Department of Electrical & Electronics Engineering

Transformers and Induction Machines Laboratory Manual

MALNAD COLLEGE OF ENGINEERING

HASSAN – 573 202.

DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

MALNAD COLLEGE OF ENGINEERING, HASSAN

(An Autonomous Institution Affiliated to VTU Belagavi)

Certificate

This is to certify that Mr./Ms. ______________________________ has satisfactorily completed the course of experiments in ***Transformers and Induction Machines*** laboratory prescribed by the Malnad College of Engineering, Hassan, under VTU, Belagavi for III semester E&E (B.E.) Program in the laboratory of this college in the year 20 - 20 .

Name of the Candidate:

Reg. No. :

Date :

Signature of the Teacher in charge of the batch.

DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING
MALNAD COLLEGE OF ENGINEERING, HASSAN.

Transformers and Induction Machines Lab.

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Expt. No.	Title	Date	Page No.

Marks Awarded

Signature of the Staff incharge

Experiment No.

OPEN CIRCUIT AND SHORT CIRCUIT TEST ON A SINGLE PHASE TRANSFORMER

Objectives: To determine

1. Equivalent circuit parameters of the transformer
2. Performance curves such as
   a) Efficiency Vs. Load
   b) Regulation Vs. Power factor and
3. Maximum efficiency.

Introduction:

Transformer is a static electrical device widely used in AC power systems to step-up and step-down the voltages to suitable values at different locations in the system. It is composed of a closed magnetic circuit using grain oriented silicon steel laminations. Two or more windings are placed on the core. There is no air gap structure and there exists a very good coupling between the windings. In the case of a two winding transformer, the winding that receives the electrical power is called primary and the one that delivers the electrical power to the load is called secondary. Transformer on no-load draws a very small current at normal voltage and frequency since the magnetic core is infinitely permeable, a small magnetizing current is required to maintain the mutual flux. In addition, the core is not perfectly ideal, it requires a small component of current to account for the hysteresis and eddy current power loss occurring in the core. Thus the net load current is the resultant of two components of currents which are 90° out of phase.

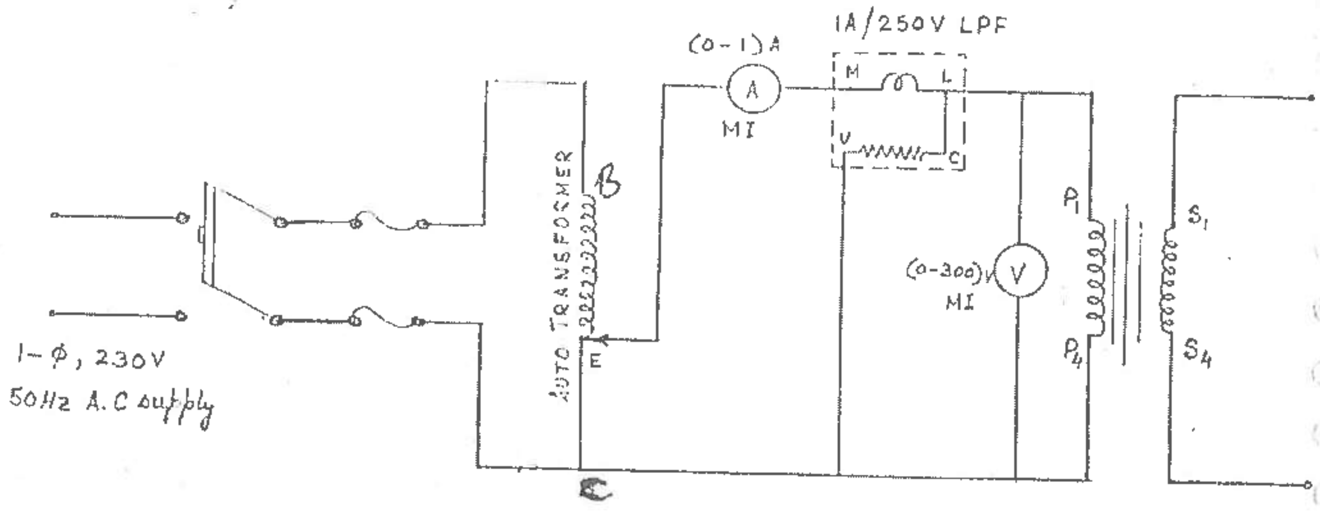
The power consumed by the transformer at no-load represents only the iron loss, since there is no current in the secondary and the current in the primary is negligibly small. Iron loss consists of hysteresis loss and eddy current loss, which depend upon the quality and quantity of the core material, frequency and maximum flux density or voltage.

Hysteresis loss $= B^{1.6}.f.v$

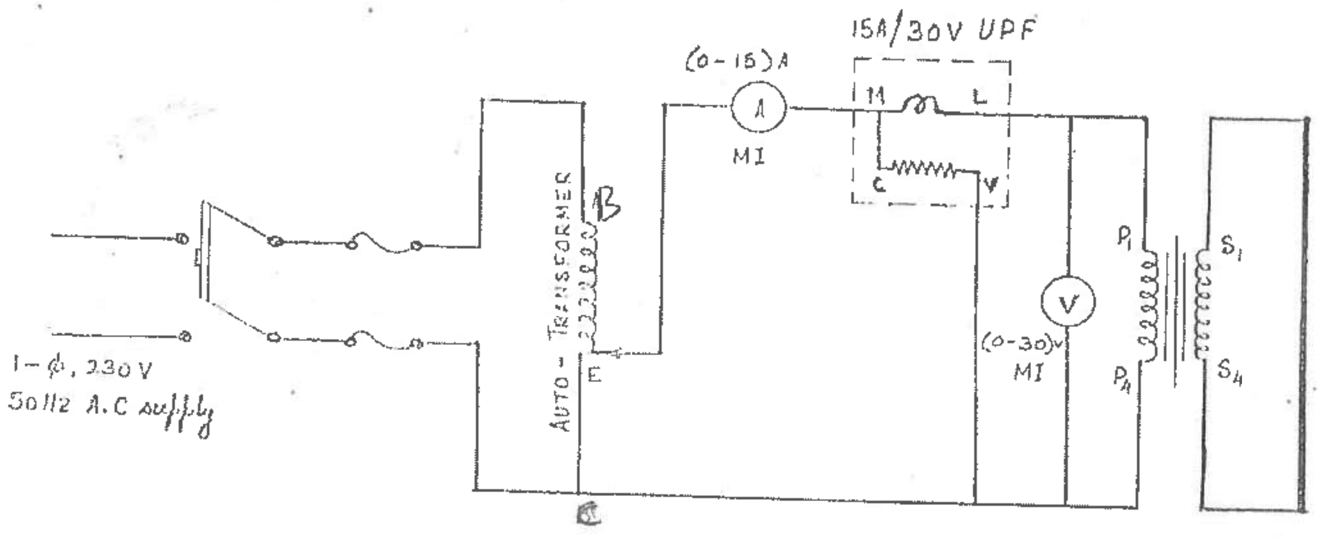
Eddy current loss $= (B.f.t)^2$

Where B is the flux density, f is the frequency, t is the thickness of the lamination used and v is the volume of the core.

Combined loss $= K.V^x$; V is the primary input voltage, K and x are constants and x is always greater than 1, i.e., greater the input voltage greater is the iron losses. That is why in



OPEN CIRCUIT TEST



SHORT CIRCUIT TEST

majority of the cases, core losses are minimized by careful selection of cross section and volume of the core material.

When the transformer is loaded the secondary induced current develops an opposing mmf by Lenz's law and tries to reduce the mutual flux. As the flux in the core tend to fall and gives room for additional current flow into the primary, applied voltage remaining constant. Thus the primary current increases on loading the transformer. The ultimate current in the primary will be such that power input to the transformer is equal to the power output neglecting the small losses in the transformer. Thus the transformer is stable in its operation in transforming power from one winding to the another, by the principle of magnetic induction.

When the windings bear currents comparable to the rated currents, each winding develops leakage flux whose effect is to impart a leakage reactance to each winding. The voltage V_1 applied to the primary must have a component to drive the current I_1 against the emf induced in the primary by its leakage flux and the main emf E_2 induced in the secondary must have a component to drive the current I_2 against the emf induced in the secondary by its leakage flux.

The emf's induced in the windings by leakage fluxes are self-induced emf's. Since these emf's are not useful as far as the load is concerned, they are voltage drops in the windings and this effect is accounted by equivalent reactances. As such on-load there are four voltage drops to be considered in the study of performance of the transformer. They are the inherent resistive voltage drops in primary and secondary windings and self-induced emf's due to these leakage fluxes. The vector diagrams for lagging and leading power factor conditions are shown in figure.

When the transformer is short-circuited at its secondary terminals its terminal voltage V_2 becomes zero and whatever emf that is induced in the secondary by the mutual flux will be dropped as impedance drop I_2Z_2. The secondary terminal voltage being zero, the primary applied voltage accounts for drop in the primary leakage impedance Z_1 and for the back emf E induced by small mutual flux. The back emf in the primary has the same magnitude as that induced in the secondary but expressed in primary terms. Thus the primary applied voltage under short circuit conditions is entirely dropped as impedance drop I_1Z_{1e}, where Z_{1e} is the impedance in primary terms. However the short circuiting of a transformer when normal voltage is acting on the primary, causes very heavy currents to flow in the windings which may damage the windings of the transformer. Hence in order to find the leakage impedance of the transformer though a short circuit test is useful, it is conducted at low voltage limiting the currents to the rated values. Efficiency in usual sense is given by the ratio of output in watts to the input watts. This is also known as commercial efficiency. However, this efficiency can not be taken as a figure of merit to assess the performance of all types of transformers. The distribution transformers which are used to supply domestic loads and general loads such as irrigation pumps etc., have their primaries energized for all the 24 hours, although their secondary supply for most of the time either light loads or no-loads. Thus the iron losses in such transformers exists for all the time whereas the copper losses occur only when there is a load. The performances of such transformers are usually judged by all day efficiency and it is computed as the ratio of output energy to input energy to the transformer for 24 hours. This efficiency is always less than commercial efficiency.

Name plate details:

KVA rating of the transformer :
Primary voltage rating :
Secondary voltage rating :
Rated primary current :
Rated secondary current :
Type of transformer :

Instruments and Accessories:

Voltmeter (MI)	(0 – 300) V	1 no.
	(0 – 30) V	1 no.
Ammeter (MI)	(0 – 1) A	1 no.
	(0 – 20) A	1 no.
Wattmeter	1A/250V LPF	1 no.
	20A/30V UPF	1 no.
Autotransformer		1 no.

S

Observations:

O C Test		
V_o Volts	I_o Amps.	W_o Watts

S C Test		
V_{sc} Volts	I_{sc} Amps.	W_{sc} Watts

Iron losses $W_i = W_o$ =

Copper losses $W_{cu} = W_{sc}$ =

No load power factor, Cos φ_o $= W_o / V_o I_o$

φ_o =

sin φ_o =

Active component of no-load current I_w $= I_o \cos \varphi_o$

Reactive component of no-load current I_m $= I_o \sin \varphi_o$

$R_o = V_o / I_w$

$X_o = V_o / I_m$

Equivalent resistance R_{1e} $= W_{sc} / I_{sc}^2$

Equivalent impedance Z_{1e} $= V_{sc} / I_{sc}$

Equivalent reactance X_{1e} $= \sqrt{Z_{1e}^2 - R_{1e}^2}$

Percentage regulation $= \dfrac{I_{sc}(R_{1e}\cos\phi \pm X_{1e}\sin\phi)}{Rated Voltage} \times 100$

S

Power factor ($\cos\varphi$)	Sin φ	Percentage Regulation	
		Lagging p.f.	Leading p.f.
0.0			
0.2			
0.4			
0.6			
0.8			
1.0			

Percentage efficiency $= \dfrac{kVA.x.pf.10^3}{kVA.x.pf.10^3 + W_i + x^2 W_{cu}}.100$

Load fraction for maximum efficiency $= \sqrt{\dfrac{W_o}{W_{sc}}}$

Load fraction (x)	Percentage Efficiency	
	For power factor =	For power factor =
0.2		
0.4		
0.6		
0.8		
1.0		
1.2		

Procedure:

Open circuit test:- Connections are made as shown in figure. The autotransfomer is kept in its initial zero position. The supply switch S is closed with the secondary terminals kept open. The voltage is gradually increased using autotransformer till the voltmeter reads rated voltage. At this point the readings of all the meters are recorded. The voltage is decreased to zero and the main switch S is opened.

Short circuit test:- Connections are made as shown in figure. The autotransformer is kept in its initial zero position. The supply switch S is closed with the secondary terminals short-circuited. The voltage is gradually increased using autotransformer till the ammeter records the rated currents. At this point the readings of all the meters are recorded. Enough care must be taken in moving the knob of autotransformer, as slight variation will cause a considerable current to flow in the transformer. The voltage is decreased to zero, and the main switch S is opened. The short circuit link of secondary winding is immediately removed.

Result:

The equivalent circuit and the performance characteristics are obtained as shown.

Maximum efficiency =

Experiment No.

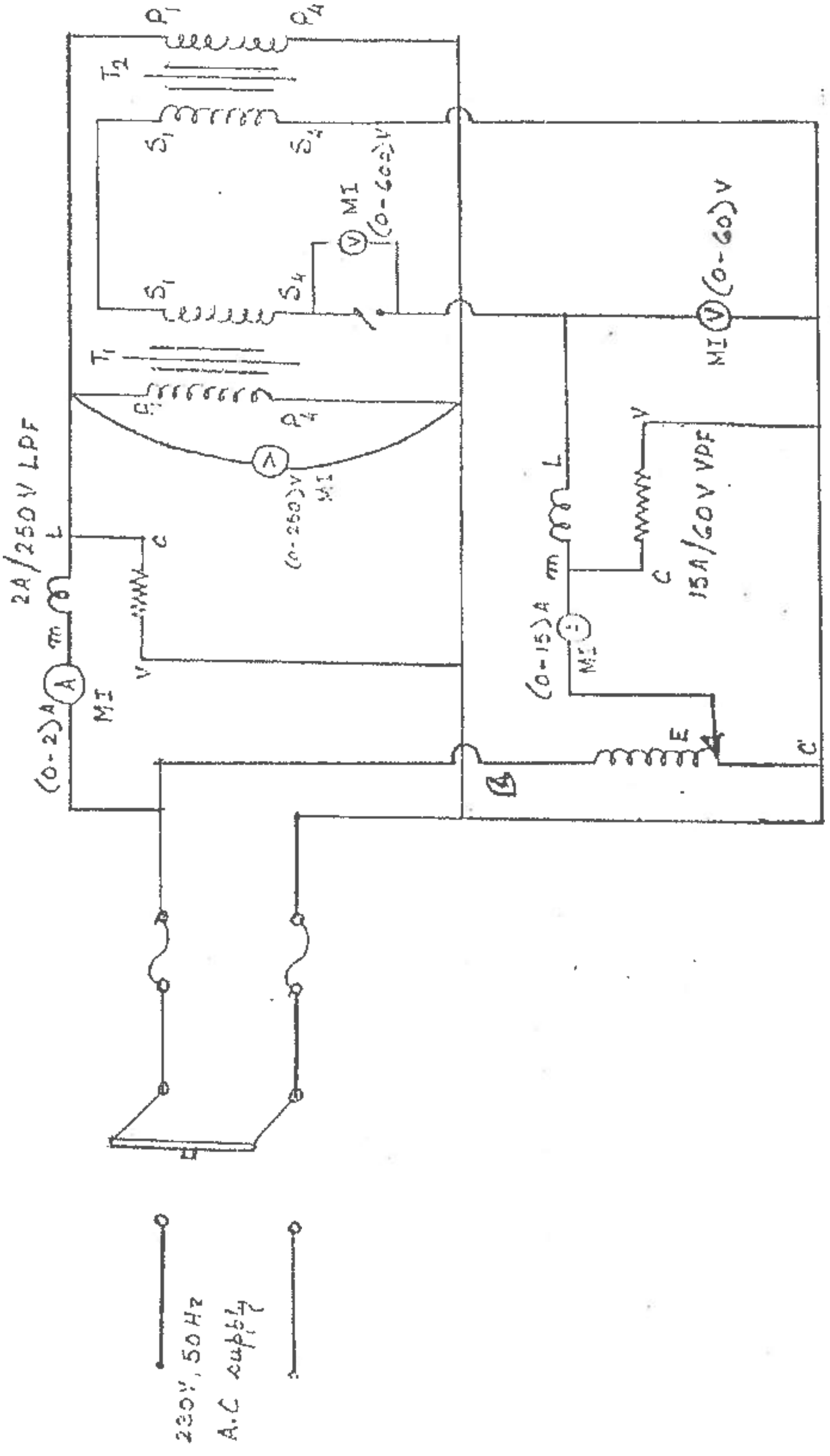
SUMPNER'S TEST

Objectives:

1) To evaluate the losses in the transformer which correspond to the actual working temperature conditions.
2) To predetermine the performance curve such as
   a) Efficiency Vs. Load
   b) Regulation Vs. Power factor

Introduction:

Open circuit test and short circuit test on a transformer give iron and copper loss, which correspond to the normal voltage and current. But these tests do not indicate any idea of the final temperature that a transformer would attain when it is under actual load for several hours. Sumpner's test is a useful test in this respect. It permits two identical transformers remain under full load conditions for several hours during which period the transformers would attain their final steady temperature which can be measured and recorded. In the laboratory however, the test is not conducted for long duration. Sumpner's test is a regenerative test and it is also called as back to back test. In this test, the primaries of the transformers are connected in parallel to the supply and the secondaries are connected in series opposition so that no current can flow if the secondaries are closed. If from an external source a small voltage is applied in series with the secondary windings it causes a current comparable to the rated value to flow. The voltage can be suitable adjusted to circulate the rated current in both the secondaries. The appearance of this secondary current, disturbs the flux in the core of each transformer and consequently the primaries assume additional current to establish proper fluxes in the cores, and back emfs in the primaries, necessary to meet the applied voltage. However the additional current that flows in the primaries is not drawn from the source. One transformer feeds the other as far as the additional current is concerned. The source feeding the primaries furnishes only the iron losses in the two transformers. The auxiliary source furnishes only the copper losses in the two transformers. The setup can be left for several hours allowing the windings to experience rated voltages and currents. Since this method avoids the use of artificial load, there is no wastage of power and hence the test is economical and it is independent of the


P1
P2
T2
S1
S2
MI
(0-60)V
S1
S2
T1
P1
P2
V
(0-250)V
MI
2A/250V LPF
M
L
C
V
A
(0-2)A
MI
MI
V
(0-60)V
L
M
C
V
15A/60V UPF
(0-15)A
MI
A
E
C'
230V, 50Hz
A.C supply

size of the transformers. Transformers of any size can be used to evaluate their performance including *heat-run* test to find the temperature raise under load conditions.

Name plate details:

KVA rating of the transformer :

Primary voltage rating :

Secondary voltage rating :

Rated primary current :

Rated secondary current :

Instruments and Accessories:

Voltmeter (MI)	(0 – 300) V	1 no.
	(0 – 30) V	1 no.
Ammeter (MI)	(0 – 1) A	1 no.
	(0 – 20) A	1 no.
Wattmeter	1A/250V LPF	1 no.
	20A/30V UPF	1 no.
Autotransformer		1 no.

Procedure:

Two similar transformers are used and their secondaries must be connected in such a way that they are in phase opposition. Hence to check the polarity, transformer secondaries are connected via a single pole switch S_1 with a double range voltmeter across it.

Connections are made as shown in the circuit diagram. Autotransformer is set to its initial zero position and zero error (if any) in the double range voltmeter is corrected. With S_1 open, supply switch S is closed. If the double range voltmeter across S_1 indicates double the voltage across any one secondary, then the polarity is incorrect. Then the supply switch is opened and terminals of any one secondary must be reversed (i.e., wire connected to S_4 goes to S_1 and vice-versa). Again the switch S is closed and the reading of double range voltmeter is carefully checked. This time it should read zero. Now the polarity is said to be correct. Switch S_1 is closed. A very small voltage is applied to the secondary circuit using autotransformer, to circulate rated current of the secondary of any one transformer. After nearly 5 to 10 minutes, the readings of all the meters are recorded. Autotransformer is brought back to zero positions and switches S_1 and S are opened.

Observations:

V_o Volts	I_o' Amps.	W_o' Watts	V_{sc}' Volts	I_{sc} Amps.	W_{sc}' Watts

Iron losses $W_i = W_o' / 2$ =

Copper losses $W_{cu} = W_{sc}' / 2$ =

No load current per transformer $I_o = I_o' / 2$ =

Short circuit voltage per transformer $V_{sc} = V_{sc}' / 2$ =

No load power factor, Cos φ_o = $W_o / V_o I_o$

φ_o =

$\sin \varphi_o$ =

Active component of no-load current I_w = $I_o \cos \varphi_o$

Reactive component of no-load current I_m = $I_o \sin \varphi_o$

R_o = V_o / I_w

X_o = V_o / I_m

Equivalent resistance R_{1e} = W_{sc} / I_{sc}^2

Equivalent impedance Z_{1e} = V_{sc} / I_{sc}

Equivalent reactance X_{1e} = $\sqrt{Z_{1e}^2 - R_{1e}^2}$

Percentage regulation $= \dfrac{I_{sc}(R_{1e}\cos\phi \pm X_{1e}\sin\phi)}{Rated\,Voltage} \times 100$

Power factor (cosφ)	Sin φ	Percentage Regulation	
		Lagging p.f.	Leading p.f.
0.0			
0.2			
0.4			
0.6			
0.8			
1.0			

Percentage efficiency $= \dfrac{kVA.x.pf.10^3}{kVA.x.pf.10^3 + W_i + x^2 W_{cu}}.100$

Load fraction for maximum efficiency $= \sqrt{\dfrac{W_o}{W_{sc}}}$

Load fraction (x)	Percentage Efficiency	
	For power factor = 1.0	For power factor = 0.6
0.25		
0.50		
0.75		
1.00		
1.25		

Results:

Experiment No.

PARALLEL OPERATION OF SINGLE PHASE TRANSFORMER

Objectives:

To connect two single-phase transformers in parallel and load them using a common load and to verify the currents shared by each of them.

Introduction:

Due to the increasing demand for electrical power and to maintain a high degree of reliability of transmission, it is very much essential to connect a number of transformers in parallel. When these transformers are operating in parallel and supplying a common load, each of the participating transformer share the load in inverse proportion to their leakage impedances. For the transformers to share the load in proportion to their KVA ratings, it is essential to full fill the few following conditions.

i) Transformers must be connected properly with regard to their polarity. Though the transformers work on alternating current system it has what is called as polarity or phase. While connecting two transformers in parallel the polarity must be determined and accounted, otherwise a short circuit will result.

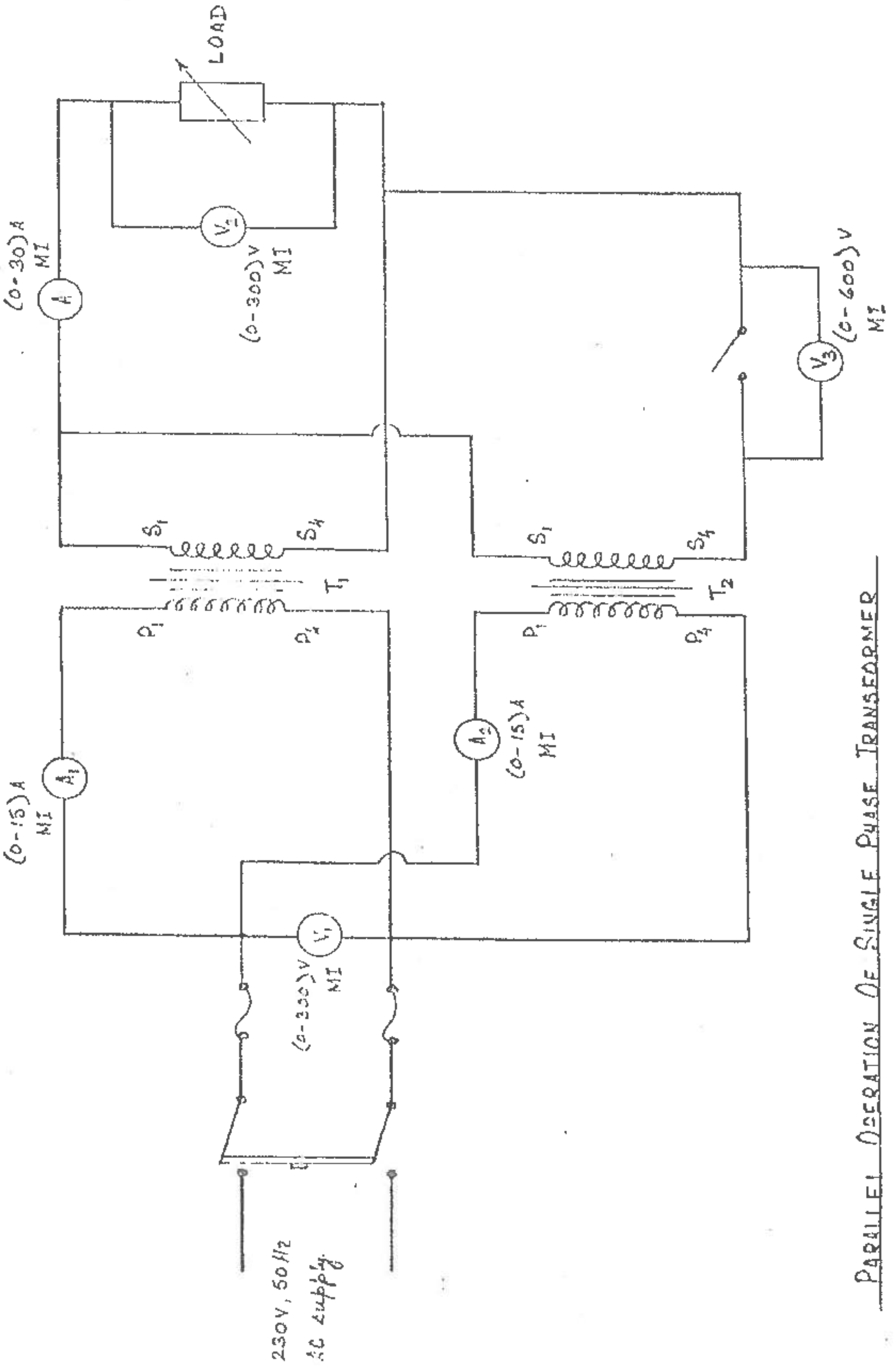
ii) Turns ratio of the transformers must be identical. Unequal turns ratio will result in large circulating current which results in unwanted power loss.

iii) The percentage impedances of the transformers should be equal in magnitude and should have the same X/R ratio. This makes the output currents of different transformers in phase with each other and that the resultant current will be the arithmetic sum of individual transformer currents.

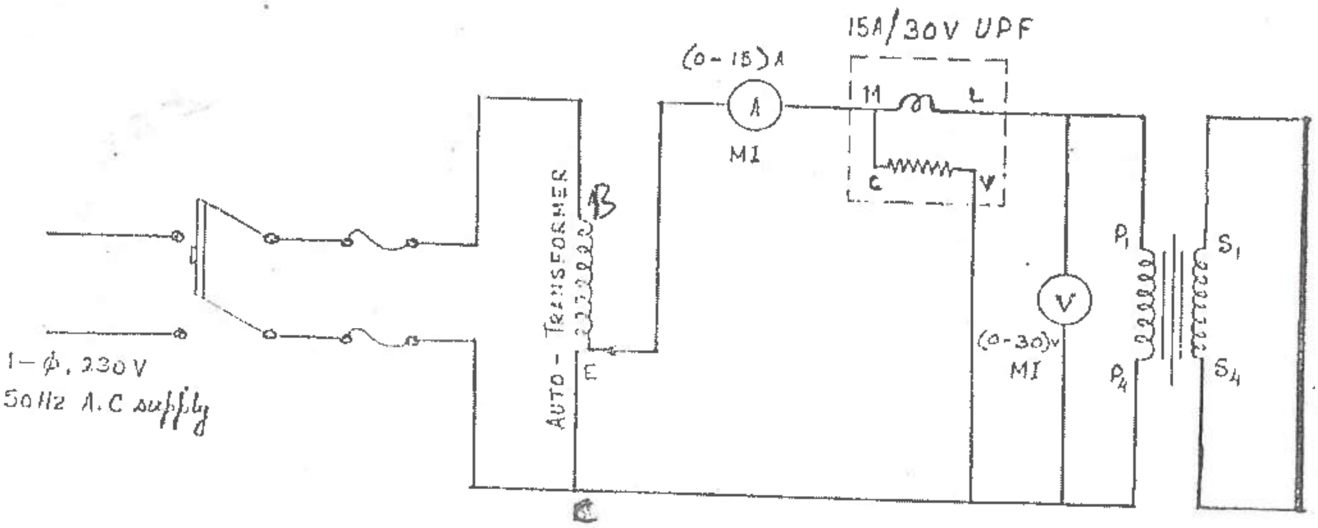
If I_1 and I_2 are the currents shared by the two transformers having leakage impedances Z_1 and Z_2 respectively. Then,

$$I_1 Z_1 = I_2 Z_2$$

$$\frac{I_1}{I_2} = \frac{Z_2}{Z_1} = \frac{\text{Volt}-\text{amp..shared.by.transformer}-1}{\text{Volt}-\text{amp..shared.by.transformer}-2}$$



PARALLEL OPERATION OF SINGLE PHASE TRANSFORMER



SHORT CIRCUIT TEST

Or if Q_1 and Q_2 are KVA shared by two transformers and Q is the load KVA. Then,

$$Q_A = Q\frac{Z_B}{Z_A + Z_B}$$

Name plate details:

		Transformer 1	Transformer 2
KVA rating of the transformer	:		
Primary voltage rating	:		
Secondary voltage rating	:		
Rated primary current	:		
Rated secondary current	:		
Type of transformer	:		

Instruments and Accessories:

Voltmeter (MI)	(0 – 300) V	1 no.
	(0 – 600) V	1 no.
Ammeter (MI)	(0 – 15) A	1 no.
	(0 – 10) A	2 nos.
Autotransformer		1 no.

Procedure:

Polarity Test: - Connections are made as shown in Figure 1. Zero error if any in the double range voltmeter is corrected. A known voltage is applied to primary of the transformer. The reading of the double range voltmeter is observed. If the reading is zero, then the emf induced in windings are in phase opposition round the local circuit. The emfs in the windings act either both upwards or both downwards at any given time. Then the terminal P_1 is said to be corresponding to terminal S_1. Like wise P_4 corresponds to S_4. This means, when the terminal P_1 is positive with respect to the terminal P_4, then the terminal S_1 is positive with respect to the terminal S_4. Thus P_1, S_1 form one set of corresponding terminals and P_4, S_4 form the other set. Instead, if the double range voltmeter records the sum of the voltages of two windings, then the polarity is opposite. That is, when the terminal P_1 is positive with respect to P_4, terminal S_4 will be positive with respect to S_1. Thus terminals P_1, S_4 form one set of corresponding terminals and P_4, S_1 form the other set.

Observations:

	Practical values			Theoretical values		
Sl. No.	I_1 Amps	I_2 Amps	I Amps	I_1 Amps	I_2 Amps	I Amps
1.						
2.						
3.						
4.						

Short circuit test on *Transformers*:

Transformer 1				Transformer 2		
V_{sc} Volts	I_{sc} Amps	W_{sc} Watts		V_{sc} Volts	I_{sc} Amps	W_{sc} Watts

$R_1 = W_{sc} / I_{sc}^2$

$Z_1 = V_{sc} / I_{sc}$

$X_1 = \sqrt{Z_1^2 - R_1^2}$

$Z_1 = (R_1 + jX_1)\ \Omega$

Similarly $Z_2 = (R_2 + jX_2)\ \Omega$

$$I_1 = I \cdot \frac{Z_2}{Z_1 + Z_2}$$

$$I_2 = I \cdot \frac{Z_1}{Z_1 + Z_2}$$

Parallel operation: - Connections are made as shown in the Figure 2. Zero error if any in the double range voltmeter is corrected. With switches S_1, S_L and the individual load switches open, the supply switch S is closed. The reading of double range voltmeter is then observed. If it shows zero, then the switch S_1 is closed. This action puts the two transformers in parallel. If the double range voltmeter records the sum of the secondary voltages then supply switch S is opened. The secondary terminals of any one transformer are interchanged to correct the polarity. Then the above mentioned steps are repeated to connect the two transformers in parallel. Now the switch S_L is closed and the set is gradually loaded in steps till the ammeters A_1 and A_2 records the corresponding transformer rated currents. The readings of all the meters are recorded. The load is removed. Switches S_L, S_1 and S are then opened in sequence. The leakage impedance of each transformer is then determined by conducting short circuit tests on each transformer.

Result:

Experiment No.

SCOTT CONNECTION OF TRANSFORMER

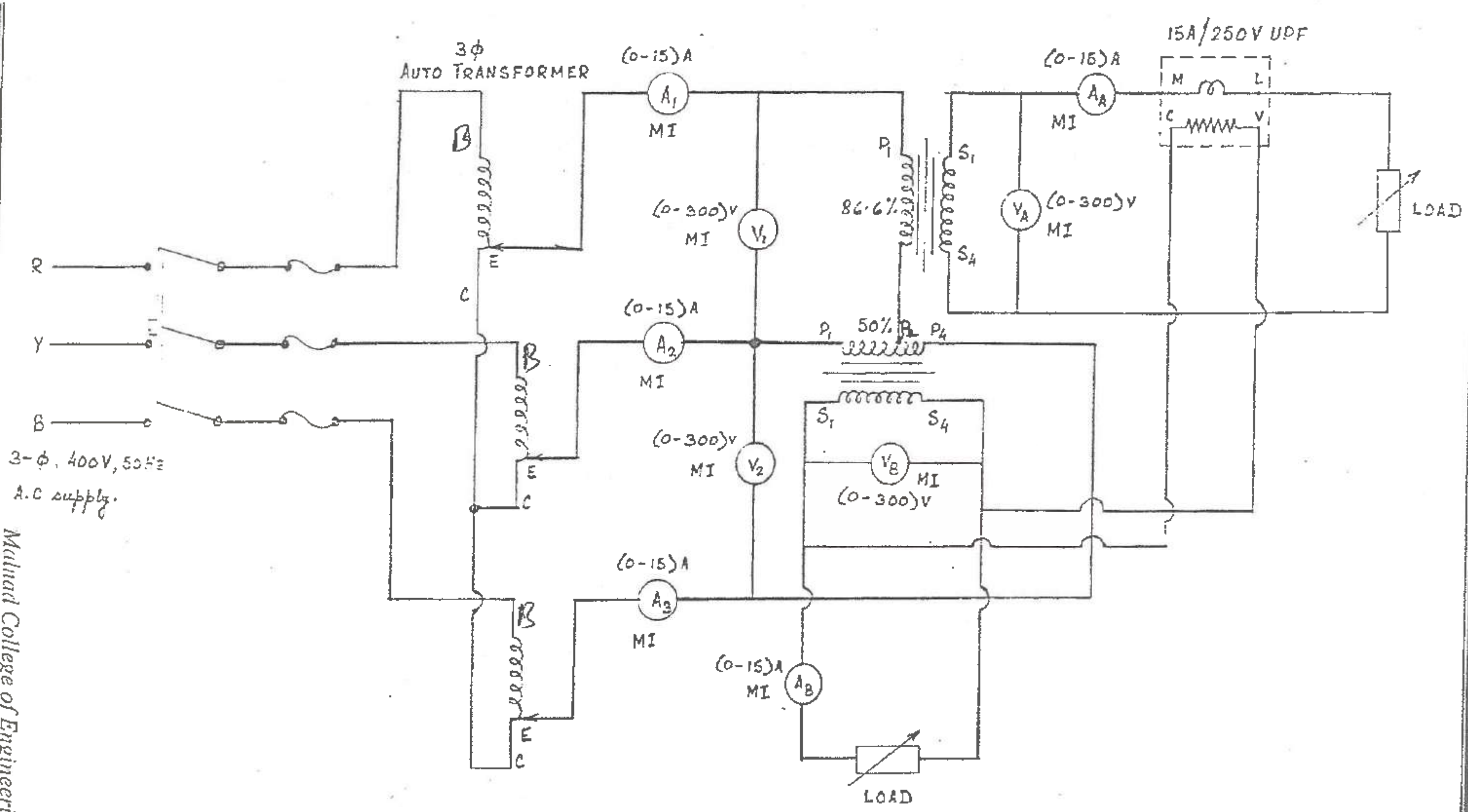
Objectives:

1) To convert a balanced 3 phase AC supply to 2 phase supply having phase difference of 90° by Scott connection
2) To verify the phase difference between the two secondary voltages.
3) To verify the amplitude and phase relationships of currents and voltages between primary and secondary.

Introduction:

Using Scott connection, it is possible to convert 3-phase supply to balanced 2-phase supply having a phase difference of 90°, using two identical single-phase transformers with special tappings. This type of connection is first proposed by Charles F Scott and hence the name. When we draw the circuit for 3 phase to 2 phase conversion using Scott connection the arrangement of primary and secondary connection appear as inverted T, and therefore this connection is also called as T – T connection. Out of two transformers, one of the transformers has center taps both on primary and secondary windings, and is known as main transformer. The other transformer has 86.6% tap on both primary and secondary, and is called as Teaser transformer.

The primary of teaser transformer is joined to the center tap of main transformer. The other end of teaser primary along with the two ends of main transformer primary constitutes 3 phase primary lines. These three lines of primary are connected to the 3-phase supply. This arrangement helps to maintain the voltage per turn in both main transformer primary and that of teaser primary same. The secondaries of both transformers will have same number of turns and are connected at one end so as to get 2 phase, 3 wire system or made independent to supply independent single phase loads constituting 2 phase, 4 wire system. If the three phase voltages are balanced, the secondary voltages will also be balanced. On the other hand, if balanced 2 phase voltages are supplied to the two secondaries, the primary voltages on the 3-phase side will also be balanced. Similarly, the currents will be balanced under balanced conditions. This type of conversion is quite popular to feed two phase induction furnaces and two phase control motors from available three phase system.


3φ
AUTO TRANSFORMER
R
Y
B
3-φ, 400V, 50Hz
A.C supply.
E
C
E
C
E
C
(0-15)A
A₁
MI
(0-300)V
MI
V₁
(0-15)A
A₂
MI
(0-300)V
MI
V₂
(0-15)A
A₃
MI
P₁
86.6%
S₁
S₄
P₁
50%
P₄
S₁
S₄
V_B
MI
(0-300)V
(0-15)A
MI
A_B
LOAD
(0-15)A
A_A
MI
V_A
(0-300)V
MI
15A/250V UPF
M
L
C
V
LOAD

To verify the phase difference between the two phases in 3 phase to 2-phase conversion, two methods are most popular. One by observing the Lissajous figure appears on the CRO. If the shape is a circle, it is the proof of the phase difference being 90°. In wattmeter method, when the current coil is energized by one phase and the potential coil by the other, the wattmeter will read zero for a upf load, if the phase difference between the two phases is equal to 90° with respect to each other.

Name plate details:

		Transformer 1	Transformer 2
KVA rating of the transformer	:		
Primary voltage rating	:		
Secondary voltage rating	:		
Rated primary current	:		
Rated secondary current	:		
Type of transformer	:		

Instruments and Accessories:

Voltmeter (MI)	(0 – 300) V	2 nos.
Ammeter (MI)	(0 – 5) A	5 nos.
Wattmeter	5A/250V UPF	1 no.
Three phase Autotransformer		1 no.

Procedure:

Connections are made as shown in the circuit diagram. The loads are open and zero error of the wattmeter is corrected. The 3-phase auto-transformer is set to its initial zero position. Now the supply switch S is closed, and the voltage is gradually increased to the rated primary voltage of the transformers by adjusting the 3-phase auto-transformer. The secondaries are loaded until the secondary ammeters read 50 – 60 % of the current rating of each transformer. To verify the phase difference between two secondary phase voltages, the wattmeter is observed which indicates zero, if the phase difference between the two phases is 90° and it is recorded. The readings of all other meters are also noted. Load is gradually

Observations:

Sl. No.	I_1 Amps.	I_2 Amps	I_3 Amps	I_A Amps	I_B Amps	V_1 Volts	V_2 Volts	V_A Volts	V_B Volts	W Watts
1.										
2.										
3.										
4.										

$$I_1 = \frac{2I_A\langle -90}{\sqrt{3}}$$

$$I_3 = \frac{I_A\langle 90}{\sqrt{3}} + I_B\langle 0$$

$$I_2 = -I_1 - I_3$$

	Practical values			Theoretical values		
Sl. No.	I_1 Amps	I_2 Amps	I_3 Amps	I_1 Amps	I_2 Amps	I_3 Amps
1.						
2.						
3.						
4.						

removed, auto-transformer is brought back to its initial position, and the supply switch S is opened.

Result:

Experiment No.

POLY PHASE CONNECTIONS USING SINGLE PHASE TRANSFORMERS

Objectives:

a) To connect three single-phase transformer units in Star-Star, Delta-Star and Open delta manner.

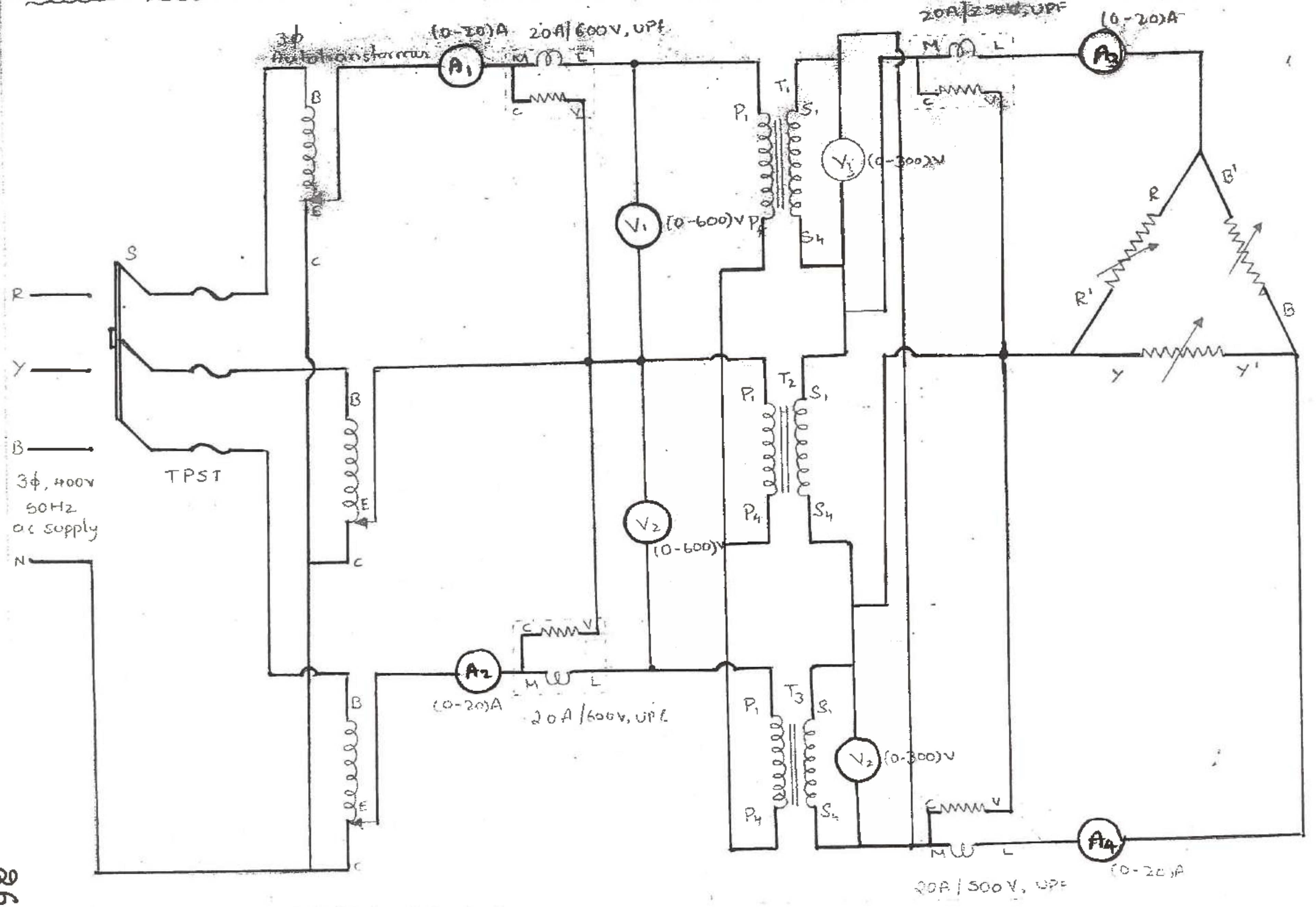
b) To verify relationship between line and phase quantities (with regard to magnitudes).

Introduction:

Generation, transmission and primary distribution and to large extent secondary distribution is accomplished by three-phase systems. Single-phase and three-phase transformers are used for this purpose. The advantages of single unit three-phase transformer being their less weight, less cost than that of single-phase banks, higher efficiency per unit weight. Less floor area demand and less maintenance. The drawbacks of single unit of three-phase transformer are in terms of transportation problems in case of higher ratings and need to disable the whole unit in case of failure of a single-phase winding causing interruption in continuity of service to consumers. If single-phase transformer banks are used for three phase operation, in case of failure of any one winding, it can be replaced within no time and till then system may be operated at lower capacities in open delta.

Star-Star Connection: - This type of connection is popular in distribution systems. The main advantage of this connection is that the insulation of the transformers is stressed only 58% times to the other connections as the phase voltage is $1/\sqrt{3}$ times the line voltage. The ratio of line voltages on primary and secondary and the line currents on secondary and primary is same as that of transformation ratio of each transformer. The neutral point shifts, in case of unbalanced loads, thereby making the three-phase voltages unequal. If there is load only on one phase, then the primary of that phase can not supply that load because the other two primaries act as high impedances. It means, even if the secondary of that phase is short-circuited, the current even reaches its rated value. However, the secondaries of other two will develop dangerously high voltages. This is due to the shift in neutral towards the loaded phase. The shift in neutral is prevented by connecting the neutral (star point) of primary to the neutral of generator. If two windings are loaded the shift in neutral will be

Circuit Diagram



less pronounced. Connecting the neutral point of transformer primary to the generator neutral, not only prevents the neutral shift, but also eliminates the distortions in the secondary output wave form. The reason for this is, it provides a path for the third harmonic excitation current, which helps to maintain the sine wave shape of flux. If it is required to isolate neutral of the transformer then, to maintain secondary voltage wave shape tertiary windings of lower KVA are required and these windings must be connected in delta.

Star-Delta or Delta-Star Connections: - These connections are in use with power transformers. Star-Delta connection is generally used in transmission end and Delta-Star at receiving ends. The ratio between secondary and primary line voltages is $1/\sqrt{3}$ times the transformation ratio of each transformer in Star-Delta connection and it is $\sqrt{3}$ in Delta-Star connection. In both cases, there exists a 30° phase shift between primary and secondary and hence, a parallel operation of these transformers is impossible with Delta-Delta or Star-Star banks even though the voltage ratio exactly matches.

Open Delta Connection: - At light load time, only two transformers can conveniently be used to supply a three-phase power from one voltage level to another voltage level. As load increases another transformer can be put and the bank is operated as a closed delta circuit. The open delta operation of transformers (usually called as V-V operation) is useful in another situation where one transformer is compelled to be removed due to some defects in it. In such a case, the remaining two transformers are over loaded for the same external load until repairs or servicing of the defective transformer is done. This situation also arises in Star-Star connection, when one of the transformers in the bank fails. Where as in Star-Star connection, it is possible only to meet two single-phase loads. However, open delta connection does introduce some voltage unbalance due to the non-symmetry of voltage regulation effects under load. When the bank of transformers is operating in a close delta, the phase current is $\sqrt{3}$ times the line current. If one of the transformer is removed, the current in that transformer becomes zero and the currents in the other two raise $\sqrt{3}$ times, since the line currents continue to flow in those two phases.

Name plate details:

		Transformer 1	Transformer 2	Transformer 3
KVA rating of the transformer	:			
Primary voltage rating	:			
Secondary voltage rating	:			
Rated primary current	:			
Rated secondary current	:			
Type of transformer	:			

Instruments and Accessories:

Voltmeter (MI)	(0 – 300) V	3 nos.
	(0 – 600) V	2 nos.
Ammeter (MI)	(0 – 10) A	3 nos.
	(0 – 5) A	3 nos.
Wattmeter	10A/250V UPF	5 nos.
Three-phase Autotransformer		1 no.
Three-phase resistance load		1 no.

Procedure:

Star-Star Connection: - Connections are made as shown in the circuit diagram, with the three-phase auto-transformer at its minimum output position, the circuit is energized and the voltage is gradually increased so that the secondary phase voltage reaches its rated value. Some three-phase balanced load is now applied and the readings of various meters are recorded. The load is reduced to zero. The voltage reduced to 80% of the secondary phase voltage. A small load on one of the phases is applied with other loads strictly open. The reading of all the meters are noted. The load is reduced to zero and the supply is switched off.

Delta-Star Connection: - The connections are made as shown in figure. With auto-transformer in initial position, supply to the circuit is switched on. Voltage is raised until the phase voltage on delta side reaches its rated value. Load is applied gradually and the readings of various meters are noted.

Type of Connection : Star-Delta Connection

SN	A_1 Amp	A_2 Amp	A_3 Amp	A_4 Amp	V_1 Volts	V_2 Volts	V_3 Volts	V_4 Volts	W_1 Watts	W_2 Watts	W_3 Watts	W_4 Watts	$(W_3 + W_4)$ Watts	% η	V_{FL}	V_{NL}	% Regulation
									Input Power		Output Power						
1.																	
2.																	
3.																	
4.																	
5.																	
6.																	

Open Delta Connection: - Connections are made as shown in the circuit diagram. The DPST switch is closed initially. The load switch is kept open. Supply switch S is closed. Voltage is increased gradually using the three-phase auto-transformer until the secondary phase voltage shows rated voltage. Now the load switch is closed. Load is gradually applied in steps until the line currents read about the rated currents of the transformers. The reading of all the meters are recorded. DPST switch is now opened without altering the load. This means that the bank is now operating in open delta connection. Once again the readings of all the meters are noted. The load is removed, voltage is reduced to zero and the supply is switched off.

Result:

Experiment No.

LOAD TEST ON SINGLE-PHASE INDUCTION MOTOR

Object:

To conduct a load test on the given single-phase induction motor and to determine it's operating characteristics.

Introduction:

Single-phase induction motor with one stator winding inherently does not produce any starting torque. In order to make the motor start rotating; some arrangement is required so that the motor produces a starting torque. The simplest method of starting a single-phase induction motor is to provide an auxiliary winding on the stator in addition to the main winding and start the motor as a two-phase machine. The two windings are placed in the stator with their axes displaced 90° in space. The impedances of the two circuits are such that the currents in the main and the auxiliary windings are phase-shifted from each other by 90°. The motor is equivalent to an unbalanced two-phase motor. However, the result is a rotating stator field that can produce the starting torque. In the running condition a single-phase induction motor can develop a torque with only the main winding. Therefore, as the motor speeds up, the auxiliary winding can be taken out of the circuit by using a centrifugal switch. At about 75% of the synchronous speed, the centrifugal switch operates and disconnects the auxiliary winding from the supply.

Nameplate details:

Output power :

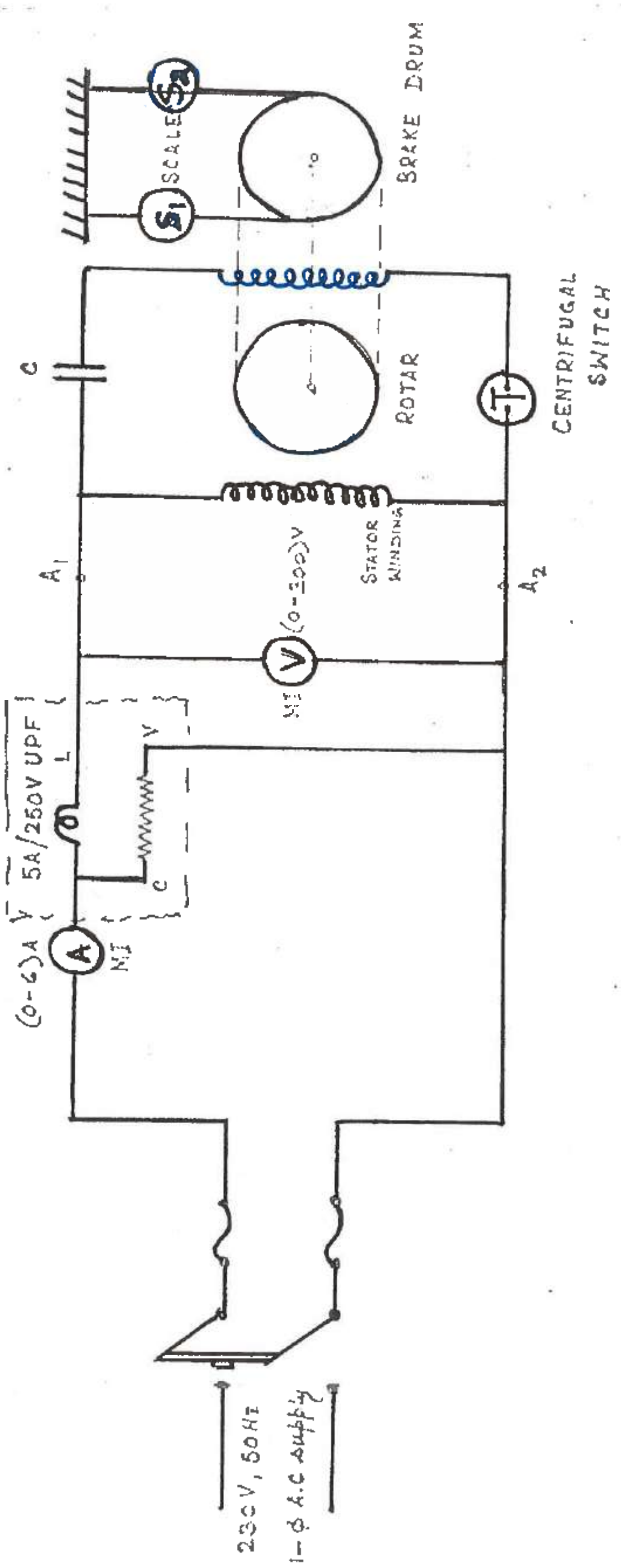
Rated voltage :

Rated current :

Rated rpm :

Frequency :

Number of poles :


S2
SCALE
S1
BRAKE DRUM
C
ROTAR
CENTRIFUGAL SWITCH
A1
A2
STATOR WINDING
V
(0-300)V
MI
5A/250V UPF
M
L
C
V
A
(0-6)A
MI
230V, 50Hz
1-φ A.C supply

Observations:

Sl. No.	V Volts	I Amps	W Watts	S Kg.		N rpm	p.f.	T Nm	Power Output (Watts)	% Efficiency
				S1	S2					
1.										
2.										
3.										
4.										
5.										
6.										

Power factor $= \frac{W}{VI}$

Radius of the brake drum r = 7.56 cm

Torque = 9.81*S*r* Nm

Output power = 2πNT/60 Watts

Input power = W Watts

Percentage efficiency $= \frac{Output\ power}{Input\ power} * 100$

Instruments and Accessories:

Voltmeter (MI)	(0 – 300) V	1 no.
Ammeter (MI)	(0 – 5) A	1 no.
Wattmeter	5A/250V UPF	1 no.
Speedometer		1 no.

Procedure:

Connections are made as shown in figure. Release the load on the brake drum. The machine is started by closing the supply switch S. The readings of all the meters are taken, and speed is measured. Next the machine is loaded in steps until the current drawn is equal to the rated current. All the readings including the spring balance readings and speed are recorded. Load is removed and the switch S is opened. The circumference of the brake drum is measured.

Result:

The performance characteristics are obtained as shown in graphs.

Experiment No.

LOAD TEST ON 3-PHASE INDUCTION MOTOR

Objectives:

To conduct a load test on a 3-phase induction motor and hence to draw the performance characteristics.

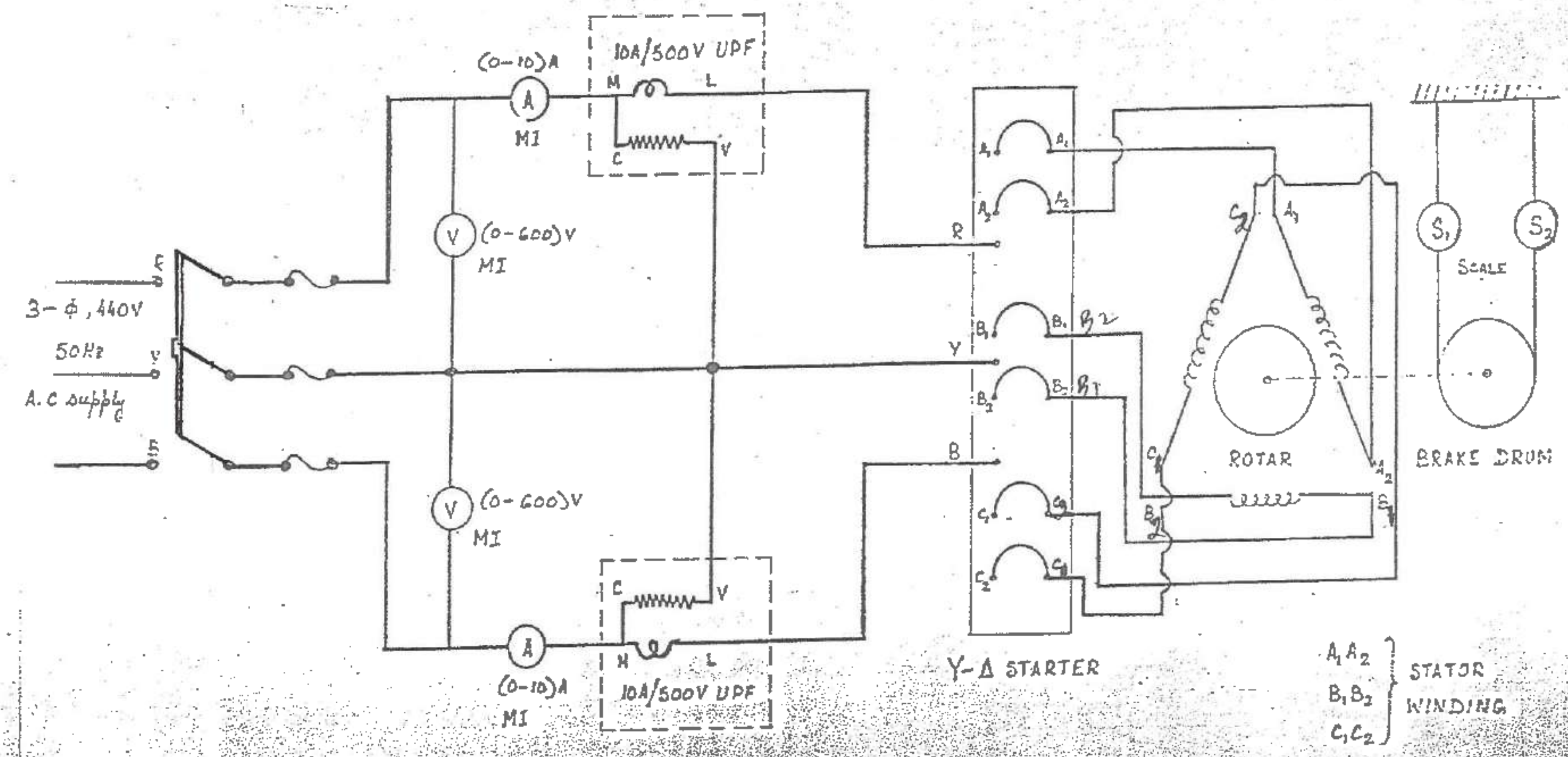
Introduction:

A 3-phase induction motor works on the principle of rotating magnetic field. A 3-phase distributed winding is placed on the stator of the induction motor which on connection to a 3-phase circuit produces a rotating magnetic field which revolves at a constant speed known as synchronous speed. The rotor, which is initially at rest, is cut by the revolving magnetic field of the stator consequent of which emfs and currents are induced in the short circuited rotor conductors. This induced current produces an electromagnetic torque on the periphery of the rotor and under whose action, it starts rotating in the same direction as the revolving field. As the speed of the rotor increases, the relative motion between the rotating magnetic field and rotor decreases, the magnitude of induced current in the rotor circuit decreases. If the rotor speed increases upto the synchronous speed, the relative speed between the rotor and stator field becomes zero as a result the induced current and hence the torque vanishes and consequently the rotor slows down. Hence, the rotor of an induction motor can never achieve synchronous speed; it will rotate at an equilibrium speed, which is less than the synchronous speed.

The power factor of induction motor at no-load is very low (less than 0.5). Due to this reason one of the wattmeter in the circuit may read negative value at light loads. As the load increases, the power factor will improve. The change in speed between full-load and no-load is very small, hence the 3-phase induction motor working at fixed frequency can be called a constant speed motor.

Nameplate details:

Output power :
Rated voltage :
Rated current :
Rated speed :


3-Φ, 440V
50Hz
A.C supply
R
Y
B
(0-10)A
MI
10A/500V UPF
M
L
C
V
(0-600)V
MI
(0-600)V
MI
C
V
M
L
(0-10)A
MI
10A/500V UPF
R
Y
B
A1
A2
B1
B2
C1
C2
Y-Δ STARTER
C2
A1
A2
C1
B2
B1
ROTAR
S1
S2
SCALE
BRAKE DRUM
A1A2
B1B2
C1C2
STATOR
WINDING

Observations:

Sl. No.	V_1 Volts	V_2 Volts	V_L Volts	I_1 Amps	I_2 Amps	I_L Amps	W_1 Wattts	W_2 Wattts	N rpm	S_1 kg	S_2 kg	W_1+W_2	T Nm	O/P Power Watts	Power factor	% Slip	% η

Radius of brake drum = $96/2\pi$ = 15.279cm = 0.15279m

Instruments and accessories:

Voltmeter (MI)	(0 – 600) V	2 nos.
Ammeter (MI)	(0 – 10) A	2 nos.
Wattmeter	10A/500V,UPF	2 nos.
Speedometer		1 no.

Procedure:

Connections are made as shown in figure. Assure that the motor is not loaded, i.e., the belt on the brake drum is released. The main switch is closed and the motor is started using the star-delta starter. The readings of the meters are observed. If any one of the wattmeter is reading negative, interchange C and V connections and the reading of which is taken as negative. The readings of the all the meters including the speed of the motor are recorded. These are the no-load readings. The motor is loaded in steps by tightening the belt on the brake drum. While loading the motor, if the wattmeter again shows a negative reading, interchange C and V terminal connections to their original positions and the reading is taken as positive. The experiment is repeated till the current reaches around the rated value and in each step all the readings are recorded. The motor is unloaded and is stopped by opening the main switch.

Result:

The following characteristics of the motor are obtained.

i) Torque Vs Output power
ii) Efficiency Vs Output power
iii) Powerfactor Vs Output power
iv) Percentage slip Vs Output power

Specimen Calculations (Set No.) :

Power input $= W_1 + W_2$ Watts

Torque T $= 9.81\,(S_1 - S_2)\,r$ Nm

Power output $= 2\pi NT/60$ Watts

Power factor $= \dfrac{W_1 + W_2}{\sqrt{3}\,V_L I_L}$

Percentage slip $= \dfrac{N_S - N}{N_S} * 100$

Percentage efficiency η $= \dfrac{Power\ output}{Power\ input} * 100$

radius of the brake drum, $r = 15.279$ cm

Experiment No.

CIRCLE DIAGRAM OF 3-PHASE INDUCTION MOTOR

Objective:

To draw the circle diagram and deduce therefrom the performance curves of the induction motor.

Introduction:

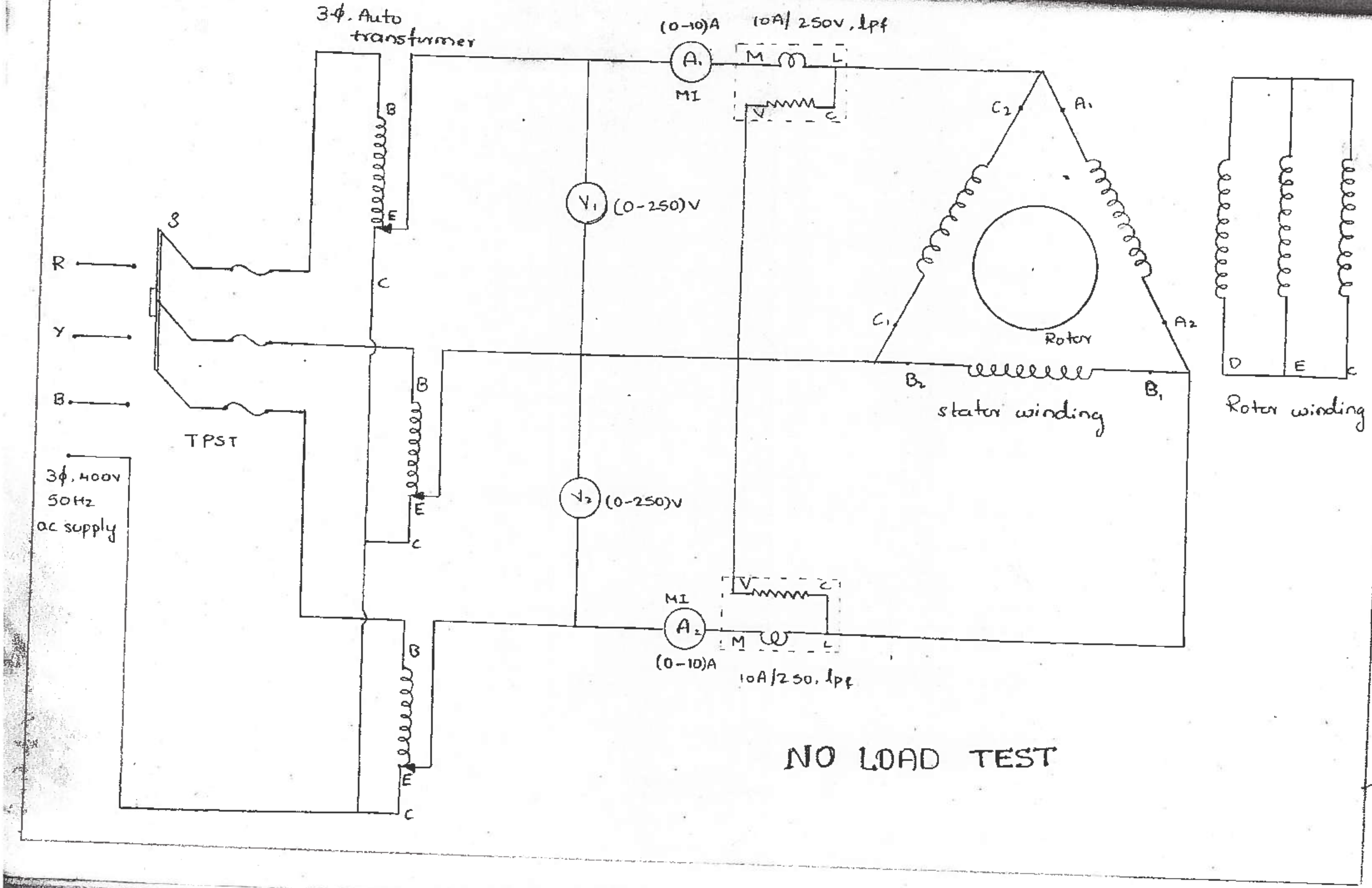
When the induction motor is run without shaft load it takes a small current, and runs at a speed very nearly equal to synchronous speed. The power input to the machine accounts for iron and friction losses only. Currents in the windings being small, copper losses are negligible. An equivalent circuit similar to that of a single-phase transformer can represent the machine. Hence the no-load test is also called as open-circuit test.

When the rotor is blocked and voltage is applied to the stator relative motion between the rotor circuit and the revolving field of the stator is maximum and the slip is unity. The rotor circuit experiences maximum currents, which are reflected in the stator circuits. Hence under blocked rotor conditions, heavy currents flow in the stator circuit. Therefore a reduced voltage is applied whose value is such that the resulting currents are equal to rated currents. Since a small voltage is sufficient to produce rated current, iron loss is negligible, and there are no friction losses. The power input represents the copper loss only. Hence the blocked rotor test is also called as short-circuit test.

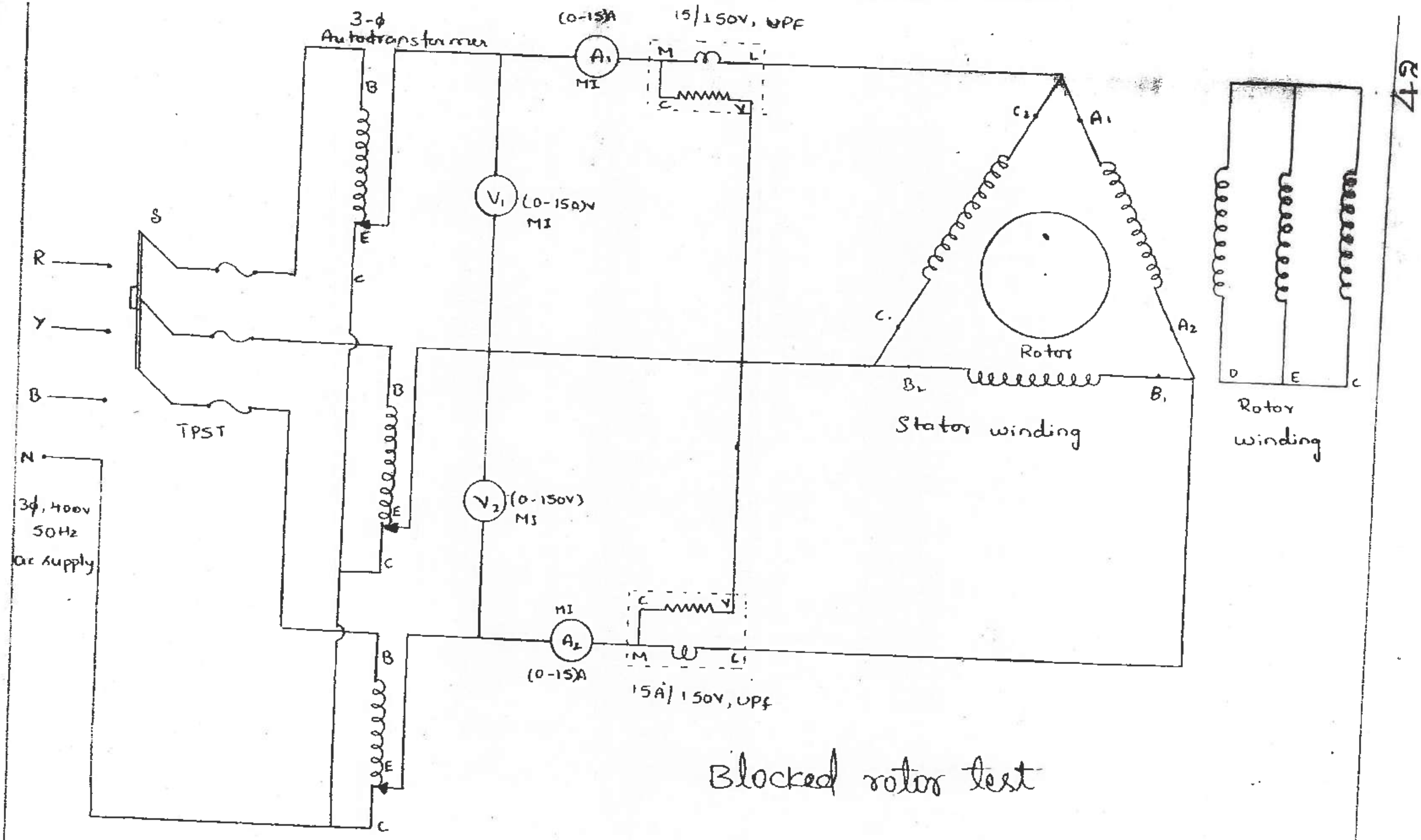
The data obtained from O.C. & S.C. tests, enables to draw the circle diagram. Some additional construction on the circle diagram helps deduce information to draw all the performance curves of the motor.

Nameplate details:

Output power :
Rated voltage :
Rated current :
Rated speed :
Frequency :
No. of poles :


3ϕ. Auto transformer
R
Y
B
TPST
3ϕ, 400V
50Hz
ac supply
B
E
C
B
E
C
B
E
C
V₁ (0-250)V
V₂ (0-250)V
A₁ (0-10)A
MI
A₂ (0-10)A
MI
10A/250V, lpf
M
L
V
C
10A/250, lpf
M
L
V
C
C₂
A₁
C₁
A₂
B₂
B₁
Rotor
stator winding
D
E
C
Rotor winding

NO LOAD TEST



Blocked rotor test

Instruments and accessories:

Voltmeter (MI)	(0 – 300) V	2 nos.
	(0-150) V	2 nos.
Ammeter (MI)	(0 – 5) A	2 nos.
	(0 – 15) A	2 nos.
Wattmeter	10A/500V,UPF	2 nos.
Speedometer		1 no.

Procedure:

O.C. Test: - Connections are made as shown in figure. The 3-phase auto-transformer is kept at its zero position. The main switch is closed. The auto-transformer is raised until the voltmeter reads the rated voltage. The readings of all meters are taken. The speed is also measured and recorded. The main switch S is open. Auto-transformer is brought to its zero position.

S.C. Test : - Connections are made as shown in figure. The main switch S is closed. Rotor is blocked by holding it by hand. Auto-transformer is slowly raised until the ammeters show the rated current of the motor. The readings of all the meters are taken. The main switch S is open. Auto-transformer is returned to its zero position.

Measurement of Stator Resistance: - Connections are made as shown in figure. Individual switches of the lamp load are all kept open. The main switch S is closed. Lamps in the load are put on one by one until the current is equal to the rated current. The readings of all the meters are taken. The main switch S is open. The individual lamp switches are also open.

To Draw the Circle Diagram:

1. Draw OA = I_o at an angle Φ_o with respect to Y-axis and draw OS = I_{SN} at an angle Φ_{sc}
2. Join AS, the output line and draw a line AB parallel to X-axis.
3. Draw a circle with A&S are the points on the circle and O_C as centre on the line AB.
4. Draw a perpendicular line segment SM to X-axis, mark the point L and divide SL at K such that $\frac{SK}{KL} = \frac{R_2'}{R_1}$
5. Draw the torque line AK

Observations:

No-load Test:

V_1 Volts	V_2 Volts	I_1 Amp	I_2 Amp	W_1 Watts	W_2 Watts	W_{NL} Watts

Blocked Rotor Test:

V_1 Volts	V_2 Volts	I_1 Amp	I_2 Amp	W_1 Watts	W_2 Watts	W_{BR} Watts

V Volts	I Amps	R Ω	R_{dc} Ω

$P_{NL} = W_{NL} / 3$ Watts

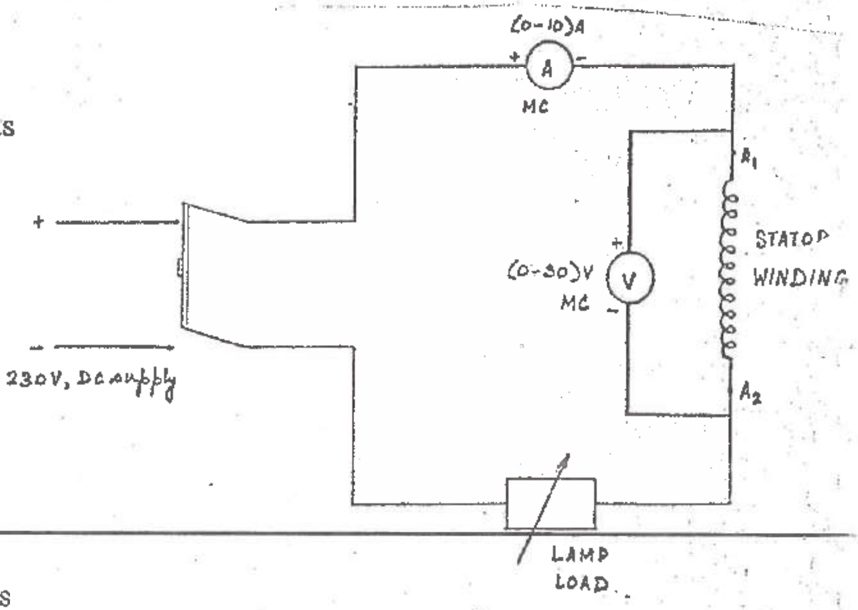
$V_L = (V_1 + V_2) / 2$ Volts

$I_L = (I_1 + I_2) / 2$ Amps

$I_{ph} = I_L / \sqrt{3}$ Amps

$$\cos \Phi_o = \frac{P_{NL}}{V_{ph} I_{ph}}$$

$\Phi_o =$



$P_{BR} = W_{BR} / 3$ Watts

$V_{sc} = (V_1 + V_2) / 2$ Volts

$I_L = (I_1 + I_2) / 2$ Amps

$I_{ph} = I_L / \sqrt{3}$ Amps

6. Draw a line $S'C$ parallel to the output line. Then CD represents total input per phase, EG represents total copper losses per phase, GD represents constant losses.
7. From the point O_C, draw a line perpendicular to the output line AS and extend it to the circle on to the point C_P. Drop a perpendicular to the reference axis from this point to the output line at C_P', which will represent the maximum power output.
8. Similarly, from the point O_C, draw a line perpendicular to the torque line AK and extend it to the circle on to the point C_T. Drop a perpendicular to the reference axis from this point to the torque line at C_T', which will represent the maximum torque.
9. Draw the vertical lines AQ and $O'Y$. O' is the point where the output line AS extended intersects the reference axis
10. Extend the output line to any convenient point P. Draw PQ parallel to the torque line and PY parallel to the X-axis. Divide PQ and PY into 100 equal parts from Q and P respectively.
11. Extend the line LS to S' such that SS' = Full load power per phase / Power scale. Divide SS' into 5 equal parts. Draw lines from each part to the circle parallel to the output line and mark the points C_1 to C_5 on the circle
12. The line AC represents the rotor current corresponding to the load point C, is then extended until it intersects QP at point R. Similarly, the line $O'C$ is extended until it intersects PY at point X. Then QR is the percentage slip and PX is the percentage efficiency.
13. To determine the power factor, draw a quadrant of a circle with center at O and a radius equal to 100 arbitrary units. On extending the primary current phasor OC until it intersects this quadrant at point Z, and projecting Z upon the vertical scale, the power factor is determined.

Result:

Cos Φ_{sc} $= \dfrac{P_{BR}}{V_{ph}\, I_{ph}}$

Φ_{sc} =

I_{SN} $= I_{sc} . V_{Rated} / V_{sc}$ Amps

R_2' $= \dfrac{P_{BR}}{I_{ph}^2} - R_1\ \Omega$

R_1 $= R_{ac} = 1.6\, R_{dc}\ \Omega$

Power Scale $= \dfrac{P_{BR}\left(\dfrac{I_{SN}}{I_{SC}}\right)^2}{LS}$

SS' = Full load power per phase / Power scale

ω_S $= 4\pi f / P$ rad/sec

Full load torque $=$ CF . power scale . 3 / ω_S Nm

Maximum power $= C_P' C_P$ * power scale * 3 Watts

Maximum torque $= C_T' C_T$ * power scale * 3 / ω_S Nm

Starting torque $=$ SK * power scale * 3 / ω_S Nm

Power output Watts	Power factor	Torque .Nm	% Slip	% Efficiency

Expt. No **Date:**

EQUIVALENT CIRCUIT OF A SINGLE PHASE INDUCTION MOTOR

Objective: To determine the equivalent circuit parameters of a single phase induction motor.

Principle:

The parameters of the equivalent circuit can be determined from the results of no load test and block rotor test. The no load test on an induction machine gives the information about exciting current and the rotational losses. The rotor is kept uncoupled from any mechanical load. The small power loss in the machine at no load is due to core loss and friction and winding loss. The total rotational loss at the rated voltage and frequency under load is usually considered to be constant and equal to it at the full load.

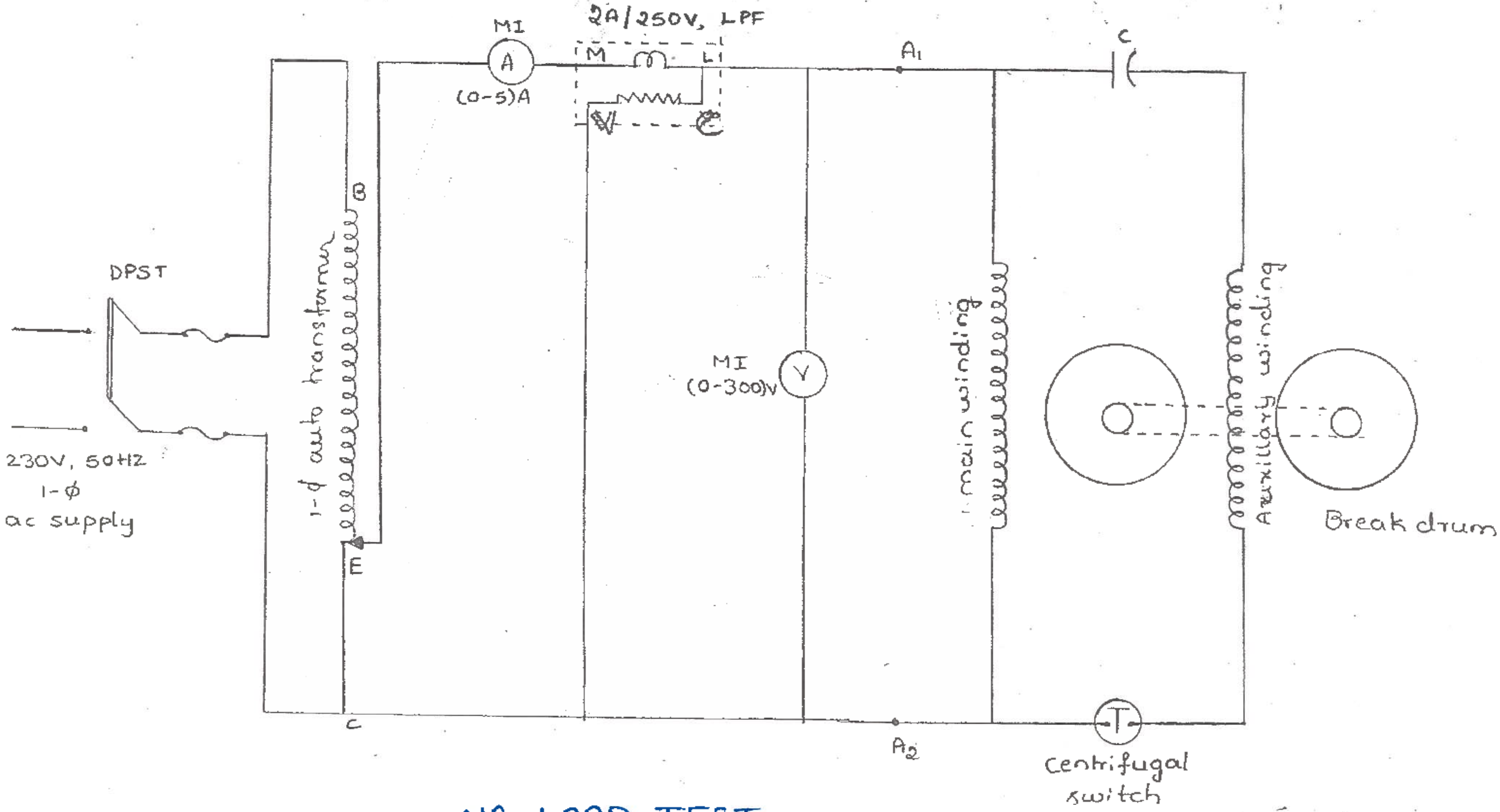
The blocked rotor test on an induction machine gives the information about leakage impedance. In this test the rotor is blocked so that the rotor cannot rotate. The blocked rotor test must be performed under the same conditions of the rotor current and frequency that will prevail in the normal operating conditions. When the rotor is blocked and voltage is applied to the stator. The relative motion between the rotor circuit and the revolving magnetic field of the stator will be maximum, and the slip will be unity. The rotor experiences maximum current which are reflected in the stator circuit. Hence high current flows in the stator circuit. Less voltage is sufficient to produce rated current in the stator. Hence iron loss is negligible and the power input represents copper loss only.

Name plate details:

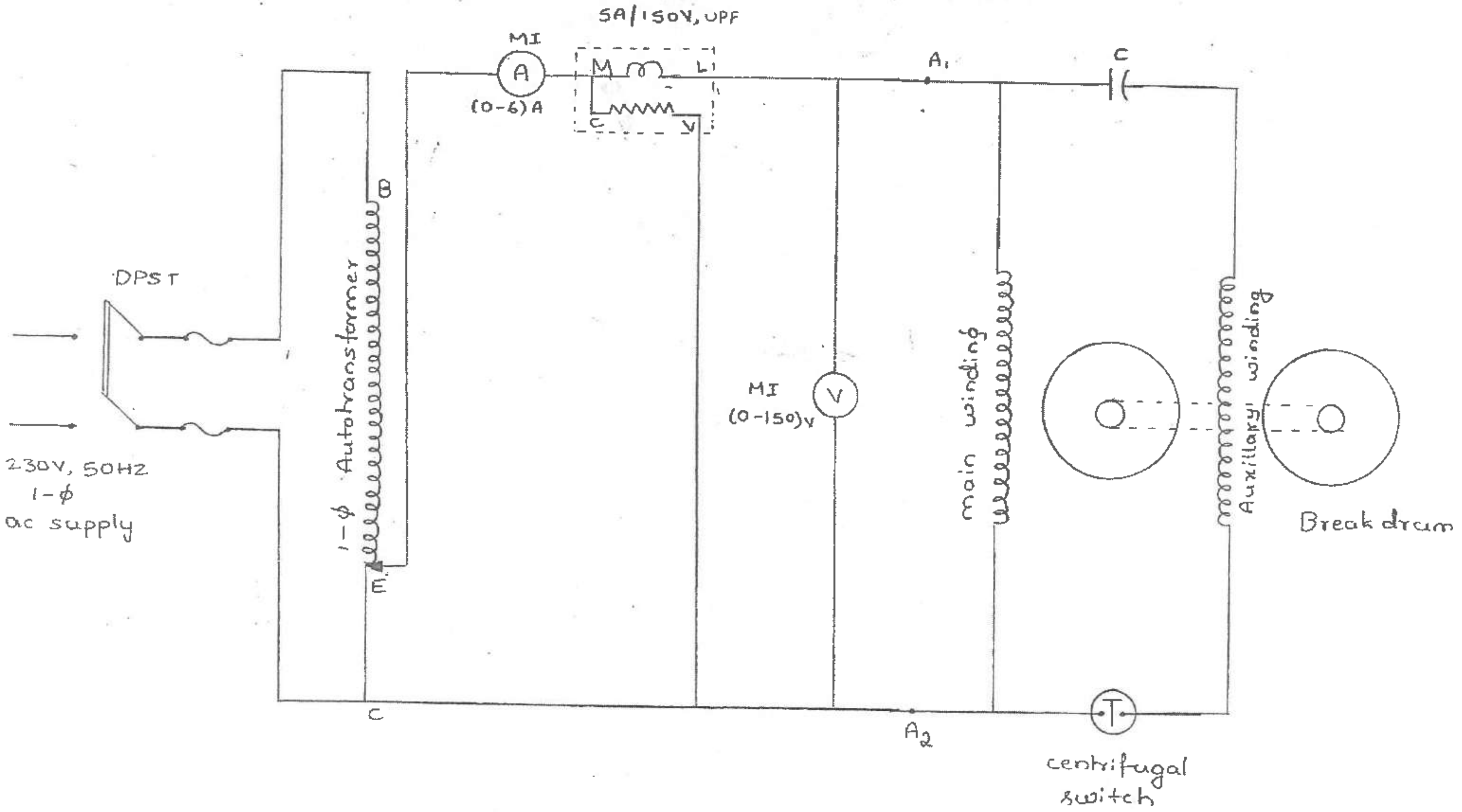
Output power :
Rated voltage :
Rated current :
Rated speed :

Apparatus required:

Ammeter(MI)	(0-5)A	1
Voltmeters(MI)	(0-300)V	1
	(0-100)V	1
Wattmeters	(LPF) 5A/250V	1
	(UPF) 5A/100V	1


MI
A
(0-5)A
2A/250V, LPF
M
L
V
C
A₁
C
DPST
230V, 50HZ
1-ϕ
ac supply
1-ϕ auto transformer
B
E
C
MI
(0-300)V
V
main winding
Auxillary winding
Break drum
A₂
T
Centrifugal switch

NO LOAD TEST



Blocked Rotor Test

Observations:

	I (Amps.)	V (Volts)	W (Watts)
No load test			
Blocked rotor test			

Calculations:

From no load test:

$\cos\theta_0 = w_0/(V_1 I_0)$

$I_m = I_0 \sin\theta_0$

$I_c = I_0 \cos\theta_0$

$R_0 = V_1 / I_c$

$X_0 = V_1 / I_m$

From blocked rotor test:

$Z_{1e} = V_{sc} / I_{sc}$

$R_{1e} = W_{sc} / I_{sc}^2$

$X_{1e} = \sqrt{(Z_{1e}^2 - R_{1e}^2)}$

Procedure:

(a) **No load test**: Initially main switch is open and autotransformer is in zero position. The machine is on no load. The supply switch S is closed and the autotransformer is gradually increased till the voltage reads the rated value and then all the readings shown by the various meters are noted.

(b) **Blocked rotor test:** The rotor is firmly held by hand. Initially supply switch S is open and the autotransformer is gradually increased till ammeter reads rated current and readings of all meters are noted.

Experiment No.

Date: ____________

SPEED CONTROL OF 3-PHASE INDUCTION MOTOR

Objectives:

To control the speed of three phase induction motor by stator voltage control method

Introduction:

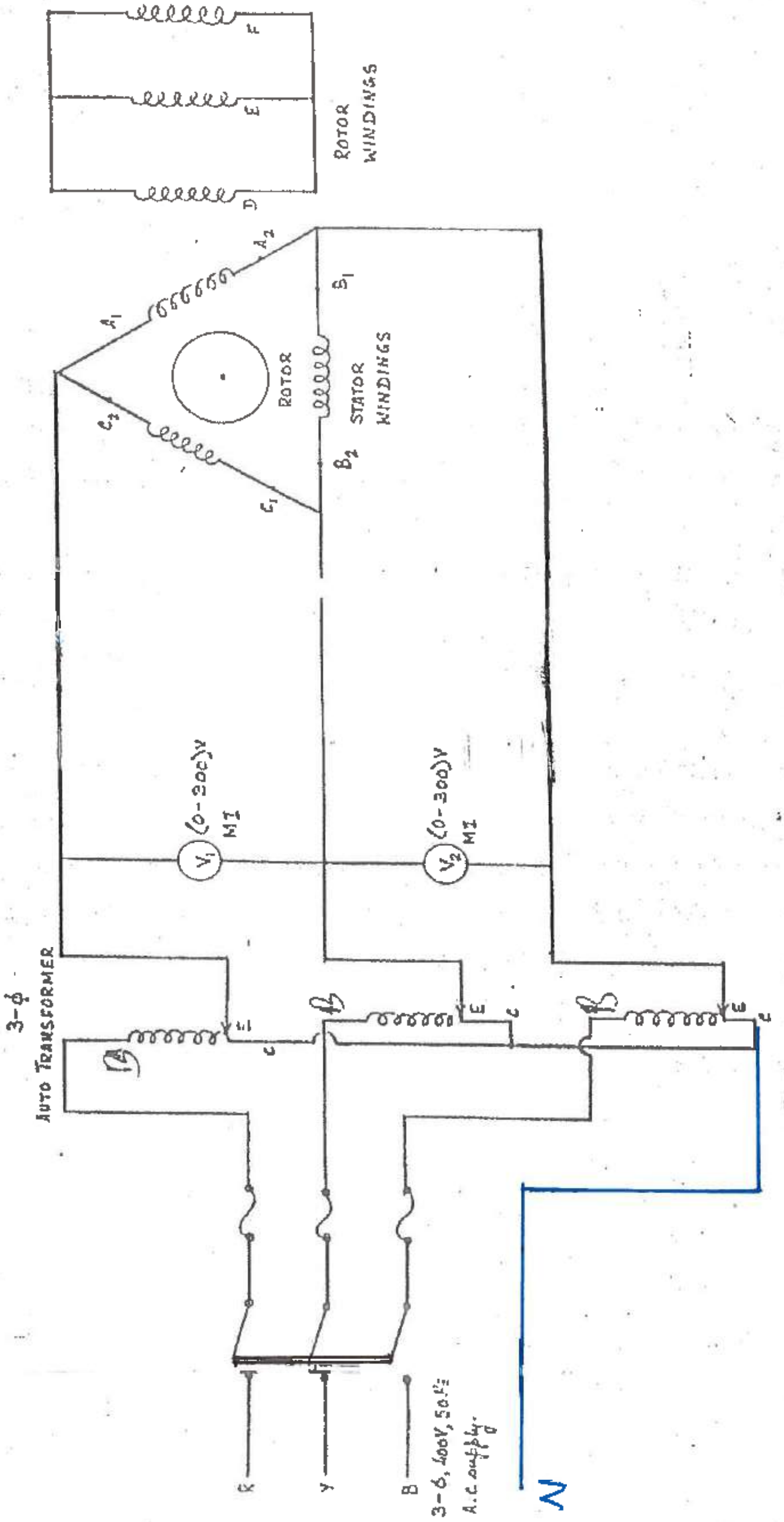
A 3-phase induction motor works on the principle of rotating magnetic field. A 3-phase distributed winding is placed on the stator of the induction motor which on connection to a 3-phase circuit produces a rotating magnetic field which revolves at a constant speed known as synchronous speed. The rotor, which is initially at rest, is cut by the revolving magnetic field of the stator consequent of which emfs and currents are induced in the short circuited rotor conductors. This induced current produces an electromagnetic torque on the periphery of the rotor and under whose action, it starts rotating in the same direction as the revolving field. As the speed of the rotor increases, the relative motion between the rotating magnetic field and rotor decreases, the magnitude of induced current in the rotor circuit decreases. If the rotor speed increases upto the synchronous speed, the relative speed between the rotor and stator field becomes zero as a result the induced current and hence the torque vanishes and consequently the rotor slows down. Hence, the rotor of an induction motor can never achieve synchronous speed; it will rotate at an equilibrium speed, which is less than the synchronous speed.

The change in speed between full-load and no-load is very small, hence the 3-phase induction motor working at fixed frequency can be called a constant speed motor. In general, there are five methods of modifying the speed – torque characteristics of 3 – phase induction motors. They are variation of applied voltage, variation of supply frequency, introduction of balanced resistances or inductances in the stator circuit, addition of balanced resistance in the rotor circuit and injection of voltages in the rotor circuit.

Variation of applied voltage: The torque equation of three phase induction motor is given by

$$T = \frac{3V_1^2 R_2}{s\omega_s[(R_1 + R_2/s)^2 + X^2]}$$

From the above equation, we can observe that the slip of the motor will change as the applied voltage change changes for a constant torque. But this method is not very effective,


ROTOR WINDINGS
D
E
F
A1
A2
B1
B2
C1
C2
ROTOR
STATOR WINDINGS
V1
(0-200)V MI
V2
(0-300)V MI
3-φ AUTO TRANSFORMER
E
C
R
Y
B
3-φ, 400V, 50Hz A.C supply
N

SN	V_1 Volts	V_2 Volts	$(V_1+V_2)/2$ Volts	Speed in rpm
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				

especially under loaded conditions, since the torque is proportional to the square of the voltage.

Nameplate details:

Output power :
Rated voltage :
Rated current :
Rated speed :

Instruments and accessories:

Voltmeter (MI)	(0 – 600) V	2 nos.
Ammeter (MI)	(0 – 10) A	2 nos.
Speedometer		1 no.

PROCEDURE:

i. Connections are made as shown in the figure
ii. Keep the three phase autotransformer in zero position and switch S in open position and machine should be on no load.
iii. Close the switch S, increase the voltage by varying the three phase autotransformer. Note down the readings of ammeter, voltmeter and speed of the motor.
iv. Vary the three phase autotransformer till the voltage reaches rated value in steps and note down the readings of all meters in each step.
v. Now bring the three phase autotransformer to its zero position and the switches are opened.

Result: