Frequency Dependence of the Ferrite-Loss Increase Caused by Premagnetization

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Abstract

Ferrite cores of magnetic components used in power electronics are often biased with a DC or low frequency premagnetization. Recent work has shown that a bias field may have significant influence on the remagnetization losses and therefore has to be considered in the component design. Using a precise measurement setup this paper investigates the frequency dependence of the power loss increase due to premagnetization. The measurements are performed on typical ferrites of two major manufacturers. The experimental results show that there are two major contributions to the total remagnetization losses of soft-ferrites whereas only one contribution is influenced by premagnetization. Finally the paper discusses some aspects of a mathematical description for the bias problem and leads to an improved understanding that might be useful for the designer of magnetic components.

1 Introduction

Ferrites are widely used in Power Electronics. Switch mode power supplies, high frequency AC-DC and DC-AC converters and many other applications contain magnetic components with ferrite cores. Most of these applications expose the magnetic core to both, high remagnetization frequency and high excitation levels. Additionally, in most cases there is a DC or low frequency component in the inductor or transformer current that leads to premagnetization. As an example one may think of the input and output chokes of switch mode power supplies, or applications like flyback or forward converters where the flux density sweep is asymmetrical. But although there are many applications where the ferrite is premagnetized, there is still very little information about the influence of the DC-bias on the remagnetization losses. Recent work has shown, that there might be a significant increase of the remagnetization losses of soft-ferrites due to premagnetization[1]. This paper goes one step further and investigates the frequency dependence of the loss increase due premagnetization by means of a precise measurement setup. Finally it discusses some aspects of a physical interpretation of the measurement results.

2 Influence of premagnetization

The data books of major manufacturers of power electronic ferrites contain no information about the
influence of premagnetization of the losses[2], [3], [4]. For silicon iron, it is known from Bozorth that the power losses are depending on a biasing field[5]. Bozorth's diagram is plotted in fig. 1.

![Bozorth's Diagram](image)

Figure 1: Specific losses as a function of biasing induction for silicon iron according to Bozorth[5]

Recent work undertaken by the authors has proven that the losses of soft-ferrites are depending on premagnetization too[1]. As an example fig. 2 shows the specific core losses as a function of biasing induction measured on a toroidal core of Philips 3F3-Ferrite at a frequency of 20 kHz. Measurements on other material grades of different manufacturers lead to similar results.

The significant influence of premagnetization on magnetic core losses is important for the design of inductors or transformers that carry direct current. Therefore it is necessary to study this problem in detail and perform measurements at different remagnetization frequencies.

3 Measurement setup

To measure the remagnetization losses of ferrites under the influence of a biasing field as a function of frequency a measurement setup according to the European Standard CECC 25 300 and CECC 25 000 [6] is used. A detailed description of this measurement setup and a discussion of the magnitude of errors introduced by its components has already been given in previous articles[1, 7]. It can be summarized that the development of the measurement setup has to focus especially on the design of the low inductive shunt because of its dominating influence on the total measurement error.

4 Measurement Results

The remagnetization losses are measured on ringcores made of Philips 3F3-Ferrite and Siemens + Matsushita N27 material. Prior to the loss measurements the magnetization curve of the test cores is measured. This is necessary because the DC-induction in the core can not be measured directly. The DC part of the flux density \(B_{DC}\) has to be calculated from the DC-part of the magnetic field \(H_{DC}\) using the measured magnetization curve.

![Measurement Results Graph](image)
4.1 Siemens-Matsushita N27-Ferrite

Siemens-Matsushita’s N27-Ferrite is a standard material suitable for frequencies below 100 kHz. Therefore the specific core losses are measured in the frequency range $10 \text{ kHz} \leq f \leq 100 \text{ kHz}$ for different values of DC premagnetization and AC flux excursion. The core under test is a R 12/5 toroidal core and the core temperature is $100\degree C$. Fig. 3 shows the measurement results.

![Figure 3: Specific losses of R 12 core made from S+M N27-Ferrite](image)

For the small R12 core, fig. 3 indicates that the increase of core losses due to a biasing field is almost not depending on the frequency. The DC premagnetization is shifting the loss curves in parallel and the slope of the curves is almost not affected. Especially for high AC-excitation, i.e. $B_{AC} = 80\text{mT}$, the frequency dependence of the loss increase caused by premagnetization can be neglected.

In the next step it has to be checked, if these findings also hold for cores with a larger cross-section or if the loss-increase due to premagnetization is depending on the geometry of the core. Therefore additional measurements are taken on a R25 core made from N27-Ferrite. Compared to the R12 core, the cross section of the R25-core is increased by a factor of 4.2. The measurement results for the R25 core at a temperature of $100\degree C$ are shown in fig. 4.

![Figure 4: Specific losses of R25 core made from S+M N27-Ferrite](image)

From the comparison of fig. 3 and fig. 4 it can be seen that there might be an influence of the geometry on the loss-increase, especially for low AC-excitation. For $B_{AC} = 25\text{mT}$ the loss curves of the larger R25-core converge and meet each other at higher frequencies, whereas for high excitation, i.e. $B_{AC} = 80\text{mT}$, the curves run in parallel.

4.2 Philips 3F3-Ferrite

In contrast to N27, Philips 3F3-Ferrite is a high-frequency material grade and therefore the measurements are performed up to 650kHz. The next fig. 5 shows the results derived from measurements on a RCC14 core made from Philips 3F3-Ferrite. The core temperature is $100\degree C$.

![Figure 5: Specific losses of RCC14 core made from Philips 3F3-Ferrite](image)

From fig. 5 it can be seen, that the small 3F3 core behaves similar to the small N27 core. The loss increase caused by premagnetization is almost not frequency dependend and the loss curves for different values of DC-flux density run in parallel to each other. As for N27-Ferrite, the measurements are repeated on a core with a larger cross section. In fig. 6 the specific core losses of a RCC36 core made from 3F3-Ferrite are plotted as a function of frequency. Compared to the R14 core, the cross section of the RCC36-core is enlarged by a factor of 7.8.
The two graphs fig. 5 and fig. 6 enable to read out some very interesting details about the frequency dependence of the loss increase caused by premagnetization. At high AC-excitation, i.e. $B_{AC} = 80\text{mT}$, both cores show almost the same behavior. For both core sizes the loss curves at high excitation run in parallel. This means that in this area premagnetization leads to increased core loss that is not influenced by frequency or geometry.

For small AC-excitation, i.e. $B_{AC} = 25\text{mT}$, the material behaves different. The loss curves of the small core still run almost in parallel whereas the curves of the large core converge. This means that for low excitation the loss increase caused by premagnetization becomes frequency and geometry dependent. Fortunately, this case of low AC-excitation is not as important for power-electronic applications as high excitation.

### 5 Analysis of the measurement results

It is not the intention of this paper to investigate the physical origin of the loss increase due to premagnetization. After more than a century of research the origin and mathematical description of remagnetization losses in ferrites is still a major interest of materials science and has been addressed by many publications \cite{8, 9, 10, 11, 12, 13, 14, 15}. The intention of this paper is to show that premagnetization might lead to a significant increase of core losses, which is particularly important in the design of magnetic components for power electronic applications. Therefore, a detailed specification of this effect in the data-sheets of the manufacturers would be highly desirable.

To find a first mathematical description of the loss increase caused by premagnetization, the remagnetization losses have to be split into two major parts. One part is influenced by premagnetization but not depending on geometry or frequency and the other part is not affected by premagnetization but depends on geometry and frequency. The general mathematical description for this behavior may be written as:

$$ p_v = C_1(B_{DC}) \, B_{AC}^{\alpha_1} \, f^{\beta_1} + C_2 \, B_{AC}^{\alpha_2} \, f^{\beta_2} \quad (1) $$

This equation describes the specific core losses $p_v$ as a function of AC-induction $B_{AC}$ and frequency $f$ using four empirical exponents $\alpha_1, \alpha_2, \beta_1, \beta_2$ and two parameters $C_1, C_2$. The parameter $C_1$ is a function of premagnetization $B_{DC}$.

Equ. 1 is an empirical description of both contributions to the total remagnetization losses. The
parameters and exponents can be found by numerical fitting. In many cases when the AC-excitation is sufficiency large, the second term of eqn. 1 can be neglected. In this case eqn. 1 is reduced to its first term:

$$p_v = C_1(B_{DC}) \dot{B}_{AC}^{\alpha_1} f^{\beta_1}$$  \hspace{1cm} (2)

This equation is well known as a general description of magnetic core losses and the parameters can be taken from the data books of the manufacturers. In case of Philips Ferrites the data that has been given by Mulder[16] can be used.

A first and simple mathematical approximation of the function $C_1(B_{DC})$ that describes the influence of premagnetization on the core losses is given by:

$$C_1(B_{DC}) = C + K_1 B_{DC} e^{\frac{B_{AC}}{K_2}}$$  \hspace{1cm} (3)

This equation is a linear approximation of the loss-increase due to premagnetization. $K_1$ and $K_2$ represent two empirical parameters that can be determined by curve fitting.

6 Conclusions

The measurements presented in this paper characterize the frequency dependence of the remagnetization-loss increase caused by premagnetization. The graphical information resulting from these extensive measurements gives the opportunity to check whether the combination of AC plus DC AC flux density and frequency will lead to a significant increase in the remagnetization losses. In addition a first empirical approach for a mathematical description of measurement results is presented, that might be useful within the design of magnetic components for power electronic applications.

References


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