Effects of Compressive Stress on Ferrites in Inductive Power Transfer

Alexander K. Bailey, Jerry Sun†, Seho Kim, Willsen Wijaya†, Tom Allen†, Grant A. Covic
Department of Electrical, Computer and Software Engineering
†*Centre for Advanced Materials Manufacturing and Design*
University of Auckland
Auckland, New Zealand
{alexander.bailey, jerry.sun, seho.kim, willsen.wijaya, tom.allen, ga.covic}@auckland.ac.nz

***Abstract*—Inductive power transfer (IPT) magnetics are often 'potted' with an encapsulant material to improve thermal performance. The difference in thermal expansion between common epoxy based encapsulant materials and ceramic ferrites creates a compressive load which permanently reduces the magnetic performance of the core material. This article measures how the core loss of Mn–Zn ferrites changes with an applied compressive stress of $10\,\mathrm{MPa}$ to $100\,\mathrm{MPa}$ at $85\,\mathrm{kHz}$. The measured data is used to predict how core losses change in a practical potted IPT pad, demonstrating a $140\,\%$ increase in core loss.**

***Index Terms*—Core loss, inductive power transfer (IPT), loss measurement, magnetic losses**

I. Introduction

Electric vehicles (EVs) are increasingly common due to lowering costs and a rising need for climate change. However, existing infrastructure favours the outgoing Internal Combustion Engine Vehicles (ICEVs), meaning charging EVs can be cumbersome. Inductive power transfer (IPT) is a wireless charging technology that enables power transfer using magnetic fields. The application of this technology to the charging of EVs could enable more reliable and convenient charging of EVs of all power levels [1].

At higher power levels, thermal issues limit power density. In order to improve the thermal performance of the IPT magnetics, both the coil and core layer (shown in Fig. 1) are 'potted' in an encapsulant material [2]. Typical encapsulant materials are resin-based with high toughness and thermal conductivity which improves the temperature profile uniformity and allows for a higher current density in the coil. However, several articles have noted the deterimental effect of encapsulant materials on the magnetic performance of ferrites.

Polycrystalline ferrites show decreased magnetic permeability and a widening B-H curve under applied pressure due to the compressed topography of the domain walls [3]. Foote et. al verified the reduction in permeability and increased core loss through the construction of a small-scale potted IPT coil assembly, demonstrating a $\sim 100\,\%$ increase in losses [4]. This article aims to measure the effect of pressure on ferrite core loss at $85\,\mathrm{kHz}$ in a material independent and reproducable manner with standard core loss measurement techniques. that designers can better predict the impacts of encapsulation on the IPT system's behaviour.

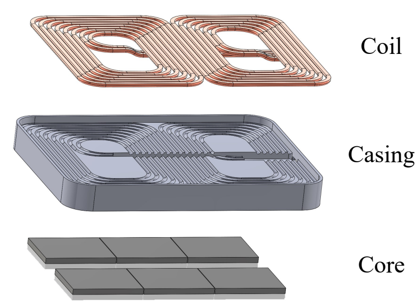


Fig. 1: Typical structure of IPT pad for EV charging

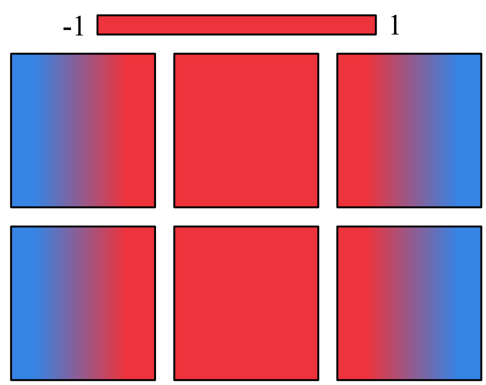


Fig. 2: FEA simulation of compressive stresses on ferrites during curing

II. Characterisation of Ferrite Under Stress

Stress is a physical quantity that describes the forces acting on a material, simple uniaxial stress in the z direction σ_z can be calculated from,

$$\sigma_z = \frac{F_z}{A} \tag{1}$$

Where F_z is the compressive force acting in the z direction and A is the cross-sectional area normal to the z-axis. Although the major stresses on ferrite tiles in IPT are shear (forces act to push layers of the material co-planar to each other), this article considers the material under compressive loading to simplify the measurement setup. The von Mises equivalent

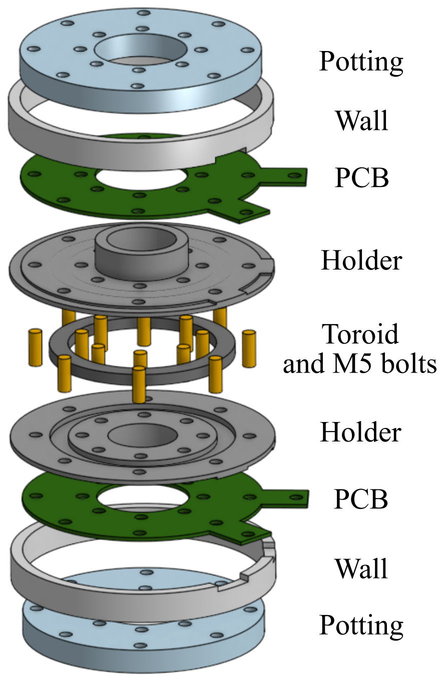


Fig. 3: Exploded diagram of designed compression toroid windings

stress is a scalar value that represents the effect of each of the individual stress components, principal and shear, the von Mises equivalent stress σ_{eqv} is used in this article to allow for comparisons between the measured compressive stress and the predicted and measured shear stresses caused by the encapsulation material. By convention, compressive stress is negative and tensile stress is positive, however for simplicity, in this paper, compressive stress is considered positive unless the von Mises equivalent stress is used.

A hydraulic press was used to apply a compressive force to the surface of toroid. However, in order to measure core loss in the hydraulic press, the toroid must be wound with two conductive windings. Conventional litz wire was eschewed since the sensitive strands would fail under significant compressive loading. Fig. 3 shows the designed holder.

The core loss P_{core} was then measured using a partial cancellation method which modifies the conventional two-winding method with a compensation capacitor C_s in series to cancel the reactive voltage across the inductor under test L_t [5]. The equivalent circuit of this method is shown in Fig. 4. C_s could be selected to completely cancel the reactive power in the system, but maintaining resonance for different operating conditions is challenging. Instead, a partial cancellation method defines a voltage cancellation factor k_v, the ratio of the cancelled reactive voltage to the total reactive voltage, to only 'partially' cancel the reactive component of L_t. The core loss can then be found from measurements of the current flowing through the primary winding $i_L(t)$, the voltage on the secondary winding $v_2(t)$ and the voltage across

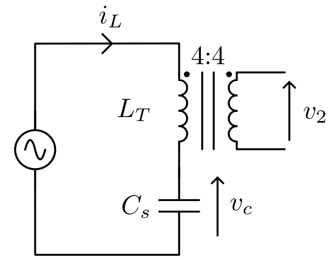


Fig. 4: Equivalent circuit of the partial cancellation method

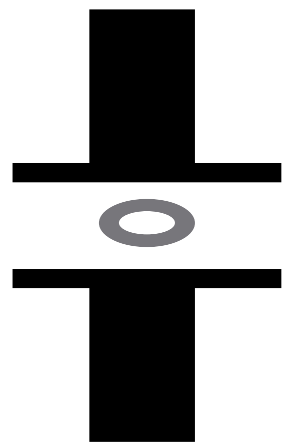


Fig. 5: Experimental setup for core loss measurement under compressive stress

the compensation capacitor $v_C(t)$ from,

$$P_{\text{core}} = f\int_0^T v_2(t)i_L(t)dt + \frac{f}{k_v}\int_0^T v_c(t)i_L(t)dt \tag{2}$$

$$P'_{\text{core}} = f\int_0^T v_2(t)i'_L(t)dt + \frac{f}{k_v}\int_0^T v_c(t)i'_L(t)dt \tag{3}$$

$$k_v = \frac{\int_0^T v_c(t)i_L(t)dt - \int_0^T v_c i'_L(t)dt}{\int_0^T v_2(t)i'_L(t)dt - \int_0^T v_2(t)i_L(t)dt} \tag{4}$$

III. Verification of Core Loss Measurements

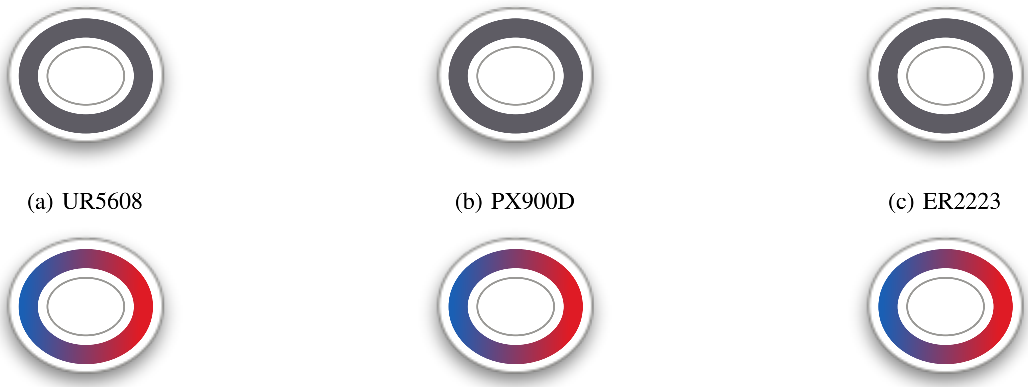
IV. Conclusion

References

[1] G. A. Covic and J. T. Boys, "Modern Trends in Inductive Power Transfer for Transportation Applications," *IEEE J. Emerg. Sel. Topics Power Electron.*, vol. 1, no. 1, pp. 28–41, Mar. 2013. DOI: 10.1109/JESTPE.2013.2264473.

TABLE I: Mechanical properties of relevant materials

Material	Manufacturer	α	Y



(a) UR5608 (b) PX900D (c) ER2223

(d) (e) (f)

Fig. 6: Experimental potted toroids and FEA structural simulations

[2] M. Kneidl, M. Masuch, D. Rieger, A. Kühl, and J. Franke, "Processing influences of resin-based insulation materials for wireless power transfer applications," in *2020 IEEE Conference on Electrical Insulation and Dielectric Phenomena (CEIDP)*, Oct. 2020, pp. 551–555. DOI: 10.1109/CEIDP49254.2020.9437503.

[3] M. Le Floc'h, J. Loaec, H. Pascard, and A. Globus, "Effect of pressure on soft magnetic materials," *IEEE Transactions on Magnetics*, vol. 17, no. 6, pp. 3129–3134, Nov. 1981. DOI: 10.1109/TMAG.1981.1061600.

[4] A. Foote, D. Costinett, W. Henken, R. Kusch, M. Mohammad, and O. Onar, "Encapsulation Residual Stress and Ferrite Loss in Inductive Coil Assemblies," in *2023 IEEE Energy Conversion Congress and Exposition (ECCE)*, Oct. 2023, pp. 1843–1850. DOI: 10.1109/ECCE53617.2023.10362318.

[5] D. Hou, M. Mu, F. C. Lee, and Q. Li, "New High-Frequency Core Loss Measurement Method With Partial Cancellation Concept," *IEEE Trans. Power Electron.*, vol. 32, no. 4, pp. 2987–2994, Apr. 2017. DOI: 10.1109/TPEL.2016.2573273.