Determination of the Magnetic Properties of Composites based on Reluctance Model

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Abstract — **This work presents a model based on magnetic reluctance to represent the average magnetic behavior of a composite. The parameters of the model are obtained through a 2D finite element simulation using, as geometry, a photograph of the composite sample obtained by optical microscopy. Analytical results are compared to data issued from tests.**

Keywords:-composite; magnetic reluctance

I. INTRODUCTION

Composite materials used for electromagnetic purposes are generally formed by iron powder and a non-magnetic material, usually air or resin. This composition results in a low relative magnetic permeability that ranges from a few unities to a few tens depending on the amount of iron present in the material together with the part density.

Those composites are used in the manufacture of some electromechanical devices, such as electric motors, with different topologies for special applications that would not be manufactured with traditional magnetic sheets. One example is the fractional power electrical motor, which must operate in confined spaces.

The magnetic permeability behavior can be understood using the concept of demagnetizing field [1]. However, for composites, the determination of such field is cumbersome due to the complexity of its geometry [2].

This paper proposes a simplified methodology for the characterization of magnetic composite materials for the design and modeling of electromechanical devices. This method aims to obtain an average relative magnetic permeability of composites with high iron concentration using a reluctance circuit whose parameters are identified by the finite element method simulation. The obtained maximal induction and susceptibility are compared with experimental data.

II. METHODOLOGY

A. Proposed Model

Fig.1 shows the proposed model in which two reluctances $\Re_1$ and $\Re_2$ are arranged in parallel. $\Re_1$ is the reluctance of the magnetic powder (hatched part in Fig.1) in series with the air, and $\Re_2$ is the reluctance of air covering the right side of the figure. The permeability of the magnetic powder in this model was considered infinite until magnetic saturation.

The equivalent reluctance can be calculated by (1):

$$\frac{1}{\Re_{total}} = \frac{1}{\Re_1} + \frac{1}{\Re_2} \qquad (1)$$

where: $\Re_1 = \frac{1}{\mu_0}\frac{L_{a1}}{S_1}$ and $\Re_2 = \frac{1}{\mu_0}\frac{L_{a2}}{S_2}$

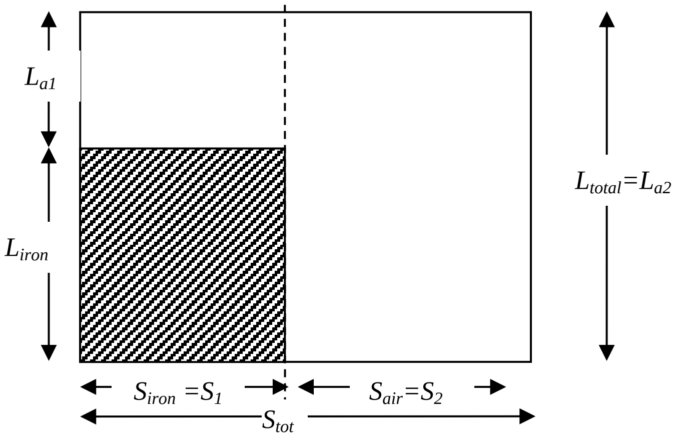

Fig.1: Proposed model based on reluctances

Assuming that there is no fringing in the field lines

$$H_{average}.L_{total} = MMF_{tot} \;\; ; B_{average} = (S_{iron\%}.B_{iron}+S_{air\%}.B_{air2})$$

where B_{iron} is the induction in the region 1 (iron) and B_{air2} is the induction in the region 2 (air) and $S_{x\%}$ represents the percentage of each section. Two geometric parameters (percentages) define the model: the length and the surface of composite magnetic phase.

The aim of this work is to obtain these parameters by using a 2D finite element method. In a 2D model the surfaces can be understood as the length multiplied by the depth of the figure.

B. Determination of the maximum induction in the composite

The maximum value of the induction B in the composite is the maximum value of the average induction, i.e. $B_{averageMax}$. For this, applying the magnetic circuit modeling, when the material reaches its saturation equation 2 can be used for the surface S_1:

$$B_1=\mu_0.H_{average}+J_{sat}\,L_{iron\%} \qquad (2)$$

The last term of (2) is defined as the material contribution for the resulting induction, $J_{ironmax}$. Thus, the maximum $B_{averageMax}$ is:

$$B_{averageMax} = S_{iron\%}.\,J_{ironmax} + \mu_0.H_{average} \qquad (3)$$

As the material is considered saturated, the composite contribution is:

$$J_{satcomposite} = S_{iron\%}.J_{ironmax} \quad (4)$$

Combining (2) and (4), it results in:

$$J_{satcomposite} = \%vol_{iron}.J_{sat} \quad (5)$$

where J_{sat} is the value of the saturated polarization of the iron powder. The proportionality between the volume of magnetic phase and the composite saturation on high density composites was already observed experimentally [6].

C. Determination of the Susceptibility

The susceptibility of the composite can be defined as:

$$\chi = J_{composite}/H_{average} \quad (7)$$

In the proposed model, as the magnetic permeability of the iron was considered infinite and since $L_{fe} < L_{tot}$, the relative permeability of the composite can be expressed as

$$\bar{\mu}_{composite} = \left(\frac{S_1}{L_{a1}} + \frac{S_2}{L_{a2}}\right)\frac{L_{total}}{S_{total}} \quad (8)$$

Thus:

$$\bar{\chi}_{composite} = \bar{\mu}_{composite} - 1 = \frac{\%vol_{iron}}{1 - L_{iron\%}} \quad (9)$$

III. Results

A. Test Case

The proposed methodology was applied to a composite with 25.5% of iron powder and 74.5% of resin, as presented in Fig. 2.

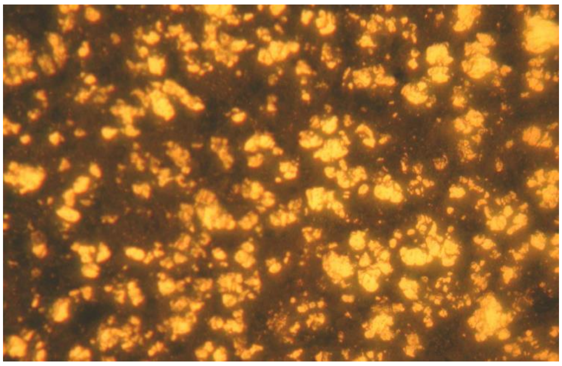

Fig. 2: Composite (iron - bright areas) obtained by optical microscopy

B. Finite Element Simulation

The susceptibility of the composite was obtained by 2D magnetostatic simulation in the geometry presented in Fig. 3. The geometry was defined by using image recognition techniques. Some adjustment of geometry was done to obtain the same volume as the experimental one. The same geometry was used to obtain the susceptibility of the composite by simulation with a very high linear permeability material.

With the obtained parameters, a series of simulation was done with no linear experimental properties of the composite. Fig. 4 presents the susceptibility obtained by the FEM simulation (proposed model and 2D geometry) and experimental tests as a function of the applied magnetic field.

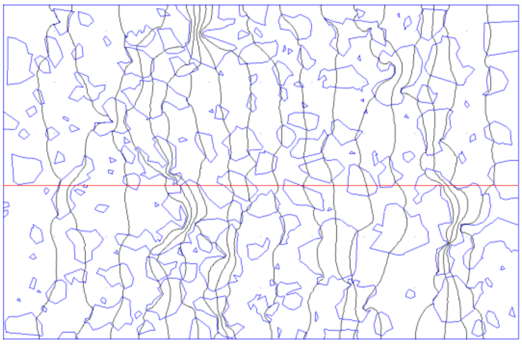

Fig. 3: 2D Magnetostatic FEM simulation.

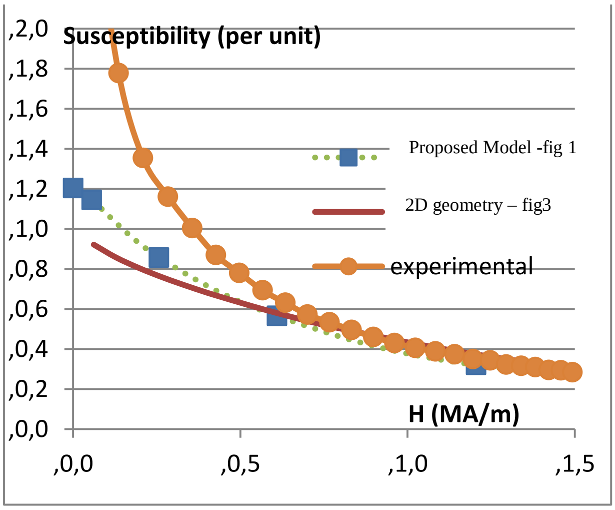

Fig. 4: Comparison of the susceptibility obtained by the proposed method, FEM simulation and experimental tests.

At high fields the proposed model represents the composite more accurately. As the permeability increases (low fields), the proposed model tends to overestimate the 2D simulated results, approaching experimental results. The fringing flux inside the geometry can partially explain these results.

Ackowledgment

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