Sensitivity-based Parameter Extraction of 3D Transient Magnetic Problems

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This paper investigates the extension of a recent technique for parameter extraction, namely the sensitivity analysis, to 3D Transient magnetic problems. For this purpose, we present few application case studies where we compare the dynamic inductance and resistance values computed using the mentioned method with their counterparts obtained using analytical and/or experimental results.

Index Terms—Sensitivity analysis, circuit parameter extraction, 3D transient magnetic problems.

I. INTRODUCTION

During the last decades, many circuit parameter extraction methods have emerged. In general, there is no closed-form technique to accurately derive the equivalent circuit parameters due to various factors, including the effects of material nonlinearity and eddy currents. Thus, three main techniques have been defined for this purpose: (i) the first uses the flux linkage and current flowing through the winding in order to derive the coil inductance [1], (ii) the second uses energy/current perturbation [2], and (iii) the third is based on sensitivity analysis [3]. On the contrary to the former two techniques, the advantage of the latter is its ability to drive both dynamic resistances and inductances for each winding.

The sensitivity analysis was successfully applied in 2D problems to extract both the dynamic and resistance matrices [3]. In this paper, we extend this work to 3D problems and evaluate the accuracy of the sensitivity-based technique compared to analytical and experimental of three distinct examples: a coaxial cable, a parallel wire pair and a two-pole electrical machine.

II. PARAMETER EXTRACTION BASED ON SENSITIVITY ANALYSIS

The parameter extraction-based sensitivity analysis for 2D problems is fully described in several papers (e.g., [4]). In this work, we simply extend this technique to 3D finite-element method (FEM) based on the T-Omega formulation.

III. APPLICATIONS

A. Coaxial Cable

Using the described method, we computed the dynamic circuit parameters of the coaxial cable model illustrated in Fig. 1. We considered a 1-A sinusoidal excitation at 1 Hz and 50 KHz. Table 1 shows the simulated dynamic inductance using the 3D sensitivity analysis-based technique compared to the analytical result based on the closed-form equations [5]. Obviously, our results compare well with the analytical values. The dynamic resistance is also shown in Table I.

<table>
<thead>
<tr>
<th>Study</th>
<th>Inductance (H)</th>
<th>Resistance (Ohm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analytical</td>
<td>Simulation</td>
<td>Simulation</td>
</tr>
<tr>
<td>Transient : 1 A sinusoidal</td>
<td>2.2343 x 10⁴</td>
<td>2.265348 x 10⁴</td>
</tr>
<tr>
<td>excitation @ 1 Hz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transient : 1 A sinusoidal</td>
<td>1.67669 x 10⁴</td>
<td>1.735754 x 10⁴</td>
</tr>
<tr>
<td>excitation @ 50 KHz</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

B. Parallel Wire Pair

The second case study consists of two parallel wires as shown in Fig. 2. Table II compares the simulated and the analytical values [5].

![Fig. 1. Coaxial cable: (a) Model dimensions (b) Flux density distribution.](image)

![Fig. 2. Parallel wire pair: (a) Model dimensions (b) Flux density distribution.](image)
TABLE II
INDUCTANCE CALCULATION OF THE PARALLEL WIRE PAIR EXPERIMENT

<table>
<thead>
<tr>
<th>Study</th>
<th>Inductance (H)</th>
<th>Resistance (Ohm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Analytical</td>
<td>Simulation</td>
</tr>
<tr>
<td>Transient: 1 A sinusoidal excitation @1 Hz</td>
<td>1.1103 × 10⁻⁷</td>
<td>1.0489 × 10⁻⁷</td>
</tr>
<tr>
<td>Transient: 1 A sinusoidal excitation @50 KHz</td>
<td>1.0078 × 10⁻⁷</td>
<td>0.9612 × 10⁻⁷</td>
</tr>
</tbody>
</table>

C. Reluctance Machine
This case study is based on the reluctance machine specified in [6]. Fig. 3 shows the simulated winding current compared to the measurement.

Fig. 4 and 5 show the simulated dynamic inductance and resistance without mechanical motion. Whereas, Fig. 6 shows the same results with motion considered.

IV. CONCLUSION
In this work, we extend the sensitivity analysis-based circuit parameter extraction method to 3D FEM problems. We presented the results of the proposed method in three distinct case studies. The proposed method gives good approximations compared to analytical and experimental results. In the conference, we will present more results.

REFERENCES