Computational Electromagnetics: the Past, the Present and the Future

Jan K. Sykulski, FIEE, SMIEEE, FInstP

University of Southampton, Southampton SO17 1BJ, United Kingdom, jks@soton.ac.uk

The research activity known as Computational Electromagnetics (CEM) has evolved alongside the modern developments in the digital computing hardware. Moreover, CEM is both a special case and part of the broader subject of computational mechanics. The paper reviews the state of the art in CEM with a focus on applications related to electrical engineering. Design and optimisation, as well as development of new materials, are emphasised as of paramount importance in the real engineering world. Modern computational methods based on finite elements and related techniques have now become a mature design tool, but the complexity of the underlying mathematics and physics often hampers widespread use of these efficient techniques. Recent advances in general purpose software are encouraging but much remains to be done in improving the standards of education to remove the mist of mystery surrounding the subject.

The CEM community has gone a long way to address the needs of designers and contemporary commercial software is capable of solving static, quasi-static and full transient problems in 2D as well as in 3D. Nonlinearity of materials, permanent magnets, various shapes of excitation coils – these are just examples of what can be solved (see an example of Fig. 1). Finally, coupled problems can be handled involving interactions between electromagnetic field, motion and supplying circuit. There has been important progress in fundamental formulations providing more solid foundations for numerical field analysis. The following is a non-exhaustive list of such advances which have recently made the greatest impact on the CEM community: a new *Finite Element Difference* (FED) method, higher order *Finite Difference Time Domain* (FDTD) approach, further developments of the *Transmission Line Matrix* (TLM) method, advances of the *Multiple Multipole Technique* (MMT), the use of *Finite Integration Technique* (FIT), a new *Subspace Projection Extrapolation* (SPE) scheme, working field theory problems with *Random Walks*, formulations in terms of differential forms, the usage of total/reduced magnetic vector potential and electric scalar potential, an introduction of *Lie derivative* as a tool for force computation, implementation of edge and facet elements, improved anisotropy models, modelling of High Temperature Superconductors (Fig. 2). Optimal design of electromechanical devices often necessitates repetitive usage of finite-element (FE) solvers, or other numerically intensive field computation. New methods such as The *Minimum Function Calls* (MFC) approach, *Response Surface Methodology* (RSM), *Evolution Strategy*, *Differential Evolution*, *Multiquadrics Interpolation* (ES/DE/MQ), *Neuro-Fuzzy Modelling* (NFM), *Pareto Optimal Front* (POF) and *Continuum Design Sensitivity Analysis* (CDSA) are subject of significant research effort.

Further progress is required and a possible list of topics for research and development may include: adaptive meshing with particular emphasis on problems with strong skin effect, reliable error estimation (a posteriori and a priori), code development for high speed computing, efficient handling of non-linearity, hysterisis and anisotropy, modelling of new types of materials (e.g. composite, superconducting), incorporation of linear movement and rotation of some parts of the device, combined modelling of fields and circuits (e.g. supply electronic circuits), coupled problems (electromagnetic + stress + temperature, etc), optimisation (deterministic and stochastic, practical implications), integrated design systems (combined mechanical, electromagnetic, thermal, economic).

It can be argued, however, that CAD in Electromagnetics is already a mature practical tool for design and optimisation of a variety of electromechanical devices and the engineering community can benefit from tremendous advances that occurred in the field over the past many years.

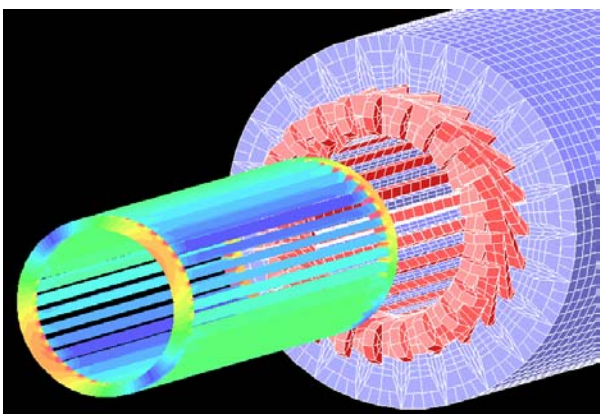

Fig. 1 A FE model of an induction motor

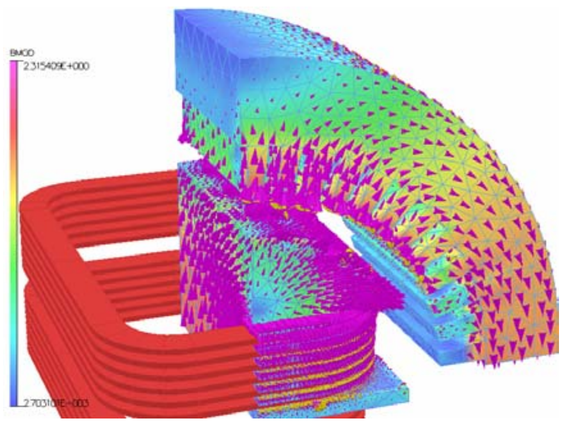

Fig. 2 Distribution of flux density in a HTS generator