3D software levels the electromagnetic field

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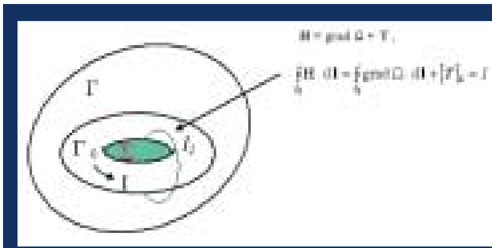
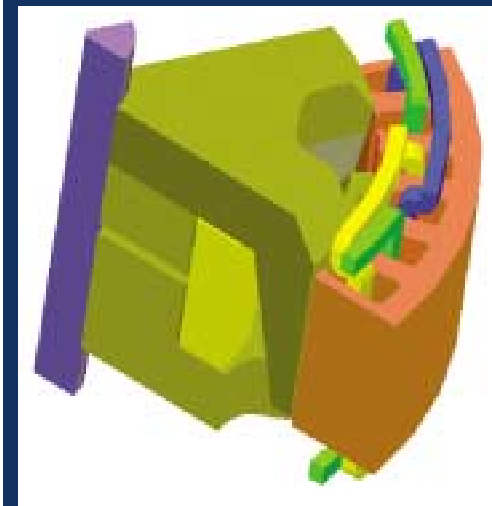
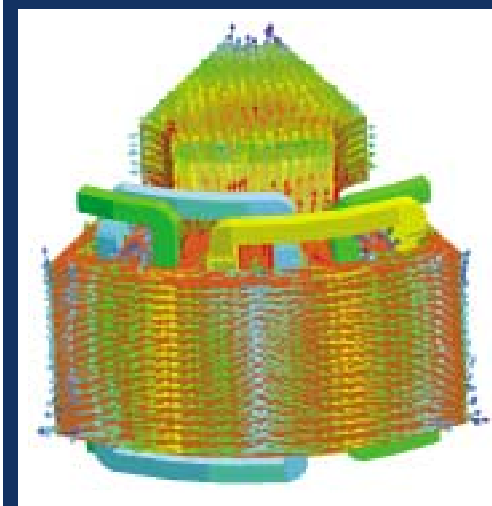
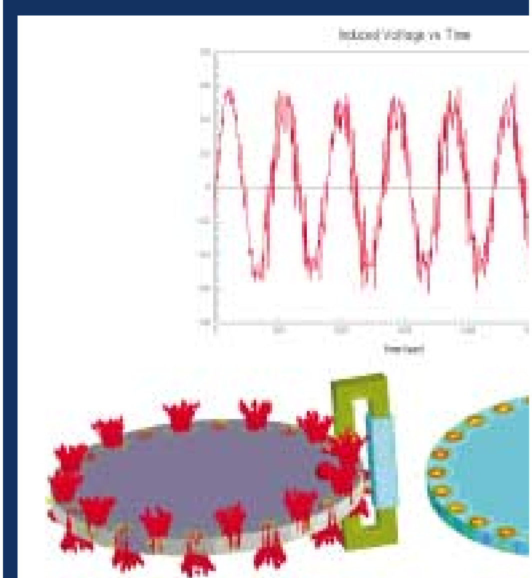
Setting up and solving complex electromagnetic-field problems can be tough but new 3D software aims to simplify matters









3D transient applications are a difficult problem to solve. The presence of non-linear materials, rotational and translational motion, coupled with electric circuits and mechanical elements, add to the difficulties.

Ansoft has developed a new version of its Maxwell 3D software specifically to solve these challenging numerical simulations. This transient solver uses a formulation based on:

- a current vector potential T in conducting regions of the solution space normally associated with the solid conductors;
- a scalar potential over the whole solution space; and
- an additional impressed current vector potential Hp describing the field associated with an arbitrary current distribution that amounts to the prescribed net current in both solid conductors (conductors with eddy current effects) and stranded conductors.

Additional equations are necessary to allow voltage-driven excitations for the coils and conductors in the application, separately for the case of solid conductors and for stranded windings. Stranded windings do not carry eddy currents and therefore are placed formally in the non-conducting region of the problem, thus having a uniform current density distribution over the respective cross-section.

The electric circuit, if part of the problem, brings its contribution to the global matrix of the application. Thus, a strong coupling formulation is used to solve simultaneously for the field quantities (magnetic field vector) and for the circuit unknowns at each time step. As a result, a non-linear algebraic system of equations is solved at each time step with a Newton-Raphson (a well known algorithm for solving equations) scheme being used in the non-linear iteration loop. The mechanical lumped elements associated with moving parts (if the application includes large rotational or translational motion) and the corresponding equations of motion also are considered in the same global solution process such that mechanical quantities, including position and velocity, are obtained at each time step.

One significant advantage of Ansoft's solution is the automatic detection of the order of connectivity of the problem. This means users do not have to manually set up the cuts that would make the solution space simply connected: a task that requires understanding of the concepts involved in physical mathematics.

The magnetic scalar potential distribution calculated by the software is unique in simply connected domains and using the magnetic scalar potential as unknown has advantages regarding the memory used to solve the problem because it is a scalar quantity. The cuts that make the domain of the problem simply connected are created automatically by the programme as shown in Figure 1. Thus, the solution is calculated accurately while preserving the ease of use and automation.

The computation of the magnetic fields is realized using tangentially continuous edge elements. Further, the use of edge elements ensure the correct behavior of calculated magnetic fields across discontinuity surfaces and this is achieved with greater computational efficiency than classical methods used by other codes.

Applications

The applications for a 3D transient simulation are broad, ranging from stationary devices, such as transformers and sensors, to rotating electric machines, magnetic bearings and brakes.

Take, for example, the simulation of the claw-pole generator in Figure 2. There are a few challenging aspects of this simulation that highlight many key capabilities of the software:

- complex geometry of the device;
- non-linearity of the magnetic core;
- motion-induced eddy currents in the solid steel claws (rotor);

Anti-clockwise from left:

Figure 1: Automatic cuts to render the domain simply connected such that the magnetic scalar potential can be unambiguously defined everywhere in the solution domain

Figure 2: Claw-pole generator geometry

Figure 3: Magnetic flux density distribution at t = 10 ms

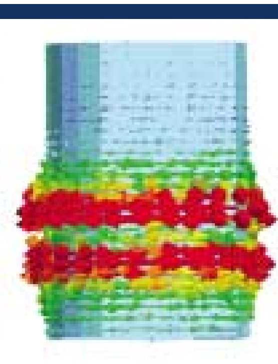
Figure 4: Magnetic flux density and voltage induced in the coil of the sensor

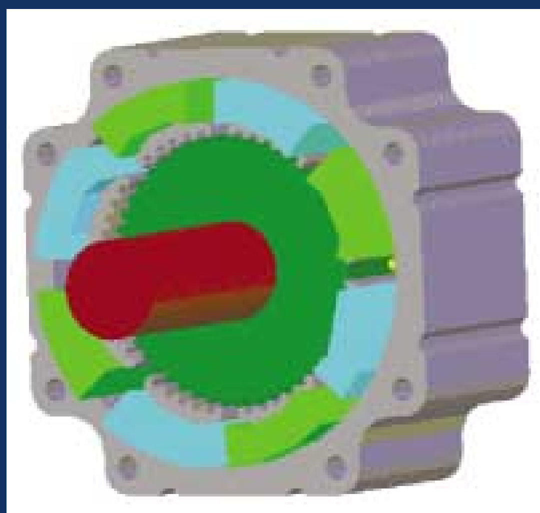
Figure 5: Induction motor model with 50 to 60 Hz conversion circuit

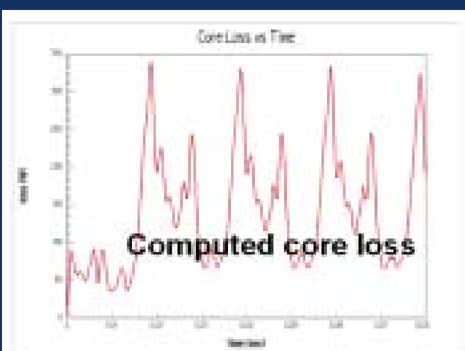
Figure 6: Transformer model with core loss calculation set up

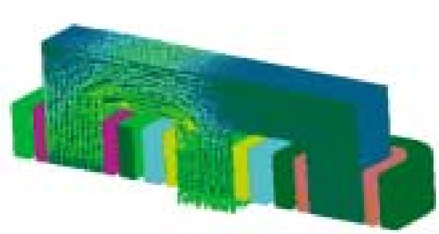
Figure 7: Stepper motor solved with 64-bit code

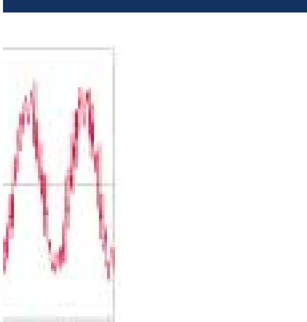
Figure 8: Motion-induced currents and structural deformation of the device

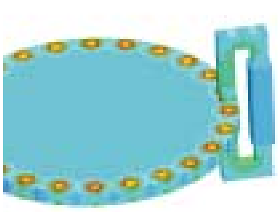


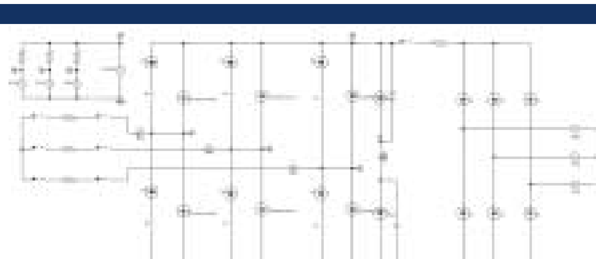


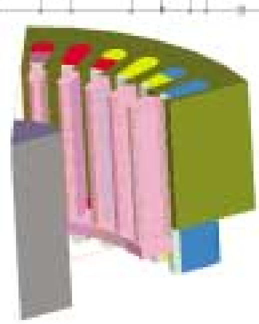












● the rectifying electric circuit attached to the windings of the stator; and
● core-loss computation in the steel of the stator.

To take advantage of the spatial symmetry of the field distribution, only a 60° wedge is modelled. Master-Slave boundary conditions are easily and conveniently defined, allowing significantly lower computer resources to be used in the simulation. The possibility to set Master-Slave boundary conditions for applications with challenging topologies, such as those in this problem, is a key advantage.

During the analysis of this device a number of electromechanical quantities are automatically calculated. Examples are torque, core loss, position, currents in the coils, voltages, etc. Field quantities are available for post processing. Figure 3 shows a plot of the magnetic flux density in the rotor and stator.

A large number of actuators and sensors applications that require a 3D Transient solution sequence can be simulated within Maxwell v10. Types of applications involving sensors and actuators include different types of position and velocity sensors, AC actuators with significant 3D effects and possibly using non-linear materials, MEMS devices, and so on.

Figure 4 presents a position and speed sensor application and the respective results. The setup includes an automatic change of the constant speed at which the sensor is analysed, such that fields and global characteristics can be simulated at a whole speed range of the device. The user-selected variable time-stepping feature is utilised to permanently synchronise the time step with the variable speed used in the application and the signal generated by the coil is automatically calculated. Furthermore, using the Signal Calculator available within the software, the coil signal can be further analysed as a whole or sampled for user-selected time intervals.

The circuit attached to the coil of the sensor in Figure 4 is quite simple. The complexity of the driving circuits of the coils can be significantly increased. For example, the three-phase induction motor in Figure 5 has attached stator circuits that consist of an inverter with 50 to 60Hz conversion circuits. Circuits attached to finite-element models can also contain simple circuit elements as well as current and voltage probes, diodes, switches controlled by time, and position or speed variables. The possibility exists to use even more complex switching circuits with current chopping capability, thus allowing a complete current control in the branches of the circuit where these switches are used. The controlled current is automatically kept within the user-specified current hysteresis window.

For more complex control situations, users can couple their own control program to exchange information continuously via a text file. Thus, input quantities such as sources and time step can be continuously monitored and, if necessary, altered by a user-control program.

Additionally, users can define and run post-processing macros. This additional capability extends the range of automatic calculations performed during the solution process and basically means that complex algebraic and calculus operations using the vector fields can be performed during the solution process at each time step and made available to the user. Combined with the possibility that the user has to stop and restart the computation process, post-processing macros give more flexibility in controlling the process.

As another post-processing feature, the 3D Transient solver in Maxwell v10 can calculate core loss (eddy current losses, hysteresis losses and excess losses) in non-linear magnetic cores. This calculation is available as an executive parameter calculation for applications with or without motion included. The necessary input data for core loss is either the set of loss coefficients (eddy, hysteresis and excess) or the loss characteristic as a function of magnetic flux density. In the latter case, the loss coefficients are automatically calculated if lamination thickness and conductivity are also supplied. Figure 6 shows the model and core-loss results for a quarter model of a three-phase power transformer with rectifying circuit attached to the secondary windings.

Figure 7 shows the geometry of a computationally large finite element model. The programme can solve extremely large models, limited only by the amount of RAM in the user's Unix system. The stepper motor model in Figure 7 was solved using the 64-bit version of the software for a model with over 1.3 million tetrahedral elements and over 2 million unknowns requiring over 7 GB RAM to be allocated. For such high-end applications, the 64-bit code capability can be combined with multi-processing features for use with multi-processor computers.

The solver couples with the 3D structural stress solver in Ansoft's ePhysics (see panel). Thus, the force distribution at user-selected time steps from the transient solution can be used in linear static mechanical stress computations to obtain von Mises stresses – principal stresses, and deformation of objects in the model. Figure 8 shows two regions with motion-induced eddy currents flowing in opposite directions and corresponding deformation (magnified) in a hollow aluminium cylinder by a coil moving with 10 m/s inside the cylinder. Results in Figure 8 correspond to t = 10 ms time after motion of the inside coil began.

Enhancing electromagnetic component design

The combination of increasing frequencies and dissipated power, together with reduced size and weight, has made temperature and stress of great concern to electrical and electromagnetic engineers designing electrical devices. Often, excessive temperatures and stresses from electromagnetic heating and forces greatly reduce a product's lifetime or performance. In other cases, electromagnetic heating and stresses can help achieve desired design goals.

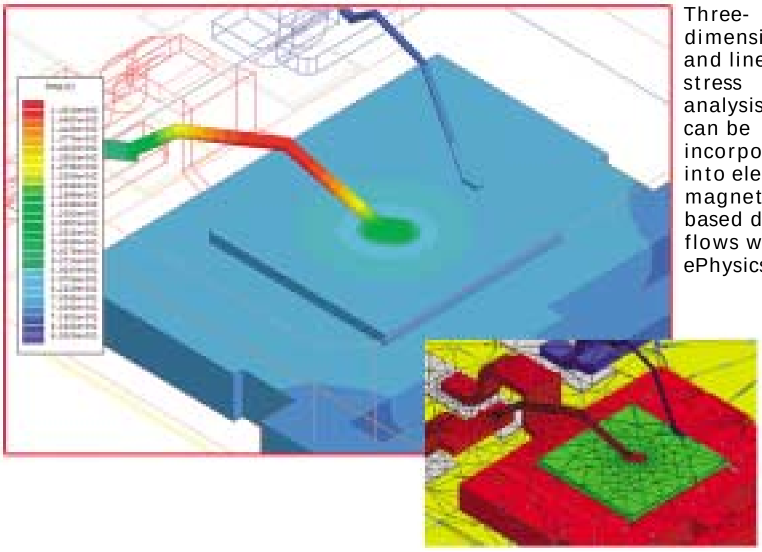
New software from Ansoft, called ePhysics, offers solutions to these problems by allowing engineers to incorporate three-dimensional, steady-state thermal, transient thermal and linear stress analysis into their existing electromagnetic-based design flows. The software expands the capabilities of the company's 3D electromagnetic analysis tools and enables engineers to optimise designs for maximum performance and cost efficiency. Coupling the software with such 3D transient solvers provides the cross-disciplinary analysis required in the design of electromechanical devices.

Features include:

- electromagnetic-centric coupled analysis;
- easy-to-use graphical user interface;
- automatic, adaptive meshing;
- automated mapping of all electrical losses to thermal sources;
- automated mapping of all electrical forces to stress analysis; and
- interactive post-processing for field visualisation.

Typical applications for the company's Maxwell 3D software include the analysis of electric machines, power-generation systems, transformers, micro-electromechanical systems (MEMS) and solenoids. Applications for HFSS with ePhysics include high-speed packages, antennas, monolithic microwave integrated circuits (MMICs), high-power microwave devices, military and broadcast communications and biological heating with radio frequency (RF) sources. These analyses include high-power, temperature-induced stress and size changes of design components.

ePhysics is available for PC and UNIX® platforms. For more information visit: www.ansoft.com/ephysics



Three-dimensional and linear stress analysis can be incorporated into electro-magnetic-based design flows with ePhysics

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