An Architecture for Embedding Knowledge in the Design of Electromagnetic Devices

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***Abstract*—The analysis and design of low frequency electromagnetic devices is a major area of research and software development. The assumption is often that a suitable field solution, usually, numerical, is sufficient to simulate and design such devices. However, from an engineering viewpoint, this is not true Considerable device knowledge is needed to translate an engineering design into a solution to a physics problem. This paper examines the roles of knowledge and numerical analysis in the design process for a device.**

***Index Terms*—Computational Electromagnetics, Design Engineering, Electromagnetic Devices, Software Design**

I. Introduction

The driving force behind the research into, and development of, the solution of the physics equations underlying the operation and performance of low frequency electromagnetic devices is the creation of a virtual simulation of the real world. In the virtual world, it is easier (and cheaper) to explore alternative designs, examine trade-offs and make design decisions. In addition, the virtual world provides opportunities, which do not exist in the real world, to investigate issues inside a device. For example, determining the flux density inside an electrical machine at a particular point and then computing the local loss and associated temperature rise cannot be done in a real machine using currently available technologies.

However, while creating the virtual environment involves the solution of the physics equations (electromagnetic, thermal, structural and fluid dynamic) given a particular distribution of materials and sources, this, on its own, is not sufficient to satisfy the needs of a designer. The structure of an electrical machine is dictated by several constraints. For example, in order to create a particular field structure in the airgap, a specific layout of electrical currents is required. To achieve this, the conductors must be placed in particular positions and then interconnected through their ends. These are three dimensional structures the shapes of which are often determined by the fact that two interconnections cannot physically occupy the same point in space.

In effect, the constraints on the physics model are imposed by physical requirements to construct a manufacturable three-dimensional structure. For the design engineer, the creation of this structure is probably the most difficult phase of the process and often requires considerable experience and knowledge. Thus, before a simulation can be performed in the virtual environment, considerable pre-processing work is required. Similarly, when measurements are made on the virtual device, they are often dictated by the interactions of the device with its external environment.

The intention of this paper is to explore the issue of including the knowledge related to the real device structure in the electromagnetic device simulation. In effect, to look at the difference between the creation of general purpose electromagnetic field equation solvers and device specific simulation systems from a point of view of enhancing the effectiveness of the numerical systems and determining the implications in terms of software architecture.

II. General Purpose versus Device Specific

Since the development of the basic electromagnetic field theory in the nineteenth century [1], there has been a recognition that this can form the basis of a powerful tool for the simulation of the performance of any electromagnetic device. However, until the emergence of reasonably powerful digital computers and the development of numerical analysis, the development of such tools was seriously limited [2], [3]. These limitations were a result of the physical structure needed to implement a real device. For example, an electrical machine can require that the current carrying conductors are embedded in slots in an iron structure. The iron is needed to guide the magnetic field that is being created by the currents in the conductors. This results in a relatively complex geometric structure consisting of regions with very different electrical and magnetic properties. The effects of the material interfaces on the magnetic field mean that the underlying equations are almost impossible to solve analytically in any but the simplest geometries. Given this, the tools that were developed used simple concepts of the "flow" of magnetic flux and combined these with knowledge of field behavior in the device structure.

The development of general purpose numerical solution systems, then, required not just the solution of the partial differential equations but also the inclusion of general interface and boundary conditions. Such systems have been proven to be effective at solving almost any field problem that is presented to them although there are significant costs involved. These arise from two sources. The first is that any general purpose system cannot take advantage of features of a particular device which may reduce the complexity of the problem. The second is that the engineer has to perform the mapping of the physical device onto the simulation environment, i.e. describe all the details of the particular device to the system. In the case of, say, an electrical machine, this can be extremely complex and time-consuming. Finally, the design process usually requires an exploration of a parameter space which is a function of the device structure and cannot be described in general purpose terms.

The alternative to a general purpose system is one which is created to be device specific, for example for a particular class of transformer. Such a system contains knowledge related to the actual device structure and maps this onto a numerical field simulation system. This could be considered to be the virtual equivalent of energizing the real device. In effect, the inclusion of knowledge constrains the general purpose solver and can result in a more effective analysis system.

These two architectures represent two ends of a spectrum of simulation systems, as shown in Fig.1. Variants on these architectures and implementations can be found in [4], [5].

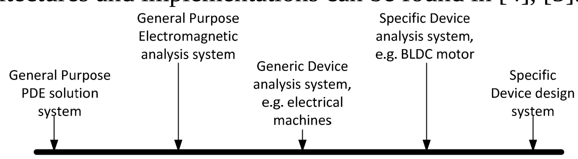

Fig. 1. Spectrum of Analysis and Design Systems from Generic to Specific

From a more classical point of view, drawn from the example of an operating system structure, the field simulation system, whether it be numerical or analytical, forms the kernel of the virtual environment. The device specific knowledge forms a series of shells around the kernel in much the same way as the system utilities in an operating system form a layer around the nucleus. This results in an onion skin structure [6]. In operating systems, this structure has evolved to simplify the user access to the complexities of the computing hardware. The higher level utilities make the underlying computer structure usable by the non-specialist. The same architecture can be applied to field simulations, Fig 2. As knowledge is built into the system with each successive "skin" or "shell", the expertise of the user in performing the field computations, or the need to understand the architecture of the field analysis system is decreased and the high level understanding of the user is leveraged more effectively.

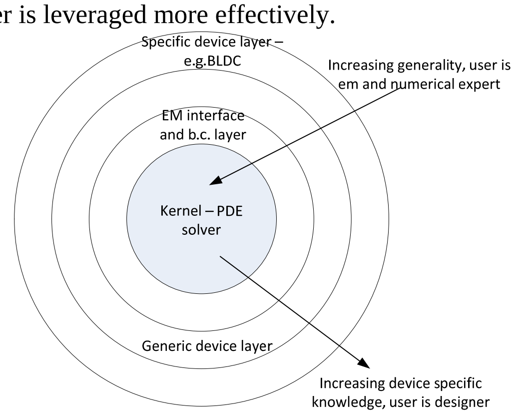

Fig. 2. The Layered Architecture – from PDE to Device Specific Knowledge.

III. THE LAYERED ARCHITECTURE

The key to building a layered architecture for a simulation system is the development of an effective interface between each layer, usually referred to as an "API" (Application Programmers Interface). This is a set of functions, accessible at the user level, exposing the capabilities of the kernel system. In a finite element based kernel system, these might control the meshing systems, solvers and result extractions.

In the outermost layer, the functions available to the user are expressed in terms which are related to the structure and performance of a particular device or class of devices and may not even refer to the functionality of the kernel. The user is not expected to need to know about the kernel system or its operation any more than a user of a mobile communications device should understand the architecture of the embedded processor. Each layer of the system adds in more specific knowledge and the high level layers of this architecture can contain considerably more code than the kernel.

This concept can be expanded to include several kernels within one shell where each kernel represents one particular physics model. For example, one kernel might be related to electromagnetic fields, another to thermal and a third to structures. A layer can be wrapped around all three to provide an effective multiphysics simulation where the connections are being handled at an intermediate layer and the user is still operating at a level which relates to the device itself.

IV. SYSTEM CLASSIFICATIONS

Given the architecture described above, systems can be classified as to where they belong within the layered structure. The classical work on field computation – differential, integral or analytical models, belong in the kernel and, in fact, for the solution of the same field problem, several kernels may exist and be embedded within one overall system. In its purest form, the kernel might be a general purpose partial differential equation solver. Beyond this a layer might be added which includes features particular to a branch of physics. For example, in electromagnetics, the constitutive relationships and material properties relevant to electromagnetics as well as specific boundary conditions might be added to produce a dedicated system. A layer above this could relate to a general concept in electrical machines and would include information related to excitations, topology and results such as torque or force and impedance. Beyond this point, the layers become ever more specialized resulting in interfaces for specific classes of a generic device. Finally, an optimization system can be built into the outermost layer providing the designer with a facility to explain the actual design problem, including manufacturing and other constraints, to the system.

The full paper will expand the architecture and provide examples of systems at the various points in the structure.

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