Identification of permeability in normal direction of anisotropic sheets using FEM mesh adaption and genetic algorithms

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Abstract — The paper proposes a method to determine the B-H curve of anisotropic magnetic laminations in the direction normal to the sheet surface. An automated procedure links an identification algorithm implemented in Matlab environment with a commercial finite-element magnetic field code Opera 3D. In particular, a genetic optimization procedure is proposed, where computation times are reduced by adjusting the refinement of the FEM mesh. The use of a multiprocessor computer made it possible to perform parallel computations and realize the calculation in a reasonable time. The finite element mesh density is adjusted during the execution of the genetic procedure depending on the difference between the calculated and measured magnetic flux density.

I. Introduction

Measured magnetic characteristics of anisotropic magnetic sheets are normally provided for different angles of anisotropy in the sheet plane, but there is very little information in literature regarding characterization of laminations in the normal direction [1]-[5]. The authors of this paper performed such measurements which yielded characteristics of magnetization, including saturation. The method is based on the use of a magnetic circuit in which a direct current is supplied to the excitation winding in order to eliminate the presence of eddy currents in the core and thereby avoid distortions in the measurement caused by these currents. The measuring system was built so that the magnetic flux was perpendicular to the sample surface [6]. Figure 1 shows the picture of the measurement system. Four U-shaped magnetic cores are assembled and form a close magnetic circuit with four air-gaps. The measured samples are placed in two air-gaps. As the flux does not change in time, in order to make it possible to measure the static flux density, a search coil is continuously being moved in and out of the third air-gap with constant velocity v. The movement is perpendicular to the principal direction of the flux density. Magnetic properties of the core, as well as of sample sheets in the rolling direction (the *x* direction) and transverse to the rolling direction (*y* direction) are assumed to be known. As the samples and the flux density measurements are located in different arms, it is necessary to identify the characteristics of the samples. In order to identify the magnetization characteristics it is convenient to represent them in an analytical form. An expression with three parameters is used, namely the saturation flux density (J_s in Tesla), the initial relative permeability (μ_r), and a coefficient to adjust the shape of the 'knee'. These three parameters are the unknowns in the identification problem.

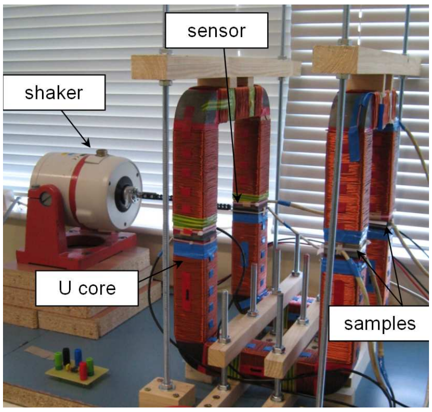

Fig. 1. The experimental rig

The 3D finite element simulation model was built using a commercial software package Opera3D. As a static solution was needed the module TOSCA of the software was used. The basic idea is to adjust the refinement of the mesh according to the level of accuracy required for the objective function calculation, rather than for the field solution itself. To this end, adaptive finite elements are coupled with an approach based on the principle of evolutionary search for single-objective optimization. The required precision is directly related to the search resolution determined by the optimizer as the actual solution gets closer to the minimum.

II. Automated Identification of the Characteristic

The flux densities for different values of excitation current are measured in the air-gap, while sample sheets are located in the second air-gap. The values of magnetic flux density measured in the air gap provide the basis for the identification of the magnetization curve of the sample. In order to identify the B-H curve of samples, it was necessary to model the measuring device. A simulation program based on the reference characteristics computes the distribution of flux density at every point of the measuring system [7]-[9]. Comparing the computed and measured values of flux density makes it possible to assess the quality of the identification. In the algorithm developed the comparisons are actually undertaken at eight different excitations. The optimization procedure requires several iterations to converge for a given search accuracy. Each iteration involves the calculation of field distribution for multiple excitations. To speed up computation, a multi-processor parallel computer was used to calculate the field for all excitations in parallel. The parallel computation and the coupling of the identification algorithm with the field analysis program were controlled from Matlab. The flow of information was provided by the files opened and closed in the identification program and in every version of the field modelling program. As Opera is not suitable for parallel computing, the authors decided to write a dedicated script in the command system language of Opera. The process starts with the preprocessor run with the version of the calculation for the corresponding value of current in the excitation coils. Then the newly generated characteristic magnetization is attributed to the sample. A file is automatically generated for the calculations and the solver is launched. After the solution is completed, the postprocessor is run and the value of the normal component of flux density is found. This value is stored in a specially created text file. This was found to be the easiest way to communicate with Matlab. The various processes of Opera are running in the background which enables the parallel execution on a multiprocessor computer. Two aspects should be pointed out. First, no evaluation of the objective function accuracy, by means of subsequent calculations, is needed at the given iteration. Secondly, the adaption parameter varies in a non-monotonic way during the search.

III. Some Results and Conclusions

In the full-length paper, the influence of the meshing accuracy on the calculation of flux density in the air-gap and in the samples will be discussed. The results of the identification procedure, the convergence and the flux density for the different values of excitation will also be presented.

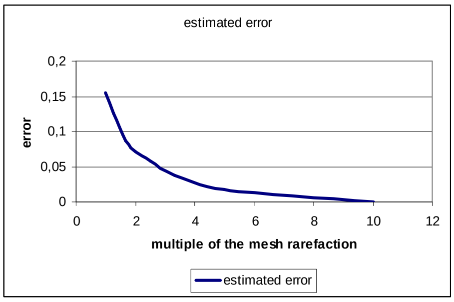

Fig. 2. Deviation from the value calculated for the finest mesh

Figure 2 and Table I summarise the main findings. The most ‘dense’ (fine) mesh consisted of 6,247,961 linear tetrahedral elements and 97,961 quadratic tetrahedral and errors are shown in relation to the results obtained using this dense mesh. As expected, the decrease in mesh density inevitably results in savings in computational times, but at the expense of reduced accuracy. The mesh adaption follows – as much as possible – the ‘h’ refinement strategy with all elements refined preserving their ‘proportionality’. During the identification procedure the mesh resolution (density) is guided by the achieved valued of the objective function. If the resolution inherited from the last accepted solution is too small, the computation is repeated with a refined mesh. The use of this adaptive strategy has resulted in noticeable savings in computing times.

TABLE I
MESH DENSITY, ERRORS, COMPUTATIONAL TIMES

Density of mesh	Deviation	Computing time	Value of flux density *B* in the middle of measurement air gap
Very dense	-	245 min	1.709 T
Rarefaction 2 times	1.2%	34 min	1.689 T
Rarefaction 3 times	2,48%	12 min	1.667 T
Rarefaction 4 times	3,8 %	7.2 min	1.644 T
Rarefaction 5 times	4,7 %	3.47 min	1.628 T
Rarefaction 6 times	5,8 %	2.22 min	1.609 T
Rarefaction 8 times	8,5 %	1.34 min	1.565 T
Rarefaction 10 times	10,3 %	1.19 min	1.533 T

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