Efficient three dimensional modelling of arbitrary shaped conductors using the finite element method

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Abstract

Advanced numerical techniques for electric and magnetic field calculations, connected with the increased computing power, available even for smaller companies, are getting widespread in industry. At the same time, the demand for analysis and simulation of more complicated structures rises. Full 3D analysis is often required. This paper describes a tool for advanced pre-processing of coils and conductors, helping to reduce the total pre-processing time in a 3D finite element method (FEM) analysis significantly. The implementation of the tool into an existing FEM package is demonstrated on an induction heating model.

roduction

ern finite element based CAD software packages cover a wide range of applications, g from mechanical over thermal to electromagnetic and dynamic analysis. The general ture of such packages is more or less the same:

-processing 50 % ⇒ solving 20 % ⇒ post-processing 30 %

of the time in a 3D FEM analysis is spend in pre-essing, especially if complicated geometrical tures have to be evaluated. This can reach up to 60% nore of the total analysis time of the analysis. Many ssional FEM packages are designed to allow the sis of a wide variety of shapes and problem types, providing a lot of general tools for pre-processing. results in rather complicated commands and user aces.

ical machines and induction heating are at the top of low frequency application list for FEM in omagnetics. Pre-processing for conductors and coils y time consuming due to the complicated shapes of devices as indicated in fig.1.

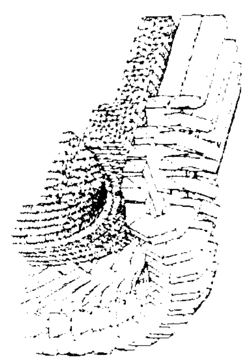

Fig. 1: Finite element model of the end winding region of a 400 kW induction machine

The tool presented in this paper is focusing on the reduction of time consuming work in t pre-processing phase of arbitrary shaped conductors and coils. A short overview of t existing techniques for mesh generation is given, as well as of their applicability for generati such structures. Splitting of material and excitation meshes is a common tool to reduce t complexity of the model geometry. It is necessary to give a brief introduction to the underlyi potential theory which allows such pre-processing strategies.

Scalar- and vector potentials in electromagnetics

Scalar potentials are widely used in magnetostatics, especially the reduced scalar potential for non-magnetic regions and the total scalar potential Ψ for magnetic material [1]:

$$\nabla\mu\nabla\Phi = \nabla\mu\mathbf{H}_S \qquad \text{with } H_S \text{ as source field strength} \qquad (1$$

$$\nabla\mu\nabla\Psi = \nabla\mu\mathbf{H}_C \qquad \text{with } H_C \text{ as coercivity, } \mu \text{ as permeability} \qquad (2$$

A current source can be applied in non-magnetic regions only, due to the reduced sca potential used there. For time-harmonic (eddy current) problems, scalar and vector poten formulations might be used. The reduced scalar potential is chosen in non-conducting regio whereas the vector potential **A** is applied in conducting regions [1,2]:

$$\nabla\times\frac{1}{\mu}\nabla\mathbf{A}+\sigma\left(\frac{\partial\mathbf{A}}{\partial t}+\nabla V\right)=\mathbf{J}_S \qquad \text{with } J_S \text{ as source current density} \qquad ($$

An elegant way of specifying the current excitation is given by providing separate material a excitation meshes. Using this approach, the excitation current density may be automatic transferred to the material mesh. Each current path can be modelled separately. The sou field at each node can be obtained by evaluating Biot-Savarts-law (4).

$$H_S=\frac{1}{4\pi}\int_\Omega J_S\times\nabla\left(\frac{1}{R}\right)d\Omega \qquad ($$

Mesh generation

Following the above described approach, two types of meshes must be provided. One mate mesh including all regions with different material and one or several excitation mesh specifying one path of excitation current each, are needed for each 3D electromagn analysis. Coils which serve as excitation only, do not have to be represented in the mate mesh. This simplifies the generation of the material mesh. The excitation in conduc materials has only to describe one possible DC-path of the current, thus having the simp possible shape. The skin effect leads to the physically correct current distribution.

Solid modelling or extrusion based mesh generation techniques can be applied for preparation of the material mesh, depending on the complexity of the geometry. The advant of extrusion based meshing in terms of memory requirement and speed can be utilised generate the excitation meshes. A cross section of the coil is meshed (base plane), and co of this cross section (planes) are appended using shifting and rotation. Most FEM-packa

... and any orientation in space by a series of three
is in a fixed order. It is very often difficult to obtain the required EULER-angles and the very tedious.

;enerator

;enerator is developed, allowing coil modelling in an easier manner than most of the purpose mesh generators. The coil generator is based on the extrusion technique. One / of the coil in preparation and the three projections allow simple verification of all ıs illustrated in figure 2.

antages of the coil generator as an on specific tool are:

- EULER-type rotations necessary;
- ne oriented use instead of co-linate oriented use;
- ıple command structure, allowing eractive and batch mode operation;
- defined macros for frequently d coil shapes;
- omatic mesh verification;

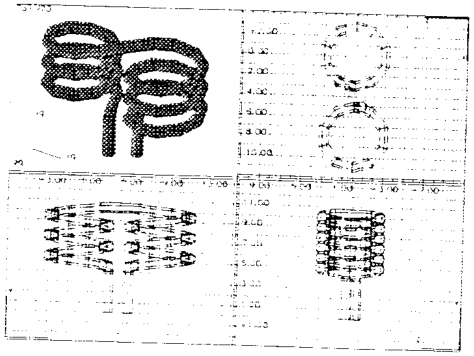

Fig. 2: Graphics of the coil generator, showing a helical coil used in an induction heating calculation

›n heating model

ion heating model is chosen to demonstrate the possibilities and the advantages of the ator. The analysis is carried out with a professional electromagnetics FEM-package.

splitting technique mentioned above, two separate e generated. The first is the material mesh, containing olid conducting cylinder and the surrounding air. This very simple extrusion in axial direction [3].

tion coil is constructed with the coil generator. Such enerated in about 5 minutes of time. It is based on oo. The aim of the analysis is the calculation of the rrents and their distribution at a frequency of 200 l as the loss distribution. This could serve as the or a thermal analysis in a coupled calculation

the induced currents inside the excitation coil are rest, this coil might be modelled separately. If the ırrent in the excitation coil is of interest, the of the coil must appear in the material mesh. This

Fig. 3: Induction heating model

will imply the need of full solid modelling of the whole geometrical structure.

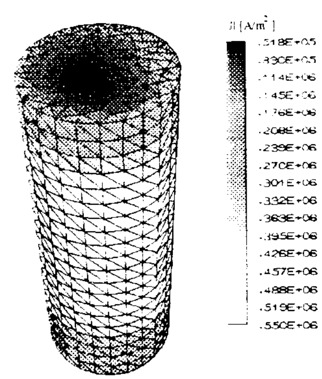

Fig. 4: Current density distribution on the surface of the conducting cylinder.

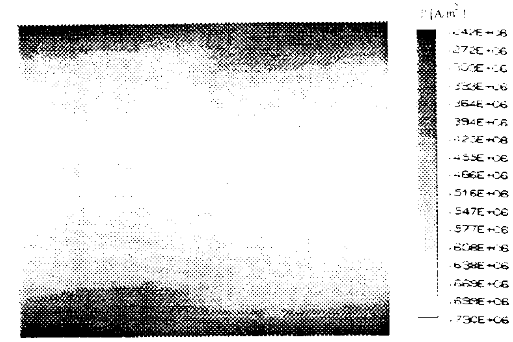

Fig. 5: Mapped cylindrical slice showing the current density distribution slightly below the surface of the solid cylinder.

Although the material mesh was purely extrusion based, the influence of the helical excitation structure can be found in the current density distribution (figure 4,5).

Conclusion

As shown in the induction heating example, complicated geometrical structures can be modelled with less expenses if a splitting of the material and the excitation mesh can be applied. Using application specific tools, like the introduced coil generator, helps to reduce the pre-processing time for 3D FEM substantially. The coil generator may be adapted to work with different FEM packages.

Acknowledgements

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