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Coupled Problems in Electromagnetic Device Design

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Introduction

When designing electromagnetic systems, the analysis of the electromagnetic energy transducers as such using advanced field calculation techniques is insufficient in order to obtain an optimized solution. The electric and magnetic parameters and properties are linked with the other physical properties and parameters of the device and the overall system surrounding it.

The paper describes the various interactions that have to be modeled in order to obtain information on the overall behavior of the electromagnetic system. Thermal, mechanical and acoustic analysis and circuit analysis have to be linked to the field solution. An other aspect of coupling is linking the field solution technique with numerical optimizing techniques, leading to a design environment that will enable future designers to offer solutions to their customers, rather than components, that although optimized on their own, do not deliver the best overall system behavior.

Coupled analysis

When electrical machines are designed for low audible noise surroundings, the electromagnetic forces have to be assessed as they will excite the stator, making it vibrate and emit audible noise. The electromagnetic force calculation is very difficult, as local forces suffer from discretisation errors in the finite element solution. Therefore, the mechanical structure is linked with the magnetic forces by the so called modal analysis technique, making use of the so-called generalized force technique. The modes of the stator structure, defining their ability to respond to a certain exciting frequency, are calculated using the finite element method. In this way, the mechanical vibrations can be predicted without actually having to calculate the forces. This improves the accuracy to a large extend. After the stator vibrations are found, the next step is the prediction of the acoustic emission behavior of the stator. Here the boundary element technique is favored. In this way, a three step analysis technique is found: reducing the audible noise of a motor can be performed by changing the magnetic circuit, reducing the forces, changing the mechanical structure to alter the vibrating modes or adapting the acoustic behavior, making it impossible for the stator to emit a given vibrating pattern.

The magnetic and electric parameters of the materials are very much dependent of the temperature. Therefore, the temperature has to be predicted as accurately as possible in order to supply the correct parameters to the magnetic calculation. However, the temperature is a function of the local losses, being a result of the magnetic field solution. An iterative procedure is therefore needed. Two examples are discussed illustrating this approach. The first one is the dielectric heating of material in which a high frequency electric field is applied to an insulating material. The dielectric loss constant is changing as the material heats up, resulting in a varying loss density as a function of time. The second example is the analysis of the temperature distribution in an induction motor.

The linking of the finite element solution with circuit analysis is also extremely important. Nowadays many electromagnetic energy transducers are coupled with the energy source (usually the grid) via power electronic converters. Ideally a full transient solution coupled with the non-linear differential equation system, describing the power electronic converter, has to be used. However, this is not feasible. Therefore, the electromagnetic energy transducer is represented by an equivalent circuit. As an example, a squirrel cage induction motor is represented by an equivalent circuit on a per pole basis. The number of elements in the equivalent circuit equals the number of stator phases plus the number of rotor bars per pole. A second example is the representation by the d-q transformation of permanent magnet motors in order to include them in the simulation of field oriented control schemes.

Also inside the finite element analysis, circuit elements may be required. As an example, the induction motor end ring impedance may be included in a two dimensional analysis. The parameters of the ring are found from a three dimensional solution.

Optimization

Two types are optimization are encountered.

The first is the optimization of the electromagnetic energy transducer as such. This may be tackled by coupling the field analyses method to numerical optimization techniques as statistical analysis, simulated annealing or evolution strategy. This technique is applied to a small, permanent magnet motor. The optimization is controlled by a set of constraints and a set of target functions. In the permanent magnet motor, the target was to minimize the material cost, while keeping the machine performance at a sufficiently high level with regard to torque and losses.

As a second example, the electric and magnetic fields under a high voltage line had to be minimized. Several designs were compared using the optimization technique. Rather than solving the field distribution using the finite element method, as in the electric motor example, the field is obtained using an analytical solution.

The second type of optimization is the overall system behavior. When a target is set for the system, the components have to be chosen before the component optimization can be started. A first example is the supply of water in dessert or third world countries. Solar arrays are used as energy source. Therefore, the efficiency of the motor is key. Rather than using the induction motor, a permanent magnet motor is chosen. The permanent magnet motor is more expensive. However, it has a higher efficiency, leading to less solar cells and therefore, a lower overall system price. A second example is the choice of the appropriate motor for driving a small hybrid van. Again induction motors and permanent magnet motors are the competitors. It depends on the traffic situation the van is intended for, which solution will be preferred.

Conclusions

Coupled problems will become increasingly important in designing optimized electromagnetic systems. Rather than looking for optimized components, the customer wants to find optimal solution for his problems. Advanced materials, that may be expensive when looking from the component point of view, may lead to improved overall performance on a system level, making them very attractive in the end.

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