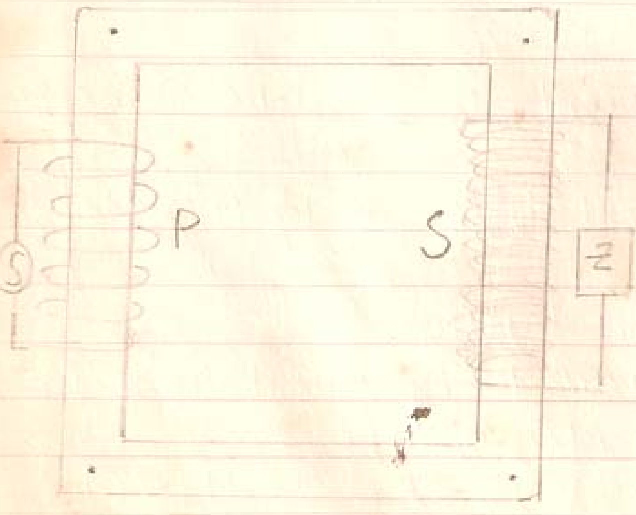
Transformer :

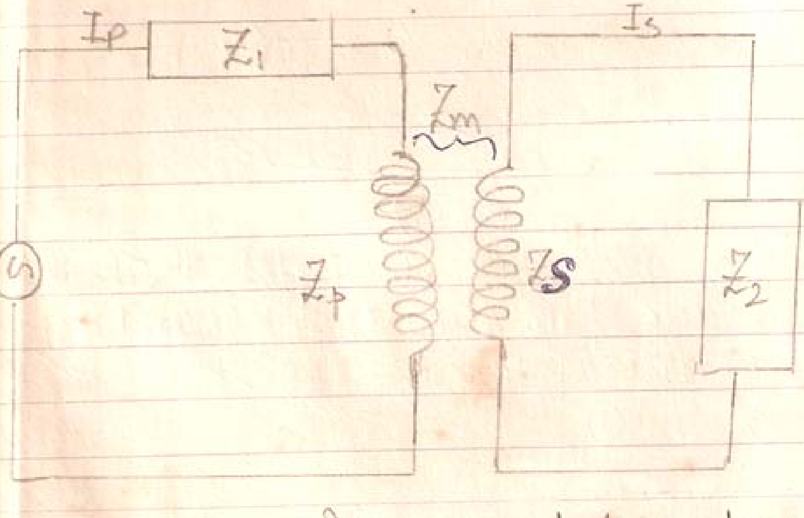
It is a device of converting high alternating current at low voltage to low alternating cu at high voltage (step-up transformer) or vice-versa. i.e low alternating current at hi voltage to high alternating current at low volt (step down transformer). A transformer wo on the principle of mutual induction.

Construction: The transformer has a clo iron path known as core. The two coil primary and secondary are wound over iron core to ensure high degree of con between them when the transformer is to be used in the audio-frequency rang from some 50 to 20,000 cs/sec. The co are insulated from each other and from core and are sod that there is as sm leakage of magn flux as possible i most of the flux produced by one links with the ot There is lesser le of magnetic flux in the case of type core. The of the core must



igh permeability, low hysteresis loss and large specific resistance. The core is laminated, i.e it is made of thin sheets or lamination of soft Iron insulated from each other to avoid eddy current loss. The transformer is immersed in oil to provide cooling and to ensure insulation. No core is however employed if the transformer is to be used in radio-frequency range from some 50 Kcs/sec to 30 Mcs/sec, as at these frequencies the use of usual laminated iron core would entail large eddy current loss. The transformer without a core is known as air-cored transformer. Thus audio frequency transformers are iron cored while radio frequency transformers are air cored.

Theory:



In the fig. an Iron cored transformer shown. Z_1 is the complex vector impedance in the primary circuit. Z_2 is the load impedance in the secondary circuit.

Z_p and Z_s are the complex vector impedance of the primary and the secondary coil respectively.
The two coils have mutual induction between them.
Z_m represents the impedance due to the mutual inductance.
For an iron cored transformer Z_m is of the form $R + j\omega M$, for an air cored transformer it is simply $j\omega M$.
Let $\vec{I_p}$ and $\vec{I_s}$ (the vectors represent the phase) be the current flowing through the primary & the secondary circuits respectively.

Applying Kirchhoff's law:
for primary circuit:

$$\vec{I_p} Z_1 + \vec{I_p} Z_p + \vec{I_s} Z_m = \vec{E} \quad \text{—— (1)}$$

For the secondary circuit:

$$\vec{I_s} Z_2 + \vec{I_s} Z_s + \vec{I_p} Z_m = 0 \quad \text{—— (2)}$$

from (2):

$$\vec{I_s} = -\frac{I_p Z_m}{(Z_2 + Z_s)} \quad \text{—— (3)}$$

The (-)ve sign in eqn (3) indicates that the current in the primary and secondary coil are just 180° out of phase.
putting eqn (3) in (1):-

$$\vec{I_p}(Z_1 + Z_p) - \frac{\vec{I_p} Z_m}{(Z_2 + Z_s)} \cdot Z_m = \vec{E}$$

$$\vec{I_p} = \frac{\vec{E}(Z_2 + Z_s)}{(Z_2 + Z_s)(Z_1 + Z_p) - Z_m^2} \quad \text{—— (4)}$$

putting eq^n ④ in ③:

$$\vec{I_s} = -\frac{\vec{E_p}\,(Z_2+Z_s)\cdot Z_m}{(Z_2+Z_s)\left[(Z_1+Z_p)(Z_2+Z_s)-Z_m^2\right]} \quad \text{—— ⑤}$$

Equation ④ and ⑤ give the current flowing through the primary and the secondary circuits respectively.

From eq^n ④ we find that the impedance of the primary circuit looking from the source is

$$\frac{\vec{E}}{\vec{I_p}} = \frac{(Z_1+Z_p)(Z_2+Z_s)-Z_m^2}{(Z_2+Z_s)}$$

or

$$\frac{\vec{E}}{\vec{I_p}} = (Z_1+Z_p) - \frac{Z_m^2}{Z_2+Z_s} \quad \text{—— ⑥}$$

Had there been no secondary coil; there would have been no mutual induction and $Z_m = 0$

& from ⑥:

$$\frac{\vec{E}}{\vec{I_p}} = (Z_1+Z_p)$$

Thus we can conclude that the effect of the presence of the secondary coil is to add or introduce an extra term in the impedance of the primary circuit & therefore is known as <u>coupled impedance</u> or reflected impedance.

Let us consider the most simple case:

$Z_1 = R_1$; $Z_p = j\omega L_p$; $Z_2 = R_2$; $Z_s = j\omega L_s$; $Z_m = j\omega M$

from eq^n ⑥ the effective impedance of the primary circuit:

$$Z_{primary} = [R_1 + j\omega L_p] - \frac{(j\omega M)^2}{R_2 + j\omega L_s}$$

$$Z_{primary} = (R_1 + j\omega L_p) + \frac{\omega^2 M^2 (R_2 - j\omega L_s)}{(R_2 + j\omega L_s)(R_2 - j\omega L_s)}$$

$$Z_{primary} = (R_1 + j\omega L_p) + \frac{\omega^2 M^2 R_2 - j\omega^3 M^2 L_s}{R_2^2 - j^2 \omega^2 L_s^2}$$

$$Z_{primary} = \left[R_1 + \frac{\omega^2 M^2 R_2}{R_2^2 + \omega^2 L_s^2}\right] + j\omega\left[L_p - \frac{\omega^2 M}{R_2^2 +}\right. \quad \text{— (7)}$$

From eq^n (7): we find that the total impedance is the sum of resistive and reactive (inductive) part.

$$R_{eff} = R_1 + \frac{\omega^2 M^2 R_2}{R_2^2 + \omega^2 L_s^2} \quad \text{— (8)}$$

$$L_{eff} = L_p - \frac{\omega^2 M^2 L_s}{R_2^2 + \omega^2 L_s^2} \quad \text{— (9)}$$

From eq^n (8) and (9) we find that the presence of the secondary coil increases the resistance of the primary circuit, but it decreases the inductance (reactance) of the primary circuit.

Let us assume that the coupling between the primary and secondary coil is perfect.

i.e coupling coefficient is $e = 1$

But

$$e = \frac{M}{\sqrt{L_p L_s}} = 1 \quad \text{or} \quad \boxed{M = \sqrt{L_p L_s}}$$

from ⑧: $$R_{eff} = R_1 + \frac{\omega^2 L_p L_s R_2}{R_2^2 + \omega^2 L_s^2}$$

Generally R_2 is very small compared to ωL_s hence R_2^2 can be neglected compared to $\omega^2 L_s^2$.

$$R_{eff} = R_1 + \frac{\omega^2 L_p L_s R_2}{\omega^2 L_s^2}$$

or $$R_{eff} = R_1 + R_2 \cdot \frac{L_p}{L_s} \quad \text{—— (10)}$$

from eqⁿ ⑨:

$$L_{eff} = L_p - \frac{\omega^2 L_p L_s L_s}{R_2^2 + \omega^2 L_s^2}$$

neglecting R_2^2;

$$L_{eff} = L_p - \frac{\omega^2 L_p L_s^2}{\omega^2 L_s^2} = L_p - L_p = 0$$

Thus under the ideal condition; the effective inductance (reactance) of the primary circuit is zero.

from eqⁿ ③; $$\frac{\vec{I_s}}{\vec{I_p}} = -\frac{Z_m}{Z_2 + Z_s}$$

" Omitting the −ve sign which indicates only the phase difference between I_s & I_p.

$$\frac{I_s}{I_p} = \frac{j\omega M}{R_2 + j\omega L_s} = \frac{j\omega\sqrt{L_p L_s}}{j\omega L_s} = \sqrt{\frac{L_p}{L_s}}$$

but $$L_p = \frac{\mu_0 \pi N_p^2 a^2}{l}, \quad L_s = \frac{\mu_0 \pi N_s^2 a^2}{l}$$

where 'l' and 'a' are length and radius of the coils. (same)

But N_p & N_s are the no. of turns in the primary & the secondary coil respectively.

$$\therefore \frac{L_p}{L_s} = \frac{N_p^2}{N_s^2} \quad \text{or} \quad \frac{I_s}{I_p} = \sqrt{\frac{L_p}{L_s}} = \frac{N_p}{N_s} \quad \text{—(11)}$$

If $N_p > N_s$ $\quad I_s > I_p$

Let E_2 & E_1 be the p.d across the load impedance in the secondary and primary coil respectively.

$$\therefore \frac{E_2}{E_1} = \frac{I_s Z_2}{E - I_p Z_1}$$

But since Z_1 is small compared to the impedance of the coil; $I_p Z_1$ can be neglected compared to E.

$$\therefore \frac{E_2}{E_1} = \frac{I_s Z_2}{E} = \left(\frac{I_s}{E}\right) \cdot Z_2$$

Putting the value of I_s/E from eq^n (5)

$$\frac{E_2}{E_1} = \frac{Zm\, Z_2}{j\omega L_p (R_2 + j\omega L_s) - j^2\omega^2 M^2}$$

$$\text{Or } \frac{E_2}{E_1} = \frac{j\omega M R_2}{j\omega L_p (R_2 + j\omega L_s) - j^2\omega^2 M^2}$$

$$\text{or } \frac{E_2}{E_1} = \frac{j\omega\sqrt{L_p L_s} \cdot R_2}{R_2\, j\omega L_p + j^2\omega^2 L_p L_s - j^2\omega^2 L_p L_s}$$

$$\text{or } \frac{E_2}{E_1} = \frac{R_2\, j\omega \sqrt{L_p L_s}}{R_2\, j\omega\, L_p} = \sqrt{\frac{L_s}{L_p}} = \frac{N_s}{N_p}$$

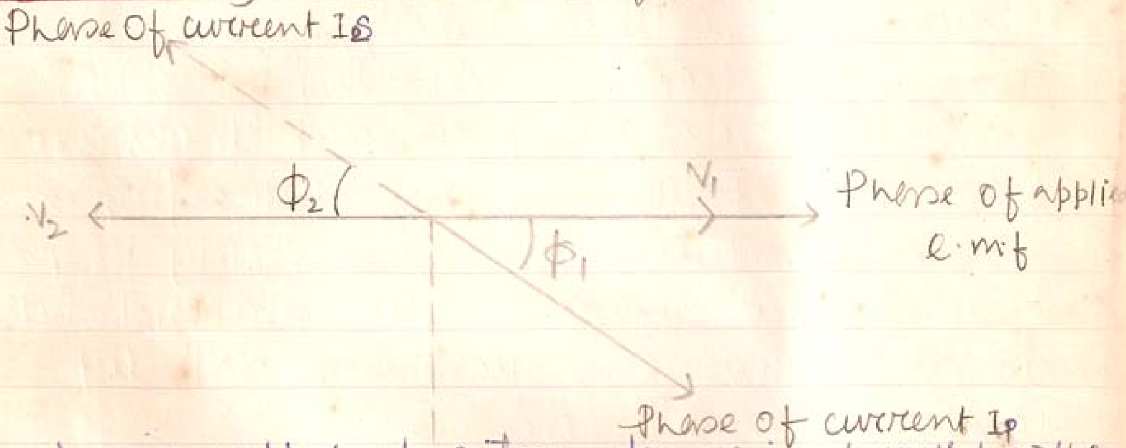
$$\frac{E_2}{E_1} = \frac{N_s}{N_p} \quad \text{—— (12)}$$

If $N_s > N_p$, $E_2 > E_1$ & from

(11) $I_s < I_p$.

Thus for a Step up transformer high current at low voltage converted into low current at high voltage ($I_p > I_s$, $E_1 < E_s$) $N_s > N_p$ i.e. the no. of turns in the Secondary should be greater than that in the primary. For a Step down transformer $E_2 < E_1$ hence $N_s < N_p$.

Vector diagram of a transformer:



The power output of a transformer is always less than the power input. Due to the following reasons :-

Losses in a transformer:

(1) Magnetic flux leakage: The whole of the flux produced by one coil does not link with the Second coil. Some flux produced by the primary which does not link with the Secondary is known as primary leakage. The part of the flux produced by the Secondary that does not link with the primary is known as Secondary leakage. This energy loss is also known as Iron losses. To minimise iron

(V). Self Capacity of winding; Different turns on both the primary and secondary coils being at different potentials at any instant form small condensors. These are known as Self Capacities. They are harmful at high frequency.

loss a core of ferro magnetic material is prefered.

(II) **Copper losses:** Some of the supplied energy is lossed in the form of Joule's heating effect due to the resistance of the primary and secondary coil.

(III). **Eddy current loss:** When the magnetic flux linked with the core changes induced current known as Eddy current is produced in the core & hence energy is lost due to the Joule's heating effect by the Eddy current. The eddy current losses are proportional to the square of the frequency, lamination thickness and inversely proportional to the resistivity of the core material. Eddy current losses can be minimised by taking laminated core.

(IV) **Hysteresis loss:** The iron core of the trans-former goes through one complete cycle of magnetisation along with each cycle of applied A.C. goes through hysteresis loop in each cycle. Since the hysteresis loss represents the energy lost is equal to the area of the B-H curve, considerable amount of energy is lost. The hysteresis loss can be minimised by choosing a core of soft iron for which area of the B-H curve is small. ✱

Q. What are the various losses in a transformer? Why are laminated iron cores used in it?

The efficiency of the transformer is given by :-

$$\eta = \frac{\text{Power out put from the Secondary}}{\text{Power input to the primary}} \times 100.$$

8.11.90

Qr. What is a rotating magnetic field ? Describe the construction of an induction motor. Calculate the torque produced in it.