Magnetization Properties

1. Introduction

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

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	Le m	Ae m^2	N_1 turn	N_2 turn
Silicon steel	8.39×10^{-2}	2.04×10^{-6}	30	30
Amorphous	5.50×10^{-2}	1.18×10^{-5}	5	5
Ferrite	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:

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

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

The measurement parameters used in Experiment are shown as Table 2.2 *Measurement parameters*.

Table 2.2: Measurement parameters

Material	Maximum excitation current	Frequency Hz	Temperature ℃
Silicon steel	0.6	100, 200, 500	24
Amorphous	0.3	1000	24
Ferrite	0.8	1000	0, 24, 70

2.2 Measurement of the magnetization curves

The relationship between K_1 and K_2 constant and

The data from X-Y Recorder and B-H Curve Trainer is shown on Table 2.3 *Measurement result of X-Y Recorder* and Table 2.4 *Measurements of the AC B-H Curve Trainer.* Where K_1 and K_2 are the code number displayed on the AC magnetic properties measurement instrument.

Scale Factors of the coercivity H and the flux density B can be calculated using Equation (2.3) and Equation (2.4). [1]

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

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

The definitions of each parameters can be referred to Clause 2.1.

Example calculations for Silicon steel, we have:

$$\begin{aligned} \mathrm{H} &= \frac{N_1}{Le} \cdot K_1 \cdot X_{xy} \\ &= \frac{30}{8.39} \cdot 0.1 \cdot 0.5 \\ &= 35.76 \end{aligned}$$

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

$$= \frac{10^{-4} \cdot 0.1}{2.04 \cdot 10^{6} \cdot 30}$$

$$= 0.163$$

While K_1 and K_2 are the code number displayed on the AC magnetic properties measurement instrument, 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, X_{xy} is the range of X axis, Y_{xy} is the range of Y axis. The values can be referred to Table 2.1, Table 2.2 and Table 2.3.

Table 2.3: 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 2.4: Measurements of the AC B-H Curve Trainer

Material	Hz	Temperature℃	AC B-H Curve Trainer			
			K_1 Code number	K_1 A/div	K_2 Code number	K_2 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.

And we can obtain the above values (H_c, B_m, B_r) as shown if Fig. 2.4.

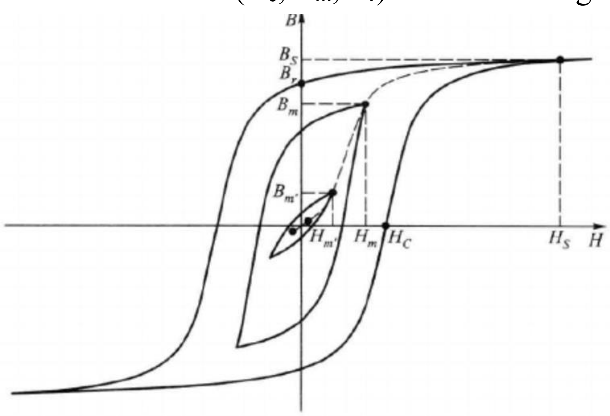

Fig. 2.4 Dynamic Hysteresis Curves[10]

Example calculation:

For Silicon steel of frequency 100Hz, Temperature of 24℃, we can calculate the values of H_c, B_m, B_r by using the values of H and B obtained in Table 2.3:

$$H_C(Measure) = H_C(Graph) \cdot H$$

$$= 1.58 \cdot 35.76$$

$$= 52.51$$

$$B_R(Measure) = B_R(Graph) \cdot B$$

$$= 5.38 \cdot 0.163$$

$$= 0.88$$

$$B_M(Measure) = B_M(Graph) \cdot B$$

$$= 6.80 \cdot 0.163$$

$$= 1.11$$

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 electric current induced in a conductor by a changing magnetic field is called eddy current[11], thus there is eddy current in our experiment.

The derivation of the classic eddy current 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 [Ω m] is defined as the resistivity, d[m] is defined as the cross-sectional dimension (thickness is for laminations, diameter is for cylinders or spheres) and β is a geometrical factor which β=16 in cylinders in our case, B_{max} is defiend the peak flux density in the cycle and f [Hz] is the frequency.

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.

Anomalous loss[14] is the loss in other than eddy-current and hysteresis losses. The Anomalous loss is defined as:

$$W_a = K_a B_{max}^{1.5} f^{0.5} \tag{3.3}$$

while K_a is the anomalous loss coefficient, B_{max} is the maximum flux density, and f is the frequency of reversal of magnetic field.

From Equation (3.1), (3.2) and (3.3), 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 contains atoms with opposing magnetic moments.

And Spontaneous magnetization[13] is the magnetization that without being affected by external magnetic field in a ferromagnetic material below a critical point called the Curie temperature or T_C.[6]

Spin wave[10] is the propagating disturbances in the ordering of different materials, and ferromagnetic materials are dominated by spin wave when the temperature is above T_C.

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

$$M(T) = M(0)(1 - \left(\frac{T}{Tc}\right)^{1.5}) \tag{3.4}$$

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, according to Equation (3.4), we can find out that higher temperature would cause decrease in spontaneous magnetization, which will cause the decrease of maximum magnetic flux density

3.3 Relationship between the differences in shapes of the three samples

Coercivity[12] is the resistance of a magnetic material to changes in magnetization. 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]

3.4 For Dynamic Hysteresis Curves

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:

$$\mu_M = \frac{B_M}{\mu_0 H_M} \tag{3.5}$$

While B_m and H_m is magnetic field and flux density.

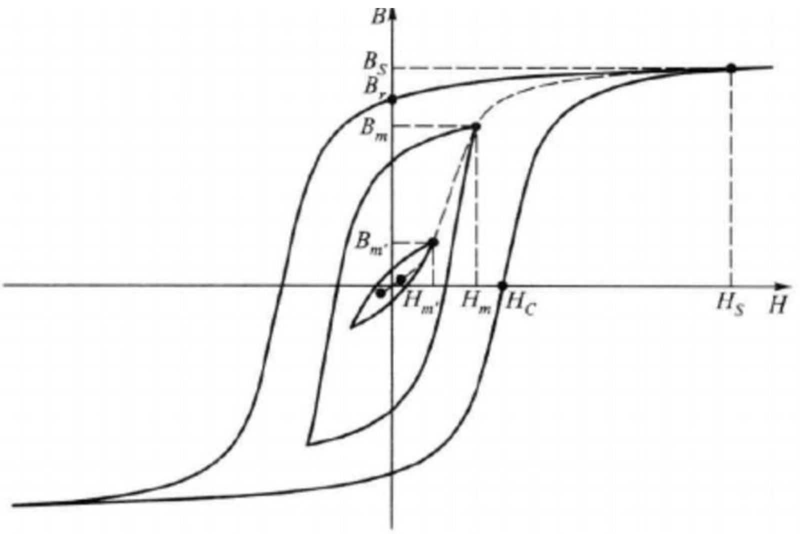

Fig. 3.1 Dynamic Hysteresis Curves[10]

4. References

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