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Paper No. T6-1.6, pp. 1-5

15th INTERNATIONAL SYMPOSIUM on
POWER ELECTRONICS - Ee 2009
XV Međunarodni simpozijum Energetska elektronika – Ee 2009
NOVI SAD, REPUBLIC OF SERBIA, October 28th - 30th, 2009

ATTENUATION OF NANOCRYSTALLINE AND FERRITE COMMON MODE CHOKES FOR EMI FILTERS

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Abstract: *The attenuation of common mode chokes based on nanocrystalline VITROPERM 500F and Mn-Zn ferrite materials are analysed. It has been proved that the nanocrystaline choke gives much higher attenuation than ferrite one.*

Key Words: ***EMI filter, common mode choke***

1. INTRODUCTION

Nowadays, electromagnetic compatibility is increasingly important issue. Most of electrical devices generates electromagnetic emissions that have negative influence on environment. Moreover, the most products to be sold have to comply with EMC directive [1], [2]. Electro-magnetic interferences are divided into radiated and conducted ones [3]

Two types of conducted interference can be distinguished. The first is termed as common mode (CM) interferences while the second one as differential mode (DM) interferences. The former are propagated in both phases having the same directions and coming back through ground.

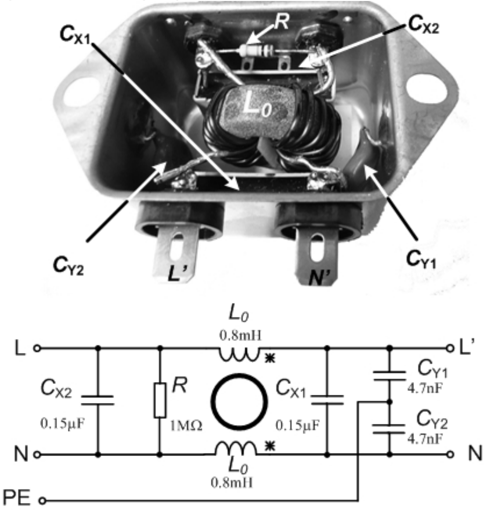


Fig. 1. The structure of one phase EMI filter.

The differential mode (DM) interferences are propagated in one phase in one direction and coming back via the second phase in opposite direction, the same like supplying current [3], [4].

Suppression of conducted interferences needs application of EMI filters. A one-stage structure of EMI filter is given in figure 1.

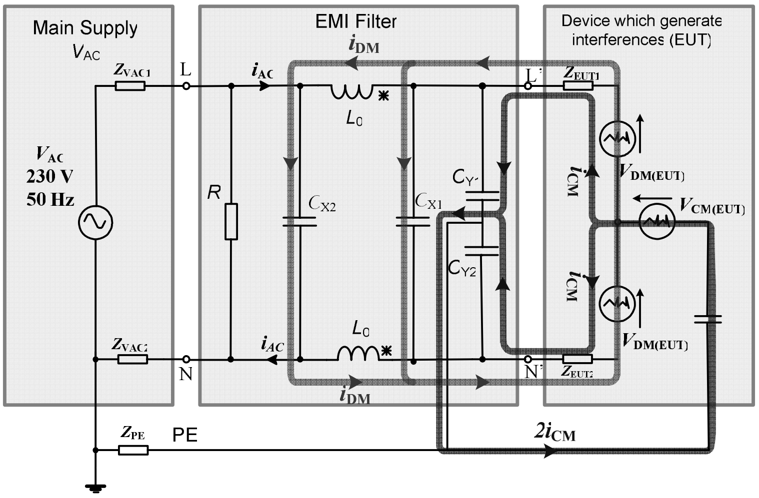


Fig.2. Propagation of CM, DM interference in EMI filter.

The CM interferences are suppressed by coupled coils L_0, and the capacitor C_{Y1}, C_{Y2}. The impedance of coupled coil is higher than impedance of capacitors C_{Y1}, C_{Y2} that's why the CM interferences flow by capacitor C_{Y1}, C_{Y2} and PE conductor (Fig.2). The DM interferences flow by capacitor C_{X1} and C_{X2}, because the impedance of AC supply is higher than C_{X2} for high frequencies (it results from mismatch impedance conditions) [3].

The efficiency of EMI filter suppression is determined by its attenuation A_{dB}.

$$A_{dB} = 20\log\left(\frac{V_1}{V_2}\right) \tag{1}$$

where, V_1 is the voltage between terminal L, N without EMI filter, while V_2 is the voltage at the same terminal L, N with EMI filter (Fig. 2). It is given in dB [3].

The measurement method of attenuation characteristic of EMI filter is described in standard [4]. According which the attenuation is measured in 50 Ω system, but it does not reflect real conditions with supply and load.

The common mode choke L_0 plays the main role in EMI filter attenuation although capacitors C_x, C_Y have decisive influence on the attenuation. That's why authors analyze only attenuation of common mode choke. What means that the analysis concerns only the attenuation of common mode interferences.

Although the analysis is based on the example chokes the results allows for generalization. Three example chokes are analyzed. Two have near the same dimensions where one is made of Mn-Zn ferrite while the second of nanocrystalline [5]. The third also made of nanocrystalline of higher permeability having smaller dimensions [5].

The attenuation of the choke is the function of the following parameters: i) value of inductance L_0 (permeability of ferromagnetic core) and its dependency on temperature, ii) geometry of the magnetic core and windings, iii) value of parasitic capacitances and iv) saturation of the magnetic flux density.

2. EXAMPLES OF THE COMMON MODE CHOKE

The first choke is wound on toroidal ferrite core Mn-Zn (Fig. 3a). It has the following dimensions: outer diameter D_o=20.35 mm, inner diameter D_{in}=8.85 mm, hight h=7.5 mm. The initial permeability is 4 300 (Fig.6). This choke will be called Mn-Zn in sequel.

The second choke based on nanocrystalline VITROPERM 500F core and is depicted in Fig. 3b. The dimensions of this core are: D_o=21.98 mm, D_{in}=11.67 mm, h=11.1 mm. The initial permeability is 15 000 (Fig.6). This choke will be called VF15 in sequel.

The third choke is also based on nanocrystalline VITROPERM 500F (Fig. 3c). The dimensions of this core are: D_o=15.95 mm, D_{in}=11.93 mm, h=6.95 mm. The initial permeability is 45 000 (Fig.6). This choke will be called VF45 in sequel.

The windings are made of 1.13 mm in diameter Cu wire. The chokes Mn-Zn and VF15 have the similar geometry and the same number of turns – 13. The inductances, at 10 kHz, of the chokes are as follows: L_0=0.85 mH for Mn-Zn and L_0=4.14 mH for VF15. The choke VF45 has 10 turns and it inductance is L_0=2.3mH.

The chokes are for nominal current of 10 A RMS.

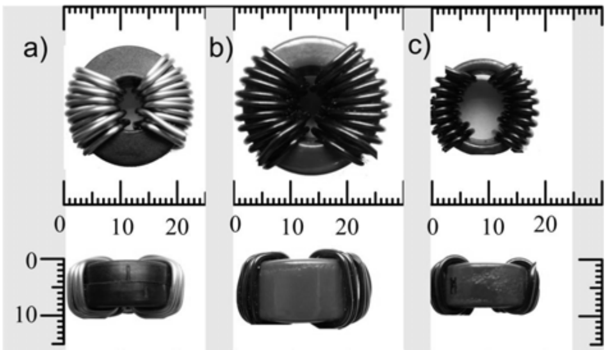


Fig. 3. Example chokes wound on: a) Mn-Zn ferrite core, b),c) VITROPERM 500F cores.

3. PARAMETERS INFLUENCE ON ATTENUATION PROPERTIES

The properties of attenuation of the EMI filter depend on: inductance L_0, parasitic parameters of the choke and parasitic parameters of C_x, C_Y capacitors.

The inductance L_0 changes with in the frequency. The higher inductance L_0 yields higher attenuation. The inductance, for given material, changes not only with frequency and permeability that in analyzed case also is frequency dependent. The inductance is described as:

$$L_0(f) = \frac{\mu_s^{'} \mu_0 S N^2}{l_{avg}} \qquad (2)$$

where,

μ'_s -real part of permeability,

μ_0 -magnetic constant $4\pi\ 10^{-7}$ H/m,

N – number of turns,

S - cross section of the torodial core,

l_{avg} – average length of core.

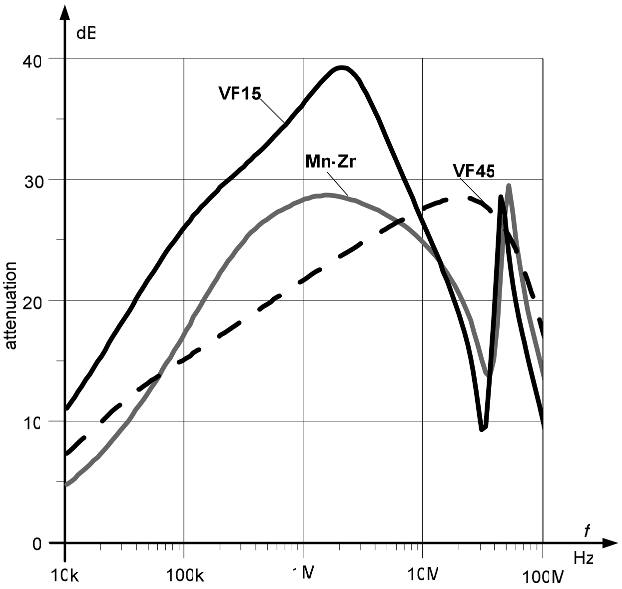


Fig. 4. Measured attenuation of Mn-Zn choke and VITROPERM 500F ones.

The core made by Mn-Zn is commonly used in EMI filters. The initial permeability of Mn-Zn core is small in comparison with initial permeability of nanocrystaline cores but exhibiting constant value for relatively broad range of frequency (Fig. 6). Although nanocrystaline materials offer higher initial permeability it changes significantly with frequency that is observed for VF45 (Fig. 6). The high permeability, of VF15, permits to achieve, for 10 kHz, the inductance 5 times higher than for Mn-Zn remembering that the geometry and number of turns are similar (Fig.4).

The VF15 choke exhibits higher attenuation in the frequency range up to 10 MHz, that is suitable for attenuation of noise, generated by switching power supplies operating at e.g., 100 kHz.

Moreover, because of high permeability of VF15 the volume and weight of core, and number of turns is reduced. This reduction results in reduction of inductance L_0 and reduction of stray capacitances (Table 1). The reduced stray capacitance of the winding yields to higher attenuation.

Table 1. *Measured parasitic parameters of Mn-Zn and VITROPERM 500F chokes.*

	Mn Zn	VF15	VF45
C_1=C_2	4.5 pF	3.7 pF	0.46 pF
C_3	0.17 pF	0.28 pF	0.15 pf
L_r	4.2 μH	4.6 μH	2.3 μH

The value of stray capacitances depends on manner of winding of chokes and number of turns.

The stray capacitances C_1, C_2 of Mn-Zn and VF15 are similar, because the chokes have the same number of turns and similar geometry. The stray capacitances of VF45 are less due to smaller dimension and number of turns (cf. chapter 2).

The stray capacitances and other parasitic parameters of common mode choke are calculated basing on its equivalent circuit - figure 5.

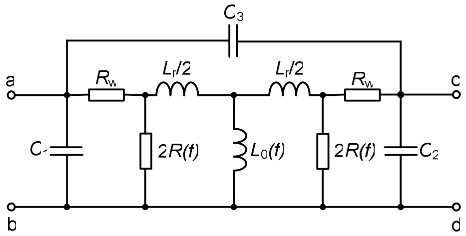


Fig. 5. Equivalent circuit of common mode choke; where:
L_0 – inductance of coil,
L_r – leakage inductance, L_r<<L_0,
R – represents the losses of the core,
R_w – represents the resistance of the wire, R_w<<R.,
C_1,, C_2 – capacitance of primary and secondary winding,
C_3 – capacitance between primary and secondary.

The methods of calculation of parameters of common mode choke are based on open-circuit and short-circuit measurement of modulus of impedance [5]. The impedance is measured between terminals ab for cd are opened or shorted.

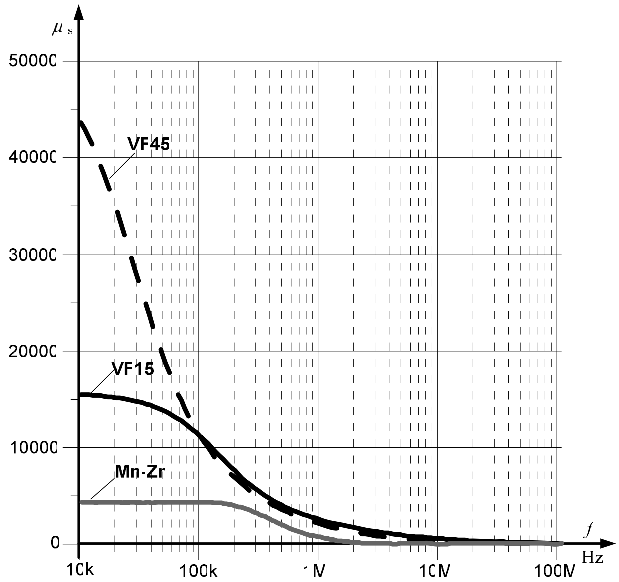


Fig. 6. Measured permeability of Mn- Zn common mode choke and VITROPERM 500F one (Agilent 4294A) [6].

The stray capacitances are calculated using resonance frequency and the value of L_0 due to (2) for this frequency. It should be underline that this method takes into account the permeability. It is very important because it changes with frequency (Fig. 6).

The permeability has to be taken into account during the designing of common chokes. When magnetic material is taken into consideration the one with possible constant permeability within broad range of frequency is the best choice. For analyzed cores Mn-Zn core is the best one as it exhibits constant permeability within the broadest range of frequency (up to 200 kHz) – Fig. 6. The worst material is VF45 for which constant permeability is up to 10 kHz. The variation of permeability influence the attenuation properties, cf. Fig. 4.

4. TEMPERATURE INFLUENCE OF ATTENUATION PROPERTIES

Temperature also influence attenuation properties of common mode choke.

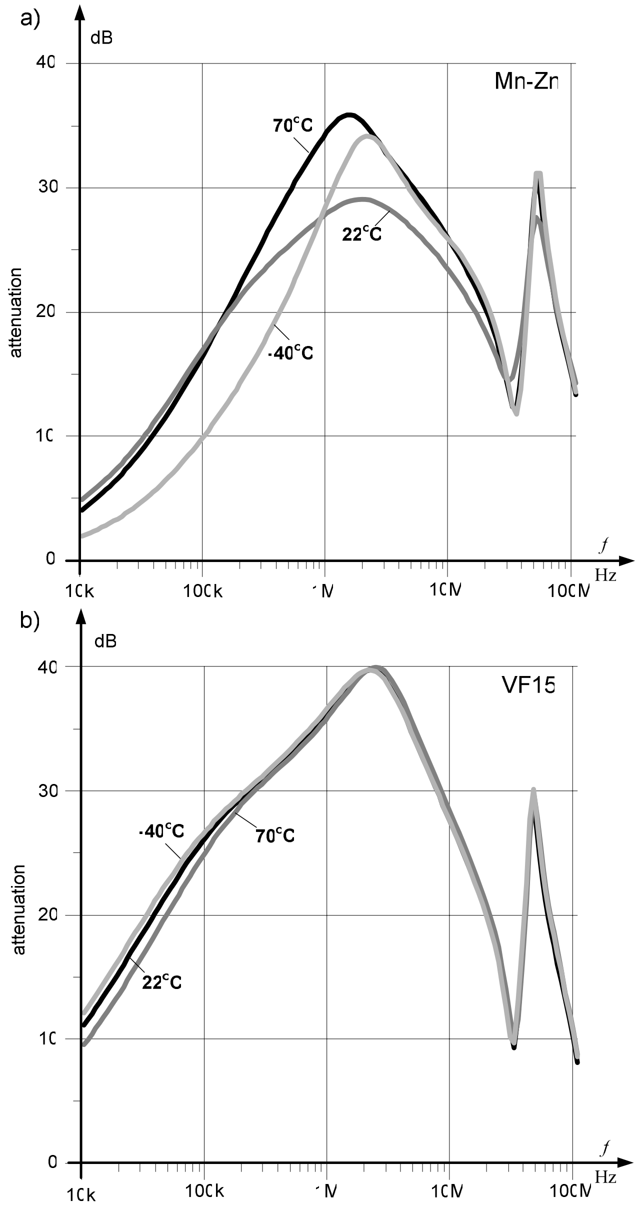


Fig. 7. Measured attenuation characteristic for three selected temperatures for: a) Mn-Zn, b) VF15.

The permeability of magnetic material is dependent on the temperature. The inductance of common choke and relevant attenuation are proportional to permeability. The attenuation of VF15 common mode choke is much stable attenuation against temperature change compared with that of Mn-Zn common mode choke. It is observed in figure 7. For frequency of 10 kHz this variations is reflected in inductance L_0 which is depicted in figure 8. The inductances are referred to the inductance at 22°C, for Mn – Zn, $L_0|_{22C}$=0.85 mH and to inductance of $L_0|_{22C}$=4.14 mH, for VF15. The inductance is measured by LCR meter at 10 kHz.

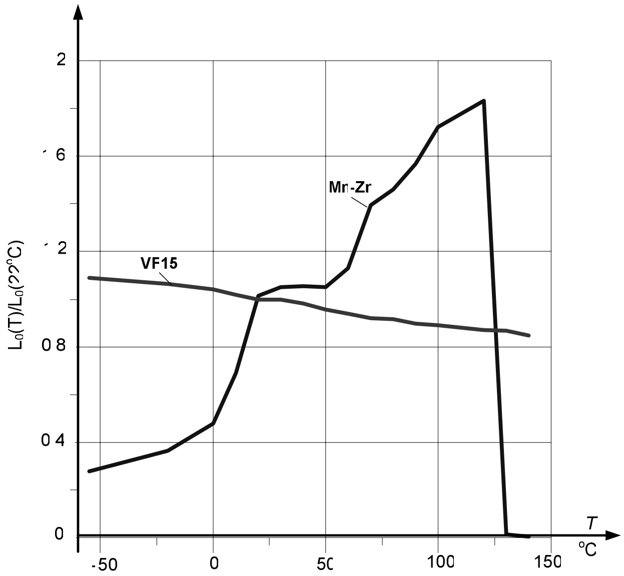
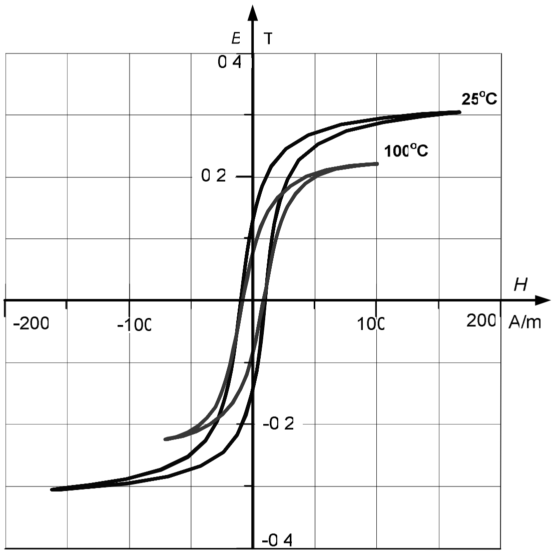


Fig. 8. Change of inductance L_0 of VF15 choke and ferrite Mn-Zn one, as a function of temperature, for 10kHz.



F*ig.9. Measured B-H characteristic of MnZn ferrite core for 25 °C and 100 °C, for 10kHz.*

Moreover the VITROPERM 500F cores have higher Curie temperature than Mn-Zn cores. The Curie temperature for VITROPERM 500F is equal 600^{0}C while for ferrite core is equal 120°C [7].

When the Curie temperature exceeds the inductance L_0 will be steeply decreased, example is given in figure 8 for Mn-Zn.

The temperature has also influence of saturation currents. Along with increasing temperature the saturation flux density is decreasing. The B-H characteristics of Mn-Zn common mode choke for core for 25°C and 100°C, as an example is presented in figure 9.

Another advantage of VITROPERM 500F core is high saturation magnetic flux density. It can be seen in figure 10 where B-H characteristics are given.

The value of saturation magnetic flux density is very important for attenuation properties. If the saturation in the core occurs the inductance of the common mode choke extremely decreases. Thus the EMI filter loses its saturation properties.

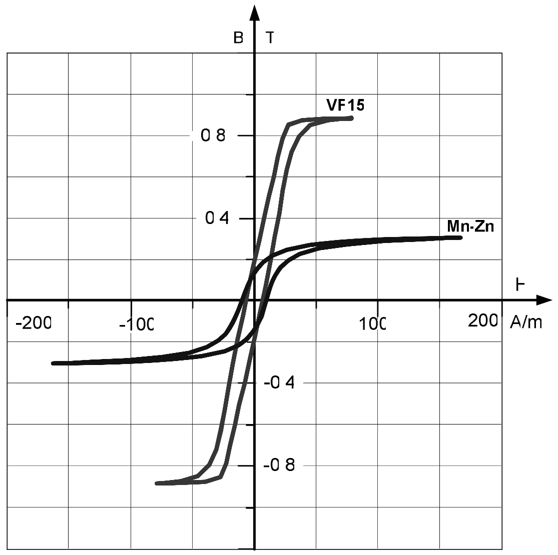


Fig. 10. Measured B-H characteristics of VF15 core and ferrite Mn-Zn core, for 10 kHz, 22^{o}C.

5. CONCLUSION

The nanocrystaline common mode chokes VF15 offer significant advantage in attenuation performance. The high permeability permits to achieve the higher inductance than for Mn-Zn common mode choke in case when the geometry and number of turns are similar (Fig.4).

The VF15 common mode choke exhibits higher attenuation in the frequency range up to 10 MHz. Therefore the nanocrystaline core is suitable for attenuation of noise, generated by switching power supplies.

The high permeability of nanaocrystaline material permits to reduce the geometry and number of turns.

The number of turns has influence of stray parasitic parameters. The value of parasitic parameters reduces the attenuation properties of common mode choke. The stray capacitances of VF15 are less in comparison with Mn-Zn even though the bigger dimensions, because the distance between windings is higher for VF15.

The high saturation of magnetic flux density, high stable in the range of temperature of nanocrystaline material is desirable in EMI filter.

However it should be noted that the change of permeability in the range of frequency has to be taking into account. The high initial permeability not yields the high attenuation in the all necessary range of frequency. (cf. VF45 attenuation characteristic in Fig. 4).

The price of common choke has the same priority as the technical solution for manufacturer and customers.

The nanaocrystaline common mode chokes are much more expensive than Mn-Zn one and overall cost of EMI filter is higher. Therefore to find cost optimized solution, ferrite Mn-Zn with initial permeability around 7000 are still leading compared to EMI filters with nanocrystaline core material.

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