Comparison of strong and weak coupled solution algorithms for coupled electromagnetic-thermal problems

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***Abstract* — Coupled electromagnetic-thermal problems using independent finite element meshes require the application of non-linear iterative solution algorithms. This paper gives an overview of the commonly used 'weak coupled' block iterative methods and relaxation techniques. Additionally, the use of an alternative stabilisation technique, the 'pseudo-transient' coupled algorithm, using transient calculation in the frequency domain, is presented. Furthermore, 'strong coupled' Newton methods, both with explicit and implicit Jacobian matrix computations are discussed. The performance of the algorithms is compared using test problems with moderate and strong interaction. This leads to decision rules that can be use to select appropriate algorithms for the considered coupled problems.**

OVERVIEW OF COUPLED PROBLEM METHODOLOGIES

Coupled electromagnetic-thermal problems are mutually non-linearly dependent physical field problems. Different meshes are required to obtain accurate subproblem solutions. The iterative non-linear solution algorithms can be classified in two categories:

- *Cascade algorithms*: performing a 'weak-coupled' block iteration at subproblem level, e.g. block Gauss-Seidel or block Jacobi. These methods can be extended to transient problems though a method consisting of a special transient time-harmonic formulation, combined with a transient thermal problem is required to avoid stiffness problems.
- *Full coupled algorithms*: implementing a 'strong-coupled' Newton algorithm. This requires the derivation of the Jacobian matrix containing the partial derivatives [1], which soon becomes a complicated matter when different meshes are used. However, matrix-free quasi-Newton methods, approximating the Jacobian implicitely, can be used and are discussed here.

GLOBAL CONVERGENCE

In order to obtain a non-linear solution iteratively, a good starting solution is required. Additionally, a relaxation technique can be used to enhance the global convergence [2]. However, for some coupled problems with a strong interaction of the subproblems, an alternative stabilisation technique often is required, consisting of the addition of an extra pseudo-transient term. In this case, modifications are required to avoid numerical problems due to stiffness.

ALGORITHM COMPARISON

The coupled problem solution algorithms are compared using a test problem consisting of a lean solid busbar, cooled by natural convection. Its electrical conductivity is temperature dependent. The considered losses are distributed joule losses. The higher the shape ratio, the more influence the temperature has on the eddy current distribution. Some algorithms diverge or converge to wrong and non-physical solutions. The impact of relaxation and stabilisation is discussed here. It is also illustrated that the use of explicit Newton methods becomes a costly operation. The solution of the asymmetrical Jacobian equation requires high performance solution algorithms. The results are summarised in Figures 1 and 2.

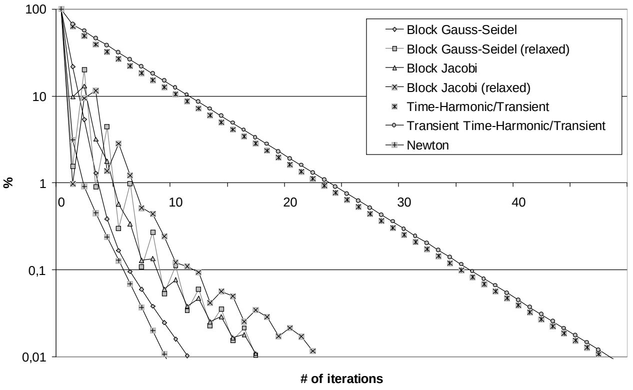

Fig. 1 : Comparison of the convergence behaviour of a coupled problem with moderate interaction; All converge to the correct physical solution.

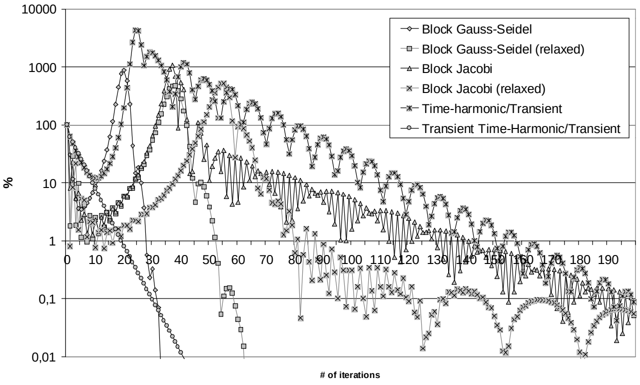

Fig. 2 : Comparison of the convergence behaviour of a coupled problem with strong interaction; All but the transient time harmonic combined with the (pseudo-)transient thermal algorithm diverge or converge to the wrong solution.

REFERENCES

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