ON THE INFLUENCE OF THE MAGNETIC DIFFUSION AFTER-EFFECT ON THE COMPLEX SUSCEPTIBILITY. – THE LOGARITHMIC DISTRIBUTION OF TIME CONSTANTS

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The general formula for complex initial susceptibility has been derived from the Néel theory of the magnetic diffusion after-effect in the case of the continuous distribution of time constants. The influence of the logarithmic distribution on the frequency dependence of the complex susceptibility and the temperature dependence of the loss-factor is examined in detail. The theoretical and experimental curves, tan δ vs. T, of three ferrite samples are compared.

1. INTRODUCTION

In a previous paper [1] formulae for the frequency dependence of complex susceptibility in non-metallic magnetic materials were derived from the Néel theory of magnetic diffusion after-effect. The vibrating motion of a single effective (mean) Bloch wall was examined assuming the diffusion process characterized by a single time constant. In spite of the great simplifications of this model it agrees with experiment in its essential features. Nevertheless, a closer examination usually shows the following deviations: the experimental curves \( \chi' \) vs. log \( \omega \) are more or less asymmetrical (see e.g. [2, 3]) as well as the curves tan δ vs. T [4], both being wider than the theory predicts; deviations can also be observed in the middle part of the curves \( \chi' \) vs. log \( \omega \).

For these reasons we have tried in this paper to generalize the above-mentioned model by assuming the diffusion process characterized by a continuous distribution of time constants instead of a single time constant. First, the general formulae for the complex susceptibility and the loss-factor will be derived from the Néel equation of motion and then we examine the case of the logarithmic distribution previously used in the study of the magnetic after-effect [5, 6]. The formulae will be presented both for the frequency dependence of the complex susceptibility and the temperature dependence of the loss-factor. A method will be shown of estimating the parameters of the supposed logarithmic distribution from the measured curves. On three examples it will be demonstrated that the assumption of logarithmic distribution appears to be sufficient — at least for some ferrites — also for a quantitative description of the curves tan δ vs. T.

2. EQUATION OF WALL MOTION AND ITS SOLUTION

Let us summarize all assumptions on which our considerations are based. As in paper [1], we suppose that only reversible displacements contribute to the initial

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susceptibility. We start from the equation [6]

\[ R(u) + P(u, t) + H(t)(M_1 - M_2) = 0 \]

which expresses the equilibrium of the forces acting on the unit area of the wall. Here \( u \) denotes the displacement of the wall from its equilibrium position. The individual terms have the following meaning:

a) \( R(u) \) is the binding force which keeps the wall in the equilibrium position and which for small displacements can be approximated by the linear expression \( R(u) = -\alpha u \);

b) \( H(t)(M_1 - M_2) \) is the effective pressure of the magnetic field \( H \). (\( M_1 \) and \( M_2 \) denote the vectors of magnetization in neighbouring domains). This term can generally be written as \( \gamma M_s H \), where \( M_s \) is the magnitude of spontaneous magnetization at a given temperature and the coefficient \( \gamma \) depends only on the type of the wall and the orientation of the field \( H \) with respect to \( M_1 \) and \( M_2 \);

c) \( P(u, t) \) is the effective pressure of the after-effect. According to [6] it holds for small displacements that

\[ P(u, t) = \frac{W_0 k}{d} \int_0^\infty [u(t) - u(t')] g(t - t') \, dt' ; \]

\[ g(t - t') = \int_0^\infty p(\tau) e^{-\frac{(t-t')^2}{\tau}} \, d\tau ; \int_0^\infty p(\tau) \, d\tau = 1 . \]

In these formulae \( g(t - t') \) is the so-called "after-effect function", \( p(\tau) \) the probability density of the distribution of time constants \( \tau \), \( W_0 \) the constant of induced anisotropy (\( F \) or \( G \)), \( d \) the effective wall thickness and \( k \) is a numerical factor depending on the type of the wall and the type of induced anisotropy [1].

Combining these expressions and Eq. (1) we obtain an integral equation of the Volterra type which in the general case cannot be solved. However, when examining the frequency dependence of the complex susceptibility we are only interested in a steady state solution (for \( t \gg \tau_{max} \)) under the action of the alternating magnetic field \( H(t) = H \exp(\omega t) \). The limit transition to the steady state will be performed in two steps. First, we assume that the time \( t \) after switching on the field is long enough for the amplitude of wall vibrations to be time independent. We then put

\[ u(t) = \tilde{u} e^{i\omega t} . \]

Further, we assume that the initial conditions influence only the time when the steady state is reached, but not this state itself. Thus we can choose the initial conditions so that (4) holds at all \( t' < t \). Substituting (4) into (1) we obtain for \( \tilde{u} \)

\[ \tilde{u} = B \left[ 1 + \eta \int_0^t g(t - t') (1 - e^{-\omega(t-t')} \, dt' \right]^{-1} \]

using the notation: \( \eta = W_0 k/\omega d, B = \gamma M_s H/\alpha \).