Numerical Optimization of Time-dependent Electromechanical Systems

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Summary

In this paper, a new approach to the computer-based optimization of the time-dependent behavior of coupled electro-mechanical systems is presented. Instead of coupling simulation and optimization by a standard black-box approach we have developed a semi-analytical solution scheme. Here, these two tasks are coupled on the equation system level by differentiating the discretized system of equations with respect to the optimization parameters. This approach leads to additional equation systems, which have to be solved and which exhibit a complex nature especially for coupled multiphysics problems. Our approach works directly in the time domain, i.e. with time dependent, nonlinear systems. However, the objective function may also be defined in the frequency range, and may represent, for example, a specified sound pressure level or an impedance curve. Several applications of our newly developed simulation scheme are considered. Automatic linearization of a nonlinear magnetic system is demonstrated, which is essential for a long-term coupled magneto-mechanic transient simulation. Here, the objective function consists of the spatial distribution of a magnetic field. As an example for an objective function specified in the frequency range, we treat the problem of fitting an impedance curve.

Keywords

Coupled systems, time domain, non-linear optimization, semi-analytical gradient calculations

1. Introduction

Electromechanical transducers, working as sensors and actuators, play an increasing role in a large variety of applications, ranging from process technology, automotive industry, electro medicine, to consumer products. In order to speed up the design of these devices, the use of simulation tools which are based on numerical methods like the FEM has become more and more attractive. Due to the presence of different electromechanical coupling effects, the simulation of such a device typically poses a simulation problem of significant complexity. Furthermore, the design of such a transducer is subject to certain boundary conditions regarding functionality, shape, or both. Therewith, an optimization problem for the coupled field problem has to be solved. This task is usually approached in coupling the simulation software with optimization software, typically attacked by applying a black-box coupling. However, this approach has limitations regarding efficiency and may easily lead to solution times of several weeks.
To overcome these shortcomings of the black box approach, we have initiated work on coupling of simulation and optimization problems on the equation system level. This approach, which has been implemented into the CAPA simulation program, enables the use of semi-analytical gradient calculations and, therewith, may lead to significant time savings by providing highly accurate results.

2. Simulation scheme

The newly developed simulation scheme relies essentially on a differentiation of the basic system of partial differential equations with respect to the optimization parameters. In the case of coupled systems, this process leads to several new systems of equations, which have to be solved in order to calculate the derivative of the objective function with respect to the optimization parameters. The principle setup of our approach is shown in figs. 1 and 2, where the computational flow for a simulation of a coupled magneto-mechanical system is shown with and without optimization coupling. It is interesting to note, that the new equation systems differ from the original system essentially in the calculation of the right hand side, and, therewith, can be solved with the same system matrices as the original systems. As a consequence, the additional computational costs can be kept pretty low, and an extremely efficient calculation scheme is derived.

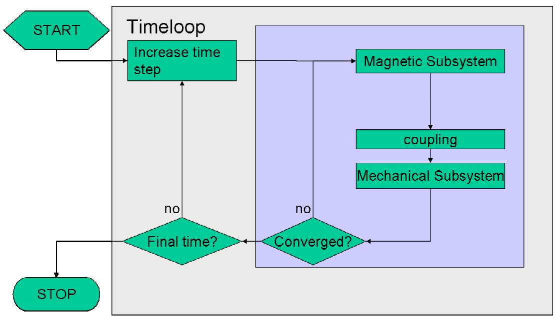

Fig. 1: flow of computation without optimization

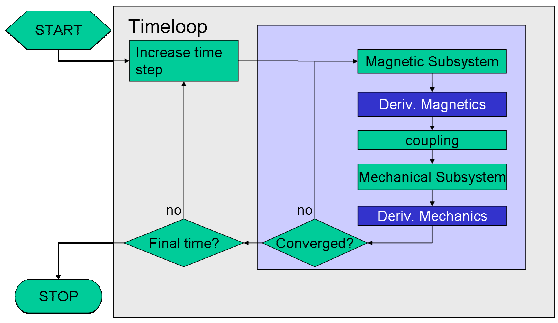

Fig. 2: flow of computation incl. optimization

3. Applications

As a first application of this new developed simulation scheme, we have treated several loudspeakers with regard to different objective functions. First, the nonlinear magnetic driver is linearized by means of an automated optimization procedure, to provide a significant speed up for follow-up calculations. Here, the objective function is given as the spatial distribution of the magnetic field. Next, the ambient air is replaced by spring elements, which are required to exhibit an equivalent influence on the loudspeaker [1]. Here, impedance curves from a previous calculation incl. fluid domain are used as objective functions. Further applications which have been successfully applied include the recovery of material data from measurements as well as material and geometry optimization for a given objective function.

4. References

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