

Power Losses and Applications of Nanocrystalline Magnetic Materials

Vencislav C. Valchev¹, Georgi T. Nikolov², Alex Van den Bossche³ and Dimitre D. Yudov⁴

Abstract – In this paper magnetic properties, power losses and applications of nanocrystalline magnetic materials are presented. It is figured out that because of their marvelous properties the nanocrystalline materials are very prospective in electronics. The loss comparison shows 2-3 times lower losses per unit weight of nanocrystalline compared to ferrites under both sine and square voltage measurements carried out.

Keywords – Nanocrystalline magnetic materials, losses

I. INTRODUCTION

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 main parameters and application advantages of nanocrystalline soft magnetic materials and ferrites for Power Electronics Components.

II. 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 favorable 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 [1],[2].

A diagram, showing the comparison of typical properties of some Soft Magnetic Materials is shown in Fig. 1 [1].

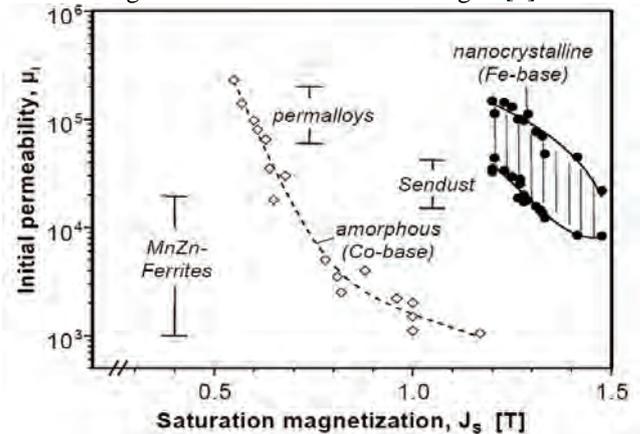


Fig. 1 Typical initial permeabilities and saturation inductions for soft magnetic materials

One of the great advantages that nanocrystalline magnetic materials offer is the ability to control their B-H curve, by applying a magnetic field during annealing. In Fig.2 three typical curves for FINEMET (Hitachi) cores are shown:

- 1) H type: a magnetic field is applied in a circumferential direction of the core plane during annealing.
- 2) M type: no magnetic field is applied during annealing.
- 3) L type: a magnetic field is applied vertically.

In manufacturer data sheets there is data about the losses under sine wave excitation. Comparison of losses under sine wave of typical magnetic materials is given in Fig.3 [1,3].

It must be emphasised that the comparison of only magnetic properties could not argue of an indisputable advantage of nanocrystalline compared to soft-ferrite materials [4]. So, integration capabilities of nanocrystalline materials must be analysed including power electronic specifications.

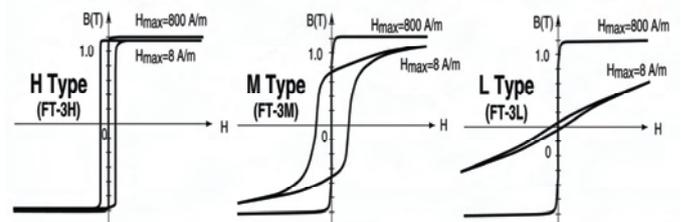


Fig. 2. Typical curves for FINEMET [5].

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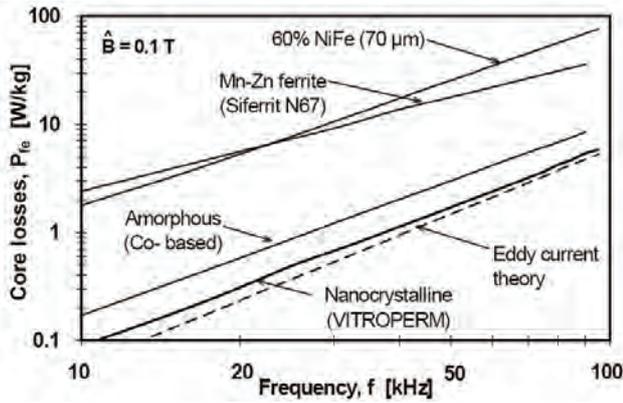


Fig. 3. Specific core losses of typical materials for power electronics under sine wave

Comparison of relative permeability μ_r of typical materials for power magnetic components is shown in Fig. 4 [5].

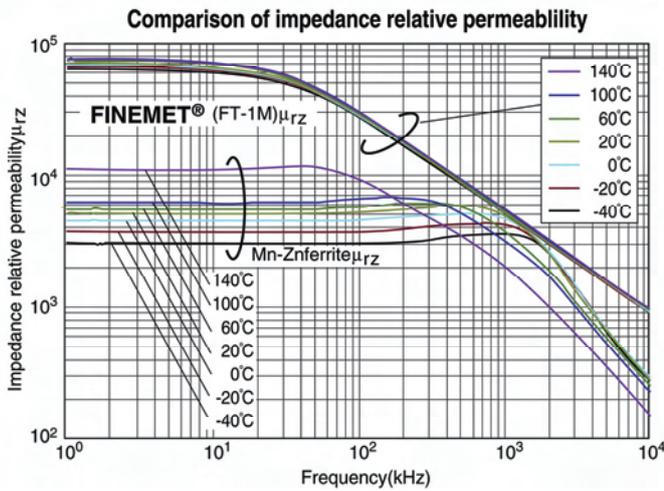


Fig. 4. Comparison of relative permeability μ_r of typical materials for power magnetic components.

III. POWER LOSSES IN NANOCRYSTALLINE MATERIALS FOR TYPICAL POWER ELECTRONICS WAVEFORMS

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.

A wide frequency loss model of nanocrystalline magnetic sheets including hysteresis effect is based on the theory of one-dimensional homogeneous transmission lines in the frequency domain [6]. The expressions for the complex impedances per unit length z_s and z_p result from the transmission line equations: $z_p = 1/(\sigma + j\omega\epsilon) \approx 1/\sigma$ with σ the conductivity. The effect of the permittivity ϵ is neglected so that z_p is real. The expression $z_s = j\omega\mu$ is combined with an impedance function in order to describe the hysteresis and the excess losses [7], represented by a constant loss angle δ_h (in radians):

$$z_s(j\omega) = j\omega\mu_h(j\omega) = \mu_{hr} \cdot (j\omega)^{1-2\delta_h/\pi} \quad (1)$$

Here, ω is the angular velocity and μ_{hr} a reference permeability. Thus, z_s represents a self inductance per unit length with a loss angle. Eq. (1) describes the magnetic behaviour of the material in the whole frequency range by only two parameters δ_h and μ_{hr} .

The measured material is VITROPERM 500F. The core shapes are all toroidal. 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.

We measured the losses at variable duty ratios - D (from 50% to 5% with a 5% step), using a high-frequency test platform [8]. To be able to compare the data correctly, we used the specific volume losses. Experimental waveforms for duty ratio of 40% are shown in Fig.6.

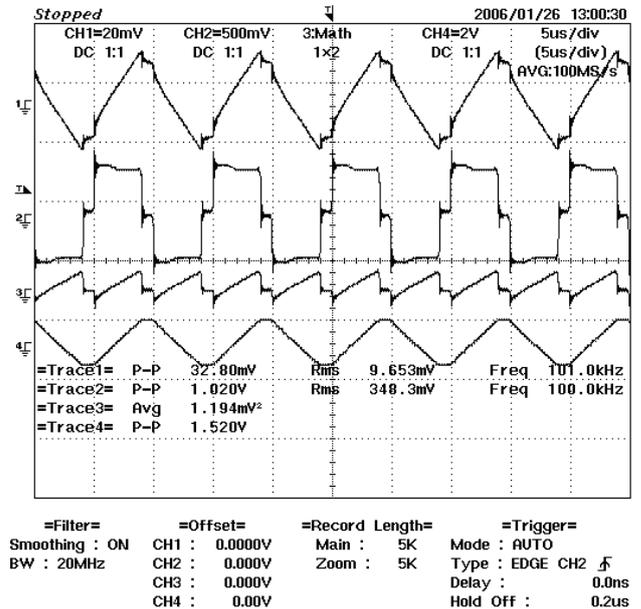


Fig. 5. VITROPERM 500F 63x50x25 core: W435-04 - Full Bridge, Square Wave, 100kHz, 25°C - 40% Duty Ratio

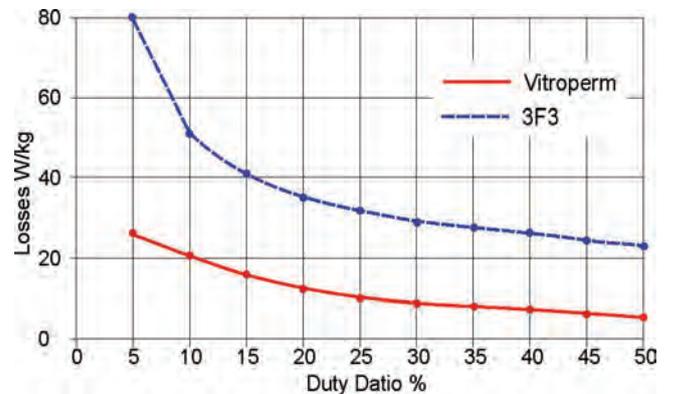


Fig. 6. Loss comparison for materials 3F3 and Vitroperm 500F, under square voltage, for variable duty ratio, from 50% to 5% with a 5% step, $f=100\text{kHz}$, $B_{\text{peak}}=0.1\text{T}$.

A comparison of the losses for materials 3F3 and Vitroperm 500, under square voltage, for variable duty ratio, from 50 % to 5 % with a 5 % step is shown in Fig.5 for $f=100$ kHz, $B_{peak}=0.1T$. As it is shown in the Figure 6, nanocrystalline materials exhibit significantly lower losses compared to the ferrites under typical power electronics waveforms.

IV. DESIGN SPECIFICS OF NANOCRYSTALLINE MATERIALS

Core shapes: With regard to core shapes, E-cores (for larger power even combinations of U- and I-cores) as well as toroidal cores are used.

Operating frequency range: A wide frequency range can be used at even high induction swing. Beside low core losses, the main inductance of a VITROPERM transformer will be dependent on frequency to a very small extent only, and as leakage inductances will be small due to the toroidal geometry and the low number of turns possible. This results in good magnetic coupling properties, and excess voltage peaks on switching transistors can be kept small. Moreover, there will be a low external leakage field.

The application temperature: The application temperatures of VITROPERM 500 F typically range from $-40^{\circ}C$ to $+120^{\circ}C$. This high maximum operating temperature provides a further volume advantage and is made possible by the large thermal stability of our materials and their properties. Core losses of most of nanocrystalline materials decrease up to 3-5% at $100^{\circ}C$, when compared to room temperature.

V. APPLICATIONS OF NANOCRYSTALLINE MATERIALS

Typical applications of nanocrystalline materials are:

- 1 telecommunications (telephone exchange power supplies, Base Stations);
 - 2 railways technology, mechanical handling equipment technology (battery charging devices);
 - 3 welding technology (switched mode Converters).
- In future, these will increasingly be extended to:
- 4 electric vehicles (battery charging devices, motor inverters);
 - 5 solar technology (inverters);
 - 6 induction heating.

The features of the nanocrystalline materials and the corresponding applications are summarized in Fig.7.

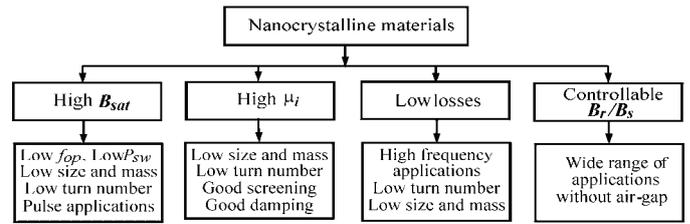


Fig.7 Features of nanocrystalline materials

Typical applications of nanocrystalline materials in Electronics and Power Electronics are shown in Fig.8. A useful comparison of properties and applications of most widely used soft magnetic materials in electronics is presented in Fig. 9.

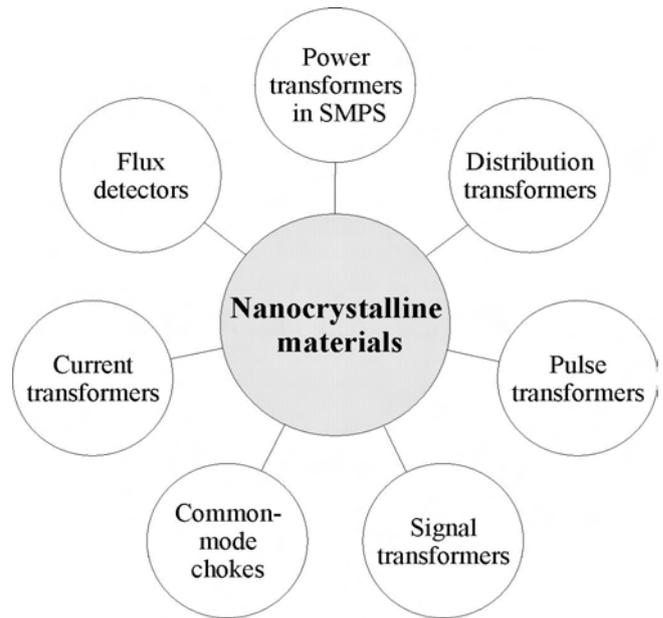


Fig.8. Typical applications of nanocrystalline magnetic materials in Electronics and Power Electronics.

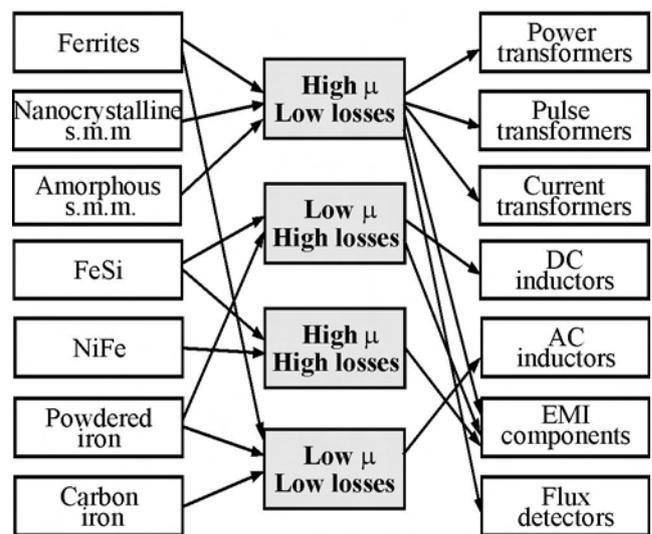


Fig.9. Comparison of the features and applications of soft magnetic materials in Electronics and Power electronics.

VI. CONCLUSION

In this paper magnetic properties, applications and global operating parameters of nanocrystalline magnetic materials are presented. The nanocrystalline materials combine high permeability of amorphous materials and low losses of ferrite materials, thus they are very promising in power electronics. Further advantage of the nanocrystalline materials is the possibility to control the B-H loop by applying magnetic field during annealing.

The loss comparison shows 2-3 times lower losses of nanocrystalline compared to ferrites under both sine and square voltages experiments and measurements carried out and depicted. A wide frequency loss model of nanocrystalline magnetic sheets including hysteresis effect is also discussed in the paper.

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