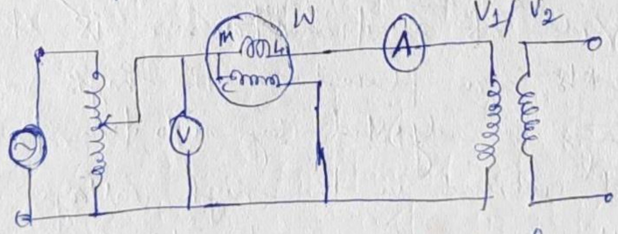
Determination of equivalent circuit parameters:-

The parameters R_0 and X_0 of the equivalent circuit are obtained by conducting open circuit test and the equivalent impedance R_1 and X_1 (or R_2 and X_2) are obtained by conducting short circuit test on transformers.

(1) Open Circuit test or No-load test:-

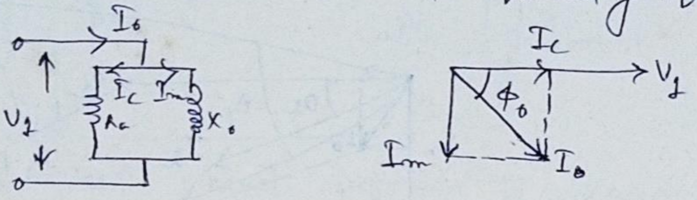
The purpose of this test is to determine no-load loss or core loss and no-load current I_0 which is helpful in finding R_0 and X_0.



The high voltage side is left open-circuited. Rated circuit voltage, applied to the primary, i.e, low-voltage side, is varied with the help of a variable ratio auto transformer. When the voltage voltmeter reading is equal to the rated voltage of the L.V. winding, all the three instrument readings are recorded.

AS the secondary is open circuited, the load current is zero and hence, the primary draws only no-load current I_0. The input power given by the wattmeter reading consists of core loss and ohmic loss. As no-load current I_0 is very small about 2% to 6% of full-load current, ohmic loss

in the primary is negligibly small. Hence, the wattmeter reading can be taken as equal to transformer core loss.
Equivalent circuit reduces to the following form —



The open circuit test is conducted by applying rated voltage (V_1) to primary and measuring the input power (W_0) and the no-load current (I_0).

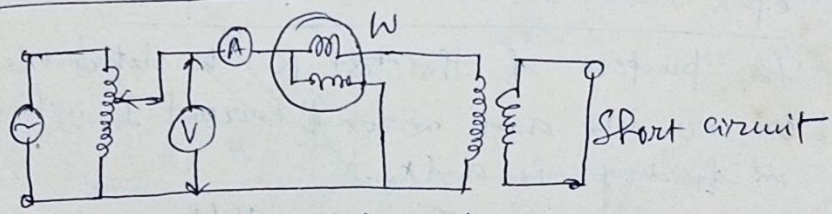
Input power, $W_0 = V_1 I_0 \cos\phi_0$

$$\therefore \cos\phi_0 = \frac{W_0}{V_1 I_0}$$

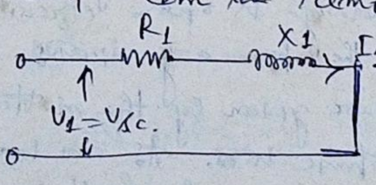
$$\therefore R_0 = \frac{V_1}{I_0 \cos\phi_0}, \quad X_0 = \frac{V_1}{I_0 \sin\phi_0}$$

$$I_c = I_0 \cos\phi_0, \quad I_m = I_0 \sin\phi_0.$$

(2) Short circuit test :-



The low voltage side of a transformer is short circuited and the instruments are placed on the high voltage side. The applied voltage is adjusted by auto-transformer, to circulate rated current in the high voltage side.
A primary voltage of 2 to 12% of its rated value is sufficient to circulate rated currents in both primary and secondary windings. As only a reduced voltage is applied, the core loss becomes very much less and may be neglected. Under these conditions, I_0 becomes insignificant and the parallel branch R_0 and X_0 in the equivalent circuit can be removed.



Readings obtained on Short circuit test are as given below –

Applied voltage, $V_1 = V_{s.c.}$ volts.

current, $I_1 = I_{sc}$ amp.

Input power, $W_1 = W_{s.c.}$ watts.

$$R_1 = \frac{W_{sc}}{\cancel{I_1}} \quad \frac{W_{s.c.}}{I_{s.c.}^2}$$

$$Z_1 = \frac{V_{s.c.}}{I_{s.c.}} , \quad X_1 = \sqrt{Z_1^2 - R_1^2} .$$

Let us consider a transformer with rating 220/3300V, 33000VA.

For open circuit test on low voltage side, the ranges of voltmeter, ammeter and wattmeter are 220V., 6A. (2 to 6% of rated current of 150A.), and 6A, 220V. respectively. These are the standard ranges for ordinary instruments. So, more accurate readings can be obtained. If the open circuit test is performed on the h.v. side, the instrument ranges are 3300V., 0.4A. and 0.4A, 3300V. which are not within the range of ordinary instruments & Hence results obtained may not be so accurate.

For short-circuit test on the h.v. side, the instrument ranges are 165V. (2 to 12% of rated voltage 3300V.), 10A. (rated current) and 10A, 165V. which are well within the range of ordinary instruments. On the other hand, instrument ranges, for a short circuit test, on l.v. side are 11V., 150A. and ~~11V.,~~ 150A., 11V. Instruments of such ranges and auto-transformer capable of handling 150A. may not be readily available and results may not be so accurate. For these reasons, open circuit and short circuit tests are conducted on l.v. and h.v. sides respectively. [220V/3300V. 33000VA. For. OC, 220V, 4% of Full load; For, S.C, 5% of Full load voltage, rated cf.]

Voltage regulation of a transformer :–

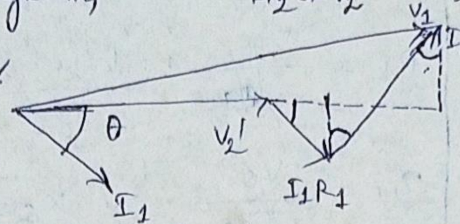
It is defined as the change in secondary terminal voltage, expressed as a percentage (or per unit) of the secondary rated voltage, when load at a given power factor is reduced to zero, with primary applied voltage held constant.

If V_2 = secondary terminal voltage at any load
and E_2 = secondary terminal voltage at no-load.

$\therefore$ Percentage regulation $= \dfrac{E_2 - V_2}{E_2 \text{ or } V_2} \times 100\%$.

Referring to the vector diagram,

% Regulation $= \dfrac{V_1 - V_2'}{V_1} \times 100\%$



For a lagging power factor load,

$$V_1 - V_2' = (I_1R_1\cos\theta + I_1X_1\sin\theta) + j(I_1X_1\cos\theta - I_1R_1\sin\theta)$$

Quadrature component $j(I_1X_1\cos\theta - I_1R_1\sin\theta)$ is very much less compared to terminal voltage and may be neglected.

$$\therefore V_1 - V_2' = I_1R_1\cos\theta + I_1X_1\sin\theta.$$

$$\% \text{ Regulation} = \frac{(I_1R_1\cos\theta + I_1X_1\sin\theta)}{V_1} \times 100\%.$$

Taking into account both lagging and leading power factor loads,

$$\% \text{ Regulation} = \frac{(I_1R_1\cos\theta \pm I_1X_1\sin\theta)}{V_1} \times 100\%.$$

Losses in a transformer:- In a static transformer, there are no friction or windage losses. There are mainly two kinds of losses in a transformer.
(1) Core or Iron loss and (2) Ohmic or copper loss.

(1) Core loss:- Core loss (P_c) consists of hysteresis loss (P_h) and eddy current loss (P_e),

i.e., $P_c = P_h + P_e$.

As the core flux in a transformer remains practically constant for all loads, the core loss is practically the same for all loads.

$$P_h = K_h f B_m^x \quad \text{and} \quad P_e = K_e f^2 B_m^2,$$

where, K_h = proportionality constant which depends upon the volume and quality of core material and the units used.

K_e = proportionality constant whose value depends on the volume and resistivity of the core material thickness of laminations and units used.

B_m = maximum flux density in the core

f = frequency.

Value of x (called Steinmetz's constant) varies from 1.5 to 2.5, depending upon the magnetic properties of core material.

② Copper loss :- When a transformer is loaded, ohmic loss (I^2R) occurs in both the primary and secondary winding resistances.

$$Cu\text{-loss} = I_1^2 r_1 + I_2^2 r_2$$
$$= I_1^2 R_1 = I_2^2 R_2.$$

In addition to these, ~~at~~ the following losses are also present in a transformer—

(i) Stray load loss :- Leakage fields in a transformer induce eddy currents in conductors, tanks, channels, bolts etc. and these eddy currents give rise to stray load loss.

(ii) Dielectric loss :- This loss occurs in the insulating materials, i.e., in the transformer oil and solid insulation of h.v. transformers.

These two losses are very small and are therefore, neglected.

Efficiency of a transformer :-

The efficiency of a transformer is the ratio of output power to input power.

$$\text{Efficiency } \eta = \frac{\text{output}}{\text{Input}} \times 100\%$$

It is very difficult to measure input and output powers under actual load conditions, hence efficiency is computed from the values of losses obtained from tests.

$$\therefore \eta = \frac{\text{output}}{\text{output} + \text{losses}} \times 100\%$$

Iron losses P_i are constant at all loads, since ϕ_m is almost constant. Copper losses P_c are proportional to square of the load current.

Transformer output $= V_2 I_2 \cos\theta_2$, where $\cos\theta_2$ is the load power factor.

$$\therefore \quad \eta = \frac{V_2 I_2 \cos\theta_2}{V_2 I_2 \cos\theta_2 + (P_i + I_2^2 R_2)}$$