

Development of a transient simulation model for rotational single sheet testers by including the nonlinear magnetic circuit behavior

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Abstract— Rotational single sheet testers allow a characterization of soft magnetic materials under rotating magnetization as occurring in electrical machines. Due to the nonlinear behavior of the materials, suitable control algorithms have to be developed. In this work, a simulation model based on finite element simulations is derived, which is able to emulate the nonlinear behavior of the magnetic circuit in a time domain simulation environment. With this model, the influence of the nonlinear magnetic circuit on the controller behavior can be examined during the measurement device design process.

Keywords—magnetic measurement; rotational single sheet tester; modelling; field-circuit coupling

I. INTRODUCTION

In electrical machines, parts of the magnetic circuit are magnetized by rotating magnetic fields. Therefore these magnetizing conditions should also be used in the material characterization. Rotational single sheet testers (RSSTs) with four magnetizing yokes are a common measurement setup for this purpose [1]. By impressing suitable time-dependent currents in the two perpendicular magnetizing windings, a rotating magnetic field can be generated. Yet the nonlinear behavior of the magnetic circuit complicates this control task. This should already be considered during the design stage of such magnetizing devices. Therefore, the influence of the nonlinear material behavior on global electromagnetic quantities such as voltages, currents and flux linkages has to be modelled.

In the next section, the measurement device and the excitation and measurement windings are described and the chosen modeling approach is explained. Afterwards, simulation results are shown.

II. MODELLING APPROACH

A. RSST excitation and measurement windings

The general setup of the measurement device is shown in Fig. 1. The magnetizing windings are wound around the

magnetizing yokes. The field quantities are determined by measurement coils using the flux-metric method. For the flux density calculation, two perpendicular windings through holes in the center of the sample.

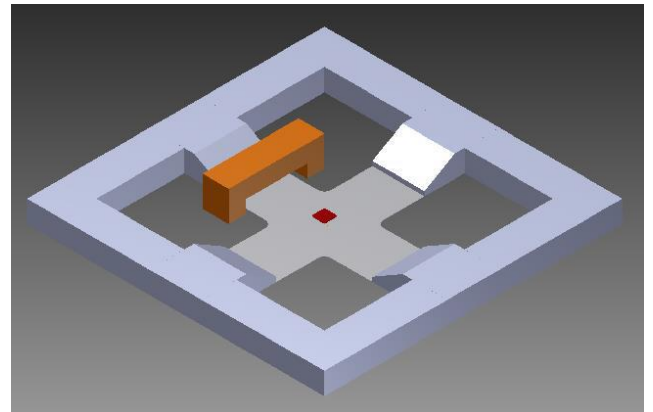


Fig. 1. Basic geometry of the measurement device (cut in symmetry plane). The orange part represents a magnetizing winding (for a better view, only one of the four excitation windings is shown).

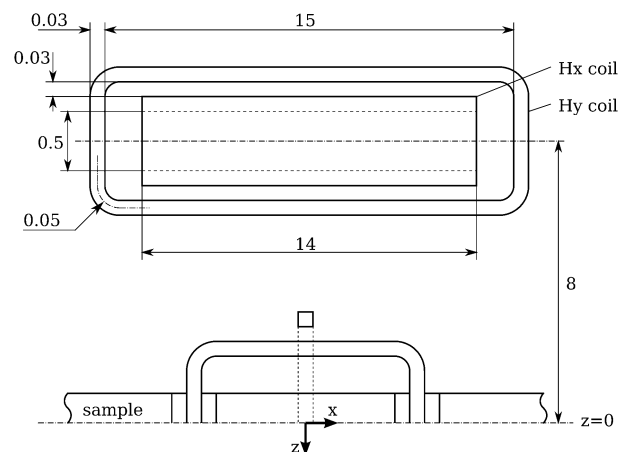


Fig. 2. Measurement winding arrangement.

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The field strength is calculated by measuring the tangential magnetic field with coils arranged below the sample. The basic measurement winding setup is shown in Fig. 2.

B. Calculation of nonlinear model parameters

For electrical machines, models which extend the linear differential equations of the windings by introducing current-dependent parameters are known [2]. The current-dependent parameters in this approach are the inductances describing the magnetic coupling of all windings in the machine and the flux linkages in those windings. They are extracted from finite element simulations [3]. The same approach can be used in case of the RSST, since the magnetizing system also produces a rotating field. The magnetizing coils, measurement coils for flux density and those for field strength all contain two coil systems arranged in perpendicular directions. In summary, the device contains three winding systems (excitation, B coils and H coils) with two windings (x and y direction), resulting in six coil systems in total. The magnetic coupling is therefore described by a 6x6 inductance matrix:

$$\vec{\Psi} = \mathbf{L} \cdot \vec{i} \quad (1)$$

The components of flux linkage and current vectors are the corresponding values for each coil system. Details on the inductance matrix and the meaning of the different entries will be given in the full paper. The matrix is extracted from FE simulations of the measurement device. Due to the magnetic circuit geometry, a 3D model has to be used. The simulations are repeated for different excitation currents to get a current-dependent inductance matrix. Current-dependent flux linkages are then calculated by (1) and interpolated. Due to the size of the FE model, the number of simulations is restricted. Therefore the values of the currents for the FE simulation have to be carefully chosen to ensure proper interpolation results.

C. Resulting time-domain simulation model

The resulting time domain model is based on the voltage equations of the winding systems, which can be summarized in vector form:

$$\vec{u} = \mathbf{R} \cdot \vec{i} + \partial_i \Psi_{\mathbf{e}} \cdot \frac{d}{dt} \vec{i} \quad (2)$$

For the measurement systems, the ohmic voltage drop is omitted, since no current flows in those windings. Instead of inserting the flux linkage equation, the total derivative formulation [4] is used, in voltage equation (2). From (1) and (2), the principal model structure shown in Fig. 3 is derived. By storing the current-dependent quantities into lookup tables, the model is implemented in Matlab Simulink®.

III. SIMULATION RESULTS

Fig. 4 shows the results of a simulation with sinusoidal excitation voltages. The influence of saturation for higher flux densities is visible in the simulated winding quantities. Further results with simulated controllers will be shown in the full paper.

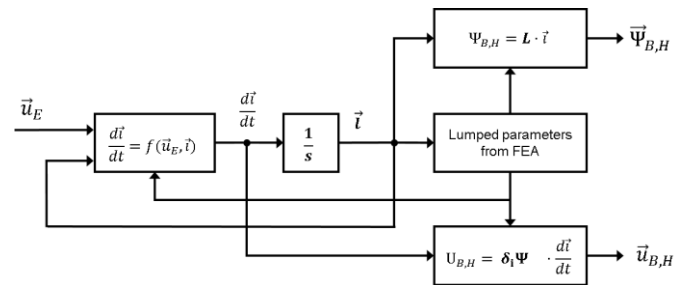


Fig. 3. Structure of the time domain simulation model. Index denotations: E-excitation coils, B-flux density measurement coils, H-field strength measurement coils.

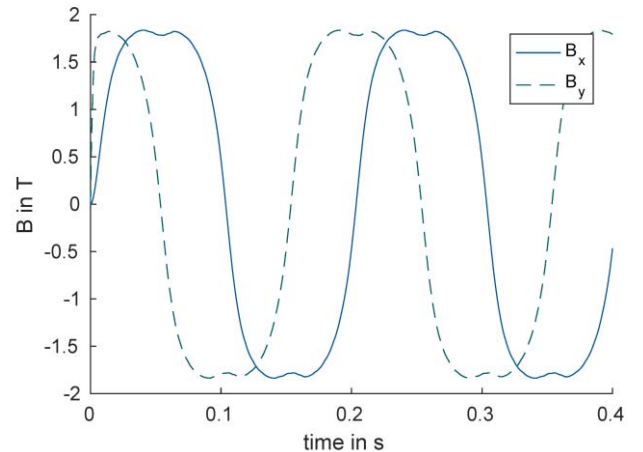


Fig. 4. Simulated flux densities for sinusoidal excitation voltages. The flux density is calculated from the flux linkage.

IV. CONCLUSION

A time domain model for RSSTs is derived by inserting current-dependent inductances and flux linkages into the differential equations describing the winding behavior. By extracting those from 3D finite element simulations, the nonlinear behavior of the magnetic materials is accounted for. Material saturation is visible in the simulation results. The influence on the controller design can be examined with this model.

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