Electromechanical Energy conversion (1) EE330

Introduction
Single Phase Transformer

Lec (2)

Assoc. Prof. Ahmed Y. Hatata
Ahmed_Hatata@su.edu.sa
College of Engineering
Shaqra University

Week (1)

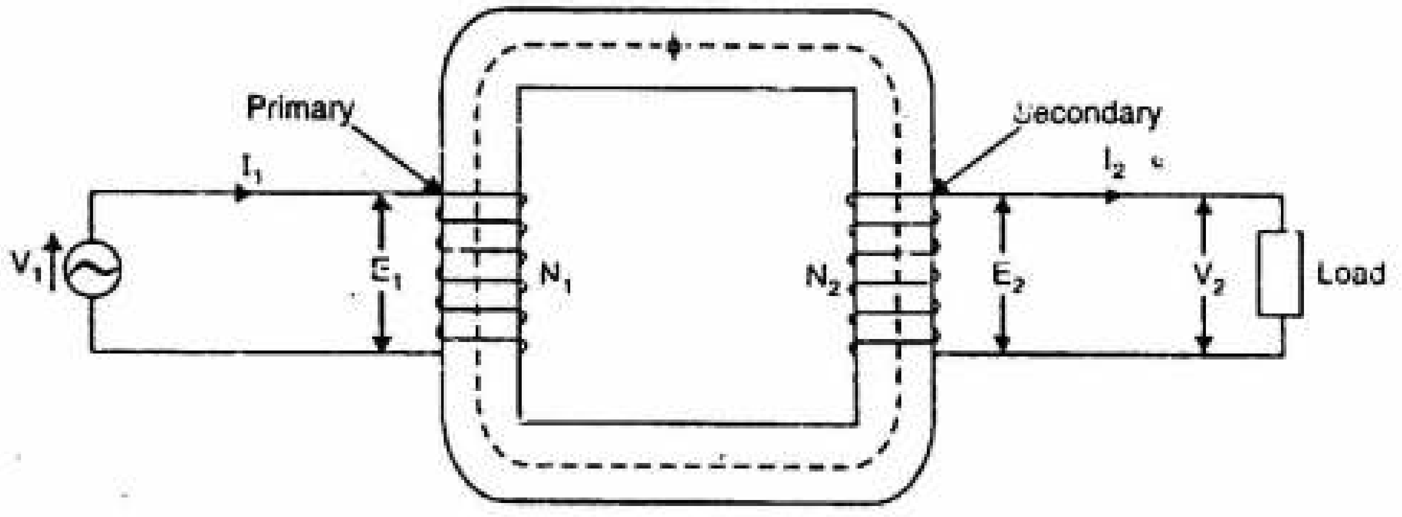
2. Objectives

1. Understand the purpose of a transformer in a power system.
2. Know the voltage, current, and impedance relationships across the windings of an ideal transformer.
3. Understand how real transformers approximate the operation of an ideal transformer.

Definitions

A transformer is a static (or stationary) piece of apparatus by means of which electric power in one circuit is transformed into electric power of the same frequency in another circuit.

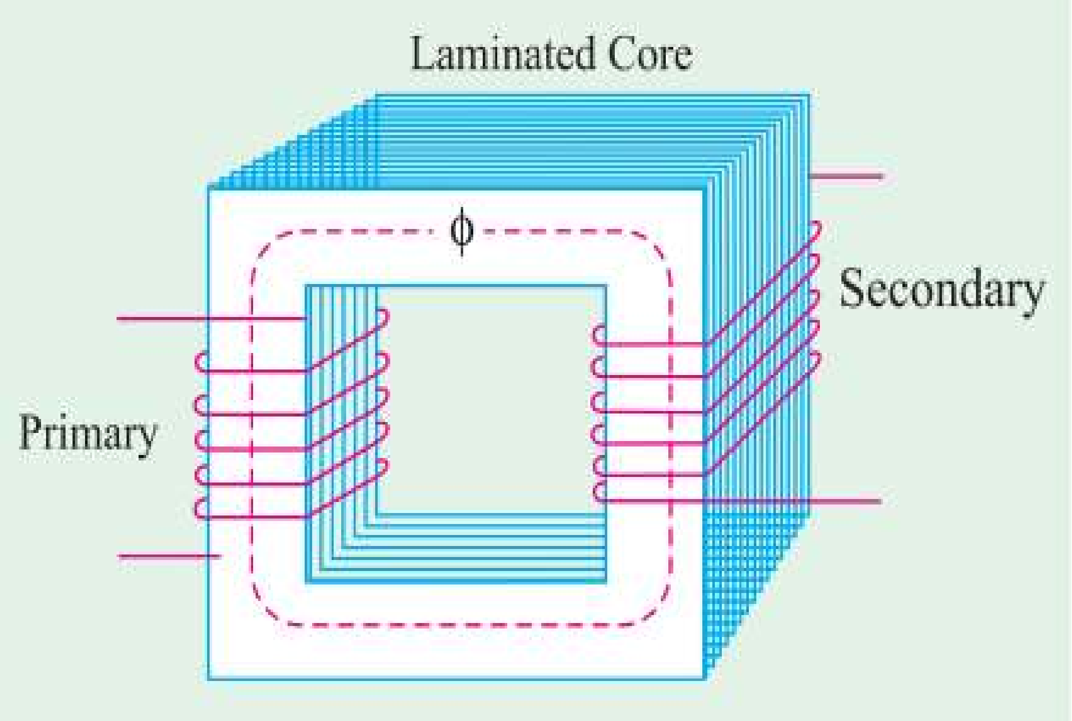
It can raise or lower the voltage in a circuit but with a corresponding decrease or increase in current.



Working Principle of a Transformer

The physical basis of a transformer is mutual induction between two circuits linked by a common magnetic flux.

In its simplest form, it consists of two inductive coils which are electrically separated but magnetically linked through a path of low reluctance as shown in Fig.



The winding connected to the AC source is called primary winding (or primary)

The one connected to load is called secondary winding (or secondary)

If one coil is connected to a source of alternating voltage, an alternating flux is set up in the laminated core, most of which is linked with the other coil in which it produces mutually-induced e.m.f. (according to Faraday's Laws of Electromagnetic Induction $e = MdI/dt$). If the second coil circuit is closed, a current flows in it and so electric energy is transferred (entirely magnetically) from the first coil to the second coil.

Function of the Transformer

In brief, a transformer is a device that

1. **Transfers electric power from one circuit to another**

2. **It does so without a change of frequency**

3. **It accomplishes this by electromagnetic induction and**

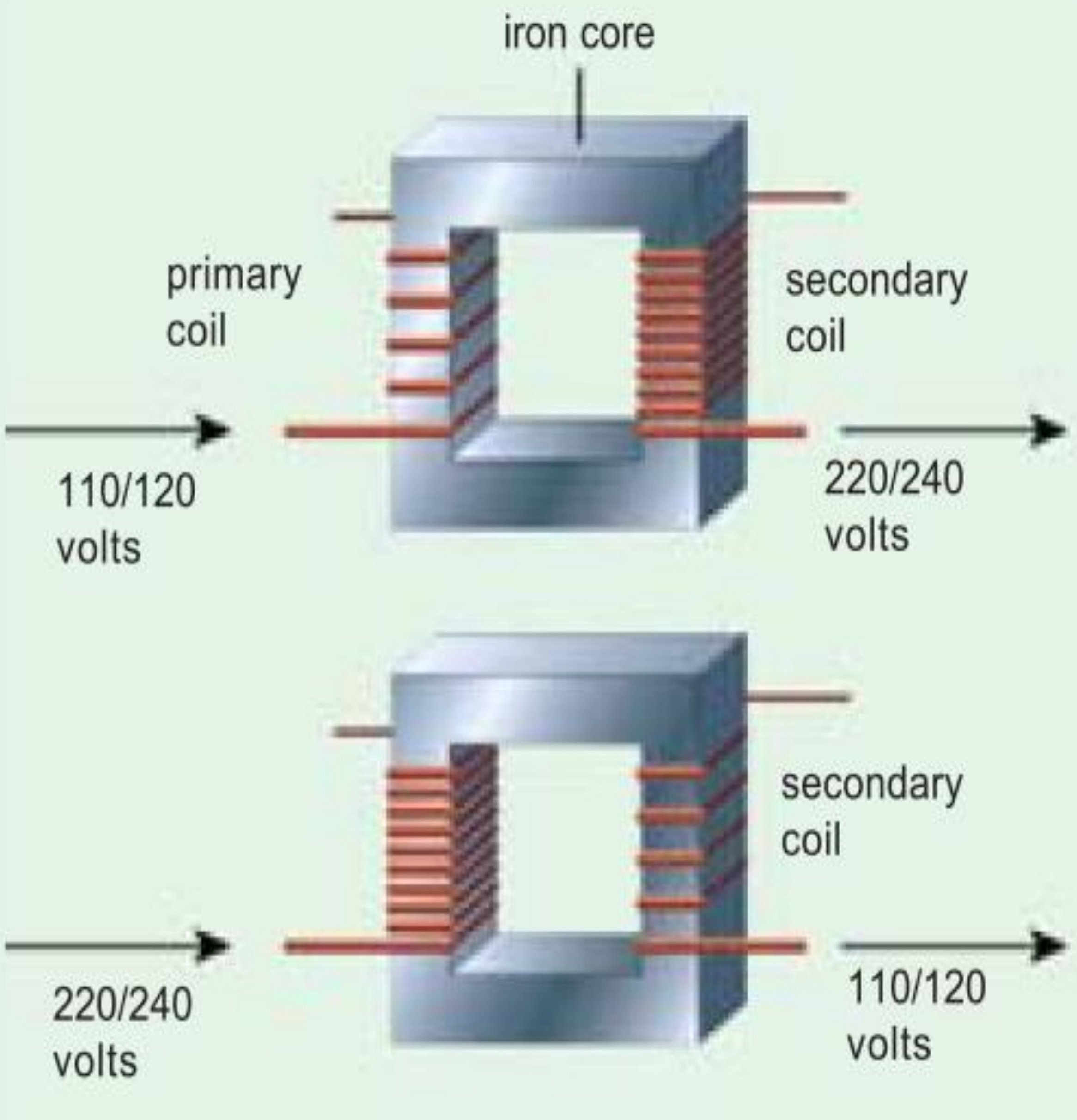
4. **Where the two electric circuits are in mutual inductive influence of each other.**

Transformer Construction

- The simple elements of a transformer consist of two coils having mutual inductance and a laminated steel core.

- The two coils are insulated from each other and the steel core.

- Other necessary parts are :
  - ❑ Some suitable container for assembled core and windings;
  - ❑ A suitable medium for insulating the core and its windings from its container;
  - ❑ A suitable bushings (either of porcelain, oil-filled or capacitor-type) for insulating and bringing out the terminals of windings from the tank.

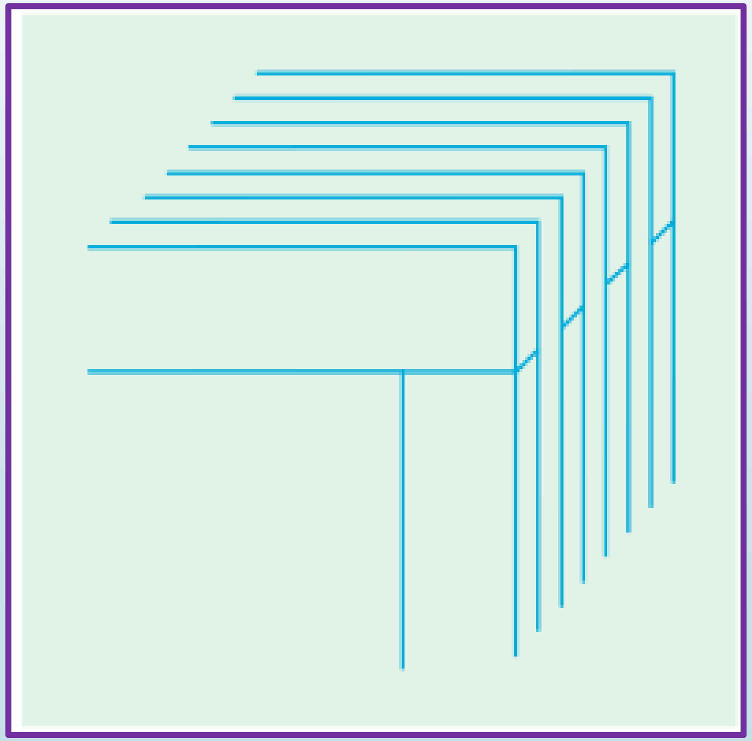


Principle of transformer

The core is constructed of sheet steel laminations assembled to provide a continuous magnetic path with a minimum of air-gap included.

The eddy current loss is minimized by laminating the core, the laminations being insulated from each other by a light coat of core-plate varnish or by an oxide layer on the surface.

The thickness of laminations varies from 0.35 mm for a frequency of 50 Hz to 0.5 mm for a frequency of 25 Hz.

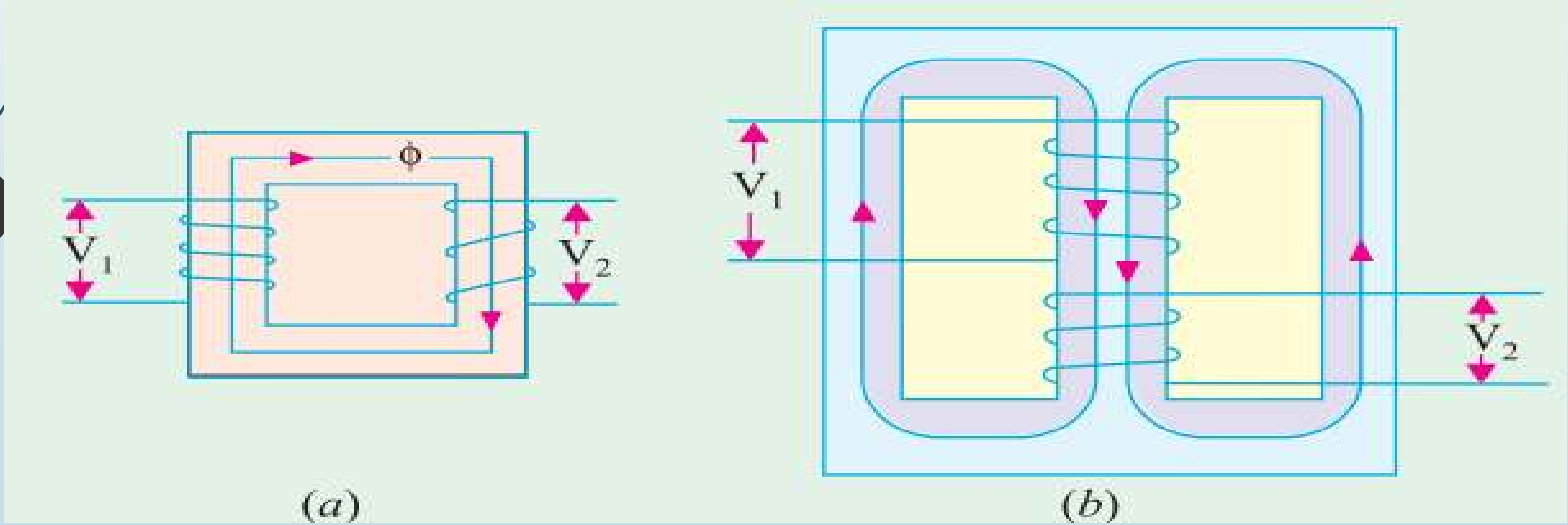


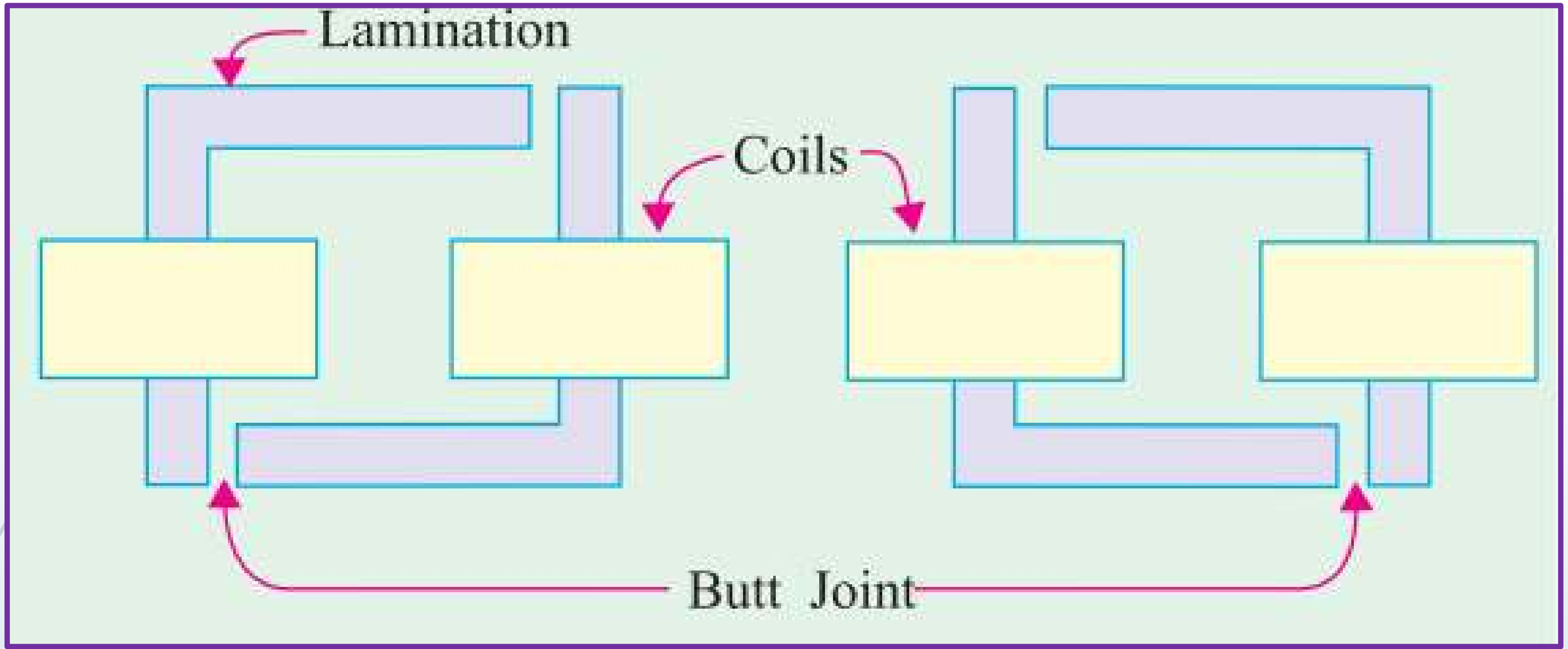
The steel used is of high silicon content, sometimes heat treated to produce a high permeability and a low hysteresis loss at the usual operating flux densities.

The transformers are of two general types,

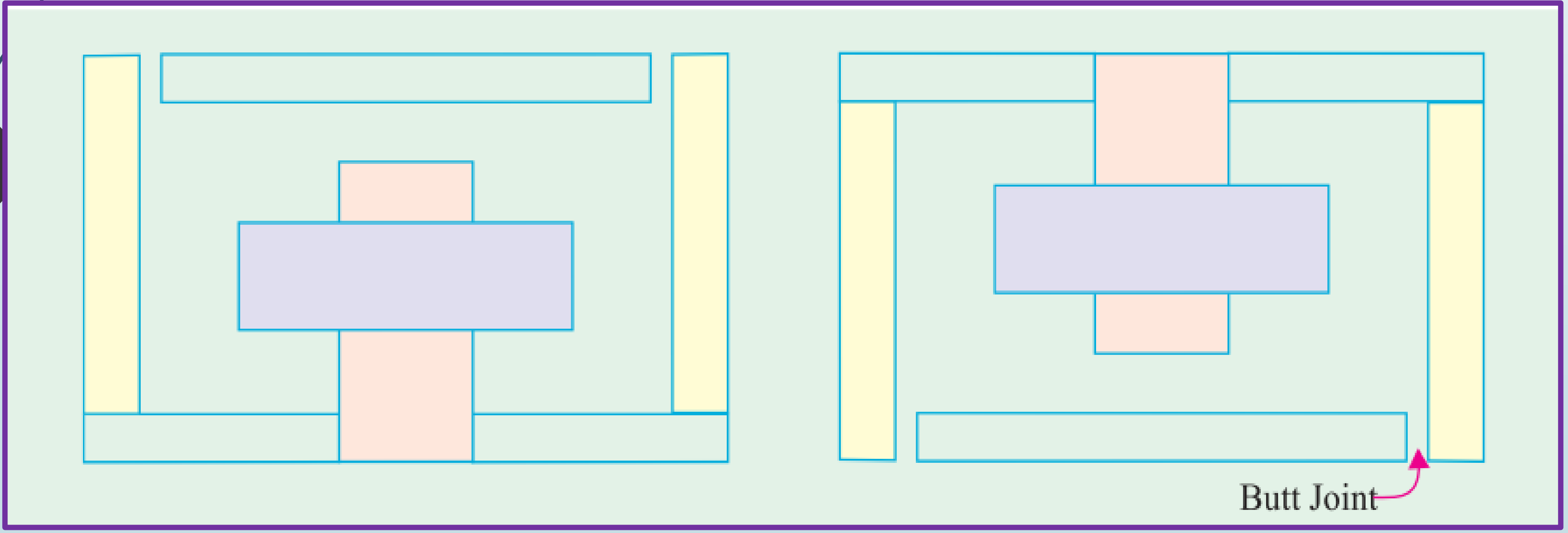
(i) core-type and (ii) shell-type.

In the so-called core type transformers, the windings surround a considerable part of the core whereas in shell-type transformers, the core surrounds a considerable portion of the windings as shown schematically





(i) core-type



(ii) shell-type

Theory of an Ideal Transformer

An ideal transformer is one **which has no losses** i.e. its windings have **no ohmic resistance**, there is **no magnetic leakage** and hence which has **no I^2R and core losses**.

In other words, an ideal transformer consists of **two purely inductive coils** wound on a loss-free core.

Consider an ideal transformer whose secondary is open and whose primary is connected to sinusoidal alternating voltage V1

Since the primary coil is purely inductive and there is no output (secondary being open) the primary draws the magnetizing current Iμ only.

The function of this current is merely to magnetize the core, **it is small in magnitude and lags V_1 by 90°.**

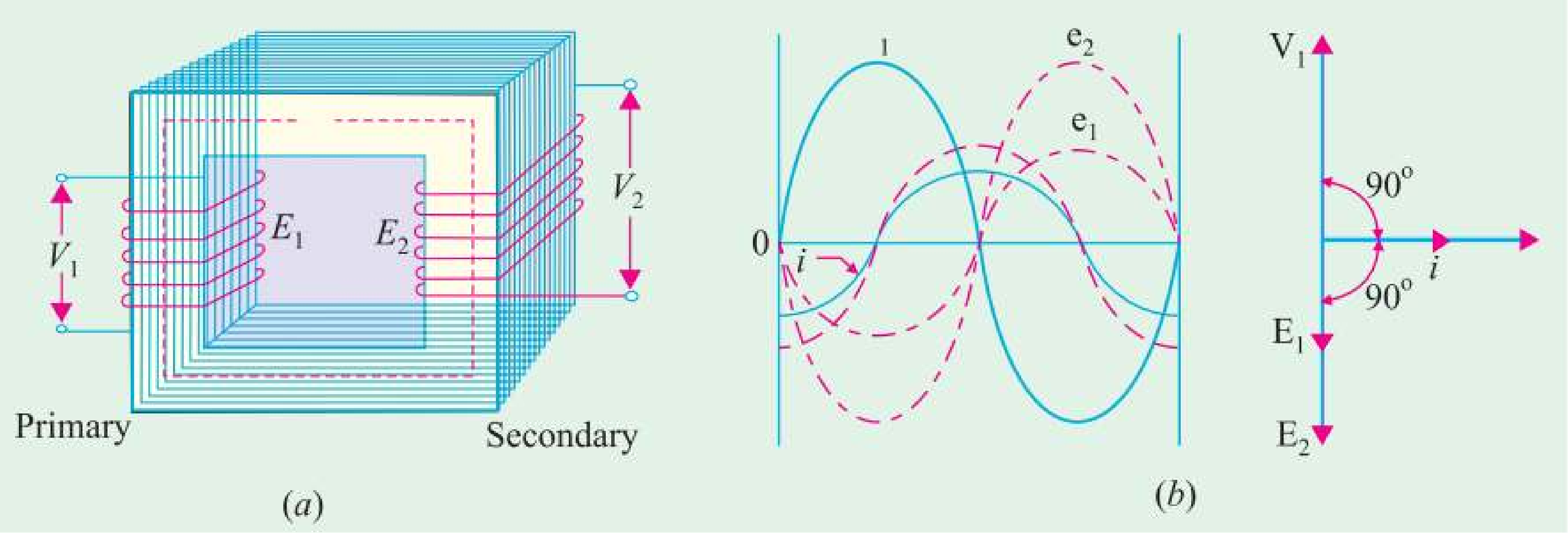
The alternating current Iμ produces an alternating flux φ which is, at all times, **proportional to the current**

This changing flux is linked both with the primary and the secondary windings. Therefore, it produces self-induced e.m.f. in the primary.

This self-induced e.m.f. (E_1) is, at every instant, equal to and in opposition to V_1. It is also known as counter e.m.f. or back e.m.f. of the primary.

Similarly, there is produced in the secondary an induced e.m.f. E_2

In an ideal transformer on no-load, $V_1 = E_1$ and $V_2 = E_2$ where V_2 is the terminal voltage.



E.M.F. Equation of a Transformer

N1 = No. of turns in primary
N2 = No. of turns in secondary
Φm = Maximum flux in core in webers
= Bm × A
f = Frequency of a.c. input in Hz

$$\varphi = \varphi_m \sin(\omega t)$$

$$E_1 = N_1 \frac{d\varphi}{dt}$$

$$E_2 = N_2 \frac{d\varphi}{dt}$$

$$E_1 = \varphi_m N_1 \omega \cos(\omega t)$$

$$E_1 = \varphi_m N_1 \omega \sin(\omega t - 90)$$

$$E_m = \varphi_m N_1 \omega$$

$$E_m = \varphi_m N_1 2\pi f$$

$$E_{rms} = \frac{\varphi_m N_1 2\pi f}{\sqrt{2}}$$

$$E_{rms} = 4.44 \varphi_m N_1 f$$

Voltage Transformation Ratio (K)

$$\frac{E_2}{E_1} = \frac{N_2}{N_1} = K$$

This constant K is known as voltage transformation ratio.

(i) If $N_2 > N_1$
i.e. K > 1, then transformer is called step-up transformer.

(ii) If $N_1 > N_2$ i.e. K < 1, then transformer is known as step-down transformer.

$$V_1 I_1 = V_2 I_2 \text{ or } \frac{I_2}{I_1} = \frac{V_1}{V_2} = \frac{1}{K}$$

Example 1. The maximum flux density in the core of a 250/3000-volts, 50-Hz single-phase transformer is 1.2 Wb/m^2. If the e.m.f. per turn is 8 volt, determine

(i) Primary and secondary turns (ii) Area of the core.

Solution. *(i)* $E_1 = N_1 \times \text{e.m.f. induced/turn}$

$N_1 = 250/8 = \mathbf{32};\ N_2 = 3000/8 = \mathbf{375}$

(ii) We may use $E_2 = -4.44\, f\, N_2\, B_m\, A$

$\therefore\ 3000 = 4.44 \times 50 \times 375 \times 1.2 \times A;\ \mathbf{A = 0.03 m^2}.$

Example 2. The core of a 100-kVA, 11000/550 V, 50-Hz, 1-ph, core type transformer has a cross-section of 20 cm×20 cm. Find (i) the number of H.V. and L.V. turns per phase and (ii) The e.m.f. per turn if the maximum core density is not to exceed 1.3 Tesla. Assume a stacking factor of 0.9. What will happen if its primary voltage is increased by 10% on no-load?

Solution. (*i*) $B_m = 1.3\ T, A = (0.2 \times 0.2) \times 0.9 = 0.036\ m^2$

$\therefore \quad 11{,}000 = 4.44 \times 50 \times N_1 \times 1.3 \times 0.036, N_1 = 1060$

$550 = 4.44 \times 50 \times N_2 \times 1.3 \times 0.036; N_2 = 53$

or, $N_2 = KN_1 = (550/11{,}000) \times 1060 = 53$

(*ii*) $\text{e.m.f./turn} = 11{,}000/1060 = 10.4\ V \text{ or } 550/53 = 10.4\ V$

Keeping supply frequency constant, if primary voltage is increased by 10%, magnetizing current will increase by much more than 10%. However, due to saturation, flux density will increase only marginally and so will the eddy current and hysteresis losses.

Example 3. A single-phase transformer has 400 primary and 1000 secondary turns. The net cross-sectional area of the core is 60 cm2. If the primary winding be connected to a 50-Hz supply at 520 V, calculate (i) The peak value of flux density in the core (ii) the voltage induced in the secondary winding.

Solution. $K = N_2/N_1 = 1000/400 = 2.5$

(i) $E_2/E_1 = K \quad \therefore \quad E_2 = KE_1 = 2.5 \times 520 =$ **1300 V**

(ii) $E_1 = 4.44 f N_1 B_m A$

or $520 = 4.44 \times 50 \times 400 \times B_m \times (60 \times 10^{-4}) \therefore B_m =$ **0.976 Wb/m²**

Example. 4. A 25-kVA transformer has 500 turns on the primary and 50 turns on the secondary winding. The primary is connected to 3000-V, 50-Hz supply. Find the full-load primary and secondary currents, the secondary e.m.f. and the maximum flux in the core. Neglect leakage drops and no-load primary current.

Solution. $K = N_2/N_1 = 50/500 = 1/10$

Now, full-load $I_1 = 25,000/3000 =$ **8.33 A.** F.L. $I_2 = I_1/K = 10 \times 8.33 =$ **83.3 A**

e.m.f. per turn on primary side $= 3000/500 = 6$ V

$\therefore$ secondary e.m.f. $= 6 \times 50 =$ **300 V** (or $E_2 = KE_1 = 3000 \times 1/10 = 300\ V$)

Also, $E_1 = 4.44 f N_1 \Phi_m$; $3000 = 4.44 \times 50 \times 500 \times \Phi_m$ $\therefore$ Φ_m **= 27 mWb**