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Research Article

Improving Permeability of Ferrite Cores Used in Switch-mode Power Supplies

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Abstract: In this study two methods are proposed to increase the permeability of ferrite cores used in switch-mode power supply applications. The first method is based on the principle of magnetic shaking where an AC magnetic field is superposed on the magnetic core. This method yields good performance in shielding applications but still facing some technical difficulties in switch-mode power supply applications. The second method is based on superimposing a DC magnetic field component equivalent to the main DC component flowing in the main winding of the switch-mode power supply. This method is verified to reduce the power supply inductor current ripple by 68% while downsizing the core of the winding.

Keywords: DC bias, magnetic permeability, magnetic shaking, switch-mode power supplies

INTRODUCTION

The principle of magnetic shaking has long been applied in the field of magnetic shielding (Cohen, 1967; Tashiro and Sasada, 2005). It is now proven that applying magnetic shaking can increase the effective permeability of amorphous materials used in magnetic shielding. The interest in applying such a technique in magnetic shielding is due to the increased price of high permeability magnetic materials used in magnetic shielding. In Cohen (1967), it was proven experimentally that the magnetic shaking process could improve the material permeability, as a consequence magnetic shielding effect, below and above the applied shaking field frequency.

In magnetic shielding, the process of magnetic shaking involves superposing an alternating magnetic field (H_s) on the disturbance field. It was shown that this results in five-fold increase in permeability (Kelha *et al*., 1980). This enhancement in permeability due to shaking can be justified due to keeping the domains in motion. This motion prevents a domain wall from being frozen on a lattice defect (Cohen, 1967; Bozorth, 1968).

In this study, it is shown that this principle is equally applicable to ferrite materials used in power electronics applications. In contrast with pure iron (with μ_r = 200 000) and Metglass (with μ_r = 1000 000), the permeability of Ferrites (with μ_r = 1600) is relatively low. Ferrites excel in high frequency applications due to their poor electrical conductivity and thus lower eddy current losses. Were the permeability of Ferrite materials to increase, this would result in lower core size and less number of turns of core winding requirements. In addition, the effect of superposing a DC magnetic field in the core is studied in order to investigate its effect on the performance of the coil in DC/DC power supply applications. Both techniques that may be efficient in reducing core size in power electronics applications are reported.

SYSTEM CONSTRUCTION

Figure 1 shows the construction of the system. It comprises a Ferrite core with three windings. The core used is an ETD39 shape made of N87 material (TDK EPCOS, 2006). Winding (W1) is the main winding that is excited by a low frequency sinusoidal signal. Its current is measured and fed to the X-Channel of an oscilloscope to represent the magnetic field (H_m). Winding (W2) is the shaking field winding and is excited by a high frequency sinusoidal signal. Winding (W3) voltage is integrated over time to obtain the magnetic flux. The integrator output is fed to the Y-Channel of the oscilloscope to represent the flux density (B). Excitation currents are obtained from two Power Amplifiers (PA). These power amplifiers are fed from two function generators (FG1 and FG2). The number of turns of the three coils is 300, 300 and 60 respectively.

EFFECT OF MAGNETIC SHAKING ON THE FERRITE CORE

To demonstrate the effect of magnetic shaking on the ferrite core, the setup described in the previous

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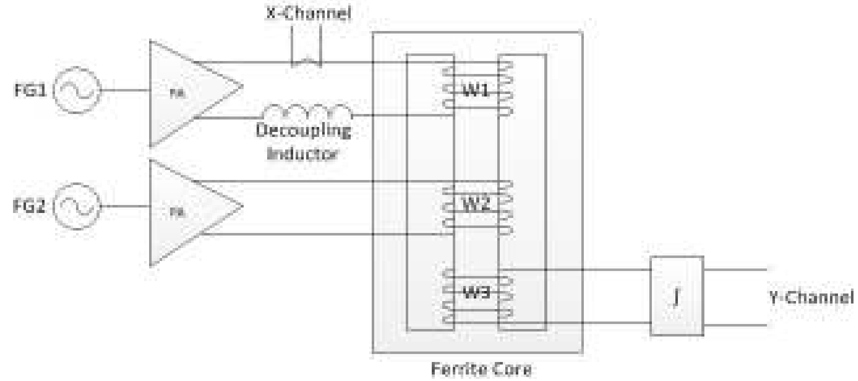

Fig. 1: Schematic of the experimental setup

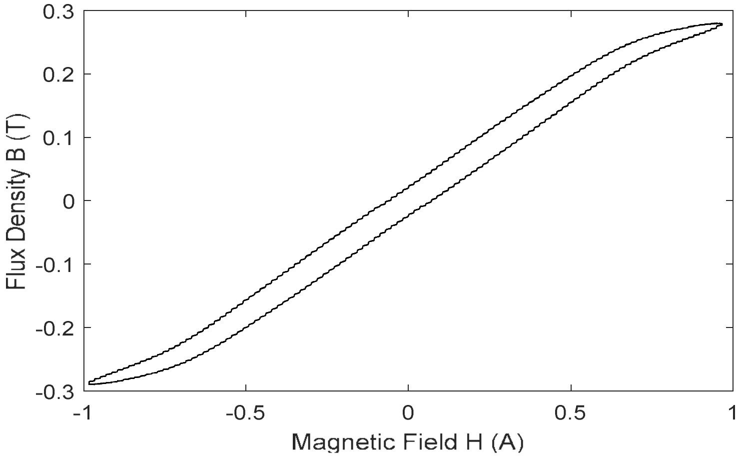

Fig. 2: DC BH curve of the ferrite core used in the experiments. The x-axis is showing the current to represent the applied magnetic field

sectionis used. The BH characteristic of the material is investigated using basic Rowland ring method. The method was adapted to the conventional EI configuration of the cores widely used in switched mode power supplies. The Rowland method is conducted by applying a slowly alternating current in the main winding. The current ranges from -1 to 1A. The integrated voltage from winding 3 is measured and then calibrated to represent the change in the magnetic flux density (B). The results show the normal DC BH loop that can be found in the datasheet of the used cores (TDK EPCOS, 2006). The DC BH characteristic of the core used is plotted in Fig. 2.

To add the effect of the shaking field, a third coil is used as mentioned earlier and shown in Fig. 1. The core is now subjected to two sources of magnetic field, one from the main slowly varying current and the other is originated from the applied higher frequency current. Figure 3 shows the BH loop of the material after adding the shaking field.

It should be stressed that in order to maintain the effect of the shaking magnetic field into the core, the two coils (i.e., shaking coil and main coil) should be decoupled to prevent transformer effect. Thus the shaking energy is locked into the core of the material, not to be transferred to the load. To achieve such decoupling, the main coil should be connected in series with a ‘decoupling inductor’, as depicted in Fig. 1, to present a high output impedance for the shaking field. In order to determine the value of the magnetic flux density generated due to the main biasing current, the resultant voltage from the integrator is averaged, resulting in Fig. 4.

It can be seen from the presented figures that the added magnetic field is causing the main BH loop to shrink. As a consequence, the coercivity of the material is reduced. A more ideal BH loop can be obtained by adding the shaking field. A more detailed explanation was introduced by Cohen (1967). Another straightforward explanation was introduced in Kelha *et al*. (1980) with a similar results obtained by applying the same method to Mumetal used in shielding applications. Figure 5 explains the main principle of shaking process. Adding an AC magnetic field is causing the main BH loop to shrink to the ideal BH loop shown in dotted line. As a result, the permeability of the material changes from the differential permeability (μ_D) to the ideal initial permeability (μ_i).

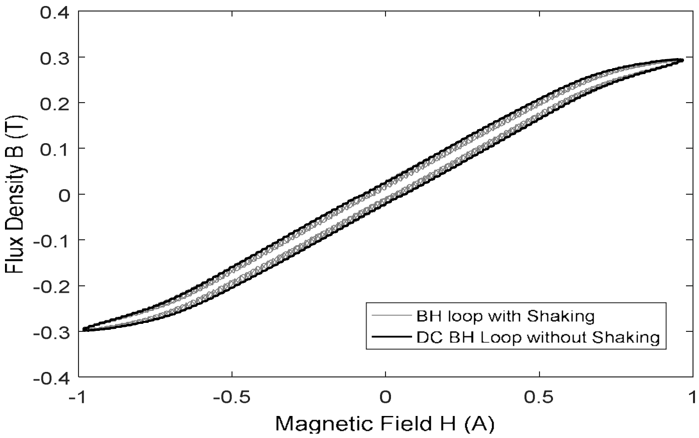

Fig. 3: BH curve of the ferrite core with and without magnetic shaking

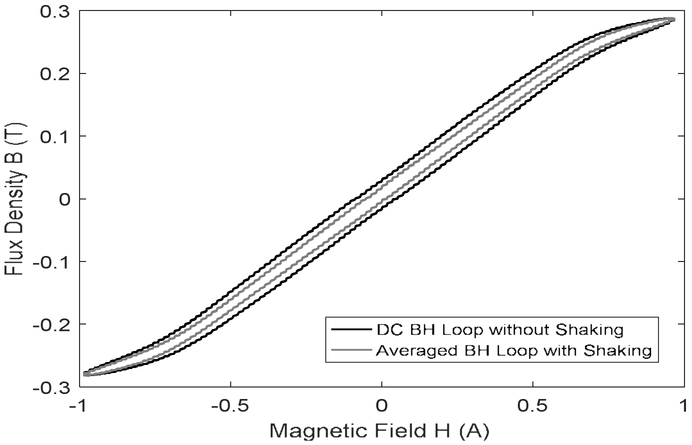

Fig. 4: BH Curve of the ferrite core without and with shaking averaged

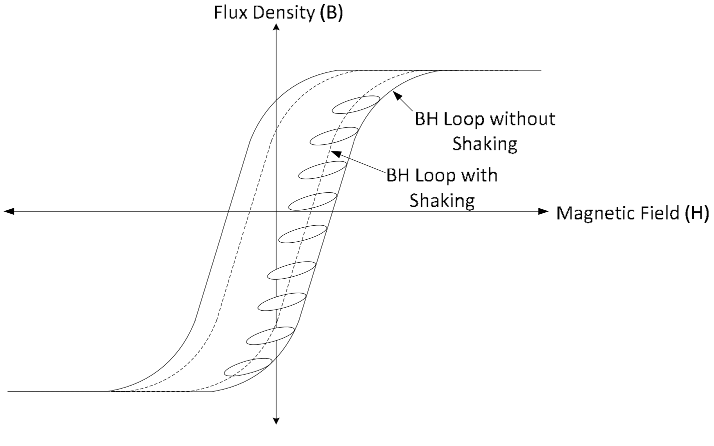

Fig. 5: Principle of shaking process

DEPENDENCE OF BH CURVE ON AMPLITUDE, FREQUENCY AND WAVEFORM OF THE APPLIED SHAKING FIELD

In this section, different parameters of the shaking magnetic field are investigated. In order to apply such technique in power electronics application such as power supplies, the applied shaking voltage is preferable to be square wave not a sine wave, as it is easier to be generated from the available sources in the circuit. Hence, two waveforms are applied to the shaking coil: A sinusoidal wave signal with a frequency

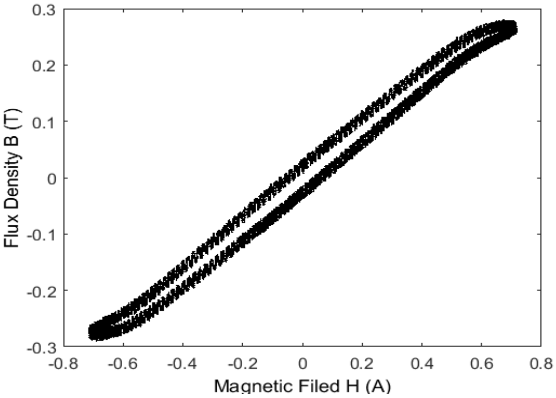

Fig. 6: BH curve of the core with sinusoidal shaking current

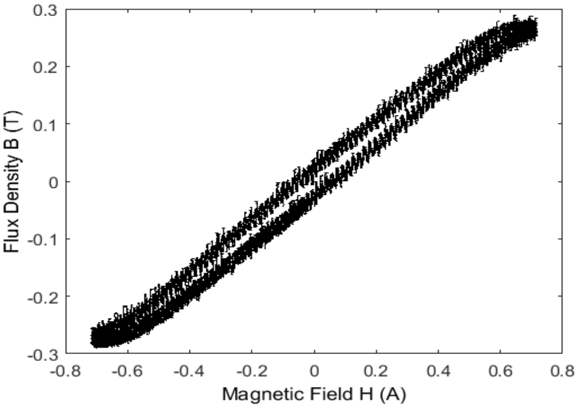

Fig. 7: BH curve of the core with square wave shaking current

of 50 Hz and a square wave signal with the same frequency. The resultant BH curve is measured in both cases to check the possible change in the performance of the material. Figure 6 and 7 show the BH curve in case of sinusoidal shaking field and square wave shaking field respectively. No noticeable change in the performance of the material can be detected in both cases. Hence, a square wave signal can be applied in remaining experiments for the sake of simplicity.

Table 1: Boost converter component values

Item	Description	Value
L_1	Main input inductor	16 mH
L_2	Shaking inductor	16 mH
C_1	Output filter capacitor	1000 μF
R_L	Load resistor	32 Ω
V_s	Input supply	15 V
$f_{shaking}$	Shaking frequency	50 kHz
f_s	Switching frequency	10 kHz

In the next experiment, different levels (depth) of shaking field are investigated. The levels of shaking magnetic field are determined experimentally such that the measured BH curves of the core have the minimum measureable hysteretic response. Figure 8 shows averaged BH curves of the core under (20 mA and 40 mA) of the applied shaking currents.

INSERTING SHAKING COIL IN A BOOST CONVERTER

In order to check the applicability of the method in switched mode power supplies, a Boost converter is selected as an application.

Table 1 shows the parameters of the implemented circuit. The shaking coil is added on the same core of the main winding. The source of the shaking current is a function generator. The shaking frequency is selected to be 50 kHz. If the shaking field is suitably applied to the core, then the permeability of the material will be improved. As a consequence, the inductance of the coil will increase, causing the ripples in the coil current to decrease. Figure 9 and 10 show ripples in the current before and after adding a shaking coil. The results show that the inductance of the coil is not improved since the ripples in the current is increased from 0.75A in the

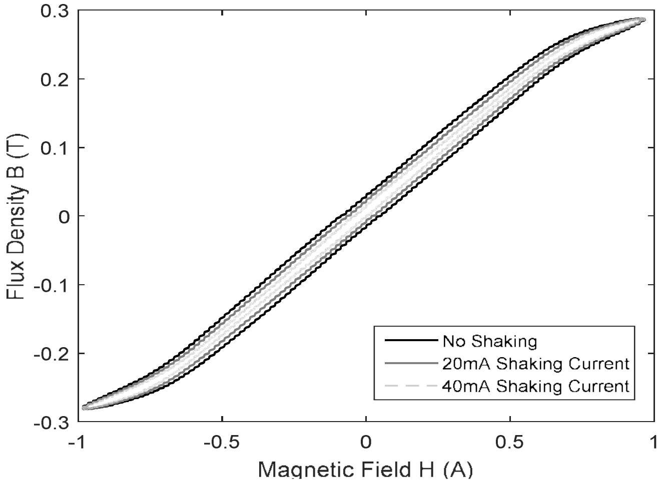

Fig. 8: BH curves of the material under different shaking levels

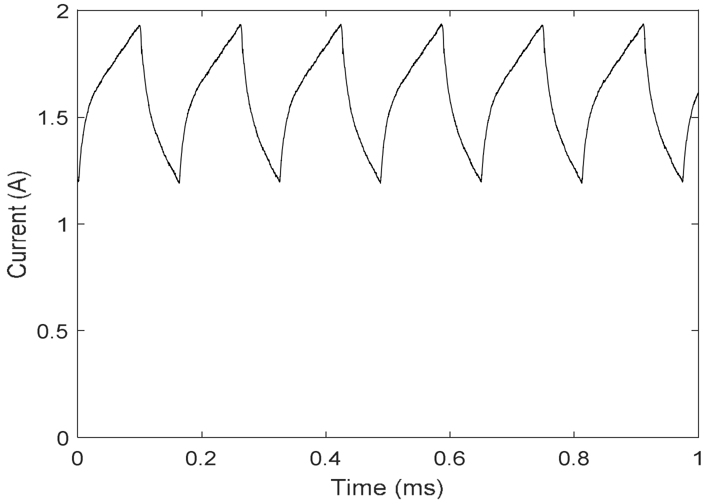

Fig. 9: Inductor current without shaking

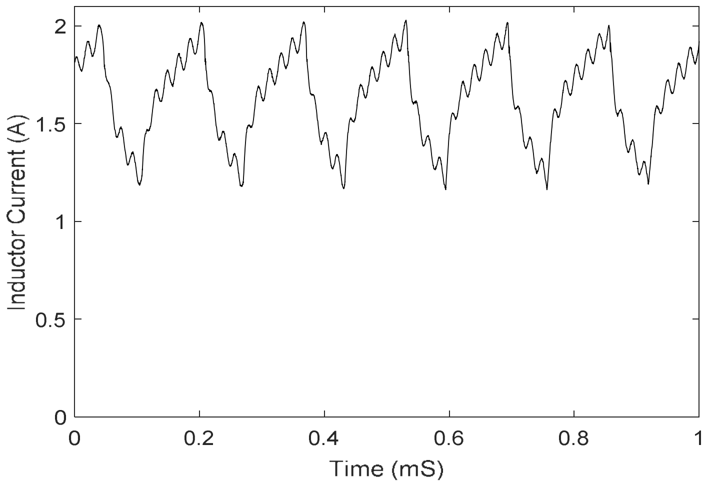

Fig. 10: Inductor current with shaking

case of no shaking field is used to 0.9A in the case of shaking field is used. A possible justification may be due to the fact that the main power circuit is not immune against high frequency currents. In other words, the existence of the LC connection in the power circuit, provide a path for high frequency current component. Hence, the energy delivered by the shaking coil is not locked into the core anymore. Alternatively, the transformer effect of the current configuration transfers shaking energy to the load. This effect can be easily noticed by measuring the high frequency component in the main current (I_L). A decoupling inductor may be needed in order to filter such high frequency current component. However, this solution is not feasible since the objective of using such technique is to decrease the size of the coils needed which will be increased by added the decoupling inductor to the total volume of the circuit.

ADDING DC MAGNETIC FIELD TO THE CORE OF THE MAIN COIL

In this section, another method is introduced to reduce the core requirement in switched mode power supplies. A similar method is applied (Mahdavikhah and Prodic, 2016). The basic concept is illustrated in Fig. 11. Assuming a current I_L flowing in the main coil of the circuit with ripples of (ΔI), a certain change in magnetic flux density (ΔB) is produced in the core of the coil according to its BH curve.

A well-suited core is the one that has a saturation limit above such values of magnetic flux densities. As the DC current increases, the requirements of the core size increases to fit the total flux needed. If the core selected is downsized, then the current flowing in the coil will derive the core into saturation as depicted in Fig. 12. As a result, the permeability of the effective

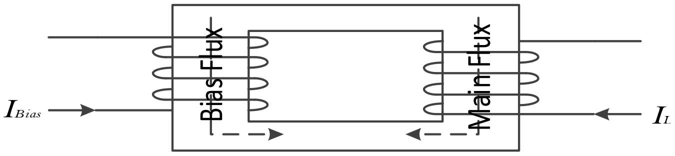

Fig. 11: DC bias experiment setup

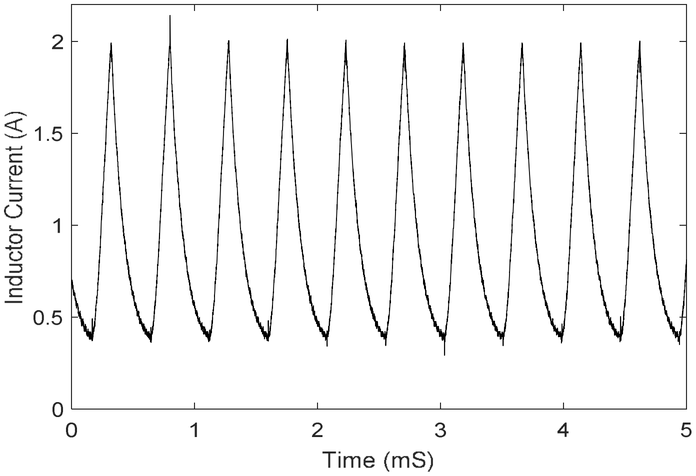

Fig. 12: Inductor current with no bias current

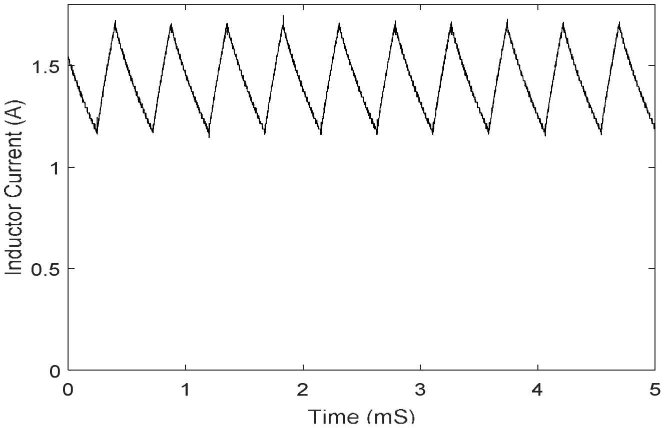

Fig. 13: Inductor current with 1.25A bias current

permeability of the material decreases, causing the inductance of the material to disappear. If the coil is utilized in SMPS applications (i.e., boost converters), then the current ripples in the coil will increase. If the dc component in the core is eliminated as shown in Fig. 13, the core will handle only the ripples in the current waveform. The effective inductance will increase. Thus, smaller core can be utilized.

In this experiment, the boost converter implemented earlier with the circuit parameters specified in Table 1 is utilized. The switching frequency was lowered to 2 kHz to easily drive the core into saturation. The load is increased till the core reach saturation. This condition can be noticed by measuring the ripples in the inductor current. The ripples are shown in Fig. 12. Another coil is placed on the same core. The current in this coil is exactly equivalent to the DC component in the main power circuit coil. The ripples in the second case are shown in Fig. 13. From Fig. 12 and 13 it can be noticed that the total ripples in inductor current is reduced by 68% while using a smaller core.

CONCLUSION

Magnetic shaking concept is applied to ferrite core to investigate its applicability in SMPS application. An AC component is added to the core to decrease the coercivity of the material. Hence, the material operates with its idealistic BH curve. The method proves effectiveness in improving the permeability of the core material. However, inserting such technique in the main power circuit is yet challenging. Another method is also introduced by adding a DC magnetic field component to the core of the winding. The method facilitates deploying smaller core size by optimizing the operating point on the BH curve of the material. The ripples in the main coil current was improved from 1.6 A to 0.7A by a factor of 68%

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