ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

Procedia Earth and Planetary Science 1 (2009) 1357–1361

Procedia Earth and Planetary Science

www.elsevier.com/locate/procedia

The 6th International Conference on Mining Science & Technology

Nanocrystalline magnetic materials versus ferrites in power electronics

Georgi T. Nikolov[a], Vencislav C. Valchev[a]*

[a]*Technical University – Varna, Varna 9010, "Studentska" №1*

Abstract

In this paper magnetic properties and global operating parameters of nanocrystalline and ferrite materials are compared. It is figured out that because of their marvelous magnetic properties the nanocrystalline materials are the future magnetic materials in power electronics. The losses of three toroidal nanocrystalline cores (Vitroperm 500F) are investigated under typical for power electronics square voltages. The loss comparison shows 2-3 times lower losses of nanocrystalline compared to ferrites under both sine and square voltages. A practical welding transformer is designed using nanocrystalline and ferrite materials. The carried out design based on a nanocrystalline core shows improvement in size of above 60% and in weight above 55%. The advantage of the nanocrystalline core transformer is obtained because of the higher induction level of the material, up to 1.2 T in general.

Keywords: Nanocrystalline magnetic materials; ferrites; power electronics.

1. Soft magnetic materials in power electronics

Nanocrystalline alloys are firstly developed to obtain great permeability. The outcome of nanocrystalline manufacturing processes suggests an alternative about the use of other materials in power electronics applications. In nowadays power electronics applications, the nanocrystalline materials are concurrent to power ferrites and amorphous materials at high frequency devices.

The purpose of this paper is to presents the results of comparison of the main parameters and the application advantages of nanocrystalline soft magnetic materials versus ferrites for Power Electronics Components.

1.1. Power soft-ferrite properties

Nowadays ferrites are still the soft magnetic materials most widely used in power electronics [1-9]. The most important characteristic of ferrites, as compared to other magnetic materials, is the high volume resistivity of the material. In high frequency applications eddy current losses are usually dominant and increase approximately with the square of the frequency. These losses are inversely proportional to the resistivity. Therefore the high resistivity

* Corresponding author. Tel.: +359-52-383266.
E-mail address: vencivalchev@hotmail.com.

doi:10.1016/j.proeps.2009.09.209

of the ferrites is the factor most contributing to their wide application in high frequency magnetic components [10, 11].

1.2. Nanocrystalline alloys properties

The nanocrystalline alloys (FeSiBCuNb) are closely related to the amorphous soft magnetic materials. The precursor amorphous FeSiB alloy, containing small additions of Nb and Cu, is elaborated by very rapid solidification on ribbons 20µm thick ("Finemet" –HITACHI, "Vitoperm" – VACUUMSCHMELZE, "NanoPhY" – IMPHY). The material is annealed at medium temperature (500-550°C) to induce optimum crystallization and to develop the remarkable and unexpected magnetic properties of the nanocrystalline structure discovered at the end of the 80's.

Due to their unique combination of favourable magnetic properties nanocrystalline cores are now well established in a wide field of applications. The major areas are: switched mode power supplies, digital telecommunications with emphasis on ISDN systems, installation techniques at 50/60 Hz and since very recently applications in the automotive electronics. Additionally particle accelerators should be mentioned where cores with masses up to 50 kg or even more are needed for converters or resonators [12,13].

A diagram, showing the comparison of typical properties of some Soft Magnetic Materials is shown in Fig.1(a) [5]. Comparison of relative permeability μ_r of typical materials for power magnetic components is shown in Fig.1(b).

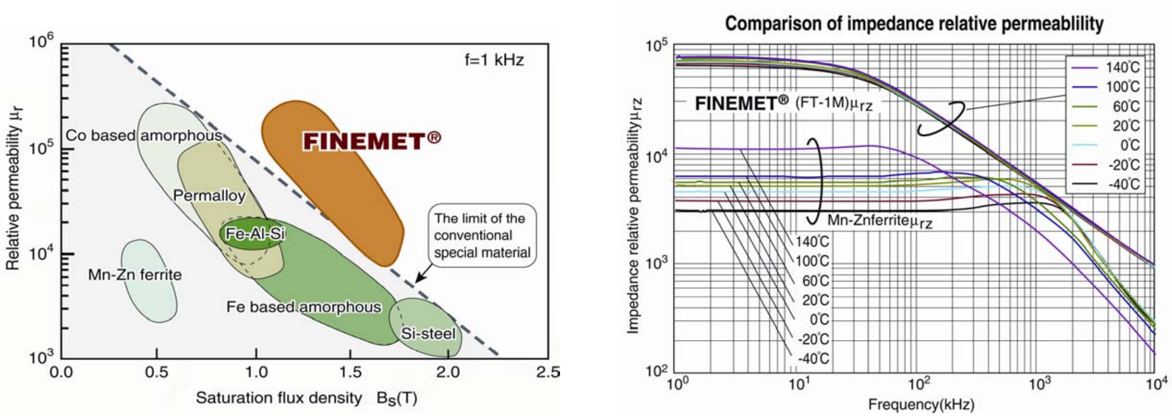

Fig. 1. (a) Typical initial permeabilities and saturation inductions for soft magnetic materials [14]; (b) Comparison of relative permeability µr of typical materials for power magnetic components

2. Power losses in nanocrystalline and ferrite materials under typical power electronics waveforms–square voltages

In power electronics sine waves are not very often used. Most frequently the voltage resemble a square wave or pulse wave with variable duty ratio. Thus, to carry out a comparison in respect to power electronics applications, we measured losses in nanocrystalline and a few ferrite materials.

The measured materials are: nanocrystalline material VITROPERM 500F, Vacuumschmelze, Germany [15,16] and ferrite materials 3F3, N67, N87. The measured nanocrystalline material shapes are all toroidal fig.2. Three different cores sizes are measured. The first coil (W435-04), is wound with four windings of 6 turns of 40 x 0,1 mm Litz wire in parallel. The secondary winding (0,25 mm double insulated) is used to measure the voltage and the flux. The number of turns is N=6. The second and third coil (W516-02 and W433-02) are wound with three windings of 5 turns of 40 x 0,1 mm Litz wire in parallel.

The measurements of losses under square voltage are carried out by a test platform for resonant converters [17]. Wide band voltage and current probes are used (150Hz-50MHz) described in [18]. A digital oscilloscope capable of channel results multiplication was used for power measurements. The accuracy was confirmed by alternative calorimeter measurements. The cores are excited by waveforms at variable duty ratios D between 5% and 50% with a 5% step. The voltage of the primary winding is controlled in order to obtain constant amplitude of the flux density B (0.1 T).

Fig. 2. The measured cores W435-04 and W516-02, Vitroperm 500F, Vacuumschmelze, Germany

The losses are measured at variable duty ratios - D (from 50% to 5% with a 5% step) at frequency of 100 kHz. To be able to compare the data correctly, we used the specific volume losses. Experimental waveforms for duty ratio of 5% and 45% are shown in Fig.3.

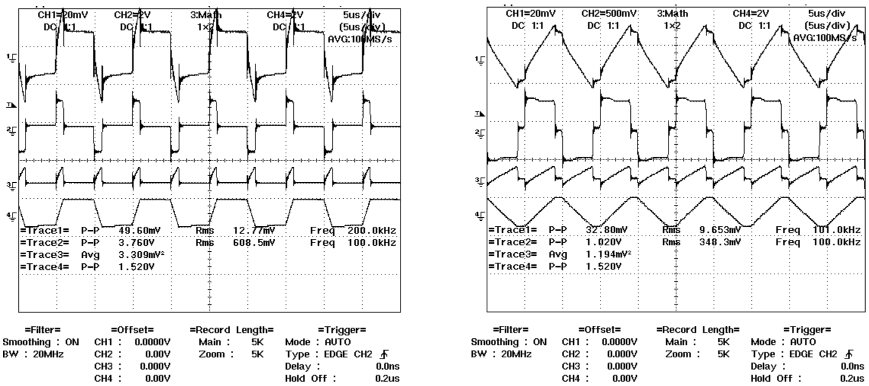

Fig. 3. VITROPERM 500F 63x50x25 core: W435-04 - Full Bridge, Square Wave, 100kHz, 25°C, 10% and 40% Duty Ratio

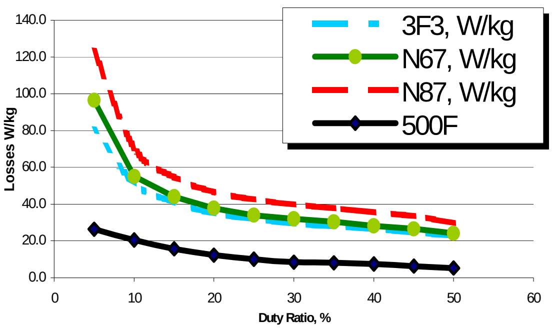

Fig. 4. Loss comparison for materials 3F3, N67, N87 and Vitroperm 500F, under square voltage, for variable duty ratio, from 50 % to 5 % with a 5 % step

A comparison of the losses for materials 3F3, N67, N87 and Vitroperm 500, under square voltage, for variable duty ratio, from 50% to 5% with a 5% step is shown in Fig.4. As shown in the Fig.4, nanocrystalline materials show significantly lower losses compared to the ferrites under typical power electronics waveforms.

3. Comparison of a welding transformer design based on nanocrystalline materials and ferrites

To carry out a practical comparison of the application of nanocrystalline and ferrites, a transformer for a welding inverter, 100kHz is calculated, based on ferrite cores and on nanocrystalline cores. The welding transformer has the input data shown in Table 1.

Table 1. Input data for the calculated welding transformer

Parameter	Value
Primary voltage	300V
Secondary voltage (no load)	60V
Secondary voltage (during welding)	26V
Secondary current (continuous)	150A
Operating frequency	100kHz

The carried out calculations are based on the fast design approach, described in [19], with natural convection assumed in the given case. The core size (a_{ch}) is selected based on the following equation [19]:

$$S_{tot} = \sum_{all\ windings} V_{rms} I_{rms} = 9kVA \tag{1}$$

$$a_{ch} = \left(\frac{S_{tot}}{A}\right)^{1/\gamma} = 8,434cm \tag{2}$$

where: a_{ch} is the largest dimension of the component (the core); A is a coefficient. A= (5–25)×10^6 if ach is in [m]; (A is in the range A=5–25 if a_{ch} is in [cm]); γ is an exponent, characterizing the material and shape of the core, $\gamma = 3$. S_{tot} is the total volt-amp rating of the component.

The found parameter a_{ch} is used to select a core size. The core EE100/60/28 (2 pieces per set) is selected, a_{ch}=10cm, for the ferrite design with ferrite grade 3F3. The same calculations as in the ferrite core section are repeated for the transformer based on a nanocrystalline core. The nanocrystalline based design uses the core FINEMET® F3CC0016B (4 pieces per one set).

The found component specifications for ferrite core transformer and nanocrystalline core transformer are shown in Table 2, where: d_1, N_1, d_2, N_2 primary and secondary winding diameters; B is the induction level, P_{cu} are copper losses, P_{fe} are core losses.

Comparison of the size and weight of the two components is done using the main dimensions and parameters. The volume and weight parameters of designs are tabulated for that comparison in Table 3.

4. Conclusion

Magnetic properties and operating parameters of nanocrystalline magnetic materials and ferrite materials are discussed. The nanocrystalline materials combine high permeability of amorphous materials and low losses of ferrite materials, thus they are very promising in power electronics. It is figured out that because of their marvelous magnetic properties the nanocrystalline materials are the future magnetic materials in power electronics. The losses in the materials are estimated also for the square voltages which are typical for power electronics. The core loss comparison shows 2-3 times lower losses of nanocrystalline compared to ferrites under both sine and square voltages. To carry out a practical comparison of the application of nanocrystalline and ferrites, a transformer for a welding inverter, 100kHz is calculated, based on ferrite cores and on nanocrystalline cores. The carried out designs show that using a nanocrystalline core leads to a much lower component size (volume) and weight - the improvement in size is above 60% and the improvement in weight is above 55%.

Table 2. Ferrite and nanocrystalline core transformers specifications

	d_1 (mm)	N_1	d_2 (mm)	N_2	B, T	P_{cu}, W	P_{fe}, W
Ferrite core	1,50	9	3,00 × 2	2	0.12	14,53	15,00
Nanocrystalline core	0.071 × 2835	11	0.071 × 1890 × 4	2	0.15	5.83	5.43

Table 3. Comparison between the designs of the transformer based on ferrite cores and on nanocrystalline cores

	Volume (cm^3)	Area (cm^2)	Core weight (kg)	Copper weight (kg)	Total weight (kg)
Nanocrystalline transformer	67,5	50,4	0,492	0,144	0,636
Ferrite transformer	202,0	120	0,986	0,406	1,392
Improvement by using nano-crystalline transformer	66.6%	58.0%	50.1%	64.4%	54.3%

References

[1] H. Chen and F. Zhuang, Novel Switched Reluctance Servo Direct-Drive System. Proceedings of 2005 IEEE International Conference on Mechatronics and Automation. (2005) 499-504.

[2] H. Chen, F. Zhuang and Y. Zhao, Frequency Spectrum Analysis of the Current for Switched Reluctance Motor Drive. Proceedings of 8th International Conference on Electrical Machines and Systems. I (2005) 543-547.

[3] H. Chen, Design of 1000KW Switched Reluctance Machine System, Indian Journal of Power & River Valley Development. 56 (2006) 212-215.

[4] H. Chen and G. Xie, Double 7.5-kW Three-Phase Switched Reluctance Motors Parallel Drive System for Electric Locomotive Traction, Proceedings of IEEE 14th International Symposium on Electromagnetic Launch Technology. (2008) 459-464.

[5] H. Chen, Implementation of a Three-Phase Switched Reluctance Generator System for Wind Power Applications, Proceedings of IEEE 14th International Symposium on Electromagnetic Launch Technology. (2008) 489-494.

[6] H. Chen, X. Zan, L. Cheng, L. Guo and J. liu, Switched Reluctance Starter/Generator System in Low Voltage, Proceedings of 11th International Conference on Electrical Machines and Systems. (2008) 1077-1081.

[7] H. Chen, L. Cheng, X. Qiu and Y. Zhao, Conductive EMI Noise Measurement for Switched Reluctance Drive, Proceedings of 20th International Zurich Symposium on Electromagnetic Compatibility. (2009) 241-244.

[8] H. Chen, X. Wang, X. Zhou, L. Guo, L. Cheng, Switched Reluctance Machine System in High Speed Operation, Proceedings of 2009 IEEE International Conference on Networking, Sensing and Control, 97 -101 (2009).

[9] H. Chen, X. Wang and H. Zeng, Electromagnetic Design of Switched Reluctance Linear Machine, Proceedings of 6th International Power Electronics and Motion Control Conference. (2009) 836-840.

[10] Philips, "Data handook: Soft-ferrite and accessories", Book MA01, Philips components, magnetic products, 1998.

[11] G. Herzer, Nanocrystalline soft magnetic alloys. in: K.H.L. Buschow (Ed.), Handbook of Magnetic Materials, Vol. 10, Elsevier, Amsterdam, 1997.

[12] J. Petzold, Advantages of softmagnetic nanocrystalline materials for modern electronic applications, Journal of Magnetism and Magnetic Materials. 242–245 (2002) 84-89

[13] Vacuumschmelze GmbH & Co.KG., Nanocrystalline VITROPERM - EMC Components, 2004.

[14] Hitachi Metals,Ltd., Nanocrystalline soft magnetic material "FINEMET®", 2005.

[15] Vacuumschmelze GmbH & Co.KG., VAC - VITROPERM 500F, Nanocrystalline tape-wound cores for power transformers, 2003.

[16] Vacuumschmelze GmbH & Co. KG., Cores and Components, Databook, 2005.

[17] A.V. Bossche, T.A. Filchev, V.C. Valchev and D.D. Yudov, Test Platform for resonant converters, 10th European Power Electronics and Applications Conference, EPE'03, Toulouse, France, 2003.

[18] A.V. Bossche, G.B. Georgiev and V.C. Valchev, Ferrite Losses with Square Voltage waveforms, 9th International Conference, 2004.

[19] A.V. Bossche and V.C. Valchev, Transformers and Inductors for Power Electronics, 2005.