Rapid Algorithm Development for Voltage Driven Coils using Diffpack and CAPA

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Summary

Many applications of magneto-mechanical transducers, such as loudspeakers, require the physically correct modelling of a moving voltage driven coil. Several formulations of such coils have been implemented in CAPA and have been applied very successfully in the past. However, the available formulations did not take account of the skin effect, which, depending upon the problem may play a significant role.
To overcome these restrictions, we have recently developed a new formulation, which allows consideration of the skin and proximity effect in such coupled magneto-mechanical simulations. In the development, we first used the Diffpack environment to implement and test the coil formulation for pure magnetic problems. Using Diffpack, the necessary algebraic systems could be set-up very easily; the applicability of various iterative solvers and preconditioners to the algebraic system could be tested and optimized for several test cases. After the implementation had been extensively tested and verified, transfer of the algorithm, i.e. the new coil formulation, to CAPA could be easily established. Coupling to magneto-mechanical problems was automatically realized inside CAPA without any further required modifications.

Keywords

Magneto-mechanic coupling, coil modelling, moving coils

0. Introduction

The standard formulation for voltage driven coils does not take account of current density variations in the coil windings [1]. Therefore, the basic equations have to be extended in order to include skin effects as well as external circuit coupling for voltage driven coils. In case of an external RLC circuit and axisymmetric structures we have to consider the magnetic vector potential $A = A_\varphi$, the voltage drop u_k per winding and the condensor voltage u_c . The latter are coupled by means of the circuit equation $LC\ddot{u}_c + RC\dot{u}_c + u_c + U_t = 0$ in which U_t denotes the total voltage drop in the coil. As for each winding the currrent inside the winding will be equal to the condensor current i_C, we get $\int_{\Gamma_k} \gamma\left(\dot{A} + 1/(2\pi r)u_k\right) drdz + i_c = 0$. Rewriting the 2nd order circuit equation as a 1st order system, we finally get the following system of equations for the magnetic system, including the voltage driven coil:

$$\begin{pmatrix} K & P & 0 & 0 \\ 0 & D & 0 & C_L \\ 0 & 0 & 0 & 1 \\ 0 & 1_U & 0 & RC \end{pmatrix} \begin{pmatrix} A \\ U \\ u_c \\ u_2 \end{pmatrix} + \begin{pmatrix} M & 0 & 0 & 0 \\ F & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & LC \end{pmatrix} \begin{pmatrix} \dot{A} \\ \dot{U} \\ \dot{u}_c \\ \dot{u}_2 \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}$$

1. Diffpack Programming and CAPA implementation

In order to provide a fast implementation of the above system, we used the Diffpack programming environment [2]. Using class LinEqMatrix, the block system structure as shown above could be maintained. Using the standard Diffpack functionality *makeSystem()* and *integrands()* only a few new classes had to be implemented to provide the functionality required for the above equation system. The iterative solvers BiCGStab and GMRES have been tested with different preconditioners for the individual blocks in the above system. In case that PrecRILU is used, care must be taken regarding the relaxation parameter, which must not be too large.
Once the new coil formulation had been verified, the transfer to CAPA was straightforward. Each coil winding is realized as a single element group with an additional equation for the voltage drop u_k . BiCGStab and GMRES solvers are also available, however, with somewhat different preconditioners ILU(k); no convergence problems have been observed. As only the coil formulation in the magnetic subsystem was involved by the new formulation, no modifications have been necessary in the magneto-mechanic coupling algorithms of CAPA. Therewith, using the same formulations in the magnetic subsystem a moving voltage driven coil is also realized, necessary for example in high-power loudspeaker simulations.

2. Application

To demonstrate the new coil formulation, we consider a coil consisting of a set of rectangular wires. A typical mesh, as used for the wires, is shown in fig. 1, whereas a snapshot of the current density distribution is shown in fig. 2. The concentration of the current density near the wire boundary and corners is clearly visible.

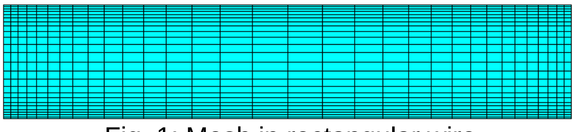

Fig. 1: Mesh in rectangular wire

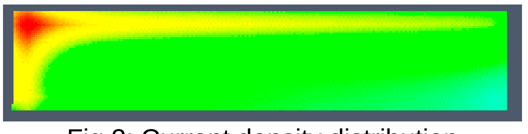

Fig 2: Current density distribution

References

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