INVESTIGATION OF MAGNETIC LOSSES

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1. Introduction

The purpose of this laboratory assignment is to examine the magnetic losses that occur in soft magnetic materials during alternating magnetization. When a ferromagnetic sample is subjected to an AC magnetic field, various internal processes convert part of the supplied energy into heat. These processes are collectively referred to as **magnetic losses**, and they primarily consist of **hysteresis losses** and **eddy current losses**.

Hysteresis losses arise from the repeated realignment of magnetic domains when the material experiences cyclic changes in the applied magnetic field. Each reversal of magnetization requires energy, and this energy is dissipated as heat. Since this realignment occurs every cycle, hysteresis losses increase **linearly** with the magnetizing frequency.

Eddy current losses originate from circulating currents induced inside the conductive material due to time-varying magnetic flux. These currents generate Joule heating and increase **quadratically** with the frequency of magnetization.

To determine the total magnetic losses within a material, the area enclosed by the **hysteresis loop** on the $B(H)$ diagram must be evaluated. The specific energy dissipated during one magnetization cycle is given by:

$$S^{(BH)} = \oint B\, dH (J/m^3) \qquad (1)$$

Under AC excitation at frequency f, the cycle repeats f times per second; therefore, the specific power loss becomes:

$$p = f \times S^{(BH)} (W/m^3) \qquad (2)$$

The magnetic loss in the entire volume of the sample is therefore:

$$P_{\mathrm{Fe}} = p \times V = f \times V \times S^{(BH)} \qquad (3)$$

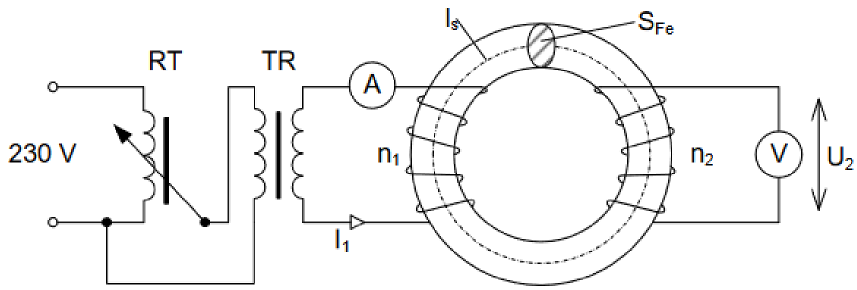

Figure 1. Schematic diagram of the laboratory equipment used for measurement of the primary magnetization curve

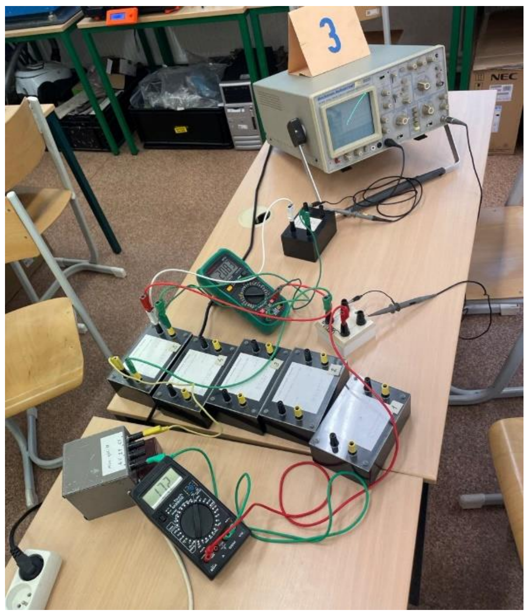

Figure 2. Experimental setup used for measuring the primary magnetization curve

In this experiment, the hysteresis curve is displayed using an oscilloscope with an integrator circuit. The displayed loop area S_h, measured in screen divisions, can be converted to physical energy using:

$$S^{(BH)} = k_x \times k_y \times S_h \qquad (4)$$

where k_x and k_y are scaling constants converting horizontal and vertical screen divisions into the corresponding H and B values.

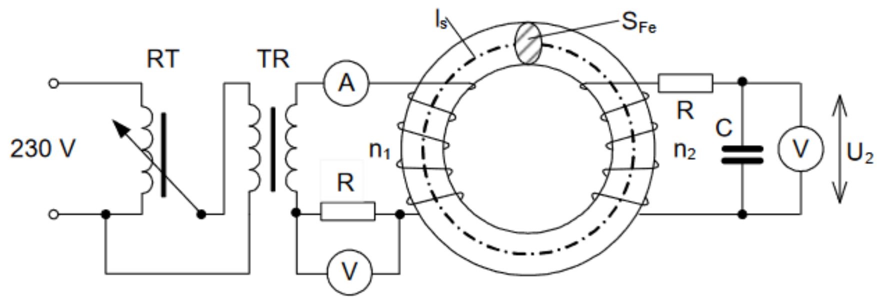

Figure 3. Modified oscilloscope setup with integrator used to display the hysteresis loop

The scaling constants depend on the measurement circuit and oscilloscope settings. The conversion constant for the horizontal axis (magnetic field strength) is:

$$k_x = \frac{n_1}{l\,xR} \times 0.2(A/m \cdot \text{per cm}) \qquad (5)$$

Where:
0.2 - voltage corresponding to one division of the oscilloscope,
l - average magnetic path length,
R - resistance inserted in the primary circuit,
n_1- number of primary turns,
x - number of divisions corresponding to 0.2 V.

The vertical axis conversion constant for magnetic induction is:

$$k_y = \frac{1}{y}(T/\text{cm}) \qquad (6)$$

with y representing the number of divisions corresponding to the selected induction amplitude.

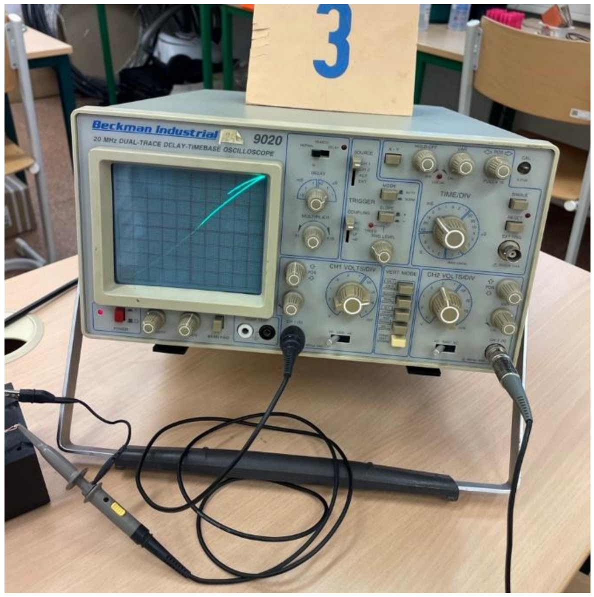

Figure 4. Example of a hysteresis curve displayed on the oscilloscope during the lab

To quantify the magnetic quality of the tested transformer sheet material, the **loss number** Z is calculated. This value expresses the magnetic loss per unit mass and is given by:

$$Z = \frac{P_{\mathrm{Fe}}}{M} = k_x \, k_y \, f \, \frac{S_h}{m} (W/kg) \qquad (7)$$

where:
m - density of the ferromagnetic material,
M - mass of the specimen.

The loss number is typically evaluated at a peak induction of $B_m = 1\,T$, denoted Z_{10}. For other induction values, such as $B_m = 1.5\,T$, the corresponding notation Z_{15} is used.

During the laboratory work, the constants k_x and S_h were obtained using the provided calculator, and the measured hysteresis loop area was used to determine the loss number of the investigated sample.

2. Measurements

At the beginning of the measurement process, the oscilloscope and integrator setup were adjusted so that two parameters remained constant throughout all observations. The vertical voltage amplitude was fixed at $V = 2.08$ V, and the vertical scaling coefficient for magnetic induction was set to $k_y = 0.25$ T/cm. All tables presented below show the measured coordinates of the left and right sides of the hysteresis curve at different angular positions under these fixed conditions.

0°		
y	x_l	x_r
0	-0.7	0.7
1	-0.4	1
2	0.3	1.5
3	1.8	2.7
4	5	5

k_x (A/m/cm)	43.56
X (cm)	9.6
S_h (cm^2)	8.4

Table 1. Measurement results of the hysteresis curve coordinates at 0°

30°		
y	x_l	x_r
0	-0.6	0.8
1	0.1	1.2
2	0.9	2
3	2.2	3.3
4	5	5

k_x (A/m/cm)	67.44
X (cm)	6.2
S_h (cm^2)	8

Table 2. Measurement results of the hysteresis curve coordinates at 30°

45°		
y	x_l	x_r
0	-0.6	0.6
1	0.1	1.2
2	1.2	2.1
3	2.8	3.4
4	5	5

k_x (A/m/cm)	113.02
X (cm)	3.7
S_h (cm^2)	6.4

Table 3. Measurement results of the hysteresis curve coordinates at 45°

60°		
y	x_l	x_r
0	-0.5	0.5
1	0.3	1.2
2	1.6	2.4
3	2.9	3.6
4	5	5

k_x (A/m/cm)	160.83
X (cm)	2.6
S_h (cm^2)	5.8

Table 4. Measurement results of the hysteresis curve coordinates at 60°

90°		
y	x_l	x_r
0	-0.4	0.4
1	0.6	1.3
2	1.6	2.3
3	2.9	3.5
4	5	5

k_x (A/m/cm)	232.32
X (cm)	1.8
S_h (cm^2)	4.8

Table 5. Measurement results of the hysteresis curve coordinates at 90°

3. Calculation

To determine the values of P_{Fe} and the loss number Z for each angle, equations **(3)** and **(4)** from the Introduction were used to compute the total magnetic losses, while equation **(7)** was used to calculate the corresponding loss number. Since the measured loop area S_h is given in cm^2, it was necessary to divide the expression for P_{Fe} by 10^4 in order to convert the result into m^2. All calculations were performed using the constants:
$f = 50$ Hz, $V = 2.08$ V, $k_y = 0.25$ T/cm, and $\rho = 7870$ kg/m^3.

(0°)

$$P_{Fe} = 50 \times 2.08 \times 43.56 \times 0.25 \times 8.4 \div 10^4 = 0.951 \text{ W}$$
$$Z = \frac{43.56 \times 0.25 \times (50 \times 8.4)}{7870} = 0.0058 \text{ W/kg}$$

(30°)

$$P_{Fe} = 50 \times 2.08 \times 67.44 \times 0.25 \times 8.0 \div 10^4 = 1.403 \text{ W}$$
$$Z = \frac{67.44 \times 0.25 \times (50 \times 8.0)}{7870} = 0.0086 \text{ W/kg}$$

(45°)

$$P_{Fe} = 50 \times 2.08 \times 113.02 \times 0.25 \times 6.4 \div 10^4 = 1.881 \text{ W}$$
$$Z = \frac{113.02 \times 0.25 \times (50 \times 6.4)}{7870} = 0.0115 \text{ W/kg}$$

(60°)

$$P_{Fe} = 50 \times 2.08 \times 160.83 \times 0.25 \times 5.8 \div 10^4 = 2.425 \text{ W}$$
$$Z = \frac{160.83 \times 0.25 \times (50 \times 5.8)}{7870} = 0.0148 \text{ W/kg}$$

(90°)

$$P_{Fe} = 50 \times 2.08 \times 232.32 \times 0.25 \times 4.8 \div 10^4 = 2.899 \text{ W}$$
$$Z = \frac{232.32 \times 0.25 \times (50 \times 4.8)}{7870} = 0.0177 \text{ W/kg}$$

4. Conclusion

In this laboratory assignment, the magnetic losses of a soft ferromagnetic material were investigated by analyzing the shape and area of the hysteresis loop obtained at different angular positions of the sample. Using the oscilloscope-integrator setup, the coordinates of the left and right sides of the hysteresis curve were measured, allowing the loop area S_h and the corresponding scaling factors k_x and k_y to be determined. These values were then used in equations (3), (4), and (7) to calculate the total magnetic losses P_{Fe} and the loss number Z for each orientation of the sample.

The results show a clear trend that both P_{Fe} and Z increase steadily as the angle of measurement increases from 0° to 90°. This behavior reflects the growing effective magnetic path or anisotropy effects within the sample, which cause the hysteresis loop area to increase with angle. Since the loop area is directly proportional to the energy dissipated during each magnetization cycle, larger areas naturally correspond to higher magnetic losses. The lowest losses were observed at 0°, while the highest were recorded at 90°, indicating that the sample exhibits directional dependence in its magnetic behavior.

Overall, the experiment successfully demonstrated the relationship between the hysteresis loop characteristics and the magnetic losses in soft ferromagnetic materials. It also confirmed the importance of material orientation when evaluating transformer sheet quality, as quantified by the loss number Z. The used procedures during the experiment provided consistent and meaningful results, validating both the measurement method and the theoretical expressions applied.