Numerical analysis of a Nondestructive Online Testing System For Dual Phase Steels

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Abstract — This paper is dedicated to the FLUX® 2D simulation of a non destructive testing system of dual phase steel developed for automotive application. The Conventional FEM simulations are not suitable because of the special geometry of the material and the measurement technique. A new strategy is then developed in order to reduce computation times and memory space. The first result validates the approach which is analysis the influence of the device parameters and the behavior of dual phase steel.

I. DUAL PHASE STEEL AND 3MA DEVICE

Dual phase steels (DP) are a recent generation of carbon strip steels for automotive applications with enhanced mechanical properties. As a result of the mechanical and thermal treatments used to process them they can be described as a multilayer material. In order to improve the consistency of their end-user properties, more and more steel manufacturers are considering on line microstructure assessment with non destructive magnetic techniques [1-4].

In this paper, we focus on a testing system developed by IZFP and called 3MA - Micromagnetic Multiparameter Microstructure and Stress Analysis. The measured technique of this system is based on incremental permeability measurement technique which consists in the evaluation of high frequency (HF) eddy current effect around a low frequency (LF) hysteresis behavior of the magnetic sample. The LF measurement is performed with the direct field determination to accurately control the local magnetization condition [4], [5]. Then the impedance is measured at each point of the cycle, with an eddy current HF coil. The results can be related to the local hysteresis cycle, and several magnetic and mechanical parameters of the specimen.

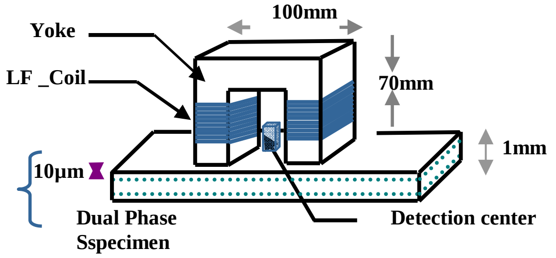

Fig.1. 3MA device

The FEM simulations of such a system are performed using FLUX® software [6]. Two main problems should be considered. First the 3MA system has a multi-scale geometry: the specimen sheet is a multilayer system: the thickness of the surface layer is about 10 µm and the center one is around 1mm. The total device width is 100 mm. This scales ratio of 10^4, requires an adapted meshing that depends on the area of the whole sample-sensor system. Secondly, two simultaneous excitations are combined: a low frequency, varying from 50Hz to 1000Hz, and a high frequency, varying between 10 kHz and 30 kHz. The time scales can then vary from 10^3 to 10^4. Therefore an adapted temporal discretization is required to identify the high-frequency phenomena.

At this stage of the system modeling, hysteresis aspect is neglected; the magnetic material is so described by a non linear isotropic behavior.

II. CONVENTIONAL COMPUTATION

This simulation requires both high and low frequency current excitations in a coupled and simultaneous manner. The same levels of induction and frequency are maintained, $I_HF = 0.2$mA and $I_LF = 2$mA for the amplitudes, $f\_HF = 20$ kHz, $f\_LF = 200$ Hz for the frequencies. The computation is conducted in the magnetic transient.

To observe the high frequency phenomena, the time should be finely sampled. Twenty points of the HF period are considered and the computation is carried out for a half of a LF period to limit computation time and memory. In spite of this limitation the simulation requires more than 1 hour. Fig.2 shows the lines flux distribution and the induction gradient in the yoke and in the sheet at the material maximum working induction.

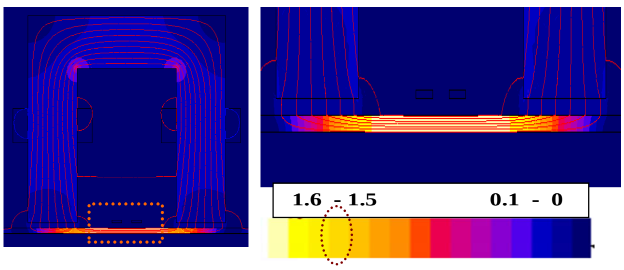

Fig.2. Distribution of line flux and gradients of the induction in the specimen in the coupled simulation.

The positive value of the detected voltage is considered to analyze the specimen. It is presented in Fig.3. A small slow is observed. This behavior is explained by non-linear properties of the materials. In fact, the differential permeability decreases when approaching the saturation.

Since the voltage is directly related to permeability, the same behavior is observed.

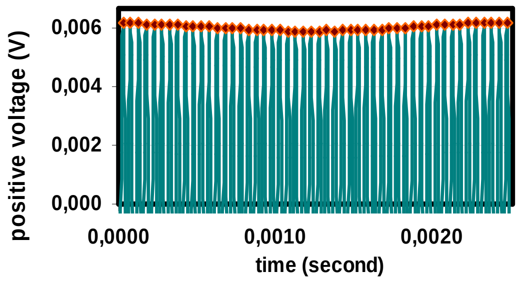

Fig.3. Time evolution of the positive value of detected HF_Coil voltage

III. NEW CALCULATION STRATEGY

The computation strategy which is illustrated in Fig. 4 consists to divide the computation in two stages considering two user Flux files. The same geometry (a half of the system) and the same physical properties are kept for simulation except the boundaries and excitation conditions. A transient low frequency excitation (LF-FluxFile) simulation is first carried out. The direction of the magnetic field should be normal to the symmetric axis. At each time step of this phase, the differential permeability value (μ_{diff}) is stored at each node of the sheet, and then is exported to the HF-FluxFile for high frequency computation. As the HF excitation level is thousand times smaller than the LF one, a magneto-harmonic computation can then be performed.

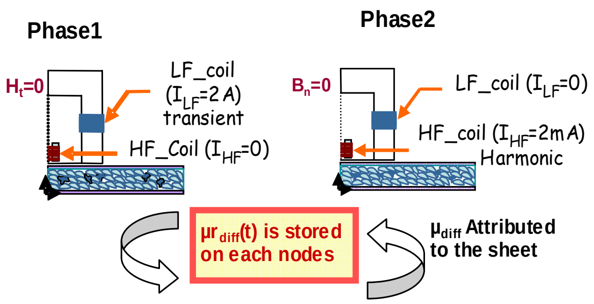

Fig.4. Computation strategy.

A macro-control in Python language is developed to implement this process automatically. Because of the simplification of the geometry and the harmonic computation, the duration and the memory space of the simulation are considerably reduced. Thus, compared to the conventional simulation this new strategy allows a 6 time quicker resolution of the same problem.

IV. VALIDATION AND RESULTS

The results obtained by this new strategy are compared to the conventional coupled LF-HF transient simulations. The maximum deviation of the voltage value does not exceed 0.9% and thus can validate the feasibility of the proposed approach.

However, the 2D hypothesis considered in the previous simulations is correct for the low frequency system (yoke and sample), but remains far from reality for the HF excitation. In practice, the HF_coil is cylindrical and has a very small size. The induced currents are developed in 3D and in a very small area. In order to take into account this phenomenon, the HF computation is performed by considering an axisymmetric geometry instead of a 2D plane. This implies that the permeability is invariant along the ortho-radial axis and the material is isotropic. This last condition is confirmed experimentally by the study on Dual phase material. In the following simulation results, only this last strategy will be used.

Fig. 5 gives an example of results obtained. It represents the variation of the imaginary part as a function of the real part of the HF-Coil voltage,. The simulation is performed in these conditions: I_LF = 0.7A, f_LF = 200 Hz and I_HF = 0.2mA, I_HF = 20 kHz.

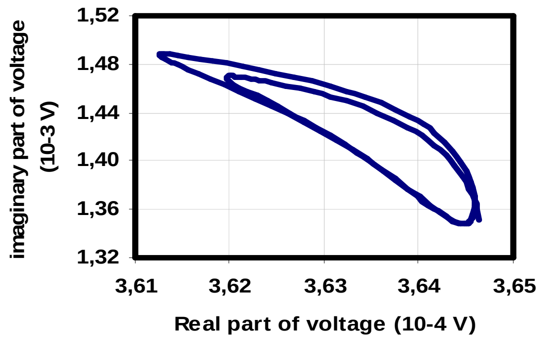

Fig.5. The evolution of imaginary with real part of voltage

Other results will be presented in the final paper. The influence of the geometrical and physical properties of both the 3MA systems and the DP specimen will be evaluated: amplitude and frequency of the LF and BF excitations, thickness and magnetic properties of the different layer of the sample, the lift off between the 3MA and the sheet surface, etc. The results can be used to optimize the geometry and operating conditions of the 3MA and particularly to improve the materials properties.

V. REFERENCES

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