Major Enhancements in OPERA V9

include TEMPO for 3d thermal analysis

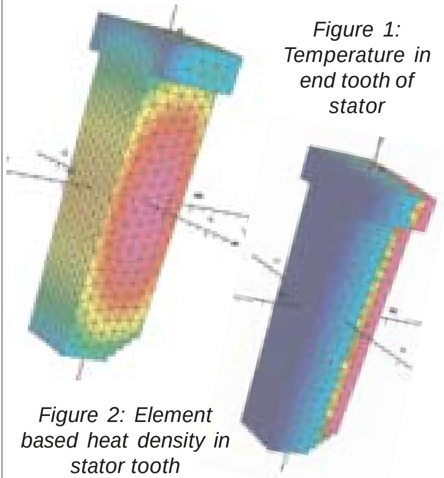

Figure 1: Temperature in end tooth of stator

Figure 2: Element based heat density in stator tooth

OPERA version 9 contains many new developments that allow users to model and solve an ever-wider range of electromagnetic problems. The most significant new development is the TEMPO module for 3d steady-state temperature analysis. The program may be used in stand-alone mode with the user defining the distribution of heat input or can be used in conjunction with any of the OPERA-3d modules to determine a volume heat distribution. Other important developments include new geometric modelling facilities, meshing improvements and BH curve definition tools in the OPERA-3d Modeller, improved display features for external circuits in OPERA-2d and advanced control features for OPERA-2d transient analyses in the RM, LM, TR and DM solvers. The OPERA-3d Modeller is also now supporting data input of IGES (International Graphical Exchange Standard) files, allowing it to interface with an even wider range of CAD tools.

TEMPO

TEMPO solves the Poisson equation for final temperature where *k* is the thermal

$$\nabla \cdot \boldsymbol{k} \nabla T = -Q$$

conductivity, *T* is the temperature and *Q* is the heat density. The thermal conductivity may be non-linear with temperature, as well as a function of the spatial variables x, y and z. Heat density values computed from one of the OPERA-3d electromagnetic analyses may be added to the unsolved TEMPO database as tables of values either at the nodes or element centroids of the thermal mesh. New table facilities in the OPERA-3d Post processor have made this a simple process. The user chooses any allowable expression for the heat density (for instance, as a function of the flux density) and renames the result in the table for the appropriate type of heat table, RELEMENHEAT or RNODALHEAT. A table with heat density from multiple sources – eddy current and iron losses in a motor, for example – can be produced using the ARITHMETIC options in the Post processor.

Four types of boundary condition are supported:

- fixed temperature
- perfect insulator (the default condition)
- heat flux
- heat transfer to fixed temperature medium

In the OPERA-3d Post processor, the user can display results of temperature, temperature gradient and heat flow. An estimate of the maximum error in the heat flow arising from the discretisation is also available.

Figure 1 shows the temperature distribution in one tooth of the end packet in a large generator stator. The heat distribution is evaluated as a function of the flux density from a TOSCA analysis and is shown in Figure 2. Axial fluxes cause a high density on the outer axial face of the tooth. Heat transfer boundary conditions have been applied on the inner and outer axial faces and at the inner and outer radial boundary surfaces.

OPERA-3d Modeller

New options in the Modeller allow existing bodies to be modified using bend, twist, stretch and general morphing functions. This enables very complex shapes to be developed from simple primitives. Figures 3 and 4 show examples of the new morphing function.

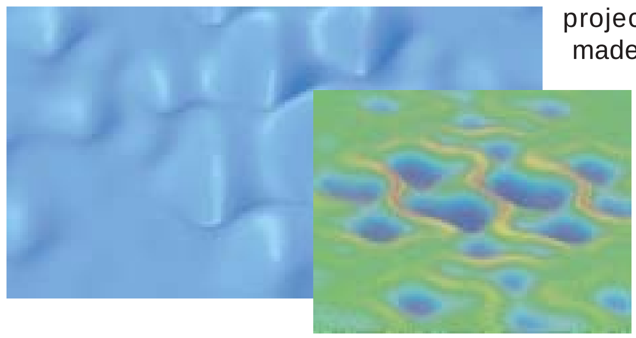

Figure 3: Standard models for rough surfaces defined using 2D fourier series morph functions, used to study electrical break-down or for characterising NDT systems.

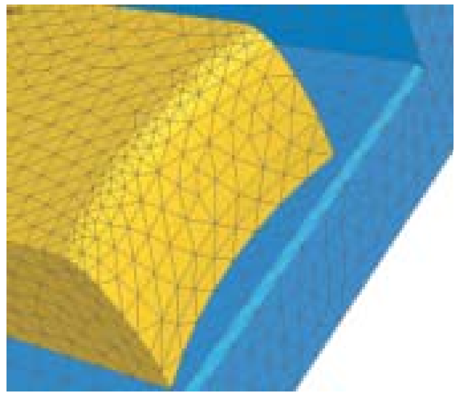

Figure 4: The curved input pole face of a spectrometer magnet, with an exponential profile generated on the curved pole using the morph function.

Another new feature is layered meshing. In many applications, the aspect ratio of some parts of the geometry is extreme. Examples of this are shields for MRI and other medical magnets and air-gaps in magnetic recording heads. Although the Modeller has always been able to mesh these structures it often resulted in an excessive number of elements. To achieve at least three layers of elements in a 10mm thick sheet of steel the maximum element size must be chosen to be smaller than 3.33mm which will produce millions of elements if the sheet is 5 metres x 5 metres! The new layering facilities overcome this by allowing the user to specify how many layers will be used in the depth of a volume irrespective of the maximum size of element chosen. The surface mesh from a user-selected face is projected onto each new face made between the layers. This also ensures that the resulting elements do not contain solid angles approaching 180 degrees. These features are also useful in eddy current problems where skin effect must be modelled correctly. The layers do not have to be the same depth and the user may specify an offset function for the layer depth in terms of the layer number. Figure 5 shows the eddy currents in an ELEKTRA-SS example where the offset function in a 10mm thick plate was given as 1.0*LAYER and the number of layers as 4, producing layers of 1, 2, 3 and 4mm.

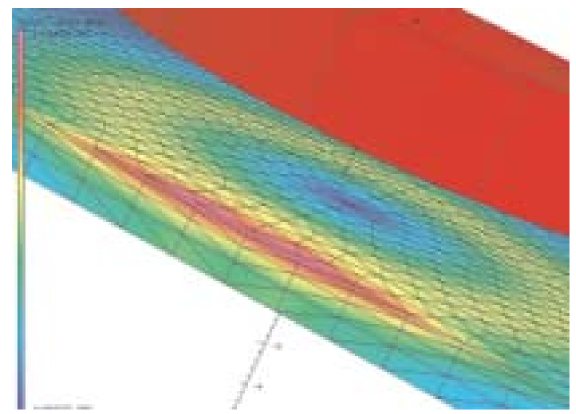

Figure 5: Layered mesh in ELEKTRA-SS model.

New facilities have been added to the Modeller for the definition of magnetic characteristics. The new BHDATA command allows the user to define, modify, display, save and load characteristics and uses a new graphical interface as shown in Figure 6. Tables of values may be directly imported from text files or a spreadsheet using "cut and paste" where appropriate. Local pan and zoom controlled by the mouse are also available. BH data files are interchangeable with all other OPERA-2d and OPERA-3d modules that support non-linear magnetic materials.

OPERA-2d

Facilities for graphically displaying region properties have been improved. As well as the region number the user can elect to display

- conductor number
- circuit number
- group membership.

The region number display also shows the region number (enclosed in parentheses) of replications. Figure 7 shows the display of the circuit numbers for an OPERA-2d/RM model of a four pole synchronous generator. In addition, the Pre and Post processor now also highlights the regions of a circuit currently being modified.

Drive functions for transient OPERA-2d analyses (TR, RM, LM and DM) have been specified as user defined tables or pre-defined functions (ramp, sine etc) in previous versions of OPERA-2d. A new option has been added to allow a functional drive specified in a command file to be included. For TR and DM, the functions may be expressed in terms of the transient time, TTIME, while in the motional solvers, RM and LM, the mechanical properties (position, speed, force, torque etc) may also be used. User defined parameters and constants may also be included in the expressions. New variables for the instantaneous voltage on the power supply (in the circuit) at each timestep has also been added.

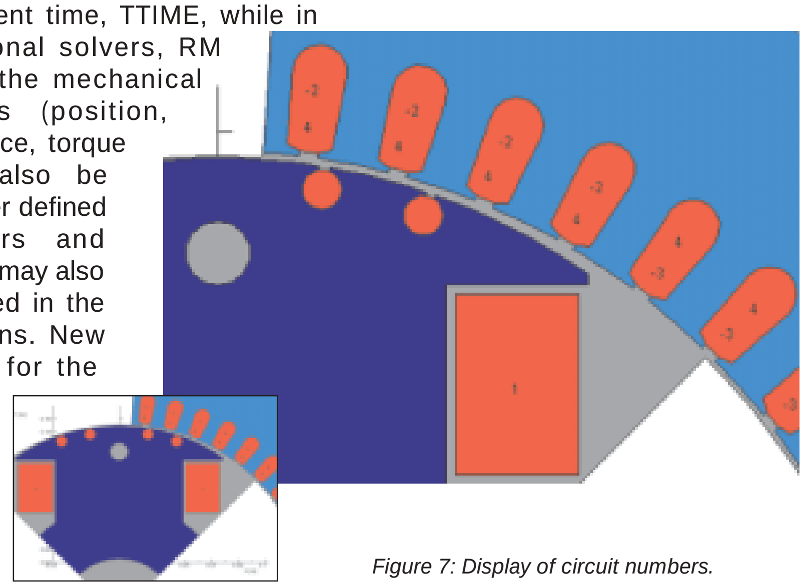

Figure 7: Display of circuit numbers.

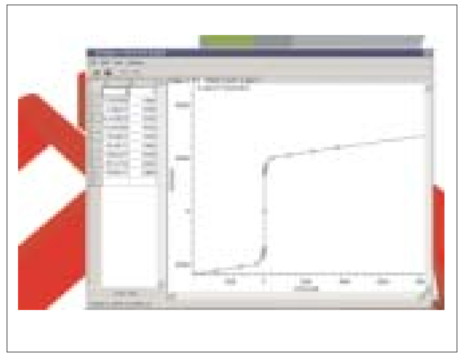

Figure 6: BH data facilities in the OPERA-3d Modeller

These new features allow simulation of "switches" found in typical power electronic circuits and can be easily programmed to support commonly used drives such as PWM and chopper circuits.

Demagnetisation in OPERA-2d

A new module introduced in OPERA-2d version 8.7 gives accurate prediction of the performance of permanent magnet machines magnetised in-situ. The Demagnetisation (DM) module developed in conjunction with a major US supplier of permanent magnets and materials has been introduced specifically to model the magnetisation process for hard magnetic materials. During a non-linear analysis, OPERA-2d/DM can use a virgin BH curve for material magnetisation and then secondary 'demagnetisation' BH curves as the field decreases.

The main use of DM is for the design of fixtures for in-situ magnetisation of fully assembled permanent magnet devices such as motors for domestic or other high volume applications. Modelling of the magnetisation process enables the designer to accurately determine the performance of the finished product and optimise material usage with the correct selection of magnet material type, design of the fixture and the specification of the capacitance discharge magnetiser.

This unique module further extends the capability of OPERA-2d into specialist areas of application.