BEM-Based Simulations in Engineering Design

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Summary. The simulation of the real-world industrial problems is nowadays faced with a number of the challenging requirements, mainly arising in the daily design praxis of power engineering devices. Complex structures, complex physics, huge dimensions and huge aspect ratio in model dimensions are just some of the critical modelling issues that need to be encountered by the simulation tools. Thanks to the advances achieved in the last several years, BEM become a powerful numerical technique for the simulations of such industrial products. Until recent time this technique has been recognized as a technique offering from one side some excellent features (2D instead of 3D discretization, open-boundary problems, etc.), but from the other side having some serious practical limitations, mostly related to the full-populated, often ill-conditioned matrices. The new, emerging numerical techniques like MBIT (Multipole-Based Integral Technique), ACA (Adaptive Cross-Approximations), DDT (Domain-Decomposition Technique) seems to bridge some of these known bottle-necks, promoting those the BEM in a high-level tool for even daily-design process of the 3D real-world problems.

The aim of this Chapter is to illustrate how this numerical technique can be used for the simulation of both single-physics problems appearing in the Dielectric Design (Electrostatics), and multi-physics problems in Thermal Design (coupling of Electromagnetic-Heat Transfer) and Electro-Mechanical Design (coupling of Electromagnetic-Structural Mechanics) of power engineering devices like power transformers or switchgears.

1 Introduction

The simulation of real-world engineering problems is nowadays faced with a number of challenging requirements, mainly arising in daily design praxis through:

- **huge dimensions** of the problem to be simulated, especially stressed when going towards *Simulation-Based Design*, including *assembly simulation* as opposed to *component simulation*. 

- **huge aspect ratio** in model dimensions. For example, in the dielectric analysis of power transformers, in order to correctly perform a simulation analysis one is forced to evaluate simultaneously handle massive parts like windings including shielding rings having a radius of $1 - 2[m]$, alongside the very thin paper insulation around them of thickness $1 - 10e^{-3} [m]$. Another example is the thermal analysis of transformers, whereby the huge aspect ratio in the dimensions of the tanks (enclosures) $1 - 10[m]$ versus their wall-thickness of 10-20 millimeters can lead to difficulties on both the meshing and numerics sides.

- **complex physics** requiring well founded mathematical formulations and proper numerical evaluation. As an example, consider the diffusion problem in low-frequency electromagnetics, where in typical devices ranging up to several meters in dimensions, the electromagnetic field penetrates into the magnetic material for just a couple of millimeters. A proper representation of this diffusion problem is a real challenge, and for the analysis of 3D problems this requires highly sophisticated numerics.

- **evaluation time**, which for the realization of a complete simulation chain for practical problems can be very long, but from the other side needs to be as short as possible for a daily design process.

Thanks to advances in numerics made in the last several years, the Boundary Element Method (BEM) has become a powerful numerical technology for 3D simulation of complex practical problems. In spite of some limitations of BEM, for certain classes of problems this method possesses several important advantages in comparison with the classical differential methods like FEM (Finite Element Method) or FDM (Finite Difference Method).

- Probably the most important feature of BEM is that for linear classes of problems the discretization needs to be performed only over the interfaces between different media. This excellent characteristic of BEM makes the discretisation/meshing of complex 3D problems more straightforward and usable for simulations in a daily design process.

- Also, this feature is of utmost importance when dealing with the simulation of moving boundary problems. Thanks to the fact that the space between the moving objects does not need to be meshed, BEM offers an excellent platform for the simulation of dynamics, especially in 3D geometry.

- Furthermore, the open boundary problem is treated easily with BEM, without needing to take into account any additionally boundary condition. When using tools based on the differential approach (FEM,FDM), the open boundary problem requires an additional bounding box around the object of interest, which has a negative impact on both mesh size and computation error.

- Another important feature of BEM is its accuracy. Contrary to differential methods, where adaptive mesh refinement is almost imperative to achieve the required accuracy, with BEM it is frequently possible to obtain good results even with a relatively rough mesh. But, at this point we also don’t