Journal of University of Science and Technology Beijing
1996, Vol 3, No 1 : 64 ~ 68

FRACTAL STRUCTURE OF THE CORE LOSS SPECTRUM OF SOFT MAGNETIC ALLOY WITH CONSTANT PERMEABILITY

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(Received 1995 - 10 - 31)

ABSTRACT The core loss spectrum $P(f)$ of magnetic alloy with constant permeability has been studied. It is found that $P(f)$ has the fractal structure. The effect of the induced anisotropy energy K_u on the fractal dimension D_f is discussed.

KEY WORDS magnetic alloy with constant permeability, core loss, fractal

1J66, 1J34H and 1J34KH soft magnetic alloys are low residual magnetization materials originally created in China. Having constant permeability within a certain range of magnetized field, they are crucial materials used to make induction device. Because they work under the conditions of rather high frequency and magnetic induction B_m, the total power loss P is an important index to evaluate their magnetic properties. Generally, P increases with the increasing frequency, thus the frequency character of $P(f)$ directly affects both the stability of permeability and quality factor Q. Traditionally, the total power loss spectrum $P(f)$ is given by following formula [1]:

$$P(f) = P_e + P_h + P_c = eB_m^2 f^2 + \eta B_m^{1.6} f + P_c \quad (1)$$

where $P_e = eB_m^2 f^2$ is the eddy-current loss, $P_h = \eta B_m^{1.6} f$ is the magnetic hysteresis loss and P_c is the residual loss. Through an assumed physical model of technology magnetization, the loss coefficients e and η can be calculated by using specific material's properties (electric resistivity and thickness, etc.) and magnetic domain structure.

Many experimental results, however, have proven that formula (1) is not suitable to high permeability soft magnetic alloys at high frequency. Their total loss per cycle $P(f)/f$ is not linear with f, and $P(f)$ can not be simply seperated according to (1). In this paper, the loss spectrum $P(f)$ of three soft magnetic alloys with constant permeability (1J66, 1J34H and 1J34KH) has been investigated in a high frequency range as $B_m = 0.1$T. It is found that $P(f)$ has a typical fractal structure [2]. This result confirms the fact that the fractal formula of $P(f)$, proposed by the author in another paper regarding the rectangular loop soft magnetic alloy, is suitable to the constant permeability alloy as well. Furthermore, the influence of the anisotropy energy K_u, induced by transverse magnetic heat treatment, on the fractal dimension of $P(f)$ is discussed.

1 SPECIMENS AND MAGNETIC MEASUREMENTS

Three constant permeability alloys have been studied. Specimen A is 1J66 alloy (Ni65Mn1Fe34), specimen B is 1J34H alloy (Ni34Co39Mo3Fe24) and specimen C is 1J34KH (Ni34Co39Mo3Nb3Fe21). After certain high temperature and transverse magnetic field heat treatments, the induced uniaxial anisotropy is produced in the specimens so that the low residual magnetizaton and constant permeability are obtained. The specimens are ring core with 16 mm in internal diameter and 26 mm in external diameter. The thin sheet used to make the core is 0.05 mm in thickness and 10 mm in width. The anisotropy energy K_u and D. C. magnetic properties were measured by magnetization work and ballistic methods respectively. The total power loss $P(f)$ and dynamic permeability as $B_m = 0.1$T were tested with a transformer – bridge.

2 RESULTS AND DISCUSSIONS

2.1 FRACTAL FORMULA OF LOSS SPECTRUM $P(f)$

Table 1 lists the $P(f)$ data of specimen A, B and C measured as B_m=0.1T. If log $P(f)$ is plotted as a function of log f, the three curves are all straight lines, which is the typical character reflecting the fractal structure of $P(f)$. Both curves of specimens A and B are illustrated in Fig. 1. The curve of specimen C is similar to those of specimens A and B.

Fig. 1 shows that within the non – scale frequency range from 10 kHz to 200 kHz, the loss spectrum $P(f)$ of the three constant permeability alloys has has fractal structure. $P(f)$ can be unitedly given by following fractal formula:

$$P(f) = P_0 f^{D_f} \tag{2}$$

Table 1 Total power loss $P(f)$ of specimen A, B and C (B_m=0.1T)

f /kHz	P/W · kg^{-1}		
	A	B	C
10	1.95	1.45	4.10
20	6.17	3.80	10.20
50	32.20	13.50	33.90
70	59.10	21.70	51.90
100	112.00	35.00	85.00
150	227.00	61.80	144.00
200	369.00	90.60	297.00

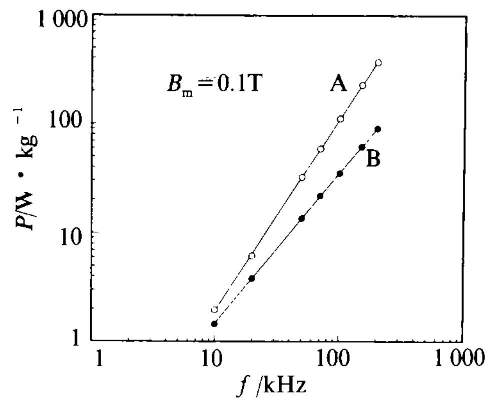

Fig. 1 log$P(f)$ vs log$f$ curves of A and B

where D_f, generally a fraction, is the fractal dimension of the loss spectrum and P_0 is a constant. Both D_f and P_0 are related to the intrinsic properties of materials and heat treatment technology conditions. The values of D_f, P_0, anisotropy energy K_u and permeability μ are given in table 2.

The value of the fractal dimension D_f is really a fraction (see table 2). Its meaning, describing the fractal structure, differs from that of integral numbers 2

Table 2 D_f, P_0, K_u and μ of the specimens

Specimen	D_f	P_0, × 10^6	K_u/J· m^{-3}	μ	Constant range /A· m^{-1}
A	1.76	0.17	17.50	2 880	0 ~ 240
B	1.38	4.43	61.90	1 170	0 ~ 796
C	1.31	24.30	119.60	616	0 ~ 1 194

and 1 appearing in the traditional eddy-current loss $P_e \propto f^2$ and magnetic hysteresis loss $P_h \propto f^1$ formulas respectively. D_f indicates the character-the total loss, caused by various mechanisms (such as eddy-current, magnetic hysteresis, relaxation, etc.), increases with the increasing frequency. The larger D_f is, the worse the frequency character of $P(f)$ is.

2.2 A COMPARISION BETWEEN TWO FORMULAE OF $P(f)$

For specimen A, the fractal formula of loss spectrum can be written as :

$$P(f)=1.73\times 10^{-7}f^{1.76} \quad \text{(W/kg)} \tag{3}$$

The traditional $P(f)$ formula can be obtained with very high confidence level according to the formula (1). It is:

$$P(f) = 7.13 \times 10^{-9}f^2 + 45.69 \times 10^{-5}f - 5.71 \quad \text{(W/kg)} \tag{4}$$

Through (3) and (4), the value of P can be calculated (listed in table 3).

From the comparision and table 3, it is found that the value of $P(f)$ calculated using both formulae agrees with the observed value well. However, the value of residual loss in traditional formula is negative, which is difficult to explain in physics. The fractal formula has no such difficulty. Moreover the fractal formula agrees with the observed $P(f)$ better than the traditional one at the whole frequency range of 10 kHz ~ 200 kHz.

Table 3 A comparision between two formulae of $P(f)$

f/kHz	P/W · kg^{-1}		
	Observed	Formula(3)	Formula(4)
10	1.95	1.90	−0.43
20	6.17	6.41	6.28
50	32.20	32.21	34.96
70	59.10	58.21	61.21
100	112.00	109.16	111.28
150	227.00	222.31	223.25
200	369.00	369.01	370.87

The conclusions of above comparision are applicable to specimens B and C, in which the fractal formulae are also superior to the traditional ones in describing loss spectrum.

In addition, above comparision illustrates that the fractal dimension D_f can represent qualitatively the ratio of eddy-current loss P_e to magnetic hysteresis loss P_h at a certain frequency. Taking specimen A as an example. For specimen A, D_f equals 1.76 and is close to 2 which appears in traditional eddy-current loss $P_e \propto f^2$. Using formula (4), the ratio of P_e to P_h can be calculated. $P_e/P_h = 0.78$ as $f = 50$ kHz, $P_e/P_h = 1.56$ when $f = 100$ kHz, and $P_e/P_h = 3.12$ while f rises to 200 kHz. Comparatively, for specimens B and C, the value of D_f decreases to 1.38 and 1.31 respectively, and the value of P_e/P_h at a same frequency also decreases. Both D_f and P_e/P_h of the specimens are shown in table 4.

Table 4 shows that in specimen A (1J66 alloy), which has high μ and narrow constant range, when $f > 70$ kHz, P_e is greater than P_h. While in specimen B (1J34H

Table 4 D_f, and P_e/P_h of three specimens

Specimen	D_f	P_e/P_h				
		50 kHz	70 kHz	100 kHz	150 kHz	200 kHz
A	1.76	0.78	1.09	1.56	2.34	3.12
B	1.38	0.29	0.41	0.58	0.87	1.16
C	1.31	0.10	0.15	0.21	0.32	0.42

alloy), the frequency must be higher than 200kHz when P_e surpasses P_h. In specimen C (1J34KH alloy), which has the least μ_i and widest constant range among three specimens, P_h is much greater than P_e at the whole frequency range from 10 kHz to 200 kHz.

As discussed in sections 2.1 and 2.2, the fractal formula of $P(f)$ can excellently describe the behavior of total power loss in constant permeability alloys. The fractal dimension D_f can indicate the frequency character of $P(f)$ and the ratio of eddy-current loss to magnetic hysteresis loss. The fractal formula is very simple and only uses two factors P_0 and D_f, which are easy to measure. We suggest that it be reasonable to use fractal formula rather than traditional seperation formula to describe the loss spectrum.

2.3 THE INFLUENCE OF INDUCED ANISOTROPY ENERGY K_u ON BOTH D_f AND P_0

By transverse magnetic heat treatment, the induced anisotropy will be produced in constant permeability alloys. Since the procedure of magnetization is mainly the rotation of magnetic domain and $\mu \propto B_s^2/K_u$, the general methods to develope constant permeability alloys are to determine saturation magnetic induction B_s by selecting the components of the alloy and to obtain appropriate value of K_u by searching for transverse magnetic heat treatment conditions. Through above methods, a constant permeability will be obtained at a certain range of magnetized field. It must be pointed out that K_u not only directly affects μ, but also makes a great impact on both the fractal dimention D_f and factor P_0. The curves of D_f and P_0 vs K_u are diagrammed in Fig. 2.

With the decrease of K_u, D_f rises rapidly(see Fig.2). Though μ increases with the decreasing K_u, the loss behavior becomes worse. This is the reason that it is hard to develop low loss alloys with high constant permeability in practice.

Also Fig. 2 shows that P_0 drops sharply with the decrease of K_u. Since $P(f)$ is determined by both P_0 and D_f, specimen B, whose P_0 is not so greater and D_f is smaller in value, has the least core loss among the three specimens.

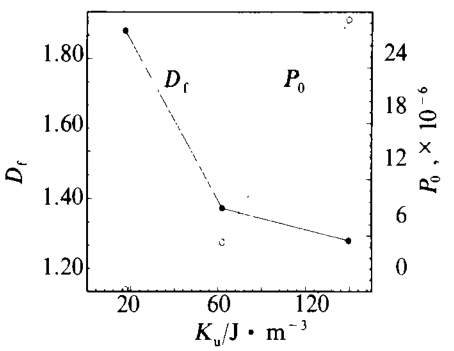

Fig. 2 Dependence of D_f and P_0 on K_u in constant permeability alloys

3 CONCLUSIONS

(1) Within the high frequency range from 10 kHz to 200 kHz, the loss spectrum $P(f)$ of the three constant permeability alloys, 1J66, 1J34H and 1J34KH, has fractal structure $P(f) = P_0 f^{D_f}$, here D_f is its fractal dimension.

(2) In these alloys, with the decrease of anisotropy energy K_u, permeability μ increases, constant range becomes narrow, fractal dimention D_f rises rapidly and P_0 drops greatly. By controlling the value of K_u, the constant permeability alloy with low core loss can be developed.

(3) In the 10kHz ~ 200kHz frequency range, the value of D_f is able to indicate qualitatively the ratio of eddy－current loss to magnetic hysteresis loss.

REFERENCES

1 Wan Defu, Ma Xinglong . Physics of Magnetism. Chendu : University of Electronic Science and Technology, 1994 . 406

2 Feder J . Fractals. New York : Plenum, 1988.

恒导磁合金损耗谱的分形结构

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摘要 研究了恒导磁合金的铁芯损耗谱 $P(f)$，发现 $P(f)$ 具有分形结构．讨论了感生各向异性能 K_u 对分形维数 D_f 的影响．

关键词 恒导磁合金，铁芯损耗，分形