Design Considerations and Loss Analysis of DC Chokes

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***Abstract*— The paper presents design considerations and a loss analysis of dc chokes in kW range, realized by different magnetic materials. Five designs under the same input parameters are realized with three different materials: ferrite (3F3), powder (sendust MS) and amorphous material (Microlite 245). An optimal design procedure is considered aimed at minimizing losses and volume of the component. A set of operating and construction parameters is analyzed. The obtained design results are verified by carried out simulations. Three of the compared DC chokes are realized, experimented and measured under the real operating conditions. The comparison of the three different materials is summarized and design recommendations are formulated regarding their use is such applications.**

Keywords—* *DC choke, magnetic materials, power electronics components, power losses

I. Introduction

In today's power electronics applications, the power ferrites [1] and amorphous materials [2], [3] are concurrent at high frequency devices. Different magnetic materials result in a different performance depending on the application. DC chokes are among the widely used magnetic components [4].

The purpose of this paper is to presents design considerations and loss analyze of DC chokes in kW range, realized by different magnetic materials.

II. Design Considerations and Results

Five designs of a DC choke under the same input parameters are realized with three different materials: ferrite (3F3), powder iron (sendust MS) [5] and amorphous partly crystallized low permeability material (Microlite 245) [3].

The main parameters of the three materials are shown in Table 1. Input design parameters for the converter and the DC choke: step down DC-DC converter, $V_{in} = 210$ V, $V_{out} = 105$ V, $\Delta I_{L,peak} = 1$ A, $I_{out} = 3$ A, $f_{op} = 70$ kHz .

The inductance of the DC choke is calculated to be L=750 µH.

A. Eddy currents calculation

The design algorithm applied includes eddy current losses calculation in copper [6], [7], [8] and consists of 15 steps. The eddy current losses are found as:

$$P_{eddy} = (R_0 . I_{ac}^2) . k_c \quad (1)$$

where k_c is eddy current loss factor;

I_{ac} is the AC current component;

R_0 is the ohmic resistance of the winding.

For inductors k_c it is derived as:

$$k_c = \frac{1}{48} . \zeta^4 . {m_E}^2 . \eta^2 . \frac{\pi^2}{4} . k_F . \frac{1}{\sqrt{\frac{1+G_T}{1024}}} \quad (2)$$

where ζ is the ratio between wire diameter and penetration depth;

$m_E$is an equivalent number of winding's layers;

η is a copper fill factor in the direction of the layer;

G_T is a quantity introduced to realize approximation of the exact analytical solution of the losses in a transverse field; here we use the expression $G_T = (\zeta + 0{,}37)^6$ found by comparison with finite element comparison;

k_F is a field factor coefficient.

The field factor coefficient k_f accounts for the magnetic field pattern over the winding cross-sectional area and its full analytical and geometric presentation are given in [8] as a function of d_{wg}- distance between the winding and the leg, t_w- thickness of the winding and w- winding width.

B. Design of DC chokes

The design includes optimization of the copper losses by use of different wire diameters or Litz wire. The specification and results of the design of the fife DC chokes is summarized in Table 2.

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TABLE 1. MAGNETIC MATERIALS USED TO BUILD THE DC CHOKES UNDER MEASUREMENTS AND COMPARISON

	Ferrite	*Sendust*	*Amorphous Fe Based ribbon*
Manufacturer	Ferroxcube	Micrometals	Hitachi Metals
Material designation	3F3	MS	MicroLite® 245
Composition	Mn-Zn ferrite	Fe-Si-Al powder	Fe-Si
type of air gap	discrete	distributed	distributed
Bsat	0,37 T	0,89 T	1,56 T
μi, initial permeability	2000	60	245

TABLE 2. DESIGN RESULTS OBTAINED

Design number and type of core		*Core dimensions* **[mm]**	*Component weight, [g] (core+copper)*	*Bac,peak* **[T]**	*Pcore* **[kW/m3]**	*Core losses* **[W]**	*Copper losses* **[W]**	*Total losses* **[W]**	*Component temperature rise, [°C]*	*Number of turns*
1	ETD 34 (ferrite)	34x34x11	51,9	0,088	33	0,252	1,383	1,635	30,9	47
2	MS130060-2 (sendust)	34x20x12	72	0,0389	71,56	0,392	0,971	1,363	18,9	94
3	MS109060-2 (sendust)	34x14x19	71	0,0395	73,66	0,474	0,846	1,319	20,2	66
4	MP3210MDG (amorphous)	34x21x11	46	0,0404	38,47	0,135	0,627	0,762	18,2	80
5	MP7930MDG (amorphous)	27x14x11	63	0,0425	46,1	0,137	0,491	0,628	11,9	66

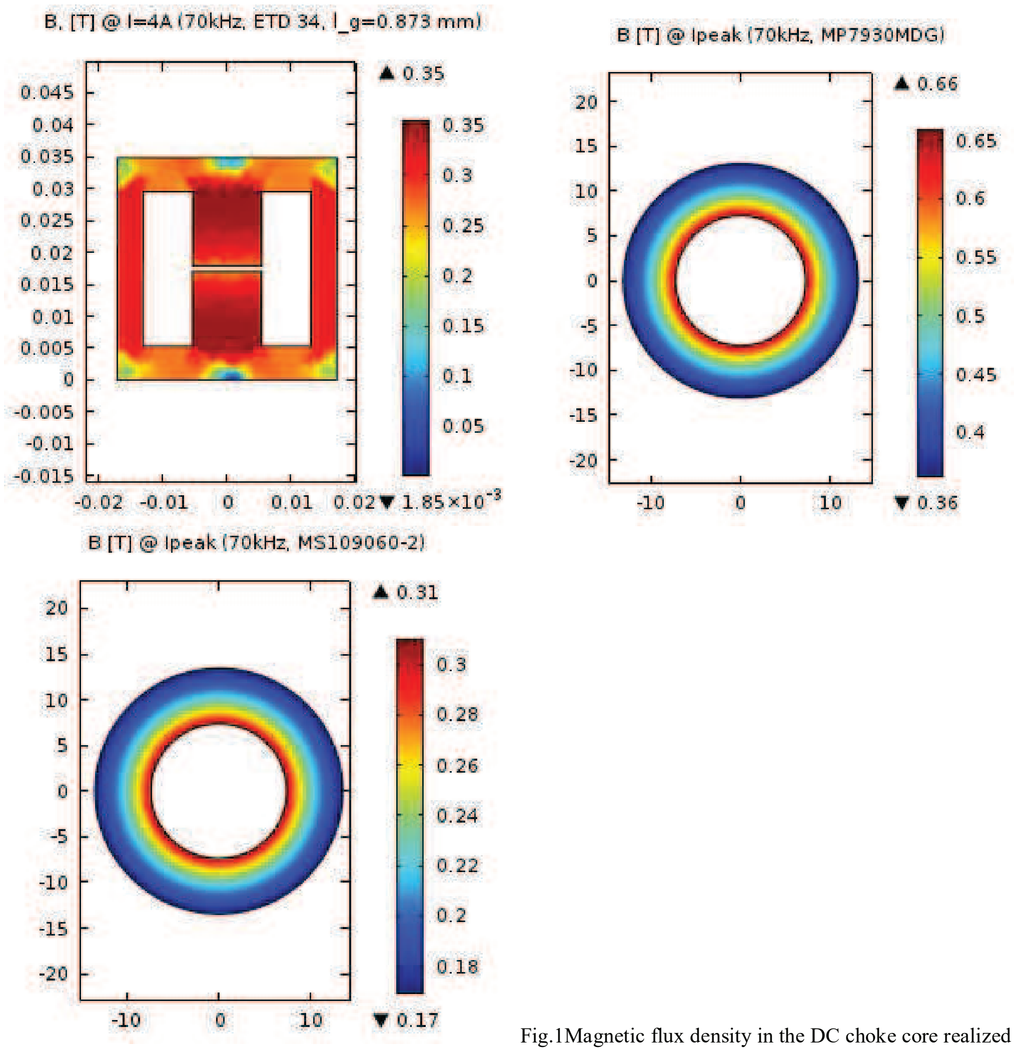
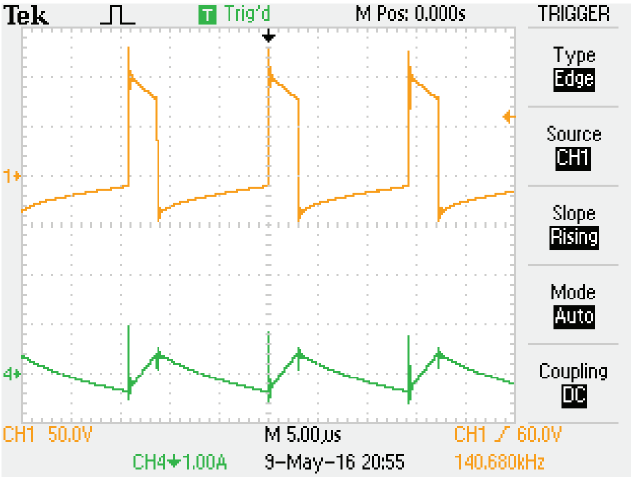


Fig.1Magnetic flux density in the DC choke core realized by:
a) ferrite material, b) amorphous material, c) sendust.



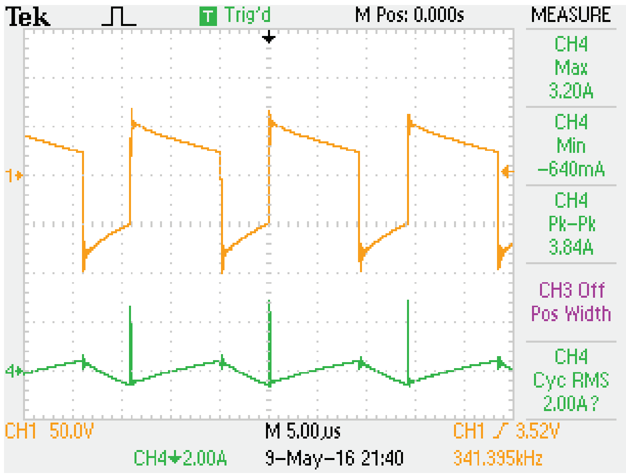


Fig.2. Voltage and current wayforms at different duty ratios D:
a) D=0,2 b) D=0,7

III. Simulations of the Designed Components

The heat transfer and magnetic field distribution in the designed components is modeled using FEM. The main operation parameters are obtained: temperature rise, magnetic field distribution.

Fig. 1 presents magnetic flux density in the DC choke cores realized by:

- 3F3 ferrite material, 70kHz, *Ipeak*=4A, ETD 34x34x11, *lg*=0.873 mm;
- amorphous material MP7930MDG, toroid 27x14x11;
- sendust material MS109060-2, toroid 34x14x19.

IV. Experimental Realization, Measurements and Validation

One of the compared DC chokes (based on the three different materials) is realized and experimented under the real operating conditions. To carry out a comparison in respect to power electronics applications, the component is supplied with variable duty ratios D:

$$D=\frac{t_{ON}}{t_{ON}+t_{OFF}}, t_{ON}+t_{OFF}=T \quad (3)$$

The results are shown in Fig.2. (there is no capacitor at the output of the converter during the oscilloscope measurements, thus the voltage across the DC choke is influenced by the output voltage, which is not constant).

The measurements of losses under square voltage are carried out by a wide band voltage and current probes described in [9] and a digital oscilloscope capable of channel results multiplication. The accuracy is confirmed by alternative calorimeter measurements [10] and the calculated losses are validated by the measured results.

V. Conclusion

The use of different magnetic materials for cores of a DC choke is compared. Five different components are designed, and simulated under real operating conditions. A set of operating and construction parameters is analyzed. The losses are measured by a calorimeter and the obtained results for total losses have verified the analytical values.

The obtained design results are compared with carried out simulations. The comparison of the three different materials is summarized and design recommendations are formulated regarding their use in such applications. The amorphous material combines low iron and low copper losses, which tends to result in lower total losses in many applications.

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