COMPARISON OF PHYSICAL AND NON-PHYSICAL STOCHASTIC MAGNETISATION FAULT APPROACHES

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Abstract. The introduction of stochastic deviations due to production faults into the finite element (FE) simulation of electrical machines requires suitable error models, describing the occurring deviations from the ideal case. This paper presents and compares two different magnetisation fault approaches to map measured magnet data into a stochastic FE model to improve deviation simulation in bulk production.

Keywords: comparison, finite element method, inverse problem, magnetisation error

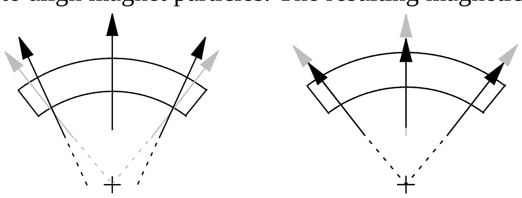
INTRODUCTION

The introduction of stochastic deviations into the finite element (FE) simulation of electrical machines requires suitable error models, describing the occurring deviations from the ideal case. In all cases, the error model's precision directly influences the prediction quality of the entire system. Most approaches for the consideration of magnetisation errors in electrical machines focus on deviations of the overall magnetised remanence induction only, being seemingly the strongest influence while keeping the number of model parameters even for a machine with a large number of magnets manageable [1]. In order to improve prediction quality, a physically motivated model, deduced from the magnet production process, is compared to a non-physical model which is based on the idea of a superposition of multiple independent magnet fragments. As a result, the pros and cons of both modelling techniques are compared using measured magnetisation curves as a basis for discussion.

MODELS

Model A – Production process based

This model allows global changes in the magnet's remanence induction (Fig. 1b)) combined with a spatial deviation of the induction depending on angle $\Delta\alpha$ relative to the magnet's middle α_{mid} (Fig. 1a)). Such deviations arise from a magnetic field which is applied to the green body of the magnet during its pressing and is used to align magnet particles. The resulting magnetic excitation is given in (1).



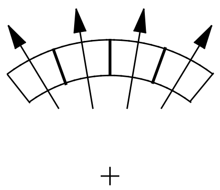
a) Angle deviation (ζ_2). b) Remanence deviation (ζ_1).

Figure 1. Modelled magnet variations which can be linked with the production process as discussed in [2].

$$\vec{B}(\Delta\alpha,\xi_1,\xi_2) = B_r(\xi_1)\cdot\begin{pmatrix}\cos(\alpha_{mid}+\Delta\alpha(\xi_2))\\ \sin(\alpha_{mid}+\Delta\alpha(\xi_2))\\ 0\end{pmatrix} \qquad (1)$$

Model B – Segmented magnetisation model

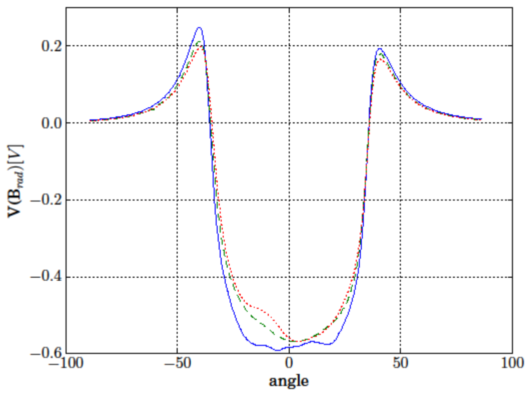
Here a magnet is modeled as the superposition of a set of basic magnetisation blocks (Fig. 2). This setup allows the reproduction of local faults inside a magnet which may be created during the magnet's shaping process. Configurations featuring a spatial superposition of the basic magnetisations are also possible, allowing the reproduction of any arbitrary measured magnetisation using (2).



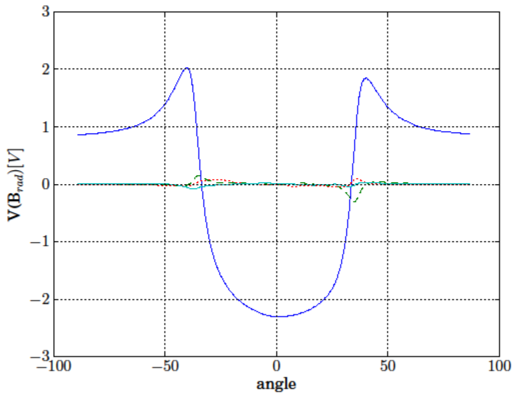
$$\vec{B}(\alpha,\vec{\xi}) = \sum_{i}^{n} M_i(\alpha)\cdot X(\xi_i) \qquad (2)$$

Figure 2. Segmented magnet model.

RESULTS



a) Three exemplary measured magnetisations.



b) The four most significant principal components of the complete data series.

Figure 3. Measured radial magnetisation voltages of the Hall sensor [3] and the separation into their principal components.

Figure 3a) shows the radial component of the measured Hall voltages of three test magnets. For both models the challenge consists in the solution of the inverse problem, fitting the measured field components onto the magnet excitations in the FE model. In model A, the stochastic parameters of angle and magnetisation strength can directly be calculated using the measured radial and tangential field component. Alternatively, the best fit from a full factorial model sampling can be searched using least square regression. For parameter determination of model B, a principal component analysis (PCA) [3] of the complete data set has been performed (Fig 3b)). The idea for the model fitting now consists in emulating each of the largest principal components with a set of basic magnetisation fragments. The stochastic parameters for the complete model can be adopted subsequently from the PCA.

Assuming the principal components can be emulated sufficiently precise, model B wins the comparison of models in terms of accuracy. The first four depicted principal components (Fig. 3b)) account for 99.96% of the system's variability. The number of needed stochastic variables for model B therefore is lower than initially expected and is acceptable. However it has to be considered, that each principal component is the sum of multiple basic magnetisation fragments. Fitting these to the (arbitrary) shape of the basic components is difficult and results in too complex, non-physical models, because the resulting magnetic excitation for some cases postulates unsteady breaks in excitation, which will not be found in the magnet. Finally, the influence onto machine calculation of the relatively small principal components has not been estimated yet. Next steps therefore require to apply the described models into a complete machine model to determine the resolution limit, until which a projection of small deviations proves useful.

CONCLUSIONS

Two models for representation of measured magnetisation have been presented and fitted to FE simulations of a sole magnet, in order to improve their stochastic fault modelling. Model A allows considerations of the production process, but is not able to account for local errors, which have been measured. Model B is able to simulate such errors, but due to its bulkiness and its non-physical nature its disadvantages seem to outweigh its benefits. For further work, thus a verification of both models as well as improvements to include the results of the PCA into model A are the next consequent steps.

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