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Dimensional effects of sample geometry and microstructure of MnZn and NiZn ferrites

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Abstract. The effects of sizes of polycrystalline ferrite ring cores on magnetic characteristic – complex initial permeability (CIP) are studied. In the case of MnZn ferrite under uncontrolled microstructure (grain sizes) clear size effect is observed: dispersion of smaller core sizes is at higher frequencies and vice versa. In the case of controlled microstructure (NiZn ferrite) no size effects were observed.

1. Introduction

At the present time for soft magnetic materials there is demand not only for “high permeability and low loss” [1] but for their predictability and stability in different applications as well.

Permeability specified as frequency f function $\mu(f)$ of magnetic materials depends on variety of factors, several of which act still in an unknown form. In the case of polycrystalline ferrites (PF) the picture is additionally complex since they can be put into use over very broad range of frequency and thus different frequency effects may appear. Among the acting factors there are geometrical ones as well which may disclose themselves at macroscopic level as the physical size (core dimension) effects and at microscopic level – as grain size (more broadly - microstructure) ones. In the former case $\mu(f)$ dependence on dimensions usually is related to the dimensional resonance [1] which manifests itself in a very rapid dropping of $\mu(f)$ with f , when within cross section of PF sample there is formed electromagnetic standing wave. Thus the dimensional resonance should manifest itself mainly near the corresponding resonance frequency f_0 ; nevertheless in the original article [3] for MnZn ferrite the cross section of samples are influencing the static permeability $\mu(0)$ as well (the lower value for smaller cross section). Additional confusion comes from data of more modern MnZn ferrite, e.g. T37 [4]: there for smaller cross section rings $\mu(0)$ is higher (≈ 6500) and inversely for higher ones is smaller (≈ 6000). In the line of this is the fact that manufacturers are presenting several characteristics (especially the frequency dependence of complex initial permeability, CIP $\hat{\mu}(f) = \mu'(f) - j\mu''(f)$) only for definite core size allowing one to guess what corrections (if any) are needed for another.

All these facts as well the ones mentioned in particular studies [5, 6] show that dimensional effect is a reality the details of which are worthy of consideration. The aim of this study is to clear up the specific details of size-effect in PF firstly at macroscopic level in frequency range (by the use of appropriate CIP spectra experimental data) with the later on attempt to provide some grounding in theory coming from microscopic level approach to PF samples.

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2. Samples and experimental results

To clear up the aforementioned dimensional effect, the toroidal samples of different composition and sizes were studied. The study herein first of all comprises the measurement of $\mu(\omega)$ and CIP spectra up to sufficient high frequencies to include the most characteristic dispersion region of PF samples – the large amplitude one. Experimental samples – ferrite toroidal cores with single layer windings of an appropriate number of turns were used for determination of CIP spectra. The meters include: phase meter (samples treated as 2-poles); vector network analyser (ZVRE from Rhode and Schwarz; samples treated as 2-poles or as 4-poles or simply as a ferrite ring in special coaxial line). Correctness of spectra measured were verified by their agreement with Kramers-Kronig relations [2] using special computer programme.

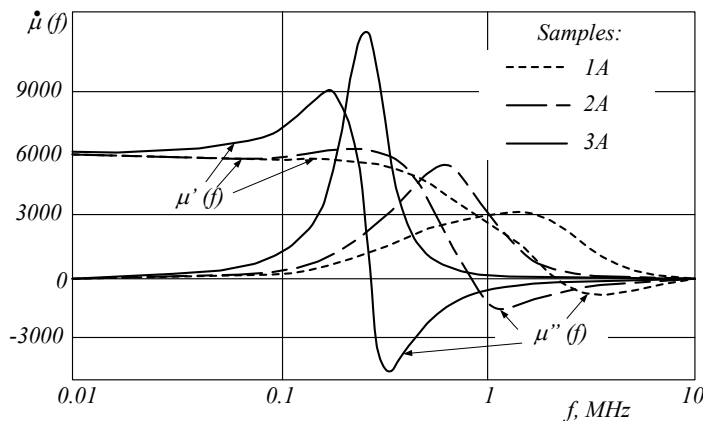


Figure 1. CIP spectra of MnZn ferrite T37

the main direction of changes in relation to geometry there are presented in Fig.1 the averaged over given geometry spectra. The analysis of these spectra involves difficulties since the samples may have different microstructure.

Table 1. Data of ring samples used in experiments

No	Dimensions (mm)	A (mm ²)	$\mu(0)$		No	Dimensions (mm)	A (mm ²)	$\mu(0)$	
			Data [4]	$\mu(0)_{exp}$				Data [7]	$\mu(0)_{exp}$
1A	R12.5x7.5x5	12.5	6500	5800	1B	R12x8x6	12	2000	2200
2A	R20x10x7	35	6500	5900	2B	R20x10x6	30	2000	2100
3A	R40x24x16	128	6000	6000	3B	R31.5x20.5x6	33	2000	2125
					4B	R40x23.5x6	51	2000	2140

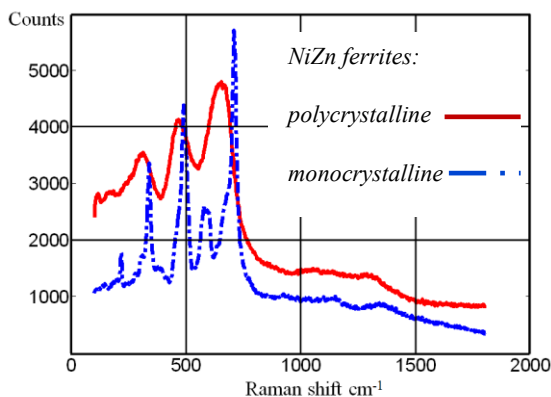


Figure 2. RAMAN spectra of NiZn ferrite

The first series of experiments (samples 1A...3A, Tab.1.) deals with standard ring cores [4] of MnZn ferrite T37. The geometrical characteristics (every geometry there is represented by three samples of same sort) as well as $\mu(0)$ for sets used are given in Tab.1 (where A stands for cross section, but $\mu(0)_{exp}$ – averaged over samples experimental value). Representatives within each geometry give similar, but non-identical CIP spectra; to grasp

The second series of experiments (samples 1B...4B, Tab.1.) deals with non-standard ring cores with controlled microstructure. The rings of different dimensions but with the same microstructure have been made from single Ferroxcube 4S60 tile [7] by waterjet assisted mechanical cutting. Since the abrasives of cutting may contaminate the ferrite, from different spots of it the RAMAN spectra (Fig.2) and composition (Fig.3) were recorded (on “Nanofinder - S” using the 532nm excitation line; the elemental composition was assessed by energy dispersive X-ray spectrometry: ESD,

Oxford Instruments 7378). In reality the spectra and all elements analysis don't reveal any appreciable contamination. Microstructural characteristics of ferrite were obtained from micrographs (examples are shown in Fig.4). They reveal that density function $f(D)$ of grain sizes D of PF actually is log-normal:

$$f(D) = (\sqrt{2\pi}\sigma D)^{-1} \exp[-(\ln D - \ln D_{med})^2 / 2\sigma_{\ln D}^2] \quad (1)$$

where D_{med} is the median, and $\sigma_{\ln D}$ is the standard deviation of $\ln D$. From micrographs (using Saltikov's method [8]) the parameters of distribution (1) follow: $D_a = 7.9\mu m = D_{med} \exp(\sigma_{\ln D}^2/2)$ and $\sigma_{\ln D} = 0.55$ (this value of $\sigma_{\ln D}$ shows that microstructure – aggregation of polycrystal grains is that of normal grain growth, when $\sigma_{\ln D} \approx 0.5$ [9]). Micrographs show as well that there are clearly observable defects within numerous of grains. CIP spectra of these samples are shown in Fig.5.

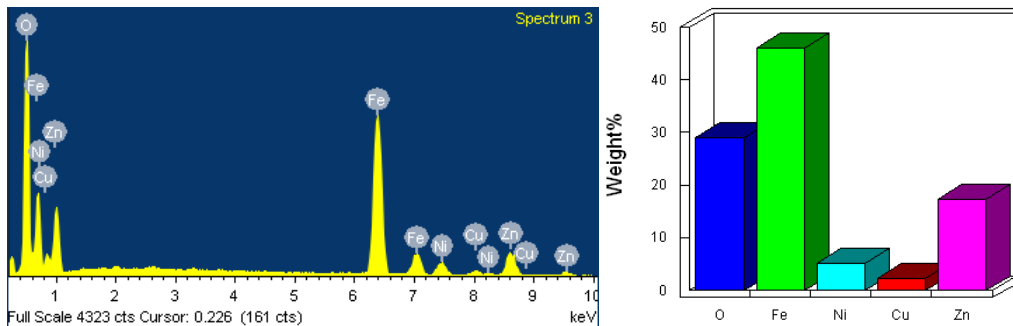


Figure 3. Elemental analysis of samples

3. Analysis of experimental data

Experimental data of previous subsection require more substantial examination and generalization.

Characteristically, the overall appearance of most of CIP spectra are similar (Fig1; 5): they are formed in fact as the combination both of relaxation attributes (dispersion and absorption within a broad range of frequency) and resonance ones (positive ups and negative downs on $\mu'(f)$ – the dispersion curves). It was shown in [10] that in such a case the most appropriate approximation comes from account of unhomogenous broadening of absorption caused in fact by the distribution of grain sizes (1). This account results in, as it is called, symmetrical (by visual evaluation along $\log f$ axes from $\mu''(f)$ standpoint) spectrum:

$$\mu''(f) = \mu''_{max} \exp[-(\log f - \log f_u)^2 / 2\sigma^2] \quad (2)$$

where f_u and $\mu''_{max} = \mu''(f_u)$ are parameters of maximum absorption, and $\sigma = 2\sigma_{\ln D} / \ln 10$. For a given spectrum the parameters of (2) follow from the experimental spectrum: μ''_{max} and f_u - directly, but σ (there used for all frequencies f) – from the relation:

$$\sigma_{A(B)} = |\log f_u / f_\sigma| / \sqrt{2 \ln(\mu''_{max} / \mu''(f_\sigma))} \quad (3)$$

where f_σ is a frequency well away from f_u (often such as to fulfil $\mu''(f_\sigma) \approx 0.5\mu''_{max}$).

Nevertheless, the majority of spectra are asymmetrical one. Such spectra is possible to present by (2) as well if formally two values of σ are used: σ_A for $f \leq f_u$ and σ_B for $f \geq f_u$. The values of these characteristics come from the experimental spectrum and (3) as well using it two times: firstly with $f_\sigma = f_A$ for $f_A < f_u$ and then with $f_\sigma = f_B$ for $f_B > f_u$.

In the case of standard cores of ferrite T37 the data clearly demonstrates the dependence of CIP spectra on the geometry (Fig.1): the dispersion shifts to lower frequencies as dimensions growth. Since $f_u \propto 1/D_{med}^2$ one can conclude that: small changes of grain sizes could give rise to considerable shifts of dispersion; formally the shifts in Fig.1 signals about different microstructure in different geometry of standard cores. This means that smaller rings are with finer grains and vice versa. But the form of spectra is changing from practically relaxation type (sample 1A: $\sigma_A = 0.55$; $\sigma_B = 0.24$) to resonance one (sample 3A: $\sigma_A \approx \sigma_B \approx 0.1$). These rather radical changes are not possible to explain by dissimilarity of microstructure; obviously in the sample 3A conditions for dimensional resonance are realizing. In the case of non-standard cores with fixed microstructure no dimensional effects are observed (Fig.5) – different geometry spectra are practically identical. It is particularly notable that these spectra are pronounsly asymmetrical. Asymmetry of the spectra and the values $\sigma_A = 0.417$ and $\sigma_B = 0.841$ show that grains of this PF contains considerable amount of intergrain defects (partially seen in Fig.4 as well).

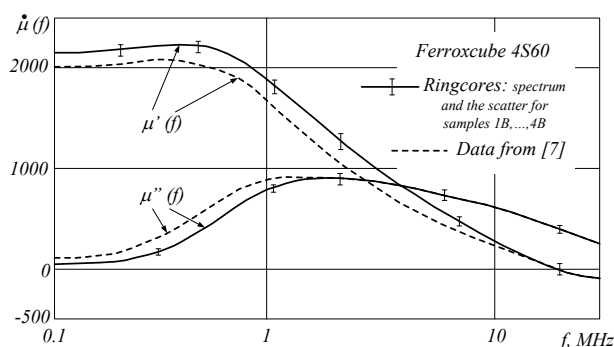


Figure 5. CIP spectra of NiZn ferrite

4. Conclusions

Thus it is possible to summarize that particular size-effects can appear in MnZn ferrites first of all because of changes in microstructure of samples, but more clearly size-effect demonstrates itself as electromagnetic effect in the samples of reasonably large dimensions. In NiZn ferrites no size-effect is observed under conditions of similar microstructure at least for medium sized cores. It is possible to say as well that CIP spectra can be used as an important adjunct to other methods in the non-destructive identification of microstructure of PF.

5. References

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