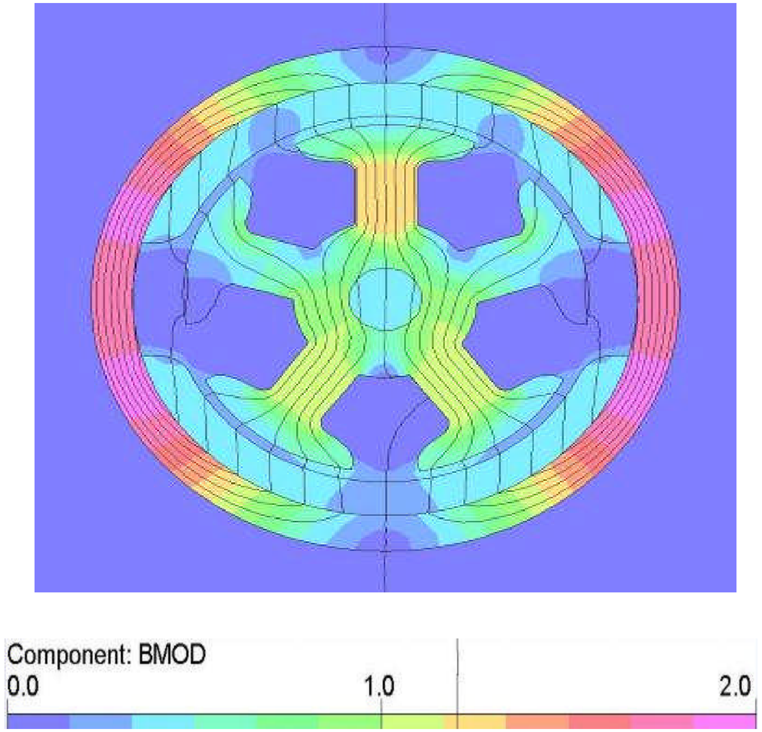
The original de-magnetisation solver was developed in collaboration with Magnequench

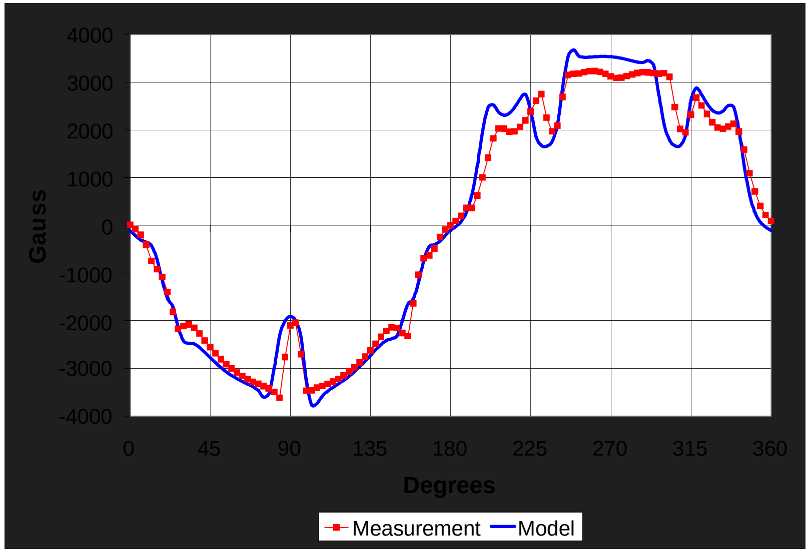
- Magnetisation on 'virgin' BH curve
- Demagnetisation on 'demag' curves.
  - 2nd order polynomials



Opera version 13
Hysteresis modelling - example

- Magnet Inserts mounted in a Steel Ring
- Magnetized in a fixture using a magnetic core
- Transferred into the application device





Radial Field in the Airgap

Results courtesy of Magnequench

Opera version 13
Limitations of the first model

- The model was designed for representing hard magnetic materials (the NdFeB magnet materials produced by Magnequench)

  Their Demagnetisation curves could be well represented by a 2nd order polynomial

- But the model could not be used for less hard permanent magnets, for example ferrites and alnico

- A third phase of development was completed so that ferrites and alnico could be represented
  - This development used Opera tabulated functions to describe the measured magnetisation characteristics of the material, rather than the restricted polynomials used in the original model, eg.
  - M(B;Bmagnetising;Temperature)

Opera version 13
Limitations of the demagnetisation model

- The heuristic models were only capable of representing relatively hard magnetic materials whose state of magnetisation could be inferred from the peak magnetising field and the minimum demagnetising field

- However there was stong commercial pressure to provide tools for accurate calculation of the losses in high speed electrical machines and the effect of these losses on machine performance
  - Ohmic heating losses in the winding can be calculated accurately
  - Hysteresis losses in the steel were only calculated approximately

- Final phase of development – Hysteresis models
  - Specifically for ferromagnetic materials
  - But the technique can be applied to permanent magnet materials

Opera version 13
Modeling Magnetic hysteresis

- This required a different approach to including material properties in Maxwell's equations
  - Based on a Magnetization formulation M(B) (ie. not using μ)

$$\nabla \times \upsilon(B)\nabla \times A \Rightarrow \nabla \times \left(\upsilon_0 \nabla \times A + M\right)$$

  - Input to the model is a measured major symmetric loop
  - The model follows turning points of the B-H trajectory
  - The model is practical (realistic computation times)
  - It treats 'wiping out' of minor loops
  - It has an automatic transition to saturation

Opera version 13
Modeling Magnetic hysteresis

- The method uses the turning points of the B(H) trajectory to predict the behaviour of arbitrary minor hysteresis loops.
  - It is practical, based on fitting to measured data:

    Minimum requirement is the measured major BH loop

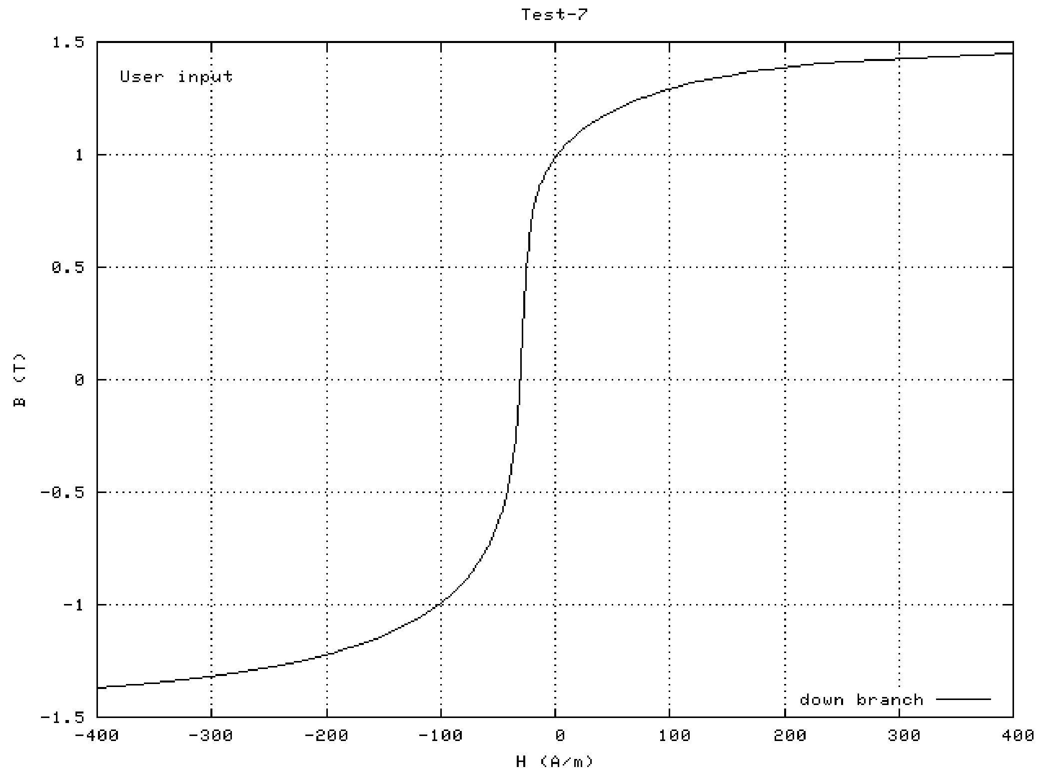
- It provides a good approximation to the true physical behaviour

- Including more complicated issues of nested minor loops and the `wiping out' of minor loops, which occurs when the B(H) trajectory goes through an earlier turning point

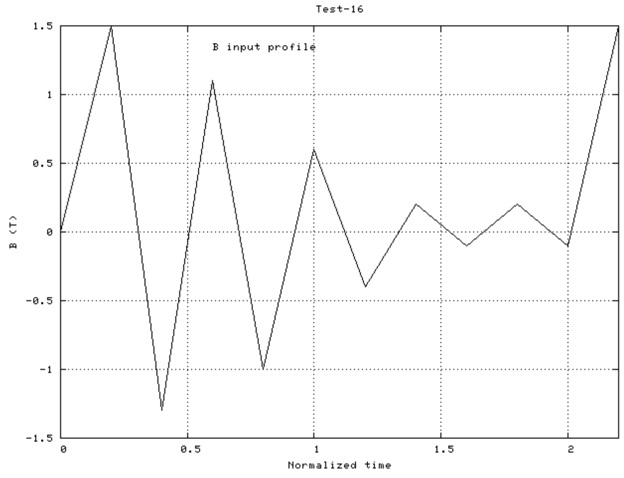
- Recognizes oscillating fields and minimizes the storage of turning points in that case

Opera version 13
Descending Major hysteresis loop

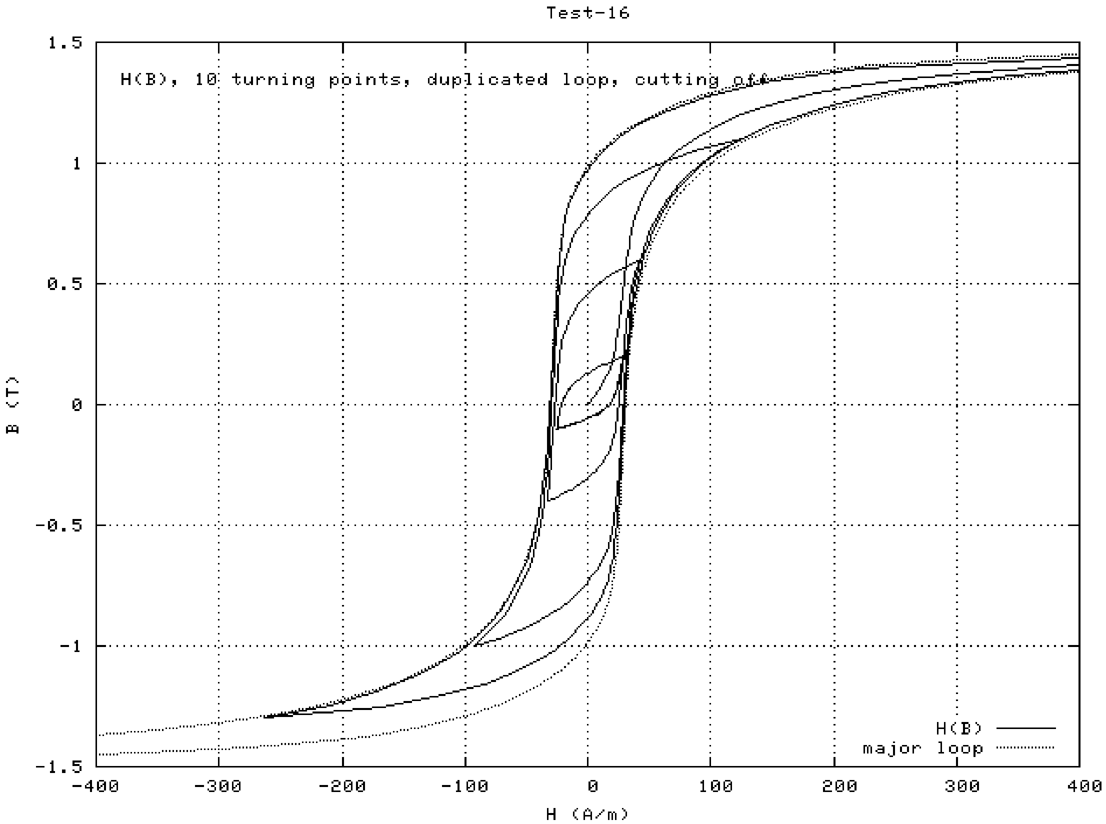
The minimum material description required by the model is a tabulated descending major hysteresis loop



Opera version 13
Predicted BH trajectory



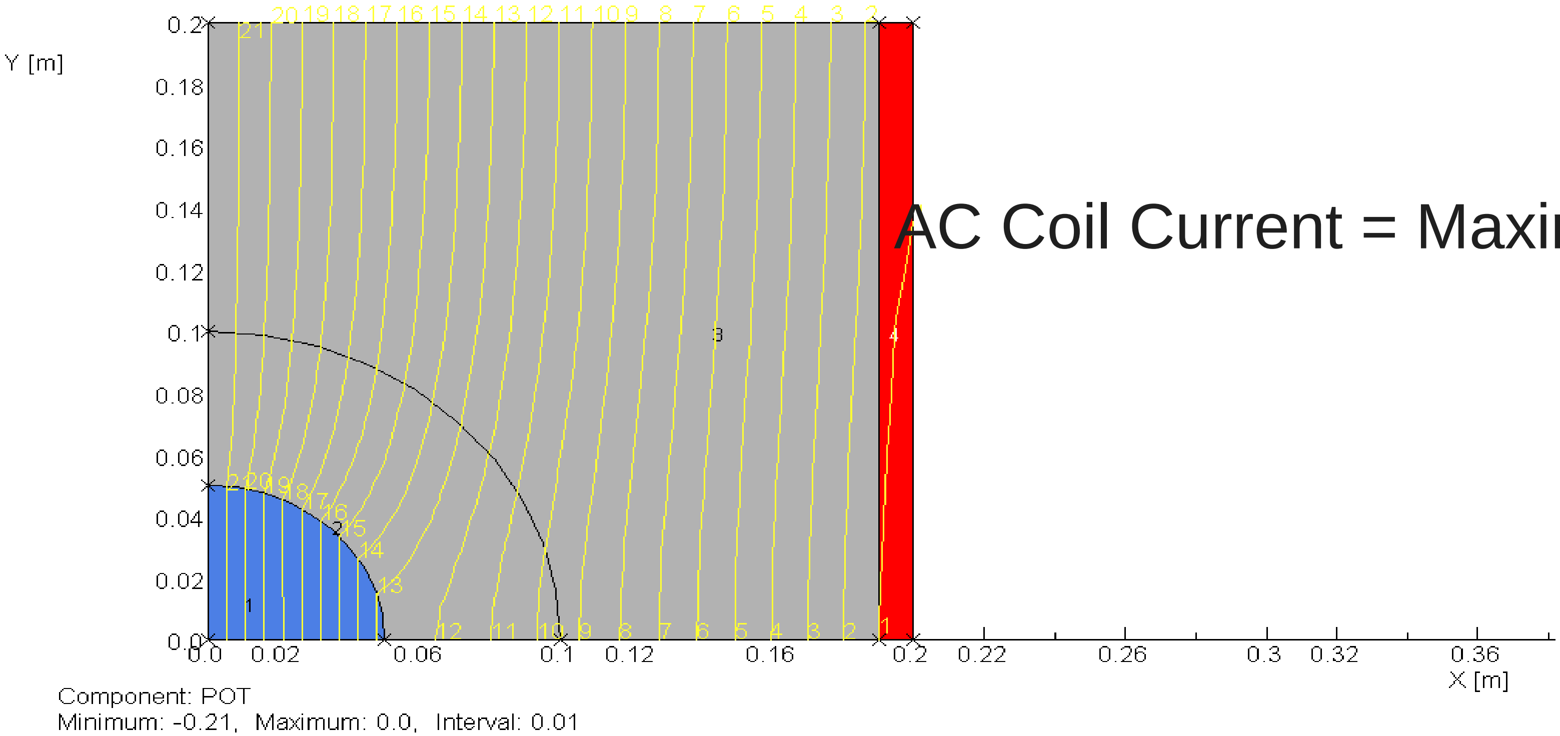
‘Drive Function’ - B



Resultant BH trajectory in material

Opera version 13
Validation tests

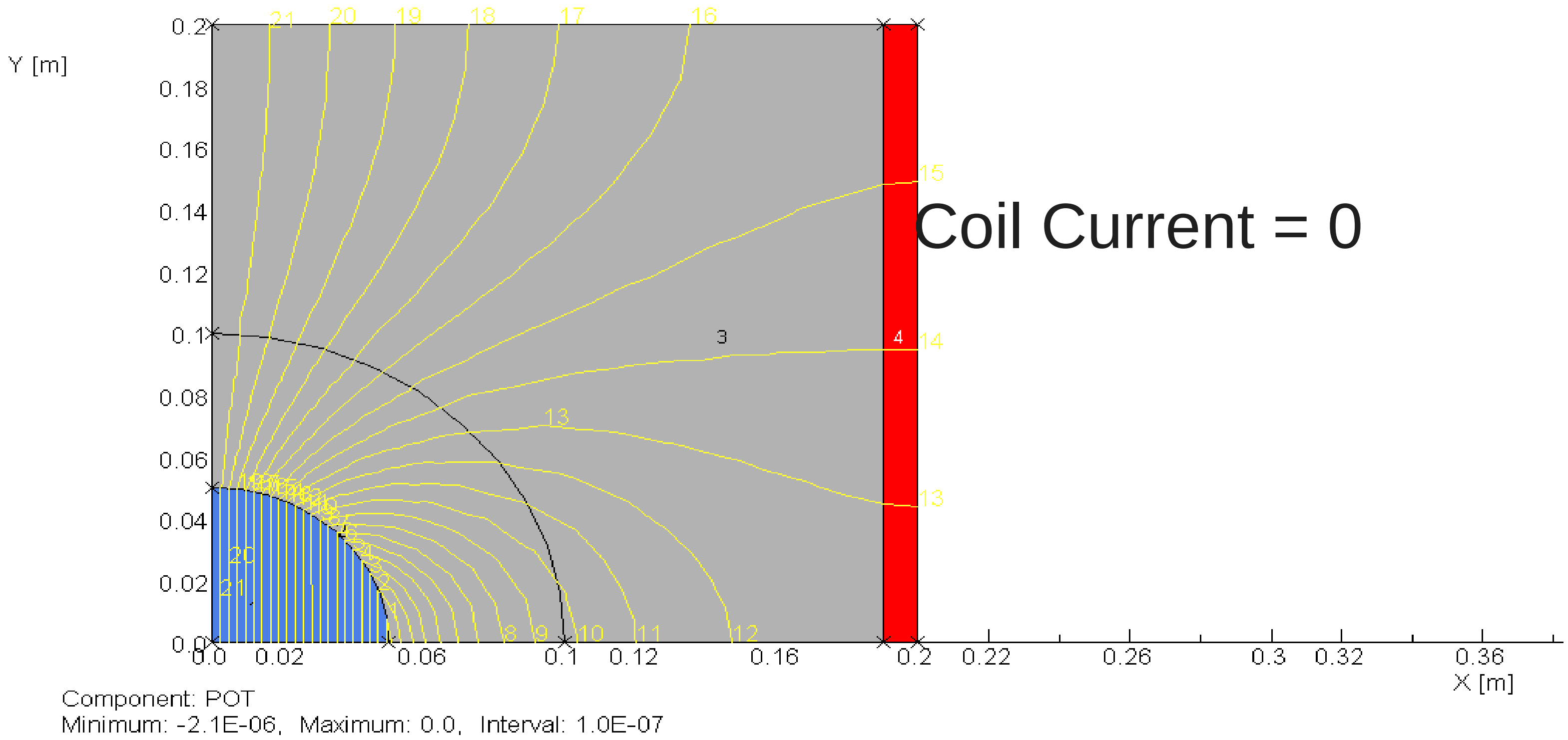
- Hysteretic Cylinder in alternating field (no eddy currents)



AC Coil Current = Maximum

Opera version 13
Predicted remanence

- Hysteretic cylinder in alternating field (static solutions)



Opera version 13
Vector hysteresis

- The hysteresis model described in the previous slides only applies to scalar hysteresis. However magnetic materials exhibit vector hysteresis

- Extension of the model to include vector hysteresis

- A first order approximation is used to include vector hysteresis
  – The rotation of the magnetisation of the material is assumed to be subject to a frictional drag proportional to the magnitude of the magnetisation, with a strength determined by the material’s coercive field

Opera version 13 : Hysteresis Comparison with measurement

- The model for ferromagnetic hysteresis was developed in collaboration with TRW-Conekt.

- TRW-Conekt measured the magnetic characteristics of the several steels and manufactured an automotive electric steering motor with two different types of steel rotor.

- Measured and calculated drag torques are shown below

Material	Measured drag Torque (mNM)	Calculated drag Torque (mNM)
Polycor	39	50
Silicon Iron	7.3	7.5

Opera version 13
Discussion of Hysteresis models

- For materials that show no hysteresis, the magnetisation formation agrees exactly with existing methods based on permeability

- The scalar hysteresis model is extremely accurate, and Opera’s implementation gives calculated losses that agree exactly with the areas in the BH trajectory

- The first order vector hysteresis approximation gives good results for electrical steels and silicon iron (3% error), but the results are in error by 20% for strongly hysteretic materials.

- The model can be extended to include higher order terms in its vector hysteresis approximation, but this will require additional measurements to characterise a material.

Opera version 13
Hysteresis models in 2d and 3d

- The de-Magnetisation modules in Opera-2d and 3d have been extended to include ferromagnetic hysteresis approximations, based only on measured major BH loops.

- Comparison with measurements in other applications (apart from electrical machines) is now required to confirm the range of validity of the vector hysteresis approximations.

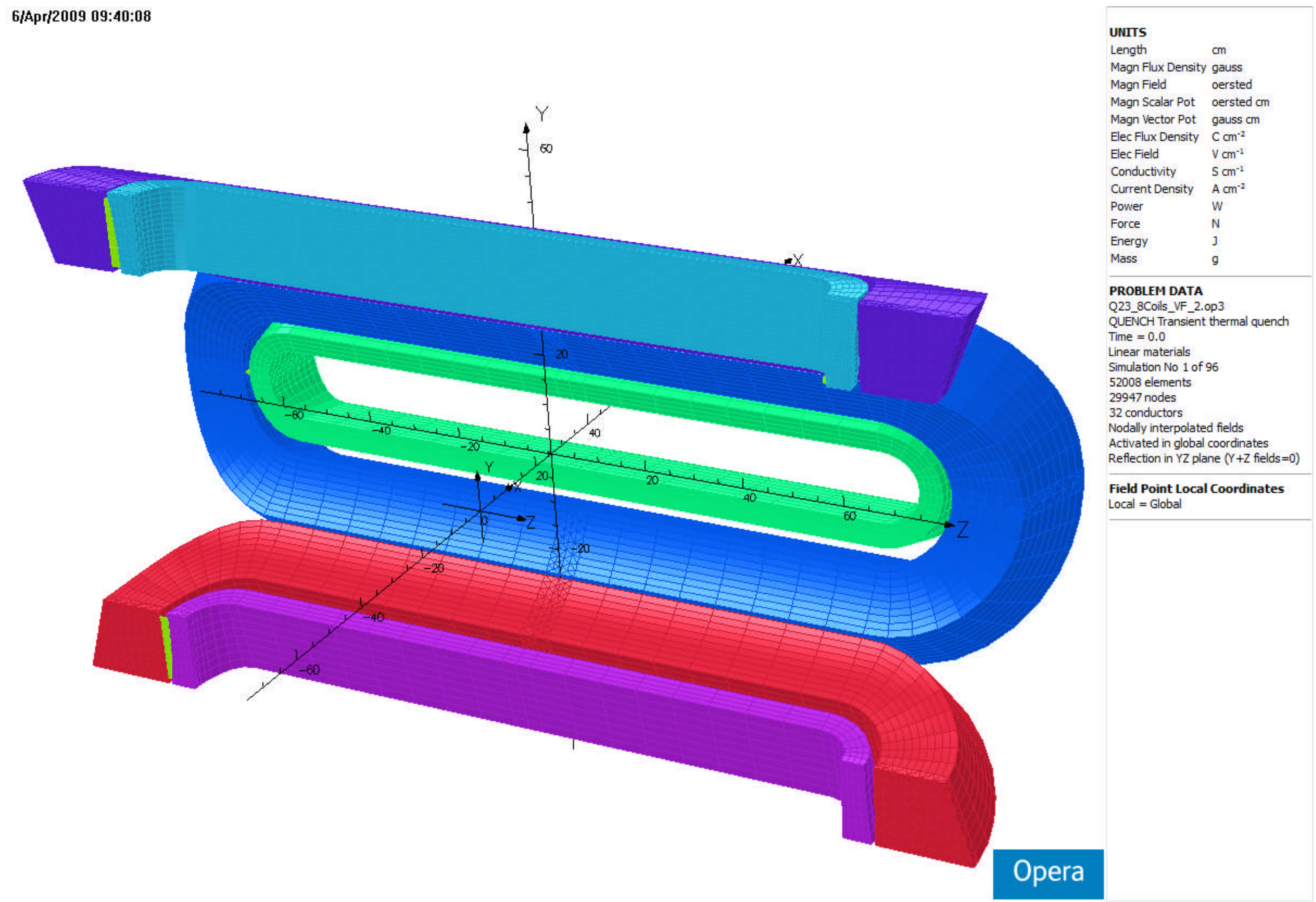
Opera version 13
Hidden developments (1)

- In the subsequent presentation on the IMPDAHMA project, the 3D mesh generator developments for hexahedra, tetrahedra, prisms and pyramids is discussed (Mosaic mesh?).

- This facility will be available in version 13, but elegant tools for controlling size variation of the hexahedra have not yet been developed.

- If you have an application that demands hexahedral meshing set:
  $CONSTANT #VF_MESHTYPE 3
  in the Modeller to automatically generate a mapped hexahedral mesh in simple cells.

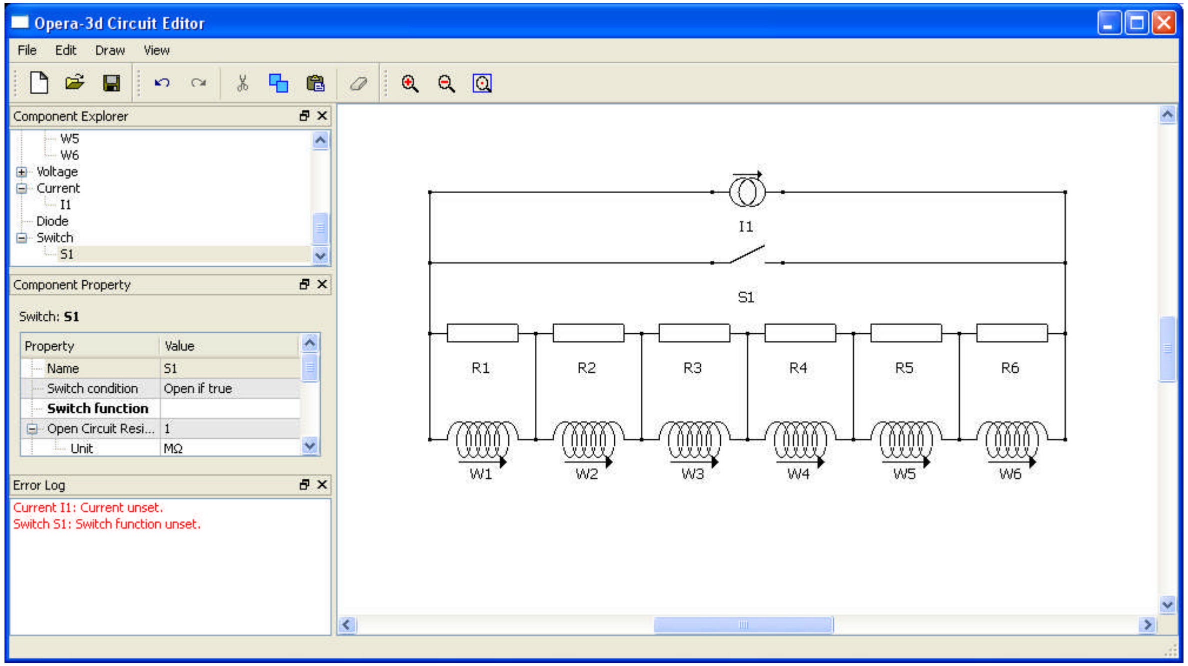
Opera version 13
Example hexahedral mesh



Opera version 13
Hidden developments (2)

- Also in the subsequent presentation on the IMPDAHMA project, the improved non-linear circuit solution options are discussed. These developments are used as the default in version 13.

- And the Circuit schematics editor is also available as a stand alone program with version 13, it will be fully integrated in the next release.



Opera version 13

- Release date : end of May

- And what happens next?
  - Improved look and feel for all the programs
  - Opera-2d – the next generation based on the 3D Modeller
  - Conductors (wire wound coils) generated from geometry (with minimum variation of turns density if the cross section varies)
  - Parallel processing
    - First tests with Opera-2d very encouraging
    - Nearly linear scaling with number of processors (up to 4)
  - Links to Stress analysis (See the IMPDAHMA presentation)