Magnetization Properties

1. Objectives

Measure the magnetization curves of a variety of magnetic materials to understand the basic concepts of ferromagnetism. Understand the properties of different materials under different frequency, temperature. Learn the method of using X-Y recorder and oscilloscope.

2. Experimental results

2.1 Properties of specimens and different materials

The basic information of specimens is shown on Table 2.1 *Properties of specimens*.

Table 2.1: Properties of specimens

Material	Type	Le m	Ae m^2	N_1 turn	N_2 turn
Silicon steel	6.5%Si	8.39×10^{-2}	2.04×10^{-6}	30	30
Amorphous	MB	5.50×10^{-2}	1.18×10^{-5}	5	5
Ferrite	H5A	5.33×10^{-2}	2.04×10^{-5}	15	15

Where, L_e is the average length of the inner and outer perimeters of the toroidal specimen, $\mathrm{A_e}$ is the cross-sectional area, N_1 and N_1 turns are the turns of the coil.

Below are the equations to calculate:

$$L_e = \pi r^2 = \frac{\pi}{2}(\text{Outer diameter} + \text{Inner diameter}) \tag{2.1}$$

$$\mathrm{A_e} = \frac{1}{2}(\text{Outer diameter} - \text{Inner diameter})\times(\text{Height}) \tag{2.2}$$

2.2 Measurement of the magnetization curves

The data from X-Y Recorder and B-H Curve Trainer is shown on Table 2.2 *Measurement result of X-Y Recorder* and Table 2.3 *Measurements of the AC B-H Curve Trainer*

Scale Factors of the coercivity H and the flux density B can be calculated using Equation (2.3) and Equation (2.4).

$$\mathrm{H} = \frac{N_1}{Le} \cdot I = \frac{N_1}{Le} \cdot K_1 \cdot X_{xy} \tag{2.3}$$

$$\mathrm{B} = \frac{N_2 \cdot \Phi}{Ae \cdot N_2} = \frac{K_2 \cdot Y_{xy}}{Ae \cdot N_2} \tag{2.4}$$

Example calculations for Silicon steel, we have:

$$\mathrm{H} = \frac{N_1}{Le} \cdot K_1 \cdot X_{xy}$$
$$= \frac{30}{8.39} \cdot 0.1 \cdot 0.5$$
$$= 35.76$$
$$\mathrm{B} = \frac{K_2 \cdot Y_{xy}}{Ae \cdot N_2}$$
$$= \frac{10^{-4} \cdot 0.1}{2.04 \cdot 10^{6} \cdot 30}$$
$$= 0.163$$

Table 2.2: Measurement result of X-Y Recorder

hgMaterial	X-Y Recorder		Scale Factors	
	Range X axis V/cm	Range Y axis V/cm	H A/m/cm	B T/cm
Silicon Steel	0.5	0.1	35.76	0.163
	0.5	0.1	35.76	0.163
	0.5	0.1	35.76	0.163
Amorphous	0.5	0.5	4.55	0.085
Ferrite (H5A)	0.25	0.25	28.14	0.082
	0.25	0.25	28.14	0.082
	0.25	0.25	28.14	0.082

Table 2.3: Measurements of the AC B-H Curve Trainer

Material	Hz	Temperature ℃	AC B-H Curve Trainer			
			K1 Code number	K1 A/div	K2 Code number	K2 Wb-turn/div
Silicon steel	100	24	5	0.2	0.5	1.0×10^{-4}
	200		5	0.2	0.5	1.0×10^{-4}
	500		5	0.2	0.5	1.0×10^{-4}
Amorphous	1000	24	4	0.1	0.5	1.0×10^{-6}
Ferrite (H5A)	1000	0	5	0.4	0.25	1.0×10^{-4}
		24	5	0.4	0.25	1.0×10^{-4}
		70	5	0.4	0.25	1.0×10^{-4}

2.3 Readings from the graph and Measurement result

We can read the data from Fig. 2.1 *The hysteresis magnetization curve of silicon steel*, Fig. 2.2 *The hysteresis magnetization curve of amorphous* and Fig. 2.3 *The hysteresis magnetization curve of ferrite*, thus we have Table 2.4 *Readings from the graph and Measurement result* which contains values of coercivity H_c, the maximum magnetic flux density B_m, and the residual magnetic flux density B_r.

Example calculation:

For Silicon steel of frequency 100Hz, Temperature of 24℃, we have:

$$H_C = 1.58 \cdot 35.76 = 52.51$$

$$B_M = 5.38 \cdot 0.163 = 0.88$$

$$B_r = 6.80 \cdot 0.163 = 1.11$$

Table 2.4: Readings from the graph and Measurement result

Material	Frequency Hz	Temperature ℃	Reading from the graph			Measurement result		
			Hc cm	Br cm	Bm cm	Hc A/m	Br T	Bm T
Silicon steel	100	24	1.46	5.38	6.80	52.21	0.88	1.11
	200		1.80	5.69	6.73	64.37	0.93	1.10
	500		2.43	5.88	6.69	86.90	0.96	1.09
Amorphous	1000	24	0.58	7.08	7.11	2.64	0.60	0.60
Ferrite (H5A)	1000	0	0.46	1.00	5.31	12.94	0.08	0.44
		24	0.41	1.00	4.90	11.54	0.08	0.44
		73	0.31	0.88	3.91	8.72	0.07	0.32

3. Discussion and Conclusion

3.1 Frequency dependency of the hysteresis curve

We can learn from Fig.2.1 that as the frequency dependency increases, the area of hysteresis curve (hysteresis loss) increases and the maximum magnetic flux density stays the same.

The derivation of the classic eddy loss frequency obtained equation[2] can be expressed as:

$$\frac{dW_{EC}}{dt} = \frac{\pi^2 B_{max}^2 \, \mathrm{d}^2 \mathrm{f}^2}{\rho\beta} \tag{3.1}$$

While ρ is the resistivity in Ω m, d is the cross-sectional dimension in meters (thickness for laminations, diameter for cylinders and spheres) and β is a geometrical factor which varies from β=6 in laminations to β=16 in cylinders and β=20 in spheres, B_{max} is the peak flux density in the cycle and f is the frequency in Hz.

And we can also learn Hysteresis loss in transformer's Equation[3]:

$$W_h = K_h B_{max}^{1.6} f \tag{3.2}$$

Where, K_h is the Hysteresis constant, B_{max} is the peak flux density in the cycle and f is the frequency in Hz.

From Equation (3.1) and (3.2), we can learn that the loss increases when the frequency increases, hence the area increases as well.

3.2 Temperature dependency of the hysteresis curve

We can learn from Fig 2.3 that as the temperature increases, the maximum magnetic flux density B_m decreases. And the coercivity H_c and the residual magnetic flux density B_r shows no connections with the temperature.

Oxides that contain Fe^{3+} ions are generally called ferrite[1]. Ferrite contains a strong magnetic property called ferrimagnetism which the material has populations of atoms with opposing magnetic moments.

And Spontaneous magnetization is the appearance of an ordered spin state (magnetization) at zero applied magnetic field in a ferromagnetic material below a critical point called the Curie temperature or T_C.[6]

And the temperature dependence of spontaneous magnetization at low temperatures is given by Bloch's Law[6]:

$$M(T) = M(0)\left(1 - \left(\frac{T}{Tc}\right)^{1.5}\right) \tag{3.3}$$

while M(0) is the spontaneous magnetization at absolute zero, and Tc is the curie temperature which is around 771°C[7]. And we can also learn that the decrease in spontaneous magnetization at higher temperatures is caused by the increasing excitation of spin waves[8].

And therefore, higher temperature would cause decrease in spontaneous magnetization, which means the decrease of maximum magnetic flux density

A Preisach model[5] with parameter of temperature can be used to explain the effects of temperature on magnetic hysteresis. The temperature parameter was introduced into the existing model by adding parameters like curies temperature and critical exponent.

3.3 Relationship between the differences in shapes of the three samples

All the samples are made of ferromagnetic materials. And we can use different models to explain the differences in shapes of the three samples: Preisach Model, Globus Model, Jiles-Atherton Model[9].

Different materials have different coercivity, and the differences in shapes can be explained by the differences of coercivity. For low coercivity materials, we call them magnetically soft (Hc ~ 1A/m), for example, the ferrite in the experiment. It has characteristics like high Permeability, low intrinsic coercive force and hence the hysteresis curve is narrow.

For high coercivity materials, which are called magnetically hard (Hc ~ 10^4 ~10^6 A/m), the remanence is high and the coercivity is strong, which makes the hysteresis wide.[10]

And for different Dynamic Hysteresis Curves, the shapes are related to the frequency and ranges of the magnetic fields. For example, as B_m and H_m in Fig 3.1. *Dynamic Hysteresis Curves,* we have the equation for amplitude permeability:

$$\mu_M = \frac{B_M}{\mu_0 H_M} \tag{3.4}$$

While B_m and H_m is magnetic field and flux density.

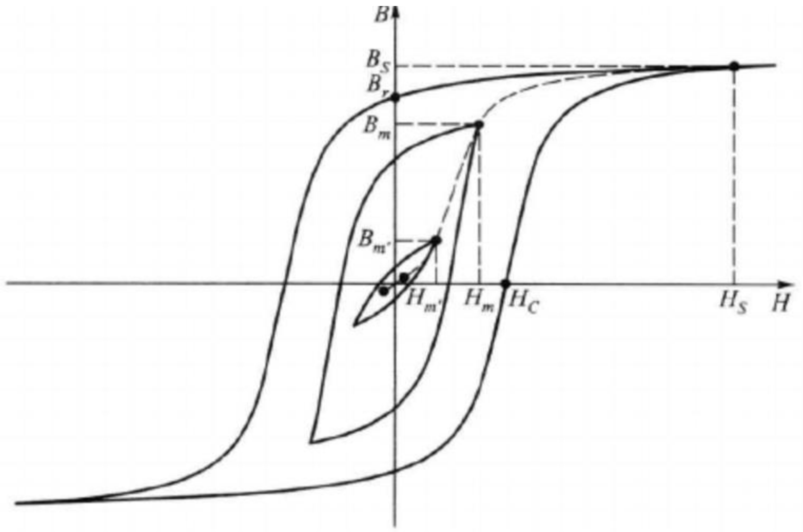

Fig. 3.1 Dynamic Hysteresis Curves

4. References

1) Waseda university, Science and Engineering Laboratory 2A, Laboratory for Basic Experiments in Science and Engineering, pp.42-49, 2017.

2) Jiles, D. C. "Frequency dependence of hysteresis curves in'non-conducting'magnetic materials." IEEE Transactions on Magnetics 29.6 (1993): pp. 3490-3492.

3) De Leon, Francisco, and Adam Semlyen. "A simple representation of dynamic hysteresis losses in power transformers." IEEE Transactions on Power Delivery 10.1 (1995): pp.315-321.

4) Ball, P. C., and R. Evans. "Temperature dependence of gas adsorption on a

mesoporous solid: capillary criticality and hysteresis." Langmuir 5.3 (1989): pp.714-723.

5) Bertotti, Giorgio. "Dynamic generalization of the scalar Preisach model of hysteresis." IEEE Transactions on Magnetics 28.5 (1992): 2599-2601.

6) Ashcroft, Neil W.; Mermin, N. David (1976). Solid State Physics. Holt, Rinehart and Winston. ISBN 0-03-083993-9.

7) Matsuki, H., and K. Murakami. "High quality soft heating method utilizing temperature dependence of permeability and core loss of low Curie temperature ferrite." IEEE Transactions on Magnetics 21.5 (1985): 1927-1929, pp.708

8) Chikazumi, Sōshin (1997). Physics of Ferromagnetism. Clarendon Press. ISBN 0-19-851776-9., pp. 128–129

9) Wilson, Peter R., J. Neil Ross, and Andrew D. Brown. "Optimizing the Jiles-Atherton model of hysteresis by a genetic algorithm." IEEE Transactions on Magnetics 37.2 (2001): pp. 989-993.

10) 张奕雄. "高阶多项式在拟合铁磁物质磁滞回线中的应用." 大学物理 27.2 (2008): 45-45.