Accurate Field and Harmonic Calculations for Accelerator magnets (*Using OPERA*)

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Overview

- Accurate Fields
  - Total and reduced Potentials
  - Integral Fields
    - Existing procedures & Developments
- Material Models
  - Anisotropic magnetic properties
  - Models for superconductor hysteresis and loss
    - Existing procedures & Developments
- Developments

Accurate Fields

Total and Reduced Potentials

H_{TOTAL} $H_{coil}+H_{iron}$

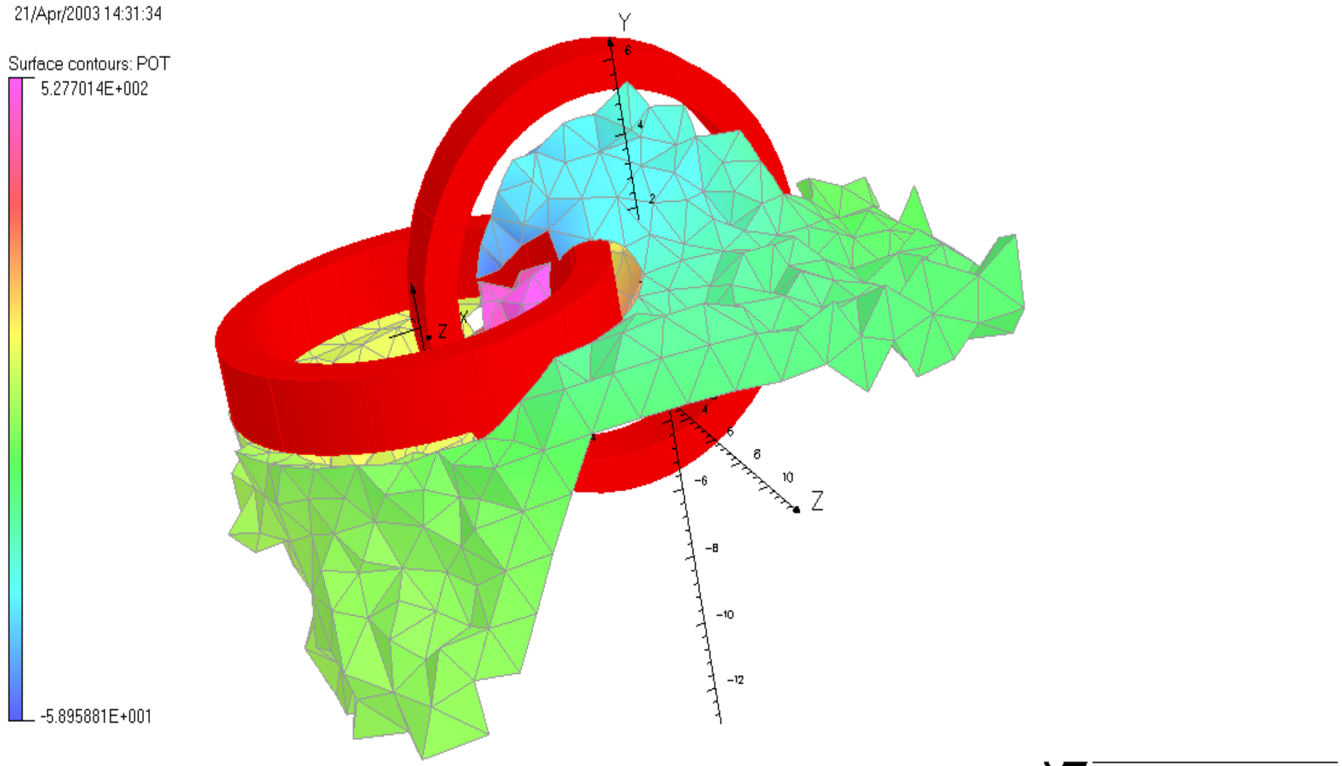
- Gives the best results for a given mesh
  - Providing it is used intelligently
    - Simple rules

Inside Coil	- REDUCED
Coil fields dominate	- REDUCED
Iron & Coil fields cancel	- TOTAL

However, the cost $\propto$ volume of reduced potential

Multiple Connectivity and cuts

- Cuts required to make scalar potentials single valued are calculated completely automatically



Accurate fields in the working Volume

- Fields direct from the FE solution
  - Model should use high order elements (locally)
  - Post processing: Switch to coil fields by integration

    (otherwise interpolated using the FE mesh)
  - Check the error in the solution (errB)
- Fields by Integration

$$\vec{H}_{iron} = \nabla\left(\iiint \vec{M}.\nabla\left(\frac{1}{R}\right)dv\right)$$

  - Available in OPERA-2d and OPERA-3d
  - Impressive improvement in accuracy (not too close to the iron)
  - But it’s expensive (do as many points as possible at one time)

Low order numerical integration for speed $\propto$ even worse answers close to iron

Developments

- Fields by Surface Integration

Use Green's theorem to evaluate the field at any point inside a volume given the fields on its surface eg.

$$\phi = \oiint_{\gamma} \phi \nabla \left(\frac{1}{R} \right) \cdot \hat{n} + \frac{1}{R} \nabla \phi \cdot \hat{n} \, ds$$

- Advantages:
  - Speed – compare number of surface and volume 'elements' (and accuracy because we can afford better integration methods)
  - Flexibility – Could be done in a selected volume

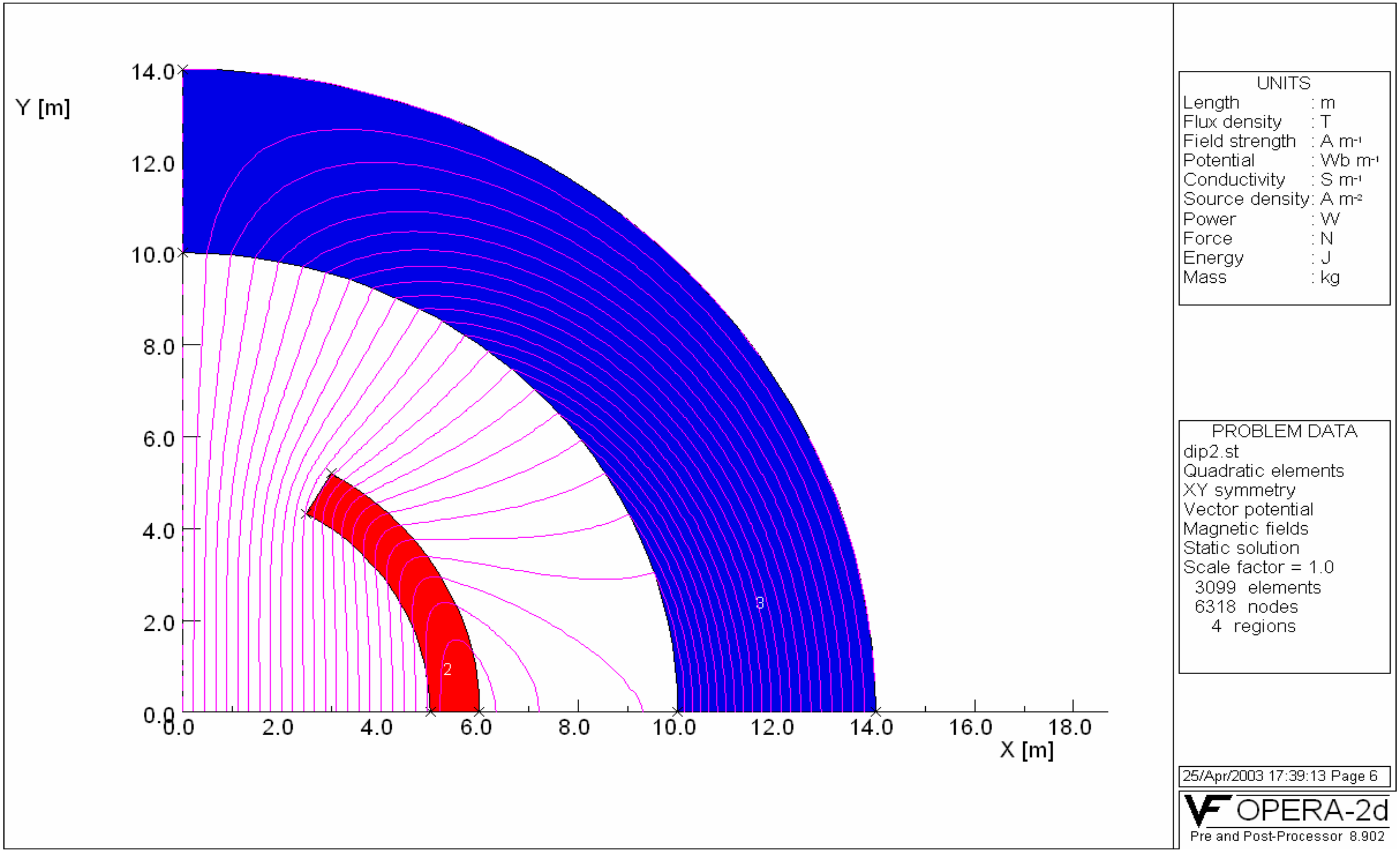
Should there be :

- Direct access to Field integrals

$$\vec{F} = \int_{-\infty}^{+\infty}\left[\nabla\left(\iiint \vec{M}.\nabla\left(\tfrac{1}{R}\right)dv\right)+\iiint J \times R \Big/ \left|R^{3}\right| dv\right]dz$$

- Would it be good enough to only integrate wrt Z

Fitting to Fields or Potentials



Fitting to Fields or Potentials …..

- For best accuracy should you fit to the calculated potentials or fields
  - Comparison of the RMS errors in the first 5 non-zero harmonics for a dipole magnet

		% RMS Error in harmonics	
	Element size	Fitting to A_z	Fitting to B_r
FE Interpolate	0.5	0.017	0.077
FE Interpolate	0.25	0.004	0.016
FE Integral	0.25	N/A	0.001

Modelling Superconducting windings

Multi-turn coil with filamentary conductor

- Calculate maximum magnetisation as a function of B (for the given J), and use this to specify the magnetic characteristics of the material.
  - Approximation, not accurate near transition (up-down)
    - Assuming field change has caused saturation
  - Isotropic property M(|B|)
  - Easier to solve with + magnetisation

GSI/BNL/Martin Wilson

- Requirement to model both hysteresis and rate dependent eddy currents in cable wound coil
  - Anisotropic Magnetisation
    - Different transverse and parallel rate dependence
    - Isotropic hysteresis components
    - Terms depend on

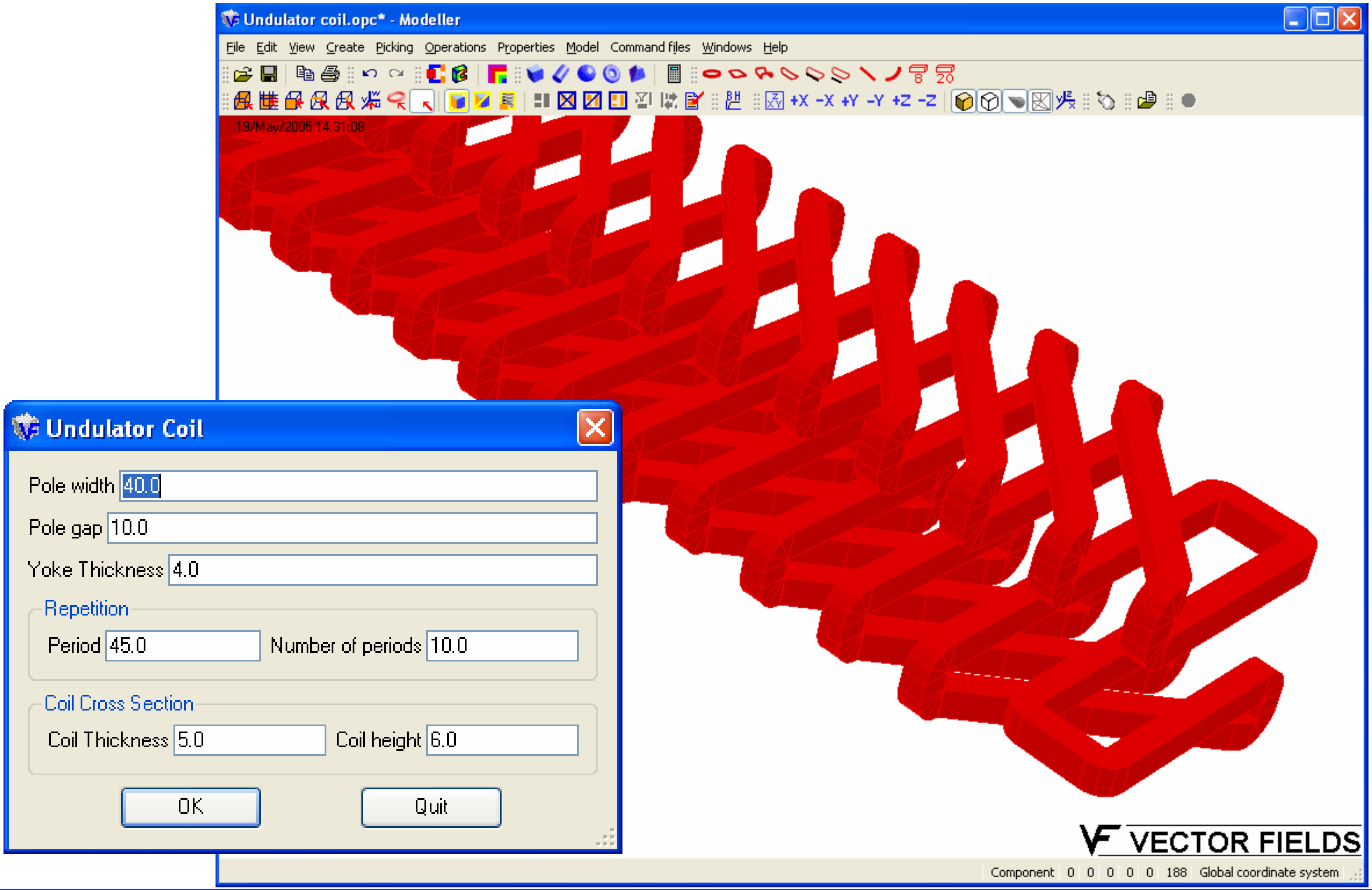
      B dB/dt B_p Bt dB_p/dt and dB_t/dt

- Not possible to define magnetic characteristics with this this vector dependence

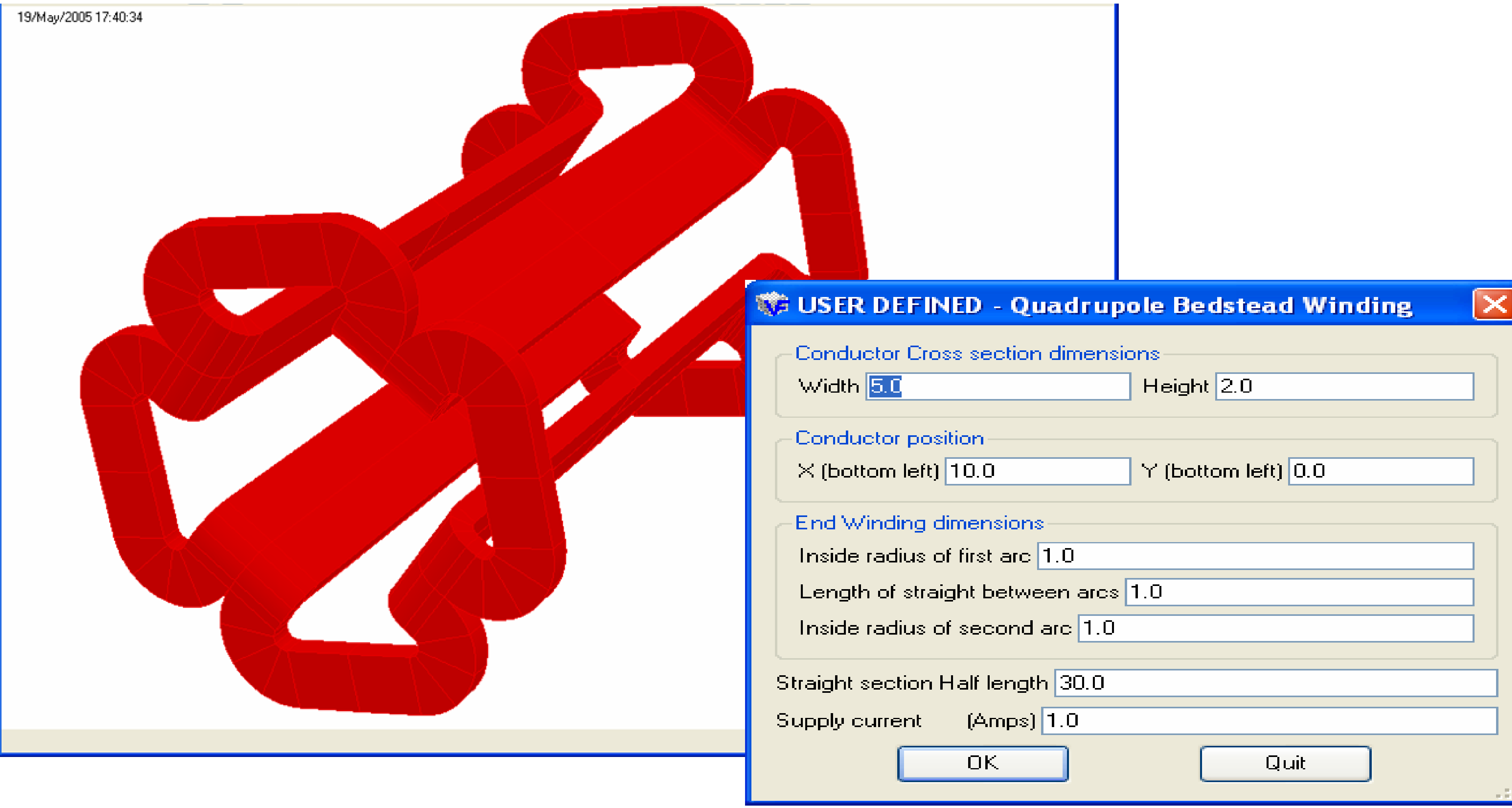
Development

- User defined permeability tensor function has been added to OPERA-2d
  - But its not very easy to use
- Is this useful to other people?
  - Should we put in the effort to make it easy

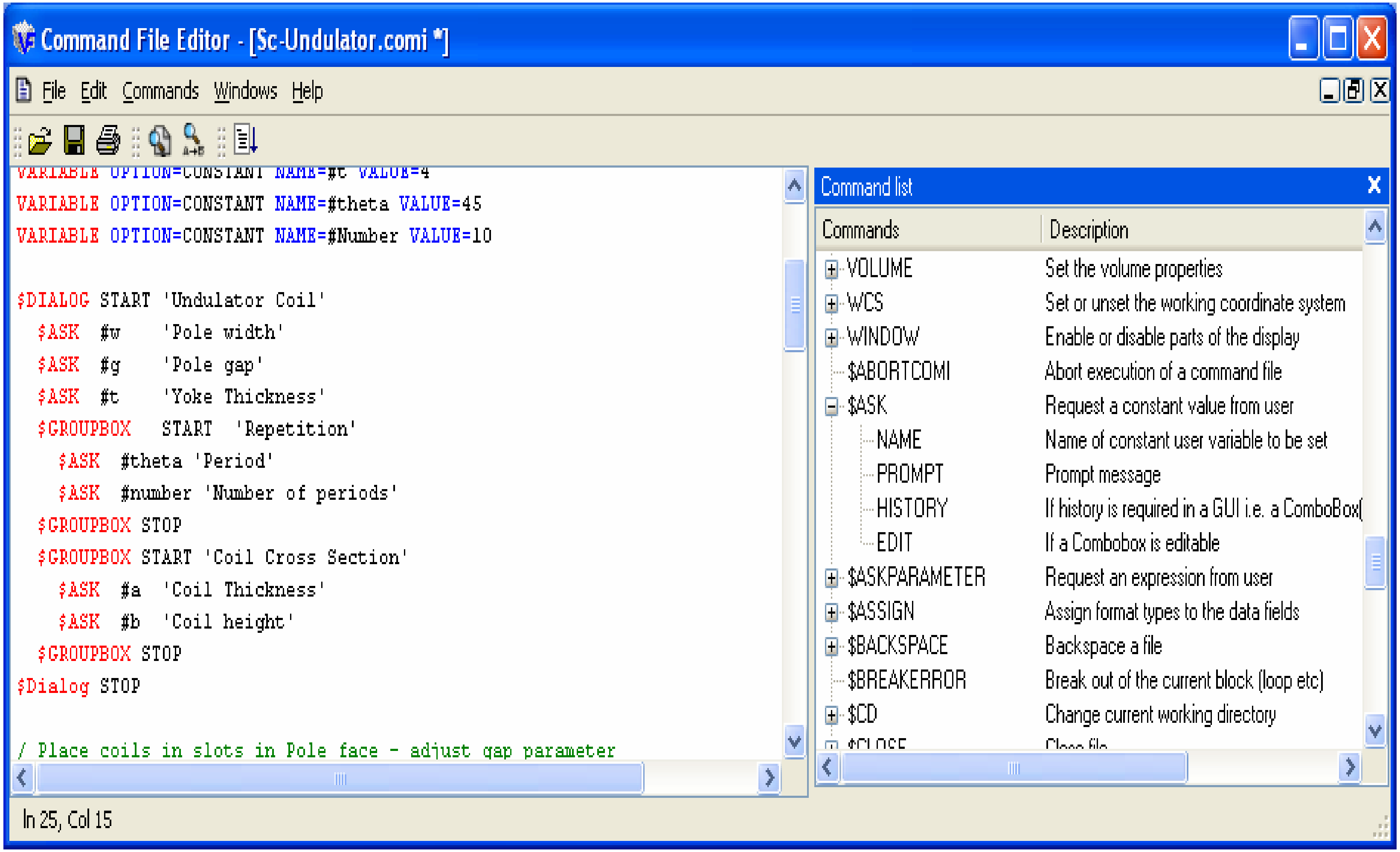
Making it easy - User Dialogs



Another example



Constructed using the Command file editor



Make the optimiser easy to use