# Comparison of 2D and 3D Coupled Electromagnetic and Structure-Dynamic Simulation of Electrical Machines

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*Abstract*— **For the coupled electromagnetic and structure-dynamic simulation of electrical machines, various 2D and 3D techniques are available. This paper reviews and compares them. The strength as well as the weaknesses of these methods are pointed out. Numerical results of the analysis of relevant machine types evaluate their accuracy and the computational effort.**

## I. Introduction

The simulation of vibration and acoustic noise of electrical machines requires the solution of a multi-physics problem. Therefore, a triple coupling between electromagnetic field calculation, structure-dynamic and acoustic simulation has to be established.

In both senses, decreasing numerical effort and including more physical aspects, it is desirable to use 2D techniques, whenever possible. On the other hand, the informational value of a 2D structure-dynamic simulation of electrical machines may be limited, due to 3D effects that cannot be captured in 2D. Both simulation approaches, 2D and 3D have been widely used [1], [2]. However, a detailed evaluation of both methods, a comparison of their strength and weaknesses as well as a numerical comparison of accuracy and computational effort is still missing.

Therefore, this paper compares 2D and 3D coupled electromagnetic and structure-dynamic simulation of electrical machines. The studies are carried out for various types of electrical machines.

## II. Coupled Simulations

It can be distinguished between a numerically weak or strong coupling. Both approaches have its advantages and disadvantages. Numerical weak coupling allows for using different grids, on which the different problems are solved. The solution from one ore more 2D electromagnetic finite element (FE) simulations can be transformed on to a 3D structure-dynamic model, which includes the housing of the machine and its mounting [1], [2].

On the other hand, a strong coupling, i.e. coupling the simulations on matrix level, allows for an efficient implementation of reaction and close interaction between the solution quantities. Using this technique, additional aspects, such as magnetostriction and the influence of the deformation on the electromagnetic excited forces, can be taken into account [3]. Strong coupling of electromagnetic and structure-dynamic simulation including the aforementioned aspects, has only been implemented in 2D so far [3] and are not part of the studies, here. Figure 1 gives an overview of the available simulation methods.

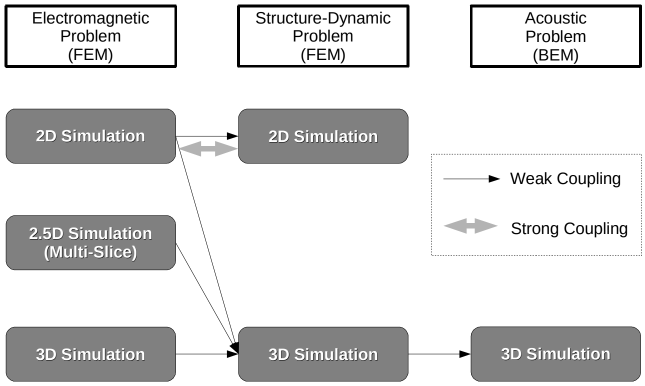


Fig. 1. Overview of simulation methods.

### A. Electromagnetic Simulation

For electrical machines, which are homogenous in the axial direction and of which the axial dimension is sufficiently large compared to its diameter, it is possible to use 2D electromagnetic FEM to obtain the field distribution. For machines, of which the cross section is only varying slightly with respect to the axial direction, the Multi-Slice-Method (MSM) can be applied [4].

Due to a high ratio between accuracy and computional effort, the 2D or 2D MSM has become a standard for the electromagnetic simulation of electrical machines.

### B. Structure-Dynamic Simulation

Coupling the electromagnetic to a structure-dynamic simulation, both approaches 2D and 3D are used [1], [5]. Due to the significantly lower number of unknowns, the 2D problem can of course be solved with much less computational effort. The 3D approach will typical yield higher accuracy, if the considered 3D effects are relevant to the structure-dynamic behavior. A closer look however reveals, that both approaches have additional strengths and weaknesses.

In the 2D case, the generation of the mesh is fairly simple. One approach would be to take the same mesh as in the electromagnetic case, or at least use the same routines with different element sizes. The 3D approach however requires a complete 3D model of the machine, which takes some effort to construct.

Due to its computational speed, the 2D method can be used to evaluate the structure-dynamic behavior over an entire frequency band. Where as the 3D approach, due to its high computational effort, is typically used for only several selected frequencies, which can be identified by modal analysis, analytical considerations of the specific machine type and by considering the excitation spectrum. Also, the 2D structure-dynamic simulation can be used advantageously to identify relevant frequencies and to give a first overview of the deformation spectrum.

The 2D approach cannot consider any vibrations in the axial direction of the machine. Therefore, all 3D mode shapes are neglected. They may be due to a non uniform force excitation, or the non uniform structure of the machine. This can be for example the skewing of the rotor bars of an induction motor, or the mounting of the machine at the front face, respectively.

In addition to neglecting 3D mode shapes, the 2D simulation is not capable of considering the effect of the vibrating rotor. In theory, the rotor can be included in the model, however since it is not connected to the rest of the model, there would be no influence.

In general, in structure-dynamic simulations quadrangle and hexahedron elements produce more accurate results than triangle and thetraeder elements [6]. This leads to an additional advantage of the 2D method, since mesh generation of triangle, thetraeder and quadrangle elements is much easier than generating a mesh consisting of hexahedron elements.

As one further advantage of the 3D method may be given the capability to couple in a next simulation step to an acoustic boundary element calculation, where the meaning of doing this in 2D would be very limited.

Since a strong coupling and the consideration of magnetostriction have only been implemented in 2D so far, this may also be called an advantage of this method. Table I summarizes this comparison.

TABLE I
COMPARISON 2D/3D SIMULATION.

| Structure-Dynamic-Simulation | |
|---|---|
| 2D | 3D |
| fast | slow |
| easy mesh generation (quads) | complicated mesh generation |
| frequency band | selected frequencies |
| no 3D mode shapes | full 3D mode shapes |
| no consideration of rotor | consider rotor vibration |
| no coupling to acoustics | coupling to acoustic simulation |
| strong coupling and magnetostriction possible | only weak coupling implemented so far |

## III. NUMERICAL RESULTS

An example of a coupled electromagnetic and structure-dynamic simulation of a switched-reluctance machine (SRM) is given in Figures 2 and 3. It can be clearly seen, that the 2D simulation, though showing the same principle behavior, is not able of capturing the 3D effects. The magnitude of the deformation is lower in the 3D case due to the stiffness of the end caps, which are not included in the 2D model.

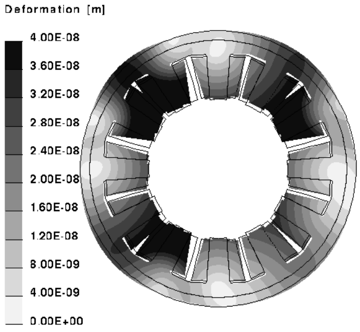


Fig. 2. 2D structure-dynamic simulation of an SRM.

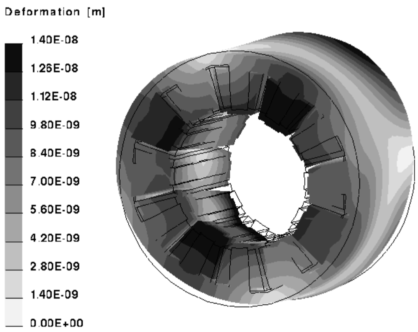


Fig. 3. 3D structure-dynamic simulation of an SRM.

A detailed analysis of 2D and 3D coupled simulation of a switched reluctance machine and of an induction machine will be presented in the full paper.

## IV. CONCLUSIONS

This paper evaluates the differences between 2D and 3D coupled electromagnetic and structure-dynamic simulation of electrical machines. State-of-the-art simulation methods are compared and strengths and weaknesses are pointed out. Numerical results for relevant machine types and the comparison in terms of computational effort and accuracy are presented in the full paper.

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