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Analysis of Grains Distribution Effects on the Magnetic Spectra of Polycrystalline Ferrites

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Abstract. The effects of grain size distribution of soft polycrystalline ferrites on its domain wall initial susceptibility magnetic spectra are analyzed. It is shown that absorption component of spectrum may be inhomogeneously broadened, and that it formally reproduces the grain size distribution density function. Explicit relations for the absorption component and some characteristic parameters of spectrum are presented.

1. INTRODUCTION

The initial magnetic susceptibility (IMS) χ_i of soft polycrystalline ferrites (PF) decisively depends on their granular (micro-) structure - on average grain size D_a and size distribution. Dependencies of the first type have been much investigated (most systematically by A. Globus a.o. from Laboratory de Magnetisme, C.N.R.S.). Prevailing conclusions are that χ_i is linear with D_a ; nonlinearity usually appears when samples with the wider range of D_a sizes are analyzed. The second type of dependencies - influences of grain size distribution - are less investigated. We try to extend the already known as well as our previous [1] studies for linear region of χ_i in radio-frequency range where domain wall (DW) processes are dominating. In our analysis we assume that magnetism in elementary volumes of PF material is in relation with grains (much the same as in A. Globus' models). We also are forced to make a guess *a priori* about possible relations used as interior ones (mostly on the base of the data gained from many PF samples). Validity of these assumptions is ascertained later on from derived solutions.

2. THEORETICAL ANALYSIS

We assume that in PF there are elementary volumes $v(\chi)$ with susceptibility χ (continuously distributed in the range $\chi_{\min} \dots \chi_{\max}$). After relating χ with the definite value of D , it is possible to write for the quasi-static IMS $\chi_i(0)$ of isotropic sample:

$$\chi_i(0) = \frac{2}{3} \int_{\chi_{\min}}^{\chi_{\max}} \chi \frac{v(\chi)}{v_a} \varphi(\chi) d\chi = \frac{2}{3} \int_{D_{\min}}^{D_{\max}} \chi(D) \frac{v(D)}{v_a} \varphi(D) dD \quad (1)$$

where v_a is the average of elementary volumes, $\varphi(\chi)$ and $\varphi(D)$ are density functions. For explicit evaluation of $\chi_i(0)$ we also assume that

$$\chi(D) = gD; \quad v(D) = aD^N \quad (2)$$

where g, a, N are const., and $\varphi(D)$ is log-normal [2] with median D_{med} and standard deviation σ of $\log D$. Insertion of Eq. (2), $\varphi(D)$ and $v_a = aD_{med}^N \exp(0.5N^2 \sigma^2 \ln^2 10)$ in Eq.(1) and the assumption that $D_{\min} \rightarrow 0$, $D_{\max} \rightarrow \infty$ (that sets up negligible error [3]) allow to represent IMS in typical linear form with constant's G value elucidating the influence of grains dispersion on $\chi_i(0)$:

$$\chi_i(0) = (2/3)g \exp(N \sigma^2 \ln^2 10) = G D_a. \quad (3)$$

To investigate dependence of IMS on frequency f , we assume that volumes $v(\chi)$ contain domain wall (walls), displacements of which are responsible for χ value and which are resonating on frequency f_0 . This allows to replace Eq.(1) by

$$\chi_i^*(f) = \frac{2}{3} \int_0^{\infty} \chi^*(f, f_0) [v(f_0)/v_a] \varphi(f_0) df_0. \quad (4)$$

Eq.(4) implicitly represents both parts of complex IMS $\chi_i^*(f)$ - dispersion (DP) $\chi_i'(f)$ and absorption (AP) $\chi_i''(f)$ ones of magnetic spectrum (MS). To estimate these parts, we use harmonic oscillator approximation for DW displacement processes [4]; this allows to represent imaginary part of $\chi^*(f, f_0)$ in the form:

$$\chi''(f, f_0) = 2\chi_0 \xi f f_0^3 / [(f_0^2 - f^2)^2 + 4\xi^2 f^2 f_0^2] \quad (5)$$

where χ_0 is the static IMS of elementary oscillator; ξ - dimensionless damping coefficient. Value of χ_0 is related to f_0 : in agreement with many MS of PF samples for which more or less is fulfilled relation [4]: $\chi_0(0)f_u/M_s \approx 4\pi C$ where f_u - maximum absorption frequency, M_s - magnetization, C - constant, we may assume that

$$\chi_0 = C_0 M_s / f_0; \quad v(f_0) = \alpha (C_0 M_s / g f_0)^N. \quad (6)$$

(The latter relation comes from Eq.(2) when there is assumed that in PF $f_0 \sim 1/D$ and for PF sample $f_u \sim 1/D_a$). Density function $\varphi(f_0)$ is still log-normal with the same σ and $f_{med} = C_0 M_s / g D_{med}$. Insertion of Eqs. (5), (6) and $\varphi(f_0)$ in Eq.(4) allows to represent AP $\chi_i''(f)$ in integral form. From this form it is possible to derive a more useful approximate relation, if in the elementary absorption line's Eq.(5) even part and its integral is replaced by δ -function. This replacement allows to obtain:

$$\chi_i''(f) = A f^{-(N+1)} \exp[-(\log f - \log f_{0med})^2 / 2\sigma^2] \quad (7)$$

where A is const. Differentiation of Eq.(7) allows to obtain:

$$f_u = f_{0med} \exp[-\sigma^2(N+1)\ln^2 10]. \quad (8)$$

From this relation and Eq.(3), it follows that

$$\chi_i(0)f_u/M_s = (2/3)C_0 \exp(-0.5\sigma^2 \ln^2 10). \quad (9)$$

AP $\chi_i''(f)$ may be presented in a form that is more convenient for applications, using Eqs.(7), (8) and the aforementioned definitions of constants:

$$\chi_i''(f) = \chi_{i\max}'' \exp[-(\log f_u / f)^2 / 2\sigma^2] \quad (10)$$

where $\chi_{i\max}''$ stands for maximum absorption at f_u and has value:

$$\chi_{i\max}'' = \chi_i(0) / 3.67\sigma. \quad (11)$$

The value of σ , when Eq.(10) is fitted for real MS, may be evaluated from characteristics $f_{1/L}$ and f_u (viewed as experimental ones): $\sigma = (1/\sqrt{2\ln L}) \log(f_u / f_{1/L})$, where $f_{1/L} < f_u$ and corresponds to definite absorption level $L = \chi_{i\max}'' / \chi_i''(f_{1/L})$. Explicit expression for DP $\chi_i'(f)$ from Eq.(4) is not get yet, but it is possible to calculate DP from AP, using Kramers-Kronig relations (KKR). For presentation of DP (and also for the experimental MS quality estimation), we use our computer program for KKR.

3. APPLICATIONS

Normalized MS, with AP calculated by Eq.(10) and DP from AP by KKR for $f_u=1$, $\chi_{i\max}''=1$ and several values of σ , is shown in Fig. 1a. The curves show the typical features which can be observed in real MS, e.g., resonance - for the lower value σ and relaxation - for the greater one (for simple relaxation MS [4] from Eq.(11) $\sigma \approx 0.55$). When using the relations for

Fig.1. Magnetic spectra of PF: a) theoretical, b) approximation of YIG spectrum from [5].

approximation of real MS, it must be noted that in the above analysis we have dealt only with typical DW resonance / relaxation region. Such regions are well-presented only in a few spectra, e. g., in similar ones for YIG in [5] and [6] (besides they adequately obey KKR; this is not so with many other MS). Approximation for the first spectrum is in reasonably good agreement with the data (Fig. 1b, $\sigma=0.7$, dotted lines); for the second one agreement is not so good for frequencies $f > f_u$, because experimental AP is non-symmetrical in log-scale. For both approximations DW component $\chi_{iDW}''(0)$ fulfills Eq.(11). **Conclusions.** The analysis show that AP of PF magnetic spectrum may be considerably broadened by grain size distribution (inhomogeneous line broadening), and that it formally reproduces the grain size density function.

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