

Trade of Electrician

Standards Based Apprenticeship

The Transformer

Phase 2

Module No. 2.1

Unit No. 2.1.10

COURSE NOTES

Created by Gerry Ryan - Galway TC

Revision 1 April 2000 by
Gerry Ryan - Galway TC
John Watters - Sligo TC

Revision 2 Nov. 2002 by
Gerry Ryan - Galway TC
Chris Ludlow - DundalkTC

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Chris Ludlow - DundalkTC

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Introduction

Welcome to this section of your course, which is designed to introduce you the learner, to the transformer.

Objectives

By the end of this unit you will be able to:

- Recognise and use appropriate symbols
- Understand the principle of the transformer
- State the relationship between **turns ratio**, **voltage ratio** and **current ratio**
- Explain the difference between a **step down** and a **step up** transformer
- Select a suitable power rating for a given load
- Test transformer winding resistance and insulation resistance

Reasons

The transformer is a very widely used piece of electrical equipment. The importance of understanding how it operates cannot be over emphasised.

The Transformer

A transformer is an electrical device used to change the value of an **alternating voltage**. Transformers are widely used in electrical work. They are encountered daily, in industrial, commercial and domestic situations. They vary in size from miniature units used in electronics to huge units used in power stations. The efficient transmission and distribution of electricity throughout the country would be impossible without the use of power transformers.

Transformers are also used for safety reasons on construction sites when using power tools and in domestic bathroom situations in shaver units. They are used in doorbell operation and also to power electronic equipment, battery chargers, televisions, computers, alarm systems, etc. Transformers vary considerably in construction, size and shape depending on their application.

All transformers rely on the principle of mutual inductance for their operation. Mutual inductance was discussed in detail in Unit 2.1.6 Magnetism, Electromagnetism and Electromagnetic Induction.

Transformer Symbols

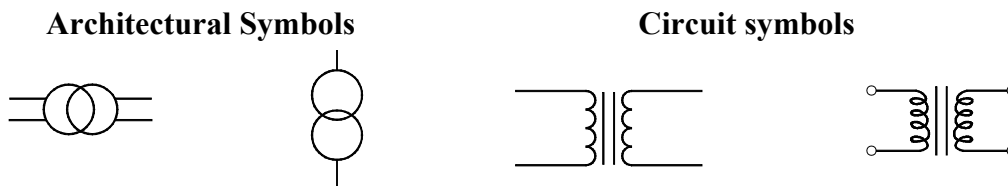


Figure 1

Transformer Construction

A transformer consists of two coils of wire called windings, which are wound onto a common iron core. The wire used in the two windings, primary and secondary, is coated with an insulating varnish. Both coils are wound onto, but insulated from the iron core.

See Figure 2.

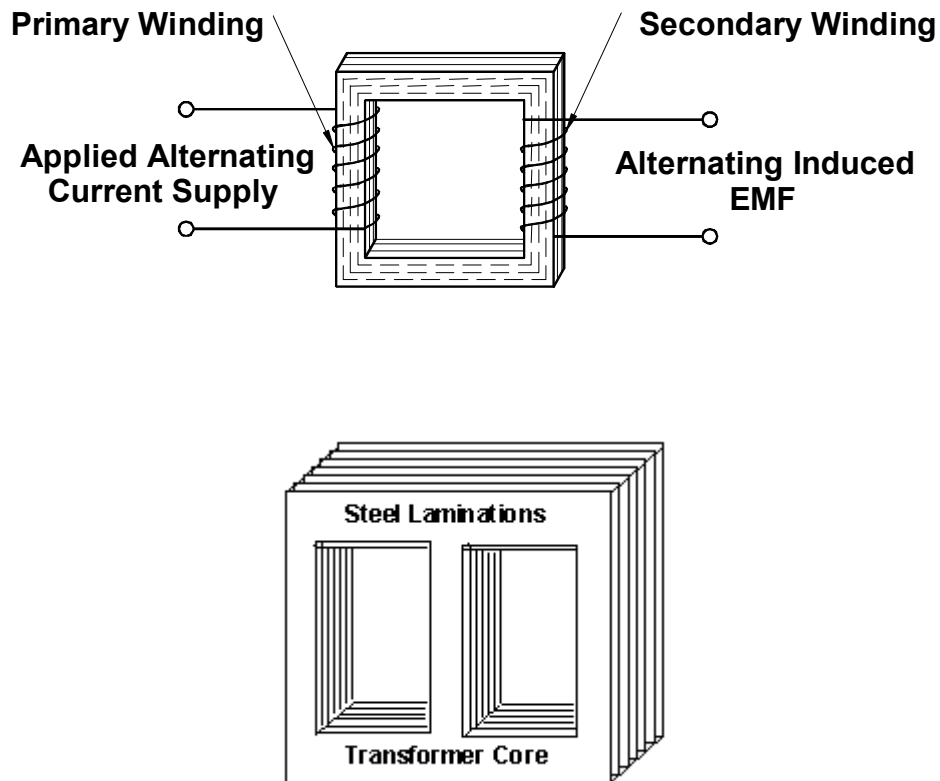


Figure 2

The Transformer Principle

When a conductor or coil is moved in a stationary magnetic field it cuts the lines of magnetic flux and an EMF is induced in the conductor or coil. This same principle also applies when a conductor is held stationary and the magnetic flux is made to change or vary.

Now consider an alternating current applied to a stationary coil. A magnetic field will build up and collapse in the coil, continually rising and falling in harmony with the applied AC current as shown in Figure 3.

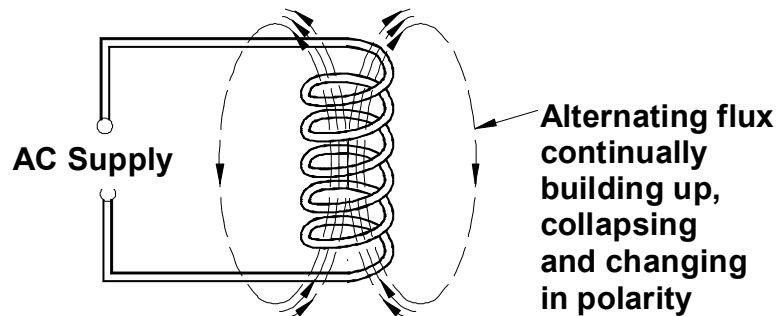


Figure 3

If a second coil (coil 2) is placed close to the first coil (coil 1) the alternating magnetic flux in coil 1 links with coil 2. See Figure 4. This results in an EMF being induced in coil 2. This is a process known as **mutual induction**.

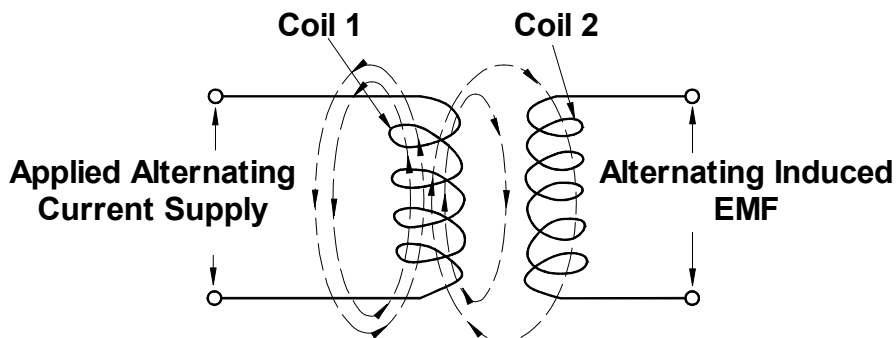


Figure 4

If coil 1 and coil 2 are mounted on an iron core the magnetic flux around both coils will be concentrated. This arrangement of coils and an iron core form the complete device known as a **transformer**. See Figure 5.

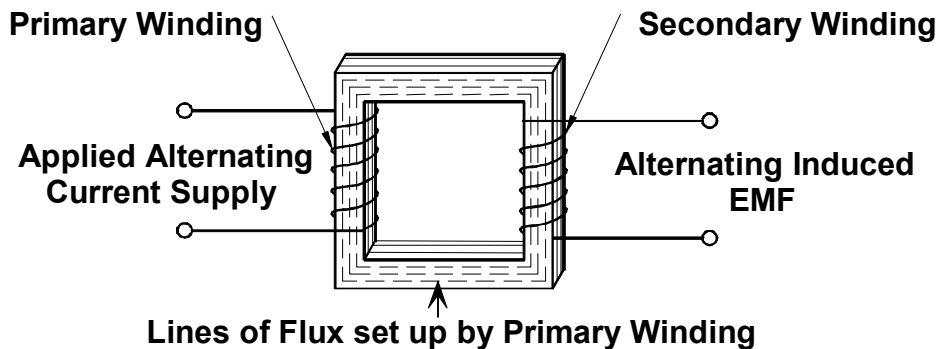


Figure 5

The input coil of a transformer is fed from the AC supply and is called the **primary winding**. The output coil, to which the load is connected, is called the **secondary winding**.

It is important to remember that there is no electrical connection between the primary winding and the secondary winding of a transformer. The only common link between the two windings is the magnetic field.

Turns and Voltage Ratio

The relationship between the number of primary winding turns (N_1) and the number of secondary winding turns (N_2) together with the primary input voltage (U_1) and the secondary output voltage (U_2) can be expressed as a ratio or equation as shown below.

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

Where:

N_1	=	Number of Primary Winding turns
N_2	=	Number of Secondary Winding turns
U_1	=	Primary Input Voltage
U_2	=	Secondary Output Voltage

This formula can be transformed to find any one unknown provided the other three are known.

$$U_1 = \frac{U_2 \times N_1}{N_2} \qquad U_2 = \frac{U_1 \times N_2}{N_1}$$

$$N_1 = \frac{U_1 \times N_2}{U_2} \qquad N_2 = \frac{U_2 \times N_1}{U_1}$$

Example:

A transformer has 100 turns on the primary winding and 20 turns on the secondary winding. If the primary voltage is 230VAC, what is the secondary voltage?

Solution

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

$$U_2 \times N_1 = U_1 \times N_2$$

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

$$U_2 = \frac{230 \times 20}{100}$$

$$U_2 = \underline{\underline{46 \text{ Volts.}}}$$

The transformer referred to in this example is a step-down transformer and is said to have a turns ratio of 100:20. This may be expressed as a ratio of 5:1. Primary turns are always stated first.

Step-Down Transformer

Because the same magnetic flux lines cut both coils of a transformer, the induced EMF in the secondary winding, is proportional to the number of turns on both the primary and secondary windings.

If the number of turns on the secondary winding is less than the number of turns on the primary winding, then the secondary output voltage will be less than the primary input voltage. This type of transformer is called a **step-down transformer** and is illustrated in Figure 6.

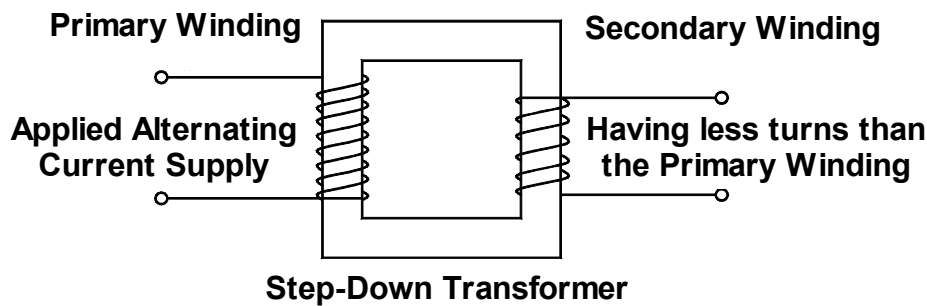


Figure 6

Example

A transformer has 2660 turns on the primary side and 140 turns on the secondary side. If the primary voltage is 230 Volts AC, find the secondary voltage?

Solution

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

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

$$U_2 = \frac{230 \times 140}{2660}$$

$$U_2 = \underline{\underline{12.10 \text{ Volts.}}}$$

This is a step down transformer and is said to have a turns ratio of 2,660:140 or 19:1.

Step-Up Transformer

If the number of turns on the secondary winding of a transformer is greater than the number of turns on the primary winding, then the secondary output voltage will be greater than the primary input voltage. This type of transformer is called a step-up transformer and is illustrated in Figure 7.

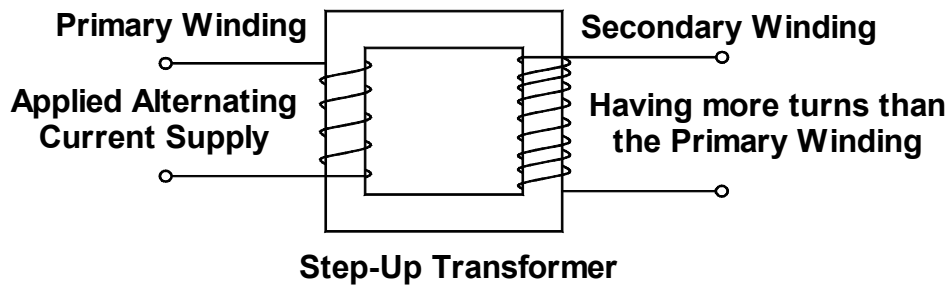


Figure 7

Example:

A transformer has 200 turns on the primary winding and 1200 turns on the secondary winding. If the primary voltage is 230VAC, what is the secondary voltage?

Solution

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

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

$$U_2 = \frac{230 \times 1200}{200}$$

$$U_2 = \underline{\underline{1380 \text{ Volts.}}}$$

This is a step-up transformer and is said to have a turns ratio of 200:1200 or 1:6.

Current Ratio

With zero losses assumed for a transformer, the power in the secondary output winding equals the power in the primary input winding. This relationship can be expressed as a ratio or equation as shown below.

$$\text{Power Input} = \text{Power Output}$$

$$U_1 \times I_1 = U_2 \times I_2$$

or

$$\frac{U_1}{U_2} = \frac{I_2}{I_1}$$

From the above equations it can be seen that the current ratio is the inverse of the voltage ratio, that is, a voltage step-up in the secondary winding results in a current step-down in the secondary winding, and vice versa.

Example:

A transformer has a primary voltage of 230 Volts and a secondary voltage of 115 Volts. A current of 6.5 Amps is flowing in the primary winding. Find the load on the secondary winding.

$$\frac{U_1}{U_2} = \frac{I_2}{I_1}$$

$$I_2 = \frac{U_1 \times I_1}{U_2}$$

$$I_2 = \frac{230 \times 6.5}{115}$$

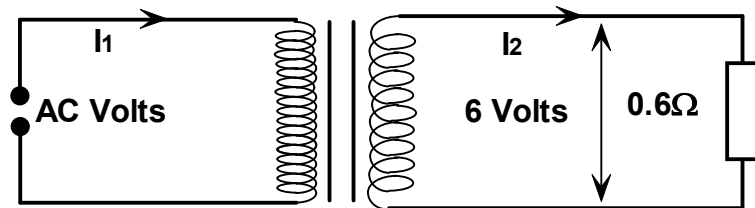
$$I_2 = \underline{\underline{\mathbf{13\ Amps}}}$$

The secondary winding does not generate its own power but rather takes it from the primary winding. Therefore, the current step-up or step-down is in terms of the secondary current. The primary current is determined by the load resistance across the secondary winding. These points are illustrated by the following example.

Example:

A transformer with a 20:1 voltage ratio (step-down), provides a secondary voltage of 6 Volts AC across a 0.6 Ohm load resistor. Calculate the following values:

1. Secondary Current (I_2)
2. Primary Current (I_1)

Solution**Figure 8**

$$\begin{aligned}
 (1) \quad I_2 &= \frac{N_1}{N_2} \\
 I_2 &= \frac{6}{0.6} \\
 I_2 &= \mathbf{10 \text{ Amps}} \\
 \\
 (2) \quad U_1 &= \frac{U_2 \times N_1}{N_2} \\
 U_1 &= \frac{6 \times 20}{1} \\
 U_1 &= 120 \text{ Volts} \\
 \\
 I_1 &= \frac{U_2 \times I_2}{U_1} \\
 I_1 &= \frac{6 \times 10}{120} \\
 I_1 &= \mathbf{0.5 \text{ Amp}}
 \end{aligned}$$

Power Transfer in Transformers

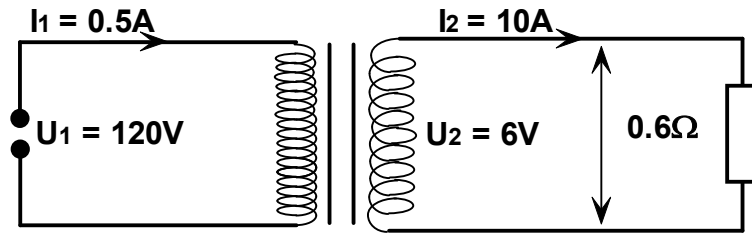


Figure 9

In Figure 9 we can now look at the circuit from the previous example, redrawn with the calculated voltage and current values included. The power in the primary winding of a transformer transfers to the secondary. This is illustrated in the example below.

$$\begin{aligned}
 \text{Power in Primary} &= \text{Power in Secondary} \\
 U_1 \times I_1 &= U_2 \times I_2 \\
 120 \times 0.5 &= 6 \times 10 \\
 60 \text{ VA} &= 60 \text{ VA}
 \end{aligned}$$

Remember that the winding with the higher voltage has the lower current and the winding with the lower voltage has the higher current. In the above example the voltage ratio is 20:1 while the current ratio is 1:20. The secondary winding would need to be wound with wire of a larger cross sectional area than that of the primary winding in order to carry the larger current.

Reflecting on Formulae

$$\begin{aligned}
 \frac{U_1}{U_2} &= \frac{N_1}{N_2} \\
 \text{and} \\
 \frac{U_1}{U_2} &= \frac{I_2}{I_1}
 \end{aligned}$$

Therefore

$$\frac{U_1}{U_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1}$$

And so

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

Power Rating of Transformers

The power rating of a transformer may be calculated by multiplying the secondary AC voltage by the full load secondary AC current.

$$\text{Rating} = \text{Secondary Voltage} \times \text{Secondary Current}$$

$$\text{Rating} = V \times A \quad (U_2 \times I_2)$$

$$\text{Rating} = VA$$

A rating quoted in VA will apply to small transformers. The rating of larger transformers will be quoted in kVA or MVA

$$\text{That is} \quad \frac{VA}{1000} = \text{kVA}$$

$$\text{or} \quad \frac{VA}{1000,000} = \text{MVA}$$

$$\text{or} \quad \frac{\text{kVA}}{1000} = \text{MVA}$$

Transformer Losses

Iron Losses in a Transformer

Eddy currents are induced into the transformer core. These unwanted eddy currents, cause heating of the core. They represent a loss in the transformer and are referred to as **iron losses**. The iron core is made up of steel laminations, to reduce eddy currents to a minimum. Silicon steel is generally used as its magnetism is easily reversed.

Copper Losses in a Transformer

Copper losses are due to, **current** flowing through the **resistance** of the windings, and are often referred to as the I^2R losses ($P = I^2 \times R$). The greater the current flow through the windings, the greater the copper losses.

Transformer Efficiency

A transformer has no moving parts and is a highly efficient device. Normal transformer efficiency is around 98%. In general, the larger the transformer the higher its efficiency. Efficiency is defined as the ratio of power output to power input.

Warning

Great care must be exercised when connecting the primary and secondary windings of transformers.

The rated voltage of the windings must never be exceeded otherwise damage will result to equipment, property and may also present a danger to the Health and Safety of person(s).

Resistance Test on a Transformer

Connect an ohmmeter across the two ends of the primary winding of the transformer and record the resistance. See Figure 10.

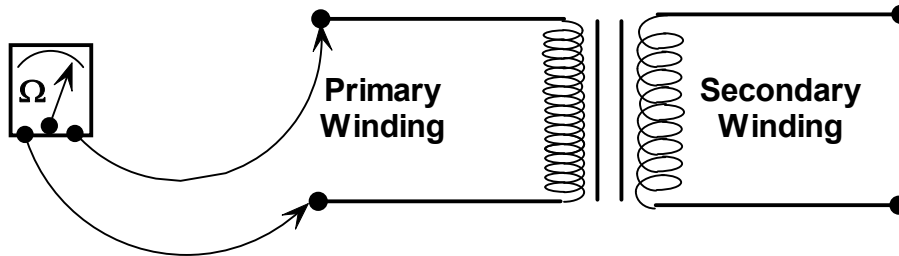


Figure 10

Connect an ohmmeter across the two ends of the secondary winding of the transformer and record the resistance. See Figure 11.

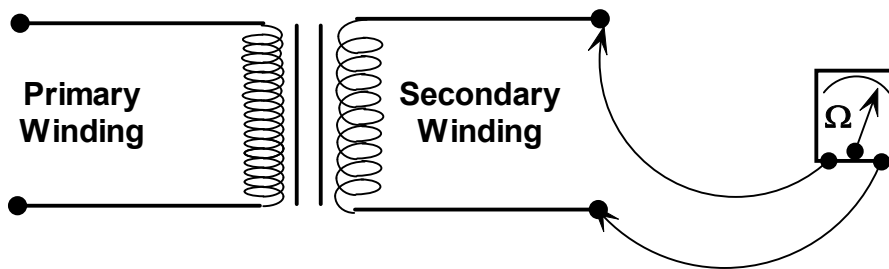


Figure 11

Conclusion:

If an infinite resistance is obtained in either of the two tests this will indicate an open circuit in that winding and hence non-function of the transformer.

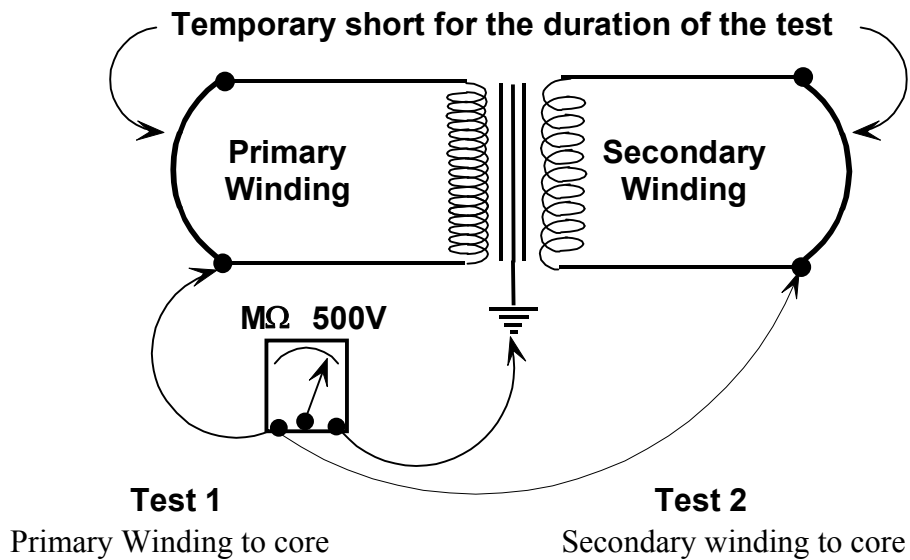
The resistance values of both windings may differ quite substantially due to the difference in the number of turns on each winding and also the difference in the cross sectional area of the wire in the primary and secondary windings.

To determine if the resistance values measured are correct, the manufacturer's specifications will have to be obtained and both resistance readings compared.

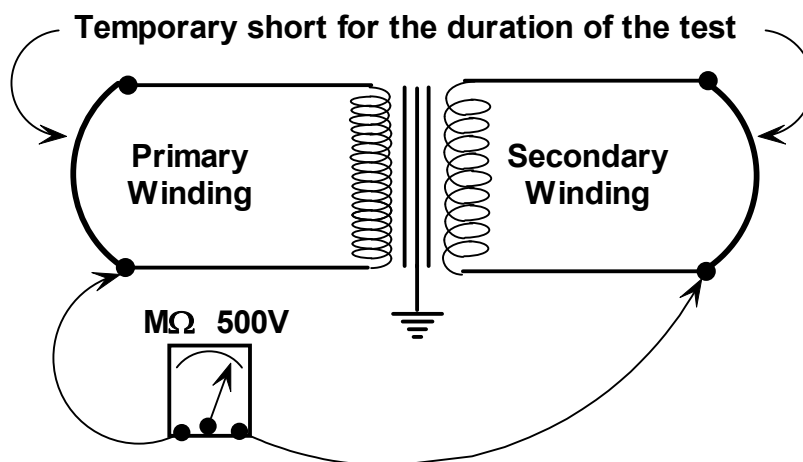
Insulation Resistance Test on a Transformer

Class 1 Transformer

Insulation resistance tests between each winding and earth



Insulation resistance test between windings



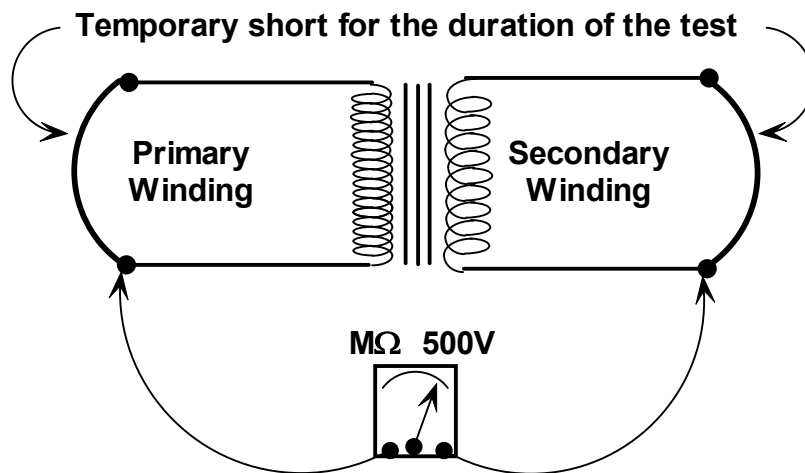
The minimum insulation resistance value accepted in each of the above tests is $2M\Omega$.

A 500V Insulation Resistance Test is suitable for 110 – 400 Volt transformers.

Class 2 Transformer

Double Insulated Symbol 

Insulation Resistance Test Between Windings



The minimum insulation resistance value accepted in the test is 2 MΩ.