THE UNIVERSITY OF SCRANTON

PHYSICS AND ELECTRICAL ENGINEERING DEPARTMENT

Electromagnetics Laboratory
Dissectible Transformer

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Abstract

This experiment demonstrates the procedures, theory, and experimental background of high voltage transformers. The objectives were to use a dissectable transformer consisting of a static primary and removable secondary coils coupled through a ferromagnetic core to determine primary current, secondary current, power consumed by the coils, efficiency of the device, and finally the flux density of the core.

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1 Introduction

This project will examine the usage of transformers and their use in transmission lines. The main topics covered by this experiment are; an investigation into the power transfer of transformers, how different coiling ratios factor into the power transfer, and ultimately to observe the voltage, current, and power characteristics of a transformer.

1.1 Equipment

- Sargent Welsh Heavy-Duty Dissectible Transformer
- Electro-Technique Hardened Dissectible Transformer
- Several replacement transformer coils
- Several multimeters
- Temperature probe

1.2 Transformer Theory

The phenomenon of electromagnetic induction was discovered independently by Michael Faraday and Joseph Henry in 1831. However, Faraday was the first to publish the results of his experiments and thus receive credit for the discovery. The relationship between electromotive force (EMF) or "voltage" and magnetic flux was formalized in an equation now referred to as "Faraday's Law of Induction":

$$|\epsilon| = \left|\frac{d\Phi_B}{dt}\right| \tag{1}$$

The transformer is based on two principles: first, that an electric current can produce a magnetic field (electromagnetism), and, second that a changing magnetic field within a coil of wire induces a voltage across the ends of the coil (electromagnetic induction). Changing the current in the primary coil changes the magnetic flux that is developed. The changing magnetic flux induces a voltage in the secondary coil.

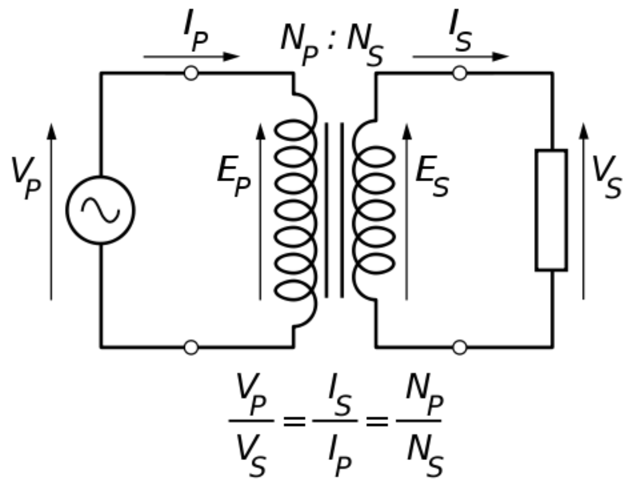

Figure 1: Circuit Diagram of an Ideal Transformer

Current passing through the primary coil creates a magnetic field. The primary and secondary coils are wrapped around a core of very high magnetic permeability, such as iron, so that most of the magnetic flux passes through both the primary and secondary coils.

The voltage induced across the secondary coil may be calculated from Faraday's law of induction, which states that:

$$V_s = N_s \frac{d\Phi}{dt} \tag{2}$$

where V_s is the instantaneous voltage, N_s is the number of turns in the secondary coil and Φ is the magnetic flux through one turn of the coil. If the turns of the coil are oriented perpendicular to the magnetic field lines, the flux is the product of the magnetic flux density B and the area A through which it cuts. The area is constant, being equal to the cross-sectional area of the transformer core, whereas the magnetic field varies with time according to the excitation of the primary. Since the same magnetic flux passes through both the primary and secondary coils in an ideal transformer, the instantaneous voltage across the primary winding equals

$$V_p = N_p \frac{d\Phi}{dt} \tag{3}$$

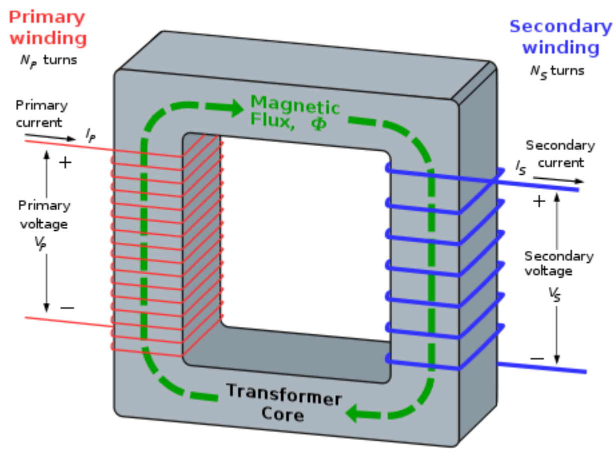

Figure 2: Three Dimensional Rendering of an Ideal Transformer

Taking the ratio of the two equations for V_s and V_p gives the basic equation for stepping up or stepping down the voltage:

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} \tag{4}$$

Where $\frac{N_s}{N_p}$ is known as the turns ratio, and is the primary functional characteristic of any transformer. In the case of step-up transformers, this may sometimes be stated as the reciprocal, $\frac{N_p}{N_s}$. Turns ratio is commonly expressed as an irreducible fraction or ratio: for example, a transformer with primary and secondary windings of, respectively, 100 and 150 turns is said to have a turns ratio of 2:3 rather than 0.667 or 100:150.

2 Data

2.1 Sargent Welsh Transformer

The following data was observed throughout the experiment:[1]

I_s	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
V_s		26.0	23.6	20.9	18.0	15.2	12.3	8.5	3.6	3.0
I_p		0.38	0.49	0.62	0.72	0.87	1.00	1.13	1.25	1.37
V_p		123.7	123.7	123.6	123.0	123.4	123.1	123.0	122.6	123.3

Table 1: Observed Values for Sargent Welsh Transformer with 200 Turns

[1]Experimental values for I_s equal to 0.5 Amps on the transformer with 200 turns were unable to be obtained because of the high temperature of the apparatus. As the value of I_s decreased below 1.5 Amps, the temperature of the apparatus quickly increased to near 125°C, permitting only several seconds worth of data collection time.

I_s	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
V_s	12.0	11.7	11.5	11.0	10.6	10.3	9.9	9.5	9.2	8.7
I_p	0.23	0.26	0.29	0.33	0.37	0.42	0.47	0.51	0.56	0.61
V_p	124.2	124.3	124.2	124	123.7	124.1	124.1	123.8	122.6	124.2

Table 2: Observed Values for Sargent Welsh Transformer with 80 Turns

I_s	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
V_s	5.9	5.8	5.7	5.5	5.4	5.3	5.1	5.0	4.9	4.8
I_p	0.22	0.23	0.24	0.25	0.26	0.28	0.30	0.32	0.34	0.36
V_p	124.3	124.4	124.0	124.0	124.0	124.1	124.3	124.1	124.3	124.1

Table 3: Observed Values for Sargent Welsh Transformer with 40 Turns

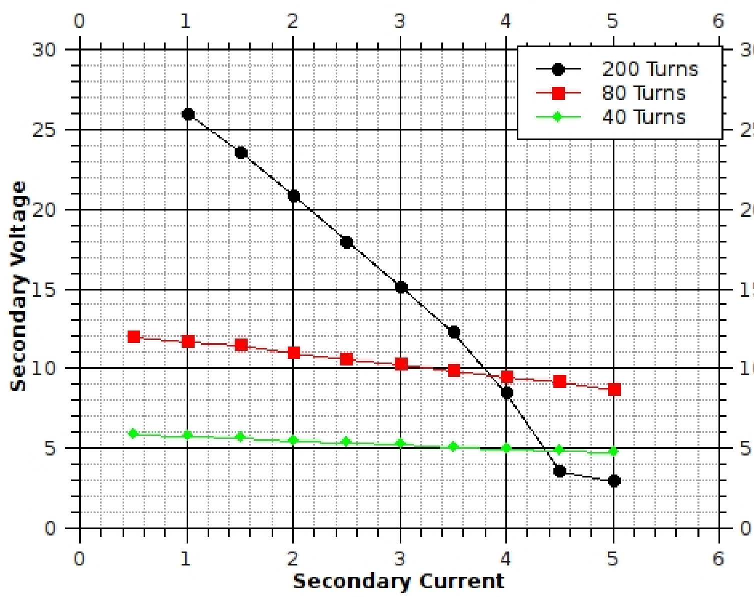

Figure 3: Observed Secondary Voltages for Sargent Welsh Transformer

2.2 Electro-Technique Transformer

I_s	0.66	0.76	0.99	1.21	1.50	1.66	2.00	2.50	2.77
V_s	16.5	16.1	14.9	13.7	11.9	10.9	8.6	4.5	1.5
I_p	0.86	0.85	0.87	0.89	0.93	0.99	0.95	1.06	0.94
V_p	123.3	123.4	123.7	123.7	124.0	124.1	124.3	124.3	124.1

Table 4: Observed Values for Electro-Technique Transformer with 220 Turns

I_s	0.38	0.50	0.60	0.70	0.80	0.81	1.10	1.31	1.55
V_s	9.5	9.4	9.4	9.3	9.2	9.1	9.0	8.8	8.5
I_p	0.80	0.79	0.79	0.79	0.79	0.80	0.81	0.82	0.81
V_p	123.5	123.8	123.7	123.7	123.5	124.1	123.4	124.3	124.1

Table 5: Observed Values for Electro-Technique Transformer with 110 Turns

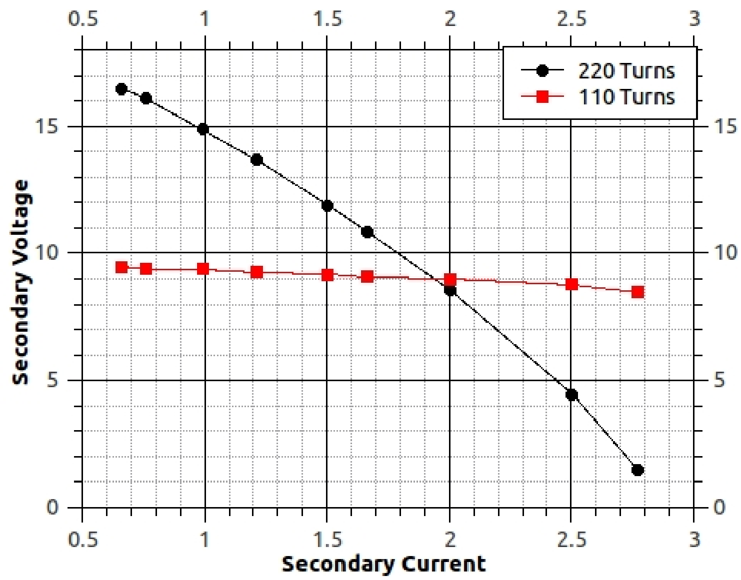

Figure 4: Observed Secondary Voltages for Electro-Technique Transformer

3 Analysis and Conclusions

After data analysis, the Sargent Welsh model transformer was determined to be roughly 50% efficient, meaning that it loses approximately half of it's power as heat, hysteresis, eddy currents, and copper or winding loss. The Electro-Technique transformer, however, was approximately 86% efficient, which would be much more useful since its power loss is nearly $\frac{1}{4}$ that of the Sargent Welsh. These calculations were performed using equations from the manual[1] and by measuring the cross sectional areas of the transformers.

The optimal operating points of the Sargent Welsh model was at an I_s value of 0.22 A, while optimal operating point for the Electro-Technique model was at 0.79 A. Both of these current values were the lowest possible currents achievable throughout the experiment.

It is also useful to calculate the flux through the iron core of the apparatus. Using the equations from the lab manual[1], it was possible to calculate the flux in each leg of the transformer and then sum them to calculate the total flux of the iron core. Leg 1 had a flux of $3.48 \times 10^{-4} Wb$ and Leg 2 had a flux of $3.11 \times 10^{-4} Wb$ for a total flux of the iron core equal to 6.59×10^{-4}. Using this information, the magnetic induction of the circuit was calculated to be $0.909\frac{Wb}{m^2}$.

References

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[3] Chow, Tai L. (2006), Introduction to electromagnetic theory: a modern perspective. Sudbury, Massachusetts (USA), Jones and Bartlett Publishers, p. 171. ISBN 0763738271.

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[5] Friedrich Uppenborn: History of the Transformer, page 35.

[6] Winders. Power Transformer Principles and Applications. pp. 2021.