Relationship between Residual Loss and Microstructure of Mn-Zn Ferrites

H. Kobiki, A. Fujita, S. Gotoh

► To cite this version:

H. Kobiki, A. Fujita, S. Gotoh. Relationship between Residual Loss and Microstructure of Mn-Zn Ferrites. Journal de Physique IV Proceedings, 1997, 07 (C1), pp.C1-103-C1-104. 10.1051/jp4:1997130 . jpa-00255066

HAL Id: jpa-00255066

<https://hal.science/jpa-00255066>

Submitted on 1 Jan 1997

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Relationship between Residual Loss and Microstructure of Mn-Zn Ferrites

H. Kobiki, A. Fujita and S. Gotoh

Technical Research Laboratories, Kawasaki Steel Corporation, 1 Kawasaki-cho, Chuo-ku, Chiba 260, Japan

Abstract. The core loss characteristics of the Mn-Zn ferrite cores with various grain sizes, electric conductivities and cross sectional areas are analyzed. A part of the residual loss depends on the grain size. It is 4 orders of magnitude larger than the intragrain eddy current loss estimated classically. On the other hand, the core loss calculated by using the dynamic magnetic loss parameter recently introduced by Saotome and Sakaki includes the part. This indicates that the part of the residual loss is related to the interaction between the applied field and the induced magnetic flux.

1. INTRODUCTION

The magnetic core loss of Mn-Zn ferrites has so far been analyzed by various methods. The core loss of a Mn-Zn ferrite core, P_c , consists of the hysteresis loss P_h , the eddy current loss P_e and the residual loss P_r . They are conventionally written as the following equation (1),

$$P_c = P_h + P_e + P_r = W_h \cdot f + \alpha \cdot A \sigma \cdot f^2 B_m^2 + P_r \quad \dots \quad (1)$$

where f , B_m , W_h , A and σ are the exciting frequency, the maximum flux density, the hysteresis loss per one cycle, the cross sectional area of the core and the conductivity respectively. α is a coefficient which depends on the geometry of the material specimen [1].

However, the details and the origins of the residual loss have not been made clear yet. In this study, we report the new results of the analyses of the relationship between the residual loss and the microstructure of Mn-Zn ferrites.

2. EXPERIMENTAL

The Mn-Zn ferrite cores with various grain sizes (d), electric conductivities (σ) and cross sectional areas (A) were prepared. The grain size was varied by changing the sintering time, and the conductivity was changed by increasing the amount of addition of SiO₂, which is one of the additives. Their characteristics of the specimens are shown in table 1. The core losses of the toroidal cores were measured at the various exciting frequencies (f =1kHz~1MHz) and magnetic flux densities (B_m =25~200mT). The DC conductivity (σ), the equivalent conductivity (g) and the dielectric constant (ϵ_r) were determined by the frequency dependence of the impedance of the ferrite bar, which was measured with an impedance analyzer. The equivalent conductivity is used for the dielectric loss estimation. The permeability μ_r was also measured by using the impedance analyzer. The microstructures were examined by optical micrograph. All characteristics were measured at room temperature.

Table 1. The materials and their characteristics

Specimen No.	A (mm ²)	d (μm)	σ (S/m)	g (S/m)	μ _r	ε _r	λ _{h0} (Ω/m)		λ _f (Ω/m)
							at 25mT	at 200mT	
A	1 25.7	11	0.12	44	2920	90000	570	310	45000
	2 51.2								
	3 102.5								
B	1 37.9	15	0.20	54	3510	120000	500	340	41000
	2 37.9	17	0.20	55	3530	120000	530	360	34000
	3 38.4	19	0.20	60	3510	120000	510	380	28000
C	1 37.9	12	1.08	52	3390	80000	520	270	36000
	2 37.8	12	0.18	51	3370	100000	520	300	44000
	3 37.7	12	0.10	46	3050	100000	540	290	47000

3. RESULTS AND DISCUSSION

3.1 Conventional Method

The eddy current loss, calculated with the equation (1), was less than 2% of the core loss except for the specimen C-1. P_e [W/m³], obtained by subtracting the measured P_h and the calculated P_e from P_c , increased in proportion to the square of the product of f [Hz] and Bm [T]. Moreover the factor a [S·m] depended on the grain size d [m] and the equivalent conductivity g [S/m], but did not depend on the other parameters. The equivalent conductivity corresponds with the conductivity of the grain, therefore the intragrain eddy current loss P_{eg} is given as $\beta d^2 g f^2 Bm^2$. The residual loss could be fitted by the following formula,

$$P_r = P_{eg} + P'_r \approx a \cdot f^2 Bm^2 = \left[(1.4 \pm 0.1) \cdot 10^4 d^2 g + (4.8 \pm 0.1) \cdot 10^{-4} \right] \cdot f^2 Bm^2 \quad \dots (2)$$

However, P_{eg} is 4 orders of magnitude larger than the intragrain eddy current loss calculated by the classical formula[1]. It is too large to be explained by the intragrain eddy current or the intergrain eddy current through several grains with the defective boundaries. Therefore, it was attempted to analyze the core losses with a new model in order to find out the origin of this loss.

3.2 Analyses Of Core Losses By New Model

Saotome and Sakaki[2,3] have recently introduced a new parameter which represents the dynamic behavior of the residual loss, and the parameter is named "dynamic magnetic loss parameter, λ_f ". According to this model, the magnetic field H and the electric field E are given as the equations (3) and (4), and the core loss is calculated by using the equation (5),

$$H = \frac{1}{\mu_0 \mu_r} B + j \frac{\omega_0}{\lambda_{h0}} B + j \frac{\omega}{\lambda_f} B \quad \dots (3), \quad E = \frac{1}{\epsilon_0 \epsilon_r} D + j \frac{\omega}{g} D \quad \dots (4)$$

$$P_c = P_e + P_d + P_m$$

$$= \int_V \omega E(r)^2 dv + \int_V \frac{1}{2} \left[E(r) \{ j \omega D(r) \} + \overline{E(r)} \{ j \omega D(r) \} \right] dv + \int_V \frac{1}{2} \left[H(r) \{ j \omega B(r) \} + \overline{H(r)} \{ j \omega B(r) \} \right] dv \quad \dots (5)$$

where B is the flux density, D is the electric displacement, μ_0 and ϵ_0 are the permeability and permittivity of vacuum, λ_{h0} is the hysteresis parameter which is estimated from the core loss measured at ω_0 ($=1$ kHz), ω is the exciting circular frequency, and j is the imaginary unit. P_d is the dielectric loss, which is the ohmic loss by the displacement current. P_m is the magnetic loss including the hysteresis loss.

Our results almost agreed with this model in a wide range of flux densities up to 200mT as shown in figure 1. It shows that this model is also applicable in the high induction range. The estimated P_m occupied more than 90% of P_c at even 1MHz. P_d increased in proportion of the fourth power of the exciting frequency, and it was much smaller than P_{eg} below 1MHz. The calculated λ_f depended on the grain size as shown in figure 2. These results indicate that the residual loss includes the one related to the magnetic domain structure depending on the grain size.

4. CONCLUSION

This paper has pointed out that a part of the residual loss depends on the grain size. It is much larger than the intragrain eddy current loss, and besides it is not produced by the induced electric field but by the direct interaction between the applied field and the induced magnetic flux.

Acknowledgments

We would like to Dr. H. Saotome and Dr. Y. Sakaki for helpful discussions about the measurements and the analyses of the core loss.

References

- [1] Bozorth R.M., "FERROMAGNETISM", p.778-779, (1951)
- [2] Saotome H. and Sakaki Y., Proc. of Denki Gakkai Magnetics Kenkyukai, MAG-95-44, (1995)
- [3] Saotome H. and Sakaki Y., Proc. of ICF7, (1996)

Fig. 1. The frequency dependence of the core loss of the specimen B-1.

Fig. 2. The grain size dependence of the dynamic magnetic loss parameter λ_f .