APPENDIX A

*Calculation of the excess loss associated with spin damping in ferrites*

The starting point of this calculation is the phenomenological equation for the damped motion of a domain wall

, (A1)

stating the proportional relationship existing between the wall velocity and the pressure by the dynamic field *H*exc = *H*a – *H*c, the difference between the applied field *H*a and the coercive field *H*c [50]. The damping coefficient is the sum of eddy current and spin damping contributions β = βeddy + βsd. As previously shown, βeddy << βsd in polycrystalline ferrites and we can concentrate on the assessment of the spin-damped motion of the wall. It is recalled that the spin damping coefficient can be expressed as βsd = (2*J*s / μ0γδ)⋅α, where γ is the electron gyromagnetic ratio, δ is the dw thickness, and α is the Landau-Lifshitz damping constant [51]. Let us therefore consider, for the sake of simplicity, a slab of cross-sectional area *S*, subjected to a constant magnetization rate at a given frequency *f* and let us assume, as hypothetical limiting case, that the magnetization reversal is carried out by one single dw (i.e. MO) inside a grain of size <*s*>. We wish to find the corresponding dynamic frictional field . The wall velocity associated with the flux rate across the sample cross-section is then be expressed as

(A2)

and, according to Eq. (A1), we obtain

. (A3)

The magnetization reversal at a given frequency *f* will be actually shared at a given instant of time by a number *n* of MOs, whose speed will be then reduced in inverse proportion to *n*. The dynamic counterfield will become *H*exc =/*n*. The *n* simultaneously active MOs are bound to increase, together with *H*exc, with the frequency. Since is proportional to *f*, the law of increase of *H*exc, that is of the excess loss

*W*exc = 4*H*exc*J*p, (A4)

with *f* will necessarily be less than linear. According to Bertotti [42], we can quite generally assume a relationship between *n* and *H*exc of the type

(*m* ≤ 1), (A5)

where *V*0 is a statistical parameter depending on the distribution of the local coercive fields and . For a uniform distribution, *m* = 1. To simplify the calculations, we disregard for the time being in (A5) and we obtain from the previous equations that that the excess loss in ferrites at a given *J*p value is given, assuming full reversal by dw motion and triangular flux waveform , by the equation

(*m* ≤ 1). [J/m3] (A6)

With *m* = 1, we retrieve the usual square root dependence of the excess loss on frequency exhibited by steel sheets at power frequencies. We actually know that, depending on *J*p, a substantial portion of the magnetization reversal in ferrites is accomplished by rotations and the flux is ubiquitously sinusoidal. By considering that the dw contribution *J*p,dw < *J*p and assuming sinusoidal *J*(*t*), we obtain for Eq. (A6)

(*m* ≤ 1), [J/m3] (A7)

where

. (A8)

For *m* = 1, it is .

APPENDIX B

*Calculation of the rotational loss associated with spin damping in ferrites*

Let us consider the classical case of a domain endowed with anisotropy field *H*k, normally directed with respect to the exciting field of frequency ω = 2π*f*. The Landau-Lifshitz equation permits us to derive a frequency dependent constitutive equation of the material associated with the rotation of the spin assembly, in terms of real and imaginary susceptibilities

(B1)

, (B2)

where γ is the free electron gyromagnetic ratio, α is the Landau-Lifshitz damping constant, and *M*s the saturation magnetization. If we consider now the polycrystalline aggregate, we have to include the relevant role of the intergrain demagnetizing fields, which, in view of the intrinsically low value of the magnetocrystalline anisotropy in soft ferrites, can significantly interfere and combine with the magnetocrystalline anisotropy fields. We need to deal with a distribution of effective anisotropy fields *H*k,eff, which we describe by means of the lognormal function

, (B3)

where  and σ is the standard deviation of ln(*H*k,eff). If we assume an isotropic orientation distribution function *p*(θ) for the easy axes in the half-space, it is , with 0 ≤ *θ* ≤ π/2. We integrate over amplitude and orientation of the effective anisotropy field, assuming *g*(*H*k,eff) and *p*(θ) independent,

 (B4)

 (B5)

and, after integration over the angular distribution, we obtain (B6)

. (B7)

We remark that, as the grains increasingly pass through resonance under increasing frequency, they become transparent to the AC field and unable to compensate the magnetic poles appearing on the active surrounding grains, whose resonance frequency will on the average be raised. A grain merged in a medium of quasi-static susceptibility χ(*f*) is endowed with an effective demagnetizing coefficient *N*d,eff ~ *N*d / (1+ χ(*f*)), so that, with decreasing χ(*f*) at high frequencies (see Fig. 5), the local demagnetizing field is expected to increase by a quantity

. (B8)

Consequently, the distribution *g*(*H*k,eff) will be broadened towards higher *H*k,eff values, following the decrease of the total susceptibility χ(*f*) with frequency. This effect is lumped into a frequency dependent quantity *h* in (B3)*,* according to

, (B9)

with *C* a constant.

The experimental rotational permeability components μ’rot(*f*) andμ’’rot(*f*), independent of *J*p up to *J*p = 0.1*J*s – 0.2 *J*s, are extracted from the measured permeability and separated from the dw permeability by means of a self-consistent procedure, as fully discussed in [55]. This is based on the idea that only the dw displacements can contribute to μ’’(*f*) at low frequencies. The relative permeabilities μ’rot(*f*) = 1 + <χ’rot (*f*)> and μ’’rot (*f*)  = <χ’’rot (*f*)> are then calculated using the distribution function (B3) with defined value *h*, assuming an average value of the anisotropy field consistent with the experimentally obtained μ’rot,DC and inserting it in Eqs. (B6) and (B7). In a successive step we take the so calculated χ’rot(*f*) andχ’’rot(*f*) and introduce them in Eq. (B9), and recalculate novel χ’rot(*f*) andχ’’rot(*f*) behaviors, and so on. The dashed lines in Fig. 12 show an example of prediction of this rapidly converging procedure. By taking Eq. (10), now written as

, [J/m3] (B10)

we can eventually analyze the broadband *W*(*f*) behavior in terms of dw and rotational contributions and proceed to the loss decomposition.