TRANSFORMERS

EXPERIMENT PROCEDURE

- **Measure the voltage across the secondary coil as a function of the voltage across the primary with no load for a fixed number of windings.**
- **Measure the current in the primary coil as a function of the current in the secondary with a fixed number of windings and a short-circuited output.**
- **Measure the primary voltage, the primary current, the secondary voltage and the secondary current, for a specific load resistance.**
- **Determine the power loss and the efficiency.**

OBJECTIVE

Make measurements on a transformer with and without load

SUMMARY

Transformers are devices based on Faraday's law of induction which are used for converting voltages. One major use is for the transmission of electrical power over large distances, whereby power losses can be minimised by converting the voltage up to the highest possible levels thus reducing the current to a minimum. This experiment investigates the way the voltage and current depend on the number of windings with and without a load and with the output short-circuited. You will also calculate the power losses and efficiency.

REQUIRED APPARATUS

Quantity	Description	Number
2	Low Voltage Coil D	1000985
1	Transformer Core D	1000976
1	AC/DC Power Supply 1/ 2/ 3/ … 15 V, 10 A (230 V, 50/60 Hz)	1008691 or
	AC/DC Power Supply 1/ 2/ 3/ … 15 V, 10 A (115 V, 50/60 Hz)	1008690
3	Digital Multimeter P3340	1002785
1	Rheostat 10 Ω	1003064
1	Two-pole Switch	1018439
1	Set of 15 Safety Experiment Leads, 75 cm	1002843

BASIC PRINCIPLES

Transformers are devices based on Faraday's law of induction which are used for converting voltages. One major use is for the transmission of electrical power over large distances, whereby power losses can be minimised by converting the voltage up to the highest possible levels thus reducing the current to a minimum.

The simplest form of transformer consists of two coils coupled together, a primary coil with N_1 winding turns and a secondary coil with N_2 winding turns, both of which are wound around a common iron core. This means that the magnetic flux Φ_1 resulting from the current I_1 flowing in the primary coil fully surrounds the secondary coil.

The following treatment considers an ideal, i.e. loss-free, transformer. When there is no load on the transformer, no current flows in the secondary, i.e. $I_2 = 0$. If an alternating voltage U_1 is applied to the primary coil, a no-load or open-circuit current I_1 flows, thereby generating a magnetic flux Φ_1 and inducing a voltage U_{ind}. Kirchhoff's 2nd law implies that this induced voltage is opposite to and equal to U_1 since ($U_1 + U_{ind} = 0$):

(1) $$U_{ind} = -L_1 \cdot \frac{dI_1}{dt} = -N_1 \cdot \frac{d\Phi_1}{dt} = -U_1$$

L_1: inductance of primary coil
Φ_1: magnetic flux generated by I_1

Since the magnetic flux Φ_1 completely encompasses the secondary coil, a voltage is induced there:

(2) $$U_2 = -N_2 \cdot \frac{d\Phi_1}{dt}.$$

Equations (1) and (2) then lead to the following conclusion:

(3) $$\frac{U_2}{U_1} = -\frac{N_2}{N_1}.$$

The negative sign indicates that U_1 and U_2 are phase-shifted by 180° when the windings are in the same direction. If the windings are wound the opposite way round, the voltages will be in phase.

When there is a load on the transformer, a current $I_2 = U_2 / R$ flows in the secondary coil. R is the resistance of the load. This current gives rise to a magnetic flux Φ_2 which, according to Lenz's law, is opposed to the magnetic flux Φ_1 generated by the primary current I_1. Since the primary voltage U_1 remains constant, the primary current I_1 therefore increases. In the ideal case, the power output of the secondary coil P_2 is equal to the power input to the primary P_1:

(4) $$P_1 = U_1 \cdot I_1 = U_2 \cdot I_2 = P_2.$$

Combining this with equation (3) the following results:

(5) $$\frac{I_1}{I_2} = \frac{N_2}{N_1}.$$

The first part of the experiment involves connecting a voltmeter to the secondary side of the transformer and measuring the secondary voltage U_{2o} as a function of the primary voltage U_{1o} without any load (hence $I_{2o} = 0$). The ratio of the number of coil windings remains fixed at $N_1/N_2 = 1/2$. Then the secondary side is shorted through an ammeter (such that $U_{2c} = 0$) and the primary current I_{1c} is measured as a function of the secondary current I_{2c}, again for a fixed winding ratio $N_1/N_2 = 1/2$. Finally a load resistor $R = 2\ \Omega$ is connected across the secondary and the primary voltage U_1, primary current I_1, secondary voltage U_2 and secondary current I_2 are all measured, still with a fixed winding ratio $N_1/N_2 = 1/2$.

EVALUATION

From equation (3) it follows for the voltages that

$$U_2 = \frac{N_2}{N_1} \cdot U_1$$

and from equation (5) correspondingly for the currents that

$$I_1 = \frac{N_2}{N_1} \cdot I_2$$

Consequently, the linear gradients found in the diagrams in Figures 2 and 3 are determined by the ratio of the number of windings.

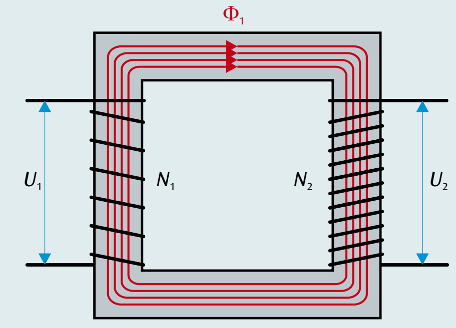

Fig. 1: Schematic depiction of the transformer

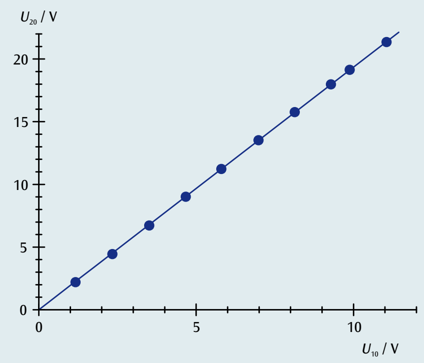

Fig. 2: Secondary voltage U_{2o} as a function of primary voltage U_{1o} with no load ($I_{2o} = 0$), $N_1 = 36$, $N_2 = 72$

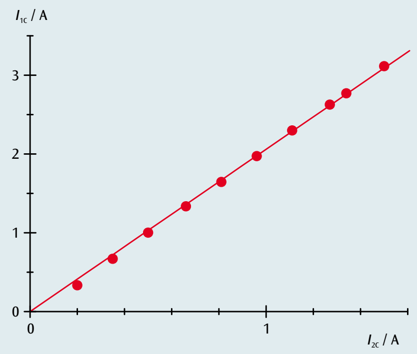

Fig. 3: Primary current I_{1c} as a function of secondary current I_{2c} with short-circuited secondary ($U_{2c} = 0$), $N_1 = 36$, $N_2 = 72$