Modelling of nanocrystalline flake laminated materials

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This article presents the modeling and analysis of nanocrystalline flake laminated material used in an LVDT position sensor. The armature's magnetic permeability and electrical conductivity are essential parameters for the optimum design of position sensors, especially when the sensor operates at high frequencies. The nanocrystalline flake laminated material tape consists of multiple ferromagnetic layers separated by nonconductive and nonmagnetic layers. Therefore, its magnetic and electrical characteristics are not isotropic. Non-destructive eddy current testing is an efficient approach to obtaining them. The relative magnetic permeability and electrical conductivity are estimated using measurement and theoretical calculations.

Keywords: nanocrystalline flake laminated materials; 3D FEM; relative permeability; conductivity

1. Introduction

Linear variable differential transformer (LVDT) position sensors are widely used for industrial applications. Flat-type position sensors with thin armature can help to use less space [1]. The authors used Silicon steel lamination for the armature in the developed position sensor [1]. The main disadvantage of silicon steel lamination is induced eddy currents and skin effects, limiting the position sensor's maximum operating frequency. Ferrite can be an alternative material for armature, which can be operated up to MHz frequency. However, a thin layer of Ferrite is less flexible and more brittle than silicon steel lamination. Therefore, choosing a suitable ferromagnetic material with minimum skin effect for the armature helps operate the position sensor at high frequency [2]. The value of conductivity and relative magnetic permeability of used ferromagnetic material is essential for the position sensor design. Therefore, they should be measured or estimated.

The inductance difference, ΔL, and resistance difference, ΔR, of a rectangular coil with a circular armature are used for the measurement and theoretical calculations, as shown in Fig. 1. The inductance and resistance differences are inductance and resistance of the coil with armature minus inductance and resistance without armature (air core). The armature is VITROLAM with five 18 μm layers of VITROPERM separated by 6 μm thickness nonferromagnetic layers [3].

2. Results and discussion

The 3D finite element method (FEM) with an eddy current solver is used for the modeling. The complete model comprises five very thin sheets with a high aspect ratio. Therefore, the number of nodes is very high, resulting in high computational time. The eddy current distributions on the armature surface are shown in Fig. 1 when the coil and armature centers are aligned and unaligned. The calculated ΔL and ΔR values depend on material parameters. In this case, we solved the inverse problem by finding material parameters that fit the computed values to the measured ones. Table 1 presents the result of this fitting process comparison between 3D FEM results and experiments for a single frequency of 200 kHz. The corresponding isotropic value for relative magnetic permeability for each layer is 8000, and conductivity is 0.087 MS/m. In the full paper, we will show a simplified model using effective permeability and resistivity in the transverse direction, which allows us to consider the armature as a single layer. This model enables fast parametric design of the position sensor.

Table 1: Experimental and 3D FEM results comparison – inductance and resistance difference (200 kHz)

	Aligned		Unaligned	
	Induct. diff.	Resist. diff.	Induct. diff.	Resist. diff.
FEM	4.74 μH	0.851 Ω	10.72 μH	0.608 Ω
EXP.	4.46 μH	0.21 Ω	10.2 μH	0.60 Ω

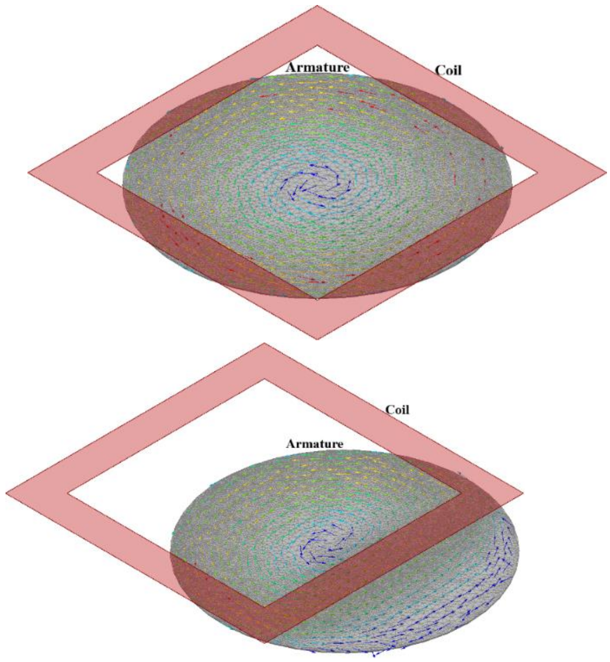

Figure 1: Eddy current distribution in the armature, aligned position (up), unaligned position (down).

References

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[2] P. Ripka, M. Mirzaei, J. Maier. IEEE Sens. Lett. 8 (2024), 3414375
[3] VITROLAM® Thin and flexible shielding material designed for wireless power transfer applications (e.g., smartphones, tablets, …) , www.mouser.com

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