Impact of Non-Uniform Flux Density on Core Losses: A Case Study on Standard Core Geometries

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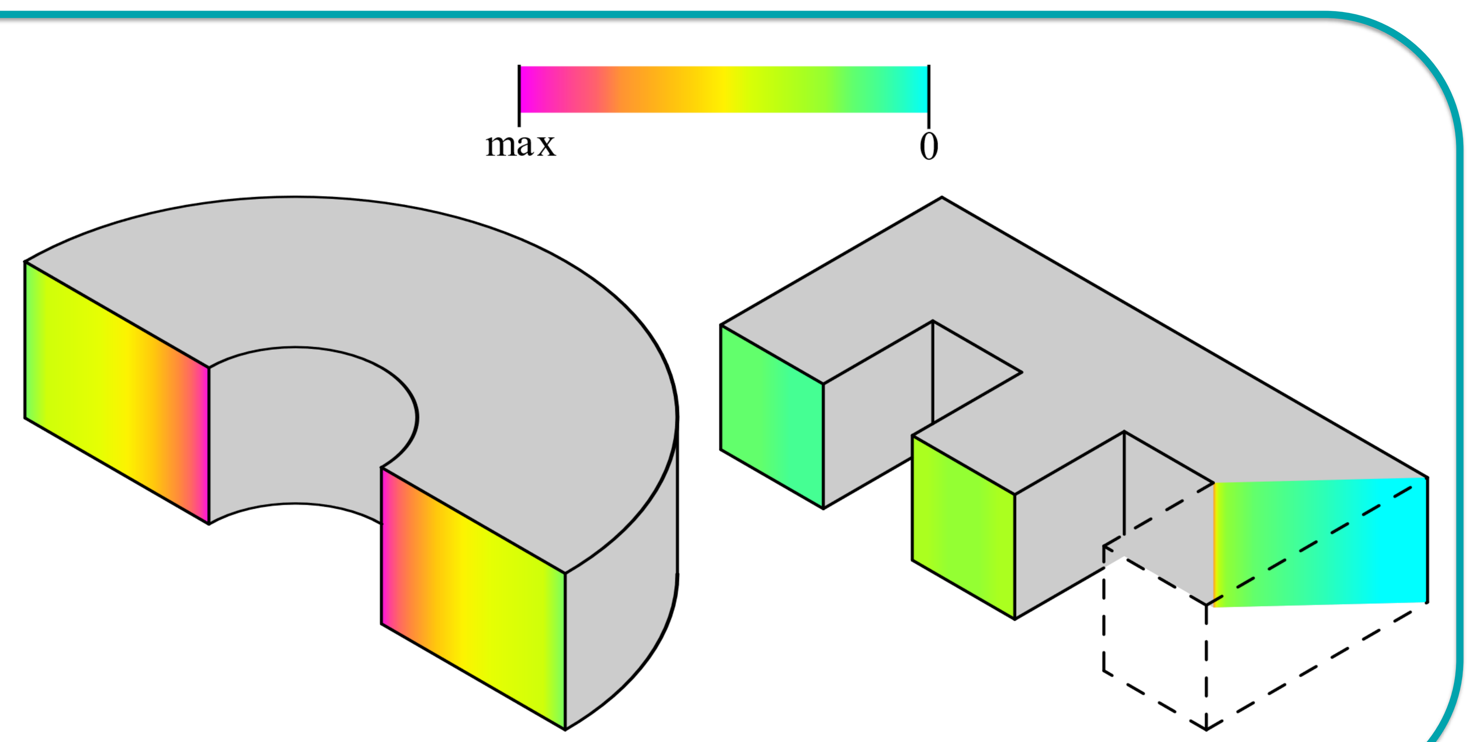
INTRODUCTION

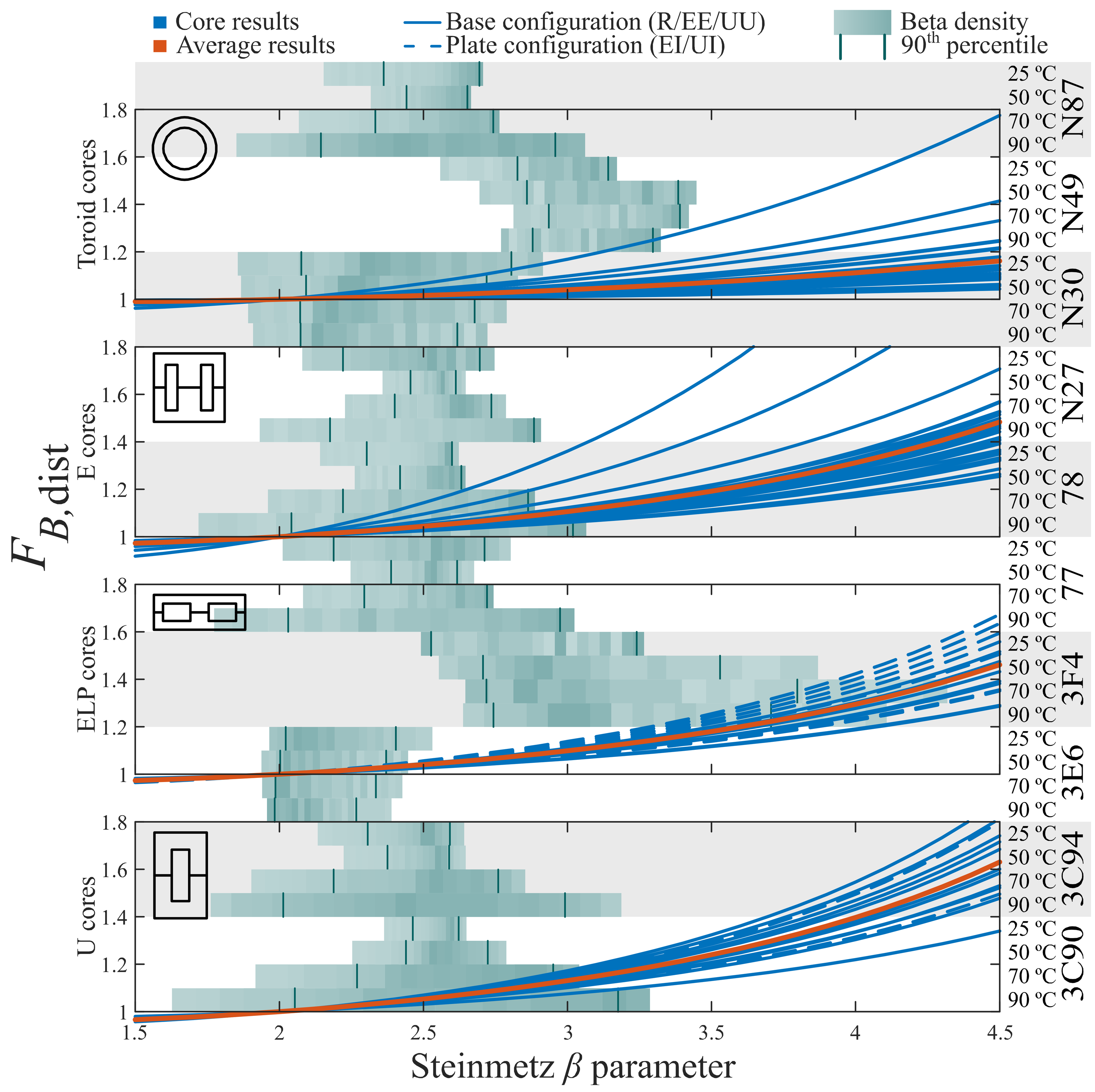
Core loss estimation is a critical task for the design of inductors and transformers. Assumptions of uniform flux distribution is used to estimate the core losses, which does not reflect the real flux distribution on the core:

- Flux crowding in the core corners results in the flux density concentrating in the core edges.
- Unbalanced core legs results in higher average flux densities in different core sections.
- Differences between inner and outer radius of toroid cores results in higher flux in the inside.

The influence of non-uniform flux distribution in the core losses must be explored to understand how much of an impact it has and how it affects different standard core geometries.



RESULTS



Flux distribution is evaluated for standard core geometries found in the TDK Electronics product catalogue for ferrites and accessories [1]. The following core geometries are studied:

- 41 R cores.
- 34 E cores
- 16 ELP cores (8 ELP/ELP + 8 ELP/I)
- 13 U cores (11 U/U + 2U/I)

All cores are evaluated with 2-D FEM simulations to get an accurate distribution of the flux density (limited to low frequency effects).

Resulting flux density per finite element is used to evaluate the losses:

$$P_{\mathrm{loss,uniform}} \propto B_{\mathrm{uniform}}^{\beta} \qquad P_{\mathrm{loss,non-uniform}} \propto \frac{\sum V_i B_i^{\beta}}{V_{\mathrm{core}}}$$

$$P_{\mathrm{loss,non-uniform}} = F_{B,\mathrm{dist}} \cdot P_{\mathrm{loss,uniform}}$$

Using the Steinmetz Equation, the loss increase due to non-uniform flux density is a function of β, which is material/temperature/frequency dependent [2]. Thus, the increase in losses $F_{B,\mathrm{dist}}$ is evaluated in a wide range of β based on experimental data from the MagNet opensource core loss database [3].

Results for all cores per value of β are shown, with indications of common ranges of β. The loss increases curves for all the cores are fitted to third degree polynomial functions, and all the coefficients are tabulated.

CONCLUSIONS

This work demonstrates how a uniform flux density distribution in the core is not an accurate representation of the real distribution, and how it underestimates the core losses. Most toroid cores are unaffected for typical β values, but increments of >10 % are common for E, ELP and U cores

In addition to the presented curves, all the coefficients used for the fitted polynomials are tabulated. A more accurate approximation of the real losses for the different core geometries at any value of β can be made in the initial design stages of any magnetic device.

Core name	$F_{B,\mathrm{dist}}$		$F_{B,\mathrm{dist}} = p_0 + p_1\beta + p_2\beta^2 + p_3\beta^3$			
	β=2.5	β=3.5	p_0	p_1	p_2	p_3
U 11/9/6	1.0480	1.2082	0.0121	-0.0524	0.1429	0.8285
U 15/11/6	1.0596	1.2697	0.0207	-0.1018	0.2561	0.7326
U 17/12/7	1.0636	1.2845	0.0200	-0.0942	0.2411	0.7378
U 20/16/7	1.0669	1.3041	0.0241	-0.1201	0.2999	0.6915
U 25/20/13	1.0582	1.2609	0.0189	-0.0912	0.2324	0.7512
U 26/22/16	1.0528	1.2335	0.0156	-0.0724	0.1887	0.7895
U 30/26/26	1.0500	1.2236	0.0160	-0.0767	0.1961	0.7887
U 93/76/16	1.0453	1.2029	0.0146	-0.0699	0.1782	0.8086
U 93/76/16 + plate	1.0640	1.2946	0.0250	-0.1281	0.3156	0.6850
U 101/76/30	1.0419	1.1852	0.0125	-0.0584	0.1519	0.8314
U 126/91/20	1.0314	1.1357	0.0079	-0.0340	0.0933	0.8877
U 126/91/20 + plate	1.0432	1.1917	0.0132	-0.0624	0.1618	0.8224
U 141/78/30	1.0697	1.3236	0.0286	-0.1481	0.3617	0.6445
Average	1.0534	1.2399	0.0176	-0.0851	0.2164	0.7696

REFERENCES

[1] TDK Electronics ferrite product catalogue, https://www.tdk-electronics.tdk.com/en/ferrites

[2] S. A. Mulder, “Fit Formulae for Power Loss in Ferrites and their Use in Transformer Design,” in proc. 26th International Power Conversion Conference, 1993.

[3] MagNet Database for Sharing and Visualization, https://mag-net.princeton.edu/