# The Influence of Core Shape and Material Nonlinearities to Corner Losses of Inductive Element


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**Introduction**: Soft ferrite cores are popular in various applications related to energy transformation. Their losses are usually determined from loss equations for uniform magnetic materials (modified Steinmetz equation). Sharp corners in the magnetic core, however, can cause flux enhancement effects. These induce variations in the core magnetization leading to higher losses than in a bulk material.

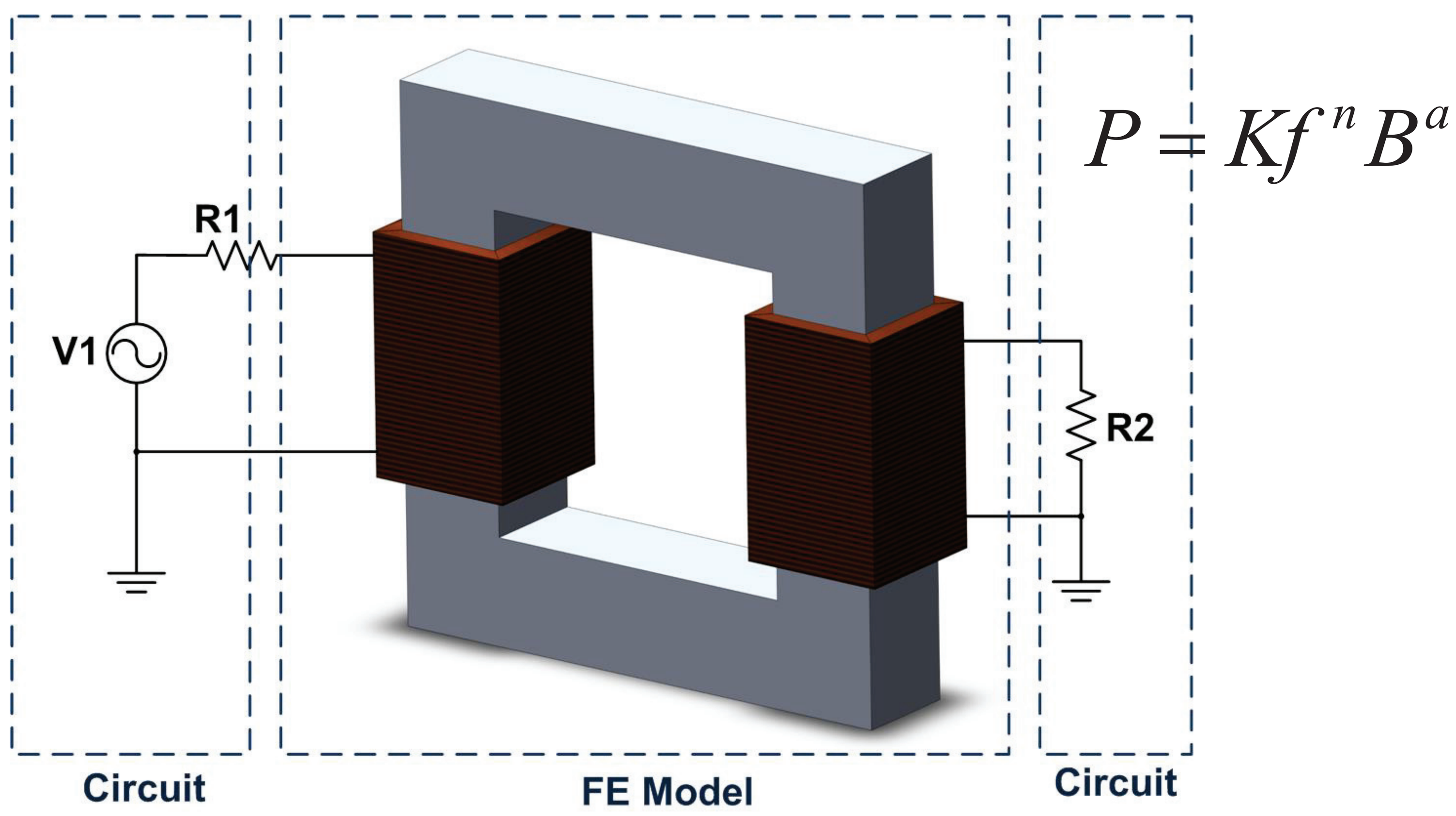


**Figure 1.** Two coils wound around a core, modeled as a finite element model while the load and power source are represented by an equivalent electrical circuit.

**Simulation setup description**: The magnetic device under investigation consists of a square-shaped core and two coils (Figure 1). The AC/DC Module was utilized with the Magnetic Field and Electrical Circuit interfaces to describe the model. Magnetic properties of the Molypermalloy Powder (MPP) 550μ core were assigned to the core volume (isotropic, nonlinear). The function of coils in the model is to magnetize the core to a mean flux density of 0.56 T, which is just below the point where the hysteresis curve of the material becomes nonlinear. As this analysis was restricted to only the magnetic effects inside the core, coils were modeled as Multi Turn Coil Domains.

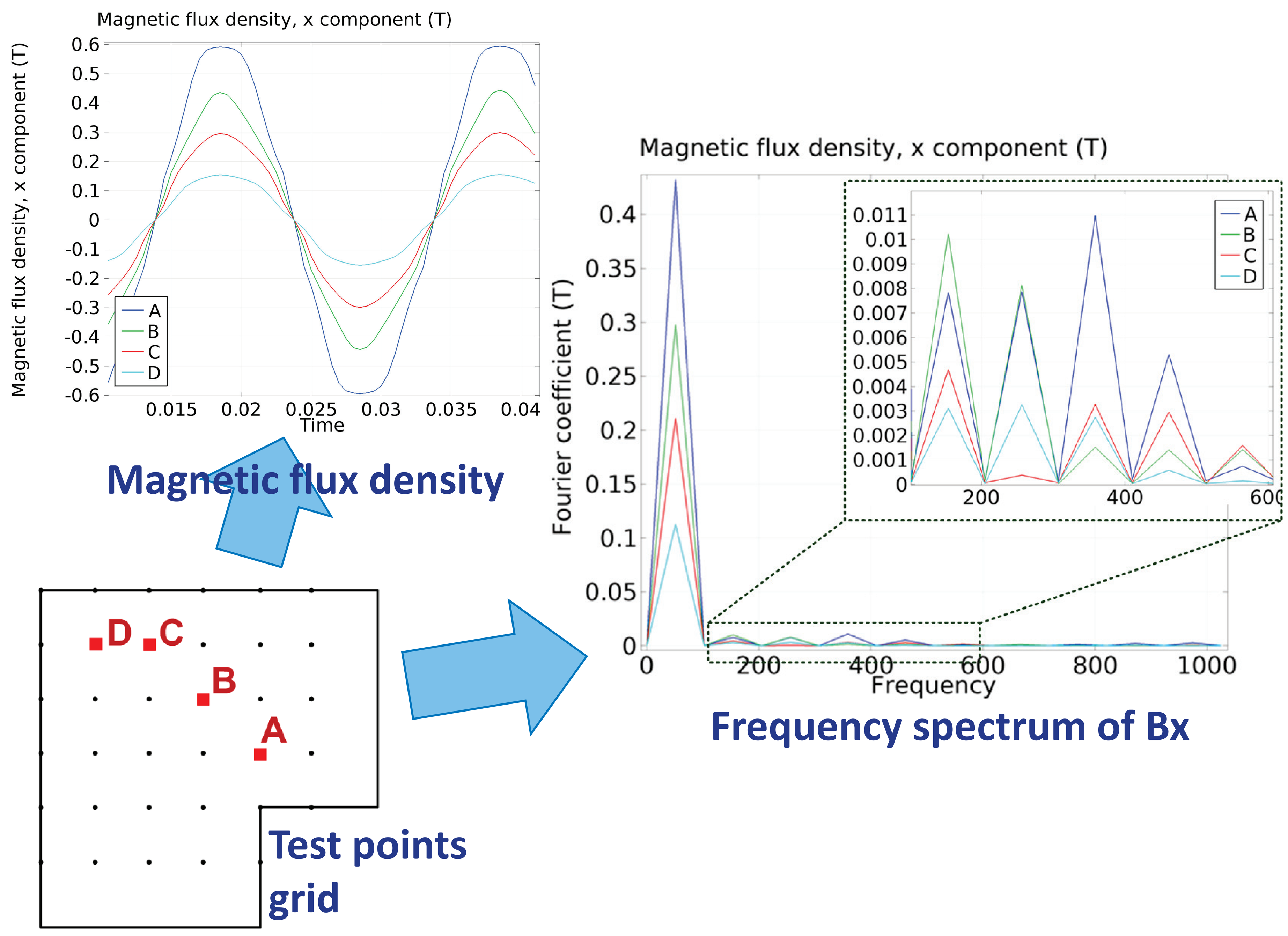


**Figure 4**. Simulation method description: simulated points in the corner region reveal higher harmonic distortion of magnetic flux density.

**Results**: The magnetic flux is enhanced around the inner square corners and reduced significantly in the outer square corners (Figure 2).

A grid of testing points was drawn in the corner region to measure magnetic flux density B and magnetic field H inside the core. Figure 4 shows the time waveforms of the x components of B for the exemplary points placed inside the core

To analyze the importance of higher harmonic losses at the corner, the losses caused in a point by harmonics of order higher than the fundamental were calculated. These were shown as a percentage of the average total core loss at each point (Figure 3)

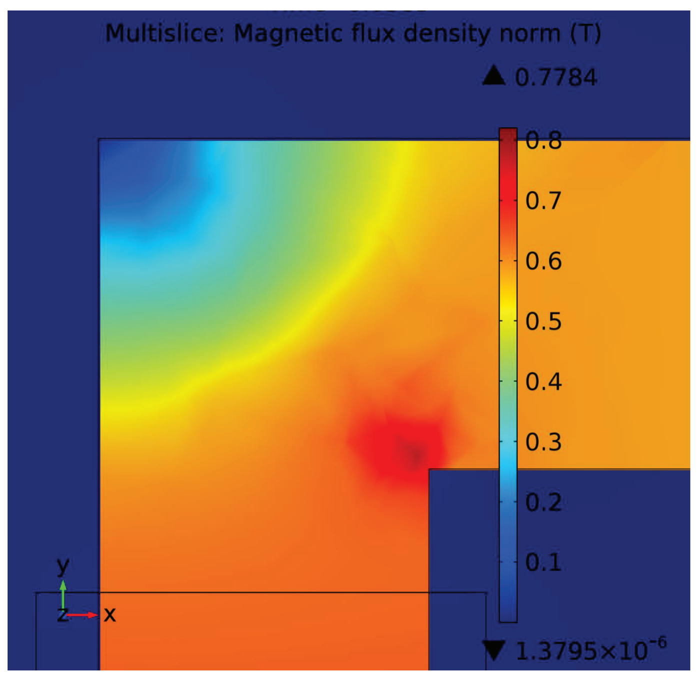


**Figure 2**. Magnetic flux density around a right-angled corner of the choke.

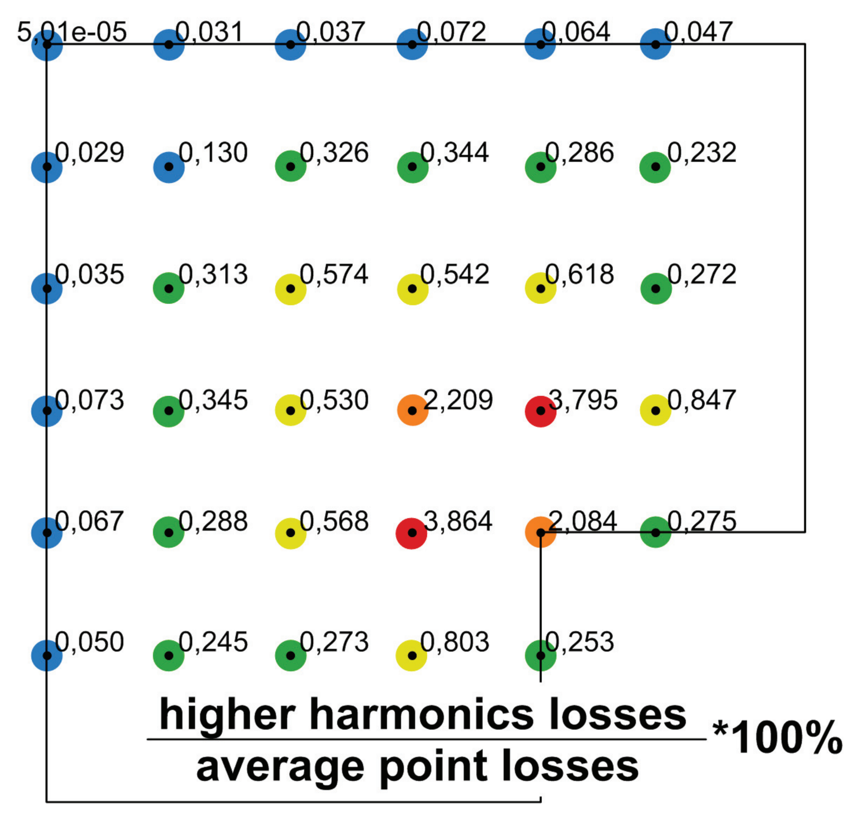


**Figure 3**. Percentage ratio of higher harmonics losses shown against a heat map of average point losses for the test grid.

**Conclusions**: Although the coil, which magnetizes the core, is powered by a sinusoidal signal the magnetic flux in the corner regions of the core is definitely not sinusoidal. Even though the applied field was designed to not push the core into the nonlinear hysteresis region, the enhancement effects caused areas of the core to be driven well into this region.

Because of flux distribution nonlinearities, higher-order harmonics (order ≥ 3) are present in the flux waveform which cause additional losses. Thus the losses in corner region are higher than calculated according to modified Steinmetz equation for this material, as this equation assumes there will be only a single (fundamental) harmonic of the magnetizing field in the core.

Analysis of Figure 3 reveals that in the inner region of the core the higher harmonic losses are up to 3.8% of the fundamental harmonic losses. For low-power cores this value is relatively small and can be neglected but for high power applications these losses are quite significant**.**

This analysis shows that the losses due to harmonics are significant in the corner region of a core and are not uniform and scalable as they would be in a bulk material.


**References**:

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