Chapter 5

VOLTAGE TRANSFORMER TESTING

Voltage transformer tests are necessary to insure that the design and construction of the transformer are adequate to meet specified requirements, i.e., has adequate insulation and accuracy characteristics for the stated ratings.

The tests specified in IEC Recommendation Publication 186 (1969) are classified as type tests or routine tests.

5.1 Routine Tests

All transformers shall receive the routine tests as specified below.

5.1.1 Verification of terminal markings.

5.1.2 Power frequency tests on primary winding.

5.1.3 Power frequency tests on secondary winding.

5.1.4 Determination of errors according to the requirement of appropriate accuracy class.

5.2 Type Tests

Type tests are tests performed only on a single transformer or on a few transformer of each type. The voltage transformer must be capable of withstanding of the following type tests.

5.2.1 Temperature rise test.

5.2.2 Impulse voltage tests.

5.1 Routine Tests.

5.1.1 Verification of terminal markings.

The relative instantaneous polarity of the leads or terminals of voltage transformer shall be clearly indicated by permanent markings that cannot be easily obliterated.

When the polarity is indicated by letters, the capital letters A, B, C and N shall be used to distinguish the leads or terminal connected to the primary or excited winding, and the lower - case letters a, b, c and n shall be used to distinguish the leads or terminals connected to the secondary winding (The letter A, B, C denote fully insulated terminals and the letter N denotes the terminal intended to be earthed and the insulation of which is less than that of the other terminals). The terminal having corresponding capital and lower - case marking shall have the same polarity at the same instant.

There are three methods in common use for determining the polarity of instrument transformers. These are inductive kick with direct current, comparison with a standard (calibrated) transformer of the same ratio, and the comparison of winding voltages.

For this case, we used the inductive kick with direct current method, as described below.

Apparatus required

1. D.C. Voltage Rectifier (or battery)

2. Multi - Meter (or D.C. Voltmeter)

3. Three - Way Switch

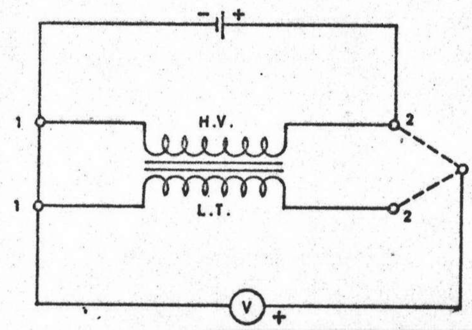


FIG.5-1 POLARITY BY INDUCTIVE KICK.

Test procedure

1. Connect the high - voltage and low - voltage winding as indicated in Fig. 5 - 1.

2. Connect the multi - meter to the high - voltage winding as a d.c. voltmeter, select the range of 120 volts.

3. Connect d.c. voltage rectifier to the high - voltage winding and increase its voltage to 50 volts.

4. Disconnect the d.c. voltmeter from terminal 2 of the high - voltage winding, connect it to terminal 2 of the low - voltage winding by three - way switch, then select the range of 12 volts.

5. Disconnect the d.c. voltage rectifier from the circuit and observe the direction of kick on the voltmeter. If the voltmeter kicks down scale, terminal 1 of the high - voltage winding and terminal 1 of the low - voltage winding are of the same polarity.

6. The results may be checked by connecting and disconnecting the d.c. voltage rectifier circuit. If the terminal 1 are of the

same polarity, the voltmeter will kick up scale on make and down scale on break.

In order to minimize high inductive kicks that might injure person or equipment, d.c. voltage is preferably applied to high - voltage winding.

Test result

The result obtained are used to mark the symbols A, 1a to the terminals 1 of the high and low - voltage winding respectively. B, 1b to the terminal 2 of the high and low - voltage windings respectively and similarly the symbols 2a and 2b are marked to the secondary low - voltage winding.

All the terminals of the transformer under test are marked.

5.1.2 Power frequency tests on primary winding

The purpose of power frequency tests on primary winding is to check the insulation of the voltage transformer which has been designed to withstand the specified insulation test.

Before the power frequency tests on primary winding are made the insulation - resistance would be measured by Insulation Tester (Megger) at 2500 V.d.c. The insulation - resistance measurements are made to be sure that the moisture has been removed from the insulation during the drying out process. The insulation - resistance were shown in table below.

Terminals connection	Insulation - resistance (Mega - ohms)
High - voltage winding and ground	5,000
Low - voltage winding and ground	3,000
High and low voltage windings	5,000

5.1.2.1 Applied potential test

This test followed the IEC Recommendation Publication 186 (1969) clause 12.2 a.

Apparatus required

1. High - voltage step - up transformer
2. Variac
3. Voltmeter
4. Timing clock

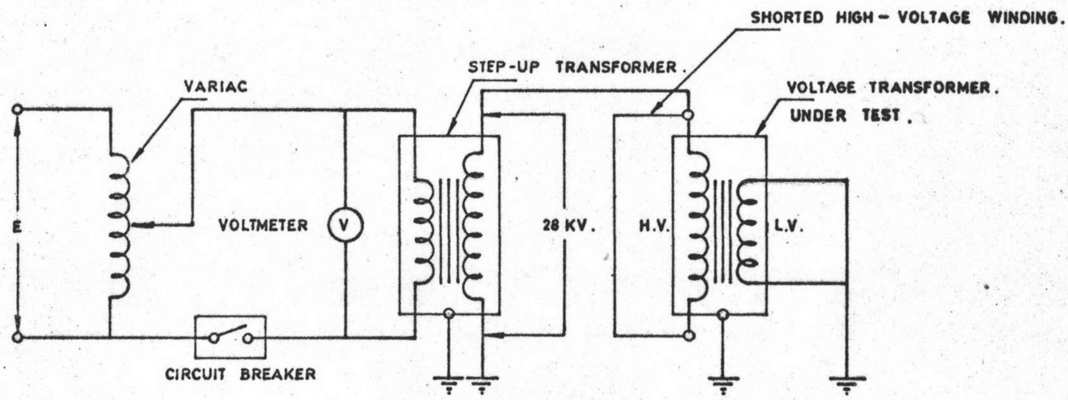


FIG. 5-2 APPLIED POTENTIAL TEST CONNECTION DIAGRAM.

Test procedure

1. Connect together the terminals for low - voltage winding and ground it.

2. Ground the transformer tank.

3. Connect together the terminals of high - voltage winding and then connect it to the high - voltage step - up transformer as shown in Fig. 5 - 2.

4. Raise the voltage of the high - voltage step - up transformer to 9 KV. and then increase gradually to 28 KV. within 15 seconds.

5. After holding for 1 minute at 28 KV. 50 Hz., reduce the voltage gradually to 9 KV. within 15 seconds.

6. Open the circuit.

Test result

After the test, all parts of the transformer under test were in normal condition. The result showed that the insulation was adequate and conformed to IEC Recommendation Publication 186 (1969) clause 12.2 a.

5.1.2.2 Induced voltage test

This test followed the IEC Recommendation Publication 186 (1969) clause 12.2 b.

Apparatus required

1. High - frequency generating set (200 Hz.)

2. Timing clock

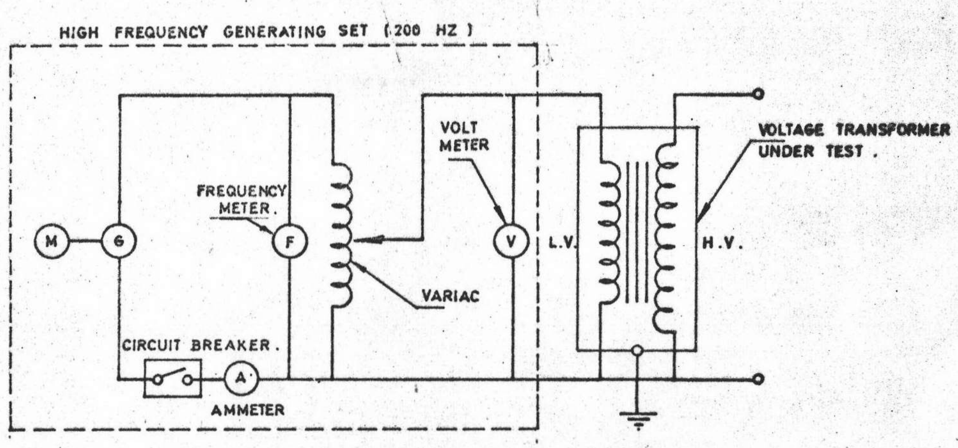


FIG.5-3. INDUCED VOLTAGE TEST CONNECTION DIAGRAM.

Test procedure

1. Connect one terminal of high - voltage winding to one terminal of low - voltage winding and ground it.

2. Earth the transformer tank.

3. Connect the low - voltage winding to the high - frequency generating set (the high - voltage winding remains open) as shown in Fig. 5 - 3.

4. Generate the voltage at 200 Hz. to 160 volts and then increase gradually to 480 volts within 15 seconds (for the voltage and frequency supplied could reduced the exciting current in the core).

5. After holding for 30 seconds at 480 volts 200 Hz., reduced the voltage gradually to 160 volts within 15 seconds.

6. Open the circuit.

The duration of test could be derived from the equation below,

$$\text{duration of test frequency} = \frac{\text{twice the rated frequency}}{\text{test frequency}} \times 60 \text{ seconds}$$

with a minimum of 15 seconds

$$= \frac{2 \times 50}{200} \times 60$$

$$= 30 \quad \text{seconds.}$$

Test result

After the test, all parts of the transformer under test were in normal condition (no damage occured).

The result showed that the insulation was adequate according to IEC Recommendation Publication 186 (1969) clause 12.2 b.

5.1.3 Power frequency tests on secondary winding

This test followed the IEC Recommendation Publication 186 (1969) clause 13.

Apparatus required

1. High - voltage step - up transformer
2. Variac
3. Voltmeter
4. Timing clock

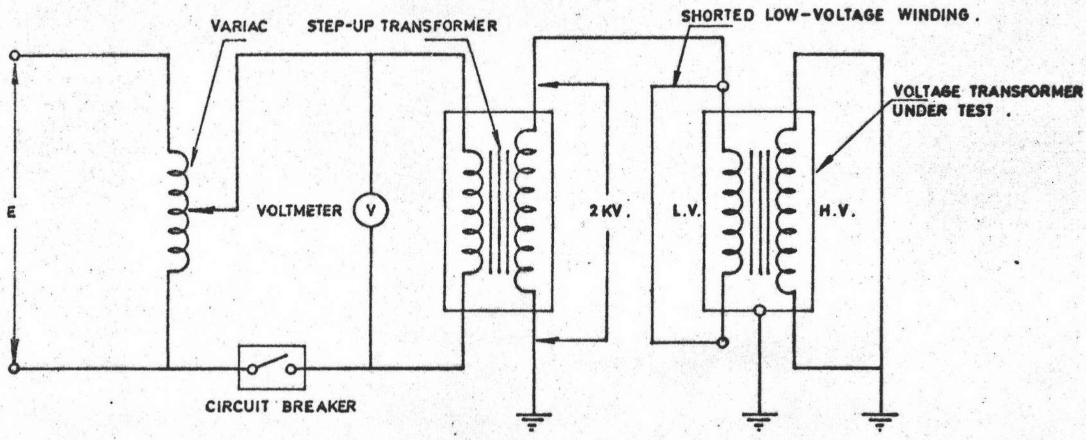


FIG.5-4. POWER FREQUENCY TEST ON SECONDARY WINDING CONNECTION DIAGRAM.

Test procedure

1. Connect together the terminals of high - voltage winding and then earth it.

2. Earth the transformer tank.

3. Connect the low - voltage windings in series, and shorted it.

4. Connect one terminal of low - voltage winding to the high - voltage step - up transformer as shown in Fig. 5 - 4.

5. Raise the voltage of the high - voltage step - up transformer to 0.6 KV. and then increase gradually to 2 KV. within 15 seconds.

6. After holding for 1 minute at 2 KV. 50 Hz., reduce the voltage gradually to 0.6 KV. within 15 seconds.

7. Open the circuit.

Test result

No damage appeared during the test the insulation was adequate.

The result was satisfied according to IEC Recommendation Publication 186 (1969), clause 13.

5.1.4 Determination of error according to the requirement of appropriate accuracy class

In IEC Recommendation Publication 186, 1969 there are five classes of accuracy, all these classes are given in Table 5.1.

Class	Percentage voltage (ratio) error ±	Phase Displacement ±	
		Minutes	Centiradians
0.1	0.1	5	0.15
0.2	0.2	10	0.30
0.5	0.5	20	0.60
1.0	1.0	40	1.20
3.0	3.0	not specified	not specified

Table 5.1 Limits of voltage errors and phase displacement.

The voltage error and phase displacement (γ) at rated frequency shall not exceed the value given in Table 5.1 at any voltage between 80% and 120% rated voltage and with burdens between 25% and 100% of rated burden, at a power factor of 0.8 lagging.

In testing the voltage ratio error and phase displacement shall be made at 80%, 100% and 120% of rated voltage, at rated frequency and at 25% and 100% of rated burden.

There are two methods in testing voltage transformers accuracy; i.e. Indirect Method and Direct Methods.

5.1.4.1 Indirect Method.

The indirect method of testing voltage transformer has only occasionally been used, the most through investigation of the method being made by Illiovici. Briefly, the method follows the procedure of the well known open circuit and short - circuit tests used to find the regulation of power transformers. The ratio on open - circuit can be found by the use of a suitable electrostatic voltmeter, or by a dynamometer. The magnitude and phase of the exciting - current are obtainable from ammeter, voltmeter and wattmeter readings taken on one of the windings with the other open. This test is usually made, for convenience on the low - tension side. Resistance are found by the usual bridge method; reactance are determined by the short circuit test. The results of both test are used in the usual expression for the ratio and the phase angle between primary and secondary voltage that can be obtained from the equation (2.1) and (2.7).

5.1.4.2 Direct Methods.

The direct methods are, however, so simple, and of such superior accuracy in practice; the indirect method may, therefore be reguarded as superseded by them. The direct methods for testing voltage transformer may be either absolute or relative. The absolute methods are all based upon the principle of comparing the secondary voltage with an almost equal portion of the primary voltage, the difference being measured in magnitude and phase. The comparison may be made by a deflectional method, using suitable dynamometers or electrometers seperately excited by an auxiliary phase - shifting supply. Alternatively a null or bridge method can be devised by the inclusion of a suitable compensating circuit to balance out the vector difference concerned and the use of one of the usual detectors. In practically all these methods the required fraction of the primary voltage is obtained from a resistance voltage divider. Modern networks operate at such high voltages that the construction of suitable voltage - dividers constitutes, an extremely difficult problem, the most up - to - date methods overcome these difficulties by the substitution of condenser voltage dividers in which an essential feature is a high - voltage air - condenser, many types of which have been successfully developed for use in Schering bridge technique.

It will be realized that all absolute methods essentially necessitate the connection of some part of the testing apparatus to high - voltage side; this is entirely avoided in the relative methods where the errors of one transformer are compared with those of another by measurements made entirely upon their secondary sides. Since the secondary voltage does not exceed 120 volts, the possibility of dangerous shock is avoided; the apparatus is compact and readily portable: and bring a difference method adequate accuracy can usually be secured by use of pointer instruments. These advantages make the relative methods specially valuable for use in the works test and on site.

In testing this voltage transformer, the uniload test set was used. The set consists of:

1. Supply transformer, supplies primary voltage to the voltage transformer under test and to the precision transformer.

2. Precision transformer, used for comparing the voltage ratio error and phase shift. Its no load voltage always 120 volts at rated supply voltage.

3. Comparator unit, detects the voltage ratio error and phase shift of voltage transformer under test in no load or load condition with standard burden (ASA standard burden, W, X, Y, Z, ZZ). The unit will show the different value of voltage and phase shift of the voltage transformer under test compares to the precision transformer.

Apparatus required

1. Voltage transformer uniload test set.

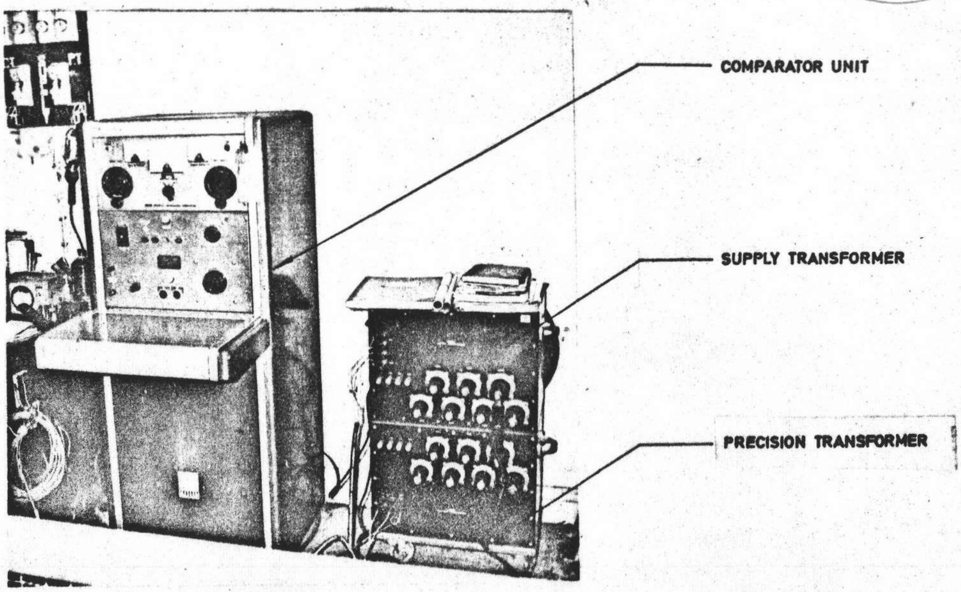


FIG 5.-5 VOLTAGE TRANSFORMER UNILOAD TEST SET .

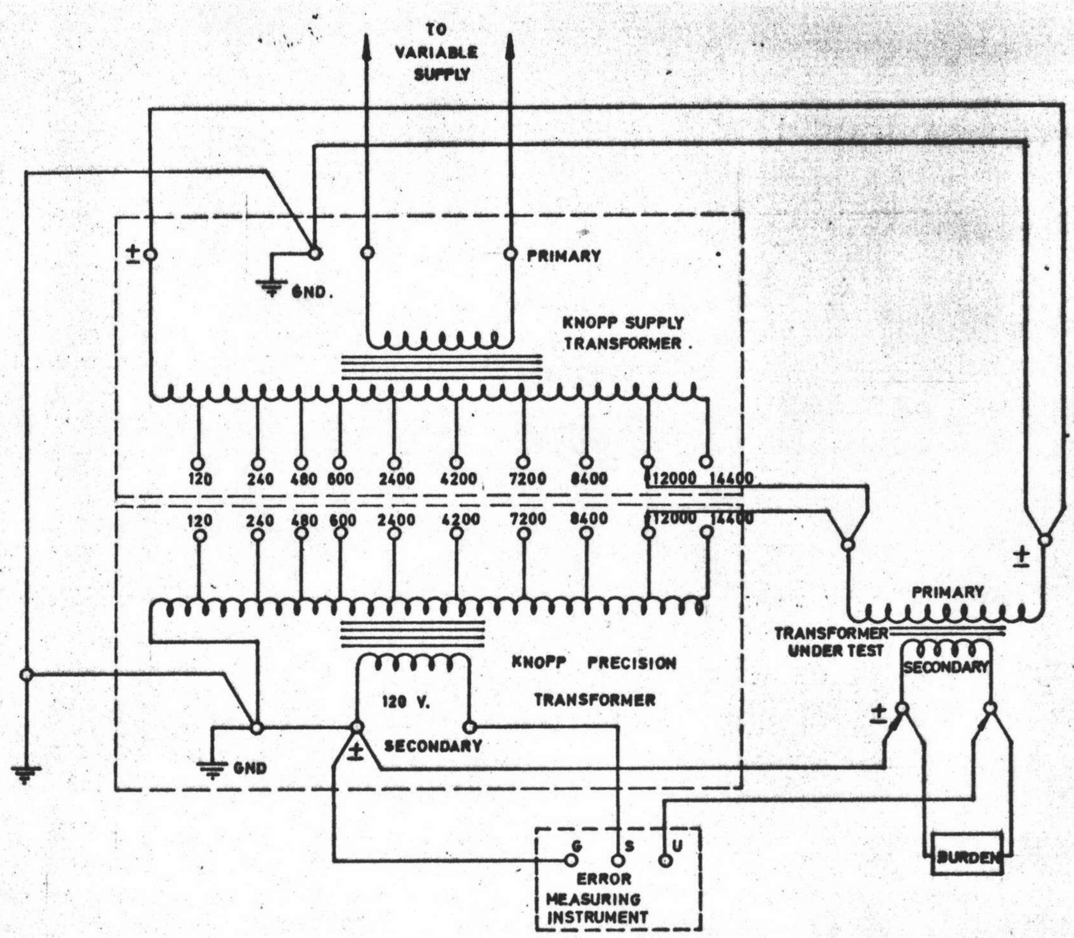


FIG 5.-6 VOLTAGE TRANSFORMER UNILOAD TEST SET CONNECTION DIAGRAM .

CAUTION : BOTH GROUND TERMINALS MUST BE SOLIDRY GROUNDED AS SHOWN NOTE THAT THESE TERMINALS ARE INTERNALLY CONNECTED TO THE CORE CASE .

Test Procedure

1. Connect the voltage transformer under test to the voltage transformer uniload test set as shown in Fig. 5 - 6.

2. Turn the Burden selector to no load position, for no load condition measurement.

3. Supply power to the voltage transformer uniload test set.

4. Raise the voltage to 120 volts.

5. Adjust the voltage ratio error & phase angle knobs until the galvanometer indicate zero.

6. Reduce the voltage supply and off it.

7. Read voltage ratio error and phase angle from the dial and record.

8. For 200 VA 0.85 P.F. condition, the voltage ratio error and phase angle at 120 volts as the same previous method (by turning Burden selector to "Z" position).

Test Results

1. The values of voltage ratio error, ratio correction factor and phase angle at the condition of no load and load with burden 200 VA. 0.85 P.F. measured by voltage transformer uniload test set at ratedsecondary voltage 120 volts are shown in table 5 - 2 below.

Secondary Voltage (volt)	No load			200 VA 0.85 P.F.		
	% voltage ratio error	Ratio Correction Factor(RCF_o)	Phase angle (minute)	% voltage ratio error	Ratio Correction Factor(RCF_c)	Phase angle (minute)
96	0.45High	0.9955	0	0.16 Low	1.0016	0.8 Lead
120	0.44High	0.9956	0.2 Lead	0.17 Low	1.0017	1.0 Lead

Table 5 - 2 Percent voltage ratio error, Ratio correction factor and phase angle at no load and 200 VA 0.85 P.F. at 80% and 100% rated voltage.

2. The ratio correction factor and phase angle at 80%, 100% and 120% rated voltage in the condition of no load, 25% and 100% burden are shown in the table below.

% rated Voltage	No Load		25% rated Burden (0.8 P.F.)		100% rated Burden (0.8 P.F.)	
	RCF_o	γ_o (minute)	RCF	γ (minute)	RCF	γ (minute)
80% (96V)	0.9955	0	0.9970	0.66	1.0016	2.65
100% (120V)	0.9956	0.2	0.9971	0.86	1.0017	2.85
120% (144V)	0.9958	0.67	0.9973	1.31	1.0019	3.21

3. The ratio correction factor and phase angle of the voltage transformer when varying the burden at rated voltage (120 V), 0.8 lagging power factor, rated frequency (50 Hz) are shown in table below.

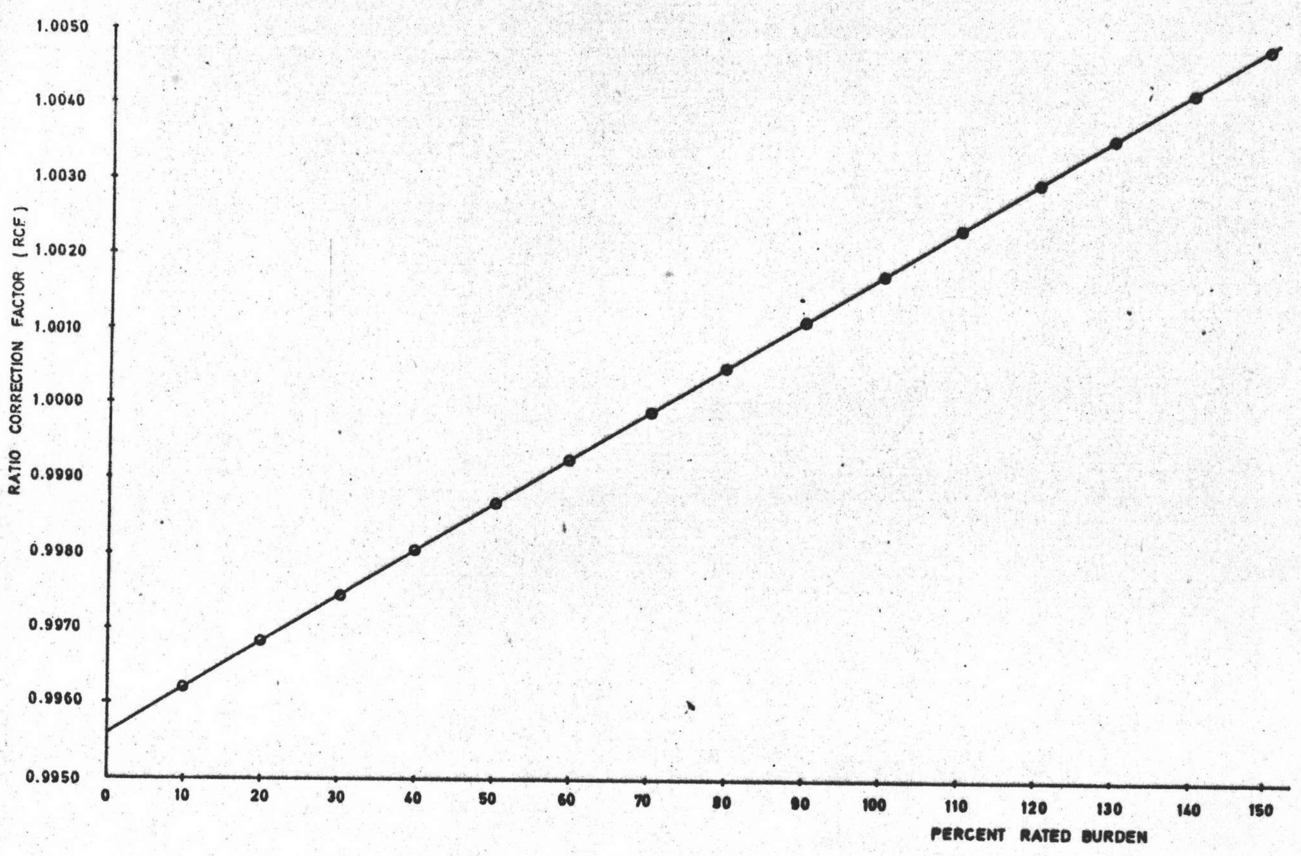
% Rated burden at 0.8 P.F. lagging	Ratio correction Factor (RCF)	Phase angle (γ) (minute)
10	0.9962	0.4650
20	0.9968	0.7300
30	0.9974	0.9950
40	0.9980	1.2600
50	0.9987	1.5250
60	0.9993	1.7900
70	0.9999	2.0550
80	1.0005	2.3200
90	1.0011	2.5850
100	1.0017	2.8500
110	1.0023	3.1150
120	1.0029	3.3800
130	1.0035	3.6450
140	1.0041	3.9100
150	1.0048	4.1750

4. The ratio correction factor and phase angle of the voltage transformer at any power factor at rated voltage (120 V), rated burden (200 VA) and rated frequency (50 Hz) are shown in table below.

Power factor	Ratio correction Factor (RCF)	Phase angle (γ) (minute)
0	0.9986	18.45
0.1	0.9991	17.32
0.2	0.9996	16.01
0.3	1.0001	14.50
0.4	1.0005	12.78
0.5	1.0009	10.82
0.6	1.0012	8.58
0.7	1.0015	5.97
0.8	1.0017	2.85
0.9	1.0017	-1.03
1.0	1.0009	-10.17

5. The ratio correction factor and phase angle at 80%, 100% and 120% rated voltage (rated secondary voltage = 240 volts), according to IEC standard accuracy limit, are shown in table below.

% Rated Voltage	No load		25% rated burden (50 VA 0.8 P.F.)		100% rated burden (200 VA 0.8 P.F.)	
	RCF_o	γ_o (minute)	RCF	γ (minute)	RCF	γ (minute)
80% (192V)	0.9955	0	0.9970	0.64	1.0016	2.54
100% (240V)	0.9956	0.2	0.9971	0.84	1.0017	2.74
120% (288V)	0.9958	0.67	0.9973	1.31	1.0019	3.21



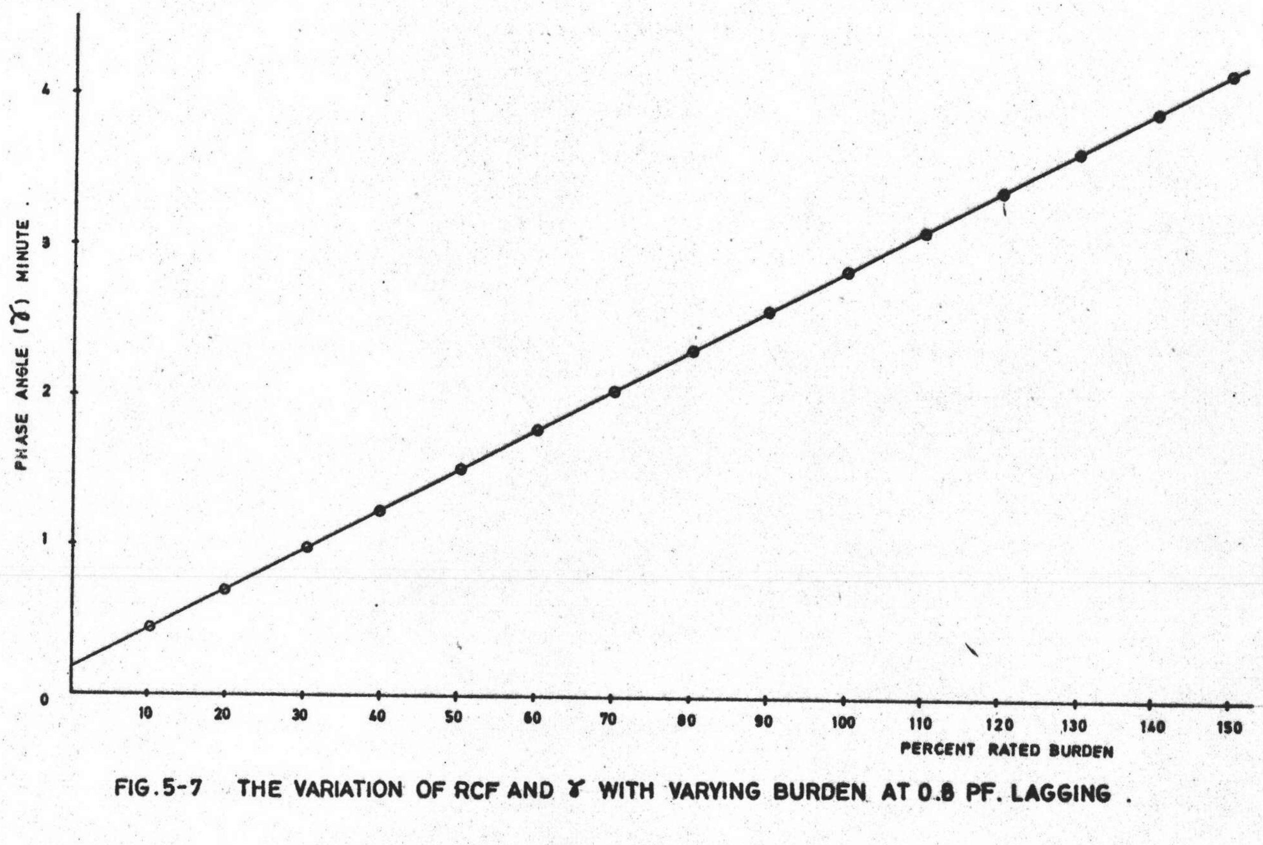


FIG.5-7 THE VARIATION OF RCF AND γ WITH VARYING BURDEN AT 0.8 PF. LAGGING .

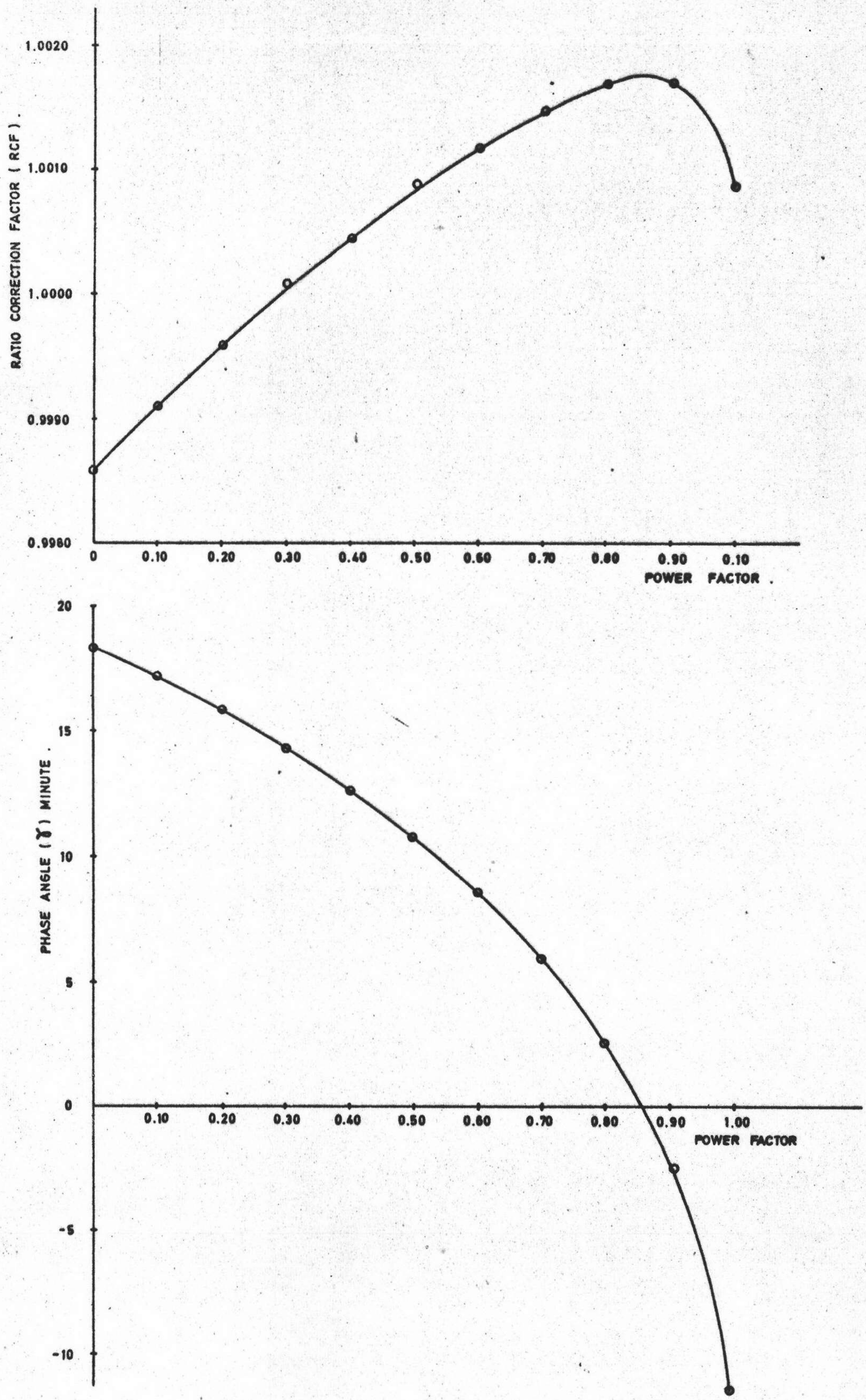


FIG. 5-8 THE VARIATION OF RCF AND γ WITH VARYING POWER FACTOR AT BURDEN 200 VA .

5.1.4.3 Short circuit test

The short circuit test, along with the open circuit test, of which the description follows, form the two most important used to predict the behavior of a transformer when conditions are such that its rated load cannot be supplied.

Connections are made as shown in Fig. 5 - 9. The low - voltage side of the transformer is short circuited. The reduced voltage on the input is varied until normal current flows through either side of the winding. Under these conditions the equivalent impedance of the transformer is equal to the ratio of V_1/I_1. In as much as any impedance in the secondary produces an effect on the magnitude of the short circuit current, the impedance so determined is the equivalent value in terms of the input side. The resistance of the winding can be obtained roughly by measurement with direct current or from the readings of the wattmeter and ammeter. For the latter

$$R_{tp} = \frac{Watts}{I_1^2}$$

Such a determination includes the stray losses; these are usually negligible. The total input for this test respresents the copper losses in both windings.

With the equivalent impedance and resistance both determined in terms of the input, the equivalent reactance is

$$X_{tp} = \sqrt{(Z_{tp})^2 - (R_{tp})^2}$$

or from short circuit data

$$X_{tp} = \sqrt{(V_1 / I_1)^2 - (W / I_1^2)^2}$$

This process considers the transformer in terms of a simple, equivalent series circuit with no parallel magnetizing branch.

Apparatus required

1. Variac
2. Wattmeter
3. A.C. milliammeter
4. Voltmeter

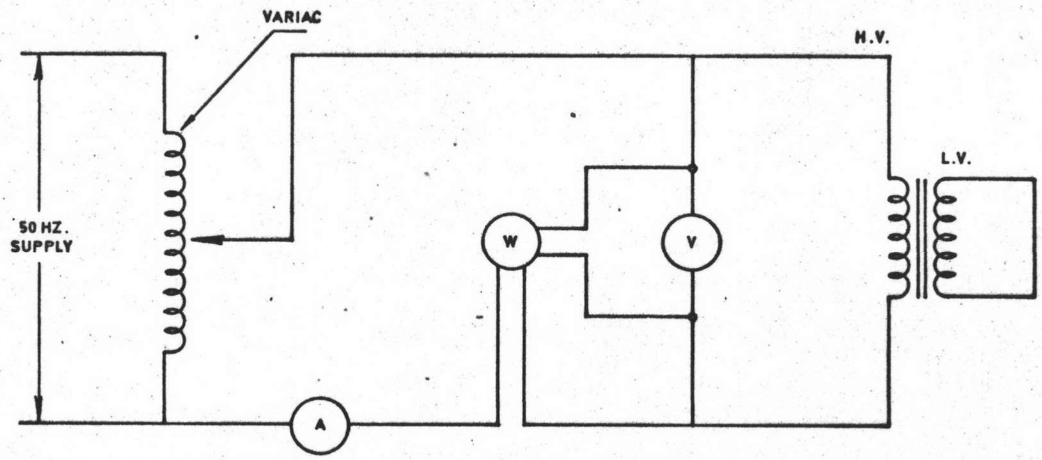


FIG.5-9 CONNECTION FOR THE SHORT CIRCUIT TEST

Test procedure

1. Connect the circuit as shown in Fig. 5 - 9
2. Short the low - voltage winding.
3. Raise the voltage until the milliammeter read 16.67 mA.
4. Record the voltage and watt from voltmeter and wattmeter respectively .

Test Result

Ambient temperature = $28^\circ c$

Short circuit test voltage (V_1) = 69 volts

Short circuit test current (I_1) = 16.67 mA

Short circuit test watt = 0 (could not be read)

Because of the short circuit test watt could not be read (very small copper loss), the a.c. resistance of the windings could not calculated, so that the equivalent resistance and reactance could not be found.

Impedance at $28^\circ c$ (Z_{tp}) $= V_1 / I_1$

$$= 69/16.67 \times 10^{-3} = 4139.79 \text{ ohms}$$

and

$$\text{Impedance voltage at } 28^\circ c = \frac{I_1 Z_{tp}}{E_p} \times 100$$

$$= \frac{16.67 \times 10^{-3} \times 4139.79}{12,000} \times 100$$

$$= 0.5750 \%$$

5.1.4.4 Open - circuit or Core - loss test

If normal voltage and frequency are applied to one winding of a transformer and if the other winding or windings are "open - circuited" the watts input represent hysteresis and core eddy - current losses, I^2r loss in the winding to which the voltage is supplied and dielectric losses in the insulation. Since the no load current is relatively small, it is usually unnecessary to substract the I^2r loss which it causes; consequently the no - load input can be taken as a measure of the core loss with fair accuracy.

This loss remains constant at all loads. A diagram of connections is shown in Fig. 5 - 10 on this connection the wattmeter reads the loss in the voltage coil of its own meter and in the voltmeter. To eleminate this error, if the low - voltage winding is opened and the wattmeter read, this second reading may be substracted from the previous reading to obtain the correct no - load loss such an error is appreciable in testing small transformers.

Apparatus required

1. Variac
2. Wattmeter
3. Ammeter
4. Voltmeter

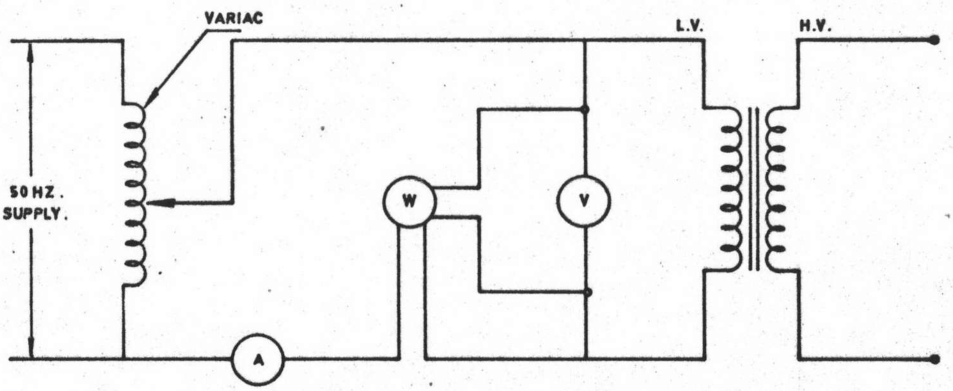


FIG.5-10 CONNECTION FOR THE OPEN CIRCUIT TEST.

Test procedure

1. Connect the low - voltage winding in parallel.
2. Connect the circuit as shown in Fig. 5 - 10.
3. Raise the voltage on low - voltage winding to 120 volts.
4. Read ampere, watt and voltage from ammeter, wattmeter

and voltmeter respectively and then record.

5. Open the low - voltage winding to find the tare - value of wattmeter and ammeter.
6. To find the values of ampere and watt when varying the voltage, do as the previous method.

Test result

The exciting current and watt loss of the core from open circuit test were shown in table below, Fig. 5 - 11 and Fig. 5 - 12 respectively.

Input voltage (volt)	No load current (mA)	No load loss (watt)	No load current Refer to primary side
50	42.00	2.10	0.42 (mA)
60	49.00	2.90	0.49
70	56.50	3.96	0.57
80	67.00	5.26	0.67
90	76.50	6.50	0.77
100	92.00	8.10	0.92
110	115.00	9.80	1.15
120	150.00	11.50	1.50
130	195.00	12.70	1.95
140	285.00	14.50	2.85
150	380.00	16.40	3.80
160	510.00	18.80	5.10

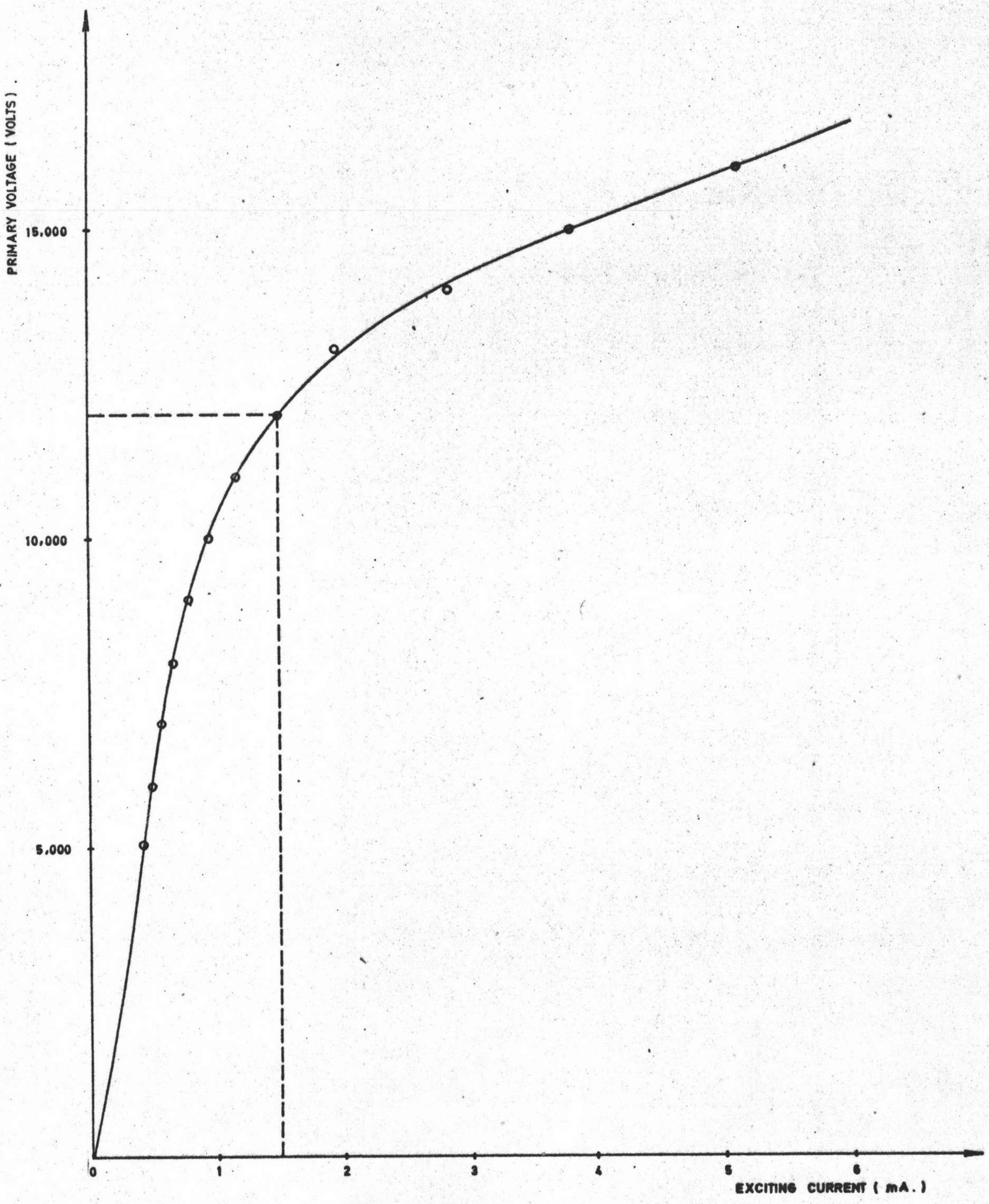


FIG. 5-11 EXCITING CURRENT CURVE .

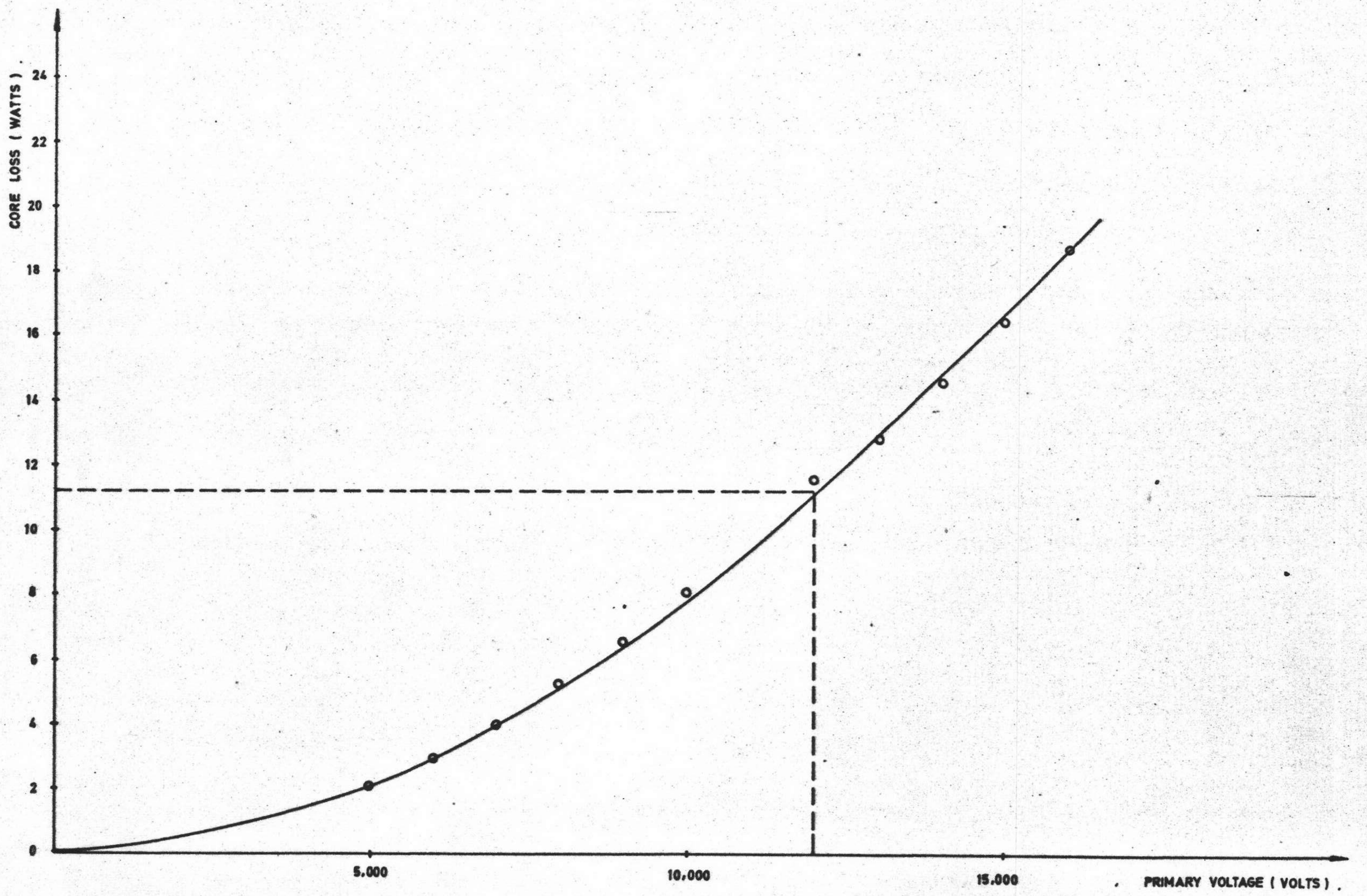


FIG. 5 - 12 CORE LOSS CURVE .

5.1.4.5 Sample of calculation

1. Calculation of voltage ratio error and phase angle from known zero and rated burden data at the same voltage and frequency from U.S.A. standard (USAS C 57.13 - 1968) clause 6.1.11 at secondary rated voltage 120 volts.

$$RCF_c = RCF_o + \frac{B_c}{B_t}\left[RCF_d \cos(\theta_t - \theta_c) + 0.000291\gamma_d \sin(\theta_t - \theta_c)\right] \quad ....(5.1)$$

$$\gamma_c = \gamma_o + \frac{B_c}{B_t}\left[\gamma_d \cos(\theta_t - \theta_c) - 3438\, RCF_d \sin(\theta_t - \theta_c)\right] \quad ....(5.2)$$

where

B_o, B_t and B_c = 1. Zero Burden for which RCF and γ are known.

2. A Burden for which RCF and γ are known, and

3. The Burden for which RCF and γ are to be calculated, respectively.

θ_t and θ_c = Power factor angle (degree of Burdens B_t and B_c respectively (θ_t and θ_c are positive angles for lagging power factor).

RCF_o, RCF_t and RCF_c = Transformer ratio correction factor for burdens B_o, B_t and B_c respectively.

γ_o, γ_t and γ_c = Transformer phase anglex in minutes for burden B_o, B_t and B_c respectively (γ is considered positive when the secondary voltage leads the primary voltage).

$RCF_d = RCF_t - RCF_o$ = Different between the transformer ratio Correction factors for burden B_t and B_o.

$\gamma_d = \gamma_t - \gamma_o$ = Difference between the transformer phase angles for burden B_t and B_o.

From table 5 - 2 at 100% rated voltage (120 volts)

$$B_t = 200 \text{ VA}$$

$$\text{Power factor} = \cos \theta_t = 0.85$$

$$\theta_t = 31.7883 \text{ degrees}$$

$$RCF_t = 1.0017$$

$$RCF_o = 0.9956$$

$$\gamma_t = 1 \text{ minute}$$

$$\gamma_o = 0.2 \text{ minute}$$

The RCF_c and γ_c were calculated at 200 VA 0.8 P.F.

$$\therefore B_c = 200 \text{ VA}$$

$$\text{Power factor} = \cos \theta_c = 0.80$$

$$\theta_c = 36.8699 \text{ degrees}$$

$$\theta_t - \theta_c = -5.0816 \text{ degrees}$$

$$\cos(\theta_t - \theta_c) = 0.99607$$

$$\sin(\theta_t - \theta_c) = -0.08857$$

$$RCF_d = 1.0017 - 0.9956 = 0.0061$$

$$\gamma_d = 1 - 0.2 = 0.8 \text{ minute.}$$

Substituted in Equation (5 - 1) and (5 - 2)

$$RCF_c = 0.9956 + \frac{200}{200}\left[0.0061 \times 0.99607 + 0.000291 \times 0.8 \, (-0.08857)\right]$$

$$= 1.0017$$

$$\gamma_c = 0.2 + \frac{200}{200}\left[0.8 \times 0.99607 - 3438 \times 0.0061 \, (-0.08857)\right]$$

$$= 2.85 \text{ minutes}$$

and for 25% rated burden 0.8 P.F. at 120 volts rated voltage

$$B_c = \frac{200}{4} = 50 \text{ VA}$$

$$RCF_c = 0.9956 + \frac{0.006055}{4}$$

$$= 0.9956 + 1.5140 \times 10^{-3} = 0.9971$$

$$\gamma_c = 0.2 + \frac{2.65}{4} = 0.2 + 0.6625$$

$$= 0.86 \text{ minute}$$

2. Calculation of ratio correction factor and phase angle at 120% rated voltage (144 volts).

From table 5 - 2 at rated secondary voltage 120 volts

$$RCF_o = 0.9956$$

$$\gamma_o = 0.2 \text{ minute}$$

From open circuit test Fig. 5 - 11 and Fig. 5 - 12 at rated voltage (12,000 volts)

$$V_p = 12{,}000 \text{ volts}$$

$$I_e = 1.5 \text{ mA}$$

$$W = 11.2 \text{ Watts}$$

$$\text{Cos. } \theta = \frac{11.2}{1.5 \times 10^{-3} \times 12{,}000} = 0.6222$$

$$\theta = 51.5214 \text{ degrees}$$

$$\sin\theta = 0.7828$$

$$I_m = 1.5 \times 0.7828 = 1.17 \text{ mA}$$

$$I_w = 1.5 \times 0.6222 = 0.93 \text{ mA}$$

$$n = 99.5316$$

From eq. (2.3) and (2.4)

$$R_o = n + \frac{I_w R_p + I_m X_p}{V_s} \quad \text{...........(2.3)}$$

$$\gamma_o = \frac{R_p I_m - X_p I_w}{nV_s} \quad \text{.............(2.4)}$$

$$\therefore \quad R_o = 0.9956 \times 100 = 99.56$$

$$\gamma_o = \frac{0.2}{3438} = 5.82 \times 10^{-5} \text{ radian}$$

Substituted in Equation (2.3) and (2.4)

$$99.56 = 99.5316 + \frac{0.00093 R_p + 0.00117 X_p}{120}$$

$$0.00093 R_p + 0.00117 X_p = 3.408 \quad \text{.................(5.3)}$$

$$5.82 \times 10^{-5} = \frac{0.00117 R_p - 0.00093 X_p}{99.5316 \times 120}$$

$$0.00117 R_p - 0.00093 X_p = 0.695 \quad \text{.................(5.4)}$$

From Equation (5.3) and (5.4)

$$X_p = 1495 \text{ ohms}$$

$$R_p = 1784 \text{ ohms}$$

From open circuit test Fig. 5 - 11and Fig. 5 - 12 at 120% rated voltage (14,400 volts)

$$V_p = 14{,}400 \text{ volts}$$

$$I_e = 3.1 \text{ mA}$$

$$W = 15.6 \text{ watts}$$

$$\cos \theta = \frac{15.6}{3.1 \times 10^{-3} \times 14{,}400} = 0.3495$$

$$\theta = 69.55 \text{ degrees}$$

$$\sin \theta = 0.9370$$

$$I_m = 3.1 \times 0.9370 = 2.9050 \text{ mA}$$

$$I_w = 3.1 \times 0.3495 = 1.084 \text{ mA}$$

Substituted in eq. (2.3) and (2.4)

$$R_o = 99.5316 + \frac{0.001084 \times 1784 + 0.002905 \times 1495}{144}$$

$$= 99.5752$$

$$\gamma_o = \frac{1784 \times 0.002905 - 1495 \times 0.001084}{99.5316 \times 144}$$

$$= 2.4851 \times 10^{-4} \text{ radian}$$

$$= 0.85 \text{ minute}$$

$$\therefore RCF_o = 0.9958$$

From eq. (2.5) and (2.6)

$$R = R_o + \frac{nI_s}{V_s} (R_{ts} \cos \theta + X_{ts} \sin \theta) \quad \text{........(2.5)}$$

$$\gamma = \gamma_o - \frac{I_s}{V_s} (X_{ts} \cos \theta - R_{ts} \sin \theta) \quad \text{........(2.6)}$$

From table 5 - 2 at rated secondary voltage (120 volts)

$$RCF = 1.0017$$

$$RCF_o = 0.9956$$

$$\gamma = 1.0 \text{ minute} = \frac{1.0}{3438} = 2.91 \times 10^{-4} \text{ radian}$$

$$\gamma_o = 0.2 \text{ minute} = \frac{0.2}{3438} = 5.82 \times 10^{-5} \text{ radian}$$

$$\text{Power factor} = \cos \theta = 0.85$$

$$\sin \theta = 0.53$$

$$R = 1.0017$$

$$R_o = 99.56$$

$$\frac{I_s}{V_s} = \frac{1.6667}{120} = \frac{1}{72} \text{ mohs}$$

$$n = 99.5316$$

Substituted in eq. (2.5) and (2.6)

$$100.17 = 99.56 + \frac{99.5316}{72}(0.85\,R_{ts} + 0.53\,X_{ts})$$

$$0.85\,R_{ts} + 0.53\,X_{ts} = 0.4484 \quad .....(5.7)$$

$$\frac{1.0}{3438} = \frac{0.2}{3438} - \frac{1}{72}(0.85\,X_{ts} - 0.53\,R_{ts})$$

$$0.53\,R_{ts} - 0.85\,X_{ts} = 0.0168 \quad .....(5.8)$$

From eq. (5.7) and (5.8)

$$X_{ts} = 0.22 \text{ ohm}$$

$$R_{ts} = 0.382 \text{ ohm}$$

Calculated ratio correction factor and phase angle at 200 VA 0.8 P.F. lagging at 120% rated voltage (144 volts)

$$R = 99.58 + \frac{99.5316}{72}(0.80 \times 0.382 + 0.60 \times 0.22)$$

$$= 1.0019$$

$$\gamma = \frac{0.67}{3438} - \frac{1}{72}(0.22 \times 0.8 - 0.382 \times 0.60)$$

$$= 9.34 \times 10^{-4} \text{ radian}$$

$$= 3.21 \text{ minutes}$$

$$RCF = \frac{100.19}{100} = 1.0019$$

3. Calculation of ratio correction factor and phase angle at rated secondary voltage 240 volts.

From Table 5 - 2 at no load condition of rated secondary voltage 120 volts

$RCF_o = 0.9956$

$\gamma_o = 0.2$ minute

From previous calculation at condition of rated secondary voltage 120 volts.

$R_{ts} = 0.382$ ohm

$X_{ts} = 0.22$ ohm

Refer to primary side

$$R_{tp} = (0.382)(99.5316)^2$$

$$= 3784.29 \text{ ohms}$$

$$X_{tp} = (0.22)(99.5316)^2$$

$$= 2179.44 \text{ ohms}$$

Refer to secondary side at rated 240 volts

$$n = \frac{99.5316}{2} = 49.7658$$

$$R_{ts} = \frac{3784.298}{(49.7658)^2} = 1.528 \text{ ohms}$$

$$X_{ts} = \frac{2179.44}{(49.7658)^2} = 0.88 \text{ ohm}$$

From Eq. (2.5) and (2.6)

$$R = R_o + \frac{nI_s}{V_s}(R_{ts}\cos\theta + X_{ts}\sin\theta) \quad ......(2.5)$$

$$\gamma = \gamma_o - \frac{I_s}{V_s}(X_{ts}\cos\theta - R_{ts}\sin\theta) \quad ......(2.6)$$

$$R_o = 0.9956 \times 50 = 49.78$$

$$\gamma_o = 0.2 \quad \text{minute}$$

$$= \frac{0.2}{3438} \quad \text{radian}$$

$$I_s = \frac{200}{240}$$

$$= 0.8333 \quad \text{ampere}$$

$$V_s = 240 \quad \text{volts}$$

$$\frac{I_s}{V_s} = \frac{0.8333}{240}$$

$$= \frac{1}{288} \quad \text{mohs}$$

Calculate ratio correction factor and phase angle at 200 VA 0.8 Pf. lagging at 100% rated volt. e (240 volts).

$$R = 49.78 + \frac{49.7657}{288} (1.528 \times 0.8 + 0.88 \times 0.6)$$

$$= 49.78 + 0.3025$$

$$= 50.0825$$

$$RCF = \frac{50.0825}{50}$$

$$= 1.00165 = 1.0017$$

$$\gamma = \frac{0.2}{3438} - \frac{1}{288} (0.88 \times 0.8 - 1.528 \times 0.6)$$

$$= 7.97053 \times 10^{-4} \quad \text{radian}$$

$$= 2.74 \quad \text{minutes}$$

5.2 Type Test

5.2.1 Temperature rise test

The temperature measurements demonstrate that the transformer will carry its load without excessive heating.

All temperature measurements shall be made with the rated secondary burden at any power factor between 0.8 lagging and unity and 1.2 time the rated voltage at rated frequency. The test shall be continued until the temperature of the voltage transformer has reached a steady state (when the rated of temperature rise does not exceed 1°C per hour). The test site ambient temp. may be between 10°C and 30°C. The altitude shall not be more than 1000 metres above sea level.

The oil temperature of the transformer under test will be measured by thermometer immersed approximately 5.00 cm. below the top oil surface in the transformer tank.

The ambient temperature of the cooling air shall be measured by the average reading of several thermometers at different points around the transformer at its mean height and at one or two meters distant. The average is to be taken at equal intervals over the last quarter of the test. The thermometers are to be protected from draught and from radiation and their time lag is to be so small as possible.

The temperature of the winding to be determined from their increase of resistance. Let R_1 be the resistance of a winding when its temperature is t_1 at the beginning of a test, t_1 should be as nearly as possible equal to the initial temperature of the surrounding air. Then if R_2 is the resistance at the end of the heat run when the winding temperature is t_2

$$R_2 / R_1 = (t_2 + 234.5)/(t_1 + 234.5)$$

and temperature rise

$$= t_2 - t_a = \left[(R_2 - R_1)/R_1\right](t_1 + 234.5) + t_1 - t_2$$

Where t_a is the ambient air temperature at the end of the test. The heat run must be continued long enough to ensure that the limit of temperature rise is not exceed.

Thermometer of thermocouples are also necessary for measuring the iron surface temperature and that of the oil. In all cases where thermometers are used the indicating fluid should be alcohol rather than mercury, since not only are the readings of mercury - in - glass thermometers apt to be inaccurate in alternating magnetic field, but if the glass is broken. The mercury may seriously damage the transformer winding by amalgamating with the copper, especially if the coil are of fine wire.

There are three methods in testing transformer i.e. direct loading method, back - to back method and short circuit method. The direct loading method was used for this test.

This test followed The IEC Recommendation Publication 186 clause 8 and 14.

Apparatus required.

1. High voltage step - up transformer
2. Variac
3. Ammeter
4. Wattmeter
5. Incandescent lamps 3 x 60 watts
6. Alcohol thermometer (4 units)
7. Double Bridge
8. Wheatstone Bridge
9. Timing clock
10. Watch

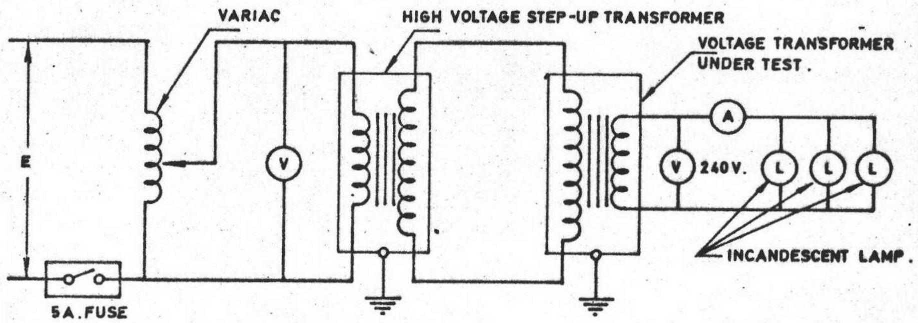


FIG 5.-13 TEMPERATURE RISE TESTING CONNECTION DIAGRAM.

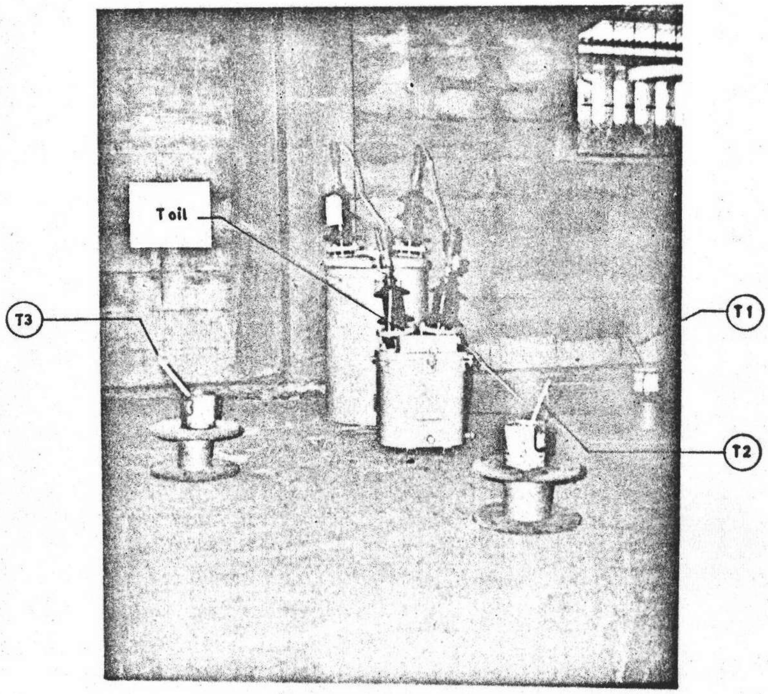


FIG 5.-14 TEMPERATURE RISE TEST.

Test procedure.

1. Record the room temperature.
2. Measure the low - voltage winding resistance by Double Bridge then record (Secondary winding are connected in series).
3. Measure the high - voltage winding resistance by Wheatstone Bridge, then record.
4. Putting the alcohol thermometer into the oil, 5.00 cm. deep from its surface, in the transformer tank. Measure the top oil temperature (t_4) (see Fig. 5 - 14).
5. 3 other units of alcohol thermometer are put in the transformer oil canning separately. The canning must be placed far about 1 meter around the transformer (see Fig. 5 - 14). Measure the ambient temperature (t_1, t_2, t_3) from these thermometers.
6. Incandescent lamps (pure resistive load) are used for burden. Measure its value at 240 volts, we can find that 3 x 60 watts at 220 volts of the lamp will be equal to 200 watts at 240 volts.
7. Connect the circuit as shown in Fig. 5 - 13.
8. Raise the voltage of high voltage step - up transformer until the ammeter at the secondary circuit reaches 1 ampere. (It shows approximately the primary voltage equal to 1.2 time the rated voltage)
9. Record the value of temperature t_1, t_2, t_3, t_4 and time interval as shown in Table 5 - 3.

10. The test will be held for 9 hours to get sure that the temperature rise does not exceed 1 °C per hour. Then the voltage supply and all equipments in the loading circuit are removed from the voltage transformer.
11. Measure the after shutdown resistance of the high - voltage winding by the wheatstone bridge as fast as possible. Then record the values.
12. The voltage transformer under test is load again as the previous condition for 2 hours then remove the voltage supply and equipment.
13. The after shutdown resistance of the low - voltage winding will be measured by the double bridge as fast as possible. Record the resistances at any time.
14. Record the room temperature at shutdown.

Test results

1. The temperature rise of the top oil, by method of extrapolation[2] from Fig. 5 - 15 and Table 5 - 3 is equal to 3.12 °C.
2. The data of high-voltage winding resistance after shutdown was shown below.

Time after shutdown (second)	High - voltage winding resistance (ohms)
42	1926
60	1923
90	1922
120	1921

2. INTERNATIONAL ELECTROMECHANICAL COMMISSION. Power Transformer IEC Recommendation Publication 76 second edition, P. 95.

By method of extrapolation[3] as shown in Fig. 5 - 16 the high - voltage winding resistance at shutdown equal to 1937.55 ohms.

$$\text{The temperature rise} = \frac{(R_2 - R_1)}{R_1} (t_1 + 234.5) + t_1 - t_2$$

$$= \frac{1937.55 - 1879}{1879} (27.7 + 234.5) + 27.7 - 30.43$$

$$= 5.44^{\circ}C$$

3. The data of low - voltage winding resistance after shutdown was shown below.

Time after shutdown (second)	Low - voltage winding resistance (ohm)
40	0.624
55	0.622
65	0.621
80	0.620
140	0.619

By method of extrapolation as shown in Fig. 5 - 17 the low - voltage winding resistance at shutdown equal to 0.63485 ohm. The ambient temperature at shutdown = 30°C. Compute the temperature rise as high - voltage winding. The temperature rise of the low - voltage winding = 10.18°C

The specified maximum temperature rise for all classes of transformer immersed in oil is 60°C. So that the results shown above are satisfied as IEC Recommendation Publication 186 (1969) clause 8 and 14.

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3. BRITISH STANDARDS INSTITUTION Specification for Power Transformer. British Standard 171:1970 P. 53.

Heat Run Test

Direct Loading Method

Voltage transformer No. CU - 54126 | Rated Burden 200 VA

Rated Voltage 12,000/120 - 240 volts.

Cold resistance LT. 0.6060 ohm Temperature 27.7°C

HT. 1879.0 ohms Temperature 27.7°C

24 Feb. 1976.

Time	Primary Voltage (KV)	Secondary Current (Amp)	Ambient temperature				t oil top oil (°C)	Temp. Rise of oil (°C)	Remark
			t_1 (°C)	t_2 (°C)	t_3 (°C)	T average (°C)			
8.45	1.2 x 12	1.0	27.00	27.80	27.80	27.87	27.70	-0.17	
9.00	1.2 x 12	1.0	28.20	28.00	28.00	28.07	28.10	0.03	
9.15	1.2 x 12	1.0	28.20	28.20	28.20	28.20	28.30	0.10	
9.30	1.2 x 12	1.0	28.50	28.20	28.50	28.40	28.70	0.30	
9.45	1.2 x 12	1.0	28.80	28.50	28.50	28.60	29.00	0.40	
10.00	1.2 x 12	1.0	28.90	28.70	28.70	28.77	29.30	0.53	
10.30	1.2 x 12	1.0	29.10	28.90	29.00	29.00	29.80	0.80	
11.00	1.2 x 12	1.0	29.40	29.00	29.20	29.20	30.20	1.00	
12.00	1.2 x 12	1.0	29.60	29.30	29.40	29.43	31.00	1.57	
13.00	1.2 x 12	1.0	29.80	29.50	29.70	29.67	31.60	1.93	
14.00	1.2 x 12	1.0	30.00	29.80	29.90	29.90	32.20	2.30	
15.00	1.2 x 12	1.0	30.50	30.00	30.30	29.27	32.80	2.53	
16.00	1.2 x 12	1.0	30.70	30.20	30.50	30.47	33.10	2.63	
17.00	1.2 x 12	1.0	30.60	30.40	30.50	30.50	33.30	2.80	
18.00	1.2 x 12	1.0	30.50	30.30	30.50	30.43	33.40	2.90	

Table 5 - 3 Temperature rise test data

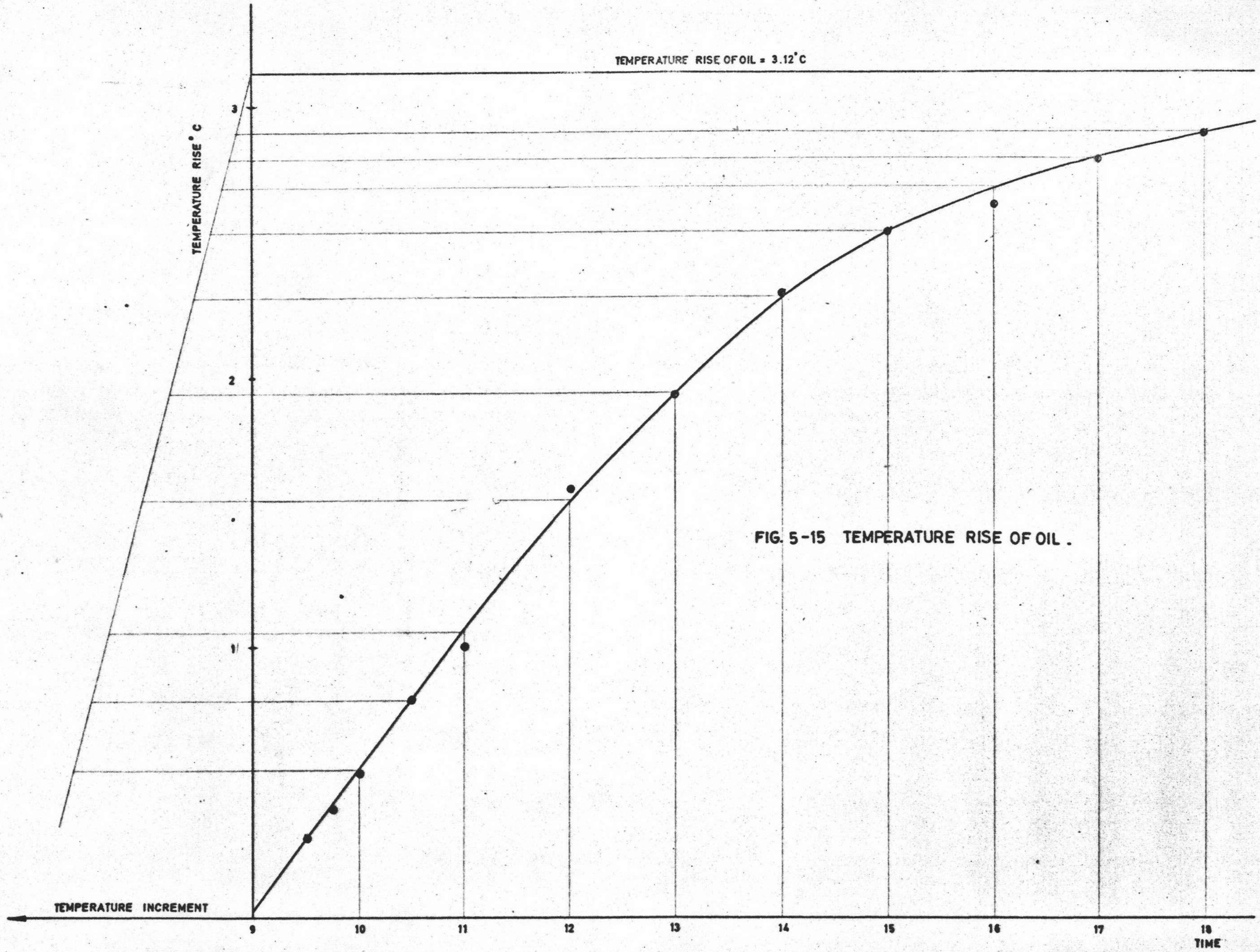

FIG. 5-15 TEMPERATURE RISE OF OIL.

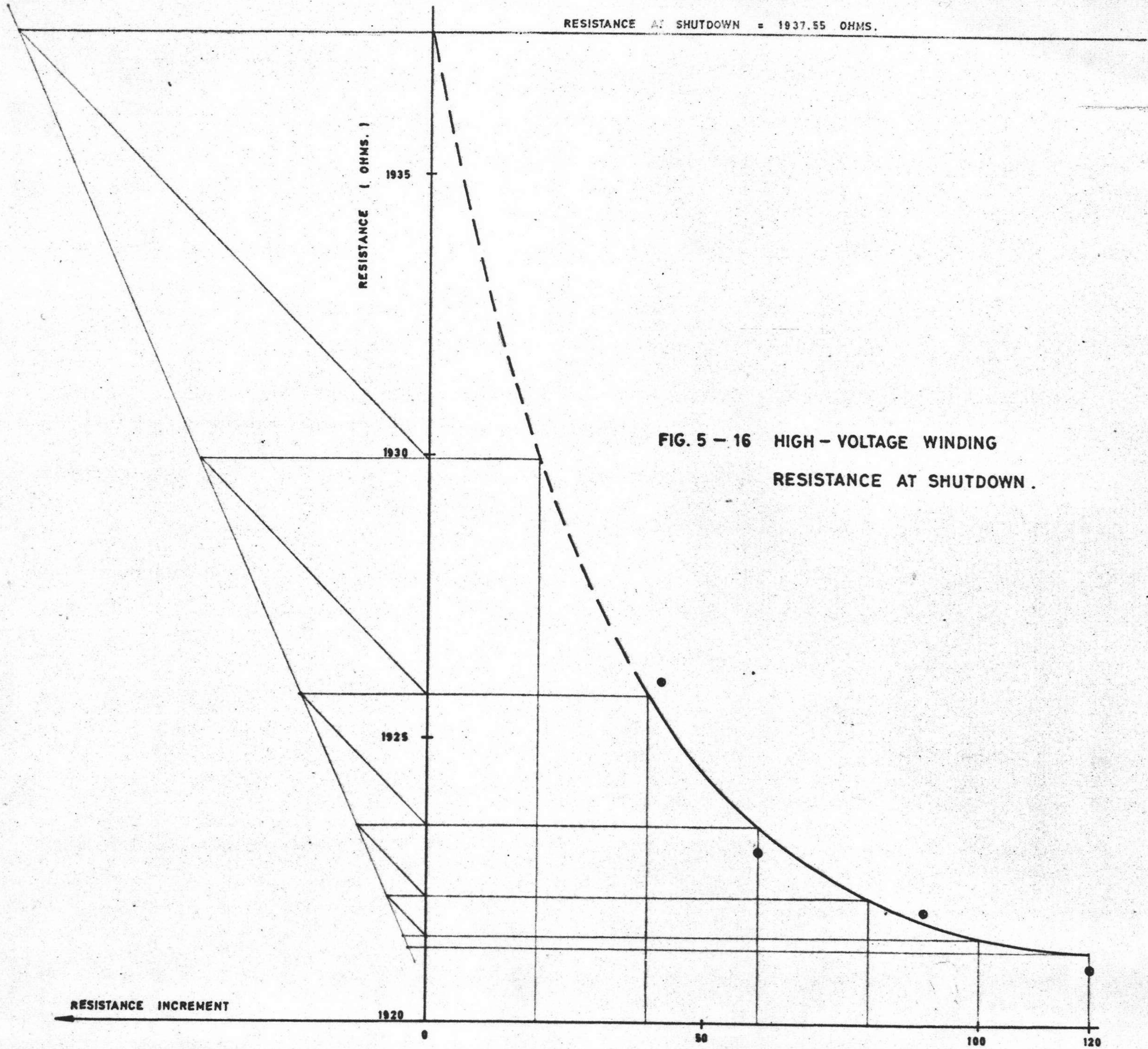

FIG. 5 – 16 HIGH – VOLTAGE WINDING RESISTANCE AT SHUTDOWN.

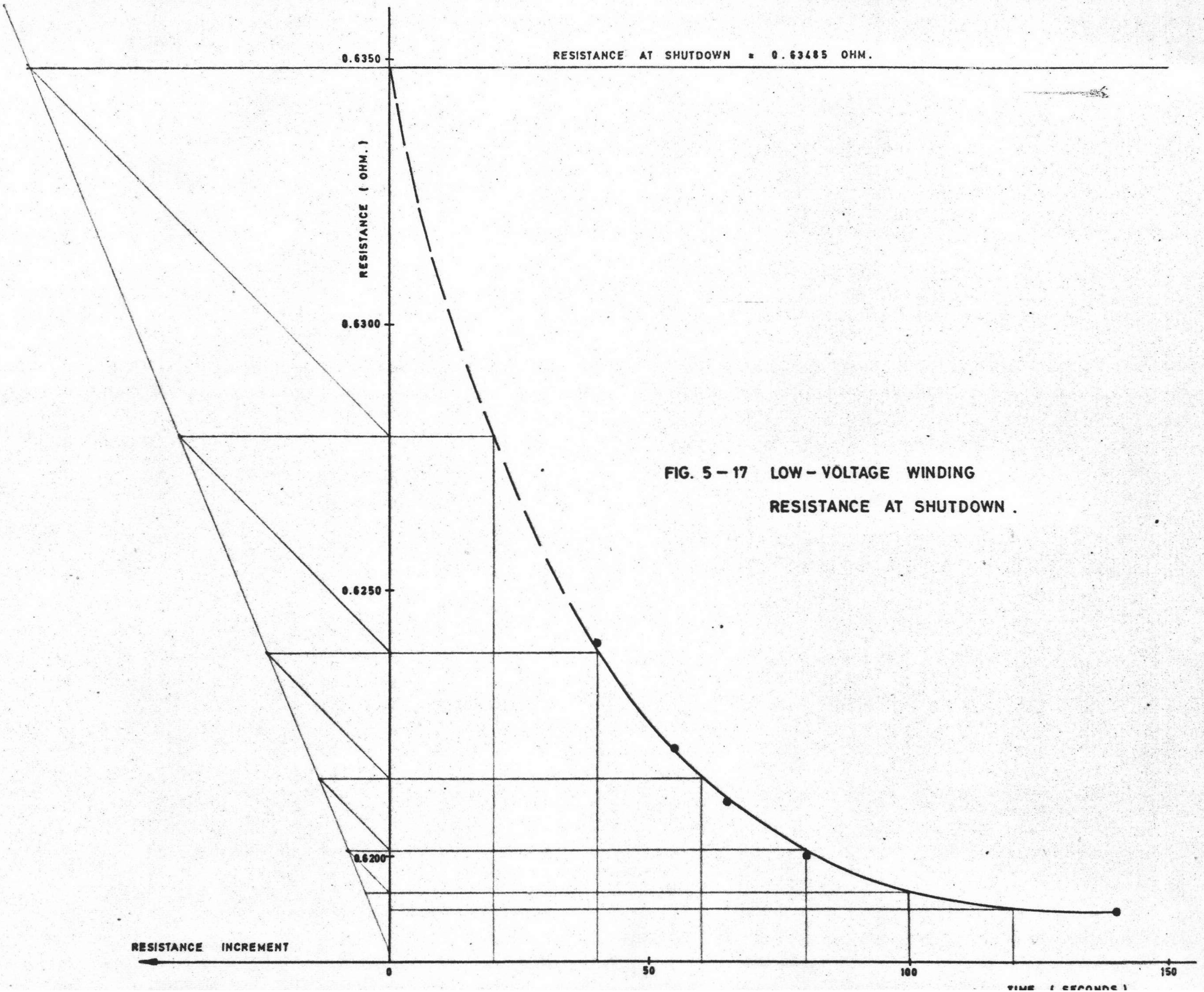

FIG. 5 – 17 LOW – VOLTAGE WINDING RESISTANCE AT SHUTDOWN .

5.2.2 Impulse voltage tests

The impulse voltage tests demonstrate the strength of the insulation against the impulse voltages which are permitted by the lightning arresters and line shielding to reach the transformer. The transformers are designed to have certain standard impulse strengths which are demonstrated by testing.

High - voltage test techniques (IEC Recommendation Publication 60) defines the standard wave shape as being 1.2/50 microseconds. The impulse is usually generated by a circuit arrangement in which a number of capacitors are changed in parallel from a direct voltage source and then discharged in series through a circuit which includes the test object.. The impulse test voltages are shown in table 8 of IEC Recommendation Publication 76 (Power transformers) according to the highest system voltage and the specified insulation level.

The test voltage shall be applied to each primary terminal, one terminal of the winding under test shall be grounded. The terminals of each of the other winding may be grounded.

The voltage transformer shall capable of withstanding voltage of both positive and negative polarity, but where there is no doubt which polarity is the more onerous, it shall be sufficient to test with that polarity only. The peak value and wave - shape of the impulse voltages shall be recorded by mean of Cathode - Ray Oscillographs.

When the five impulses of the specified peak value are applied.

If no disruptive discharge take place, the requirements of the test have been satisfied. If more than one disruptive discharge takes place, the apparatus is considered to have failed the test. If only one disruptive discharges, ten additional impulses shall be applied. The apparatus is considered to have passed the test if, during these additional ten applications no disruptive discharge occurs.

Apparatus required

1. D.C. High - voltage generator
2. Impulse voltage generator
3. Cathode - ray oscillograph
4. Sphere gap

Test procedure

1. Adjust the voltage wave shape of the reduced full wave equal to 1.2/50 microseconds at peak value equal to 37.5 KV (Full wave = 75 KV).

2. Short circuit the low - voltage winding and ground.

3. Ground the tank.

4. Connect one terminal of the high - voltage winding to the impulse generator as shown in Fig. 5 - 19.

5. Apply the reduced full wave voltage (positive polarity) to the voltage transformer under test and record the wave shape with cathode - ray oscillograph.

6. Apply five full wave voltage (wave - shape 1.2/50 micro-second, crest voltage 75 KV) respectively to the voltage transformer and record the wave shape.

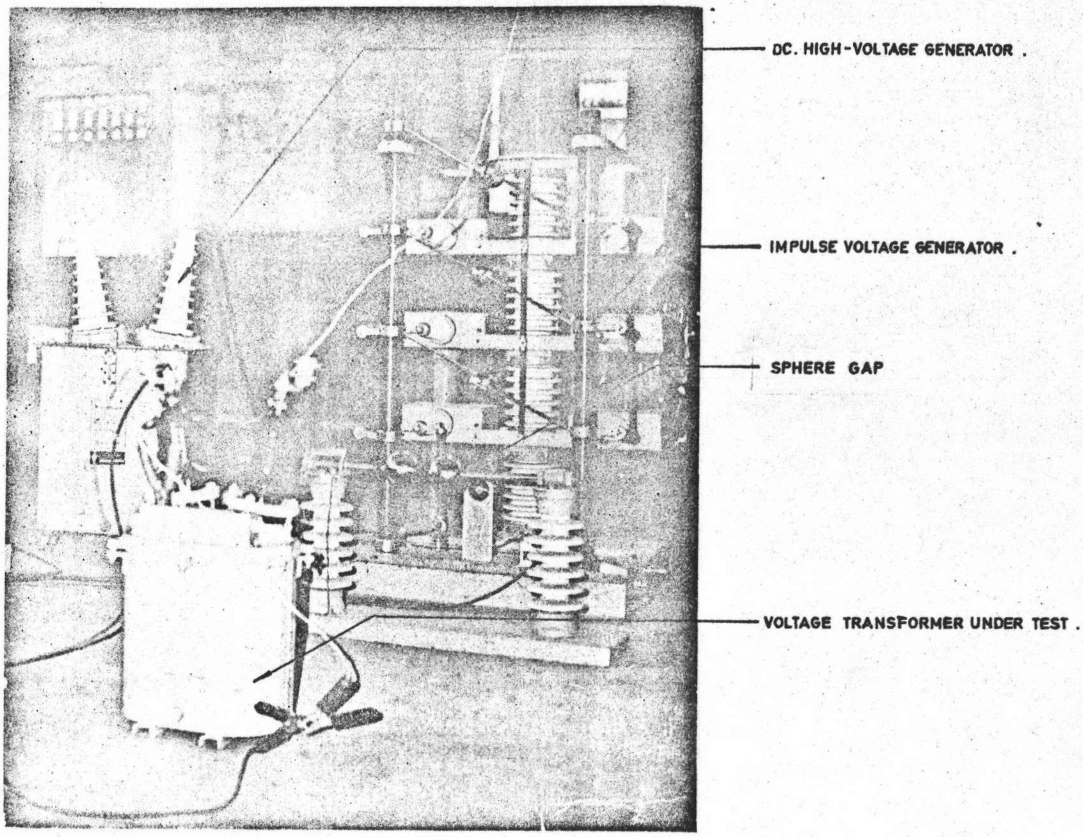

FIG 5-18 . IMPULSE VOLTAGE TEST .

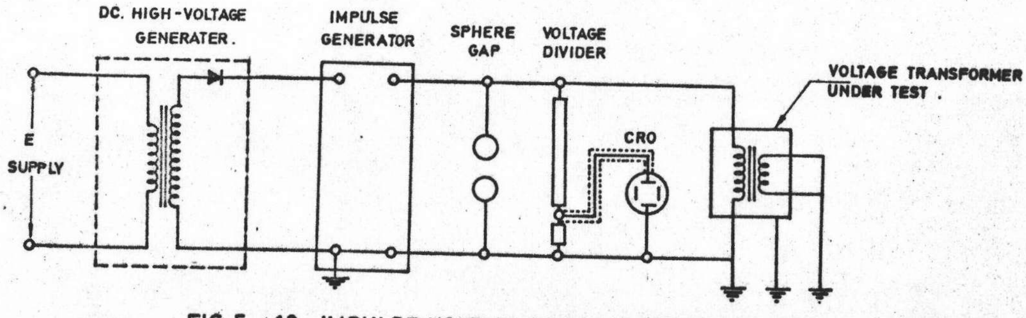

FIG 5.-19 IMPULSE VOLTAGE TEST CONNECTION DIAGRAM .

Test result

The wave shape of impulse voltage applied to high - voltage winding of the voltage transformer under test were shown in Fig. 5 - 20 to Fig. 5 - 25 respectively.

By comparison of the full wave impulse voltage with the reduced full wave voltage, no differences in the wave form are noticed. It show that the voltage transformer could withstand impulse voltage test according to IEC Recommendation Publication 186 (1969) clause 15.

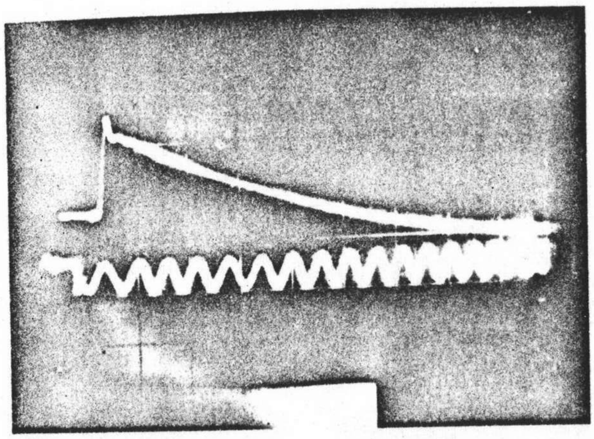

FIG 5.-20 REDUCED FULL WAVE VOLTAGE OSCILLOGRAPH.

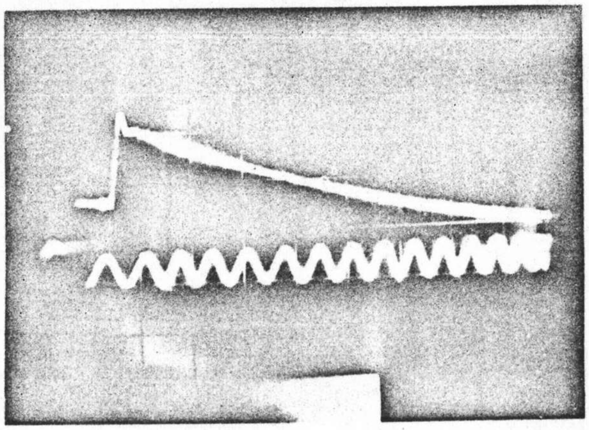

FIG 5.-21 1st. FULL WAVE VOLTAGE OSCILLOGRAPH.

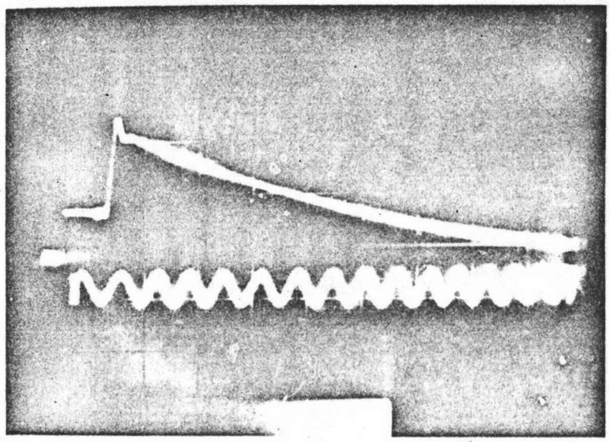

FIG 5.-22 2nd. FULL WAVE VOLTAGE OSCILLOGRAPH.

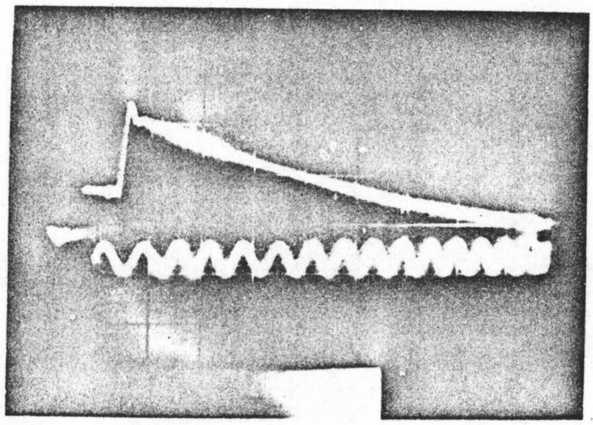

FIG 5.-23 3rd. FULL WAVE VOLTAGE OSCILLOGRAPH.

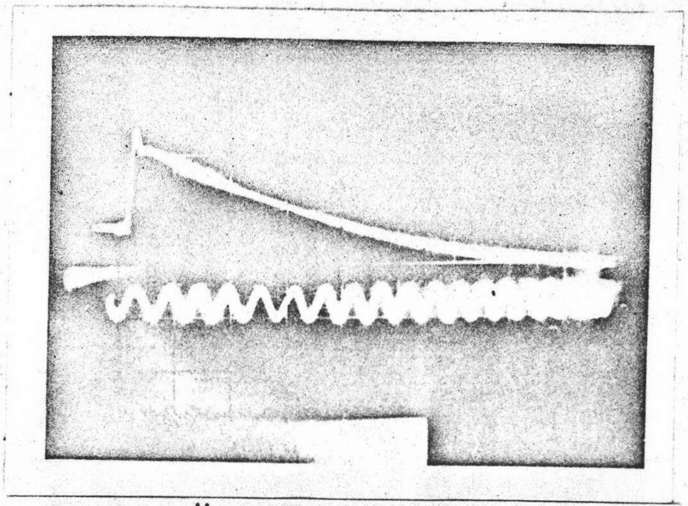

FIG 5.-24 4th. FULL WAVE VOLTAGE OSCILLOGRAPH.

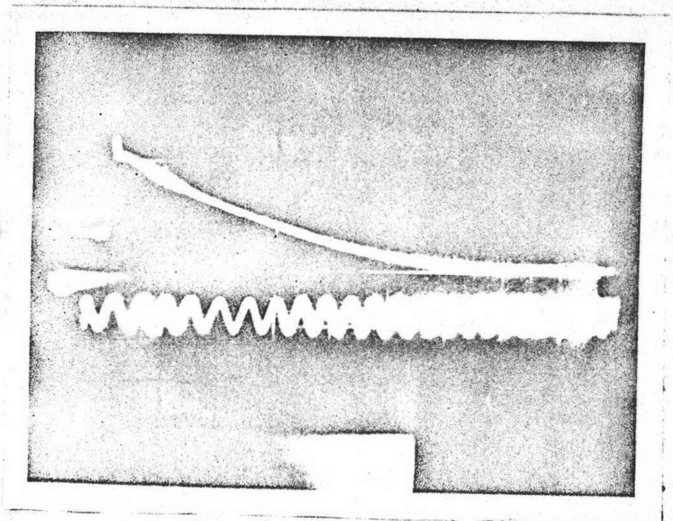

FIG 5.-25 5th. FULL WAVE VOLTAGE OSCILLOGRAPH.