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Crosstalk in Gapped-core Contactless Current Sensor

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***Abstract* – A detailed analysis of the crosstalk in the gapped-core current sensor is presented in this paper. The gapped-core current transducer with a magnetic field sensor in the airgap is widely used to measure current in industries and laboratories. We examine the effect of a nearby current-carrying conductor on the performance of the gapped-core transducer, for the first time in this paper. The crosstalk is studied by considering various factors such as angular and linear displacement of the external conductor, core material, and position of the main conductor. A 3D Finite Element Method (FEM) based model is used to analyse the cross talk and results are presented in this paper. This analysis helps the designer to get detailed insight into the effect of the external conductor on the gapped core current transducer.**

I. INTRODUCTION

The gapped core current sensor with a magnetic field sensor in the airgap is used for the measurement of DC and AC currents [1]- [2]. The cut in the magnetic core reduces the saturation effects that otherwise affect the performance of Current Transformers (CT) [3]. The width of the air gap, the material, and shape of the core, and the position of the magnetic field sensor affect the performance of the gapped core current transducer, and it is studied in the literature [4]-[5]. It is also important to analyze the crosstalk from nearby current-carrying conductors because this situation is common in electric vehicles and their chargers where gapped core current transducers are used [6]- [7].

A detailed analysis regarding the crosstalk effect in the gapped core current transducer is presented in this paper. We consider the effect of change in relative permeability of the core, and off-centered measured conductor when an external current is present near (at various linear and angular positions) to the current transducer. The details about the crosstalk effect in the gapped core current transducer are presented in the next section of the paper.

II. CROSSTALK IN GAPPED-CORE CURRENT TRANSDUCER

A gapped-core current transducer with a magnetic field sensor placed in the airgap is shown in Fig.1a. The dimensions of the gapped core and conductors that are used in the 3D-FEM analysis are provided in Fig.1b. The 3D model developed in the Ansys Maxwell software exactly replicate actual gapped core transducer for current measurement. The dimensions provided in Fig. 1b is the dimension of a nanoperm core from Magnetec GmbH [8]. The air gap length of 1.8 mm is required to keep the Hall-Effect [9] or TMR [10] magnetic field sensors in the gap. A 10 A DC current was passed through the conductors during the analysis. The magnitude of flux density at the airgap is proportional to the current in the measured conductor. The change in magnitude of flux density the airgap due to the presence of an external conductor (as shown in Fig.1a.) is prone to introduce error in the measurement. An analysis of the error introduced in the

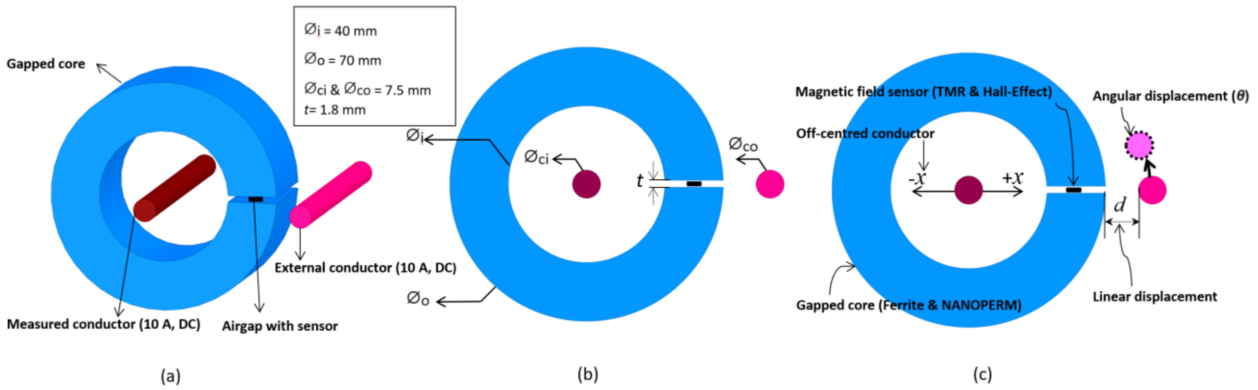

Fig. 1. (a) The gapped-core current transducer with an external conductor. The dimensions of the transducer is provided in (b). The crosstalk by external conductor is analysed for various conditions provided in (c).

measurement due to the crosstalk effect is provided in the following subsections of the paper.

A. Crosstalk in ferrite and nanoperm based gapped cores

The core in the gapped core current sensor is made of materials with high relative permeabilities. We have used ferrite gapped core with a relative permeability of 2100 and Nanoperm (from Magnetec GmbH) with a relative permeability of 10000 [8] in the 3D-FEM analysis. Fig. 2 shows the flux line distribution in the core (relative permeability = 2100) and the air gap when only the external conductor is excited. It is visible in Fig.2 that some of the flux lines choose the path through the airgap. Fig. 3 shows the flux line distribution for a gapped core with a relative permeability of 10000. It is visible from Fig.3 that most of the flux lines use the path as core and none of the lines crosses the air gap. This scenario happens because for the core with low relative permeabilities, the reluctance offered by the core is high (compared to the core with high relative permeability) and this tends the flux lines to cross the air gap. In both cases, the external conductor is in the closest position (d = 0) to the airgap and only the external conductor was excited.

During the FEM analysis, the distance (d, as shown in Fig.1c.) between the gapped core and the external conductor varied from 0 to 20 mm. The error introduced in the measurement due to the change in magnitude of the flux density at the airgap due to the external conductor for each distance is obtained and provided in Fig. 4. It is visible from Fig. 4 that crosstalk error is high if the external conductor is near to the air gap and for the ferrite-gapped core. We found this interesting and analyzed the crosstalk error for different permeabilities of the gapped core and which is provided in Fig.5. The results are presented in Fig.4. shows the importance of selecting a gapped core with higher permeabilities for a low crosstalk effect.

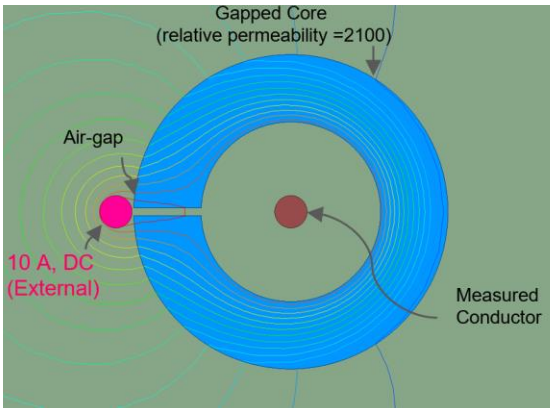

Fig. 2. Fluxline distribution in the ferrite-gapped core transducer when only the external conductor is excited.

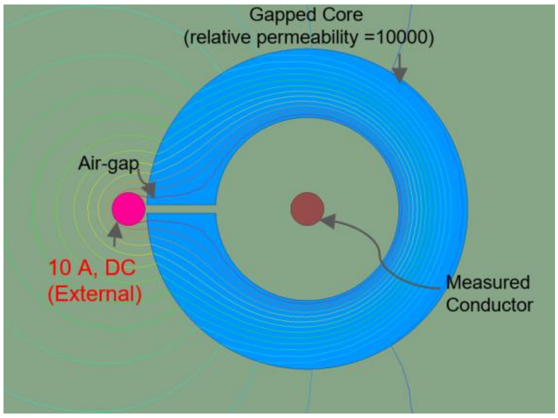

Fig. 3. Fluxline distribution in the nanoperm gapped core transducer when only the external conductor is excited.

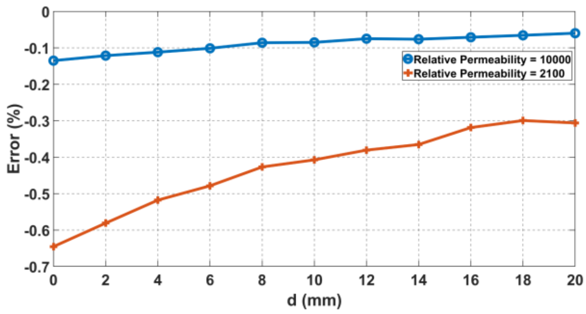

Fig. 4. Crosstalk error characteristics for ferrite and nanoperm core.

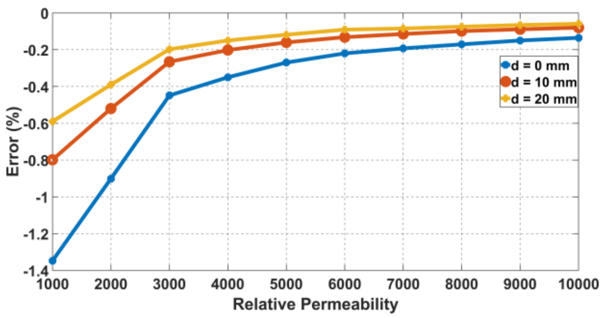

Fig. 5. The crosstalk error for various relative permeability of the gapped core.

B. Crosstalk error for angular displacement of external conductor

The crosstalk error for linear displacement of the external conductor (at different permeabilities of the core) is presented in the previous section. It is also important to analyze the crosstalk error at different angular positions (θ, as shown in Fig.1c.) of the external conductor. The same is analyzed using the 3D-FEM and results are

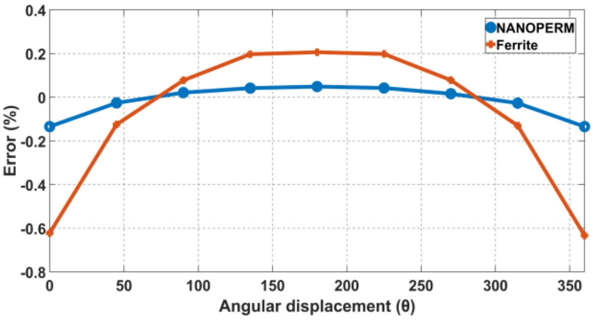

Fig. 6. Crosstalk error at different angualr postion of the external conductor.

provided in Fig. 6. It is visible from Fig. 6 that the crosstalk effect is low for angualr postion of 75 (also 275) degress for the external conductor.

C. Effect of off-centered measured conductor on corsstalk error

The effect of an off-centered measured conductor on the crosstalk error is presented in this section. The measured conductor is moved from its ideal center position (in the gapped core) along the *X*-axis in both directions (as shown in Fig.1c.). The results are presented in Fig.7. shows that the crosstalk is dependent on the position of the measured conductor.

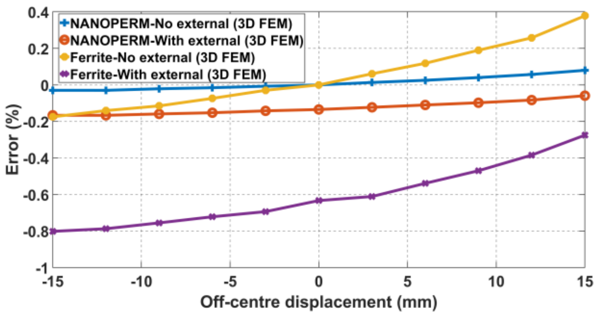

Fig. 7. The effect of off-centered measured conductor on crosstalk by external conductor.

D. Crosstalk in a dual-gapped core current transducer

This section of the paper analyses the crosstalk effect on a dual-gapped core transducer. The dimension of the transducer used for the FEM analysis is shown in Fig. 8. The flux line distribution in the dual-gapped core current transducer is provided in Fig. 9. The FEM analysis showed that the magnitude of the flux density at one airgap increases due to external field but the magnitude of the flux density at second airgap decreases due to external field. This enables to cancel the effect of the external field with the help of differential measurement [11]. So, the crosstalk effect in low permeability single-gapped core can be improved by using a dual-gapped core current transducer, and the same is shown in Fig. 10.

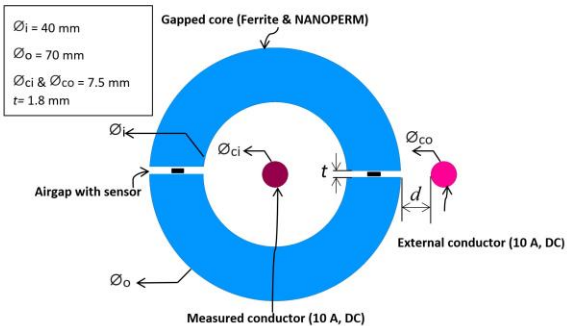

Fig. 8. The gapped core current sensor with two gaps in the core.

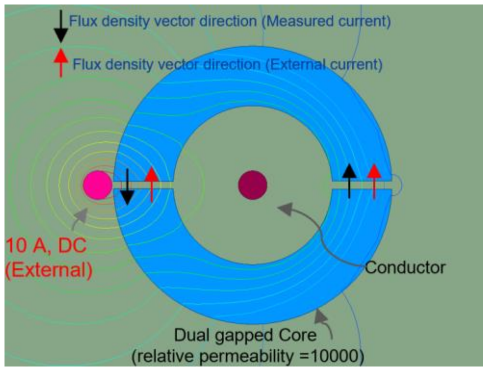

Fig. 9. Fluxline distribution in the nanoperm dual gapped core transducer when only the external conductor is excited.

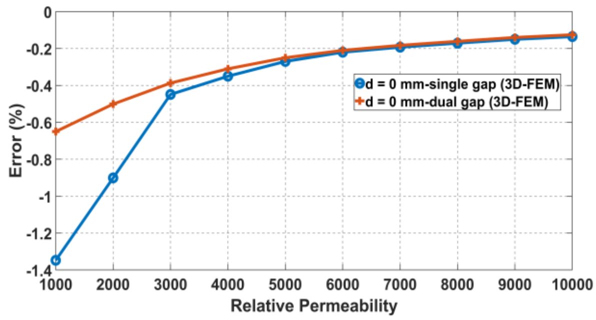

Fig. 10. The comparison of the crosstalk in the single and dual gapped core current transducer.

III. CONCLUSION

The effect of crosstalk from the external conductor in a gapped core current sensor is presented in this paper. The results presented in this paper show that the crosstalk error depends on the relative permeability of the core, the angular and linear position of the external conductor, and the position of the measured conductor. The NANOPREM core with a relative permeability of 10000 showed better resistance to the crosstalk effect compared to a ferrite core with relative permeability of 2100. The crosstalk effect of single gapped low permeability cores can be improved using dual gapped core current transducers.

REFERENCES

[1] P. Ripka, “Electric current sensors: A review,” Meas. Sci. Technol.,vol. 21, no. 11, pp. 1–23, Sep. 2010.

[2] M. Crescentini, S. F. Syeda and G. P. Gibiino, "Hall-Effect Current Sensors: Principles of Operation and Implementation Techniques," IEEE Sensors Journal, vol. 22, no. 11, pp. 10137-10151, 1 June1, 2022.

[3] M. Davarpanah, M. Sanaye-Pasand and R. Iravani, "A Saturation Suppression Approach for the Current Transformer—Part I: Fundamental Concepts and Design," IEEE Transactions on Power Delivery, vol. 28, no. 3, pp. 1928-1935, July 2013.

[4] R. Rushmer, J. Annis, R.D. Marasch, and G. Voborsky, “Hall Effect Sensor Core With Multiple Air Gaps,” U.S. Patent 9,285,437 B2, Mar. 15, 2016.

[5] D. Geisler, and S. D . Milano, “Current Sensor,” U.S. Patent 10,114,044 B2, Oct. 3, 2018.

[6] A. Patel and M. Ferdowsi, "Current Sensing for Automotive Electronics—A Survey," IEEE Transactions on Vehicular Technology, vol. 58, no. 8, pp. 4108-4119, Oct. 2009.

[7] S. Cong, Hein, I. Ansari, A. Armento, A. Hurlburt, R. Cleveland, and M. Zamieski “Electric Current Sensor for Detecting Leakage Current,” U.S. Patent 11,313,917 B2, Apr. 26, 2022.

[8] “*M-712 MAGNETEC*”, [Online]. Available at: https://www.magnetec.de/en/?s=M-712.

[9] “Datasheet for MLX91209,” Melexis. [Online]. Available: https://www.melexis.com/en/documents/documentation/datasheets/datasheet-mlx91209.

[10] “Datasheet v1.0a TMR2505 - aecsensors.com” [Online]. Available at: https://www.aecsensors.com/components/com_virtuemart/shop_image/product/Magnetic-Tunnelling-Magnetoresistive-TMR-Linear-Sensors/pdfs/TMR2505-Datasheet-EN-V1.0a.pdf.

[11] P. Ripka and A. Chirtsov, "Influence of External Current on Yokeless Electric Current Transducers," IEEE Transactions on Magnetics, vol. 53 (2017), 1-4.