Transformer

Related topics
Induction, magnetic flux, loaded transformer, unloaded transformer, coil.

Principle and task
A voltage is applied to one of two coils (primary coil) which are located on a common iron core. The voltage induced in the second coil (secondary coil) and the current flowing in it are investigated as functions of the number of turns in the coils and of the current flowing in the primary coil.

Equipment

Coil, 140 turns, 6 tappings	06526.01	2
Clamping device	06506.00	1
Iron core, U-shaped, laminated	06501.00	1
Iron core, short, laminated	06500.00	1
Multitap transf., 14VAC/12VDC, 5A	13533.93	1
Two-way switch, double pole	06032.00	1
Rheostat, 10 Ohm, 5.7 A	06110.02	1
Digital multimeter	07134.00	3
Connecting cord, 500 mm, red	07361.01	6
Connecting cord, 500 mm, blue	07361.04	6

Problems
The secondary voltage on the open circuited transformer is determined as a function

1. of the number of turns in the primary coil,
2. of the number of turns in the secondary coil,
3. of the primary voltage.

The short-circuit current on the secondary side is determined as a function

4. of the number of turns in the primary coil,
5. of the number of turns in the secondary coil,
6. of the primary current.

With the transformer loaded, the primary current is determined as a function

7. of the secondary current,
8. of the number of turns in the secondary coil,
9. of the number of turns in the primary coil.

Fig.1a: Experimental set-up for investigating the laws governing the transformer.

Fig. 2: Connection of the multi-range meters.

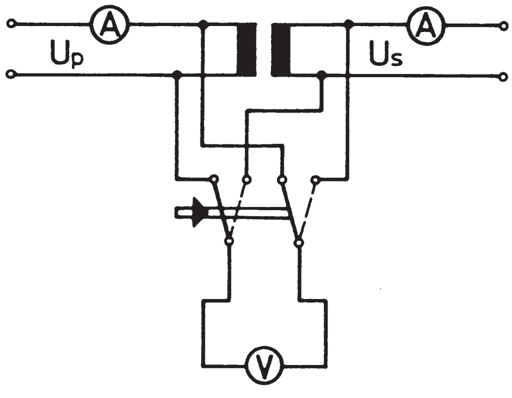
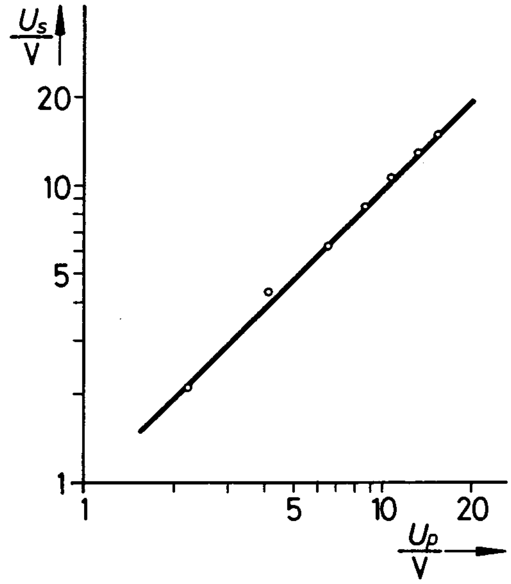


Fig. 3: Secondary voltage on the unloaded transformer, as a function of the primary voltage.



Set-up and procedure

The experimental set-up is as shown in Fig. 1. The multi-range meters should be connected as shown in Fig. 2, while the voltmeter can be used through a double-pole two-way switch for the primary and secondary circuit. The iron yoke should be opened only when the supply is switched off, as otherwise excessive currents would flow. When loading the rheostat, the maximum permissible load of 6.2 A for 8 minutes must not be exceeded. The power unit is non-grounded, so that the phase relationship of current and voltage can be displayed with a dual-channel oscilloscope, if available.

At constant supply voltage, the primary current is adjusted using the rheostat in the primary circuit, with the secondary short-circuited. When the transformer is loaded, the rheostat is used as the load resistor in the secondary circuit.

Theory and evaluation

If a current I flows in a coil because of the alternating voltage applied, then according to Maxwell's 2nd equation the induced voltage in the coil is

$$U_{ind} = -n_1 \frac{d\phi}{dt} \qquad (1)$$

where n_1 is the number of turns in the coil and ϕ is the magnetic flux density. This voltage is opposite in polarity to U_1 and there fore

$$U_1 = n_1 \cdot \frac{d\phi}{dt} \; . \qquad (1)$$

If there is a second coil (secondary coil) on the same iron core, so that the same flux density ϕ passes through the secondary coil, then the induced voltage U_2 is

$$U_2 = -\frac{n_2}{n_1} U_1 \qquad (2)$$

or, from (1)

$$U' = -\frac{n_2}{n_1} U. \qquad (2)$$

From the regression line to the measured values of Fig. 3 and the exponential statement

$$Y = A \cdot X^B$$

there follows the exponent

$$B = 1.02 \pm 0.002 \qquad \text{(see (2))}$$

From the regression line to the measured values of Fig. 4 and the exponential statement

$$Y = A \cdot X^B$$

there follows the exponents

$$B_1 = 1.002 \pm 0.001 \qquad \text{(see (2))}$$
$$B_2 = -0.993 \pm 0.002.$$

If a current I_2 flows in the secondary circuit, the resultant magnetic flux is superimposed on the flux density in the primary coil: the a.c. impendance of the primary coil decreases as a result. Therefore the current in the primary coil increases with constant supply voltage U.

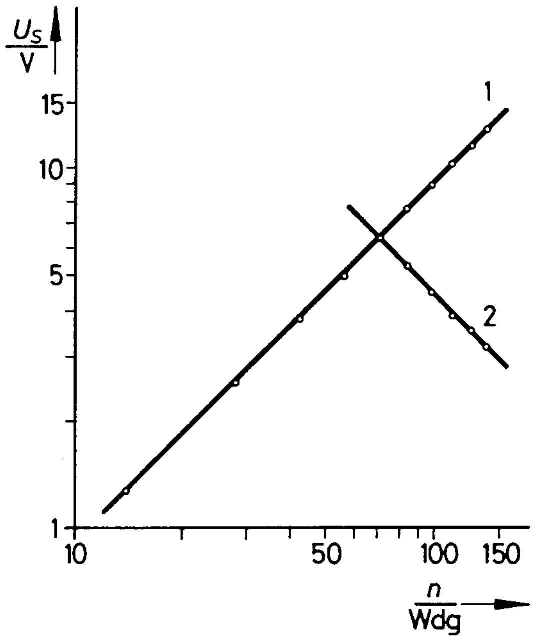
Since the flux produced by I_2 in the secondary coil is equal to the flux produced by the additional current I_1 in the primary coil, it follows that

$$I_2 = -\frac{n_1}{n_2} I_1. \qquad (3)$$

The quotient $n1/n2$ is called the transformation ratio.

If the load on the secondary side is purely resistive and if the current flowing in the primary when the transformer is unloaded is small in comparison with I_1, then I_1 is the total current flowing on the primary side.

Fig. 4: Secondary voltage of the unloaded transformer as a function
1. of the number of turns in the secondary coil,
2. of the number of turns in the primary coil.



From the regression line to the measured values of Fig. 5 and the exponential statement

$Y = A \cdot X^B$

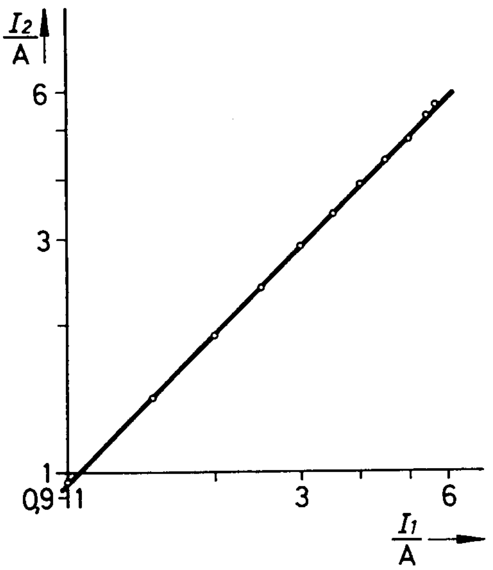
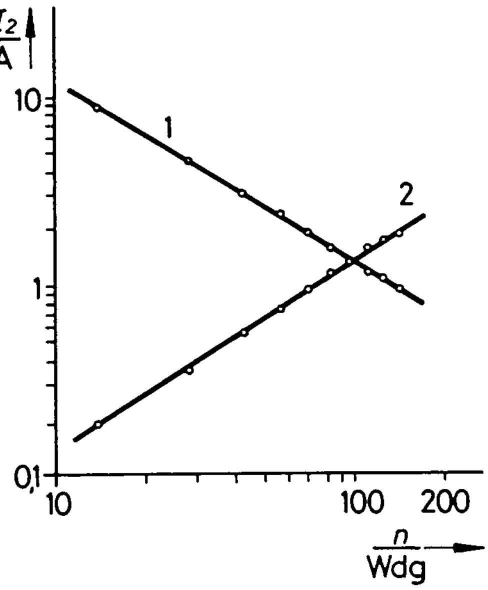


Fig. 5: Secondary short-circuit current as a function of the primary current in the transformer.

Fig. 6: Secondary short-circuit current of the transformer as a function
1. of the number of turns in the secondary coil,
2. of the number of turns in the primary coil.



there follows the exponent

$B = 1.02 \pm 0.01$ (see (3))

From the regression line to the measured values of Fig. 6 and the exponential statement

$Y = A \cdot X^B$

there follows the exponents

$B_1 = -0.989 \pm 0.003$ (see (3))
$B_2 = 1.025 \pm 0.002$.

The losses of a transformer are mainly given by the ohmic resistance of the coil, the magnetisation and hysteresis losses of the iron core, and losses through stray fields arising because the total primary magnetic flux does not pass through the secondary coil, and vice versa. The inductive reactances and ohmic resistances of the primary and secondary circuits vary because of this.

Fig. 7: Secundary current as a function of the primary current, with the transformer loaded.