FAST STRUCTURE-DYNAMIC SIMULATION OF ELECTRICAL MACHINES USING 2D-3D-COUPLING

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Abstract

Structure-dynamic finite-element simulations of electrical machines allow for vibration analysis concerning geometric variants of the regarded motor without prototyping. The huge disadvantage of these types of simulations is their long computing times ever since. In this paper a novel method for the transformation of the surface-force density from the electromagnetic to the mechanical model of the machine is introduced leading to an enormous speed up and more accurate results by far.

1 Introduction

The idea behind the novel method is to avoid expensive 3-dimensional, electromagnetic simulations of the regarded electric machine if possible, which is state of the art [1]. Classic machines without 3-dimensional flux paths can be simulated by 2-dimensional models as well as skewed machines when applying the Multi-Slice Method (MSM) [2]. Next to the speed up the new transformation benefits from the higher accuracy of the 2D electromagnetic FEM models in general, although the end effects are neglected. The surface-force density on the stator teeth is represented with higher precision as well in space as in time domain.

2 Novel Transformation

For the novel method of surface-force density-transformation a MSM-model is applied for the electromagnetic simulation in general. In case of non-skewed machines the models consists of only one slice. Fig. 1 shows the principle of the MSM for a model with five slices. For each slice an electromagnetic simulation is performed. Global values like the torque are estimated by weighting of the single slice's results [3].

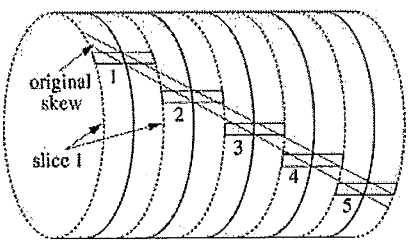

Fig. 1 **Multi-Slice Model with Five Slices.**

The simplest distribution for the slices is a Uniform Distribution (UD) shown in Fig. 2 for 5 slices. l_z is the active length of the machine, η_i the weight of the slice and γ_i the relative position of the slice to the centre of the machine. The dots represent the location of each slice. There are several distributions in use as for instance the Gauß (GD), the Edge-Uniform (EUD), and the Lobatto Distribution (LD).

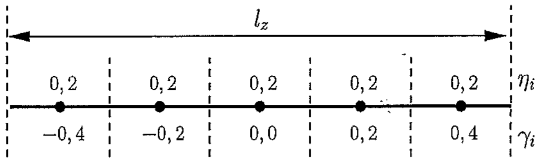

Fig. 2 **Uniform Distribution of MSM-Model.**

The surface-force density σ is derived for each element of the stator teeth for every slice of the MSM-model and transformed to the frequency domain. For structure-dynamic analysis of the machine the surface-force density is then transformed to the mechanical model by the following means. The force density of each slice of the MSM-model is assigned to a certain axial region of the mechanical model depending on the distribution and weighting of the slices in the MSM-model [3]. Fig. 3 describes this procedure.

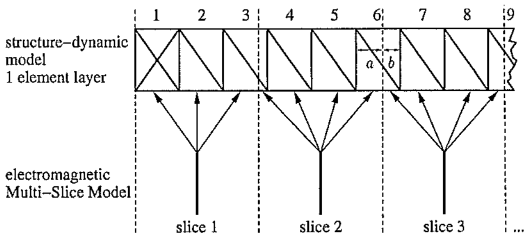

Fig. 3 **Principle of Transformation.**

Due to the fact that the axial discretisation of the stator teeth of both models differ – in fact the MSM-model consists of as many element layers as slices – there are "mechanical" elements which are assigned to two slices of the electromagnetic MSM-model. For example the "mechanical" element no. 6 in Fig. 3 is connected to the "electromagnetic" slices 2 and 3. The values of both ranges are weighted corresponding to the axial portion of the mechanical element layer (*a* and *b*) and averaged. Fig. 4 demonstrates this procedure. The "mechanical" element layer 6 corresponds to the slice ranges 2 and 3 resulting in:

$$\overline{\sigma} = \frac{a\sigma_2 + b\sigma_3}{a+b} = \frac{\eta_{23}\sigma_2 + \eta_{32}\sigma_3}{\eta_{23} + \eta_{32}}. \qquad (1)$$

with $a = \eta_{23} \cdot l_{z,6}$ and $b = \eta_{32} \cdot l_{z,6}$. Where $l_{z,6}$ is the length of the "mechanical" element layer 6. As previous studies have shown this averaging procedure does not affect the discretisation error defined in [3].

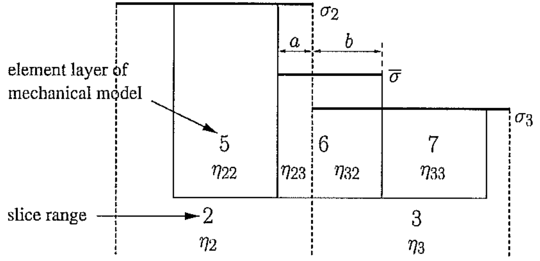

Fig. 4 **Weighting and Averaging.**

Instead of the surface-force density the flux density can be averaged as well. This is closer to the physical condition that the surface-force density results from the flux density. With $\sigma \sim B^2$ it follows

$$\overline{\sigma} \sim \underbrace{\left(\frac{a\sigma_2 + b\sigma_3}{a+b}\right)^2}_{b_{23}} \neq \underbrace{\frac{aB_2^2 + bB_3^2}{a+b}}_{b_2 b_3}. \qquad (2)$$

The term marked with $b_2 b_3$ results from (1) if σ is replaced by B_2. The discretisation error for the surface-force density is minimised by adopting this interrelationship to the transformation scheme. This will result in much higher efforts in data handling since the flux density has to be transformed to the mechanical model, the surface-force density then is calculated, and must be transformed to the frequency domain at last. For this reason the transformation scheme is not adopted and (1) is used instead.

3 Results

For verification of the novel transformation scheme an induction machine with squirrel-cage rotor is simulated. One specific point of operation is regarded in detail. Electromagnetic models in 2 and 3 dimensions are applied and the resulting force-density of both is used for simulation of the structure-dynamic model of the motor. The deformation of the model is compared to experimental values. Depending on the point of operation there are only a few significant frequencies to be analyzed. Fig. 5 shows the radial component of the body-sound level L_S at a single position on the housing of the machine for both 2D and 3D force excitation in comparison to measurement results.

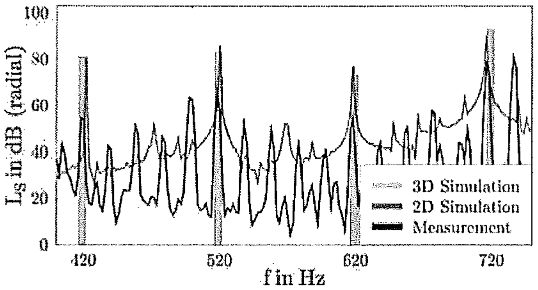

Fig. 5 **Comparison of Body-Sound Levels.**

As can be seen the simulated results reach higher values in general. But the 2D force excitation has exactly the same resolution (Δf = 2 Hz) as the measurement. Due to the long computation time the 3D model only allows Δf = 20 Hz. Furthermore, the computational time is reduced by 16 days to about 4 in total for the electromagnetic model. Therefore, the new transformation scheme allow for significantly faster and exacter simulation.

4 Conclusion

With the new transformation scheme presented in this paper the structure-dynamic FEM-simulation is sped up significantly. Applying 2-dimensional electromagnetic FEM-models results in higher accuracy in space, time, and therefore frequency domain. For any electric machine whose physical conditions allow for 2-dimensional electromagnetic simulation these advantages can be taken as the results of an induction machine with squirrel-cage rotor show exemplarily.

5 Literature

[1] M. Furlan; A. Cernigoj: A coupled electromagnetic-mechanical-acoustic model of a DC electric motor, COMPEL, Vol. 22, No. 4, Nov. 2003, pp 1155-1165.

[2] F. Piriou; A. Razek: A model for coupled magnetic-electric circuits in electric machines with skewed slots. IEEE Transactions on Magnetics, Vol. 26, No. 2, March 1990, pp. 1096-1100.

[3] J. J. C. Gyselinck; L. Vandevelde; J. A. A. Melkebeek: Multi-Slice FE Modelling of electrical machines with skewed slots – the skew discretization error. IEEE Transactions on Magnetics, Vol. 37, No. 3, Sept 2001, pp. 3233-3237.