Republic of Iraq Ministry of Higher
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Ashur University
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Electrical technology

Transformer

Open and short circuit test of transformer

المحاضرة الرابعة

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2023-2024

Open Circuit Test (O.C. Test)

The experimental circuit to conduct O.C. test is shown in the Fig. 1

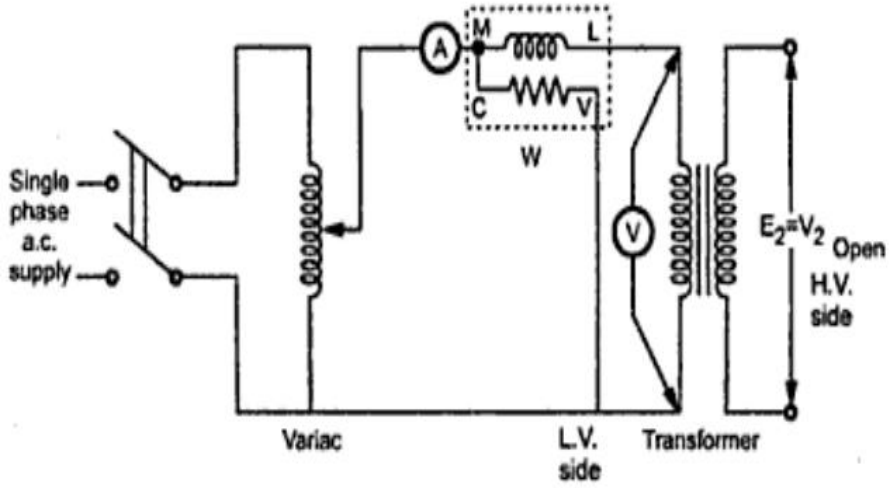


Fig. 1 Experimental circuit for O.C. test

The transformer primary is connected to a.c. supply through ammeter, wattmeter and variac. The secondary of transformer is kept open. Usually low voltage side is used as primary and high voltage side as secondary to conduct O.C. test.

Activate Wind
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When the primary voltage is adjusted to its rated value with the help of variac, readings of ammeter and wattmeter are to be recorded.

The observation table is as follows.

V_o volts	I_o amperes	W_o watts
Rated		

V_o = Rated voltage

W_o = Input power

I_o = Input current = No load current

As transformer secondary is open, it is on no load. So current drawn by the primary is no load current I_o. The two components of this no load current are,

$$I_m = I_o \sin \phi_o$$
$$I_c = I_o \cos \phi_o$$

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where $\cos \phi_o$ = No load power factor

And hence power input can be written as,

$$W_o = V_o I_o \cos \phi_o$$

The phasor diagram is shown in the Fig. 2

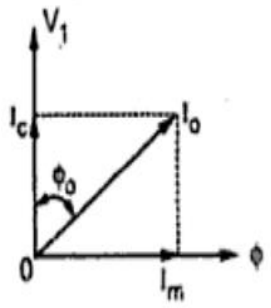


Fig. 2

As secondary is open, $I_2 = 0$. Thus its reflected current on primary I_2' is also zero. So we have primary current $I_1 = I_o$. The transformer no load current is always very small, hardly 2 to 4 % of its full load value. As $I_2 = 0$, secondary copper losses are zero. And $I_1 = I_o$ is very low hence copper losses on primary are also very very low. Thus the total copper losses in O.C. test are negligibly small. As against this the input voltage is rated at rated frequency hence flux density in the core is at its maximum value. Hence iron losses are at rated voltage. As output power is zero and copper losses are very low, the total input power is used to supply iron losses.

This power is measured by the wattmeter i.e. W_o. Hence the wattmeter in O.C. test gives iron losses which remain constant for all the loads.

$$\therefore \quad W_o = P_i = \text{Iron losses}$$

Calculations : We know that,

$$W_o = V_o I_o \cos \phi$$

$$\therefore \quad \cos \phi_o = \frac{W_o}{V_o I_o} = \text{No load power factor}$$

Once $\cos \phi_o$ is known we can obtain,

$$I_c = I_o \cos \phi_o$$

and

$$I_m = I_o \sin \phi_o$$

Once I_c and I_m are known we can determine exciting circuit parameters as,

$$R_o = \frac{V_o}{I_c} \quad \Omega$$

and

$$X_o = \frac{V_o}{I_m} \quad \Omega$$

Short Circuit Test (S.C. Test)

In this test, primary is connected to a.c. supply through variac, ammeter and voltmeter as shown in the Fig.3

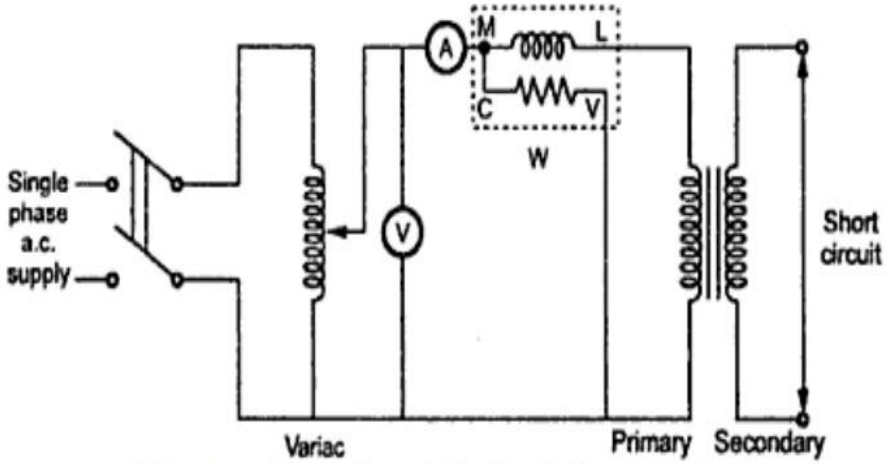


Fig.3 Experimental circuit for S.C. test

The secondary is short circuited with the help of thick copper wire or solid link. As high voltage side is always low current side, it is convenient to connect high voltage side to supply and shorting the low voltage side.

As secondary is shorted, its resistance is very very small and on rated voltage it may draw very large current. Such large current can cause overheating and burning of the transformer. To limit this short circuit current, primary is supplied with low voltage which is just enough to cause rated current to flow through primary which can be observed on an ammeter. The low voltage can be adjusted with the help of variac. Hence this test is also called **low voltage test** or **reduced voltage test**. The wattmeter reading as well as voltmeter, ammeter readings are recorded. The observation table is as follows.

V_{sc} volts	I_{sc} amperes	W_{sc} watts
	Rated	

Now the currents flowing through the windings are rated currents hence the total copper loss is full load copper loss. Now the voltage applied is low which is a small fraction of the rated voltage. The iron losses are function of applied voltage. So the iron losses in reduced voltage test are very small. Hence the wattmeter reading is the power loss which is equal to full load copper losses as iron losses are very low.

Activate Wir

$$\therefore \quad W_{sc} = (P_{cu})\ \text{F.L.} = \text{Full load copper loss}$$

Calculations : From S.C. test readings we can write,

$$W_{sc} = V_{sc}\, I_{sc} \cos \phi_{sc}$$

$$\therefore \quad \cos \phi_{sc} = \frac{V_{sc}\, I_{sc}}{W_{sc}} = \text{Short circuit power factor}$$

$$W_{sc} = I_{sc}^2\, R_{1e} = \text{Copper loss}$$

$$\therefore \quad \boxed{Ro1 = \frac{W_{sc}}{I_{sc}^2}}$$

While $$\boxed{Z_{o1} = \frac{V_{sc}}{I_{sc}} = \sqrt{R_{o1}^2 + X_{o1}^2}}$$

$$\therefore \quad \boxed{X_{o1} = \sqrt{Z_{o1}^2 - R_{o1}^2}}$$

Example 1 *Obtain the equivalent circuit of a 200/400-V, 50-Hz, 1-phase transformer from the following test data :*

O.C test : 200 V, 0.7 A, 70 W – on L.V. side

S.C. test : 15 V, 10 A, 85 W – on H.V. side

Calculate the secondary voltage when delivering 5 kW at 0.8 p.f. lagging, the primary voltage being 200V.

Solution. From O.C. Test

$$V_1 I_0 \cos\phi_0 = W_0$$

$$\therefore \quad 200 \times 0.7 \times \cos\phi_0 = 70$$

$$\cos\phi_0 = 0.5 \text{ and } \sin\phi_0 = 0.866$$

$$I_w = I_0 \cos\phi_0 = 0.7 \times 0.5 = 0.35 \text{ A}$$

$$I_\mu = I_0 \sin\phi_0 = 0.7 \times 0.866 = 0.606 \text{ A}$$

$$R_0 = V_1/I_w = 200/0.35 = 571.4\,\Omega$$

$$X_0 = V_1/I_\mu = 200/0.606 = 330\,\Omega$$

As shown in Fig. 32.48, these values refer to primary *i.e.* low-voltage side.

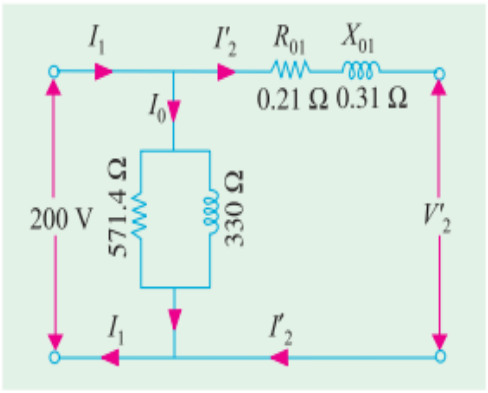


Fig. 32.48

From S.C. Test

It may be noted that in this test, instruments have been placed in the secondary *i.e.* high-voltage winding whereas the low-voltage winding *i.e.* primary has been short-circuited.

Now, as shown in Art. 32.32

$$Z_{02} = V_{sc}/I_2 = 15/10 = 1.5\,\Omega\,;\; K = 400/200 = 2$$

$$Z_{01} = Z_{02}/K^2 = 1.5/4 = 0.375\,\Omega$$

Also $$I_2^2 R_{02} = W\,;\; R_{02} = 85/100 = 0.85\,\Omega$$

$$R_{01} = R_{02}/K^2 = 0.85/4 = 0.21\,\Omega$$

$$X_{01} = \sqrt{Z_{01}^2 - R_{01}^2} = \sqrt{0.375^2 - 0.21^2} = 0.31\,\Omega$$

Output kVA = 5/0.8 ; Output current $I_2 = 5000/0.8 \times 400 = 15.6$ A

This value of I_2 is approximate because V_2 (which is to be calculated as yet) has been taken equal to 400 V (which, in fact, is equal to E_2 or ${}_0V_2$).

Now, $Z_{02} = 1.5\,\Omega$, $R_{02} = 0.85\,\Omega$ $\quad\therefore\quad X_{02} = \sqrt{1.5^2 - 0.85^2} = 1.24\,\Omega$

Total transformer drop as referred to secondary

$$= I_2(R_{02}\cos\phi_2 + X_{02}\sin\phi_2) = 15.6(0.85 \times 0.8 + 1.24 \times 0.6) = 22.2 \text{ V}$$

$$\therefore \quad V_2 = 400 - 22.2 = \mathbf{377.8\ V}$$

Example 1 : *The open circuit and short circuit tests on a 10 kVA, 125/250 V, 50 Hz, single phase transformer gave the following results :*
O.C. test : 125 V, 0.6 A, 50 W (on L.V. side)
S.C. test : 15 V, 30 A, 100 W (on H.V. side)
Calculate : i) Copper loss on full load. ii) Full load efficiency at 0.8 leading p.f.
iii) Half load efficiency at 0.8 leading p.f.

Solution : From O.C. test we can write,

$$W_o = P_i = 50 \text{ W} = \text{Iron loss}$$

From S.C. test we can find the parameters of equivalent circuit. Now S.C. test is conducted on H.V. side i.e. meters are on H.V. side which is transformer secondary. Hence parameters from S.C. test results will be referred to secondary.

$$V_{sc} = 15 \text{ V}, I_{sc} = 30 \text{ A}, W_{sc} = 100 \text{ W}$$

$$\therefore \quad R_{o2} = \frac{W_{sc}}{(I_{sc})^2} = \frac{10}{(30)^2} = 0.111 \ \Omega$$

$$Z_{o2} = \frac{V_{sc}}{I_{sc}} = \frac{15}{30} = 0.5 \ \Omega$$

$$\therefore \quad X_{o2} = \sqrt{Z_{o2}^2 - R_{o2}^2} = 0.4875 \ \Omega$$

i) Copper loss on full load

$$(I_2) \text{ F.L.} = \frac{\text{VA rating}}{V_2} = \frac{10 \times 10^3}{250} = 40 \text{ A}$$

In short circuit test, $I_{sc} = 30$ A and not equal to full load value 40 A.
Hence W_{sc} does not give copper loss on full load.

$$\therefore \quad W_{sc} = P_{cu} \text{ at } 30 \text{ A} = 100 \text{ W}$$

$$\text{Now} \quad P_{cu} \propto I^2$$

$$\therefore \quad \frac{P_{cu} \text{ at } 30 \text{ A}}{P_{cu} \text{ at } 40 \text{ A}} = \left(\frac{30}{40}\right)^2$$

$$\therefore \quad \frac{100}{P_{cu} \text{ at } 40 \text{ A}} = \frac{900}{1600}$$

$$\therefore \quad P_{cu} \text{ at } 40 \text{ A} = 177.78 \text{ W}$$

$$\therefore \quad (P_{cu}) \text{ F.L.} = 177.78 \text{ W}$$

ii) Full load η , $\cos \phi_2 = 0.8$

$$\% \eta \text{ on full load} = \frac{V_2(I_2) \text{ F.L. } \cos \phi_2}{V_2(I_2) \text{ F.L.} \cos \phi_2 + P_i + (P_{cu}) \text{ F.L.}} \times 100$$

$$= \frac{250 \times 40 \times 0.8}{250 \times 40 \times 0.8 + 50 + 177.78} \times 100 = \mathbf{97.23\ \%}$$

iii) Half load η , $\cos \phi_2 = 0.8$

$$n = 0.5 \text{ as half load}, \quad (I_2) \text{ H.L.} = \frac{1}{2} \times 40 = 20 \text{ A}$$

$$\therefore \ \% \eta \text{ on half load} = \frac{V_2(I_2) \text{ H.L. } \cos \phi_2}{V_2(I_2) \text{ H.L.} \cos \phi_2 + P_i + n^2 (P_{cu}) \text{ F.L.}} \times 100$$

$$= \frac{n \text{ (VA rating)} \cos \phi_2}{n \text{ (VA rating)} \cos \phi_2 + P_i + n^2 (P_{cu}) \text{ F.L.}} \times 100$$

$$= \frac{0.5 \times 10 \times 10^3 \times 0.8}{0.5 \times 10 \times 10^3 \times 0.8 + 50 + (0.5)^2 \times 177.78} \times 100$$

$$= \mathbf{97.69\ \%}$$

Example 2 : *The following readings were obtained from O.C. and S.C. tests on 8 kVA 400/120 V, 50 Hz transformer.*

O.C. test on L.V. side	120 V	4 A	75 W
S.C. test on H.V. side	9.5 V	20 A	110 W

Clculate the *efficiency at full load, 0.8 p.f. lagging.*

The meters are on H.V. side i.e. primary hence,

$$Z_{o1} = \frac{V_{sc}}{I_{sc}} = \frac{9.5}{20} = 0.475\ \Omega$$

$$R_{o1} = \frac{W_{sc}}{I_{sc}^2} = \frac{110}{(20)^2} = 0.275\ \Omega$$

$$\therefore \quad X_{o1} = \sqrt{Z_{o1}^2 - R_{o1}^2} = 0.3873\ \Omega$$

$$I_1(FL) = \frac{KVA}{V_1} = \frac{8\times10^3}{400} = 20\ A = I_{sc}$$

$$\therefore \quad W_{sc} = P_{cu}(FL) = 110\ W$$

For $\cos\phi = 0.8, \quad \sin\phi = 0.6$

$$\%\,\eta_{FL} = \frac{KVA\cos\phi}{KVA\cos\phi + P_i + P_{cu}(FL)} \times 100$$

$$= \frac{8\times10^3\times0.8}{8\times10^3\times0.8+75+110} \times 100 = 97.19\ \%$$

Tutorial problems

Q1: A single phase transformer gave the following results:

Open circuit test 250V, 1A, 80W, on low voltage side

Short circuit test 20V, 12A, 100W on high voltage side

Calculate the circuit constants and show them on an equivalent circuit.Ans: (Ro=781.25Ω, Xo=264Ω, Ro1=0.173Ω, Xo1=0.379Ω)

Q2: A 20 kVA, 2500/250 V, 50 Hz, 1-phase transformer has the following test results :

O.C. Test (l.v. side) : 250 V, 1.4 A, 105 W

S.C. Test (h.v. side) : 104 V, 8 A, 320 W

Compute the parameters of the approximate equivalent circuit referred to the low voltage side and draw the circuit. ($R_0 = 592.5\ \Omega$; $X_0 = 187.2\ \Omega$; $R_{02} = 1.25\ \Omega$; $X_{12} = 3\ \Omega$)