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The Role of the Critical Induction for Off-plane Flux in Transformer Cores

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Abstract – Corners and T-joints of cores of transformers or shunt reactors contain overlaps of reduced effective cross section of material. Depending on the so-called step number, the "critical induction" B_C characterizes the flux density beyond that flux is taken up by air gaps. The present study shows that in real cores that consist of several packages, B_C is linked with a distinct onset of off-plane fluxes, in direction normal to the laminations. This means that core operation above B_C is characterized by disadvantageous, 3-dimensional flux re-distributions.

1. Introduction

Transformer cores tend to be stacked from highly grain oriented SiFe that shows high permeability for the rolling direction. However, corners and T -joints contain air gaps that represent strongest magnetic reluctance. To reduce their impact on the global magnetization, industry assembles the core with overlaps (OLs) of so-called step-lap, where an individual gap is bridged by N laminations. In [1,2], it was demonstrated that the step number N corresponds to a well defined "critical induction" B_C where the bridges are saturated, as a reason for the onset of flux through the gaps. Recently, this was confirmed also by FEM modelling [3]. Fig.1 (from [1]) shows the corresponding increases of OL-excitation for model cores with mitred OLs as being typical for transformers, and for linear OLs as arising in shunt reactors.

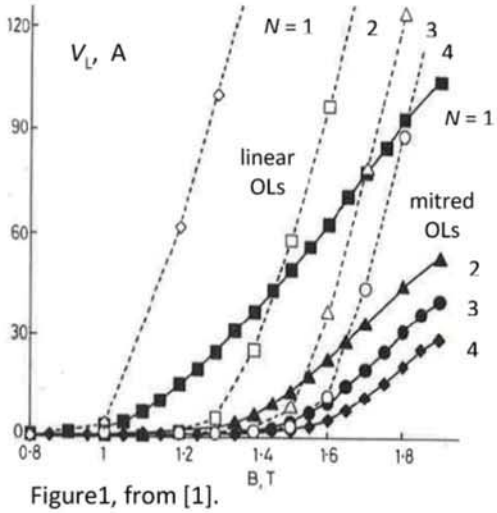

Figure1, from [1].

Our new study revealed that the induction B_{CRIT} has an analogous significance for *global* flux distributions in multi-package cores, as used in industry – in particular, for fluxes in normal direction, as reported in the following.

2.Experimental

In contrast to earlier measurements on model cores of constant sheet width, this study was made on a more realistic core of three packages with widths of 15 cm, 11 cm and 8 cm, respectively. Assembling was made with $N = 4$ steps. The tendency of circular limbs in connection with semi-circular yokes was considered by package shifts that cause shifts also of OLs. The core was magnetized with 50 Hz, with nominal induction values B_{NOM} between 1 T and 1.6 T.

In order to study interactions of the packages, measurements of normal-direction flux density B_{ND} were made by novel detector band sensors [4, 5]. They consisted of three flat frame-coil windings of 25 mm mean size, print on a 20 μm thick plastic substrate, by means of an electrical

paint "Bare Conductive" suspension, to prevent substantial inter-laminar air gaps. The focus of measurements was put on border regions between the packages, in particular close to OLs. From the sensor signal, the normal direction induction $B_{ND}(t)$ was calculated, as an average over the sensor area.

3.Results

Fig.2 shows an example of results for a yoke region beside the V-elements of the T-joint, between the packages of 15 cm and 11 cm thickness. We see time courses $B_{ND}(t)$ for B_{NOM} of 1 T, 1.3 T, 1.4 T, 1.5 T and 1.6 T.

For low nominal magnetization $B_{NOM} = 1$, the induction B_{ND} remains under the level of 3 mT for the whole period of magnetization. As an interpretation, throughout the core, the OLs do not attain local saturation, according to $B < B_{CRIT}$. The packages operate quite independent from each other, their fluxes remaining within each package.

The global flux distribution changes substantially when we increase B_{NOM} to - and beyond - the critical induction B_{CRIT} of ca. 1.3 T. In instants of $B > B_{CRIT}$, the flux tends to avoid the partly saturated OLs. It bridges the latter by "escaping" to the neighbour package through flux in normal direction. This yields distinct instantaneous increases of B_{ND} up to the level of 35 mT for B_{NOM} = 1,6 T (Fig.2a).

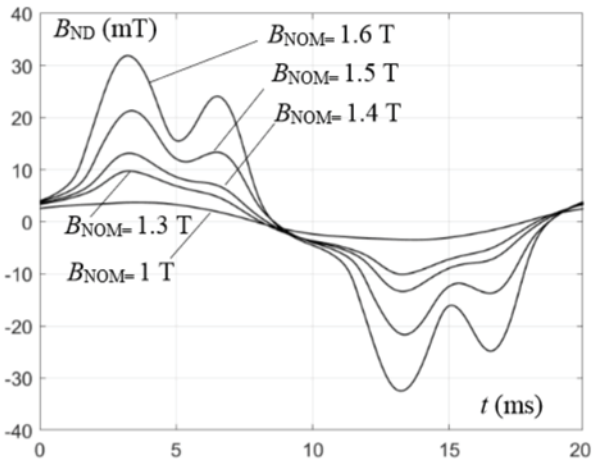

Figure 2

4.Conclusions

The study indicates that the practical relevance of the "critical induction" B_{CRIT} is not restricted to the performance of overlaps, i.e. to their excitation and local losses. Rather, B_{CRIT} can be assumed to influence the cores *global* flux distribution in significant ways. For $B_{NOM} > B_{CRIT}$, the packages get in distinct inter-connection through off-plane fluxes in normal direction. This means that the core is characterized by complex 3-dimensional flux distributions. As disadvantageous consequences, the levels of flux distortion increase throughout the core, but in particular close to overlaps. This yields an increase of building factor. But even more, it enhances the audible noise of the core, as a parameter of rising relevance.

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