Electrical Engineering Experiments

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Publisher: David Pallai
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(800) 232-0223

G.P. Chhalotra. *Electrical Engineering Experiments.*
ISBN: 978-1-683921-14-1

Library of Congress Control Number: 2017915453

171819321 This book is printed on acid-free paper in the United States of America.

CONTENTS

EXPERIMENT 1

1.1 Object: To Determine Internal Resistance of a Battery

1.2 Apparatus

One battery, one ammeter, and one voltmeter.

1.3 Experimental Setup

The voltmeter is used to measure the open circuit voltage of the battery and the ammeter is used to measure the short circuit current of the battery, shown in Figures 1.1 and 1.2.

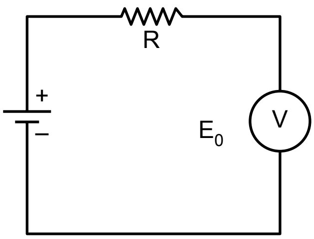

Figure 1.1

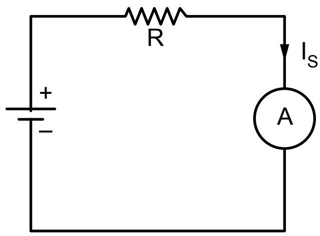

Figure 1.2

EXPERIMENTAL RESULTS

S.N.	E_0	I_s	$R=E_0/I_s$	*V*	*I*	*Remarks*
1						
2						
3						
4						
5						
6						
7						
8						

Experimental results are tabulated in the observation table. The internal resistance of the battery is given by:

$$R = \frac{\text{Open circuit voltage}}{\text{Short circuit current}} \tag{1.1}$$

This is also tabulated in the observation table.

1.4 Questions and Answers on the Experiment

The experiment is made to represent a battery by an electrical circuit. The EMF and terminal voltage of the battery can be determined. The EMF of the battery will be constant, but the terminal voltage will fall when the current taken from the battery increases. We call it a load test on the battery.

Q1. How does the EMF differ from the terminal voltage or voltage of the battery?

Ans. The EMF of the battery will always be higher than the voltage. The EMF and voltage differ by a voltage drop in the internal resistance R .

$$E = V + IR_B \tag{1.2}$$

or

$$E - V = IR_B \tag{1.3}$$

The V–I curve is shown in Figure 1.3.

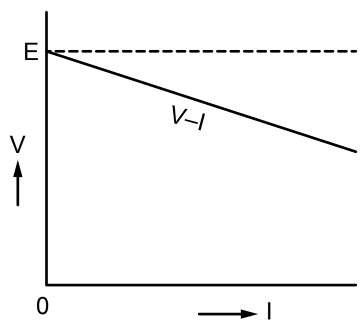

Figure 1.3

Q2. A battery has an EMF of 1.1 volts and an internal resistance of 0.1 ohms. If a resistance of 1 ohm is connected to the terminals, find the current and the terminal voltage. Draw the electrical equivalent circuit of the battery.

Ans.

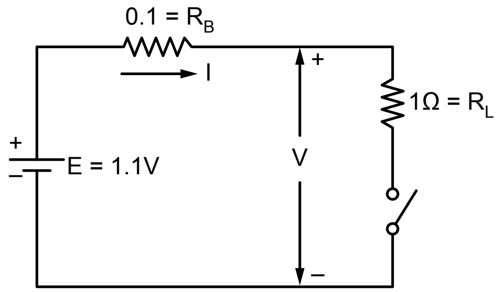

Figure 1.4

$$I = \frac{E}{1 + 01} = \frac{1.1}{1.1} = 1 \text{ A} \tag{1.4}$$

$$V = IR_L = 1 \times 1 = 1 \text{ volt} \tag{1.5}$$

EXPERIMENT 2

2.1 Object: Load Test on a D.C. Series Generator

2.2 Experimental Setup

A D.C. series machine is used as a series motor and is rarely used as the generator. If we wish to run the motor as a generator, this experiment will be useful. The series generator is used in traction as a booster, and we cannot disregard this for special purposes.

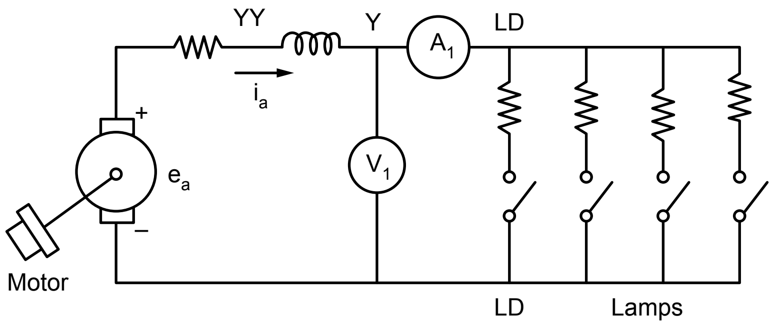

Figure 2.1

We require one ammeter and one voltmeter to read the terminal variables of the generator. If we wish to find the input and output relation of the generator, we connect the instruments at the motor side.

The load test on the generator means to measure the fall of the terminal voltage when the load current increases. We call it plotting the *V-I* (Volt-Ampere) characteristic. We keep the speed constant and switch the lamps one by one in parallel to the generator terminals. We observe the current in the ammeter at every switching of a lamp. Let the transients die, and then read the current and voltage in Figure 2.1. Output/input will be obtained from Figure 2.2 if we desire to determine it.

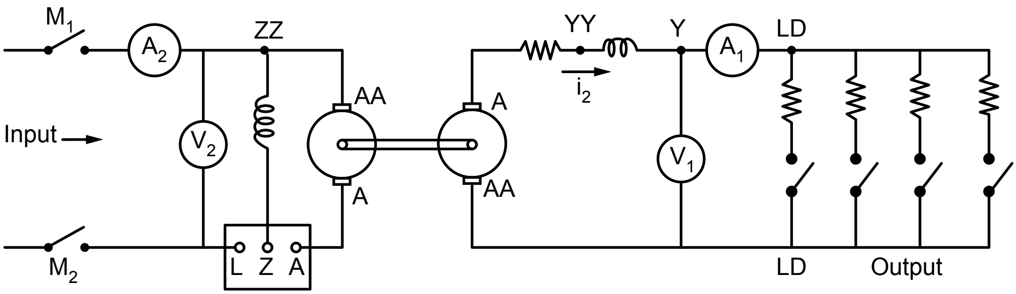

Figure 2.2

For the *V-I* characteristic, plotting the efficiency will not be required, but we need it as an additional requirement. Some engineers refer to the efficiency plot as the load test. In my opinion the two graphs will be satisfactory to define the load test on any generator.

EXPERIMENTAL RESULTS

S.N.	*Ammeter Reading $A_1(I_1)$*	*Voltmeter Reading V_1*	*A_2 (I_2)*	*V_2*	*Speed N (RPM)*	*Remarks*
1						
2						
3						
4						
5						
6						
7						

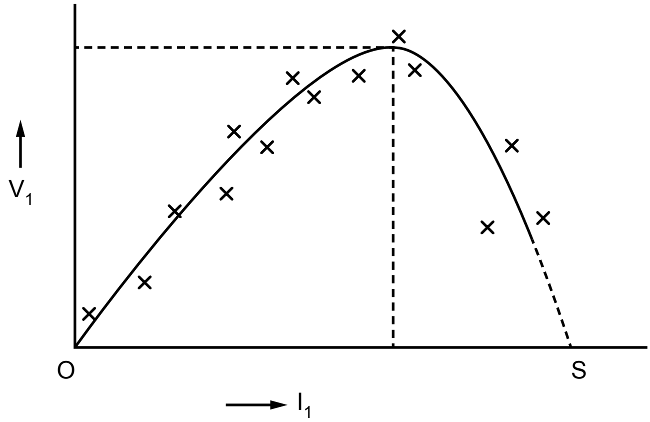

Figure 2.3

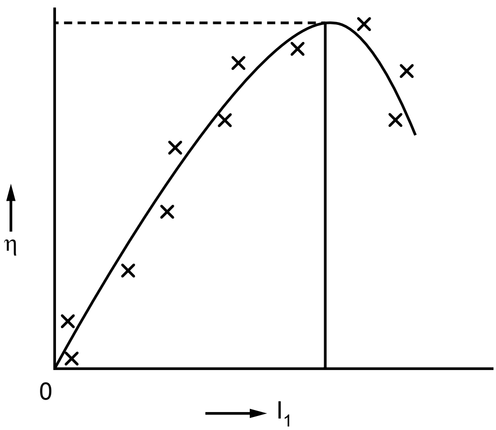

Figure 2.4

The *V-I* curve is shown in Figure 2.3. The readings are located on the graph paper, and the graph is drawn in such a manner that it passes through the points as shown.

The efficiency of the generator will be

$$\eta = \frac{\text{Output}}{\text{Input}} = \frac{A_1\, V_1 \text{ watts}}{A_2\, V_2 \text{ watts}} \tag{2.1}$$

Efficiency and I_1 are plotted to give a load curve, as shown in Figure 2.4. The current I_1 is called the load current and, therefore, we name the curves of Figures 2.3 and 2.4 load curves.

2.3 Discussion on Results

The graphs are observed. It is of interest to observe the maximum voltage developed by the generator and the current when the voltage becomes zero. The maximum efficiency will be of interest as well as the load taken by the lamps at this point.

2.4 Questions and Answers on the Experiment

Q1. Why are series generators not used for power generation at the power house?

Ans. The high current taken by the load will make a dead short circuit and the voltage will become zero. The generator may be damaged.

Q2. Where does the efficiency maximum occur? What will be a condition of maximum efficiency?

Ans. The maximum efficiency generally occurs at the full load.

The condition for maximum efficiency will be:

$$\text{Copper loss} = \text{Iron loss}$$
$$\text{or Variable loss} = \text{Constant loss}$$

Q3. Why does the voltage rise with the load current?

Ans. This is due to the field current

$$e_a = Ki_f \tag{2.2}$$

And

$$i_f = I_1 \tag{2.3}$$

The voltage e_a rises, hence the voltage V at the terminal rises as well.

Q4. Why does the voltage fall from a certain point where the maximum voltage reached?

Ans. The armature drop becomes very large. Moreover, leakage and armature reaction reduce the voltage. The increased load means low load resistance and consequently a fall of voltage.

EXPERIMENT 3

3.1 Object: Load Test on a D.C. Series Motor

3.2 Experimental Setup

The series motors are very powerful machines used in common applications such as traction loads, lifts, winches, cranes, hoists, cutters, digging machines, and so forth. We require a D.C. series motor connected to a power supply.

The power supply is given from a separate generator in the laboratory, since no D.C. supply is available from a powerhouse.

One ammeter and one voltmeter will be required as well as a tachometer and torque measuring belt.

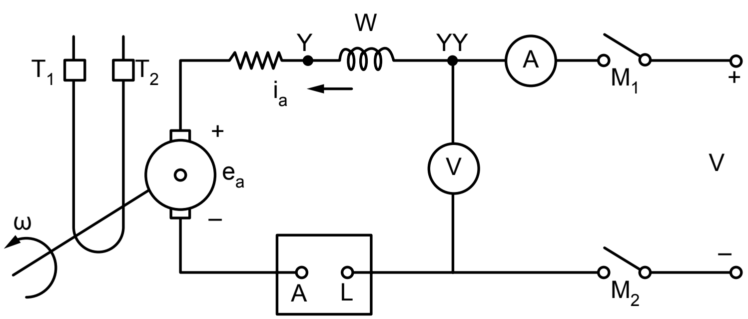

Figure 3.1

The load test is made to measure the speed when load torque is increased. The purpose of the experiment is to determine the speed-torque curve and the efficiency curve. The speed-torque curve is called the *shaft characteristic*.

Do not run the motor at no load; keep the rotor moving with applied torque when starting. A two-point starter is used to start the motor.

EXPERIMENTAL RESULTS

S.N.	*$T_1 - T_2 = T$ Torque*	*Speed (RPM) (N)*	*Ammeter Reading (I)*	*Voltmeter Reading (V)*	*Remarks*
1					
2					
3					
4					
5					
6					
7					

3.3 Speed-Torque Curve

A graph is plotted between the torque and the speed, as shown in Figure 3.2.

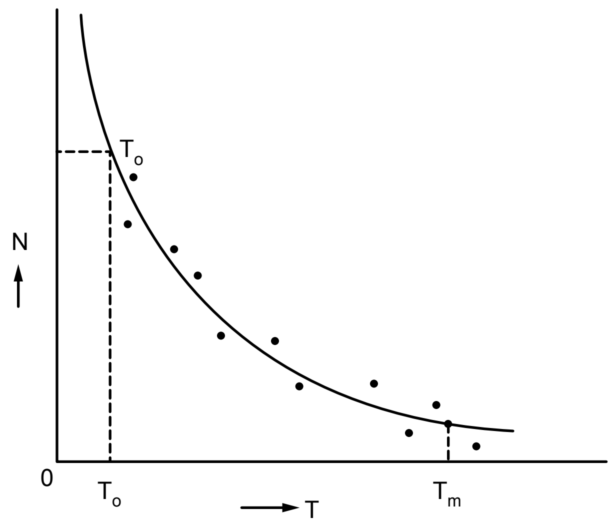

Figure 3.2

If the experimental results are as shown in Figure 3.2, fix the curve so that it can pass through the points as shown.

3.4 Input and Output Relations

The input to the motor will be:

$$\text{Input} = VI \text{ watts} = P_1 \tag{3.1}$$

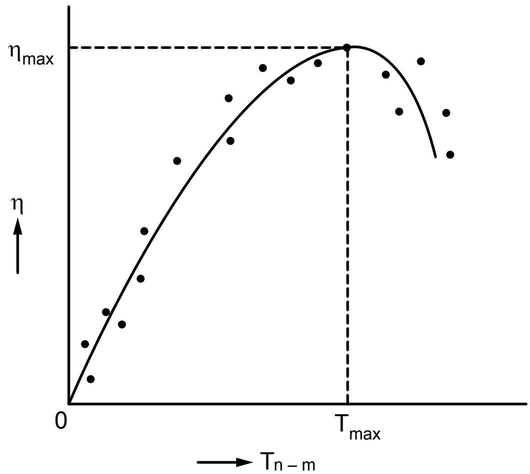

Figure 3.3

The output will be:

$$\text{Output} = \frac{2\pi\, NT}{60} \text{ watts} = P_o \tag{3.2}$$

The efficiency of the motor will be:

$$\eta = \frac{\text{Output}}{\text{Input}} = \frac{2\pi\, NT/60}{VI} \tag{3.3}$$

Plot the efficiency and the torque T in Newton-meters.

The efficiency-torque curve is shown in Figure 3.3. The object is to find the maximum efficiency and the maximum torque.

3.5 Current-Torque Curve

The current-torque curve is shown in Figure 3.4. When starting, the torque is related to the current as follows:

$$T = KL^2 \tag{3.4}$$

and afterward

$$T = KI \tag{3.5}$$

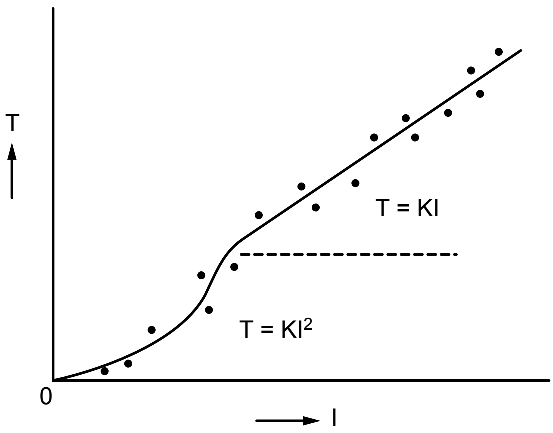

Figure 3.4

3.6 Questions and Answers on the Experiment

Q1. What are the applications of a D.C. series motor?

Ans. Series motors are used to supply the torque and speed to

(*a*) Traction loads
(*b*) Lifts
(*c*) Winches
(*d*) Hoists
(*e*) Cranes
(*f*) Digging appliances
(*g*) Cutting appliances

Q2. What are the special features of a D.C. series motor?

Ans. (*a*) High starting torque for loads.
(*b*) High capacity to meet the load fluctuations.

Q3. Which type of starter is used for a D.C. series motor?

Ans. Two-point starter.

Q4. How will you control the speed with a D.C. series motor?

Ans. We can use a field diverter with the series field.

Q5. What will happen to the speed of a D.C. series motor when the supply voltage is reduced?

Ans. The speed will be reduced.

Q6. If we connect a resistance in series with the armature, what will happen to the speed?

Ans. The speed will be reduced.

EXPERIMENT 4

4.1 Object: Load Test on a D.C. Shunt Motor

We have pointed out that a load test has other names, such as a brake test, speed-torque curve test, or shaft characteristic test. Our object is to find the variation of speed when the torque is changed.

4.2 Experimental Setup

A shunt motor, voltmeter, ammeter, tachometer, and torque measuring device are needed.

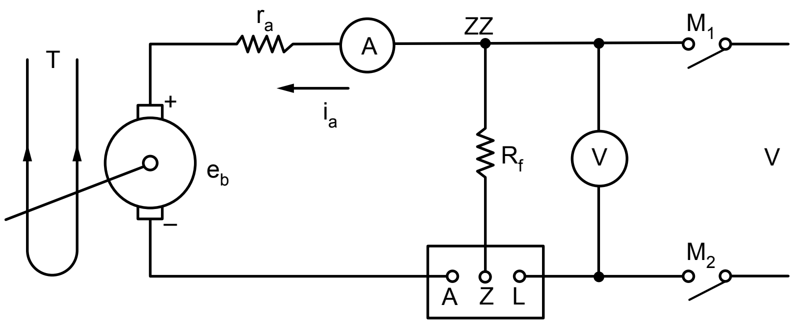

Figure 4.1

Figure 4.1 represents the D.C. shunt motor with the voltmeter and ammeter connected to the power supply. Power supply to the motor may be received from a separate powerhouse in the laboratory.

The range of the instruments will depend on the capacity of the motor. Read the motor nameplate and note the specifications. The study of the nameplate will decide the range of the instruments.

Start the motor by making a switch "on." Make the switch on for the motor. Use the three-point starter for starting.

Move the starter handle slowly and steadily; otherwise transients will enter into the machine.

Read the speed, torque, and current. The voltage being constant, we require only one reading. Note this reading in the experimental results.

EXPERIMENTAL RESULTS

S.N.	***Speed N***	***Torque T = $T_1 - T_2$***	***T_a***	***V***	***Remarks***
1					No-load speed = N_o RPM.
2					
3					
4					
5					
6					

Plot the speed-torque curve. Consider the origin at *O*, *O* and plot the graph.

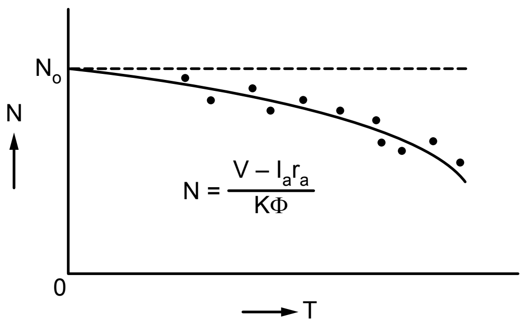

Figure 4.2

Plot the graph between torque and current, considering the origin at *O*, *O*. The graph is shown in Figure 4.3.

The torque is directly proportional to the armature current. The speed falls with the armature current as shown in the following mathematical expression:

$$N = \frac{V - I_a r_a}{K\phi} \tag{4.1}$$

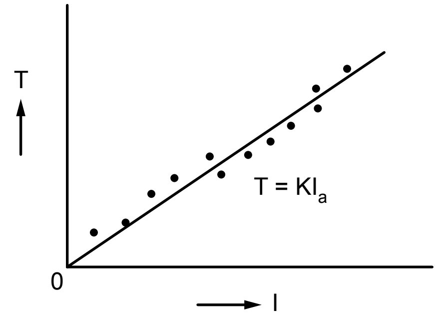

Figure 4.3

A graph plotting speed and torque is shown in Figure 4.1. We show a speed-current curve in Figure 4.4.

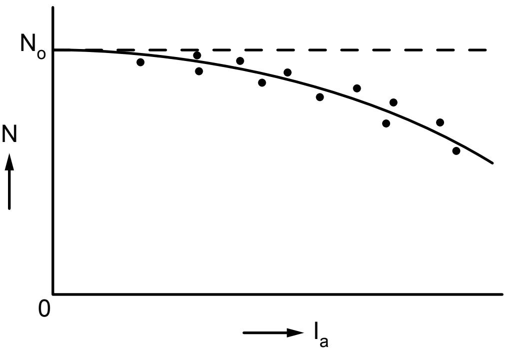

Figure 4.4

4.3 Discussion

The experimental results are tabulated. The speed falls when we increase the torque. This is due to the armature drop $i_a r_a$. The speed-torque and torque-current curves are shown in Figures 4.2 and 4.3 along with the shaft characteristic.

4.4 Input and Output Relations

The input can be found simply as the *VI* watts

$$\text{Input} = VI \text{ watts} \tag{4.2}$$

The output will be t

$$\text{Output} = \frac{2\pi NT}{60} \text{ watts} \tag{4.3}$$

The efficiency will be:

$$\eta = \frac{\text{Output}}{\text{Input}} = \frac{\frac{2\pi NT}{60}}{VI} \tag{4.4}$$

$$\eta = 1 - \frac{\text{Losses}}{\text{Input}} \tag{4.5}$$

The efficiency of the motor varies with torque or current, as shown in Figure 4.5.

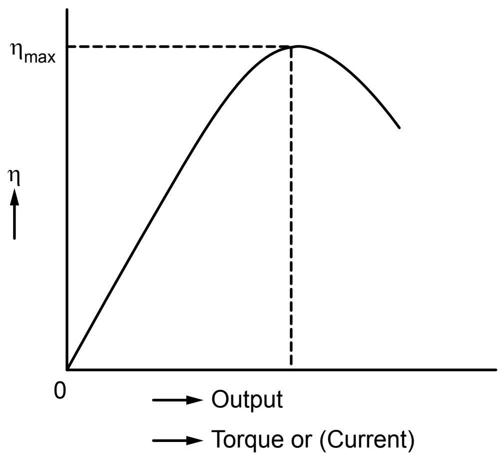

Figure 4.5

The load is referred to as the torque, T or the current I_a. Some engineers call the current the load in the case of the generator. The current may also be called the load in the case of the motor.

4.5 Questions and Answers on the Experiment

Q1. What is the importance of the no-load current of the motor?

Ans. No-load losses such as mechanical losses (friction and windage losses) and copper loss in the field may be determined.

Q2. What will be the efficiency of the motor at a no-load current?

Ans. Zero.

Q3. Which speed will be higher, either no-load speed or full-load speed?

Ans. The no-load speed will be slightly higher than the full-load speed.

Q4. How will you control the speed of a D.C. shunt motor?

Ans. By changing the terminal voltage and changing the field current.

Q5. Which type of starter is used to start the shunt motor?

Ans. Three-point starter.

Q6. Why do we use a starter?

Ans. To build the back EMF slowly. The back EMF takes time to build up as the field current rises. If we apply full voltage to the motor with the back EMF, a high current flow will burn the motor insulation.

Q7. Where would we use shunt motors?

Ans. Shunt motors are used in fans of railway trains, paper mills, textile mills, and flour mills. All appliances which require constant speed are coupled to the shunt motor. The centrifugal pump is connected with a shunt motor.

EXPERIMENT 5

5.1 Object: Load Test on a D.C. Shunt Generator

All types of load tests are similar for generators. We are interested in determining the volt-ampere curve of the generators. The *V-I* characteristic of the generators will be similar to the *V-I* curve of a battery.

5.2 Experimental Setup

A shunt generator, which is available in the laboratory, is required. If the generator is not installed, it may be installed on a foundation base. The load test should be started after one week, as the foundation will take time for drying and setting.

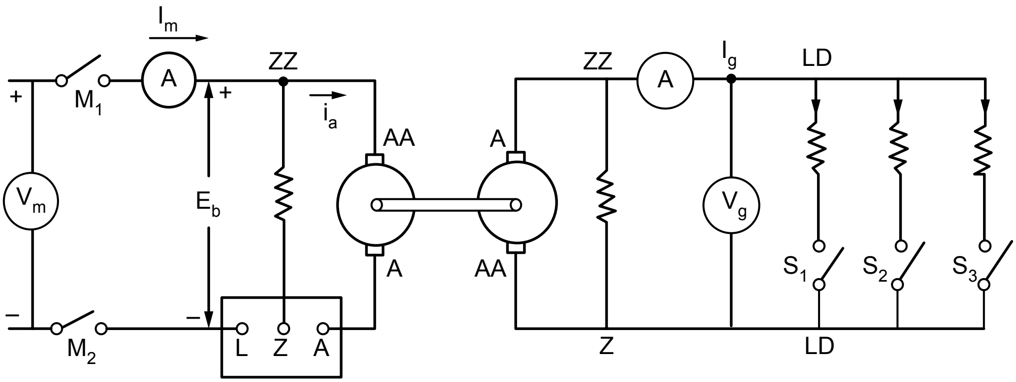

Figure 5.1

A circuit diagram of the shunt generator driven by a shunt motor is shown in Figure 5.1. A lamp load is connected to the terminals of the generator and switched one by one with the help of switches S_1, S_2, S_3, and so on. The lamps are connected in parallel; this should be noted.

We are interested in noting the current and voltage read by the instruments at the generator terminals only. In addition, we may find the efficiency of the generator when it is run at a constant speed. The *V-I* curve is plotted in Figure 5.2, where V and E stand for terminal voltage and EMF, respectively. I_a and V_a stand for armature current and armature resistance, respectively.

EXPERIMENTAL RESULTS

S.N.	Current I_g Amps	Volts V_g	V_m volt	I_m Amps	Power input $V_m I_m$ watts	Power output V_g I_g watts	η
1							
2							
3							
4							
5							
6							

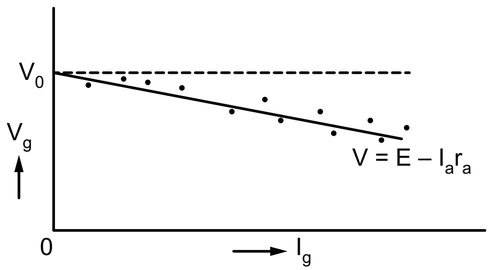

Figure 5.2

The efficiency curve will be plotted with a variation of the load current I_g.

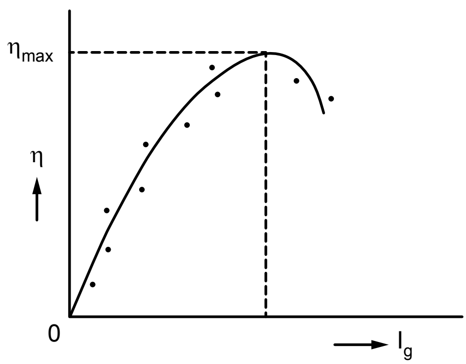

Figure 5.3

The voltage V decreases due to the armature $I_a r_a$ as shown by the equivalent circuit in Figure 5.4. The generators are equivalent to a battery. The open circuit voltage, called EMF, decreases when the load current is increased.

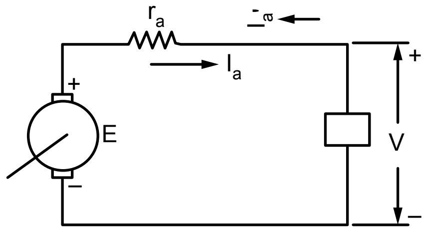

Figure 5.4

5.3 Discussion

The load curves of a shunt generator are shown in Figures 5.2 and 5.3. We have already pointed out in the series generator that the two curves are the load curves.

5.4 Questions and Answers on the Experiment

Q1. What will you do if the shunt generator fails to build up voltage?

Ans. Reverse the field terminals and change the field rheostat setting.

Q2. Why does the shunt generator fail to build up voltage?

Ans. The critical resistance condition is changed. The field rheostat setting is more than the critical resistance.

Q3. Why does the terminal voltage of the shunt generator decrease when the load increases?

Ans. The armature resistance causes an armature reaction which reduces the field current.

Q4. Why do we call it a shunt generator?

Ans. The field winding is connected in shunt to the armature current.

Q5. The efficiency of the generator rises to a maximum value and then decreases. Why?

Ans. The copper loss increases more than the fixed losses, so the efficiency will decrease.

EXPERIMENT 6

6.1 Object: Load Test on a D.C. Compound Motor

A compound motor has both series and shunt fields on the same pole and the speed can be changed at greater flexibility. The electrical equivalent circuit of a D.C. compound motor is shown in Figure 6.1; the connected instruments are YY–Y, the series winding, and ZZ–Z, the shunt winding. After reading the nameplate of the motor, we decide the range of the instruments.

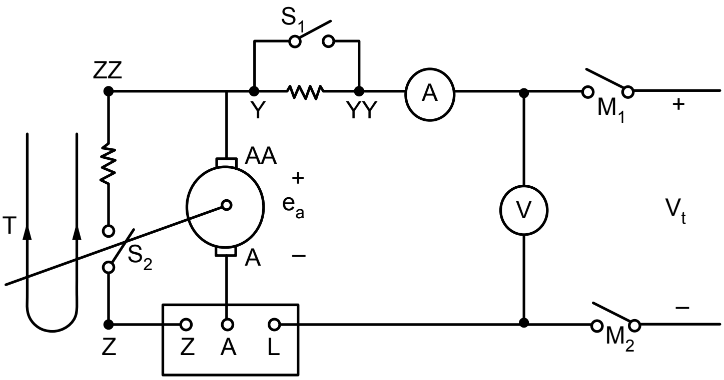

Figure 6.1

6.2 The Load Test

A load test is simple when we require the speed and torque of the motor for various steps of loading. We increase the torque $T = T_1 - T_2$ by a belt and measure the RPM by a tachometer.

EXPERIMENTAL RESULTS

S.N.	*Torque* $T = T_1 - T_2$	*Speed RPM* N	*Output* $\frac{2\pi NT}{60}$	*Input VI*	η	*Remarks*
1						
2						
3						
4						
5						
6						
7						

Plot the graph between torque and speed. Note that the torque must be located on the X-axis and speed N on the Y-axis, because speed is the dependent variable and torque is the independent variable.

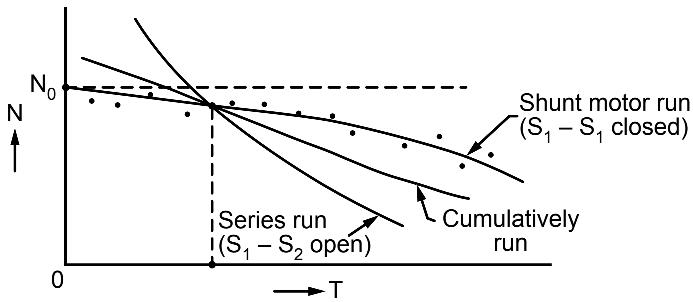

Figure 6.2

From the characteristic equation of the machine we have:

$$e_b = V_t - I_a (R_a + R_{fs}) \tag{6.1}$$

Refer to Figure 6.2 to obtain the characteristic equation of the motor.

$$K\phi N = V_t - I_a R \tag{6.2}$$

$$N = \frac{V_t - I_a R}{K\phi} \tag{6.3}$$

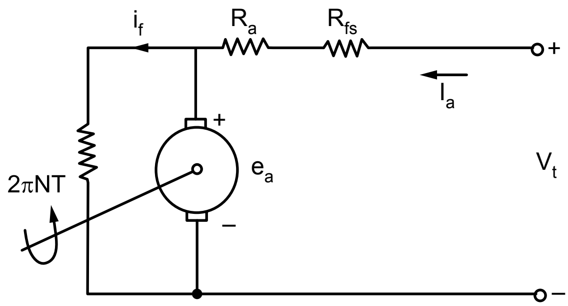

Figure 6.3

The speed will depend on I_a and ϕ will also produce a flux in the series winding.

6.3 Input and Output Relations

The efficiency will be

$$\eta = \frac{\text{Output}}{\text{Input}} = \frac{\text{Input} - \text{losses}}{\text{Input}}$$

$$= 1 - \frac{\text{Losses}}{\text{Input}} \tag{6.4}$$

6.4 Current and Torque Relations

The current and torque relations are shown in Figure 6.5. The torque will be linearly proportional to the current.

$$T = K_1 I_a$$

This can be found from all the machines:

$$2\pi NT = e_a I_a \tag{6.5}$$

or

$$T = KI_{\text{a}} \tag{6.6}$$

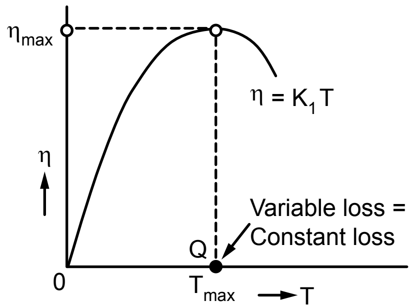

Figure 6.4

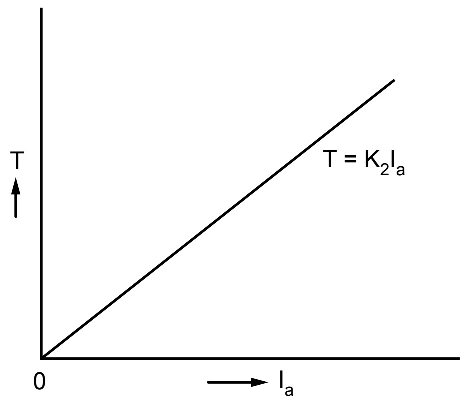

Figure 6.5

6.5 Discussion

The load characteristics are shown in Figures 6.1, 6.4, and 6.5. All three are called the load curves, in a broad sense. But the speed-torque curve is referred to as the load curve for the motor.

6.6 Questions and Answers on the Experiment

Q1. How will you change the flux of the series winding in the compound motor?

Ans. By using a diverter.

Q2. The differentially compounded motor has a tendency to start in the opposite direction. Why?

Ans. The series winding flux will be in the opposite direction from the main field direction and sets earlier than the shunt field flux.

Q3. What are the advantages of a compound motor?

Ans. It can run as a series motor or shunt motor. Speed can be increased or decreased from the normal speed.

Q4. Where are the series and shunt windings?

Ans. On the main poles.

Q5. A cumulatively compounded motor is running at a loaded condition and the series winding is short-circuited; discuss the speed variation.

Ans. Speed will rise due to flux reduction.

Q6. A differentially compounded motor is running at a loaded condition and the series winding is short-circuited; discuss the speed variation.

Ans. The speed will fall due to the rise of flux in the air gap.

EXPERIMENT 7

7.1 Object: Load Test on a D.C. Compound Generator

7.2 Experimental Setup

There may be two, three, or four types of load characteristics for a compound generator: level compounding, over-compounding, under-compounding, and shunt characteristic. The test may be made for a cumulatively compounded or differentially compounded generator. The connections may be either the long shunt or the short shunt type.

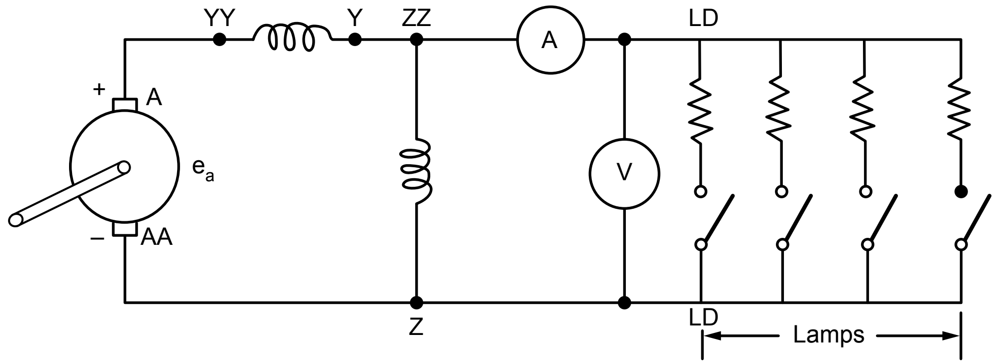

Figure 7.1

Figure 7.1 represents a circuit diagram for the experiment. We can perform the load test to plot the volt-ampere characteristic by taking readings by voltmeter and ammeter.

The efficiency test will require a motor generator set. The input to the motor and output of the generator will be found by voltmeters and ammeters, as shown in Figure 7.2.

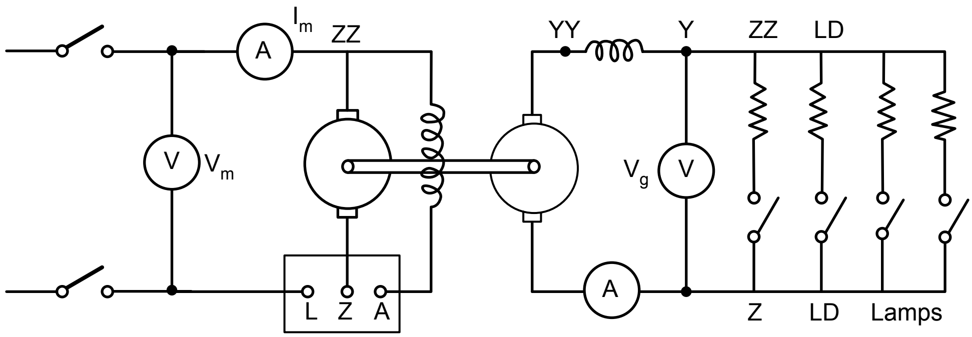

Figure 7.2

A shunt motor will run the compound generator. The lamps connected in parallel are switched one by one and the readings are obtained from the instruments.

EXPERIMENTAL RESULTS

S.N.	V_g	I_g	V_m	I_m	*Input* $V_m I_m$	*Output* $V_g I_g$	η	*Remarks*
1								
2								
3								
4								
5								
6								
7								

The efficiency will be

$$\eta = \frac{\text{Output}}{\text{Input}} = \frac{V_g I_g}{V_m I_m} \tag{7.1}$$

The volt-ampere characteristic is plotted in Figure 7.3.

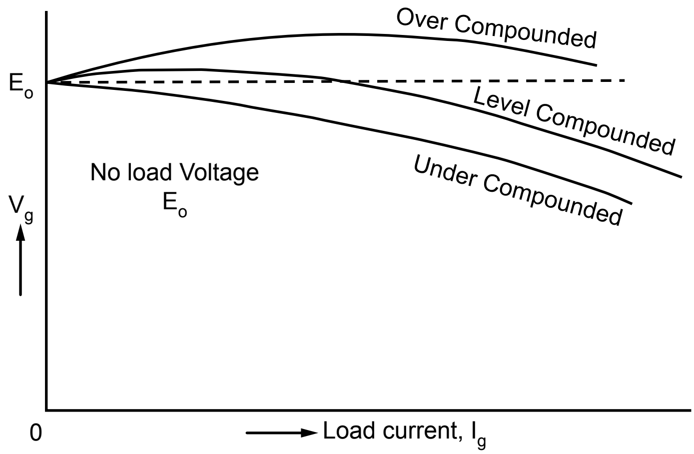

Figure 7.3

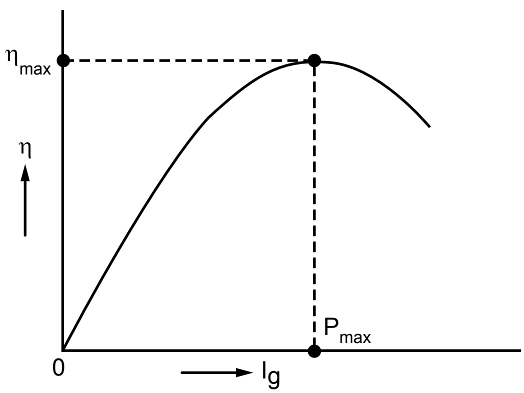

Figure 7.4

7.3 Discussion

The load characteristics are shown in Figures 7.3 and 7.4. The maximum efficiency and output power can be obtained from the efficiency curve. The *V-I* curve will provide us the no-load voltage, full-load voltage, and half-load voltage. The decrease of the terminal voltage is due to the armature drop and the series field resistance drop. The armature reaction and leakage also cause a drop of the voltage.

7.4 Questions and Answers on the Experiment

Q1. How much flux is contributed by the shunt field and series field?

Ans. A flux of 80% is contributed in the air gap by the shunt field winding and 20% by the series field winding.

Q2. If we use only series winding of the generator, discuss the performance.

Ans. It will perform as a series generator.

Q3. If we use only shunt winding of the generator, discuss the performance.

Ans. It will perform as a shunt generator.

Q4. What will happen to the terminal voltage of a level compound generator when a full load is switched off?

Ans. There will be no change of the terminal voltage.

Q5. The series winding of a compound generator is short-circuited at full load when working as a differentially compounded generator; discuss the change in terminal voltage.

Ans. The terminal voltage will rise.

Q6. What is a reason for raising the terminal voltage when the series winding of a differentially compounded generator is short-circuited at full load?

Ans. The resultant flux in the air gap will be greater.

EXPERIMENT 8

8.1 Object: No-Load Test on a Separately Excited D.C. Generator (Magnetization Characteristic)

8.2 Experimental Setup

A separately excited D.C. generator coupled mechanically with a motor is used to obtain a magnetization characteristic. The generator is run at rated speed, and the open circuit voltage is measured by a voltmeter. Field current is measured by an ammeter in the separately excited winding of the generator.

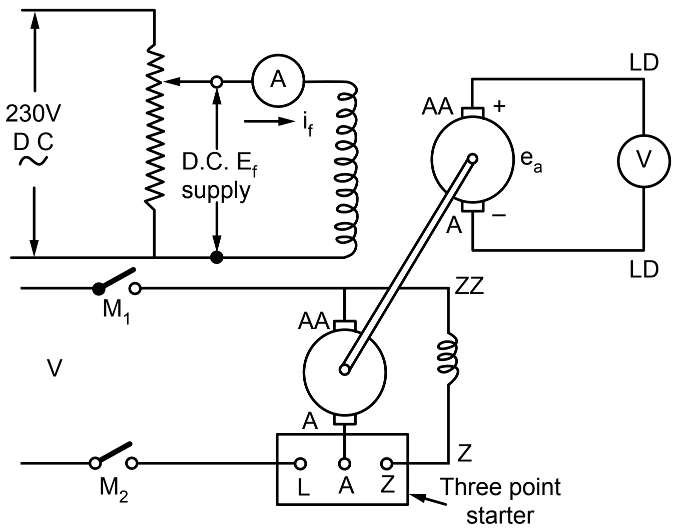

Figure 8.1

The ranges of the ammeter and voltmeter will depend on the specifications of the generator. The no-load voltage will go on increasing with field current i_f and will reach a maximum point and become constant due to saturation. The field current i_f is increased from zero to some value till e_a becomes constant. The i_f is then decreased and e_a is measured correspondingly. The i_f is brought to zero and e_a is noted. Experimental remits are tabulated.

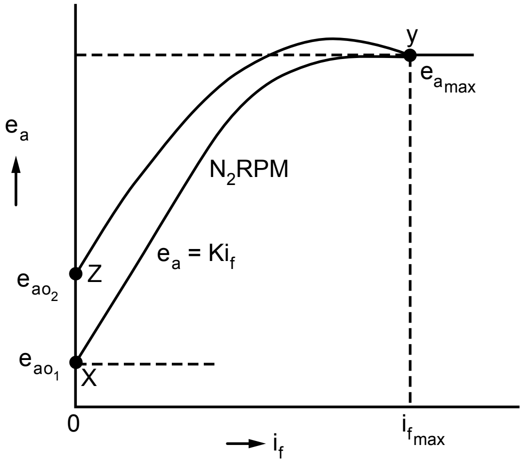

Figure 8.2

This experiment is made to find the voltage induced in the machine. The induced voltage will be

$$e_a = Ki_f \tag{8.1}$$

The constant K of the machine can be obtained as follows:

$$K = \frac{e_a}{i_f} \text{ volt per field amperes} \tag{8.2}$$

EXPERIMENTAL RESULTS (*if increasing*)

S.N.	*Open Circuit voltage (e_a)*	*Field current (i_f)*	*Speed of generator (N)*	*Remarks*
1		Zero	Constant	
2				
3				
4				
5				
6				

A graph between i_f and e_a is plotted as shown in Figure 8.2. It is called an *initial magnetization curve*, from point *X* and *Y*. The decrease of voltage e_a with i_f is also plotted to obtain curve *YZ*.

The magnetization curve is shown in Figure 8.2. The curve *XY* is called the *open circuit characteristic* of a separately excited generator.

EXPERIMENTAL RESULTS (*if decreasing*)

S.N.	Open Circuit voltage e_a	Field current i_f amps	Speed of generator (RPM)	Remarks
1			Constant	
2				
3				
4				
5				
6		Zero		

8.3 Discussion

The experiment is made to find a constant *K* volts per field ampere for the machine, maximum voltage $e_{a\ max}$ and the maximum excitation current $i_{f\ max}$. The *YZ* curve encloses an area that will give us the hysteresis loss for a half cycle of field current reversal.

8.4 Questions and Answers on the Experiment

Q1. What information do we obtain from the magnetization curve?

Ans. A value of generated EMF is obtained at a given field current and speed. The EMF varies with field current i_f and speed; we have

$$e_a = Ki_f,\ K = e_a/i_f \tag{8.3}$$

K is a constant of machine volts per field amperes. The determination of constant *K* is obtained. A voltage due to residual flux is also obtained.

Q2. How does the magnetization curve change when we change the speed?

Ans. The curve as a whole rises with the increase of speed and goes down with decrease of speed.

Q3. What factors affect the shape of the magnetization curve?

Ans. The number of turns on poles, size, shape, and materials of the poles, air gap length, and rotor core dimensions and material affect the shape of the magnetization curve.

EXPERIMENT 9

9.1 Object: No-Load Test on a D.C. Shunt Generator (Magnetization Characteristic)

9.2 Experimental Setup

A shunt generator is coupled with a motor mechanically. The motor may be induction, synchronous, or any D.C. motor.

We may assume that it is connected with a shunt motor. The motor has no impact on the experiment when we perform a no-load test. The experimental setup is represented in Figure 9.1. A shunt generator is coupled mechanically with a shunt motor.

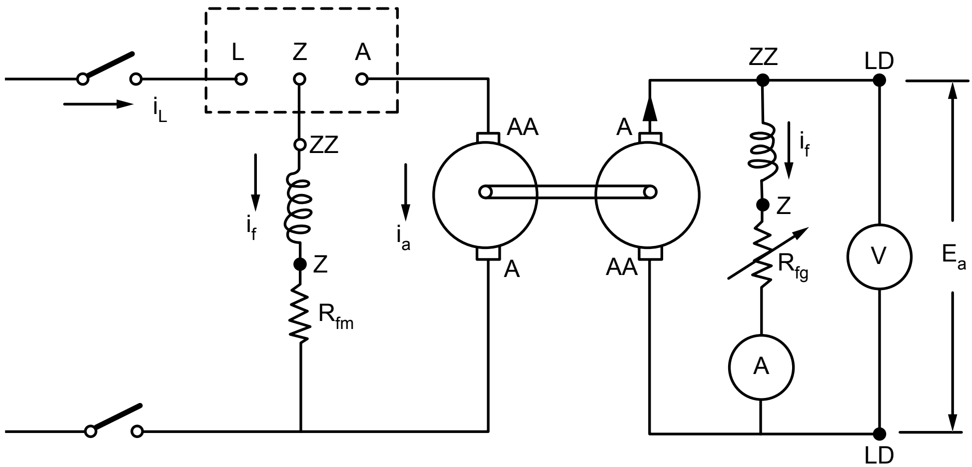

Figure 9.1

We vary the field current with a rheostat connected in the field circuit of the generator designated R_{fg}. We read the voltmeter readings as the open circuit voltage.

EXPERIMENTAL RESULTS

S.N.	*Field current of generator (amps)*	*Open Circuit voltage E_a (volts)*	*Speed N (RPM)*	*$i_f R_f$ (volts)*	*Remarks*
1	Zero		Constant		
2					
3					
4					
5					
6					
7					

The experimental results are tabulated. It should be noted that E_a must be read at the zero field current, in reading number 1. The speed is kept constant.

Graphs are plotted with i_f for E_a and $i_f R_f$ in Figure 9.2

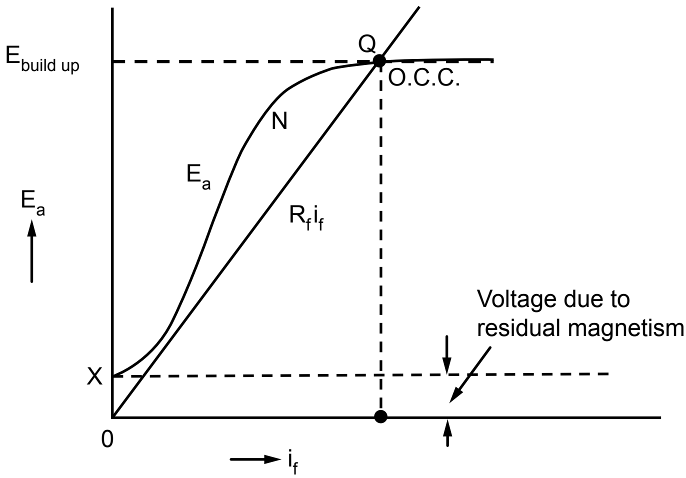

Figure 9.2

9.3 Discussion

We have plotted the graphs in Figure 9.2 for E_a and i_f R_f with the variation of field current i_f. *OX* is the voltage produced by the residual flux in the pole faces.

The O.C.C. and $R_f\, i_f$ line meet at a point, Q. The voltage $E_a = i_f R_f$ at this point; E_a is the buildup voltage at R_f ohms.

9.4 Questions and Answers on the Experiment

Q1. What important information may be obtained from the magnetization curve?

Ans. The determination of induced voltage e_a can be obtained for various values of field current i_f. A constant $K = e_a / i_f$ will be obtained for the generator.

Q2. What is the information that may be obtained from a no-load curve?

Ans. Residual magnetization, the constant K, critical resistance of the shunt field, and the maximum voltage developed at a speed.

Q3. What is a critical resistance?

Ans. A resistance of field rheostat at which the machine will build up a voltage, and, if we increase the resistance a little, the voltage will not develop. The machine will refuse to be excited.

Q4. We increase the field current to the saturation value, then decrease it to zero. We again increase it in a negative direction and bring it up to saturation value, and then decrease to zero. Discuss the nature of the curve drawn between e_a and i_f.

Ans. The hysteresis loop will be obtained.

Q5. For the torque T = K i_a, what will be a condition of the equation?

Ans. The shaft losses are neglected.

Q6. What is an air gap line?

Ans. The line drawn between e_a and i_f without saturation. A linear part of the O.C.C. is called the air gap line.

EXPERIMENT 10

10.1 Object: No-Load Test on a D.C. Shunt Motor (Swinburne Test)

10.2 Experimental Setup

The Swinburn test is made on a shunt motor to determine efficiency of the motor. Measure the field resistance and armature resistance designated R_f and R_a, respectively. Run the motor at no-load and measure the current and voltage by the instruments. A full voltage is applied to the motor terminals, and i_f, i_L, and i_a are found. We require only one reading for the no-load test, and that will be at the full load. If we wish to find the no-load loss variation with voltage, the voltage will be increased.

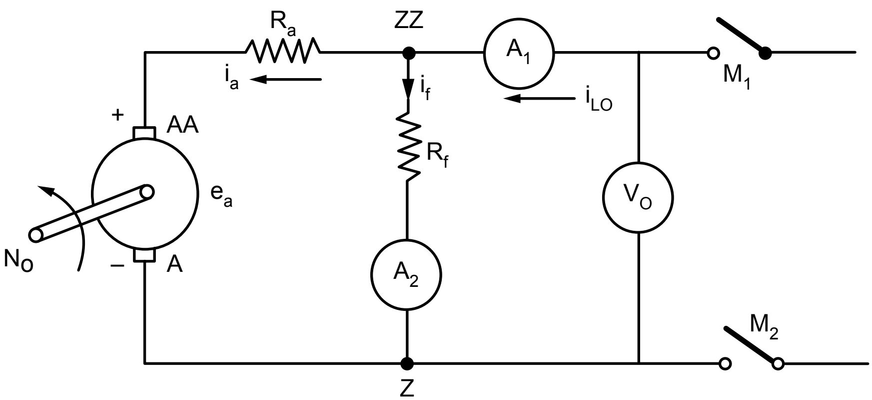

Figure 10.1

EXPERIMENTAL RESULTS

S.N.	A_1 (i_{Lo})	A_2 (i_f)	V_o (volts)	i_a amps	R_a ohms	R_f ohms	Remarks
1							Full voltage applied
2							Voltage increased
3							
4							
5							
6							
7							

The results are tabulated in an experimental result table. The input power will be given by:

$$\text{Input} = VI_{Lo} \text{ watts at no-load}$$

This power will be a loss in the machine in the form of:

(i) Copper loss

(ii) Iron loss

No load loss } (iii) and Friction and windage loss.

In the Swinburn test the R_a and R_f measured at room temperature are converted to a value of 75°C because at actual loading the machine temperature goes up to this point. We have:

$$R_{f(75°C)} = R_{f(30°C)}\,[1 + \alpha t] \tag{10.1}$$

Where room temperature may be 30°C or 27°C as the case may be:

$$R_{f(75°C)} = R_{f(30°C)}\,[1 + \alpha(75°C–30°C)] \tag{10.2}$$

Similarly, for R_a we have:

$$R_{a(75°C)} = R_{a(30°C)}\,[1 + \alpha(75°C–30°C)] \tag{10.3}$$

RESISTANCES

S.N.	$R_{a(75°C)}$	$R_{f(75°C)}$	$R_{a(30°C)}$	$R_{f(30°C)}$
1				
2				
3				
4				

The field copper loss will be:

$$P_f = i_f^2 R_{f(75°C)} \text{ watts.} \tag{10.4}$$

The armature copper loss will be:

$$P_a = i_a^2 R_{a(75°C)} \text{ watts} \tag{10.5}$$

The total copper loss at no-load will be:

$$P_{fa} = [i_f^2 R_{f(75°C)} + i_a^2 R_{a(75°C)}] \text{ Watts} \tag{10.6}$$

The fixed loss (no-load loss) will be:

$$P_o = (VI_L – P_{fa}) \text{ watts} \tag{10.7}$$

The P_a watts will be the no-load loss or iron loss free from the copper loss in the machine.

If we wish to determine the efficiency of a motor at a particular load, for example, 20 amps, then we have

$$i_L = 20 \text{ amps}$$

$$i_f \text{ is fixed} = 230/R_f = 1 \text{ amp}$$

$$i_a = i_L - i_f = 19 \text{ amps}$$

The copper loss will be

$$P_{copper} = i_a^2 R_a + i_f^2 R_f = P_c \tag{10.8}$$

The total loss will be

$$P_{loss} = (P_o + P_c) \text{ watts} \tag{10.9}$$

The efficiency will be

$$\eta = 1 - \frac{\text{Loss}}{\text{Input}} \tag{10.10}$$

Where input at 20 amps will be

$$P_i = VI_L = 230 \times 20 \text{ watts} \tag{10.11}$$

The input P_i will vary at every load of the motor. The copper loss will also change with the load, but the P_o will remain constant.

If we wish to plot a graph between the no-load voltage and the power loss VI_L watts, we obtain the following in Figure 10.2:

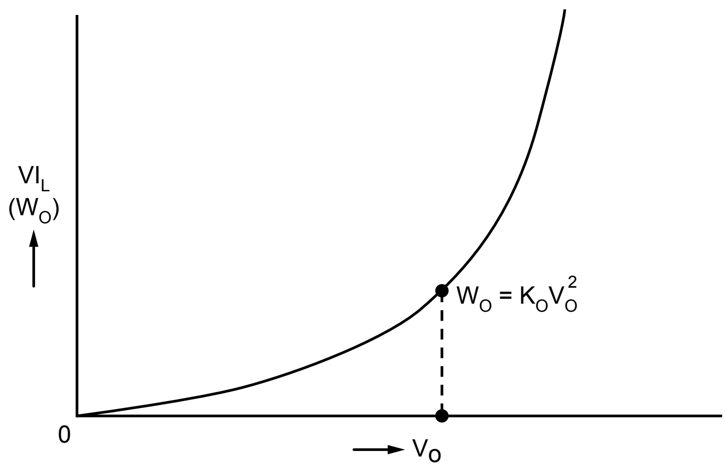

Figure 10.2

10.3 Discussion

The Swinburn test is made to determine the exact no-load losses at 75°C of temperature. Exact efficiency can be determined by this test when the machine is actually loaded. The no-load loss variation with voltage is shown in Figure 10.2.

10.4 Questions and Answers on the Experiment

Q1. Can you perform the Swinburn test on a series motor? Why or why not?

Ans. No, because the motor cannot be run at no-load.

Q2. What is a difference between an ordinary no-load test and the Swinburn no-load test?

Ans. Resistances r_a and r_f measured at room temperature are converted to 75°C of temperature, which will be the working temperature at high load.

Q3. How will you determine windage and friction loss of the shunt motor?

Ans. Go on reducing the terminal voltage and let the machine run at no-load. A voltage will be obtained at which the rotor will stop. Note the current I_o and voltage V_o. The power V_oI_o will be the windage and friction loss in watts.

EXPERIMENT 11

11.1 Object: To Perform a Hopkinson Test on Two Identical D.C. Shunt Machines

11.2 Experimental Setup

This test is called a back-to-back test, in which two identical D.C. shunt machines are required. These two machines are coupled mechanically and connected electrically in parallel. One of the machines runs as a motor and the other as the generator. Mechanical energy of the motor drives the generator, and electrical energy of the generator is used in supplying most of the input to the motor.

If the machines were lossless, they would run with the help of external power input. The losses are supplied from the external supply source.

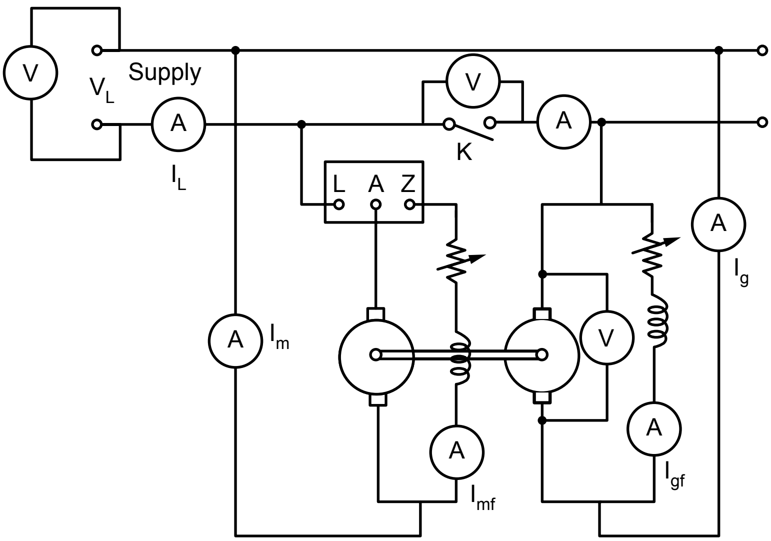

Figure 11.1

The circuit diagram is connected as shown in Figure 11.1 with instruments. The range of the voltmeters and ammeters will depend on the ratings of the machines. Read the nameplates and find the ranges of the instruments.

The motor is run from the supply mains, and rated current is fed to the motor. The voltage of the generator is adjusted so that the voltmeter connected across the switch *K* reads zero volts. This will ensure the same magnitude and polarity of the generator output voltage as that of the supply. The readings of the instruments are noted.

EXPERIMENTAL RESULTS

S.N.	I_m motor current	I_{mf} motor field current	Line voltage V_L	Line current I_L	Ea_g generator voltage	I_{gf}	I_g	R_a	Remarks
1									
2									
3									

The symbols used in the previous table are:

I_m : motor current
I_{mf} : motor field current
V_L : line voltage
I_L : line current
E_{ag} : generator voltage
I_{gf} : generator field current
I_g : generator current

11.3 Calculations

The copper loss in the two machines can be calculated as follows:

(*i*) Copper loss in motor field

$$= V_L I_{mf} \text{ watts}$$

(*ii*) Copper loss in motor armature

$$= R_a(I_m - I_{mf})^2$$

$$= R_a I_{am}{}^2 \text{ watts}$$

(*iii*) Copper less in generator field

$$= V_{-L} I_{gf} \text{ watts}$$

(*iv*) Copper loss in generator armature

$$= R_a(I_g - I_{gf})^2$$

$$= R_a I_{ag}{}^2 \text{ watts}$$

Total copper loss will be

$$P_c = R_a I_{am}{}^2 + R_a I_{ag}{}^2 + V_L I_{gf} + V_L I_{mf}$$

$$P_c = R_a(I_{am}{}^2 + I_{ag}{}^2) + V_L(I_{gf} + I_{mf}) \tag{11.1}$$

Input power to the two machines will be

$$P = V_L I_L \text{ watts} \tag{11.2}$$

Constant loss = Iron+Friction+Windage

$$P_i = V_L I_L - P_c \tag{11.3}$$

The loss for one machine will be:

$$P_c/2 \text{ and } P_i/2 \tag{11.4}$$

This experiment is made to find the losses in the machines when the machines have large capacity and when large power will be consumed in testing.
The efficiency will be:

$$\eta = 1 - \frac{\text{Losses}}{\text{Input}}. \tag{11.5}$$

11.4 Questions and Answers on the Experiment

Q1. What are other names for the Hopkinson test?

Ans. Back-to-back test and regenerative test.

Q2. What are the advantages of the Hopkinson test?

Ans. Large capacity generators can be tested in a laboratory without wasting a large amount of energy in the loads. Large loads are avoided and actual load is applied on the machine.

Q3. How much power is taken from the supply?

Ans. To meet the losses in windings and core, the copper loss and iron loss are fed from the supply.

EXPERIMENT 12

12.1 Object: Open-Circuit Test and Short-Circuit Test on a Single-Phase Transformer

12.2 Experimental Setup

Open-circuit and short-circuit tests are performed to determine the power losses and the parameters of the transformer. Moreover, the power factor at open-circuit and short-circuit conditions is also an important requirement.

12.2.1 Open-Circuit Test

An open-circuit test is performed by applying a full voltage in the transformer at the high voltage side. Power transformers are connected to the high voltage side for the whole time and the low voltage side may create an open circuit for a period. The readings in the wattmeter are read at full voltage.

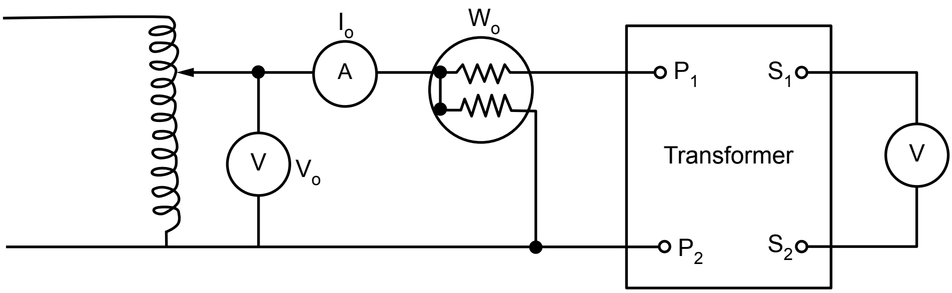

Figure 12.1

A circuit diagram is shown in Figure 12.1. The readings are tabulated at full voltage. The voltage supply is increased from 0 V to more than full voltage, and wattmeter readings are tabulated.

EXPERIMENTAL RESULTS

S.N.	***Voltage V_0***	***Current I_0***	***Power W_0***	***Remarks***
1	0	0	0	
2				
3				
4				
5	Full	—	—	Full voltage supply
6				
7				

If we increase the voltage from 0 *V* to some value more than full voltage in the primary, we must remember the reading at full voltage and note it in the table at S.N. 5, for example.

The voltage is increased from the auto-transformer. A graph is plotted between the voltage V_0 and power loss W_0.

The W_0 is called iron loss in the case of the transformer. The graph is shown in Figure 12.2. It may be shown that the iron loss

$$W_0 = K_0 V_0^2 \text{ for the curve,}$$

where K_9 is a constant.

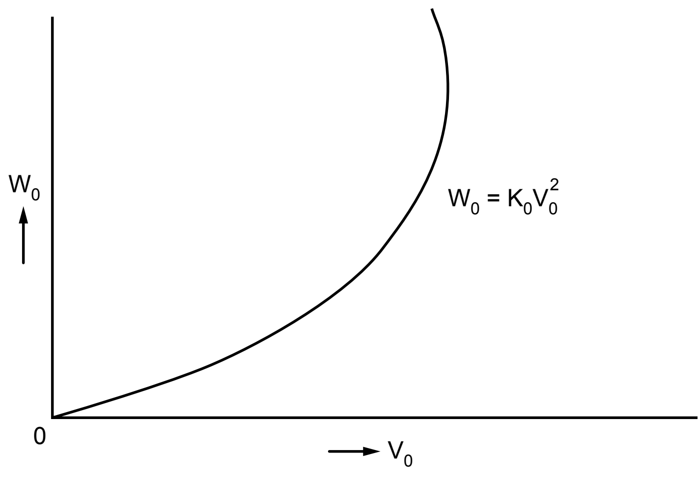

Figure 12.2

12.2.2 Calculation of Parameters and an Open-Circuit Equivalent Circuit

The power input will be dissipated in the form of loss because there is no output. The W_0 will be

$$W_0 = V_0 I_0 \cos \phi_0 \tag{12.1}$$

where $\cos \phi_0$ is the power factor at no-load condition and will be:

$$\cos \phi = \frac{W_0}{V_0 I_0} \tag{12.2}$$

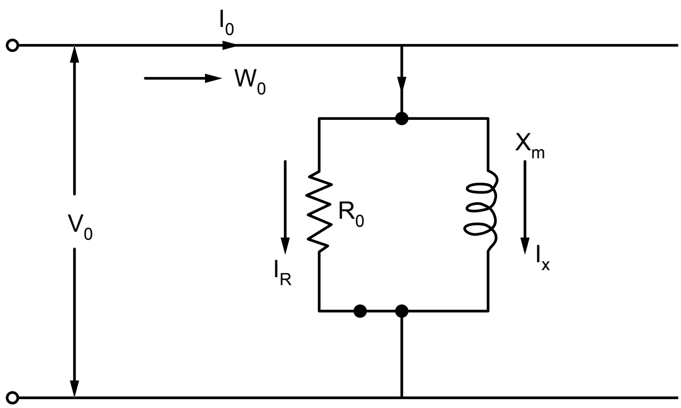

Figure 12.3

Figure 12.3 will be the equivalent circuit of the transformer at no-load.

The no-load current I_0 will be divided into two branches of R_0 and X_m, as follows:

$$I_R = I_0 \cos \phi_0 \tag{12.3}$$

$$I_X = I_0 \sin \phi_0 \tag{12.4}$$

The parameters R_0 and X_m will be

$$R_0 = \frac{V_0}{I_0 \cos \phi_0}$$

$$X_m = \frac{V_0}{I_0 \sin \phi_0} \tag{12.5}$$

12.2.3 Discussion on Open Circuits

The open-circuit test itself is a full test and is performed to determine iron loss and the open-circuit equivalent circuit of a transformer. The iron loss W_0, equivalent circuit, and no-load power factor are determined.

12.2.4 Short-Circuit Test

A short-circuit test is performed to determine copper loss, the short-circuit power factor, and the equivalent circuit at short-circuit conditions.

The experimental circuit is shown in Figure 12.4.

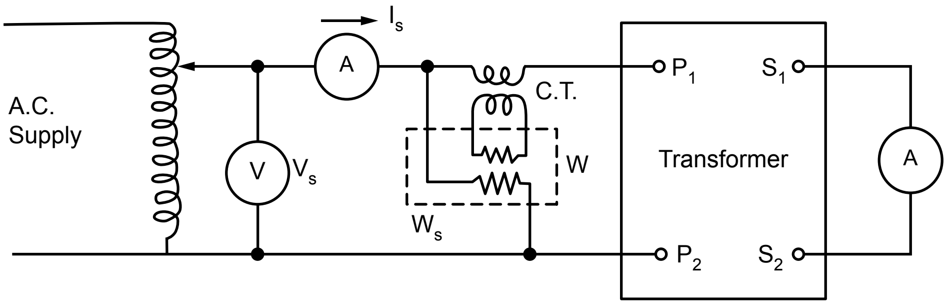

Figure 12.4

A 20% reduced voltage is supplied to the transformer. For example, if full voltage is 230 V, 46 V will be supplied to the transformer. Approximately 50 V will be enough. A full current is adjusted in the ammeter, and the voltage is reduced to about 20%.

Readings in the instruments are observed. The I_s, V_s, and W_s are designated for short-circuit current, voltage, and power. The results are tabulated as follows.

EXPERIMENTAL RESULTS

S.N.	I_s	V_s	W_s	COS ϕ_s	*Remarks*
1	0	0	0		
2					
3	Full	—	—		Full current injected at reduced voltage.
4					
5					
6					
7					

The reading W_s stands for copper loss and varies with the current I_s. We plot a graph between current I_s and W_s in Figure 12.5.

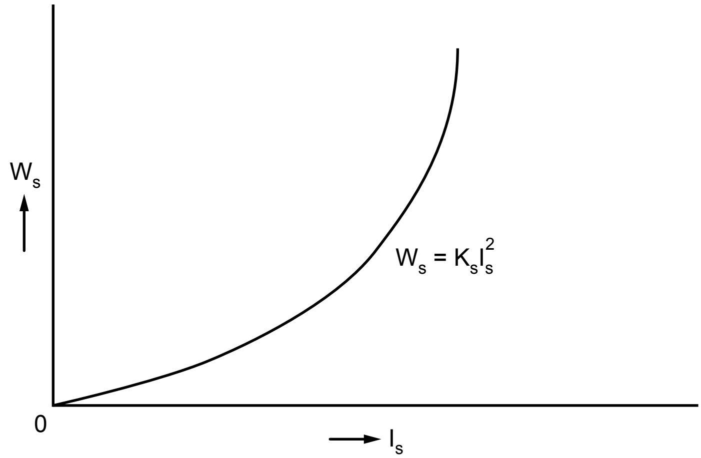

Figure 12.5

It may be shown that

$$W_s = K_s I_s^2$$

where K_s is a constant. The equivalent circuit of the transformer under short-circuit conditions is shown in Figure 12.6.

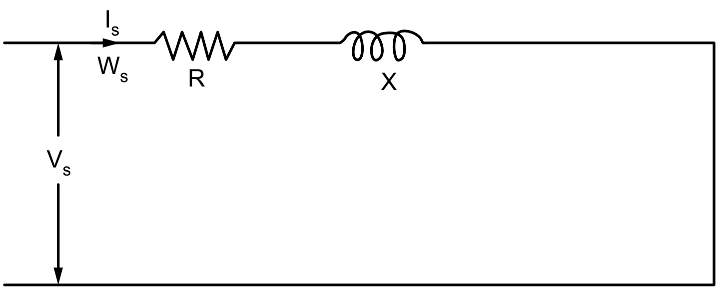

Figure 12.6

The parameters R and X will be found from simple series circuit principles.

$$Z = \frac{V_s}{I_s} \tag{12.6}$$

$$\cos \phi_s = \frac{W_s}{I_s V_s} \tag{12.7}$$

The resistance R and X will be

$$R = Z \cos \phi$$
$$X = Z \sin \phi \tag{12.8}$$

12.2.5 Discussion

Copper loss, short-circuit power factor, and equivalent circuit under short-circuit conditions are determined as shown previously.

12.3 Questions and Answers on the Experiment

Q1. If the O.P. and S.C. tests are made on 60 c/s instead of 50 c/s, what will be the effect?

Ans. The reactance will be high.

Q2. In a short-circuit test a watt meter reads 200 W at a short-circuit of 15 A. What will be the readings of the wattmeter at 30 A of current?

Ans.

$$W = 200 \times \left(\frac{30}{15}\right)^2$$
$$= 200 \times 4 = 800\ W.$$

Q3. Do O.C. and S.C. tests provide accurate regulation?

Ans. We obtain approximate regulation by a phasor diagram when the impedance is calculated from the two tests.

Q4. How will we calculate efficiency by open-circuit and short-circuit tests?

Ans. The efficiency will be

$$\eta = \frac{K(\text{output})}{K(\text{output}) + P_i + K^2 P_c} \tag{12.9}$$

P_i, iron loss is constant P_c; copper loss determined at a short-circuit current can be multiplied by the square of the load fraction K, where

$$K = \frac{I_{load}}{I_{full}} \tag{12.10}$$

EXPERIMENT 13

13.1 Object: Load Test on a Single-Phase Transformer

13.2 Experiment

A load test on a single-phase transformer is performed by connecting the lamps in parallel on the terminals. The transformer is run on the actual condition of input and output. The efficiency is calculated at every load. The regulation can also be found by the actual loading method. The efficiency and regulation will be:

$$\eta = \frac{\text{Output power}}{\text{Input power}}$$

$$\text{Regulation} = R_e\% = \frac{\text{No load voltage} - \text{Load voltage}}{\text{Load voltage}}$$

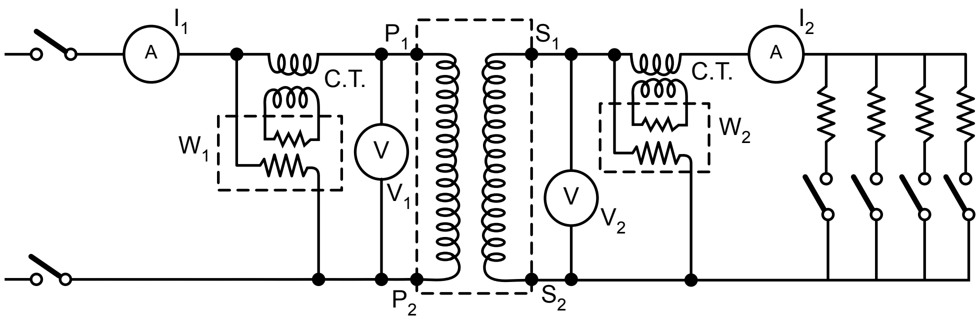

Figure 13.1

A circuit diagram for a load test on a single-phase transformer is shown in Figure 13.1. One ammeter, one voltmeter, and one wattmeter are connected on the primary side as well as on the secondary side. Current transformers are used with the wattmeter's current coil if the current is more than 5 A.

EXPERIMENTAL RESULTS

S.N.	V_1	I_1	W_1	V_2	I_2	W_2	η	R_{eg} %	No load Voltage V_0	Remarks
1										
2										
3										
4										
5										
6										
7										

A graph is plotted between W_2 and η in Figure 13.2.

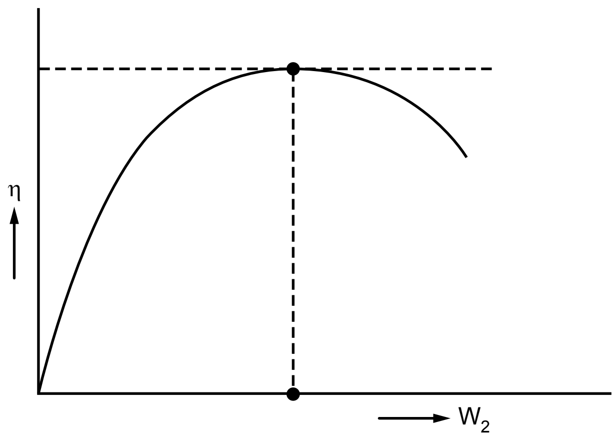

Figure 13.2

The open-circuit voltage or no-load voltage is read by a voltmeter once and tabulated in the table of experimental results.

The efficiency will be:

$$\eta = \frac{W_2}{W_1} \tag{13.1}$$

The regulation will be:

$$\text{Reg }\% = \frac{V_0 - V_2}{V_2} \tag{13.2}$$

13.3 Discussion

We take seven readings for each load and plot a graph for efficiency and load current I_2 or W_2. The regulation for full load, half load, and 75% of load is specified.

13.4 Question and Answers on the Experiment

Q1. What is a load?

Ans. Load means equipment or an electric device switched to take a current. The impedance of the device is called the load impedance. Most often the current taken by the load impedance is called the load.

Q2. Why do we perform load tests when the efficiency can be determined by O.C. and S.C. tests?

Ans. Actual loading is made to find the regulation and efficiency. Input and output relations can be obtained at a given power factor. The temperature rise curve can be obtained. As a matter of fact, the load test means the measurement of the temperature rise in the case of a transformer.

Q3. Why do we not plot a volt-ampere curve of a transformer like the other load curves for rotating electric machines?

Ans. Instead of a volt-ampere curve, we determine the regulation of the transformer. The terminal voltage depends on the power factor of the load and not only on the current. We may plot a *V-I* curve if required for a particular load.

EXPERIMENT 14

14.1 Object: Back-to-Back Test on Two Identical Transformers (Sumpner Test)

14.2 Experimental Setup

In this test power is required to overcome the total losses in two identical transformers. The power loss is divided equally in the two transformers. The primary windings of 60th transformers are connected in parallel and a supply of 50 Hz frequency is given. See the circuit of Figure 14.1.

The wattmeter W_i reads total iron loss of the two transformers. The wattmeter W_0 reads the copper loss of the two transformers. I_2 is the secondary current and V_2 is the secondary voltage.

To create a short-circuit we connect the secondary of the two transformers in opposition, so that there will be no voltage and no secondary current. The polarity is checked by the voltmeter. The voltmeters will read 0 V when the polarities are in opposition.

The voltage of the primary transformer varies till the rated secondary current flows.

Through the secondary winding circuit, the readings of the wattmeters are noted down for secondary currents. The constants of the current transformers and wattmeters are noted. A table for experimental results follows. The V_1 and I_1 designate the primary voltage and current, respectively. The V_2 and I_2 designate the secondary voltage and current, and W_i and W_c designate the iron loss and copper loss, respectively. Temperature θ_1 and θ_2 can be tabulated with time t in hours, at full load. The object is to find the losses and the parameters of the transformers.

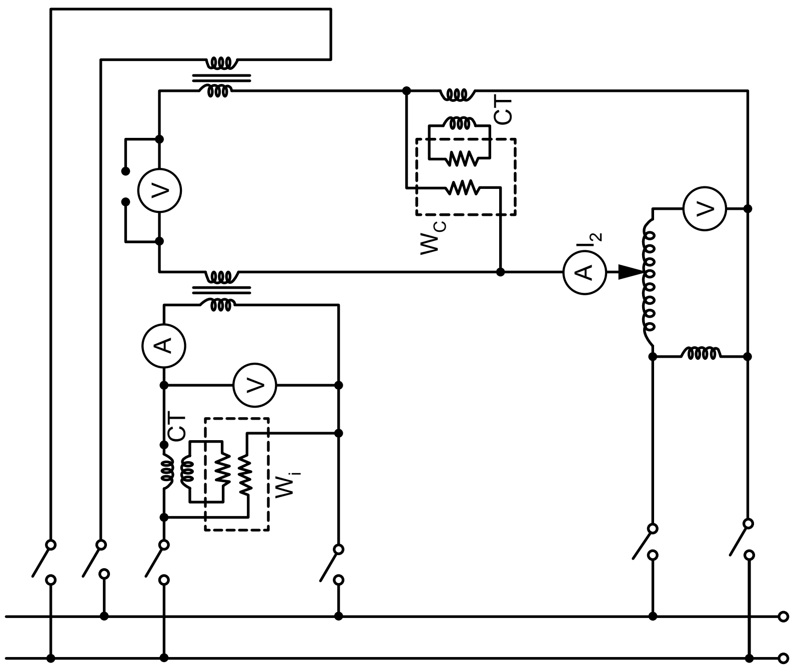

Figure 14.1

EXPERIMENTAL RESULTS

S.N.	V_1	I_1	W_i	V_2	I_2	W_c	*t*	θ_1	θ_2	*Remarks*
1										
2										
3										
4										
5										
6										
7										
8										

A rated open-circuit voltage, a no-load current, and power are noted to find the equivalent circuit at no load. The rated short-circuit current, voltage input, and power are noted to find an equivalent circuit at the short-circuit.

14.3 Discussion

Efficiency can be found when the losses are measured according to the open-circuit and short-circuit tests described earlier. Refer to the O.C. and S.C. tests described (Experiment 12) previously. The efficiency can be determined with considerable accuracy from the O.C. and S.C. tests. The full-load test is made to determine the temperature rise. A small transformer can be tested on full load by using an artificial load. A water resistance may be an artificial load.

The large units require the Sumpner test or regenerative test due to the difficulty of absorbing a large load. The energy cost will be high for a test. In the back-to-back test we can load the two transformers on full-load condition for several hours to find the temperature rise. The only energy required in the back-to-back test will be to meet the losses.

14.4 Questions and Answers on the Experiment

Q1. Why do we use this method when it is very complicated?

Ans. It is used to save the energy loss and because large loads are not needed. Large capacity transformers will require the large load and the back-to-back method will be required. With wasting energy two transformers are tested at full load.

Q2. How are the open-circuit and short-circuit conditions recognized?

Ans. The windings have full-load current to give short-circuit conditions. The rated voltage is applied to give the core loss. Hence the working conditions are recognized.

EXPERIMENT 15

15.1 Object: Separation of Losses in a Single-Phase Transformer (Separation of Eddy Current and Hysteresis Loss)

15.2 Hysteresis and Eddy Current Losses

Hysteresis and eddy current losses are called iron loss and take place in the core of the transformer. Hysteresis loss is given by:

$$W_h = K\,B_{max}{}^{1.6} f = K_n f \tag{15.1}$$

Eddy current loss also depends on the frequency, F and is given by:

$$W_e = K\,B^2_{max} f^2\, t^2 = K_e f^2 \tag{15.2}$$

where

K = Constant

B_{max} = Maximum flux density Wb/m^2

f = Frequency cycles/seconds

t = Thickness of stamping.

The iron loss will be expressed by:

$$W = K_n f + K_e f^2 \tag{15.3}$$

or

$$\frac{W}{f} = K_n + K_e f, \quad y = mx + c \tag{15.4}$$

This is the equation of a straight line $y = mx + c$, where

$$y = w/f_1\; c = K_n \text{ and } m = K_e \tag{15.5}$$

$$x = f$$

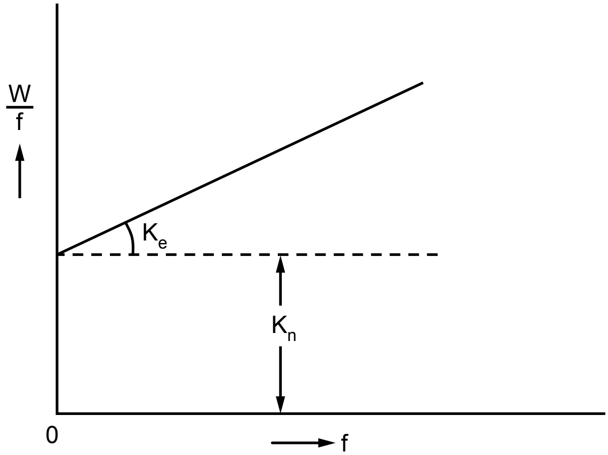

Figure 15.1

Eddy current and hysteresis loss can be separated when K_e and K_n are found.

An experiment will require measurement of power W at no load and frequency of the supply voltage.

15.3 Experimental Setup

The experiment will require a transformer, a voltage supply of variable frequency, and one wattmeter.

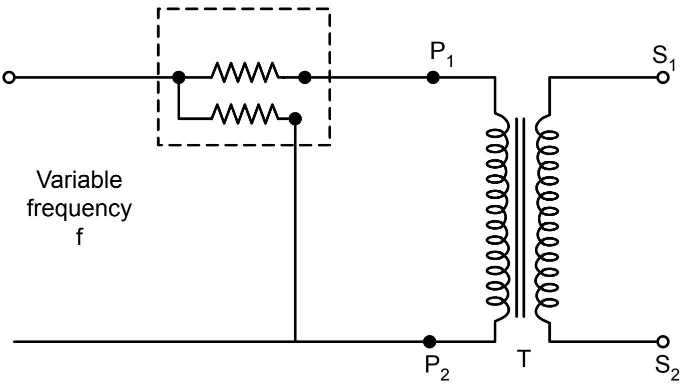

Figure 15.2

The variable frequency supply is obtained from an alternator whose frequency can be varied. The secondary transformer is kept open-circuited.

EXPERIMENTAL RESULTS

S.N.	*W*	*f*	*W/f*	K_e calculated	K_n calculated
1					
2					
3					
4					
5					

15.4 Discussions

The eddy current and hysteresis loss can be calculated when the K_e and K_n are determined, from the equations (15.1) and (15.2).

15.5 Questions and Answers on the Experiment

Q1. How can the eddy current loss be reduced?

Ans. By making the iron core laminated.

Q2. Can you reduce the hysteresis loss by making the core laminated?

Ans. No.

Q3. How will you reduce the eddy current loss by another method?

Ans. Flux frequency and thickness of the core can be reduced. Any one of the three factors can be reduced to reduce the eddy current loss.

Q4. How will you reduce the hysteresis loss?

Ans. Flux and frequency can be reduced. Any one of the two factors can be reduced for the purpose.

EXPERIMENT 16

16.1 Object: Separation of Losses in a D.C. Shunt Motor

16.2 The Various Losses in a D.C. Machine

The various losses in a D.C. machine are as follows:

(*i*) Copper losses
- (*a*) armature copper loss
- (*b*) field copper loss
- (*c*) losses due to brush contact resistance

(*ii*) Magnetic losses
- (*a*) hysteresis loss
- (*b*) eddy current loss

(*iii*) Mechanical losses
- (*a*) friction loss in bearings and commutator
- (*b*) windage loss (air friction loss).

Magnetic losses and mechanical losses are collectively called stray losses. The components of the stray losses are functions of the speed of the motor.

$$\text{Friction loss} = AN \tag{16.1}$$

$$\text{Windage loss} = BN^2 \tag{16.2}$$

$$\text{Hysteresis loss} = CN \tag{16.3}$$

$$\text{Eddy current loss} = DN^2 \tag{16.4}$$

The no-load loss will be:

$$W_o = (A + C)N + (B + D)N^2 \tag{16.5}$$

or

$$\frac{W_o}{N} = (A + C) + (B + D)N \tag{16.6}$$

If we plot a graph between W_o/N and speed N we obtain a straight line:

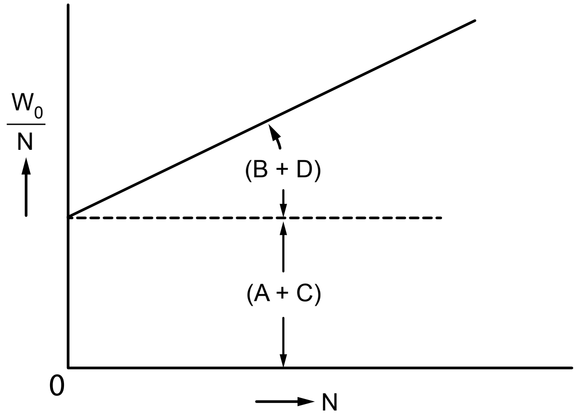

Figure 16.1

$$Y = mx + c \text{ where } Y = W_o / N, x = N$$

$$m = (B + D) \text{ and } c = (A + C) \qquad (16.7)$$

16.3 Experimental Setup

The experiment will require a shunt motor and its speed variation, N RPM, a wattmeter to measure the no-load losses W_o, an ammeter in the armature circuit, and one ammeter in the field circuit. If a wattmeter is not available, use a voltmeter to read the line voltage. The line current will be a sum of the armature current and the field current.

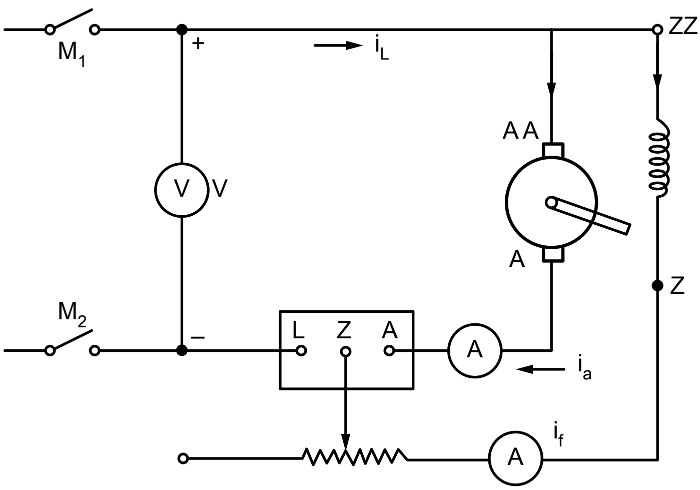

Figure 16.2

The armature current i_a, field current i_f, and terminal voltage V are entered into the following table. The circuit diagram of Figure 16.2 is used for this purpose.

EXPERIMENTAL RESULTS

S.N.	i_a	i_f	$i_L = i_a + i_f$	V	N RPM	$= \frac{VI_L}{W_o}$
1						
2						
3						
4						
5						
6						
7						

A rated voltage V in the motor is applied. The motor is run at light load. The speed is varied by a rheostat in the armature circuit. If the motor is run at no load, the input given to the motor will be the power loss W_o, and no power is taken by the load.

16.4 The Power Input to the Motor

The power input to the motor will be:

$$W_o = VI_L \text{ watts} \tag{16.8}$$

The armature copper loss will be:

$$P_{ca} = I_a^2 R_a \text{ watts.} \tag{16.9}$$

The field copper loss will be:

$$P_{cf} = I_f^2 R_f \text{ watts} \tag{16.10}$$

The brush contact loss may be added in the armature copper loss, or it may be estimated separately.

$$P_{c(ac)} = I_a^2 R_{(contact)} \text{ watts} \tag{16.11}$$

The total copper loss will be:

$$P_c = I_a^2 (R_a + R_{(contact)} + I_f^2 R_f \text{ watts} \tag{16.12}$$

The copper loss will be independent of speed and can be calculated at no load or at light load.

16.5 The No-Load Loss W_0 / N Is Plotted for Various Speeds N

The no-load loss W_o/N is plotted for various speeds N. The constants $(A + C) = r$ and $(B + D) = y$ are found with the help of the graph. The losses varying with N and N^2 may be separated from the no-load loss.

16.6 Discussion

The experiment on the separation of loss in a D.C. machine is performed as explained previously and the constants are obtained.

16.7 Questions and Answers on the Experiment

Q1. What is no-load loss and how does it vary?

Ans. The no-load loss occurs when the machine runs at no load. Mainly iron loss is encountered for our purpose in the transformer. Other machines have windage and friction loss in addition to iron loss.

The loss varies as the square of the voltage.

Q2. What are the losses which vary with the square of the speed of a machine?

Ans. Eddy current loss and windage loss vary with the square of the speed of a machine.

Q3. What are the losses which vary with the speed directly?

Ans. Hysteresis loss and friction loss vary with the speed of a machine.

EXPERIMENT 17

17.1 Object: To Perform a Load Test on a Three-Phase Slip-Ring Induction Motor

17.2 The Load Test on a Speed-Torque Curve

The object of the experiment is to find how speed varies with the variation of the torque. When we vary the torque, the power factor of the motor also changes. Since the current and torque are related in the motor, the power factor will vary with the current of the motor.

17.3 Experimental Setup

The experiment will require two watt meters for the measurement of power input to the motor. One ammeter and one voltmeter will be required. A torque-measuring device and a tachometer will be required for the measurement of shaft parameters, *T* and *N*.

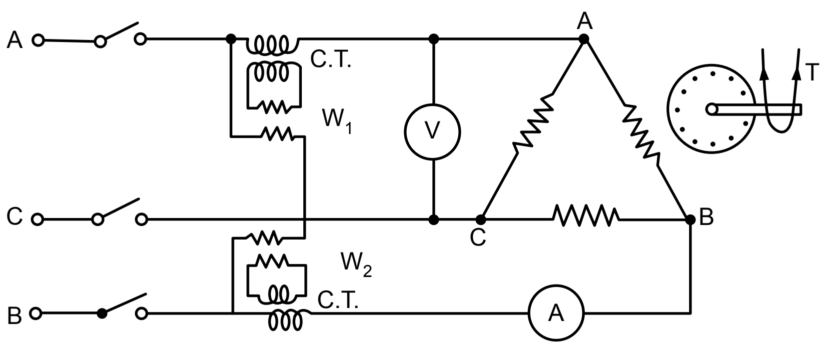

Figure 17.1

To decide the range of instruments, we read the nameplate of the motor. Suppose we have a three-phase, 50 c/s motor with 7.5 hp, 230 V, 22.3 A, and a rotor of 200 V and 18.5 amps. We may determine the range of instruments, wattmeters 0-1000 W, ammeter 0-50 A or 0;12A, voltmeter 0-300 V current transformers. A 50:5 ratio will be required.

Make the connections as shown and vary the torque on the motor. Remember that you have noted the no-load speed of the motor.

EXPERIMENTAL RESULTS

S.N.	Torque $T = T_1 - T_2$	Speed N (RPM)	W_1	W_2	$W_1 \pm W_2$	V_L	I_L	cos ϕ	Remarks
1									
2									
3									
4									
5									
6									

The major part of the load test is the speed-torque curve of the motor. The other part may be the torque-efficiency curve.

The torque-power factor and torque current may be the supplementary graphs. The efficiency graphs for all machines will be similar. The efficiency will be:

$$\eta = \frac{\text{Output}}{\text{Input}} = \frac{\dfrac{2\pi NT}{60}}{\sqrt{3}\ V_L I_L \cos\phi} = KT$$

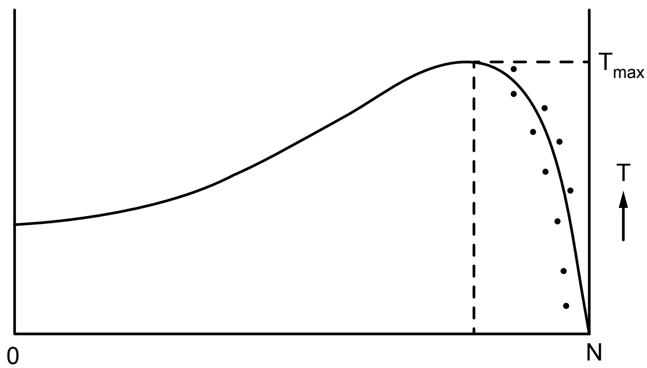

Figure 17.2

17.4 Speed-Torque Curve

The speed-torque curve of the motor is plotted in Figure 17.2. The slip-torque curve and speed-torque curve will be similar. The no-load speed is nearly equal to the synchronous speed and decreases when torque is increased.

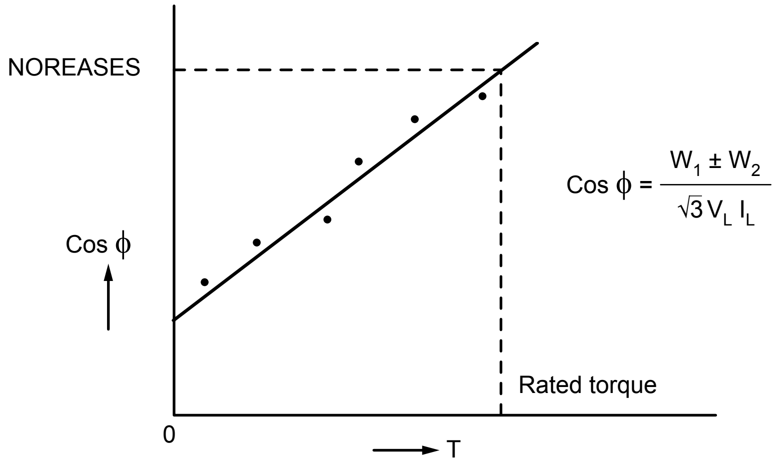

Figure 17.3

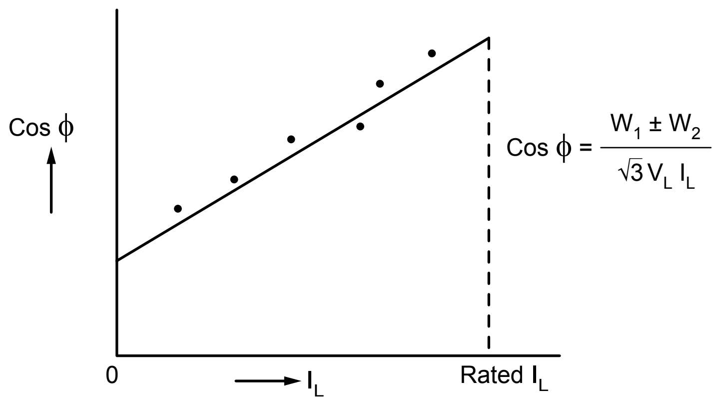

Figure 17.4

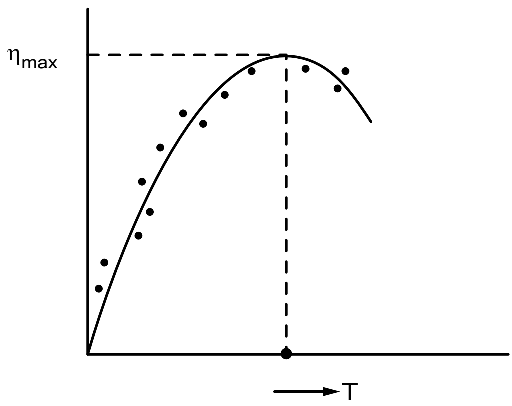

Figure 17.5

17.5 The Torque-Power Factor Curve

When the motor runs at no load, its power factor is low, and the power factor increases with load torque.

17.6 Discussion

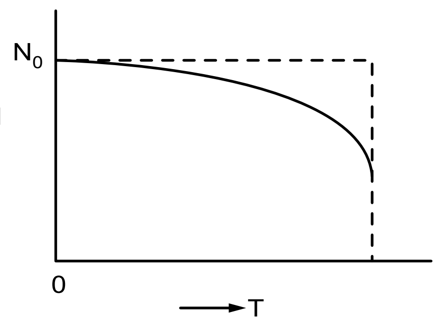

Figure 17.6

The speed-torque curve of the motor is drawn in Figure 17.2, which is the major part of the experiment. The speed torque is like the load curve of a D.C. shunt motor shown in Figure 17.6. The load-power factor curves of the motor are shown in Figures 17.3 and 17.4. The efficiency curve is shown in Figure 17.5.

17.7 Questions and Answers on the Experiment

Q1. What is a shunt characteristic? Is it applicable to the induction motor?

Ans. A shunt characteristic has the nature to slow down the speed slightly when the torque is increased. The induction motor has a similar speed-torque curve.

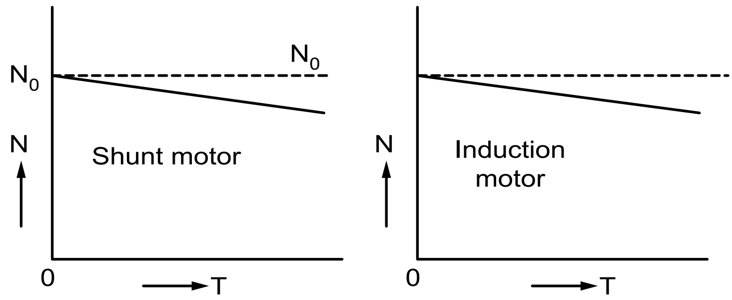

Figure 17.7

Q2. Where will you use the slip-ring induction motor?

Ans. Variable speed loads are connected with the slip-ring induction motors. Large changes in speeds will require this type of motor.

Q3. Where will you use the squirrel cage induction motor?

Ans. For constant speed loads. Fans, telephones, and so on are coupled with this type of motor.

EXPERIMENT 18

18.1 Object: To Perform a No-Load and Blocked Rotor Test on a Three-Phase Squirrel Cage Induction Motor

18.2 The No-Load Test and Blocked Rotor Test Are Performed to Find the Equivalent Circuit of the Motor

This is the major part of the object. A supplementary task may be to plot two graphs for the respective tests, a variation of no-load loss with voltage of supply and a variation of copper loss with the load current. These two tests are similar to the transformer testing for open circuit and short-circuit.

18.3 No-Load Test

A full voltage is applied to the motor terminals and the rotor is run at a no-load speed. The measurement of input power, current, and voltage will require two wattmeters, an ammeter, and a voltmeter, respectively. A circuit diagram is shown in Figure 18.1. Read the wattmeter, ammeter, and voltmeter when all transients have decayed.

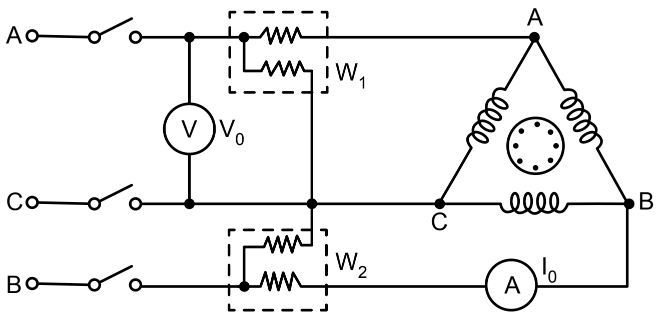

Figure 18.1

Note the experimental results in the tabular form.

EXPERIMENTAL RESULTS

S.N.	$W_0 = W_1 \pm W_2$	V_0	I_0	Speed N_0	Remarks
1	–	Full	–	–	Full voltage
2	0	0	0	0	
3					
4					
5					
6					
7					

After taking one reading at the full voltage, the voltage of the supply is varied to find various values of W_0. A graph is plotted between V_0 and W_0 in Figure 18.2.

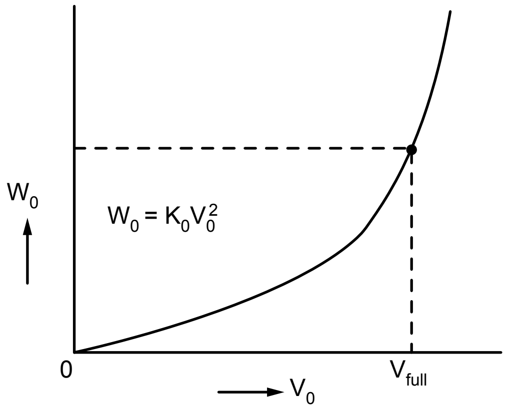

Figure 18.2

The open-circuit equivalent of the induction motor is calculated as follows:

or $$\sqrt{3}\ V_0 I_0 \cos\phi_0 = W_0$$

$$\cos\phi_0 = \frac{W_0}{\sqrt{3}\ V_0 I_0}$$

The no-load current I_0 is the line current up to this level. In the equivalent circuit we require a phase value of the current.

$$I_{op} = I_0/\sqrt{3}$$

The current I_{op} will be divided into two components:

$$I_R = I_{op} \cos \phi_0 = \text{Resistive current}$$
$$I_X = I_{op} \sin \phi_0 = \text{Inductive current.}$$

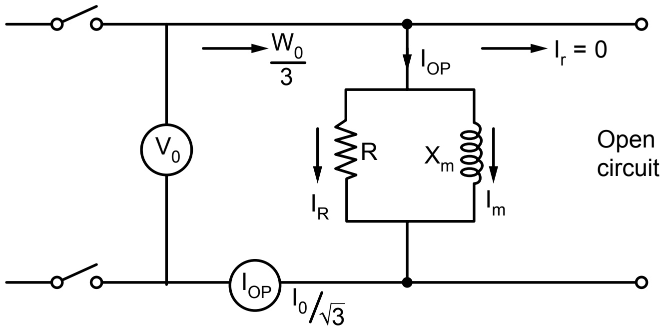

Figure 18.3

The open-circuit parameters will be given by:

$$R_0 = \frac{V_0}{I_{op} \cos \phi_0} \text{ and } X_m \frac{V_0}{I_{op} \sin \phi_0}$$

where R_0 and X_m are the resistance and magnetizing reactance of the motor and I_r is the rotor current.

We used the terminology of an open circuit in the case of the induction motor in place of no-load. Since $I_r = 0$, it is called an open circuit, as represented in Figure 18.3.

18.4 Discussion

As a matter of fact, the open-circuit test itself is a full test and is performed on three-phase induction motors independently to find no-load loss and the equivalent circuit at no load and light load. The no-load power factor and light load power factor are important requirements for power engineers.

18.5 Blocked Rotor Test

The blocked rotor test is performed to find the rotor current at high-load torque. It becomes necessary to find the power factor of the motor at high load and blocked rotor load. A variation of copper loss or short-circuit loss with the current is required for determining efficiency of the motor.

The same equipment will be required as in the case of no-load test. In addition, two current transformers will be required for the safety of the current coils of the wattmeters.

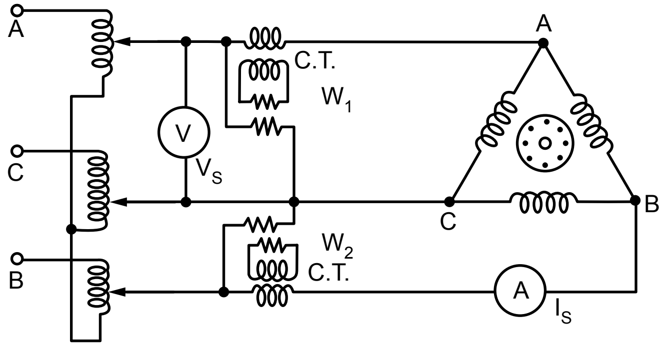

Figure 18.4

Note that a reduced voltage of 20% is applied to the motor in all three phases. Block the rotor with a belt or catch it with your hands so that it cannot move. Read the instruments. The readings at full current will be V_s, I_s, and W_s. The W_s will be

$$W_s = W_1 \pm W_2$$

If the connections of one of the wattmeters are to be changed due to the deflection of the needle in another direction, then use $W_s = (W_1 - W_2)$; otherwise, use $W_s = (W_1 + W_2)$.

EXPERIMENTAL RESULTS

S.N.	V_s	I_s	W_s	***Remarks***
1	–	Full	–	Full-load current adjusted
2	0	0	0	
3				
4				
5				
6				
7				

The adjustment of the full-load current is made by varying the supply voltage. Three auto-transformers are used for this purpose. Vary the current from 0 to full load and 125% of the load if possible when the motor is under blocked rotor condition. This is made by varying the voltage of supply. Plot a graph between I_s and W_s and find the nature of the graph as shown in Figure 18.5.

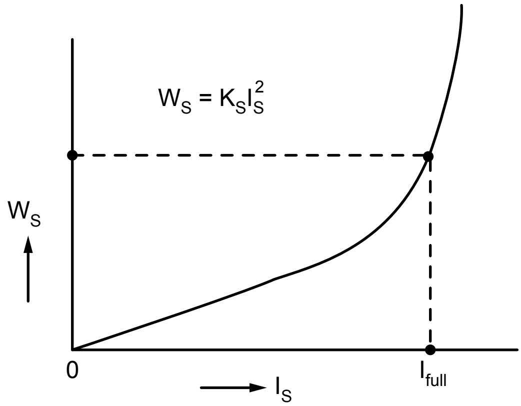

Figure 18.5

Further, we calculate the equivalent circuit of the motor at blocked rotor conditions as follows:

$$W_s = \sqrt{3}\ \ V_s I_s \cos\phi_s$$

$$\cos\phi_s = \frac{W_s}{\sqrt{3}\ \ V_s I_s}$$

The I_s is a line current but we may change it to a phase value, because the equivalent circuit is found on a phase value basis.

$$I_{sp} = I_s/\sqrt{3}$$

The impedance of the motor will be:

$$Z_s = V_s\ I/_{sp}$$
$$R_{eq} = Z_s \cos\phi_s \text{ and } X_{eq} = Z_s \sin\phi_s$$

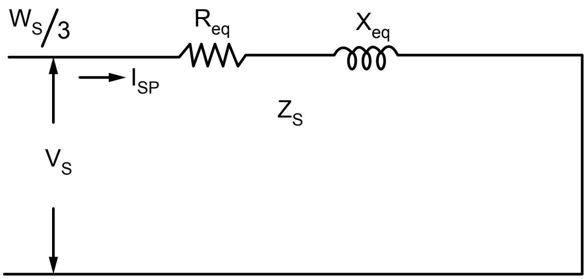

Figure 18.6

18.6 Discussion

The results are given in the table and in Figures 18.5 and 18.6. The short-circuit power factor, copper loss, and equivalent circuit are the important results to be obtained by this test. The two tests will give us a complete equivalent circuit of the motor, shown in Figure 18.7.

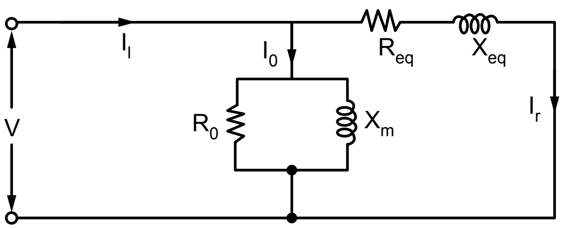

Figure 18.7

Sometimes the determination of the equivalent circuit of the motor is a major part of the tests.

18.7 Questions and Answers on the Experiment

Q1. How much voltage should you supply to the motor at the no-load test?

Ans. Full voltage.

Q2. How much voltage should you supply at the short-circuit test?

Ans. Reduced voltage to 20% of full voltage.

Q3. Why do we not supply the full voltage at the short-circuit test?

Ans. A very high current will flow and the motor will burn.

Q4. Sometimes we use skew slots in a squirrel cage induction motor. Why?

Ans. To reduce the effect of cogging and crawling, in which the motor refuses to start. Sometimes the motor only crawls.

Q5. Why do we call it a squirrel cage induction motor?

Ans. The squirrel has a typical shape and color with belts of black shadow. A similar structure and appearance of the motor is realized. In brief, the rotor of the squirrel cage motor looks like the body of squirrel.

Q6. Why do we perform no-load and blocked rotor tests?

Ans. To determine the iron loss, copper loss, and equivalent circuit of the motor.

EXPERIMENT 19

19.1 Object: No-Load Test and Short-Circuit Test on a Three-Phase Alternator

19.2 Open-Circuit Test and Short-Circuit Test on a Three-Phase Alternator

An open-circuit test and a short-circuit test are performed on a three-phase alternator to find the synchronous impedance of the alternator. If the resistance of the machine is negligibly small, we determine the reactance, which will be equal to the impedance.

Iron loss and copper loss are determined by these two tests. The open-circuit test will provide us the iron loss while the short-circuit test gives us the copper loss. The open-circuit characteristic and short-circuit characteristic are plotted from the test results.

19.3 Experimental Setup

An open-circuit test will require us to run the alternator without load. Full voltage is applied to the D.C. side of the exciter. A voltmeter will be connected in one of the phases.

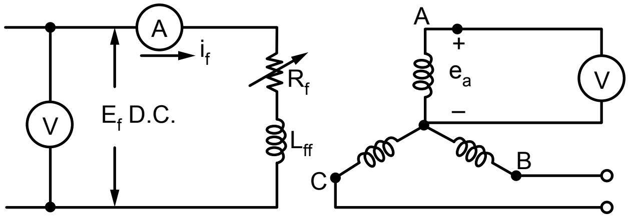

Figure 19.1

The field current i_f is varied by R_f, the field rheostat, and various readings of e_a are obtained by the voltmeter.

EXPERIMENTAL RESULTS

S.N.	i_f	e_a	*Speed No.*	*Remarks*
1				
2				
3				
4				
5				
6				
7				

The input to the exciter will be $E_f i_f$ watts, and this input will be consumed in the iron loss and field copper loss. We call it the no-load loss. The excitation voltage E_f can be varied to obtain the no-load loss in the alternator.

Since there is no current in the armature of the alternator, there is no problem of any loss in this side. The open-circuit characteristic can be plotted between i_f and e_a, the open-circuit voltage in Figure 19.2.

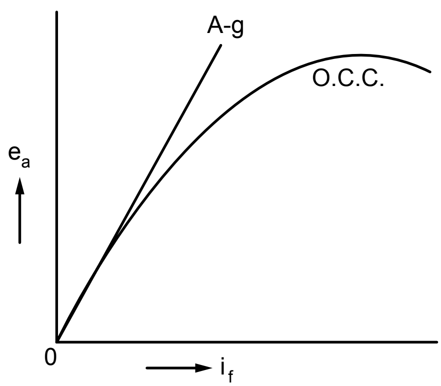

Figure 19.2

19.4 Short-Circuit Test

The short-circuit test is performed by connecting ammeters in three phases of the alternator and supplying a reduced voltage in the exciter. Figure 19.3 represents an experimental setup for a short-circuit test. The short-circuit current is read in one of the phases at reduced voltage.

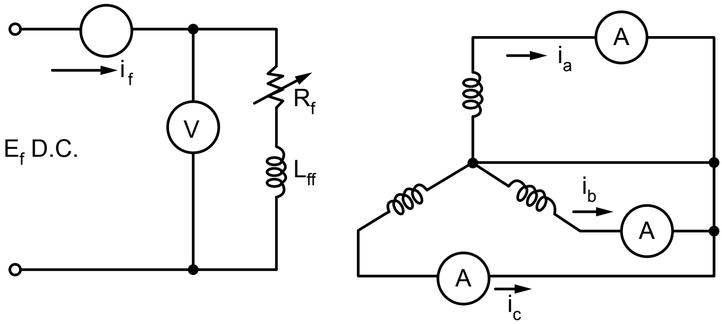

Figure 19.3

EXPERIMENTAL RESULTS

S.N.	i_f	$i_s = i_a$	*Speed*	*Remarks*
1				
2				
3				
4				
5				
6				
7				
8				
9				

A graph between i_f and i_s is plotted, which is called the short-circuit characteristic (S.C.C.).

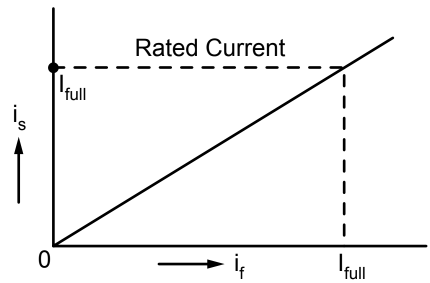

Figure 19.4

The no-load loss and short-circuit loss are plotted for the alternator.

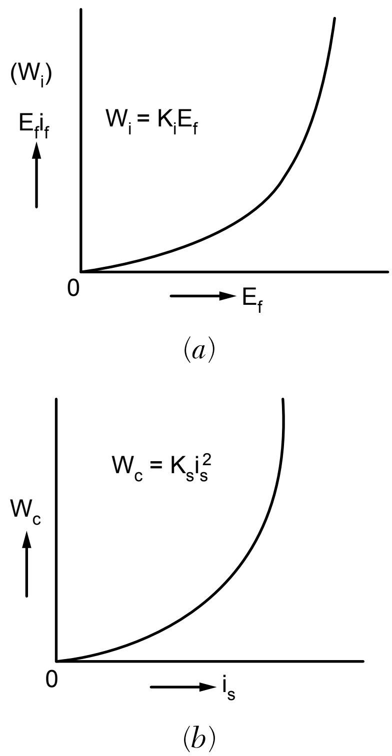

Figure 19.5

19.5 Determination of Synchronous Impedance

The synchronous impedance can be calculated from the open-circuit test and short-circuit test. A combined graph is drawn for the O.C. and S.C. tests in Figure 19.6.

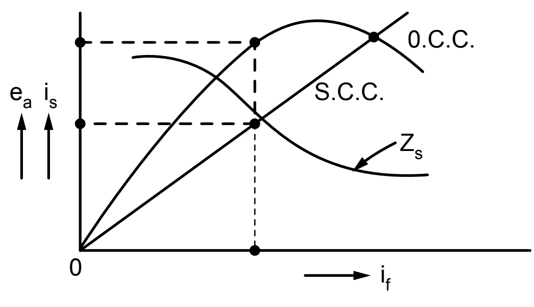

Figure 19.6

The synchronous impedance will be:

$$Z_s = \frac{\text{Open circuit voltage}}{\text{Short circuit current}} = \frac{E_{ao}}{i_f}$$

The impedance is calculated at every value of i_f and corresponding e_a. The synchronous impedance is also plotted with i_f. The results are presented in Figure 19.6.

19.6 Discussion

The no-load test and short-circuit test are performed to find the synchronous impedance of the generator. The other results that may be obtained by these tests are the no-load loss variation with excitation voltage and the short-circuit loss variation with short-circuit current.

19.7 Questions and Answers on the Experiment

Q1. Why is the impedance not constant?

Ans. The impedance varies with the field current. The reactance changes with the flux in the air gap or winding and, therefore, the impedance will change.

Q2. What is a synchronous reactance?

Ans. The synchronous reactance X_s is the reactance at synchronous speed and the field current.

Q3. What is a short-circuit ratio (S.C.R.)?

Ans. The short circuit ratio is:

$$\text{S.C.R.} = \frac{1}{X_s}$$

Q4. What is a synchronous speed?

Ans. The synchronous speed will be:

$$N_s = \frac{120f}{P}$$

It is directly proportional to the frequency of the supply and inversely proportional to the number of poles.

Q5. What do you understand by synchronous and synchronism?

Ans. To follow the step-by-step movement of two items. The soldier's hands and legs are in synchronism. When they move they make a left-right. If one of the hands or legs is out of order, the entire group will lose synchronism.

Similarly, the synchronous motor or generator has a field and rotor moving in synchronism. If there are n-machines the problem of synchronism will be analogous to the soldier's left-right

EXPERIMENT 20

20.1 Object: A Load Test on a Three-Phase Synchronous Generator

20.2 Regulation by an Actual Load Test

A load test on a three-phase synchronous generator is performed to determine the regulation at a given power factor and the terminal voltage. This method is called regulation by actual load test.

The test is simple. We run the alternator at no load and adjust the field current to obtain a no-load voltage E_a, which is measured by a voltmeter. When load is applied the E_a will change. The E_a will be obtained at the given voltage and power factor.

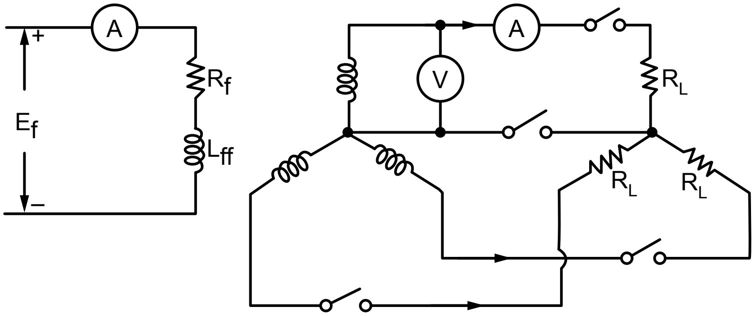

Figure 20.1

20.3 Experimental Setup

We read the specifications of the drive of the generator, and the nameplates are noted. Determine the range of the instruments. A voltmeter and ammeter will be required in the load circuit and the same for the field circuit. We read the ammeter and voltmeter when the load is switched. The load may be three lamps or six lamps connected in each phase. Four lamps connected in each phase is shown in Figure 20.2.

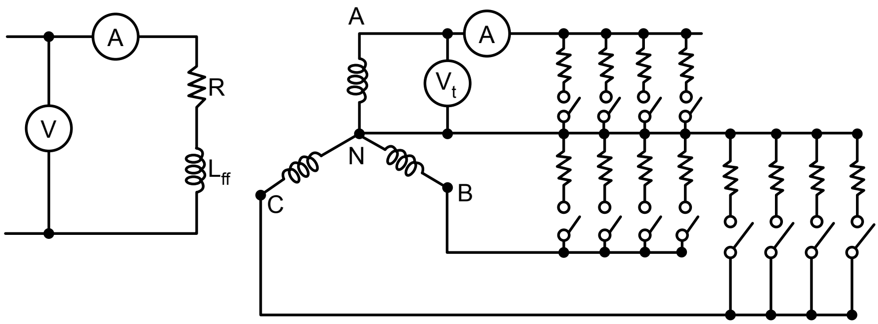

Figure 20.2

The experimental results are tabulated for every lamp switching. Let the transient decay and then read the instruments under a steady state.

EXPERIMENTAL RESULTS

S.N.	i_f	E_f	V_t	I_a	*Speed*	*Remarks*
1						
2						
3						
4						
5						
6						
7						

20.4 A Load Characteristic of the Alternator

A load characteristic of the alternator may be plotted as given in Figure 20.3. The load or V-I curve is not unique but has different forms depending on the power factor of the loads.

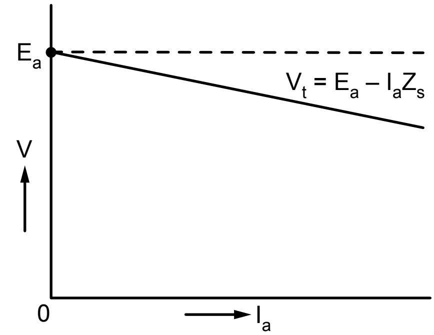

Figure 20.3

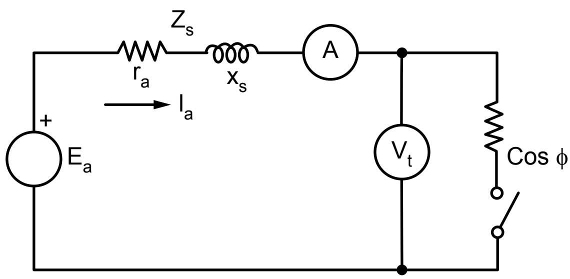

Figure 20.4

The voltage E_a at a particular load will be different from the no-load voltage. The EMF can be determined from a phasor diagram and an equivalent circuit shown in Figures 20.4 and 20.5.

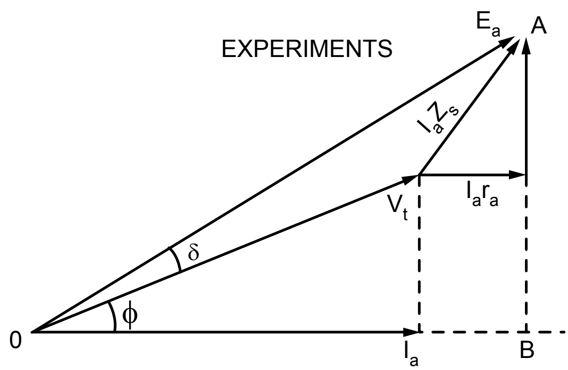

Figure 20.5

The E_a will be (from triangle *OAB*):

$$E_a^2 = (V_t \cos \phi + I_a r_a)^2 + (V_t \sin \phi + I_a X_s)^2$$

As a matter of fact, we may read E_a from the triangle *OAB* and the power angle δ.

20.5 Regulation

The regulation will be obtained as follows:

$$\text{Required percentage} = \frac{\text{No load voltage} - \text{Full load voltage}}{\text{Full load voltage}}$$

$$\text{Required percentage} = \frac{E_a - V_t}{V_t}$$

20.6 Discussion

A load test is performed on an alternator to determine the regulation and V-I characteristics. Whenever we specify the regulation, the V-I curve is not as important. As a matter of fact, the regulation is one from of the V-I curves.

Determining the regulation is our objective, but to draw the V-I curve will be an additional result.

20.7 Questions and Answers on the Experiment

Q1. What is load?

Ans. The load is a current taken by a device. Most often the load means the load impedance of the device. The lamp will be a load. It may either be specified by the current or impedance. A 100-watt lamp will take a current of 46 mA at 220 V and will be specified by an impedance of 484 Ω.

The load will be either 484 Ω or 46 mA. For simplicity we specify the current as the load.

Q2. How do you connect single-phase loads to the three-phase generator to maintain the balance?

Ans. We connect the loads in alternate phases turn by turn.

EXPERIMENT 21

21.1 Object: To Determine Regulation of a Three-Phase Alternator at Full Load, Lagging Power Factor, and Leading Power Factor

21.2 Open-Circuit and Short-Circuit Characteristic and the Synchronous Impedance at Full Load

This test will require the open-circuit and short-circuit characteristic, and the synchronous impedance at full load. We measure armature resistance r_a by a D.C. source, and the synchronous reactance X_s can be found,

$$X_s^2 = Z_s^2 - r_a^2$$

or

$$X_s = \sqrt{Z_s^2 - r_a^2}$$

The equivalent circuit of the alternator is determined and the regulation can be found with the help of the triangle as made in Experiment 20.

The open-circuit and short-circuit characteristics are plotted, and Z_s is obtained as a variation with i_f.

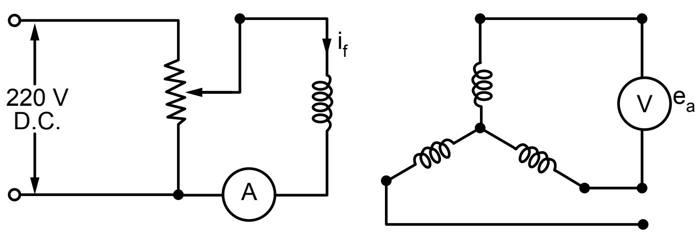

Figure 21.1

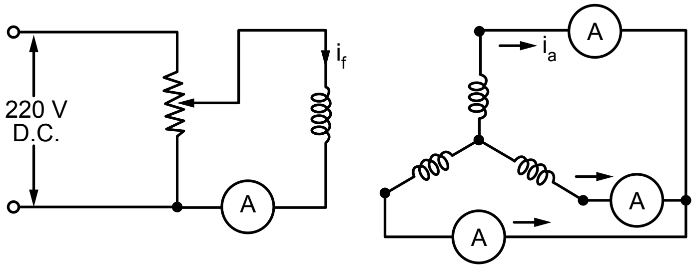

Figure 21.2

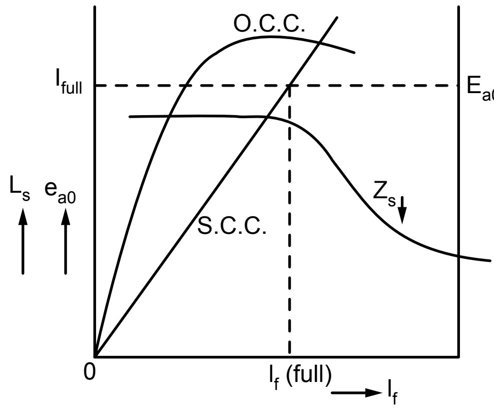

Figure 21.3

EXPERIMENTAL RESULTS

O.C. and S.C. Tests				*Measurement of r_a*		
S.N.	i_t	e_a	i_s	$V_{D.C.}$	$I_{D.C.}$	V_a
1						
2						
3						
4						
5						
6						
7						
8						
9						

Figure 21.1 represents the experimental setup for an open-circuit test, and Figure 21.2 represents the short-circuit test. Figure 21.3 represents the plotted graphs and synchronous impedance Z_3. Figure 21.4 shows the equivalent circuit of the alternator.

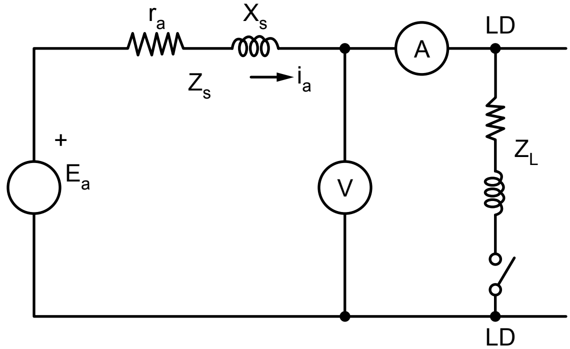

Figure 21.4

We may draw a phasor diagram at a lagging power factor in Figure 21.5. The current I_a is common in the circuit and is considered as the reference phasor. The current is lagging with the voltage V_t and, therefore, cos θ will be the lagging power factor.

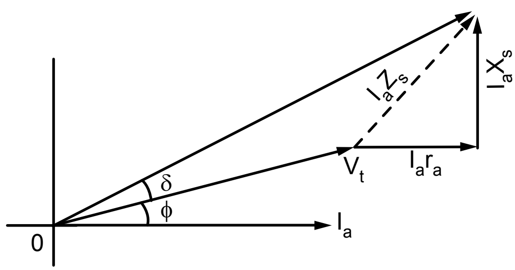

Figure 21.5

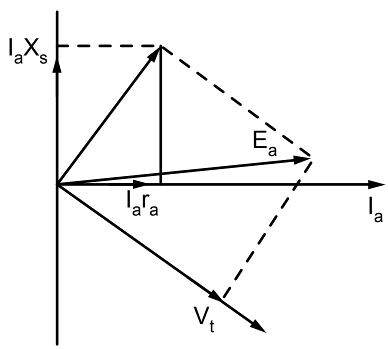

Figure 21.6

Regulation can be calculated by an approximate formula as follows:

$$\text{Reg } \% = IR\% \cos \phi + IX\% \sin \phi$$

This formula is valid for the two given power factors.

21.3 Questions and Answers on the Experiment

Q1. Why does the regulation become different at the two power factors (lagging and leading)?

Ans. At the leading p.f. the terminal voltage becomes more than the induced voltage (EMF). The regulation will be different at the leading p.f. as compared to the lagging p.f.

Q2. What are per unit values and percentage values?

Ans. The per unit values are the percentage values compared on base unity or 1. The percentage value is compared on the base 100.

Q3. If the terminal voltage is 220 V and IR% and IX% are 27 V and 44 V, find the per unit values and percentage values.

Ans.

$$IR = 22,\ IR \text{ p.u.} = 22/220 = 0.1$$
$$IR\ \% = 10\%$$
$$IX = 44,\ IX \text{ p.u.} = 44/220 = 0.2$$
$$IX\ \% = 20\%$$

Q4. When you draw a phasor diagram of an alternator, which quantity do you consider as reference?

Ans. The load current is chosen as the reference phasor.

Q5. Why do you choose current as the reference phasor?

Ans. The current phasor will be common in all the elements. A common phasor is chosen as the reference phasor.

EXPERIMENT 22

22.1 Object: To Determine the V-Curve and Inverted V-Curve of a Synchronous Motor

22.2 The V-Curve Is a Curve between the Excitation Current and the Armature Current

If we vary field current i_f, the armature current i_a varies. For a certain value of field current the i_a goes on decreasing and then increases, forming a V-curve.

An inverted-V curve is a curve between the excitation current and the power factor of the motor. The graphs are shown in Figures 22.1 and 22.2.

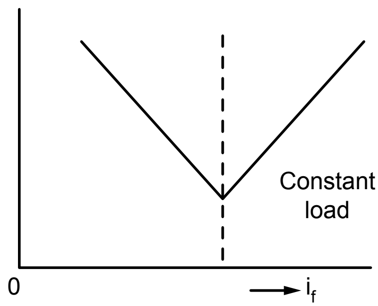

Figure 22.1

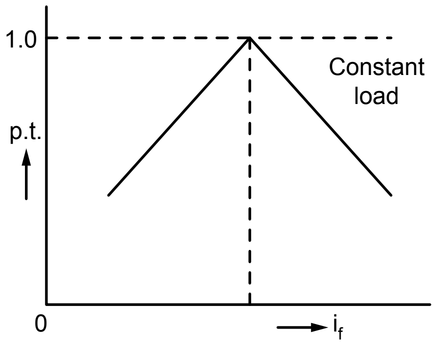

Figure 22.2

22.3 Experimental Setup

A three-phase synchronous motor will be required to be installed on a foundation base.

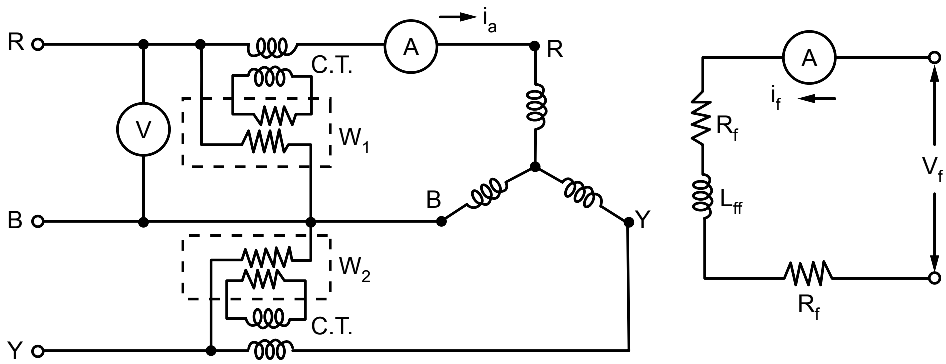

Figure 22.3

The experimental setup is shown in Figure 22.3. A two-wattmeter method will be used to measure the power input to the motor.

The field current is measured by ammeter located in the field circuit. The I_L and V_L are measured along with power input $W \pm W_1 = W$

$$W = \sqrt{3}\ \ V_L I_L \cos\phi$$

$$\cos\phi = \text{p.f.} = \frac{W}{\sqrt{3}\ V_L I_L}$$

EXPERIMENTAL RESULTS

S.N.	i_f	i_1	w_1	w_2	*W*	*p.f.*	*Remarks*
1							
2							
3							
4							
5							
6							
7							
8							

For each reading of i_f read the i_a armature current

$$i_a = i_L / \sqrt{3}$$

and the power factor (p.f.) may be calculated by the given input and v_L, i_L observations.

The graphs are drawn in Figures 22.1 and 22.2 for V-curves and inverted V-curves.

22.4 Discussion

The load on the synchronous motor will be a generator of constant output 0.5 kW or 1 kW. The two curves plotted are shown in the previous figures. The power factor increases to unity. The power factor decreases, but now it will be a leading power factor. The over-excited synchronous motor works as a synchronous condenser, which has leading p.f.

22.5 Questions and Answers on the Experiment

Q1. What happens to the armature current when the field current is increased?

Ans. The armature current goes on decreasing and reaches a minimum value in the first region. Again, the i_a increases when i_f is increased.

Q2. How will you change the real power in the synchronous machine?

Ans. The real power can be changed by changing the torque or coil input to the machine.

Q3. How will you change the reactive power in the synchronous machine?

Ans. The reactive power can be changed by the field current, i_f.

Q4. Where do we use the synchronous motor?

Ans. For the loads which require constant speed. Threading and papermaking machines are coupled with synchronous motors.

Q5. What does the V-curve provide?

Ans. A variation of armature current when excitation is changed, the load being constant.

Q6. What does the inverted V-curve provide?

Ans. A variation of power factor of the motor with the exciting current.

Q7. Where do we use the over-excited synchronous motors?

Ans. For the improvement of the power factor.

EXPERIMENT 23

23.1 Object: To Determine Regulation of a Three-Phase Alternator for Full Load at a Power Factor Using the Zero Power Factor Method or the Potier Triangle Method

23.2 This Test Requires an Open-Circuit Characteristic and a Zero Power Factor Load Test on the Alternator

Zero power factor loads are synchronous motors for the reactors. We use three reactors for the Z.P.F. (zero power factor) load.

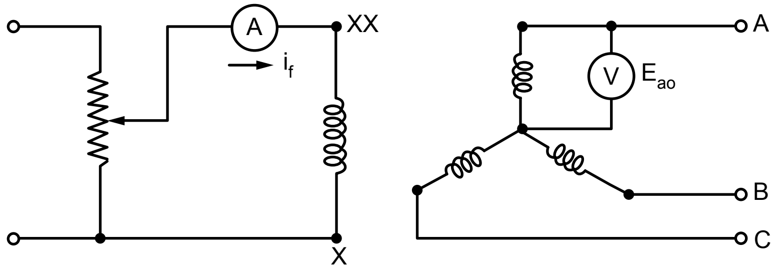

Figure 23.1

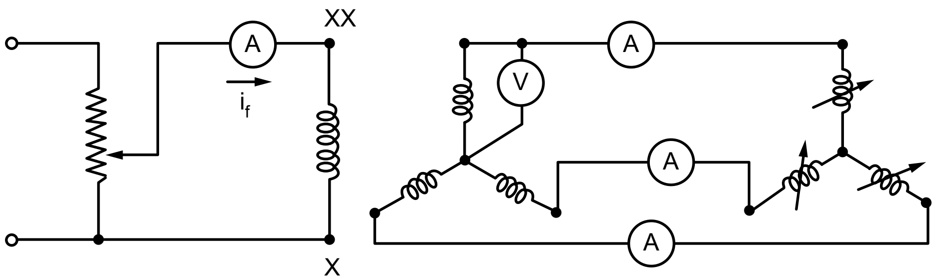

Figure 23.2

A zero power factor curve is drawn between the field current i_f and the voltage on the terminals, V.

23.3 Experimental Setup

A circuit diagram for the Z.P.F. test is represented in Figures 23.1 and 23.2. Open-circuit and Z.P.F. tests are performed one by one as follows:

EXPERIMENTAL RESULTS 1

S.N.	i_f	E_{ao}	N	Remarks
1				
2				
3				
4				
5				
6				
7				
8				
9				

Readings of experimental results are entered into two tables. The speed in the open-circuit test is kept constant equal to the full speed. However, this is a synchronous machine.

EXPERIMENTAL RESULTS 2

S.N.	i_f	V	N	I	Remarks
1					
2					
3					
4					
5					
6					
7					
8					
9					

The speed will remain constant at the synchronous speed.

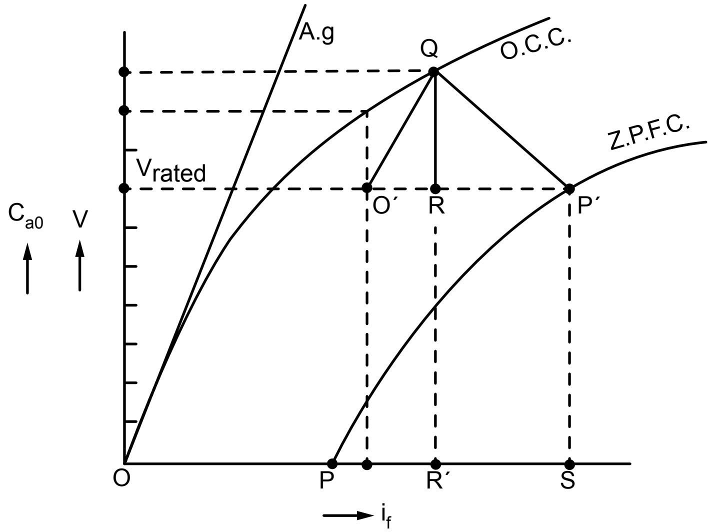

Figure 23.3

The O.C.C. and Z.P.F. curves are drawn in Figure 23.3. The air gap line *A*-*g* is drawn tangent to the O.C.C. *OP* is the exciting current corresponding and the full-load, short-circuit current. Draw *O′P′* and mark the point *P′*. Draw *O′P′* between the two curves such that *O′P′* equals *OP*. Draw a parallel line *O′Q* to the *A*·*g* line and mark the point *Q* on the O.C.C. Join *QP′* and draw a perpendicular line from *Q* to *R* and mark the *QR* line.

The *QR* will give the leakage reactance drop (IX_L). *O′R* will be the exciting current required to overcome the leakage reactance drop, and *RP′* will be the exciting current to overcome the armature reaction effect at rated current.

A phasor diagram will be drawn to determine the E_0 required to calculate the regulation at a power factor ϕ. *E* is the induced voltage when the armature reaction is neglected, and *V* is the terminal voltage, IX_L; leakage reactance drop *IR*; is the resistance drop. From the O.C.C. corresponding to the induced voltage *E*, *OK* is the

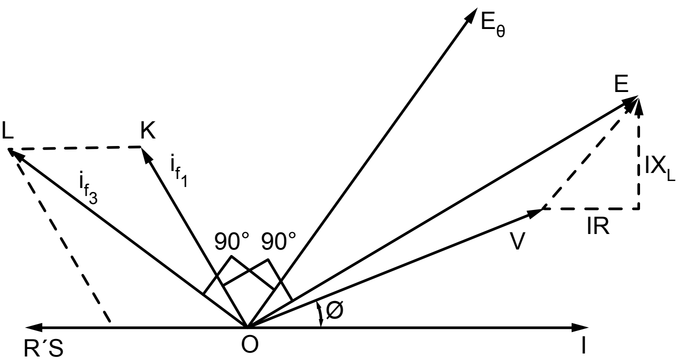

Figure 23.4

exciting current required to produce flux for the induction of E. The i_{f1} leads the E by 90°. $R'S$ or $R'P$ is the exciting current to overcome the armature reaction. This current i_{f2} will be in phase opposition to the current I. $R'S = i_{f2}$ required to overcome the armature reaction.

A sum of i_{f1} and i_{f2} will be i_{f3} which will be represented by OL. i_{f3} will be the total exciting current required to produce rated voltage and the given power factor. From the O.C.C. find the E_o corresponding to OL or i_{f3}. In this way the E_o is found and used in the regulation calculation.

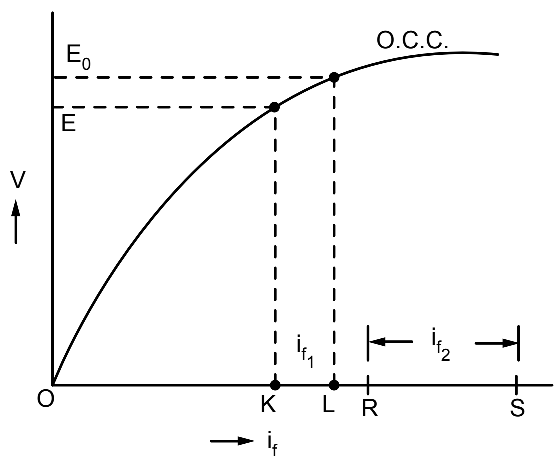

Figure 23.5

Thus, the regulation will be:

$$R_{eq} = \frac{E_o - V}{V} \times 100$$

23.4 Discussion

The zero power factor method is used to find the regulation of an alternator. Most often the alternator problems are serious at zero power factor loads. Zero power factor means inductive loads like reactors, synchronous motors, and inductors.

23.5 Questions and Answers on the Experiment

Q1. Why do we use the Potier triangle method for regulation?

Ans. The effect of armature reaction and leakage reactance is taken into account, while in the simple method, these two factors are ignored.

Q2. Why do we call it the zero power factor method?

Ans. We use a load of zero power factor.

Q3. What are the loads which have a zero power factor?

Ans. Synchronous motors, reactor coils, autotransformers, mutual inductors, and so forth.

Q4. Is the power factor zero for these loads? Why?

Ans. No, the p.f. is nearly zero. It may be 0.2 or 0.1 in value, and as compared to 1, it may be assumed as zero.

EXPERIMENT 24

24.1 Object: To Determine the Regulation of a Three-Phase Alternator at a Load and Its Power Factor by the MMF Method

24.2 The Test Will Require Open-Circuit and Short-Circuit Readings and Graphs for an Alternator

Open-circuit and short-circuit tests do not require any load; therefore, these are simple.

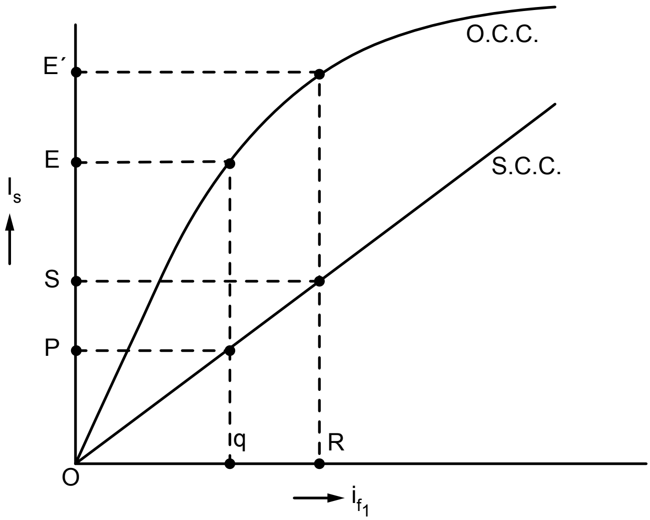

Figure 24.1

Figure 24.1 represents the O.C.C. and S.C.C. for the alternator. Oq is the exciting current required to produce rated current I_s on a short-circuit. At short-circuit conditions the terminal voltage is zero; therefore, the induced voltage is overcome by the armature reaction and leakage reactance.

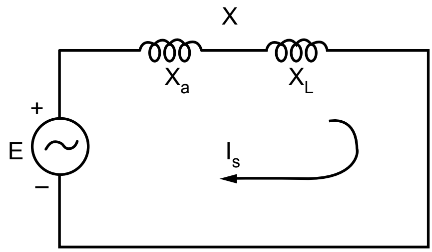

Figure 24.2

The $Oq = i_f$ is the exciting current required to give voltage which is balanced by a leakage reaction drop. The MMF (magnetomotive force) required for the armature reaction and leakage reactance drop will be proportional to Oq. From the phasor diagram, E is the voltage after subtracting the leakage reactance drop and armature reaction effect drop. From the O.C.C. find the exciting current which produces E on an open circuit.

OR will be the exciting current required. The MMF which produces E on an open circuit will be proportional to OR which leads E by 90°.

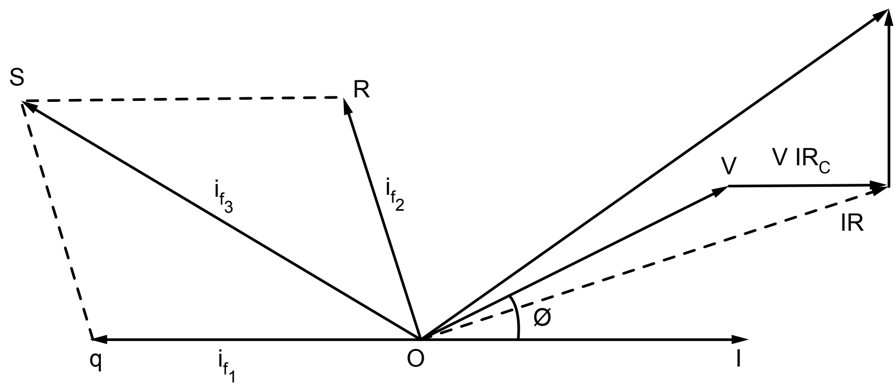

Figure 24.3

Oq is opposite to current I. A phasor sum of OR and Oq will give the exciting current required to produce the rated voltage at the rated current.

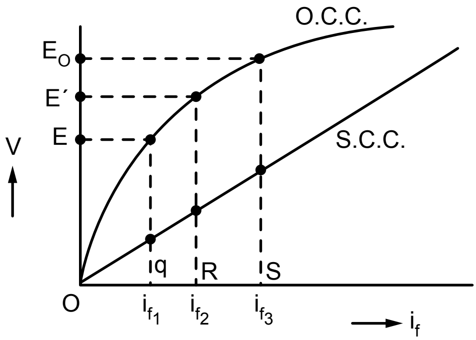

Figure 24.4

We can obtain OS, the exciting current i_{f2}, and the corresponding voltage E_0.

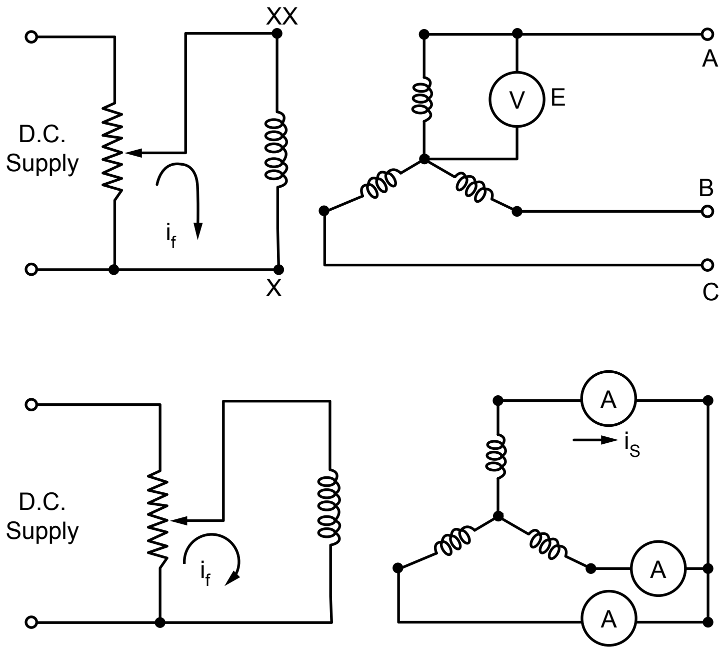

Figure 24.5

The regulation will be:

$$\text{Reg }\% = \frac{E_o - V}{V} \times 100$$

24.3 Experimental Setup

The experimental setup will require the circuits for the open-circuit test and short-circuit test. Circuit diagrams are represented in Figure 24.5 for the O.C. and S.C. tests. The range of the instruments will be decided from the nameplate specifications.

24.4 Discussion

The MMF method is used to find a no-load voltage at the resultant MMF Ni_{f2}, and regulation is determined.

24.5 Questions and Answers on the Experiment

Q1. Why do we call it the MMF method?

Ans. We obtain a resultant MMF from the two given MMFs below.

Q2. Name the two types of MMF required in the method.

Ans. (*i*) MMF required to produce the rated short-circuit current. This is required to overcome armature reaction and leakage reactance effect.

(*ii*) MMF required to produce the open-circuit voltage.

EXPERIMENT 25

25.1 Object: To Measure the Iron Loss at Different Flux Densities with a Lloyd Fisher Magnetic Square

25.2 A Lloyd Fisher Magnetic Square Is a Standard Apparatus for Measuring Power Losses in Iron Sheets

The square consists of a standard size frame on which primary and secondary windings are uniformly wound on the four sides. Test strips of standard size are placed into each side of the frame.

The losses are measured by a dynamometer type wattmeter, the current coil of which is connected in series with the primary winding, and the voltage coil is connected across one of the secondary windings. By connecting the wattmeter in this way, copper losses in the primary winding are not included in the measurement. The reading of the wattmeter should be multiplied by the turn ratio N_1/N_2 to get the correct value of the watts measured. The reading includes w loss on the secondary side, a correction which may be applied. A voltmeter is connected on the secondary winding, and flux density in the core can be calculated from its reacting knowing the number of turns, the frequency, and the cross-section area.

EXPERIMENTAL RESULTS

S.N.	*Primary current amp.*	*$E_{R.M.S.}$ volts*	*Wattmeter reading*	
			cm.	*watt*
1	0.3	3.42	2.7	0.119
2	0.5	5.37	4.9	0.216
3	0.7	7.00	9.5	0.421
4	0.8	7.82	12.0	0.530
5	0.9	8.60	14.1	0.625
6	1.0	9.30	16.4	0.726

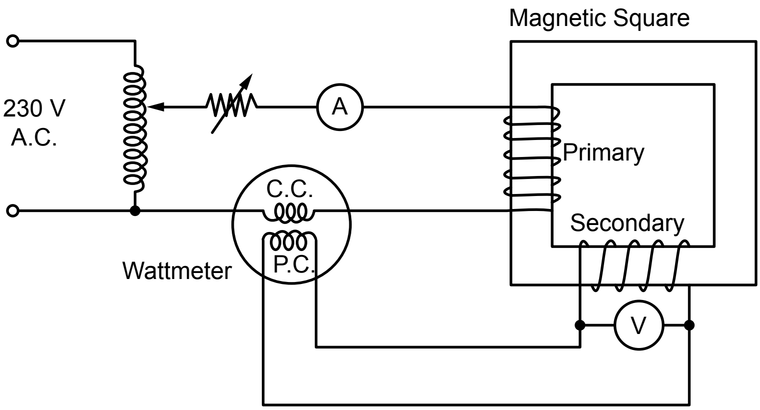

Figure 25.1

25.3 Iron Loss

1. $$W = W \times \frac{N_1}{N}$$

$$= 0.119 \times \frac{1000}{160} = 0.744\ W$$

$$\text{Iron loss} = 0.744 \times \left(\frac{1200 + 64}{1200}\right) - \frac{(3.42)^2}{1264} = 0.7756$$

2. $$W = 0.216 \times \frac{1000}{160} = 1.26\ W$$

$$\text{Iron loss} = 1.25 \left(\frac{1200 + 64}{1200}\right) - \frac{(5.37)^2}{1264} = 1.292\ W.$$

S.N.	***Item***	***Make and Maker No.***	***Range or Rating***
1	Lloyd Fisher Mag square	4270 B	50 cm.
2	Wattmeter		12 V
3	Voltmeter	757187	3A
4	Ammeter Make by H. Tinsley & Co. England.	755833	

25.4 E = R.M.S. secondary voltage
N_2 = No. of turns in secondary
A_c = Cross-sectional area of coil in m^2
A_s = Cross-sectional area of sample in m^2
B_m' = Flux density in the air gap Wb/m^2
B_{max} = M_{ax}. flux density in the sample

Then the total flux within the coil is

$$B_{max} A_s + B'_m (A_c - A_s) = B_m'$$

A_s say (l)

where $$B_m' = u_0 H_{max}$$

and $$H_{max} = \frac{N_1 2l}{4l} \tag{2}$$

3. $$W = W \times \frac{N_1}{N_2} = 0.431 \times \frac{1000}{160} = 2.7 \text{ watts}$$

$$\text{Iron loss} = 2.7 \frac{(1200 + 64)}{1200} - \frac{7^2}{1264}$$

$$= 2.76 - 0.0387 = 2.72\ W$$

4. $$W = 2.53 \times \frac{1000}{160} = 3.31\ W$$

$$\text{Iron loss} = 3.31 \frac{(1264)}{1200} - \frac{(7.82)^2}{1264} W$$

$$= 3.49 - 0.0482 = 3.4418\ W.$$

5. $$W = 0.625 \times \frac{1000}{160} = 3.91 \text{ watts}$$

$$\text{Iron loss} = 3.91 \frac{1264}{1200} - \frac{(8.6)^2}{1200} W$$

$$= 4.12 - 0.0582 = 4.0615\ W.$$

6. $$W = 0.726 \times \frac{1000}{160} = 4.55 \text{ watts}$$

$$\text{Iron loss} = 4.55 \times \frac{1264}{1200} - \frac{(2.3)^2}{1100} W$$

$$= 4.8 - 0.0682 = 4.7318 \text{ watts.}$$

I_l = R.M.S. primary current

$$4l = \text{total length of magnetic circuit}$$

$$E = 4.44\ B_m\ A_s\ N_2 \tag{3}$$

for form factor 1.11.

From this equation B_m can be calculated. Substituting in equation (1), B_{max} then can be calculated.

Let r_p = resistance of the pressure coil of the wattmeter and

r_c = resistance of the secondary winding.

Then, $E = i_2(r_p + r_c)$

If V is the voltage applied to the pressure coil, then

$$V = c_2\ r_p$$

Power loss is iron + copper loss in the secondary winding + C_u loss in the wattmeter pressure coil.

$$= W\,\frac{E}{V}$$

$$= W\,\frac{i_2\,(r_p + r_c)}{r_p}$$

$$= W\,\frac{(r_p + r_c)}{r_p}$$

where $W = \text{Wattmeter reading} \times \dfrac{N_1}{N_2}$

Copper loss in the secondary winding and pressure coil

$$= \frac{E^2}{r_p + r_c}$$

Therefore: $\text{Iron less} = W\,\dfrac{(r_p + r_c)}{r_p} = \dfrac{E^2}{r_p + r_c}$

Total No. of strips

$= 10 \times 4 = 40$

Weight of one strip

= 48.2 grams

Total weight $= 48.2 \times 40 \times 10^{-3}$ kg.

= 1.928 kg.

EXPERIMENTAL RESULTS

S.N.	Voltage volts	R_{max} Wb/m^2	Iron loss in watts	Loss in W/kg
1	3.42	0.2569	0.7756	0.403
2	5.37	0.3861	1.292	0.67
3	7.00	0.5133	2.7213	1.42
4	7.82	0.5739	3.4418	1.79
5	8.60	0.6355	4.0615	2.102
6	9.30	0.6962	4.7318	2.46

S.N.	Primary Current Amps	Secondary voltage volts	Primary voltage volts
1	0.3	3.42	21.4
2	0.5	5.37	34.6
3	0.7	7.00	43.7
4	0.8	7.82	48.8
5	0.9	8.60	53.7
6	1.0	8.30	58.1

We make connections as shown in Figure 25.1. By autotransformer vary the primary voltage and hence current, and for each primary current note the wattmeter and voltmeter reading.

We plot the following graphs:

1. Maximum flux density *vs*. iron loss in W/kg.
2. Primary current *vs*. primary induced voltages.
   (1) Size of test strips = 26 × 7
   (2) Weight of single strips = 48.2 g
   (3) Specific gravity of iron = 7.5 g/cm^2
   (4) Resistance of P.C. of wattmeter = 1200 Ω
   (5) Resistance of secondary winding = 64 Ω
   (6) 22.66 cm = 1 W

For a commutative range of one amp.

(7) No. of primary turns $= 250 \times 4$

(8) No. of secondary turns $= 40 \times 4$

(9) Area of the coil $= AC = 8 \times 1.5$ cm^2.

25.5 Questions and Answers on the Experiment

Q1. How is the copper loss of the primary winding of the magnetic square eliminated for the given connection of the wattmeter?

Ans. The connection diagram estimation for $B_{max.}$ is as follows:

$$B_{max} A_s + B_m'(A_c - A_s) = B_m'' A_s \quad (1)$$

$$E = 4.44\, B_m'' A_s N_2 f \quad (2)$$

$$B_m' = u_0\, H_{max} \quad (3)$$

$$H_{max} = \frac{N_1\, 2i}{4l} \quad (4)$$

$$H_{max} = \frac{1000 \times 2 \times 0.3}{4 \times 0.26}$$

$$= \frac{1000 \times 1.414 \times 0.3}{4 \times 0.26} = 415 \text{ AT/m}$$

$$B_m' = 1.256 \times 10^{-6} \times 415 = 522 \times 10^{-0} \text{ Wb/m}^2$$

$$A_s = 7 \times 1 = 7 \text{ cm}^2 = 7 \times 10^{-4} \text{ m}^2$$

$$A_c = 1 \times 1.5 = 12 \text{ cm}^2 = 12 \times 10^{-4} \text{ m}^2$$

$$B_m'' = \frac{3.42}{4.44 \times 7 \times 10^{-4} \times 160 \times 50}$$

$$= \frac{3.42 \times 10^4}{4.44 \times 7 \times 160 \times 50} = \frac{3.42}{4.42 \times 50}$$

$$= 0.1375 \text{ Wb/m}^2$$

$$B_{max} = 7 \times 10^{-4} + 0.522 \times 10^{-3}\,(12 - 7) \times 10^{-1}$$

$$= 0.137 \times 7 \times 10^{-4}$$

$$B_{max} = \frac{7 \times 0.1375 - 5 \times 0.522 \times 10^{-3}}{7} \text{ Wb/m}^2$$

$$= 0.1371 \text{ Wb/m}^2.$$

The pressure coil of the wattmeter is connected to the secondary side of the magnetic square; therefore, the wattmeter gives the losses which commenced only on the secondary side. The copper loss on the primary side is not included in the wattmeter. So that copper loss of the primary winding of the magnetic square is eliminated by connecting the pressure coil of the wattmeter to the secondary side of the magnetic square.

Q2. Why is it necessary to multiply the wattmeter reading by N_1/N_2?

Ans. Since N_1/N_2 is the transformation ratio and we have to calculate to the total iron loss of the magnetic square. Therefore, we should transfer the total loss in terms of the primary side so that the value obtained after multiplying N_1/N_2 to the wattmeter reading is the total secondary winding loss referred to the primary. Due to this it is necessary to multiply N_1/N_2 to the wattmeter reading.

Q3. How does the form factor control changes of the voltage wave across the primary?

Ans. Since the form factor for the sinusoidal wave is equal to 1.11 and we know that

$$\text{Form factor} = \frac{E_{\text{R.M.S.}}}{E_{\text{average}}}$$

So we should adjust $E_{R.M.S.}$ and E_{mean} such that $E_{R.M.S.}$ must be 1.11 times E_{mean}. This can be easily done by rheostatic resistance which is provided on the experiments board.

Q4. If the voltage is kept constant and frequency is increased, how will the iron loss change?

Ans. Since the iron loss is the summation of the eddy current loss and hysteresis loss and as we know:

Eddy current loss = $kf^2f^2t^2\, B^2_{max}$

Hysteresis loss = $fB_m^{1.6}$

Therefore, iron loss is directly proportional to the frequency and increases as frequency ($f^{1.5}$) increases.

Q5. Will there be any magnetic loss in the core in the case of an air core transformer?

Ans. There will be high reluctance in air the path. There will be no flux and hence and no magnetic loss will occur.

EXPERIMENT 26

26.1 Object: Study of Overcurrent Relay (I.D.M.T. Type) and Determination of the Time-Current Characteristic

26.2 An overcurrent relay consists of an aluminum disc free to rotate between the poles on an electromagnet

Current flowing through the operating coil produces flux in the air gap which is split into two out-of-phase fluxes by copper "shading rings" placed on part of the pole faces. If ϕ_s and ϕ_u are the fluxes due to shaded and unshaded portions of the pole, the torque on the disc is proportional to $\phi_s \phi_u \sin \alpha$

where α—angle by which ϕ_s lags ϕ_u.

Assuming that ϕ_s, and ϕ_u each are proportional to the current through operating coil torque $I^2 \sin \alpha$.

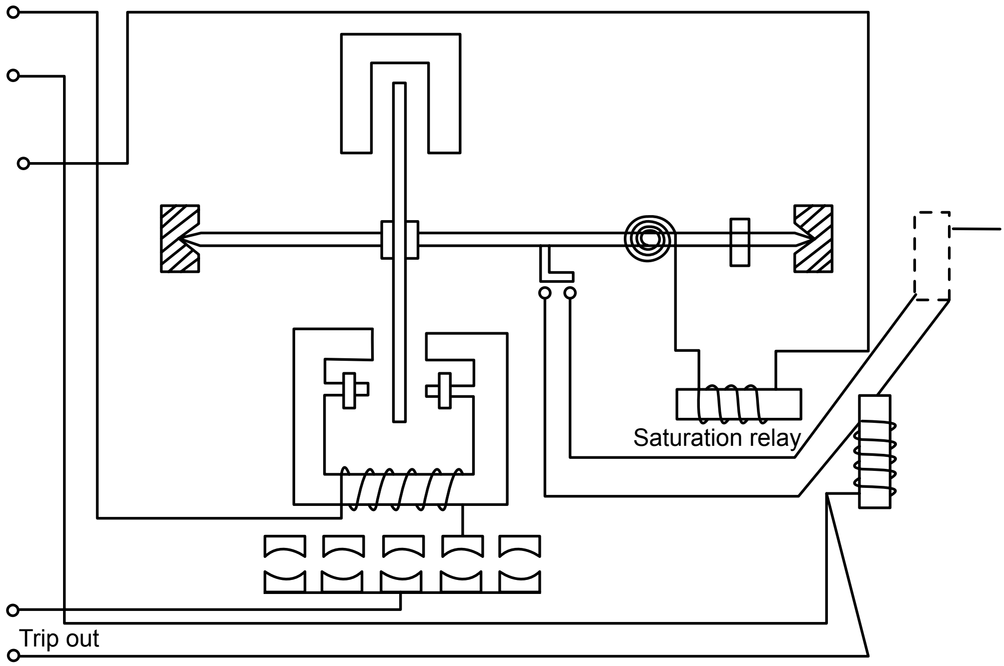

Figure 26.1

The direction of the torque depends upon which flux is leading the other.

By plug setting multipliers the effective number of turns on the operating coil and hence the pickup value of the relay can be changed.

The disc spindle carries a moving contact which bridges two fixed contacts. By means of time setting multipliers, the distance between moving and fixed contact and hence the operating time can be varied; a braking magnet is used to produce the time lag.

EXPERIMENTAL RESULTS

S.N.	Plug setting in amps	Pickup value in amps	Reset value in amps	Vol. across operating coil in volts
1	2.5	3.2	2.8	1
2	10.0	11.5	10.8	0.35

S.N.	Multiples of pickup value of relay (amp.)	Operating time with time dial setting 0.8 (sec.)	Operating time with time dial setting 0.6 (sec)
1	3.5	31.0	22.0
2	4.0	7.0	12.7
3	4.5	11.0	8.8
4	5.0	8.9	7.0
5	5.5	7.8	5.0
6	6.0	7.0	5.8
7	6.5	6.0	4.4
8	7.0	5.6	4.3
9	7.5	5.1	4.0
10	8.0	5.0	3.6
11	8.5	4.6	3.3
12	8.0	4.5	3.2
13	8.5	4.5	3.2

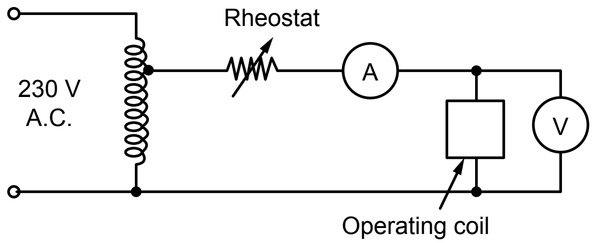

Figure 26.2

The ammeter range is 10 A. An avometer is used as a voltmeter, with a range of 10 V. An auto transformer is used for course adjustment, and a rheostat is used for fine setting.

(1) We make connections as shown in Figure 26.2. Find the pickup values and reset values of the relay for minimum and maximum plug setting. Also measure the voltage across the operating coil.

(2) To plot the time current characteristic, adjust the plug setting to its minimum. Bring the time dial setting to 0.6.

Allow the currents equal to 3.5, 4, 4.5 . . . 10 times of the pickup values to flow through the operating coil, and for each current note the operating time.

Repeat the same procedure for the time dial setting of *B* lag. Plot the time-current characteristic of the relay for a 0.6 and 0.8 time dial setting.

26.3 Questions and Answers on the Experiment

Q1. What arrangement is provided in the relay to save the G.T. from being open circuited when the plug setting is changed?

Ans. The upper electromagnet has a primary and secondary winding. The primary is connected to the secondary of C.T. in the line to be protected and is provided with tapping. These tappings are connected to a plug setting bridge which is usually arranged to give seven selections of tapping. The overcurrent range is 507 to 2007 in steps of 25% of the element, which tends to operate the relay.

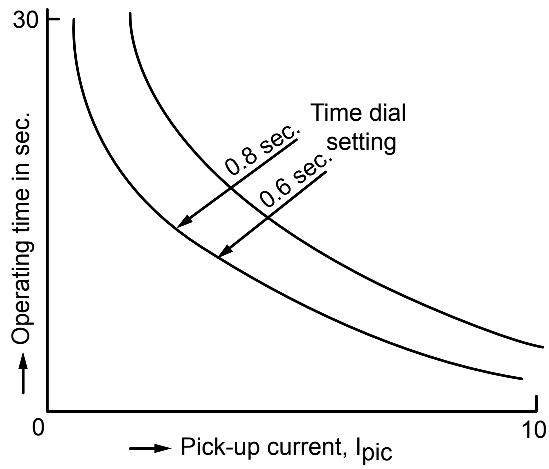

Figure 26.3

When the pin is withdrawn for the purpose of changing the setting while the relay is in service, the relay automatically adopts a high setting, thus ensuring that the C.T. secondary is not open circuited and that the relays remain operative for fault during the process of changing the setting.

Q2. Why it is preferred to take on the *X* axis of the time-current characteristic of the relay multiples of the pick-up value instead of the actual value of current in amps?

Ans. The curve time current characteristics are the inverse definite minimum time type, since the time of operation is approximately inversely proportional to the smaller values of current and tends to a definite minimum time as the current increases without limit. The multiple of the pickup value of the current is taken along the *X*-axis.

Since the actual value of the current in amperes will provide only the quantity of current and the current setting multiplier gives the number of times the relay current is in excess of the current setting. Therefore, the multiples of the pickup value current are preferable to the actual value of the current.

EXPERIMENT 27

27.1 Object: Study of the Instantaneous Relay and Determination of the Pickup and Reset Values

27.2 Apparatus

The following apparatus will be required:

1. Ammeter
2. Voltmeter
3. Autotransformer
4. Rheostat.

27.3 The Instantaneous Relay of Type CAG is the Simplest Electromagnetic Relay

It consists of a cylindrical electromagnet mounted in a case. The electromagnet attracts a hinged armature to which moving contacts are attached. When the current through the operating coil exceeds the pickup value, the armature gets attracted toward the magnet. Consequently, the moving contacts are lifted up and they come in contact with the fixed contacts. The relay has two pairs of contacts. One completes the trip circuit and the other the alarm circuit. It can be shown that the force of attraction is proportional to the square of flux, that is, current (assuming a current linear flux relationship) This relay is operative for both A.C. and D.C.

The operating time of the relay is defined as the time lapsed from the instant of energization to the instant of the closing of contacts in the order of milliseconds ranging from 20 to 100 milliseconds. Because of its small operating time, the relay is known as an instantaneous relay. The operating time is practically independent of the value of current.

Since this particular type of relay is used as an overcurrent relay, it is applied to the protection of feeders, machines, and so on.

27.4 Experimental Setup

Make connections as shown in the circuit diagram. Find the pickup values and reset values of the relay for each plug setting. Also measure the voltage across the operating coil. Take observations for both A.C. and D.C. so that the torque that develops is dependent upon the direction of the current in relation to voltage; that is, the relay recognizes the phase difference between voltage and current.

The voltage coil provided on the central limb of the upper magnet produces flux ϕ_1 lagging voltage V. The flux ϕ_2 will be almost in phase with I. The driving torque T is given as,

$$T\ \phi_1\ \phi_2 \sin\phi$$

$$VI \sin(90 - \phi)$$

$$VI \cos\phi = \text{Power}$$

Now the only condition to be satisfied for the reversal of power, that is, reversal of the directional feature, is that ϕ should exceed 90°, the torque will reverse and if it exceeds a safe limit, then the relay will trip the circuit.

27.5 Question and Answer on the Experiment

Q1. Why do V_{min} and I_{min} occur in the V-I characteristic?

Ans. If the power factor of the directional power element is assumed constant, then the torque produced is proportional to the power VI. That is,

$$T \times VI \quad T = KVI$$

Now for the operation of the directional power element, the product VI should reach the value to produce the sufficient torque. It creates the possibility that one of the two quantities V and I may reach a very high value, but the other may be very small, a little more than a zero value. Such a small value is harmful. So, the lower limits of the values of current and voltage come into the picture showing the minimum required amount for the operation of the directional element.

EXPERIMENT 28

28.1 Object: Study of the Directional Overcurrent Relay

28.2 Principle and Description of the Directional Power Relay

Overcurrent relays are the most widely used relays in the protection of electrical machines, apparatus and transformers, lines, and so forth from overload or abnormal conditions. The minimum current at which the relay operates is known as the current setting (or pickup value) and is generally expressed as a percentage of the rated current of the line or apparatus protected. It is evident that an overcurrent relay cannot have a setting less than 100%.

The directional current relay consists of an overcurrent element and the directional power element.

28.3 Experimental Setup

When two alternating fluxes ϕ_1 and ϕ_2 differ in phase by an angle, say when acting upon a metal disc, they produce torque due to the interaction of one of the fluxes and the eddy current induced by other flux.

In an overcurrent relay the air gap flux in which the disc rotates is applied into two out-of-phase components. For this purpose, a C-type electromagnet is used. The poles of the magnet are divided into two portions. The components of flux are obtained by a double winding structure. The C-type electromagnet carries two windings:

(i) primary, which is mounted on the electromagnet in series with the current coil of the directional relay element; and

(ii) secondary, which is wound on the split ends of a C-type magnet. Further, this winding is electrically connected to moving and fixed contacts of the directional element.

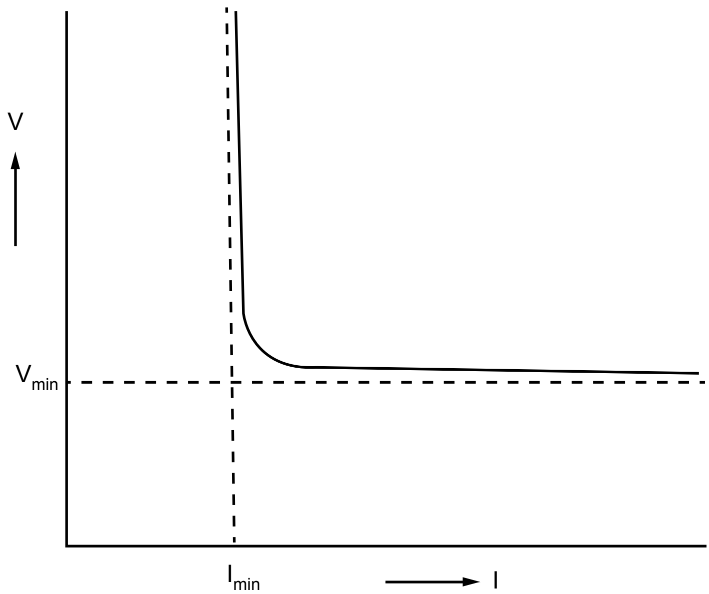

Figure 28.1

28.4 Discussion

This relay operates by voltage and current. The voltage coil is connected through a capacitor in series to a potential transformer and a current coil to the secondary C.T.

Such an arrangement is made by providing four pole structures. The moving element of the relay is in the form of a cylindrical rotor and is put in the space between the four poles. The torque produced on the rotor is proportional to voltage, current, and power factor.

The directional element is very sensitive, requiring very little power for operation.

V-I Characteristic. If the p.f. is considered constant, then *T VI* for pickup *VI* equals a constant. A graph may, therefore, be plotted between *VI*.

It is clear from the *V-I* characteristic that there are definite minimum values of voltage and current below which the directional element will not operate.

Seal-in Relay. The function of a seal-in relay is to protect the contacts of the main relay from putting and burning. It decreases the current carrying duty by providing path for the tripping current through its own contacts. The coil of the seal-in relay is connected in series with the main contracts of the overcurrent element through a battery.

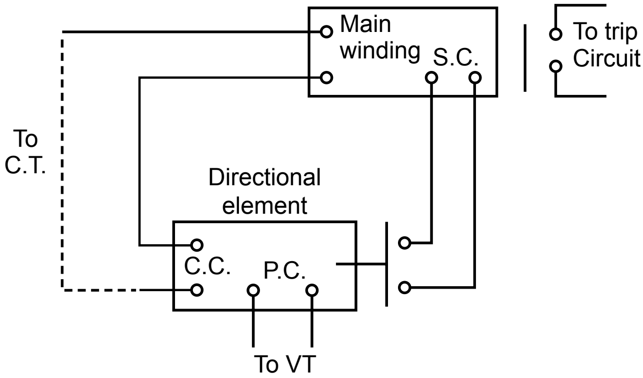

Figure 28.2

28.5 Questions and Answers on the Experiment

Q1. What are the conditions which must be satisfied before the overcurrent element can operate?

Ans. The directional overcurrent relay is set to operate for the condition when the current flowing in the given direction increases above the preset value. When the current in that direction (i.e., given direction) increases over the given value, the directional element operates first and the circuit of the overcurrent element completes and hence the overcurrent element operates. This completes tripping the circuit of the circuit breaker, and the faulty element is cut off from the circuit.

Q2. What is meant by directional control? The directional element is fitted with the directional overcurrent relay for directional control of the relay.

Ans. The directional control is required as we want the relay to operate for the current flow in a particular direction, while for the current flow in the opposite direction, the relay must not operate. This type of arrangement is called directional control and is achieved by the directional element. The necessary conditions to be fulfilled before the relay will operate are as follows:

1. First the direction of the current must reverse in order to operate the directional element.
2. Then the current in the reverse direction must reach a value greater than its plug setting.
3. Finally, the high value of the current (greater than the setting) persists for a time greater than its time setting.

Q3. Discuss the polar characteristics of the relay.

Ans. For a given voltage torque is proportional to $I \cos \phi$ and at pickup $I \cos \phi$ is a constant quantity as the pickup current is a constant quantity. Now $I \cos \phi$ taken as a whole is a constant quantity with two variables ϕ and I. We can get the values of the current and the corresponding set of values ϕ the plot of the two quantities is called the polar characteristics of the relay.

Q4. How would you reverse the directional feature of the relays?

Ans. In the case of the directional overcurrent relay, the driving torque is derived from the interaction of the fields produced from voltage and current of the circuit in which the relay is provided. Since the relay has both voltage and current windings, the relay can essentially be called a wattmeter.

EXPERIMENT 29

29.1 Object: Study of the Percentage Differential Relay

29.2 An Overcurrent Relay Can Be Used as a Differential Relay

An overcurrent relay can be used as a differential relay if connected as shown:

The arrangement offers protection to that part of the system which lies between the two current transformers. If at the two ends *A* and *B*, currents are equal with the normal conditions or for external fault conditions, the current transformers' secondary currents are also equal (assuming identical C.T.s are used) and they will flow in the circuit as shown; for the instantaneous polarities of the C.T.s as given; if obviously current through the relay will be zero and hence it will not operate.

If the fault occurs within the protected zone, then only one of the C.T.s will be energized (neglecting the load current flowing through the second C.T.) and hence most of the secondary current will pass through the relay and operate it (provided this current is greater than the pickup value). Although we said that the relay is inoperative for external fault, in practice it is possible that the relay might operate at high values of fault, owing to the difference in performance of two C.T.s.

To prevent this malfunction a coil known as a restraining coil is connected as shown.

The pilot current flowing through the restraining coil tends to restrain the operation of relay, and unbalanced current through the operating coil tends to operate the relay, yet under external fault conditions the whole restraining coil carries the current and the unbalanced current through the operating coil is very small. This causes the restraining coil torque to become greater than the operating torque, and hence the relay does not operate.

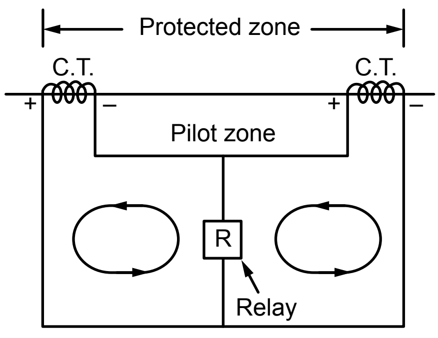

Figure 29.1

Under internal fault conditions only half of the restraining coil carries current. Neglecting the small current through the other half, unbalanced current through the operating coil increases. This causes the operating torque to become greater than the restraining torque and hence the relay operates.

29.3 Characteristics

If the characteristics are plotted for both the restraining current and the operating current which will just operate the relay, the bias characteristics will be obtained.

The characteristics show that except at low current, the ratio of differential operating current is a fixed ratio. This is due to a slight effect of the control spring at the low current.

29.4 Questions and Answers on the Experiment

Q1. What are the difficulties encountered in the differential protection of transformers?

Ans. The difficulties encountered in the differential percentages of transformers are:

1. Different ratio current transformers are required at the primary and secondary so as to balance the current and phase angle. This will cause difficulties in calculations.
2. The C.T. ratio should be changed for different types of transformer connections.

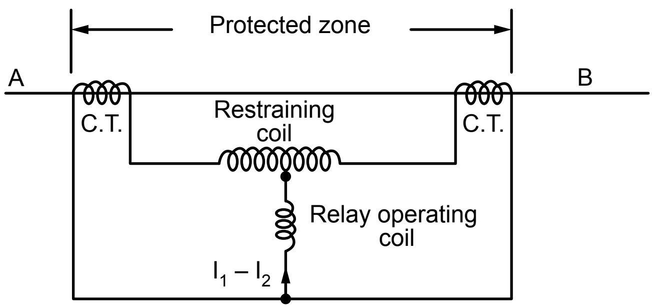

Figure 29.2

3. In case of a top changing transformer, the C.T. ratio should be changed for every tapping.

4. At the time of switching the transformer, the magnetizing current is very high; this will create the unbalancing, and so the relay will trip.
5. The C.T. and its ratio may be changed with different types of connections.

Q2. Why is the operating coil connected to the midpoint of the restraining coil?

Ans. The operating coil is connected to the midpoint of the restraining coil so it will not operate by occurrence of any fault outside the protected zone, because the secondary currents of both transformers will be the same and no current will flow through the relay. This is the case when normal conditions exist.

Q3. In how many ways can the slope of the bias characteristic be changed?

Ans. The restraining factor,

$$K_r = \frac{N_r}{N_o} \frac{K_2}{K_1}$$

where N_r = No. of turns in the restraining coil.
N_o = No. of turns in the operating coil.

So the slope of the characteristic can be changed by changing the restraining factor K_r, which can be changed either by increasing N_r or by reducing N_o.

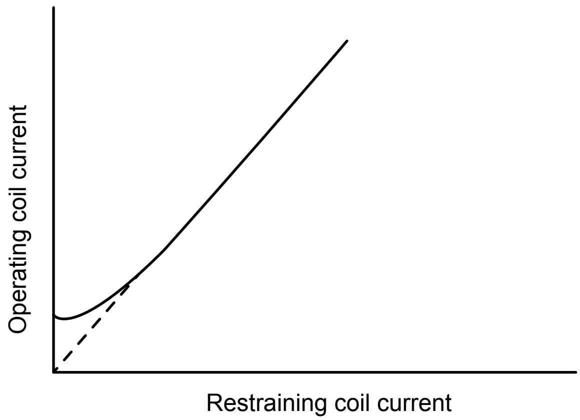

Figure 29.3

The slope can be changed by changing the operating current $(I_1 - I_2)$, but $(I_1 - I_2)$ is always constant. There are only possibilities of changing the A.T. in the restraining coil.

EXPERIMENT 30

30.1 Object: To Plot Burden Current Characteristics of the Given Current Transformers

30.2 Current Transformers May Be Regarded as a Current Energized Device

Current transformers may be regarded as a current energized device, that is, for a given primary current the secondary voltage and hence the primary voltage will be a function of secondary impedance. This is contrary to what happens in a voltage transformer, where for a given primary voltage the secondary current and hence the primary current is a function of the secondary impedance.

The equivalent voltage circuit of the C.T. can be simplified as shown in the last experiment.

It is to be noted that loss component R_o has not been shown in the equivalent circuit. There is negligible iron loss due to a very small primary voltage, and hence the flux density is also small.

It is to be noted that the magnetizing reactance is a nonlinear reactance as given by the magnetization characteristics.

When saturation is reached the magnetization on reactance becomes very small, and as a result the C.T. fails to work satisfactorily.

The following apparatus is required:

An auto transformer, L.V. high current transformers, an ammeter, a current transformer, and a rheostat.

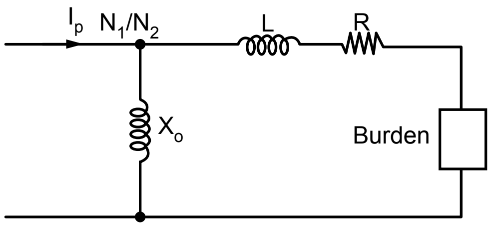

Figure 30.1 Equivalent circuit of a C.T.

L = Secondary leakage inductance
R = Secondary resistance
I_p = Primary current
N_1/N_2 = turn ratio
X_o = magnetizing reactance.

S.N.	Primary current (amp)	Secondary burden (ohm)	Secondary Current (amp)	Secondary voltage (volt)	Secondary (volt-ampere)
1	25	0.0	5	0	0
2	25	0.5	5	2.5	12.5
3	25	1.0	5	5.0	25.0
4	25	1.5	4.98	7.47	37.2
5	25	2	4.95	8.90	49.0
6	25	2.5	4.85	12.1	58.6
7	25	3.0	4.75	14.25	67.7
8	25	3.5	4.55	15.90	72.4
9	25	4.0	4.25	17.00	72.0
10	25	4.5	3.80	17.5	68.4
11	25	5.0	3.60	18.00	64.7

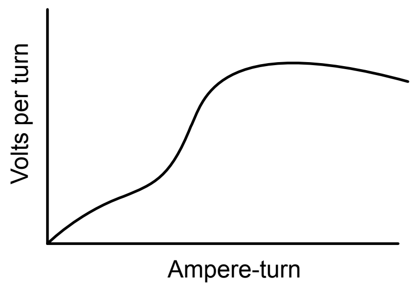

Figure 30.2

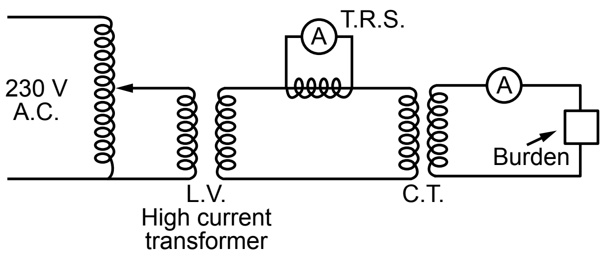

Figure 30.3

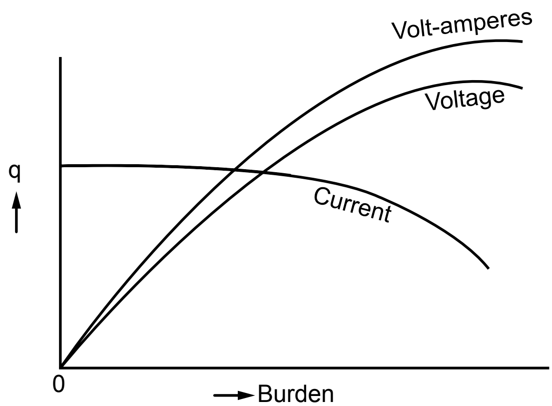

Figure 30.4

Procedure. The ratio of the C.T. under the test was adjusted to 25:5. The connections were made as shown in the diagram. A minimum burden was applied on the C.T. and by the autotransformer the current in the C.T. was adjusted to 25 A. The corresponding secondary current was noted. The burden was next increased in steps, and for each burden, adjusting the value of primary current to the secondary side is to be noted.

Graphs

1. Burden *vs*. Secondary Current
2. Burden *vs*. Secondary Voltage
3. Burden *vs*. Secondary Volt-Ampere.

30.3 Questions and Answers on the Experiment

Q1. Why does the current transformer fail to operate satisfactorily when the saturation is reached?

Ans. When the saturation of magnetization is reached, the transformer ratio is affected, resulting in an increase of exciting current. This will introduce a phase error in the current transformer, deviating the primary and secondary currents from their desired phase opposition, that is 180°. This makes the operation of the current transformer unsatisfactory.

Q2. Why is the secondary circuit of a current transformer not to be left open circuited?

Ans. In a C.T. the number of primary amp-turns is a fixed quantity (assuming a constant primary current) and is thus not reduced (when the secondary circuit is kept open, as in the case of a power transformer). When a C.T. has its secondary circuit open when the primary is connected, a very high flux density is produced in the case owing to the absence of back amp-turns due to current in the secondary circuit. This high flux density results in very high induced voltage in the secondary winding, with consequent reversal strain on the insulation and danger to the operator. Moreover, the high magnetizing force acting upon the core may if suddenly removed leave behind considerable residual magnetization in the core, so that the ratio and phase angle error obtained after such an operation may differ appreciably from those before it occurs.

For these reasons care must be taken to ensure that even when not in use for measuring purposes, the secondary current is closed if the primary current is flowing.

Q3. Distinguish between a voltage source and a current source.

Ans. *Voltage Source*. The voltage source is assumed to deliver energy with a specified transfer voltage $v(t)$ which is independent of current from the source.

Current Source. The current source is assumed to deliver energy with a specified current through the terminals $i(t)$; the symbol and reference connection for the current source differ from that of the voltage source.

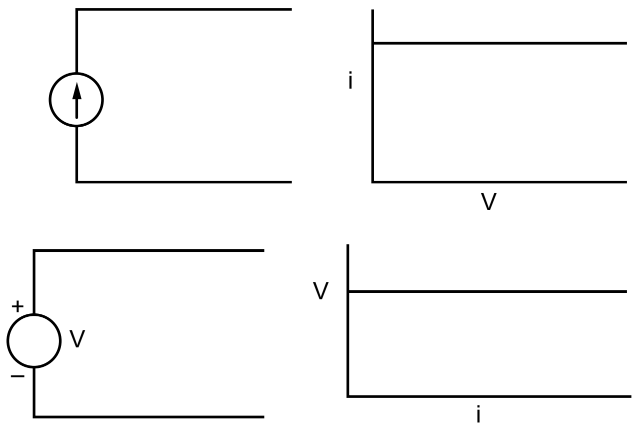

Figure 30.5

EXPERIMENT 31

31.1 Object: For the Given Current Transformer and Burden to Find the Ratio and Phase Angle Error at

(*a*) 100% Rated Current and

(*b*) 50% Rated Current by the Mutual Inductance (Absolute) Method

31.2 A Current Transformer Is a Current Operated Device as an Ammeter

A current transformer is a current operated device as an ammeter and, therefore, it has to be connected to a current source. If it is connected to a voltage source, it must be connected in series with a fairly high impedance.

31.3 The C.T. Testing Apparatus

This consists of a number of primary shunts (non-inductive heavy current resistance) immersed in an oil-filled tank. The tank can be water cooled. Motor driven stirrers along with a thermo-switch are also provided for further cooling.

The primary shunts are provided with one negative and two positive buses. Only the negative and lower positive bus are used. The second positive bus is provided to facilitate the testing of the shunts. Any suitable shunt may be chosen and can be connected to the lower positive bus bar through the connecting block.

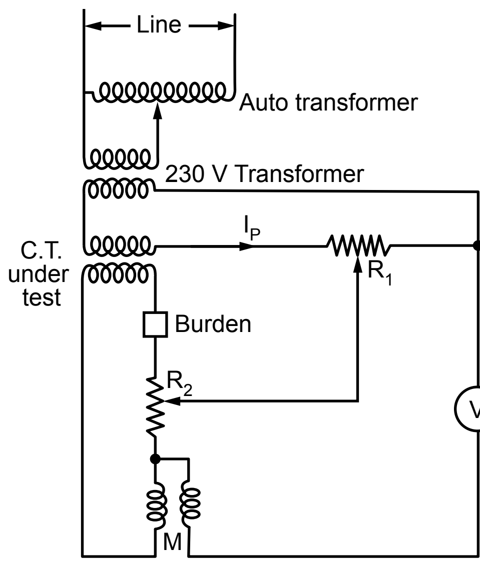

Figure 31.1

Observations

S.N.	Primary Current	% rated Current	Pry. Shunt Resistance in R_1 Ω	R_2	M
1	50 Amps	100%	0.01 Ohm	0.1 Ohm	4.8 leading
2	25 Amps	50%	0.01 Ohm	0.1 Ohm	6.6 leading

Calculations

For 100 % rated current

Phase angle error $\theta = \tan^{-1}\dfrac{WM}{R_2} = \dfrac{WM}{R_2}$ radians.

$$= \frac{3438 \times 2\pi \times 50 \times 4.8 \times 10^{-6}}{0.1}$$

$$= 51.7 \text{ minutes.}$$

Ratio Error

$$\text{Actual ratio} = \frac{I_1}{I_2} = \frac{R_2}{R_1} \times \frac{1}{\cos\theta} = \frac{0.1}{0.01} \times \frac{1}{0.999}$$

$$= 10.01$$

$$\text{Normal ratio} = \frac{I_1}{I_2} = \frac{50}{5} = 10$$

$$\text{Ratio error} = \frac{10 - 10.01}{01 - 0.01} = -0.999\%.$$

Galvanometer. A vibration galvanometer is required to obtain the null point since the voltage drops to be balanced are very small. The accuracy of the experiment will depend upon the sensitivity of the galvanometer. In fact, the null position may not be obtained at all if the galvanometer is not sensitive enough to detect the unbalanced voltage in the circuit.

Apparatus. Current transformer, burden, resistance, shunt, and mutual inductance.

Procedure. Make connections as shown. Adjust the current in the primary circuit of the C.T. (under test) to 100% rated current. Obtain the null point by varying R_2 and M. Note the corresponding readings. Similarly, adjusting the current in the primary circuit to 50% rated current again obtains the null point, and note the values of R_2 and M.

Calculations

Phase angle error $\theta = \tan^{-1}\dfrac{WM}{R_2}$

$$\text{Ratio error} = \frac{\text{Nominal ratio} - \text{Actual ratio}}{\text{Actual ratio}}$$

For 50% rated current

Phase angle error $= \dfrac{3438 \times 2\pi \times 50 \times 6.6 \times 10^{-6}}{0.1}$

$= 60$ minutes.

The ratio error will be the same.

$$\frac{I_s WM}{I_s R_2} = \frac{WM}{R_2}$$

Also $\cos\theta = \dfrac{I_s R^2}{I_p R} = \dfrac{R_2}{R_1}$; θ is very small.

$$\text{V.R.} = \frac{T_p}{I_s} = \frac{R_2}{R_1}$$

Results: For the given current transformer and burden the ratio error

and phase angle error for 100% rated current = 51°7’

and for 50% rated current = 1°

31.4 Questions and Answers on the Experiment

Q1. What are the factors on which the ratio and the phase angle error depend? How are they minimized?

Ans. A phase angle error of 0 C.T. depends on:

1. There is a difference in the current ratio and turns ratio. It depends on the magnitude of the exciting current of the transformer, and the secondary current and point of the secondary circuit. This error comes into consideration in the current measurement; it is necessary that the secondary current shall be displaced by the primary current by 180° The C.T. has a phase angle error θ. The phase angle error depends upon the value of the magnetizing current component I_m.

In order that the number of exciting ampere turns $I_0\ T_p$ shall be a small proportion of the total primary ampere turns, we take a single bar as a primary. Now to get high ampere turns of the order of 500 to 1000, the current should be very high. Metals or alloys of high permeability and loss can be used for the core, for example, M_a metal for as low as 100 A with good performance.

The winding should be close together in order to reduce the secondary leakage reactance, as this increases the ratio error. The ratio error is made less positive as the power factor is reduced. Also, the phase angle error is obviously reduced with reduction of power, since $n\ s$ moves more into phase with I_0 as it is increased.

Q2. Why can't the secondary circuit of the current transformer be left open circuited?

Ans. The number of primary ampere turns is a fixed quantity if the primary current is fixed. If, therefore, a C.T. has its secondary terminals open when current is flowing in the primary, a very high flux density is produced in the core owing to the absence of back EMF. The ampere turns due to the current in the secondary winding with consequent operate. Also, when high magnetizing forces are suddenly removed from the core, they leave behind a considerable residual magnetization in the core, causing an appreciable change in the ratio and phase angle error.

Q3. Give the vector diagram of a C.T. operating at a:

(*i*) **purely resistive load**
(*ii*) **purely reactive load.**

Ans. where, η = turn ratio = $\dfrac{\text{No. of secondary turn}}{\text{No of primary turn}}$

R_s = Resistance of secondary winding
K_s = Reactance of secondary winding
E_s = Secondary induced voltage
T_p = No. of primary turns
T_s = No. of secondary turns
V_s = Secondary terminal volume
I_s = Secondary current
I_s = Primary current
θ = Phase angle of C.T.
δ = Phase angle of burden
α = Angle between I_o and ϕ

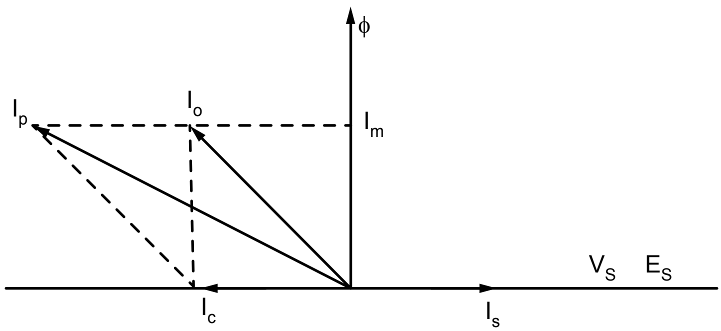

Figure 31.2

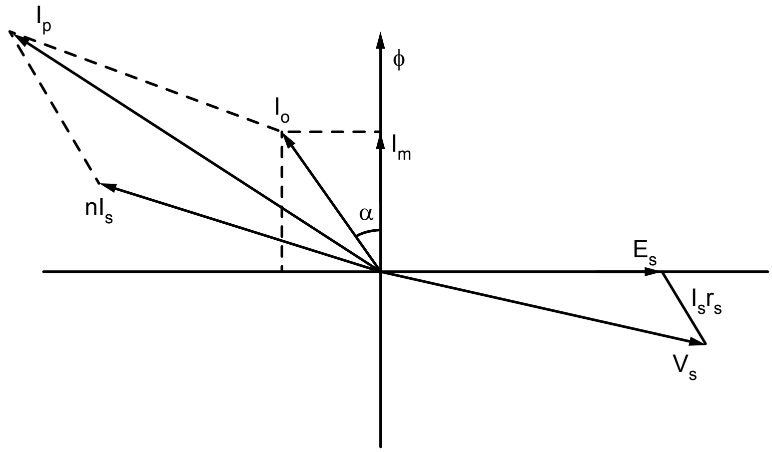

Figure 31.3

Q4. If an air gap is cut in the core of a C.T., how will its performance change?

Ans. If an air gap is cut in the core of a C.T., the reluctance of the air path as well as the magnetic path will increase considerably. This will require a large amount of exciting current. A large exciting current will make the actual ratio more than the nominal ratio and will also increase the phase angle error, which directly depends upon magnetizing current.

If we neglect the angle δ the angle between the secondary current and secondary induced voltage, which is fairly small compared to the phase angle, then:

$$\theta = \frac{I_m}{nI_s}.$$

Q5. What are the materials used for the core of the current transformer?

Ans. To minimize the ampere turns required, the core must have a low reluctance, small iron loss, and the flux density used in core should be small, not greater than 1000 lines/cm^2. M_a metal, a nickel iron alloy containing copper, has the properties of very high permeability, low loss, and small retentivity. All of which are advantageous for C.T. But it has a disadvantage in that its maximum permeability (about 90,000) occurs with a flux density of about 3500 lines/cm^2. Silicon steel is the other material with a maximum permeability of about 4500 at 5000 lines/cm^2.

The alloy permendur (45% iron, 45% cobalt, and 2% vanadium) has a very high saturation point. Mostly m_u metal is used for the core. The other materials used are hot rolled silicon, iron, cold rolled silicon, silicon iron, 36/64 alloy, ratio metal, special ratio metal, and m_u metal.

Q6. What is the utility of this experiment?

Ans. The ratio and phase angle error of the current transformer should be determined with great accuracy, because C.T.s are used in relays. Errors of a C.T. should be correctly known.

EXPERIMENT 32

32.1 Object: To Plot the Power-Angle Curve of a Three-Phase Salient Pole Synchronous Generator

32.2 Power Output of a Salient Pole Machine

The power output of a salient pole machine is given by

$$P = e_q i_q + e_d i_d \tag{32.1}$$

The equivalent circuit of the alternator is shown in Figure 32.1.

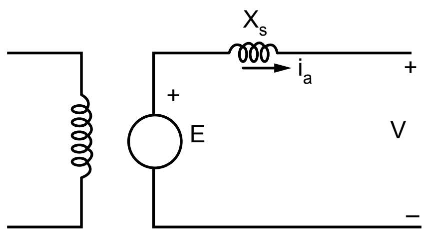

Figure 32.1

A phasor diagram of the alternator of a salient pole type operating at lagging power factor load, resistance neglected, will be drawn in Figure 32.2 based on the two-reaction theory.

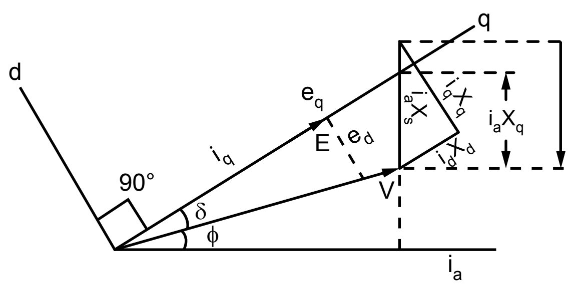

Figure 32.2

From the phasor diagram

$$\begin{Bmatrix} e_q = V \cos \delta \\ e_d = V \sin \delta \end{Bmatrix} \tag{32.2}$$

$$i_d X_d = E - e_q = E - V \cos \delta \tag{32.3}$$

$$i_d = \frac{E - V \cos \delta}{X_d} \tag{32.4}$$

Also

$$i_q X_q = V \sin \delta \tag{32.5}$$

$$i_q = \frac{V \sin \delta}{X_q} \tag{32.6}$$

If we substitute the previous equations in the power equation, we obtain

$$P = \frac{EV}{X_d} \sin \delta + \frac{V^2 (X_d - X_q) \sin 2\delta}{2 X_d X_q} \tag{32.7}$$

This is known as the power angle equation.

For a cylindrical rotor machine, $X_d = X_q$ (32.8)

and the power angle equation will be

$$P = \frac{EV}{X_d} \sin \delta \tag{32.9}$$

If we represent the power equation as follows:

$$P = P_m \sin \delta$$

where

$$P_m = \frac{EV}{X_d} \text{ at } \delta = \frac{\pi}{2}$$

Due to the second term in equation (32.7), the maximum power output of a salient pole machine will be greater than a cylindrical rotor machine. The maximum power will occur between an angle δ which lies between 75°–90°. The additional term gives the reluctance power of the machine. This is due to a difference between X_d and X_q.

32.3 Experimental Setup

Perform a slip test described in Experiment 32 and find the values *of* X_d and X_q. Make the table as shown:

EXPERIMENTAL RESULTS

S.N. (1)	δ (2)	$\sin\delta$ (3)	$\frac{EV}{X_d}\sin\delta$ (4)	$\frac{V^2(X_d - X_q)}{2X_dX_q}\sin 2\delta$ (5)	P (6)
1	0	0	0	0.091	0
2	60	0.5	2.32	0.091	2.411
3	60	0.856	4.00	0.0674	4.091
4	70	0.9397	4.35	0.0359	4.417
5	80	0.9848	4.55	0.00	4.585
6	90	1.00	4.64	–0.091	4.64
7	120	0.866	4.01	–0.091	3.919
8	150	0.5	2.32		2.299
9	180	0	0		0
10					

Determine the open-circuit excitation voltage E for power factor 0.8 lagging at full load. Keep this value of E constant. Obtain the power angle characteristic. Find X_d, X_q, E, and V in per unit form.

Plot the power angle curve between the angle δ and power P as given by columns 2 and 6, respectively.

The power angle curves for a salient pole machine and cylindrical rotor machine are shown in Figure 32.3. A circuit diagram used for this purpose is redrawn in Figure 32.4.

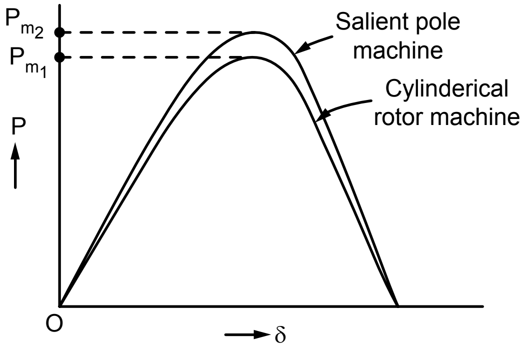

Figure 32.3

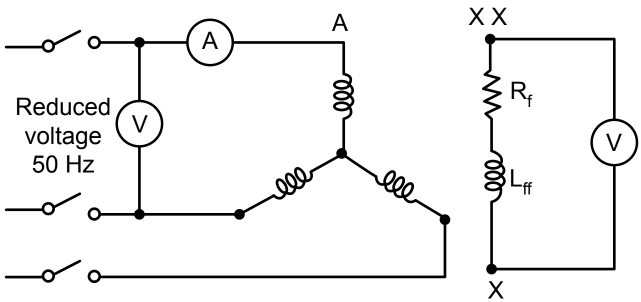

Figure 32.4

32.4 Experiment

An experiment was performed on a three-phase alternator, 220 V, 9.2 A, 1000 RPM, and 2.8 kW. The instruments used for the purpose have a range, ammeter 0–10 A, and voltmeter 0–300 V.

The voltage E was kept constant at 162 volts and the X_d and Xq were found to be

$$X_d = 5.08\ \Omega$$

and

$$X_q = 4.79\ \Omega$$

We can convert these into the per unit system. The voltage will be

$$V = 220/\sqrt{3} = 127 \text{ volt}$$

$$I_a = 9.2 \text{ Amps}$$

Then,
$$X_d = 5.08 \times \frac{9.2}{127} = 0.368 \text{ p.u.}$$

$$X_q = 4.79 \times \frac{9.2}{127} = 0.344$$

From the phasor diagram

$$E = 160 \text{ volts}$$

instead of 162 volts. The p.u. value of E will be

$$E = 160/1\ \ 7 = 1.26 \text{ p.u.}$$

We find
$$\frac{VE}{X_d} = 4.64$$

and
$$\frac{V^2(X_d - X_q)}{2X_dX_q} = 0.105$$

The power angle curves are shown in Figure 32.3 for two typical machines. These are freehand diagrams to give an idea of the power angle characteristic.

32.5 Discussion

The power angle curve is used to find power at various power angles δ. The δ is the angle between the terminal voltage V and EMF E. This curve is useful to find stability of the synchronous generator and other dynamic parameters.

32.6 Questions and Answers on the Experiment

Q1. What is a hunting in a synchronous generator?

Ans. A hunting is the sudden swinging in the rotor of the machine due to transient disturbances. The governor action causes the hunting.

Sudden change of steam in the prime-mover and boiler or furnaces may cause hunting. Hunting changes the voltage and frequency of the supply produced by the alternator.

Q2. What is hunting in the synchronous motor?

Ans. The hunting of the motor means a generation of mechanical transients. The rotor of the motor will run fast due to disturbances. The hunting for both cases may be expressed:

$$J\frac{d^2\delta}{dt} + B\frac{d\delta}{dt} + C\,\delta = P_a$$

where J is the inertia constant, B is the damping constant, C is the control constant, and P_a is the accelerating power.

EXPERIMENT 33

33.1 Object: Determination of X_d and X_q by Slip Test

33.2 A Low Voltage of Rated Frequency is Supplied to a Synchronous Generator in Three Phases

The field winding is kept open. The rotor is driven by a motor in the same direction as the synchronously rotating field of the stator current. The speed is kept below the synchronous speed.

The rotor poles slip slowly through the poles produced by the armature current. The two magnetic fields (MMFs) will be in one line at one time and in quadrature at another time. When the two fields are in line we obtain X_d, the direct axis reactance. When the two fields are in quadrature we obtain the X_q, the quadrature axis reactance. The applied armature voltage will be equal to the drop due to the X_d and X_q in the previous two cases.

If the slip is sufficiently small, the pointers of the voltmeter and ammeter will swing slowly from a maximum to a minimum. The voltage will be the least when the current is at a maximum. The voltage will be greatest when the current is at a minimum.

33.3 Experimental Setup

The experiment will require a synchronous generator run by a motor. A voltmeter and one ammeter will be required for the measurement of the voltage drop and current in the phase winding.

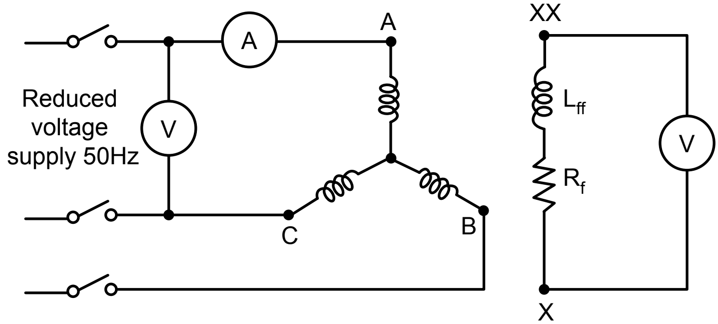

Figure 33.1

Arrange connections according to the circuit diagram. Start the mover and run the motor at nearly synchronous speed. Keep the exciter open circuited by connecting a voltmeter, if necessary. Supply a reduced voltage of 50 c/s frequency with the help of an autotransformer. Read the applied voltage, current, and the induced voltage in the field. Determine the resistance of each phase of the winding by the ammeter-voltmeter method.

EXPERIMENTAL RESULTS

S.N.	Speed N RPM	current		Voltage		X_d	X_q
		Minimum	Maximum	Min	Max		
1	975	5.6	5.8	28.9	28.3	5.15	4.88
2		6.7	6.9	33.5	32.95	5.00	4.77
3		7.8	7.95	38.8	38.2	4.87	4.81
4		9.2	9.5	45.2	44.6	4.81	4.7
5							

The armature resistance determined will be 0.69 or 0.7 ohms.

A voltage of 2 V produced a current of 2.9 A in the winding. These data are given here for an idea of the experiment.

33.4 Calculations

X_d and X_q will be given by

$$X_d = \frac{V_{max}}{I_{min}}$$

and $$X_q = \frac{V_{min}}{I_{max}}$$

For the first experimental result

$$X_d = \frac{28.9}{5.6} = 5.16\ \Omega$$

and $$X_q = \frac{28.3}{5.8} = 4.88\ \Omega$$

33.5 Specifications

An alternator of 220 V, three-phase, 2.9 kW, and 1000 RPM was tested for X_d and X_q. We used the instruments ammeter 0–10 Amps, a voltmeter 0–300 V, and a tachometer 0–2000 RPM.

33.6 Discussion

The results are given in tabular form. We find that X_d and X_q go on decreasing when the current is increased. The X_d and X_q variation with the armature current is represented in Figure 32.2.

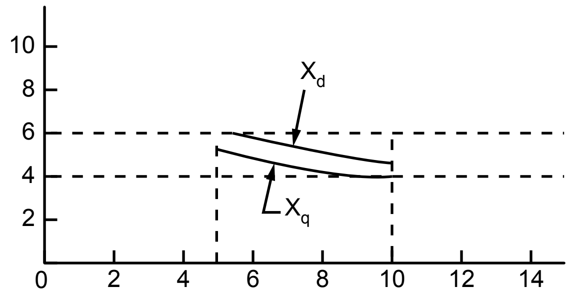

Figure 33.2

33.7 Questions and Answers on the Experiment

Q1. Why will X_q be different from X_d in a salient pole synchronous machine?

Ans. In a salient pole machine, the poles are projected out of the rotor. Therefore, the reluctance between stator and rotor in the air gap is not uniform. The reluctance of the quadrature axis magnetic circuit will be different from the reluctance in the direct axis. The quadrature axis component has a magnetic circuit passing through the air gap and interpole space while the direct axis component of the MMF acts on the magnetic circuit of the machine. For these reasons the quadrature axis synchronous reactance will be smaller than the direct axis component. The X_q^d is less affected by the saturation because it has a less magnetic path.

Q2. What would be an alternate method to determine X'_d and X_c'

Ans. The X_d' can be determined from a no-load saturation curve and short-circuit curve. Rated phase voltage on the air gap line may be used to determine the saturated value of X_d.

Q3. What are the sources of error in the experiment?

Ans. The X_d and X_q determined in the experiment are different at different values of armature current. We have no exact values for X_d and X_q.

Q4. What would be an alternate method to determine the exact values of X_d and X_q?

Ans. A method of C.R.O. (cathode ray oscilloscope) will be used to find the V_{max} and I_{min} and V_{min} and I_{max}.

EXPERIMENT 34

34.1 Object: To Study the Effect of the Brush Separation and Brush Shift on the Speed and Power Factor of the Schrage Motor

34.2 The Schrage Motor Is Essentially an Inverted Induction Motor

The Schrage motor is essentially an inverted induction motor, that is, one with the primary winding on the rotor and the secondary winding on the stator. The rotor also carries a regulating winding which is connected to the commutator segments.

The secondary winding is arranged so that two separate ranges of speed are obtained by altering the connections of the external terminals, and the brush gear is designed so that the power factor of the motor can either be improved or made more lagging.

34.3 Experimental Setup

The circuit diagrams for performing the experiment on the Schrage motor are shown in Figures 34.1 and 34.2.

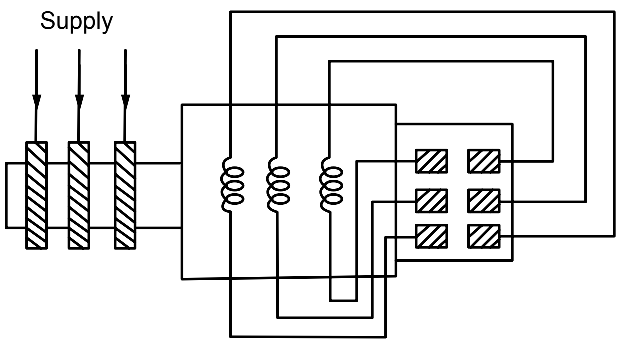

Figure 34.1

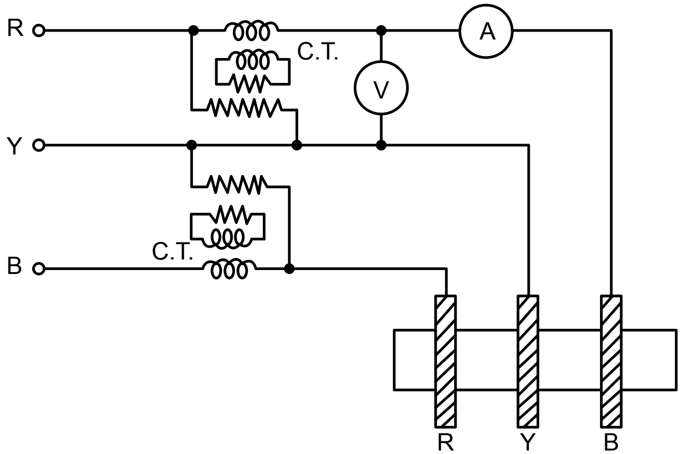

Figure 34.2

Make connections according to the circuit diagram. Adjust the brush shift to zero and increase the voltage applied to the machine until it runs at no load with rated voltage applied to the primary winding.

With the machine running on no load, vary the brush separation from -160° to +110° and not the corresponding speed of the machine. Keeping the brush shift zero and with rated voltage applied to the primary winding, perform the load test for separation of 0°, +60°, and -60°. Note the input to the primary and the speed. Keeping the brush shift of a few degrees with rated voltage applied to the primary winding, perform the load test.

EXPERIMENTAL RESULTS

S.N.	***Brush Separation***	***Speed RPM***	***Remarks***
1	-160		
2	-140		
3	-130		
4	-120		
5	+20		
6	+40		
7			

1. Brush shift = 0
2. Supply voltage =

S.N.	*I*	*V*	*Watts*	*Speed*	T_1	T_2	*Output*

1. Brush shift = 0
2. Brush separation =

Note the above readings for the brush separation of +60° and -60°.

Note the readings for brush shift of a few degrees and brush separation of 0, +60, and -60°.

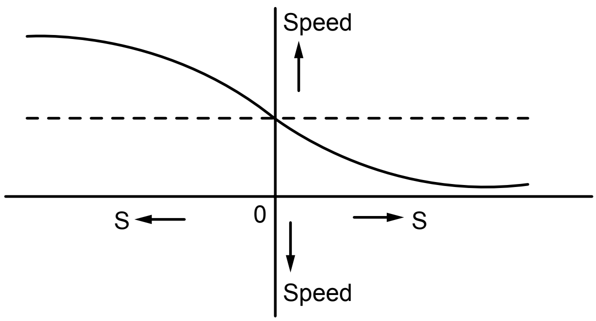

Figure 34.3

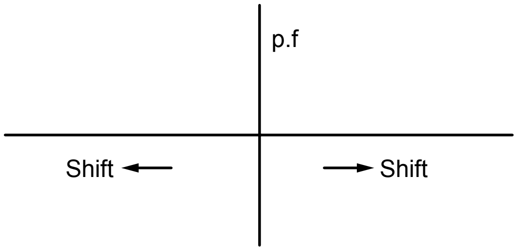

Figure 34.4

34.4 Experiment

An experiment was performed on a three-phase, 6 pole, 50 Hz, 1800 RPM, and 24 A Schrage motor with the apparatus required as follows:

Voltmeter 500 V
Ammeter 15 A
Wattmeter 500 W
Speedometer 2000 RPM

Table 1

Brush shift = 0, Supply voltage = 400 N

S.N.	Brush Separation S	Speed RPM N	S.N.	S	N
1	−140°	1480	9	+20°	840
2	−120°	1450	10	+40°	750
3	−100°	1390	11	+60°	640
4	−80°	1340	12	+80°	560
5	−60°	1240	13	+100°	465
6	−40°	1165	14	+120°	430
7	−20°	1160	15	—	—
8	0	960	16	—	—

Table 2

Brush Shift = 0, Brush Separation = 0

S.N.	I	V	W_2	W_2	N	T_2	T_2	Output $T_1 - T_2$
1	7.5	388	47.5	10	935	20	5.5	
2	9.0	392	60	6	950	48	8.5	
3	10.9	390	85	15	925	70	19	
4	13.4	392	96	36	900	105	26	
5	14.5	390	110	35	895	125	36	

Table 3

Brush shift = 0, Brush separation = +60°

S.N.	I	V	W_1	W_2	N	T_1	T_2	$T_1 - T_2$
1	12.4	385	60	–90	640	2	12	
2	13	385	70	–92	615	6	30	
3	15.5	380	95	–10	565	17	70	
4	17.75	334	15	–2	580	26	100	
5	18.75	385	122	+2	635	32	116	

Table 4

Brush Shift = 0, Brush separation = –60°

S.N.	I	V	W_1	W_2	N	T_1	T_2	$T_1 - T_2$
1	2	384	20	10	1250	2	12	
2	6	386	40	30	1235	8	30	
3	8.5	382	60	55	1210	12	34	
4	13.4	382	85	80	1190	30	112	
5								

The power factor of the motor can be calculated from the readings of the two wattmeters W_1 and W_2.

$$\phi = \tan^{-1}\sqrt{3}\,\frac{(W_1 - W_2)}{(W_1 + W_2)}$$

The shift and the power factor $\cos\phi$ are plotted in Figure 35.

34.5 Question and Answer for the Experiment

Q1. What are the industrial applications of Schrage motors?

Ans. Schrage motors are used for industrial drives which require variable speed, such as cranes, hoists, fans, pumps, papermaking machines, ring spinning frames, and so on.

EXPERIMENT 35

35.1 Object: To Plot Magnetization Characteristics and Load Characteristics of Metadyne Generators

35.2 Two Special D.C. Generators Used for Special Purposes

There are two special D.C. generators used for special purposes. These are called metadyne generators and amplidyne generators. The metadyne is a constant current generator while the amplidyne is a constant voltage generator. These are cross field machines, in which the armature reaction is compensated. A metadyne is basically a cross field machine and differs from the amplidyne, which has essential features so that output current does not have further effects on the magnetic fluxes, that is, it is 100% compensated. In the metadyne the magnetizing effect of the output current is not eliminated by compensation. There is less or more than 100% compensation or no compensation at all. The output current has some effective armature reaction which modifies the characteristics of the machine.

In addition to the exciting and compensating, other sets of windings are also used. Additional exciting windings are generally provided for the feedback system. One winding is connected in series with quadrature axis brushes, giving excitation in the quadrature axis. This winding is called ampliator winding.

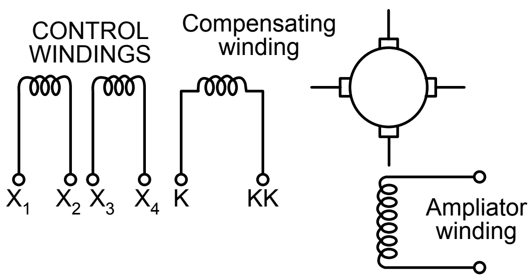

Figure 35.1 Circuit for winding representation.

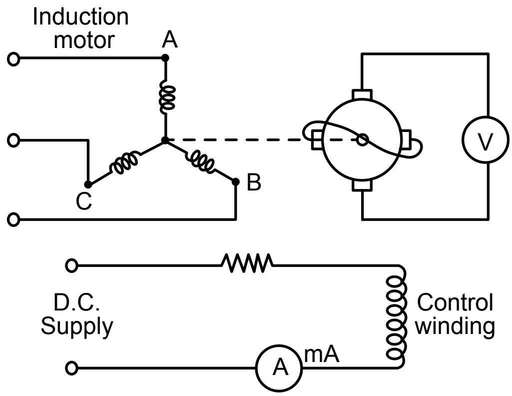

Figure 35.2 Circuit for magnetization curve.

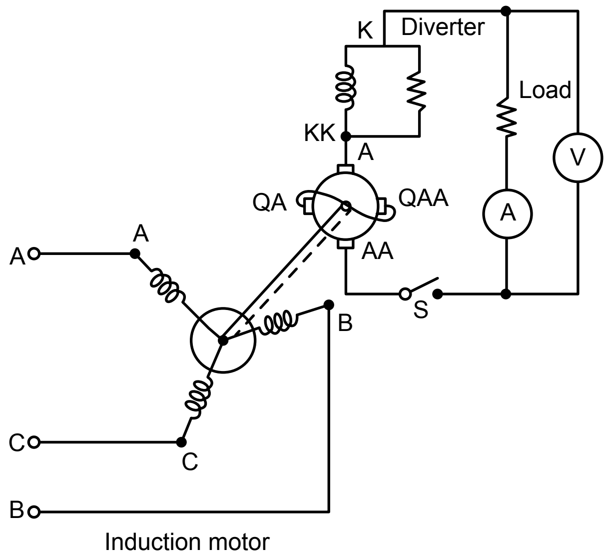

Figure 35.3 Circuit for load test.

35.3 Procedure

Use one of the control windings and use the connections shown in the circuit diagram for the magnetization curve.

Start the three-phase induction motor and run it at rated speed. Observe the voltmeter reading, if any. Switch on the supply to the control winding. Keep the excitation at a minimum. Gradually increase the control winding current and observe the corresponding EMF in the direct axis.

Increase excitation in the same direction all the time to avoid small hysteresis loops. Gradually decrease the excitation and observe the corresponding values of EMF in the voltmeter.

EXPERIMENTAL RESULTS

S.N.	*Exciting current i_f*	*Voltage V*	*Speed*	*Remark*
1				
2				
3				
4				
5				
6				
7				
8				

35.4 Load Test

For the load test make the connections shown in the circuit diagram. Adjust the desired compensation and connect the compensating winding to oppose the armature reaction along the direct axis. Note the readings with full compensation. Repeat the performance without using the compensating winding and with 80% compensation.

EXPERIMENTAL RESULTS for load curve

S.N.	*Load Current*	*Load Voltage*	*Speed*
1			
2			
3			
4			
5			
6			
7			
8			

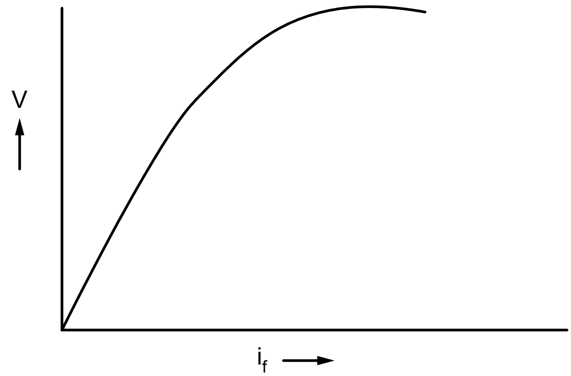

Figure 35.4

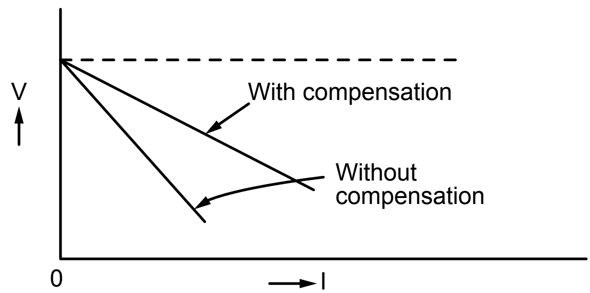

Figure 35.5

35.5 Experiment

An open-circuit test and a load test were performed on a 25 KW, 1420 RPM D.C. metadyne generator.

The following results were obtained for the O.C.C.

S.N.	i_f	V	S.N.	i_f	V	Speed
1	0.045	60	8	0.34	180	1420 RPM
2	0.08	68	9	0.38	190	
3	0.12	68	10	0.42	200	
4	0.16	108	11	0.46	208	
5	0.20	128				
6	0.26	154				
7	0.30	168				

The following results were obtained with 80% and 100% compensation.

	80%			100%	
S.N.	***Load Current***	***Voltage***	***S.N.***	***Current***	***Voltage***
1	1.47	174	1	0	220
2	3.15	130	2	1.8	200
3	3.8	114	3	3.3	185
4	4.2	100	4	4.3	172
5	4.2	88	5	5.7	160
6	4.5	80	6	7.3	142
	4.85		7	7.6	139
			8	7.8	134

The curves are represented in Figures 35.4 and 35.5 with freehand sketches. Exact graphs may be plotted if required.

35.6 Discussion

The magnetization characteristics are shown in the previous figures. The magnetization characteristics are the O.C.C. and are very similar to the O.C.C. of a D.C. generator of common purposes.

The following experimental results are obtained without compensation:

S.N.	***Load Current***	***Load Current***
1	0.29	196
2	0.30	195
3	0.35	192
4	0.40	188
5	0.45	154
6	0.50	177
7	0.55	172
8	0.60	163
9	0.70	152
10	0.80	136
11	0.90	177
12	0.100	98

35.7 Questions and Answers on the Experiment

Q1. What type of generator is a Metadyne machine?

Ans. It is a constant current generator.

Q2. Where is a metadyne generator used?

Ans. It is used in traction and in other purposes where a constant will be required.

Q3. Do you know any other generator of a special type?

Ans. Yes, the amplidyne generator, which generates a constant voltage.

EXPERIMENT 36

36.1 Object: To Plot the Magnetization Characteristic and Load Characteristic of an Amplidyne Generator

36.2 Theory of the Metadyne Generator with an Amplidyne Generator

We may link the theory of the metadyne generator with this amplidyne generator, described in Experiment 35.

36.3 Experimental Setup

The circuit diagram for the magnetization curve is shown in Figure 36.1.

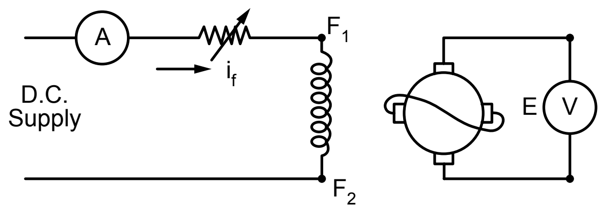

Figure 36.1

The circuit diagram for the load curve is shown in Figure 36.2.

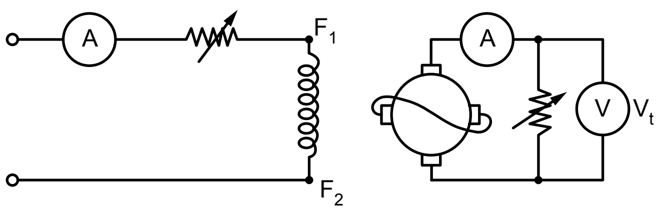

Figure 36.2

36.4 Magnetization Characteristic Test

We use one of the control windings and make the connections as shown in the circuit diagrams. Start the three-phase induction motor and run it at rated speed. Note the voltmeter reading, if any, switch on the supply to the control winding, and gradually increase the field current i_f. The corresponding readings of voltage are observed in the voltmeter. Gradually decrease the field current i_f and note the voltmeter reading.

36.5 Load Test

For the load test connect the machine circuit as shown in Figure 36.2. Vary the load and read the current and voltage in the instruments.

EXPERIMENTAL RESULTS

S.N.	i_f	V	S.N.	i_f	$V = E_o$	S.N.	i_L	$V = V_t$	S.N.	i_L	V

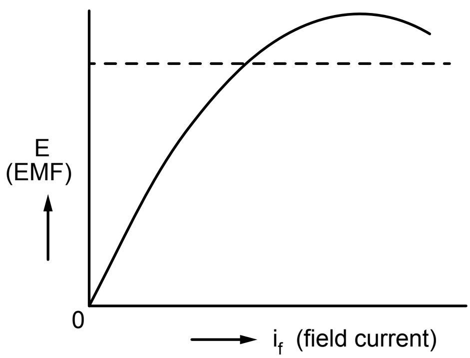

Figure 36.3

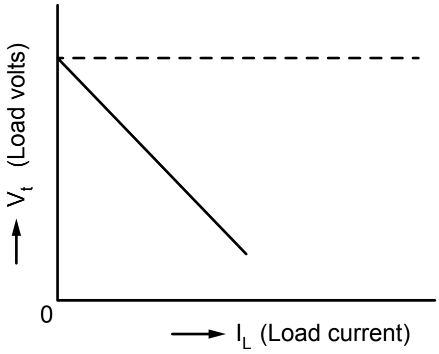

Figure 36.4

36.6 Discussion

The open-circuit characteristic and load characteristic of the amplidyne generator are shown in Figures 36.3 and 36.4, respectively.

The magnetization curve is very similar to the common D.C. machine. The load curve is a V-I curve. This machine is a special machine and uses a constant voltage generator.

36.7 Questions and Answers on the Experiment

Q1. Where will you use both the metadyne and amplidyne generators?

Ans. In the Ward Leonard system of speed control, both the generators are used to keep the voltage constant and current constant.

Q2. Why do we call these machines control components?

Ans. In a control system we apply these two generators, especially for speed control and position control.

EXPERIMENT 37

37.1 Object: To Determine Negative Sequence and Zero Sequence Reactions of a Synchronous Machine

37.2 Flow of Unit Zero Sequence Current

Zero sequence impedance is the impedance offered to the flow of the unit zero sequence current. The machine must be star connected; otherwise, no zero sequence currents will flow. The machine is run at rated speed with its field winding short-circuited. With all the phases connected in series, a current is circulated by applying a voltage to the open terminals. The zero-sequence impedance is then given by:

$$Z_o = \frac{E}{3I} \tag{37.1}$$

The power factor of the circuit will be:

$$\text{Cos } \phi = \frac{W}{EI} \tag{37.2}$$

and

$$X_o = Z_o \sin \phi \tag{37.3}$$

If three-phase motors are connected in parallel, the voltage required will be 1/3 of that required for series connections. The current will be three times as large. The circuit diagrams are shown in Figures 37.1 and 37.2.

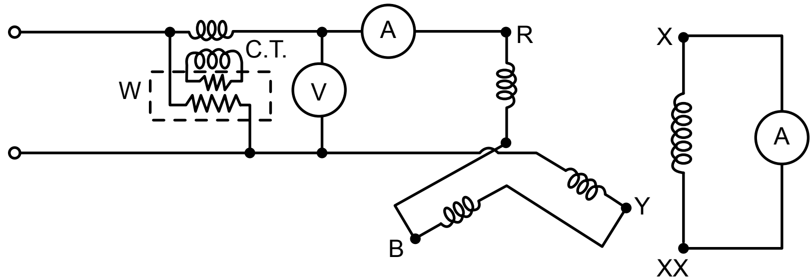

Figure 37.1 Series operation.

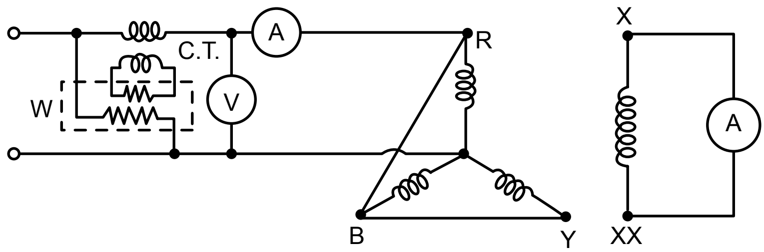

Figure 37.2 Parallel operation.

The determination of zero sequence reactance will require one ammeter, one voltmeter, and one wattmeter with a current transformer. The rotor is short-circuited by an ammeter. The circuit diagrams are shown in Figures 37.1 and 37.2.

37.3 Measurement of Negative Sequence Reactance

The negative sequence impedance is the impedance offered to the flow of negative sequence current by the machine. The machine is run at rated speed with two of its terminals *B* and *C* short-circuited, as shown in Figure 37.3. A supply of voltage is given to the terminal *A* and *BC*, short-circuited designated as *D*.

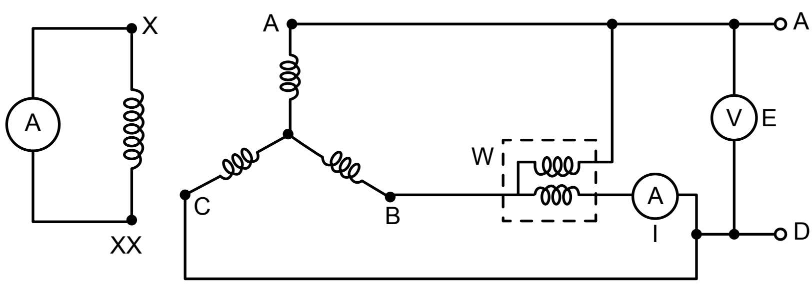

Figure 37.3

The negative sequence impedance will be:

$$Z_2 = \frac{W}{\sqrt{3}I} \text{ ohms} \tag{37.4}$$

The reactance will be:

$$X_2 = Z_2 \frac{W}{EI} = Z_2 \sin \phi \tag{37.5}$$

The negative sequence resistance will be

$$R_2 = Z_2 \cos \phi. \tag{37.6}$$

The negative sequence impedance can also be determined experimentally by applying balanced negative sequence voltage to the armature terminals while the machine is driven at the rated speed with its field winding short-circuited, as shown in Figure 37.4.

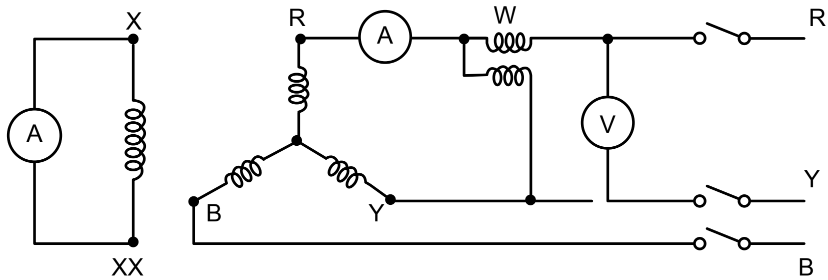

Figure 37.4

The negative sequence impedance will be

$$Z_2 = \frac{\text{Voltage per phase}}{\text{Current per phase}} \tag{37.7}$$

37.4 Experiment

The experiment was performed on a three-phase alternator 220 V, 9.2 A, 1000 RPM, run by a compound motor 220 V, 20 A, 1000 RPM, and 5 H.P. The apparatus required was one ammeter 0-30 A, one voltmeter 0-300, one wattmeter 0-600 W and one current transformer 20/5 ratio.

EXPERIMENTAL RESULTS

For zero sequence impedance (phase in parallel)

S.N.	***Current Amps***	***Voltage Volts***	***Power Watts***	***Z_o ohm***	***X_o ohm***	***Remark***
1	15.5	7.5	18 x 4	0.164	0.127	
2	12.75	6.8	12 x 4	0.177	0.144	
3	10.4	6.0	10 x 4	0.19	0.147	
4						

EXPERIMENTAL RESULTS

For negative sequence impedance

S.N.	Current Amps	Voltage Volts	Power	Z_2	X_2
1	9.2	53	455	3.32	3.07
2					
3					

37.5 Discussion

The average value of X_o is 0.138 ohms and that of X_2 is 3.07 ohms The single-phase source is of low-load capacity. Full-load current cannot be applied to the machine in case of a zero-sequence current. Experimentally, 55% of the full-load current of the alternator can be taken from a single-phase source. The autotransformer was used as a single-phase source.

37.6 Question and Answer on the Experiment

Q1. What is a negative sequence reactance?

Ans. The negative sequence reactance is the impedance to the negative sequence current when a negative sequence voltage is applied to the machine.

EXPERIMENT 38

38.1 Object: To Determine Parameters of a Single-Phase Induction Motor

38.2 Open-Circuit (No-Load) Test and Blocked Rotor Test Are Performed on a Single-Phase Induction Motor

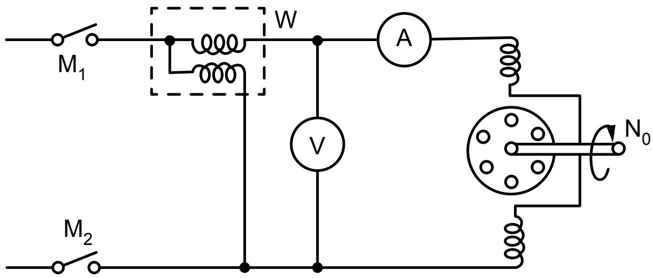

Figure 38.1

38.3 No-Load Test

For the no-load test we apply a full voltage of 220 V and observe current and power in two other instruments as follows:

S.N.	V_o	I_o	W_o	Speed RPM	Remarks
1	220	3.9	135	1440	

A no-load test was performed on a single-phase induction motor 220/230 V, 4.5 Amps, 1440 RPM, 0.75 H P., 50 c/s. The supply was given by an autotransformer. An ammeter (0.7 A), a voltmeter (0.300 V), and a wattmeter (0.200 W) were used for measurement of the results.

38.4 Block Rotor Test

For the blocked rotor test we apply reduced voltage such that rated current can be fed to the motor. The power can be observed in the wattmeter. The experimental results are tabulated as follows:

S.N.	Voltage V_s	Current I_s	Watts W_s	Cos ϕ
1	115	4.8	330	0.6

38.5 Calculations of Parameters

The short-circuit impedance will be:

$$Z_s = \frac{115}{4.8} = 2 + 2 \text{ ohm} \tag{38.1}$$

The resistance at the short-circuit will be:

$$R_s = \frac{330}{(4.8)^2} = 14.3 \text{ ohms} \tag{38.2}$$

$$X = \sqrt{Z^2 - R^2}$$

$$= \sqrt{(24.2)^2 - (14.3)^2} \tag{38.3}$$

$$X_1 = X_2' = X/2 = 9.8\ \Omega = 19.6 \text{ ohm} \tag{38.4}$$

From the no-load test the open-circuit impedance will be:

$$Z_o = \frac{V_o}{I_o} = \frac{230}{3.2} = 72 \text{ ohms} \tag{38.5}$$

$$R_o = \frac{W_o}{(I_o)^2} = \frac{135}{(3.2)^2} = 13.1\ \Omega \tag{38.6}$$

$$X_m = \sqrt{Z_o^{\,2} - R_o^{\,2}} = \sqrt{(72)^2 - (13.1)^2 = 70} \tag{38.7}$$

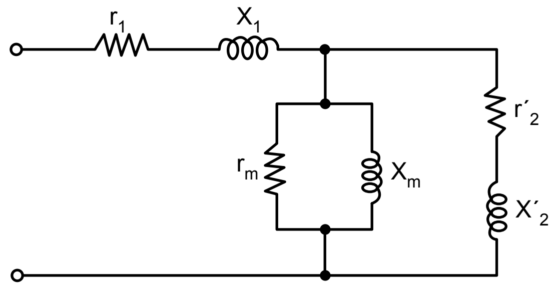

Figure 38.2

$$\frac{X_m}{2} = X_o - X_1 \frac{X_2}{2} = 55.3 \tag{38.8}$$

or
$$X_m = 110\ \Omega \tag{38.9}$$

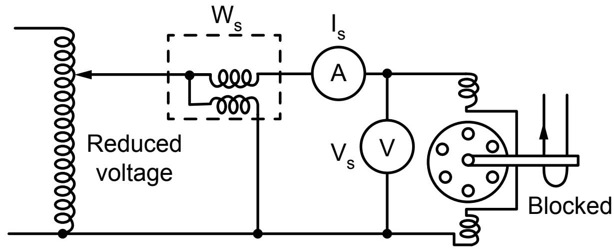

Figure 38.3

38.6 Discussion

The equivalent circuit of a single-phase induction motor can be determined by the no-load test and blocked rotor test. The impedance of the main winding and rotor winding can be found. The single-phase induction motor has low efficiency, low power factor, and low frequency. It is used mostly for fans in single-phase supply and fractional horsepower purposes.

38.7 Theory of Motor

The performance of a single-phase induction motor can be explained either by the rotating field theory or by the cross field theory. In the rotating field theory, the air gap flux is resolved into two components rotating at synchronous speed in opposite directions. The analysis is made on the basis of two components, like the three-phase induction motor. The gap flux can be represented.

$$\phi = \phi_m \sin \omega t \sin \alpha \tag{38.10}$$

The flux is sinusoidal and its space distribution will depend on angle α from the pole axis. We further express the flux as follows:

$$\phi = \frac{\phi_m}{2} [\cos (\alpha - \omega t) + \cos (\alpha + \omega t)] \tag{38.11}$$

$$\phi_1 = \frac{\phi_m}{2} \cos (\alpha - \omega t) \tag{38.12}$$

$$\phi_2 = \frac{\phi_m}{2} \cos (\alpha + \omega t) \tag{38.13}$$

The flux which will move in the direction of the motor is called the forward field and in the opposite direction is called the backward field.

We may designate the forward fluxes by

$$\phi_b \text{ and } \phi_f$$

$$\phi_f = \frac{\phi_m}{2} \cos (\alpha + \omega t) \tag{38.14}$$

$$\phi_b = \frac{\phi_m}{2} \cos (\alpha - \omega t)$$

38.8 Equivalent Circuit

With the motor stationary, the equivalent circuit will be exactly similar to that of the transformer. If the pulsating field is resolved into two equal rotating fluxes moving in the opposite direction, the effect of each will be represented by a separate impedance group. The E_f and E_b will be equal at a standstill. The two circuits are shown in Figures 38.4 and 38.5.

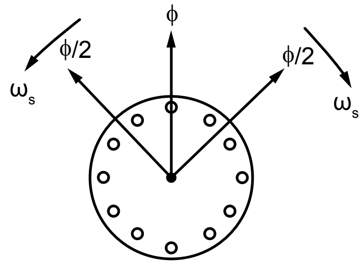

Figure 38.4

When the machine is running at slip s, the forward field group considers s, and the resistive term becomes $r_2'/2s$ like the three-phase induction motor.

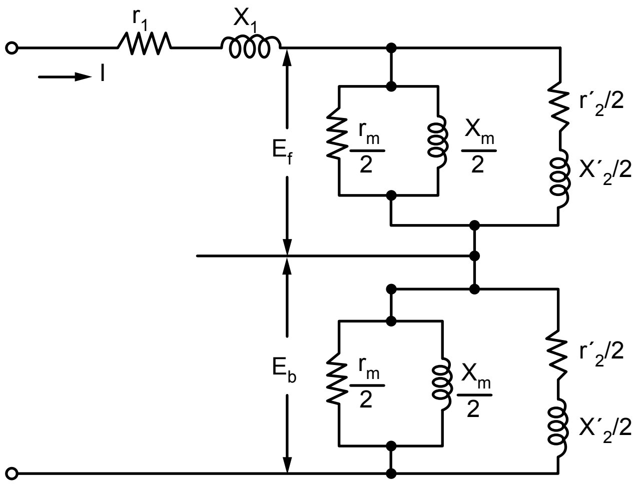

Figure 38.5

The backward slip will be (2–s), so that the resistive terms become $r_2'/2s$ (2–s). The complete equivalent circuit will be in Figure 38.6. The iron loss is represented by the resistor $r_m/2$.

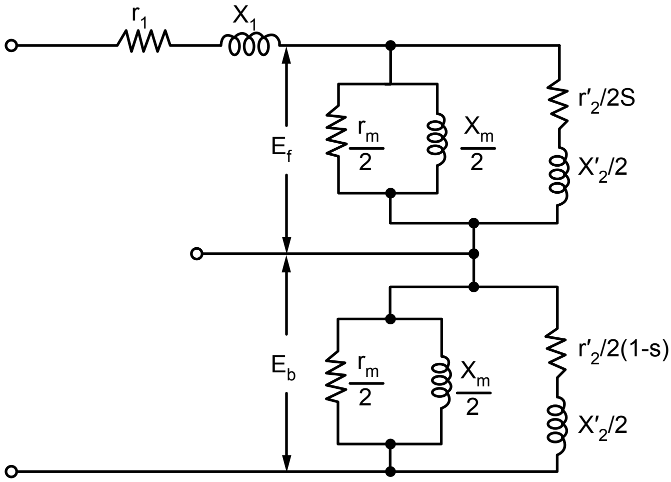

Figure 38.6

38.9 Discussion

Open circuit and blocked rotor tests are performed to determine the equivalent circuit of the motor. The procedure is very similar to the calculation of parameters of a single-phase transformer.

38.10 Question and Answer on the Experiment

Q1. Why aren't series motors self-starting? What arrangement is used for starting?

Ans. Single-phase induction motors are not self-starting due to rotating fields in opposite directions. The net torque will be zero.

A capacitor is used to start the motor and to bring the motor to 75% of speed. This is to split the single phase into two phases, and a net torque will be produced to start the motor.

EXPERIMENT 39

39.1 Object: Measurement of a Small Resistance by Kelvin's Double Bridge

Resistance below 1 ohm value is called low resistance. The Kelvin's double bridge method is the best for a correct measurement of low resistance. The bridge is shown in Figure 39.1.

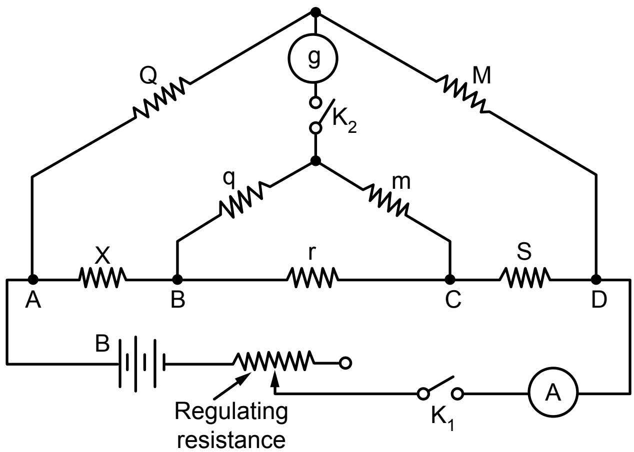

Figure 39.1

The resistance to be measured is connected between terminals *A, B* and designated as *X*.

S is standard resistance of the same order of magnitude as the *X*.

A small resistance link, r, is used between terminal B and C. Q, M, q, and m are known resistance in which one pair, Q-q or M-n, is variable.

39.2 Experimental Setup

When we obtain a balance in a galvanometer by adjusting the variable resistances, the *X* unknown resistance will be given by

$$X = \frac{QS}{M} + \frac{mr}{r + q + m}\left[\frac{Q}{M} - \frac{q}{m}\right] \tag{39.1}$$

Q/M is kept equal to q/M. The link resistance, r is nearly zero as it is made of thick copper strip. The X will be given by

$$X = \frac{Q}{M} \cdot S \tag{39.2}$$

To take into account the thermoelectric EMF, the measurement should be made with the current direction reversed. The mean of the two measurements should be taken.

We use a battery, two keys, 5 ohm resistance, S variable resistance, a galvanometer, a post office box, and high resistance. After finding out the balance measure, the Q and M (or q and m), whichever were variables on a post office box.

Connect the circuit as shown in Figure 39.1. The bridge circuit can also be drawn as shown in Figure 39.2.

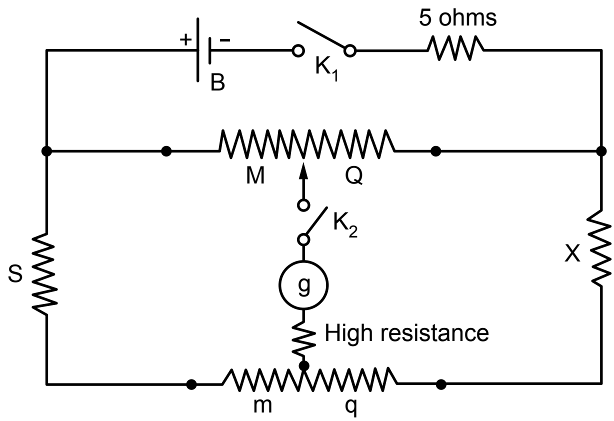

Figure 39.2

39.3 Procedure

Select a battery and connect the positive point to one of the post office boxes, S, which is working as the standard resistance. This point is connected to fixed terminal M of resistor MQ. The second point of the post office box is connected to the fixed terminal m of the other resistor mq.

Negative terminal of the battery is connected to a key, and the second point of the key is connected to 5 Ω resistance. The 5 Ω resistance is used to limit current in the low resistance. The resistance to be measured is of the order of 0.001, or even smaller. The high current may destroy the low resistance. A voltage drop takes place in a 5 ohm resistor and the current can be controlled.

The second point of this resistance is connected to one end of unknown resistance X. The same point is connected to the fixed point Q of resistor QM. The second point of X is connected to the fixed point q of resistor qm. The variable point MQ is connected to key K_2. The other point of the key is connected to one terminal of the galvanometer. The high resistance is used with the galvanometer to protect it from high current flow. The other point is connected to a resistor mq as shown.

Some resistance of 0.2 ohm is taken out from the post office box by adjusting the variable points of resistors, and the null position is obtained. Now one point of the MQ resistor (say M) is disconnected from the post office box to determine the value of the M resistance. The variable point of MQ is connected to one point of the post office box, and the value of M is found. The value of Q is also determined. The connections are reversed and M and Q are again determined.

EXPERIMENTAL RESULTS

	Current Direct			***Current Reversed***				
S.N.	***S ohm***	***Q ohm***	***M ohm***	***Q ohm***	***M ohm***	***Q ohm***	***M ohm***	***X***
1	0.2	689	345	691	347	693	348	0.399
2	0.5	441	609	443	611	442	610	0.398
								0.362
								0.363

The mean X = 0.38.

39.4 Experiment

An experiment was performed to measure a resistance of 0.38 by Kelvin's double bridge. Experimental results are presented in tabular form.

39.5 Discussion

A Kelvin's double bridge is used to measure a low resistance of the order of 1 ohm. This is the most accurate method of low resistance measurement.

EXPERIMENT 40

40.1 Object: Calibration of a Watt-Hour Meter by a Standard Wattmeter

40.2 Verification of Marks Graduated on an Instrument by a Standard Instrument

Calibration means verification of marks graduated on an instrument by a standard instrument. In this experiment calibration is made by a standard wattmeter and not by a standard watt hour meter. For a number of revolutions the time is taken and the wattmeter reading is also observed. The calculated reading will be:

$$E_1 = \text{Wattmeter reading} \times \text{Time}$$

The observed reading will be:

$$E_2 = \text{Reading of watthour meter.}$$

The percentage error will be:

$$\text{Error percentage} = \frac{E_2 - E_1}{E_1} \tag{40.1}$$

40.3 Experimental Setup

The experiment will require a constant voltage transformer output voltage 230 V, one ammeter 0.5 A, one watthour meter 230 V, 2.5 A, one wattmeter 0.500 W and a lamp load. The load will be a set of parallel lamps of 230 V. A stopwatch will be required for time.

We make connections according to the circuit diagram. We use a voltage stabilizer for keeping the voltage constant. The current coils and pressure coils are connected to the load in series and parallel, respectively.

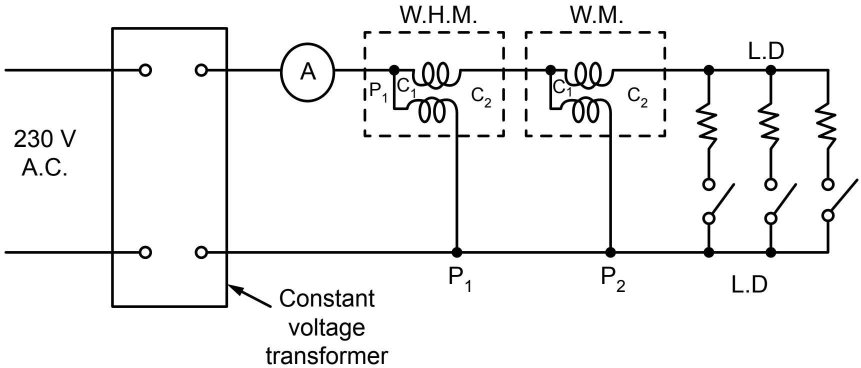

Figure 40.1

A load is switched and the reading in the wattmeter is observed. The time required for five revolutions is taken by a stopwatch. Again, the load is switched and the experimental results are tabulated.

EXPERIMENTAL RESULTS

S.N.	*Ammeter Reading (A)*	*Wattmeter Reading (watts)*	*Number of Revolutions*	*Time in seconds*	*Remark*
1	1.0	240	5	30	
2	1.4	320	5	21	
3	1.6	300	5	19	
4	1.75	400	5	16.5	
5	2.2	490	5	13.5	

S.N.	*Observed Reading watt sec*	*Calculated Reading watt sec*	*Percentage Error*	*Current Percentage*
1	7500	7200	4.16	40
2	7500	6720	11.6	56
3	7500	5700	31.5	64
4	7500	6600	13.6	70
5	7500	6615	13.3	88

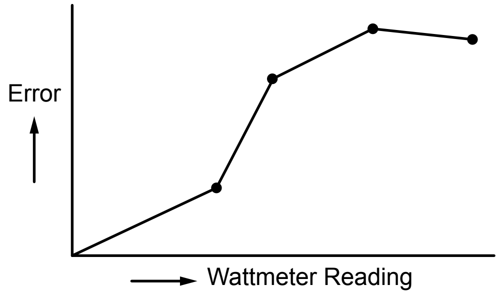

Figure 40.2

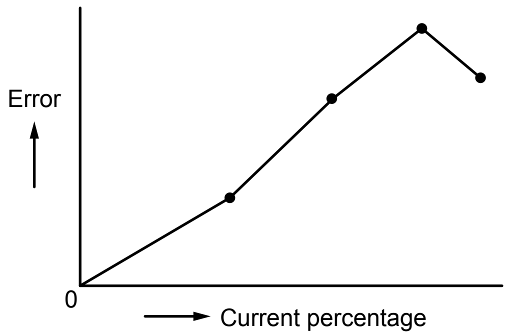

Figure 40.3

40.4 Discussion

The graphs and results show that a correction should be made to the energy meter reading. For a current of 40% of rated value, through the watt-hour meter a correction of 4.2% should be made in the reading of the energy meter. Similarly, we may make corrections for other results.

EXPERIMENT 41

41.1 Object: Calibration of A.C. Wattmeter by a Standard Voltmeter and Ammeter

41.2 Verification of Marks Graduated on Instruments

Calibration means a verification of marks graduated on instruments. In the experiment a wattmeter is calibrated by a standard voltmeter and standard ammeter. The calculated reading will be $V \times I$ watts and the observed reading will be W given by the wattmeter.

$$\text{Percentage error} = \frac{E_1 - E_2}{V_2} = \frac{W - VI}{VI} \tag{41.1}$$

where E_1 : observed value in Wattmeter = W
E_2 : calculated value = $V \times I$
W : wattmeter reading
V : voltmeter reading
I : ammeter reading.

41.3 Experimental Setup

This experiment will require a constant voltage transformer or a voltage stabilizer. One voltmeter, one ammeter, and one wattmeter will be required. A load will be parallel lamps working at 230 V.

Figure 41.1 represents a circuit diagram for the experiment. The connections are simple and can be made by seeing the circuit.

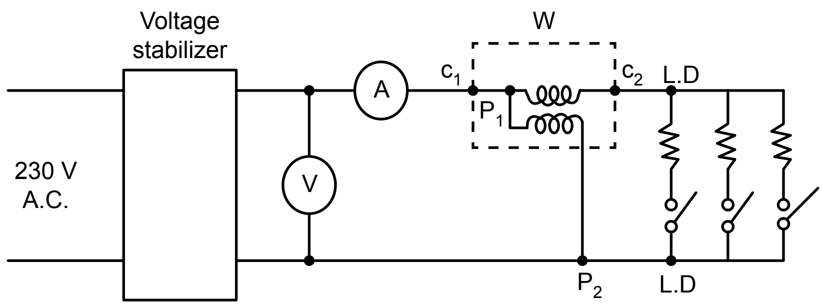

Figure 41.1

EXPERIMENTAL RESULTS

S.N.	*Ammeter reading (I)*	*Voltmeter reading (V)*	*Wattmeter reading (W)*	*VI*	*% Error x*
1	0.7	230	160	163.8	–2.3
2	1.1	230	260	257.4	1.01
3	1.5	230	350	351.0	–28
4	2.0	230	460	468.0	–1.7
5	2.3	230	540	538.2	0.33
6	2.7	230	620	631.8	–1.8
7	3.2	230	710	725.4	–2.1

41.4 Calibration Graph

A graph is plotted between the wattmeter reading and the percentage error. An approximate graph is shown in Figure 41.2. With relative positions of the readings, error is calculated for each set of the readings.

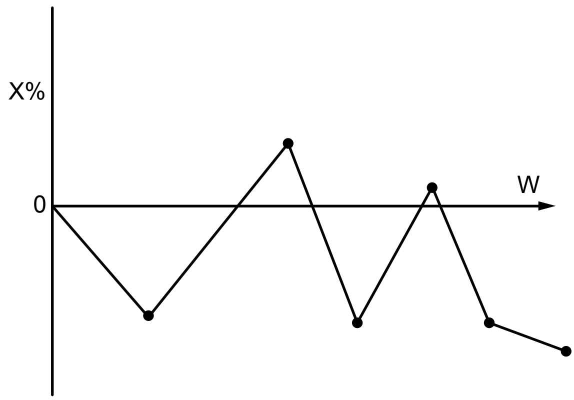

Figure 41.2

41.5 Discussion

The approximate results are given in tabular form to have an idea of experimental results for a wattmeter.

EXPERIMENT 42

42.1 Object: Calibration of an Ampere-Hour Meter by a Standard Ammeter

42.2 Verification of Marks Graduated on an Instrument

We have already explained the meaning of the calibration of an instrument. Calibration is the verification of marks graduated on an instrument. In this experiment an ampere-hour meter is calibrated by a standard ammeter. N is the designated number of revolutions of the disc of an ampere-hour meter for a given time, t. I current is read in the ammeter. If the constant of the ampere-hour meter is K, the observed ampere second will be

$$E_1 = N \times K = NK \tag{42.1}$$

For the same time, t the calculated ampere hour will be

$$E_2 = I \times t = It \tag{42.2}$$

Percentage error will be

$$X = \frac{E_1 - E_2}{E_2} \times 100 \tag{42.3}$$

A graph between NK or N and X will be a calibration graph.

42.3 Experimental Setup

The experiment will require one ampere-hour meter, one ammeter, a D.C. supply, and a load. A Mercury ampere-hour meter will be calibrated. Figure 42.1 represents a circuit diagram for the experiment. Connect the circuit as shown.

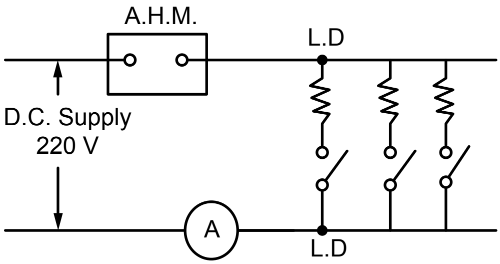

Figure 42.1

EXPERIMENTAL RESULTS

S.N.	*I*	*N*	*t sec*	*K*	*NK*	*It*	*%X*
1	0.8	7	60	6.46	48.22	48	–5.7
2	1.5	15	60	”	96.9	90	7.6
3	2.25	23	60	”	143.58	135	10.05
4	3	30	60	”	193.8	189	7.6

42.4 Calibration Graph

A calibration graph can be plotted between *NK* and *X*. An approximate graph is shown in Figure 42.2 with relative points. An exact graph can be made by results given in the table of experimental results.

42.5 Discussion

The calibration of the Mercury ampere-hour meter by an ammeter is represented by a graph as shown in Figure 42.2. The Mercury ampere-hour meter is the most common D.C. energy meter. The error may be positive or negative.

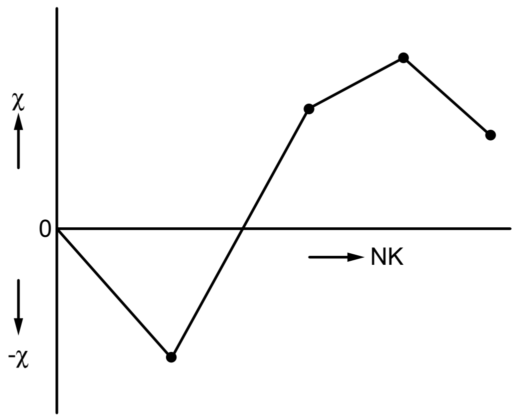

Figure 42.2

EXPERIMENT 43

43.1 Object: To Find an Unknown Inductance with Hay's Bridge

43.2 Experiment on Hay's Bridge Inductance

Hay's bridge is used to measure inductance on the basic principle of the Wheat stone bridge. Hay's bridge is shown in Figure 43.1.

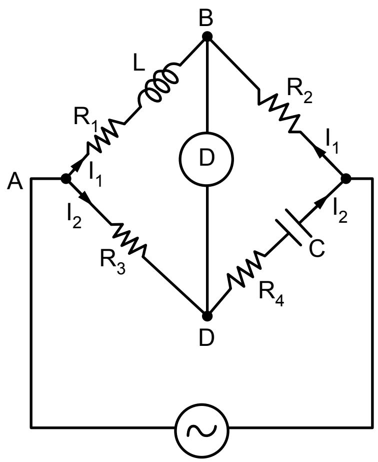

Figure 43.1

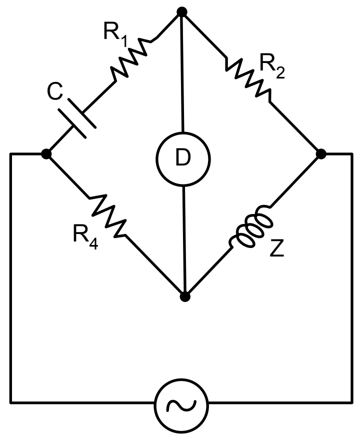

Figure 43.2

In the circuit diagram of Figure 43.1 under balanced conditions with *B* and *D* on the same potential, we have:

$$I_1(R_1 + jwL) = I_2R_3$$

$$I_1R_2 = I_2\left(R_4 - \frac{j}{\omega C}\right) \tag{43.1}$$

or
$$\frac{R_1 + j\omega L}{R_2} = \frac{R_3}{R_4 - \dfrac{j}{\omega C}} \tag{43.2}$$

or
$$\frac{R_1 + j\omega L}{R_2} = \frac{R_3}{R_4 + \dfrac{1}{j\omega C}}$$

$$\frac{R_1 + j\omega L}{R_2} = \frac{j\omega c R_3}{1 + j\omega C R_4} \times \frac{1 - j\omega C R_4}{1 - j\omega C R_4}$$

$$\frac{R_1}{R_2} + \frac{j\omega L}{R_2} = \frac{j\omega C R_3 + \omega^2 C^2 R_3 R_4}{1 + \omega^2 C^2 R_4^2} \tag{43.3}$$

Equating real and imaginary parts

$$\frac{R_1}{R_2} = \frac{\omega^2 C^2 R_3 R_4}{1 + \omega^2 C^2 R_4^2} \tag{43.4}$$

or
$$R_1 = \frac{\omega^2 C^2 R_2 R_3 R_4}{1 + \omega^2 C^2 R_4^2}$$

and
$$\frac{\omega L}{R_2} = \frac{\omega C R_3}{1 + \omega^2 C^2 R_4^2} \tag{43.5}$$

or
$$L = \frac{C R_2 R_3}{1 + \omega^2 C^2 R_4^2} \tag{43.6}$$

$\omega^2 C^3 R_4^2$ is very, very small because C will be of the order of 10^{-6} and the square 10^{-12}. In comparison to 1 it may be neglected, and we have

$$L = C R_2 R_3 \tag{43.7}$$

Procedure. Make connections as shown in Figure 43.1. Figure 43.2 is the circuit found on the Hay's bridge in the laboratory. We may have by comparing two bridges

$$R_4 = R_3;\ R_2 = R_2 \tag{43.8}$$

The other two branches are similar. The Z is to be known and C, R, R_2, and R_4 are variable and are used to bring the null point in the detector. The telephone is used as a detector. When the noise in the detector is zero, assume the null point or that the circuit is balanced.

43.3 Discussion

A high inductance is measured by the Hay's bridge. A high frequency voltage is used so that reactance may be high.

EXPERIMENTAL RESULTS

S.N.	*$R_4\Omega$*	*C μF*	*$R_2\Omega$*	*$L=CR_2R_4$*	*Remark*
1	20000	0.05	1000	1.00H	
2	40000	0.026	,,	1.04	
3	60000	0.0175	,,	1.05	
4	80000	0.012	,,	0.96	
5	20000	0.026	2000	1.04	
6	40000	0.012	,,	0.96	
7	60000	0.01	,,	1.2	
8	80000	0.007	,,	1.12	
9	20000	0.017	3000	1.02	
10	40000	0.01	,,	1.2	
11	60000	0.007	,,	1.26	
12	80000	0.005	,,	1.2	
13	20000	0.012	4000	0.96	
14	40000	0.007	,,	1.12	
15	60000	0.005	,,	1.2	
16	80000	0.003	,,	0.92	

The average value of inductance will be 1.08 H according to the given experimental results.

EXPERIMENT 44

44.1 Object: To Determine a Value of High Resistance by the Loss of Charge Method

44.2 Experiment

A capacitor is charged to a voltage V and discharged through a resistor across it with a ballistic galvanometer. The deflection in the galvanometer will be proportional to the charge or voltage V.

$$\theta_1 \alpha V_1;\ \theta_2 \alpha V_2 \tag{44.1}$$

or
$$\frac{\theta_1}{\theta_2} = \frac{V_1}{V_2} \tag{44.2}$$

The rate of loss of voltage $\frac{dv}{dt}$ will be the same as the loss of charge of the capacitor.

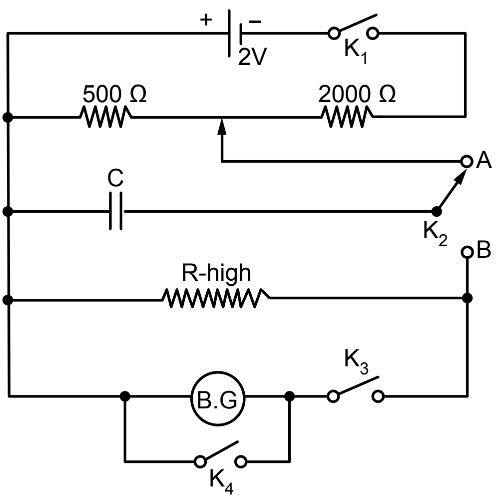

Figure 44.1

The high resistance will be given by

$$R = \frac{0.4343\,t}{C\,\log_{10}\theta_1/\theta_2} \tag{44.3}$$

where t is the time in which the loss of charge takes place, C is the capacitance of the capacitor, and θ_1 and θ_2 are the deflection produced in the galvanometer.

44.3 Experimental Setup

The experiment will require the circuit shown in Figure 44.1. We require a battery of 2 V, two resistance boxes of 2000 ohms and one ballistic galvanometer.

Make the connections as shown in the circuit diagram of Figure 44.1. The light is focused on the small mirror in the galvanometer, which moves with the variation of voltage with the markings on the scale. It is adjusted so that the reflected light comes to zero of the marking of the graduated frame. This operation is done before starting the experiment. The two resistances 500 and 2000 are taken out from the boxes. The voltage of the battery will be divided in the two resistances as V_1 and V_2 shown in Figure 44.2.

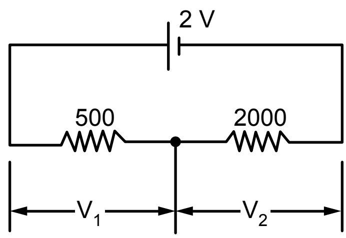

Figure 44.2

The V_1 and V_2 will be

$$V_1 = \frac{2}{500 + 2000} \times 500$$

$$= \frac{1000}{200} = 0.4\ V$$

$$V_2 = 2 - 0.4 = 1.6 \text{ volt} \tag{44.4}$$

The condenser is charged to only 0.4 V. We charge the condenser and then press the key K_4, and then it will discharge. We wish the deflection produced when it is just on the point of charging to be completed. Such deflection will be θ_1.

The key K_4 is used to discharge the condenser immediately to get no deflection. First charge the condenser and then simultaneously press the two keys K_2 to B and K_3. The deflection thus produced is read immediately, which will give θ_1. As we press K_2 to B the capacitor will discharge and at the same time we press K_3 which will make deflection θ_1.

Now the capacitor is charged and after some time, it is discharged for a known time, and then K_3 is pressed, which will produce a deflection θ_2. Time t is specified by 15, 20, 30, and 40 sec., and the corresponding deflections are noted. The value of C will be constant. Change some value of the capacitor and repeat the experiment. Plot the graph between t and θ_2. Find a value of θ_1 for a value of θ_2 = 36.8%. We will obtain $R = t/C$.

44.4 Calculations

Experimental results are given in tabular form.

$R = t/c = 30/2 \times 10^{-6} = 15 \times 10^6$ ohms. The average resistance will be $15.565 \times 10^6\ \Omega$.

44.5 Discussion

The loss of charge method is used for the measurement of high resistance of the order of $10^6\Omega$.

Insulation resistances are of this order.

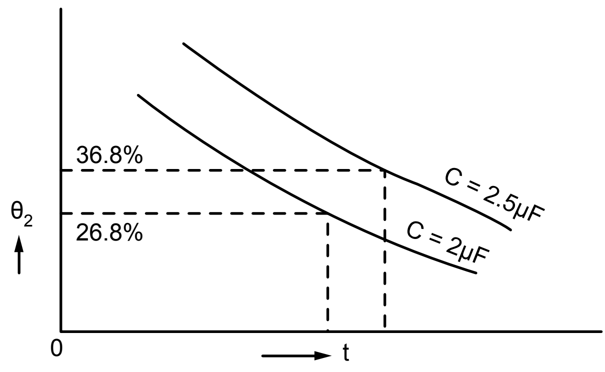

Figure 44.3

EXPERIMENTAL RESULTS

S.N.	*time*	*θ_2 cm*	*C μF*	*θ_1 cm*	*Remarks*
1	0	–	2μF	12	
2	10	8.5	2μF	12	
3	15	7.5	,,	,,	
4	20	6.5	,,	,,	
5	25	5.5	,,	,,	
6	30	4.5	,,	,,	
7	35	3.5	,,	,,	
8	0	–	25μF	15.5	
9	10	11.5	,,	,,	
10	15	10.5	,,	,,	
11	20	9.5	,,	,,	
12	25	8.5	,,	,,	
13	30	7.5	,,	,,	
14	35	6.5	,,	,,	

EXPERIMENT 45

45.1 Object: Calibration of a Wattmeter and Ammeter by Crompton's Potentiometer

45.2 Experiment

Calibration means a verification of the marks graduated on an instrument by a standard instrument. In this experiment Crompton's potentiometer is standardized by a standard cell. After standardization the potentiometer gives direct reading of voltage.

The potentiometer reading multiplied by the volt ratio box will give the value of the supply voltage. This is used for a measurement of voltage. A voltage drop across the standard resistance will give a value of current when divided by the known value of resistance. A multiplication of current and voltage will give power.

The percentage error will be obtained as follows:

$$\text{Percentage } X = \frac{\text{Observed value} \cdot \text{calculated value}}{\text{Calculated value}} \tag{45.1}$$

45.3 Experimental Setup

Connections are made as shown in the circuit diagram of Figure 45.1. The multiple switch is turned to standard cell (S.C.) position. P_1 is adjusted 1 V and P_2 to 1.83 V. R_1 and R_2 are varied till there is no deflection in the galvanometer when the key is pressed. Standardize the potentiometer. Throw the multiple switch to the X-position and apply a load. The switch is pressed to V_1 and P_1 and P_2 are adjusted in such a manner that on pressing the key, the galvanometer gives no deflection. The sum of voltages at P_1, P_2 will be equal to V_1.

For taking readings in the ammeter and wattmeter throw the switch to V_2 and adjust P_1 and P_2 to obtain no deflection in the galvanometer. At this time note the readings in the wattmeter and ammeter; the V_2 will be equal to the sum of P_1 and P_2 voltages. Thus, by switching the load switch, the same procedure is used for each step. The readings are taken on the same load.

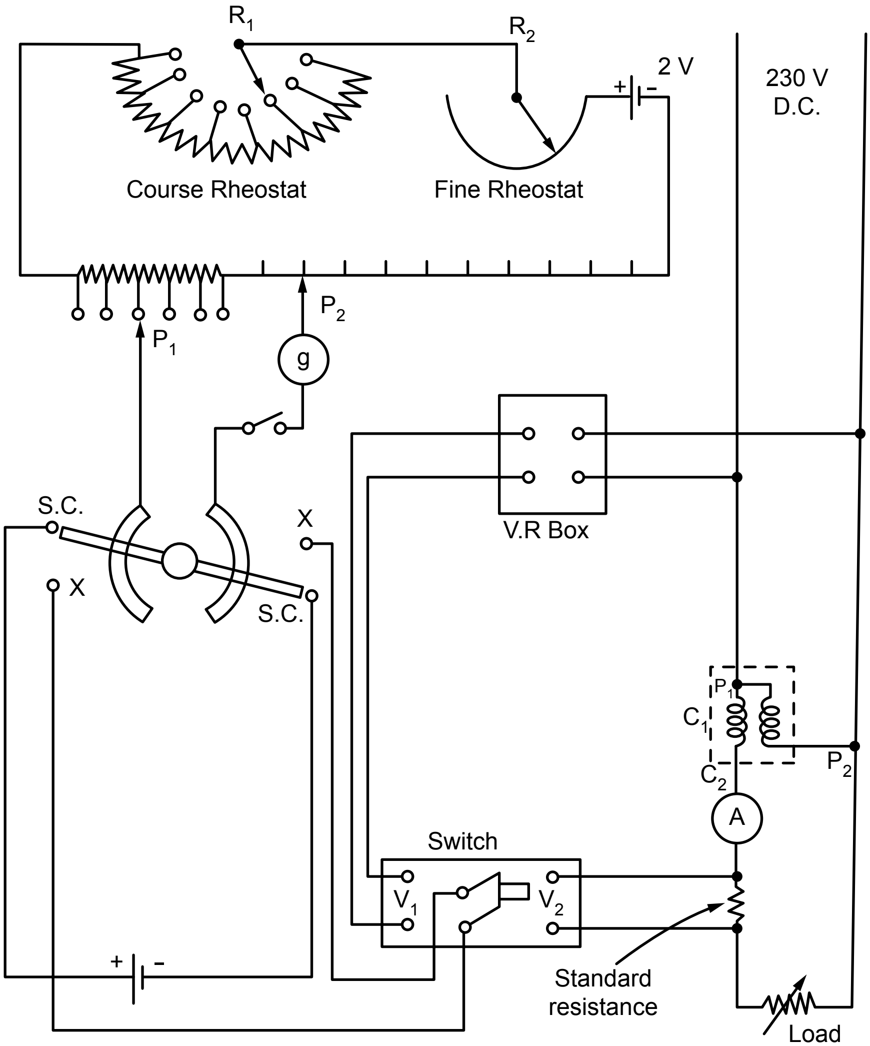

Figure 45.1

45.4 Experimental Results

Experimental results are given in tables. Results will depend on the type of instrument. We present the results to give an idea of the experiment.

EXPERIMENTAL RESULTS

S.N.	*Ammeter Reading*	*Wattmeter Reading*	*V_1 Volt*	*V_2 Volt*	*Remarks*
1	0.4	80	1.19	0.202	
2	1.15	240	1.83	0.575	
3	1.55	330	1.175	0.775	
4	2.0	410	1.172	0.927	
5	3.5	800	1.167	1.78	

S.N.	*Observed value of current*	*Calculated current*	*Error X%*	*Remarks*
1	0.4	0.404	–0.99	
2	1.15	1.15	0	
3	1.55	1.55	0	
4	2.0	1.964	+2.65	
5	3.5	3.56	–2.68	

How do we calculate the error? How do we plot the results to be clear to the readers?

We plot the approximate graph between the ammeter reading and the error in Figure 45.2. We also plot the error and observe the wattmeter reading in Figure 45.3. All errors are negative. The points are taken on the negative error axis.

S.N.	*Observed Watts*	*Calculated Watts*	*Error X%*	*Remarks*
1	80	96.152	–16.8	
2	240	271.09	–11.46	
3	330	364.2	–9.410	
4	410	458.0	–12.65	
5	800	827.1	–3.276	

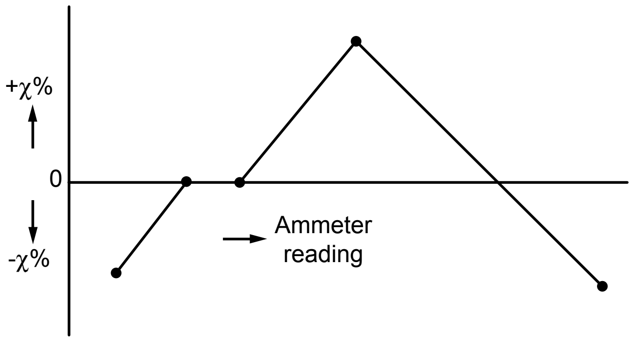

Figure 45.2

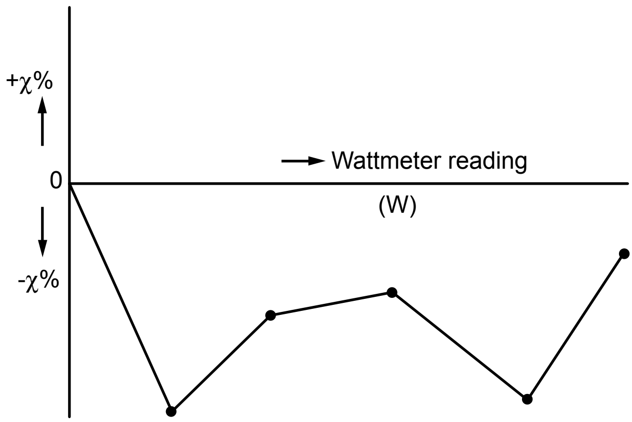

Figure 45.3

45.5 Discussion

The calibration of the ammeter and a wattmeter is made using Crompton's potentiometer. A standard resistance is used for the measurement of current.

EXPERIMENT 46

46.1 Object: Study of an Impulse Generator (1.6 Million Volts)

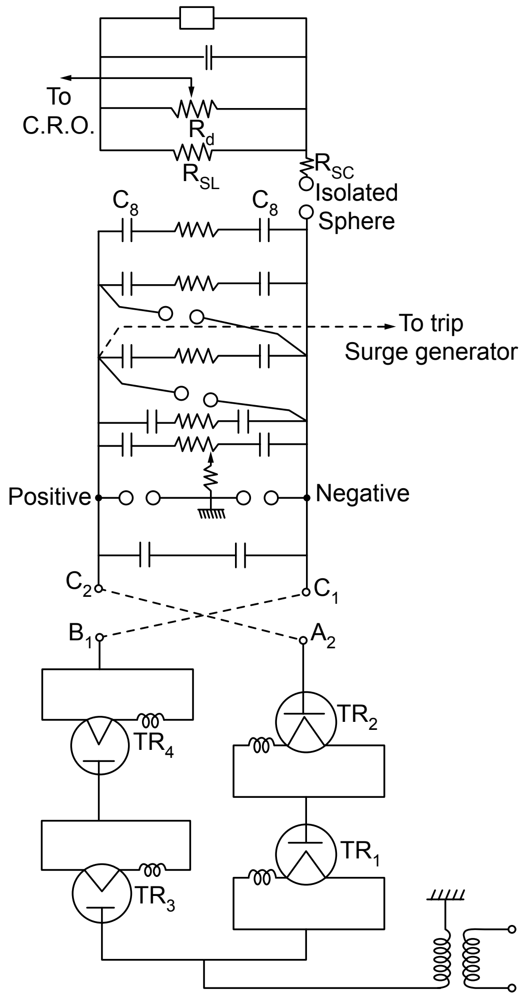

Figure 46.1

46.2 Introduction

The impulse voltage testing of an electrical apparatus is coming into great importance. The reason is that with growing extension and interconnections of electric power systems, expensive equipment is becoming more exposed to transient overvoltage of atmospheric origin.

46.3 Purpose of Impulse Voltage Testing

Impulse voltage tests are reconnected, with the object of determining the effect of voltage surfaces of a short duration of electric installation and on their individual posts. The surfaces are caused especially by lightning discharge.

The surface and lightning discharge are two slightly different terms.

46.4 Surge

A surge is a transient electrical discharge or disturbance such as caused by lightning, switching operations, faults, and so on.

Lightning is the most dangerous of these transient disturbances, which are brought about in the main by lightning strikes to or in the vicinity of the transmission lines.

A surge when applied by nature to an overhead line is a form of overhead voltage which may be defined as exceptional. Voltage is in excess of the peak voltage to the earth of the line or electrical system of which the line forms a part.

A lightning strike is a component discharge of a complete lightning flash, representing the discharge of one of the charged centers of a thundercloud.

An impulse voltage may be defined as a unidirectional voltage which, without appreciate oscillation, rises rapidly to a maximum value and falls less rapidly to zero.

In an electrical system there are two kinds of overvoltage:

(*i*) Internal voltage.

(*ii*) External voltage.

(*i*) **Internal Overvoltage.** This overvoltage is produced within the system itself and is generally caused by variation in the system parameters.

(*ii*) **External Overvoltage.** External overvoltage is caused by static charges and lightning strikes.

The impulse generator can be single stage or multistage. Wherever a single-stage or multistage impulse generator is contemplated depends partly on the output voltage required and partly on the charging equipment which provides the D.C. for changing the general capacity. Where expense is not the main consideration, a single-stage impulse generator can be made up to a voltage output of 200 KV. A great advantage of this low voltage is that recording on the GRO can be done without the intervention of potential, dividers when they contribute a small error. Another advantage lies in the large value of capacitances that can be incorporated in the generator.

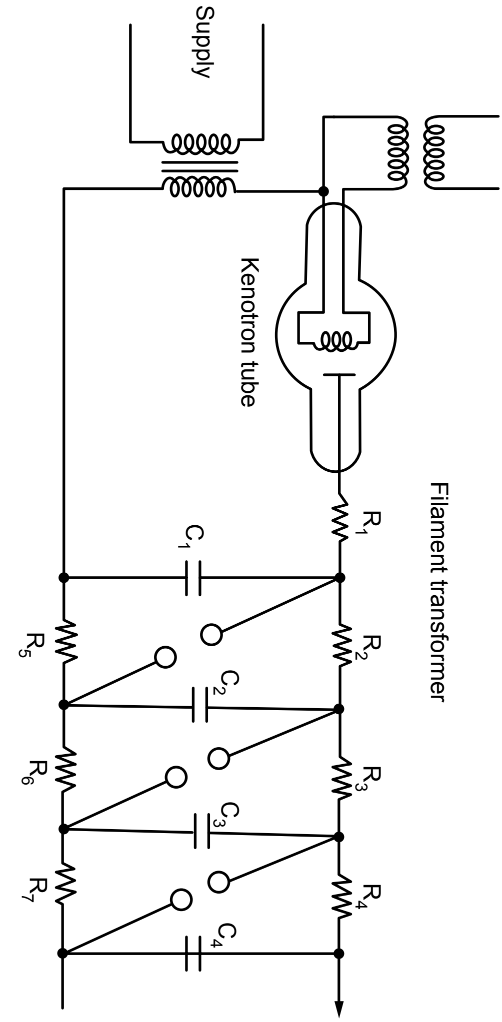

Figure 46.2

This enabling of high capacitances loads to the impulse listed, and ensuring in the case of low capacitance loads, that the load does not attract the generator wave shape.

A single-stage impulse generator for an output of 100 KV would require a large and expensive charging unit. To overcome this disadvantage multistage generators are used.

This origin of a multistage generator circuit in a vehicle capacitor (of several stages) with charges in parallel that are then discharged automatically in series is generally described as a Marx circuit.

46.5 Marx Circuit

The circuit is shown in its simplest form in Figure 46.2. Suppose that the gaps I_0, I_1, I_2, ...I_n, and so forth are set to operate one after the other gap, I_0 leading when the charging voltage has attained a value $+E$. The capacitors will, therefore, charge in parallel through the resistors shown until they reach the value E, their lower plates being the earth potential because of their connection to the ground through the bottom (known as tail) resistances.

At this instance the gap will break down, and there will be a momentary redistribution of charge potential on capacitor C_1, its top plate falling to zero potential, its lower plate, however, suddenly rising to $-E$. Across gap g_1, therefore, there suddenly appears a potential $2E(-E$ to $+E)$, and this gap then instantaneously breaks down. This process is repeated, the lower plates of the stage capacitor successively rising to $-2E$, $-3E$ . . .$-nE$, if there are n plates.

Observe that with this particular connection of n stages, if the charging potential is $+E$, the output impulse is $-nE$. The top resistance in circuit 2 is generally called the front resistance.

The impulse generator kept in our laboratory consists of a capacitor bank connected with the sphere gaps and wave front and wave tail resistance. The Marx circuit has been used.

There are sixteen cylindrical capacitors together with insulating space cylinders assembled in four cylindrical vertical columns arranged at the corners of a square. The sphere gaps are mounted on two vertical insulating columns. One of those columns is fixed, and the other is movable and driven by a motor kept underneath it. The motor is controlled from the control panel. By increasing the distance between the spheres the output voltage can be increased, but the insulation problems appear for voltage above the rated value.

After operations on the impulse generators have been done, all the capacitors have to be grounded. A steel tape is provided for this purpose, which moves over the terminals of the capacitors and short-circuits them.

Before starting the experiment the steel tape is replaced by leather tape.

46.6 Capacitors

All are rated to 100 KV (D.C.) and 33 U.F. These capacitors are mounted over four vertical columns. The cylinders are filled with pyranol. The pyranol is a non-flammable insulating liquid.

46.7 H.V. Discharge Switch

It produces a means of automatically discharging and grounding the impulse generator. Each switch consists of a fixed contact, a swing arm conductor, and a solenoid which operates the swinging conductor. The arms come in contact with the fixed contact when the solenoid is de-energized.

Sphere gaps are connected across the fixed and swing arm contacts. The gap prevents the overvoltage that may appear across the Kenotorn tube, thus preventing damage. The sphere gaps are adjusted for a voltage slightly less than the permissible voltage of the Kenotorn tubes. Therefore, if a voltage greater than the permissible value appears, it will be passed to the ground by fixing the gap.

When the impulse generator is not in operation, the movable arms remain in contact with the fixed contact, but they are driven away when the impulse generator is started.

46.8 Wave Shape Control

It consists of a shunt resistance R_{sh}, a series resistance, and a voltage driver R_s. The series resistance is primarily effective in shaping the wave front while the shunt resistance together with the potential divider controls the wave tail.

46.9 Tripping Mechanism of the Impulse Generator

Generally, two types of tripping mechanisms are used in practice.

1. Sphere gap method.
2. By using a trigatron gap.

46.10 Trigatron

A trigatron is a type of triggerable spark gap switch designed for high current and high voltage, (usually 10-100 kV and 20-100 kA, though devices in the mega-ampere range exist as well). It has very simple construction and in many cases is the lowest cost high energy switching option. The construction of the gap is as shown in Figure 46.2. The shell of the electron is of cast aluminum alloy or of brass, mechanical at the orifice to take a stainless probe or tripping needle on which is shrunk a shaped any colorless collar. The probe is adjustable in the orifice for setting purposes. The best position of the probe is with its tip about flush with the outside surface of the electrode shell.

In operation, the electrode shell is the earthed number of the bottom stage gap of the impulse generator. When a tripping pulse is applied to the probe, a discharge appears between the probe tip and the shell of its containing electrode. The insulation thus produced is fed into the main gap which, being under electrical stress, is caused to break down.

46.11 Advantages

1. The setting of the probe is not critical.
2. The operation is practically independent of the charging voltage variation due to fluctuation of supply from the mains.

EXPERIMENT 47

47.1 Object: To Determine the Breakdown Voltage of an Oil Sample

47.2 Apparatus Required

A 50 kVA portable transformer, oil testing set, stopwatch, oil sample in a container, voltage regulator, and so forth.

47.3 Theory

The oil testing set is designed for the practical testing of samples of insulating oil down from the plant on the site for checking the dielectric strength of the oil sample. The equipment is designed to operate from 200/250 V, 50 cycles A.C. supply, main test gap, and voltage up to 50 kV.

The gap setting may be adjusted according to any specified value of B.S.S. or I.S. One unit consists of a transformer and a bushing mounted on it forming the seal connection with two set spheres well below the oil surface. The second unit consists of control and metering equipment. A regulator to vary the applied voltage and a voltmeter is provided.

The purpose of making the set into two units is that no one should be within seven feet of the transformer while it is working. Hence the control unit is kept more than seven feet away from the transformer.

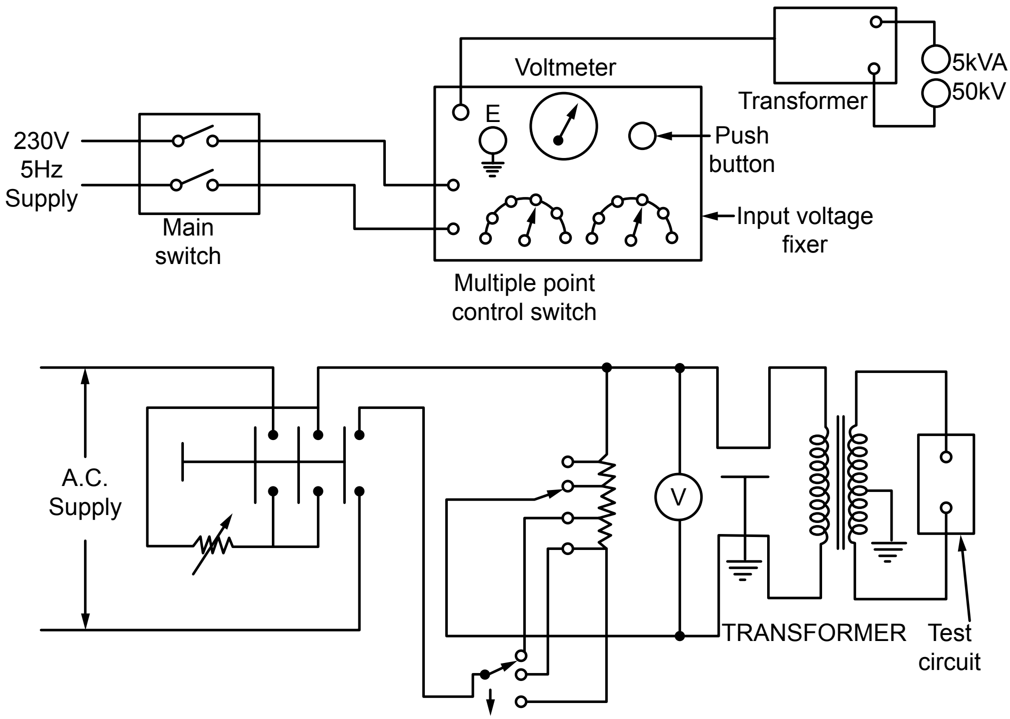

Figure 47.1

47.4 Use of Testing Set

1. Clean the test pot with dry gas by removing it from the electrode.
2. Set the gap separation at a distance of 157″.
3. Remove the gauge and fill oil in the pot. The gap is in the middle of the oil; that is, the height of the oil is same below and above to the sphere.

47.5 Procedure

The multiple panel control switch is set up at its lowest tapping point. The bottom in the control unit is first pressed for 5 sec. having released this tapping point. Now again set the switch for the next higher setting and for this the bottom is pressed for 10 sec. with the help of stopwatch. Voltage is observed if a breakdown occurs. If a breakdown does not occur, the procedure is repeated for each successive tapping point for a duration of one minute when the voltage reaches 25 kV. The voltage at which breakdown occurs is noted by instantaneously stopping the stopwatch after seeing the discharge in the oil sample. The gap becomes a black color due to this breakdown, indicating the breakdown in the oil.

47.6 Result

Dielectric strength of a given sample of transformer oil is = 7.524 kV/min.

47.7 Discussion

The result obtained experimentally must be approximately equal to the Indian standard for transformer oil which is given below according to I.S.I.

47.8 Appearance

The oil should be clean and transparent and free from suspended matters.

Density at 27°C (max) = 0.895

Kinetic viscosity at 27° (max) = 27 cst.

Flesh point (closed up) (min) = 140°C

Pour point (max) = 10°C

Neutralization point = 0.3 Mq / KOM/ q

Corrosive sulphur (in terms of classification of Cu strip) – Not worse than the classification.

Dielectric dissipation factor tan–0.005 (at 90°max)

Electric strength (B.D. voltage)

(*i*) New untreated–30 KV (R.M.S.)

If above value is not obtained the oil should be treated.

(*ii*) After treatment–50 KV (R.M.S.)

Specific resistance cm (min) at 90°C

$$= 13 \times 10^{12} \text{ at } 27°\text{C} = 500 \times 10^{12}$$

Water content (max) = 50 ppm.

47.9 Oxidation Stability

(*i*) Neutralization value after oxidation–Mq/KOH/q

(*ii*) Total sludge formation after–10% weight oxidation (max)

Saponification value–1.0 Mq/KOH/q

The low electric strength of the oil indicates that the oil is of inferior quality. The factors which are responsible for reduction of the electric strength of the oil are:

Atmospheric temperature, pressure, humidity, acidity pressure of air bubbles, and so on.

47.10 Questions for Oil Testing

1. **Composition of transformer oil.** The most common liquid insulator in the transformer oil obtained by frictional distillation of petroleum. This oil has various characteristics regarding flashing point viscosity, and so on, depending upon the specific characteristics of transformer oil that are shown in Figure 47.1.
2. **Dielectric strength.** It is the stress that the oil can withstand without a breakdown taking place, under specific conditions.
3. **Viscosity.** This is the very important property of insulating oil. Oil should possess rather low viscosity so that it can circulate well in the transformer and thereby facilitate cooling of windings and magnetic circuits. The viscosity of oil as well as other liquids increases greatly as the temperature decreases. The viscosity of the transformer oil should not exceed 4.2 at 90°C and 1.8 to 1.85 at 50°C.
4. **Effect of pressure on transformer oil.** When oil is placed under high pressure, the dielectric strength increases; to some extent this may be due to the increased strength of the occluded gases under pressure.
5. **Effect of Moisture**. The slightest trace of moisture in oil greatly reduces its dielectric strength. The effect of moisture is shown in Figure 47.1. Disc gap water is held in suspension in oil in minute drops, and when voltage is applied there, drops are attracted by the dielectric field. Thus, they are attracted to the denser portion of the field and may form larger drops by collision when attracted to and after touching a metal part, and thus having the same potential they are immediately repelled. If the field is uniform the drops form conducting chains along the lines of force. It can be seen that the effects of moisture should vary greatly with the shape of the electrode and with some shapes of the moisture may

even be removed from the space between electrodes by the action of the field in which case its presence would not be detected by low voltage breakdown. Some investigators have claimed to have an actual rise in the dielectric strength when moisture is added to dry oil under certain conditions. Dust in oil may have an effect very similar to moisture, and the small conducting particles are made to bridge between electrodes by the dielectric field.

6. **Effect of Temperature.** Temperature over the operating range has very little influence on the strength of the oil. The strength increases on the freezing point. The curve is shown in Figure 47.2. The insulation resistance is also shown.

   The increase in strength with temperature is often only apparent and due partly to the decreasing insulation resistance. This allows more current to flow through the oil, which tends to even up the stress but mostly to dry out the moisture particle by the high temperature. The increasing at freezing should be expected as an actual improvement in dielectric properties results. For a perfectly dry oil, strength decreases with increasing temperature or density as in the case of air.

   Temperature plays an important role in the disintegration of oil when the latter is heated, and exposed to air or oxygen a chemical reaction slowly takes place. The oil oxidizes to form a finely divided dark solid known as sludge. An acid is created also.

7. **Contamination in transformer oil.** It is the measure of free organic and inorganic acids present together with oil. It is explained and expressed in terms of the number of grams of KaOH required to neutralize the total force acids of one gram of material.

   The deterioration of insulation is generally due to oxidation and under prolonged conditions of high temperature operation. In sludge with normal operating temperature, contamination with water and other foreign matters including varnish as well as reducing electric strength of the oil promotes its oxidation.

   The dielectric strength does not give a turn indication of deterioration of oil. This is also attacked by foreign particles. The higher acidity content does not attack dielectric strength.

Observations

Sphere gap = 0.157″
Sphere dia = 1 cm

S. No.	*Voltage Applied kV*	*Time*	*Breakdown*
1	20 kV	1 minute	No
	25 kV	1 minute	No
2	30 kV	65 cc	Yes
3	35 kV		
4	40 kV		
5	42.5 kV		
6	45.0 kV		

Calculation

Distance between the electrodes:

$$= 0.157 \text{ inch} = 3.987 \text{ mm}$$

$$\text{Dielectric strength} = \frac{\text{Breakdown in kV}}{\text{Electrodes spacing in mm}} = \frac{30}{3.987}$$

$$= 7.524 \text{ kV/mm.}$$

EXPERIMENT 48

48.1 Object: To Determine the Breakdown Characteristics of:

(*a*) Sphere-Sphere Gap

(*b*) Rod-Rod Gap

(*c*) Needle-Needle Gap

48.2 Theory

Sphere-Sphere Gap

The sphere-sphere gap is a classic example of a weakly non-uniform field. The degree of non-uniformity increases with an increase in the ratio of the distance between the electrodes to their diameter D. The sphere gap happens to be an acknowledged means in the international practice for the measurement of amplitudes of direct A.C. and impulse voltages.

The choice of a sphere gap as a measuring spark gap is governed by the following main properties of the gap:

(*a*) Volt-second characteristics of a sphere gap over a large interval of time create a horizontal straight line and, consequently, the breakdown voltage of the gap does not depend upon the duration of the application of voltage and on the low side of its variation with time.

(*b*) Out of all the gaps having a weakly non-uniform field allows the sphere gap to be prepared most easily, and it has the fewest dimensions. For example, in the case of a gap between two planes, each plane will require having rounded edges and the same discharge distance. The diameter of the plane electrodes will have to be a few times larger than the diameter of the sphere.

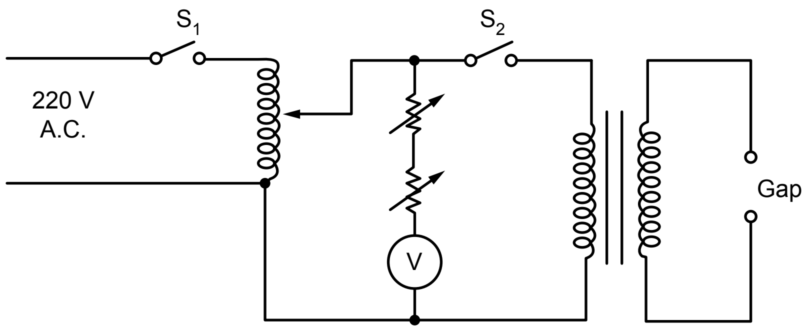

Figure 48.1 Circuit diagram.

48.3 Rod-Rod Gap

There is a square section of 5″ × 5″ (1.27 cm). The square section is perpendicular to the axis of the rod. In an electrical system the rod-rod gap is used for the coordination of the insulator which is to be protected. The rod-rod gap is a typical example of sharply non-uniform fields, and their electrical strength can be successfully used for an approximate estimation of electrical strength of a number of practical insulation constructions. In a sharply non-uniform field, the initial avalanche crosses a very small part of the gap and the streamer formed cannot spread up to the opposite electrodes. The approximate formula for a rod-rod gap at power frequency V_{bd} = 70+5.25 S

(S-spacing between the two electrodes).

48.4 Needle-Needle Gap

If the distance between two needles is larger in the considerable extent that the radius of curvature is less, thus the field between the two electrodes is a sharply non-uniform field in which the value of volume consideration coefficient falls steeply, resulting in the occurrence of discharge near the electrodes having small radius of curvature. The discharge is self-sustained and known as a corona. The development of the discharge in the streamer is only possible with increased voltage.

48.5 Procedure

The panel is to be calibrated because as soon as the voltage is increased, vibrations are observed on the voltmeter. It is calibrated to real as 80 KVR = 270 div of variance.

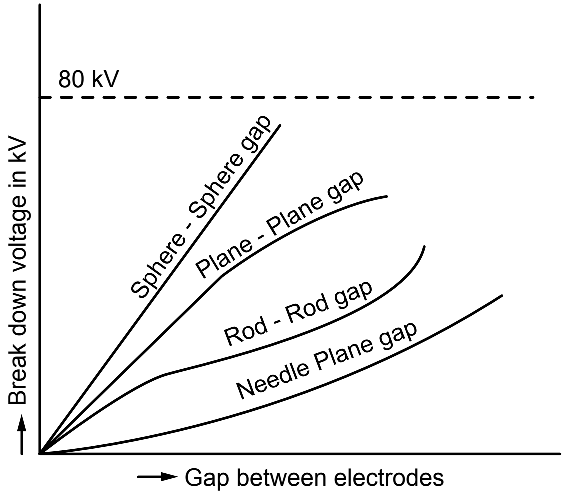

Figure 48.2

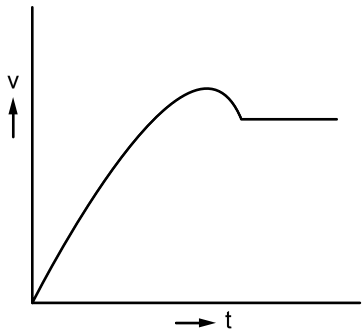

Figure 48.3

Spheres are kept standing in such a way that there is required spacing between the two. S_1 and S_2 close and increase the voltage gradually till the breakdown of the medium occurs. Instantaneously open S_2 and note the reading of S_1 open and earthed.

Now change the spacing, again S_1 and S_2 are closed, and increase the voltage till the breakdown occurs. So open out note the reading of the voltmeter.

A similar procedure is adopted for the whole set of readings for the rod-rod gap, needle-needle gap, and needle plane gap.

Plot a graph between voltage (BD) *Vs*. distance between the two electrodes.

48.6 Result

For different spacing of the electrodes, graphs are plotted between the gap and breakdown voltage.

48.7 Discussion

Unequal distribution of intensity and the space between electrodes are the importance characteristics of a non-uniform field. The spark gap between two spheres is a classic example of weekly non-uniform field the degree of none. Uniformity increases with an increase in the gap as shown in the graph.

Initial avalanches. Cross the complete gap and after this, the anode steamer is formed in the case of non-uniform weekly field as for gaps.

1. The volt-sec characteristic of a sphere gap over a larger interval of time is a horizontal straight line and, consequently, the breakdown voltage of the gap door does not depend upon the duration of application of voltage and on the law of its narration.
2. The sphere gap can be prepared easily and has the fewest dimensions.

In electrical systems rod-gaps are sometimes used for coordination of insulation. With this aim a rod-gap is placed across the insulation to be protected, and the voltage is increased to find the weakest point, where the speeding is smallest and the breakdown occurs. This is the case of a sharply non-uniform field in which the initial avalanche crosses a very small part of the complete gap and the steamers formed cannot spread up to the opposite electrode.

48.8 Questions and Answers on the Experiment

1. **Volt-sec characteristics.** The relationship between the time of discharge and the amplitude of the applied voltage is called the volt-sec characteristic of the spark gap. The time of discharge depends not only on the amplitude of applied voltage, but also on the law of its variation with time. (Figure 48.1)

2. **Breakdown flashover voltage.** When voltage increases, the ionization process increases and at an instant a spark takes place in the air as a medium, which is called spark over voltage.

   When breakdown occurs in the air along the surface of a solid dielectric, the term flashover voltage is used. The material of the dielectric and the condition of its surface along which the discharge develops and the form of electric field influence flashover voltage.

3. **Puncture voltage.** Failure of electric strength of an insulator can occur by way of the puncture of the solid dielectric when the voltage is increased gradually or suddenly as a voltage dielectric goes completely out of service or can be damaged mechanically. The voltage at which this occurs is called puncture voltage.

4. **Dry and wet flashover voltage.** Surfaces of insulators may be dry or wet for indoor installation. Insulators are dry and for outdoor purposes insulators become wet due to rain, direction, and form of its jet and on the conductivity of rainwater. The flashover voltage for these two conditions is different due to air density, temperature, and pressure.

5. **Uniform, non-uniform field.** Equal distribution of intensity in the space between electrodes is called a uniform field. For small gaps a uniform field is possible because for two large gaps, dimensions of the electrodes should be very large.

   Unequal distribution of voltage between two electrodes is called a non-uniform field. If both electrodes are of similar dimensions, field intensity has a maximum value on the surface of the electrodes, and in the middle of the surface if the dimensions are not the same. The greatest field intensity occurs on the surface of the electrodes having a smaller radius of curvature, and the region of minimum intensity is shifted to the opposite electrode.

6. **Corona discharge.** Corona discharge is a discharge of its own kind characteristic of sharply non-uniform fields when ionization takes place only in a very small region of space in the neighborhood of an electrode. Corona is one of the forms of self-sustained discharge.

Q7. Why are spheres used as a standard of measurement?

Ans. Spheres are used as measuring spark gap due to the following property of gaps:

(*a*) The volt-sec characteristic of a sphere gap over a large interval of time is a horizontal straight line and so the breakdown voltage of the gap does not depend upon the duration of application of voltage and on the law of its variation of time.

(*b*) Out of all the gaps having a weakly non-uniform field, the sphere gap can be prepared most easily and it has the fewest dimensions.

8. Horizontal and vertical arrangement of the gap.

In sphere gaps used in practice the effect of earth cannot be neglected since the voltage to be measured is usually applied between high-voltage terminals, and so the sphere should be earthed. The vertical arrangement of spheres should be earthed. The horizontal arrangement of spheres is used for relatively lower voltages.

Observations

Diameter of the sphere = 15 cm

270 Dia = 80 kV

$\therefore$ 1 Div. = 0.296 kV /Div.

Pressure P = 734 mm

Temperature = 273 + 23 = 296 K.

Relative air density factor

$$s = \frac{386 \times 734}{296} = 0.957$$

For Sphere-Sphere gap

S.N.	***Gap in cm***	***Division***	***Breakdown voltage Vo-Div. × 296 kV***	***V = V S kV***
1	0.5	62	18.35	17.56
2	1.0	98	29.00	27.75
3	1.5	140	41.44	39.66
4	2.0	182	58.87	51.55
5	2.5	224	66.30	63.45
6	3.0	260	77.00	73.70

Rod-Rod Gap

S.N.	*Gap in cm*	*Division*	*Voltage B.D.* V_o *= Div. × 0.296 kV*	$V = V_o \times S$ *kV*
1	0.5	38	11.25	10.76
2	1.0	55	16.28	15.58
3	1.5	60	17.76	17.0
4	2.0	76	28.08	22.1
5	2.5	84	94.85	23.8
6	3.0	100	29.6	28.33
7	3.5	125	37.0	35.41
8	4.0	130	38.48	36.82

Needle-Plane Gap

S.N.	*Gap in cm*	*Division*	*B.D. voltage* v_0 *= Div. × 0.296 kV*	$v = v_0 \times s$ *kW*
1	0.5	22	6.51	6.23
2	1.0	42	12.43	11.9
3	1.5	55	16.28	15.58
4	2.0	60	17.76	17.0
5	2.5	7.6	22.5	21.5
6	3.0	7.8	23.0	22.0
7	3.5	80	23.68	22.66
8	4.0	88	26.04	24.93

Plane-Plane Gap

S.N.	*Gap in cm*	*Division*	*B.D. voltage* v_0 *= Div. × 0.296 kV*	$v = v_0 \times s$ *kW*
1	1.0	76	22.5	21.5
2	20	145	42.9	41.0
3	3.0	78	52.69	50.4
4				

EXPERIMENT 49

49.1 Object: To find the voltage distribution across a string of a suspension insulator having five units, and to determine the efficiency of a string of insulators and to plot a graph between percentage voltage and the number of insulators from the line end.

49.2 Apparatus

1. Insulator having equipment
2. 100 kV H.T. transformer
3. String of insulators.
4. Sphere gap arrangement.

49.3 Theory

In a string having suspension insulators, the porcelain portion between the two metal fittings forms a capacitance called mutual capacitance, and the whole of the string will consist of five such capacitors in addition to capacitance between each metal fitting and metal cross arm. So due to these capacitances, it will be observed that the potential across each unit is not same; the potential across the first top unit has less potential across the bottom insulator. So the insulator adjacent to the line conductor is under maximum stress and is liable to puncture.

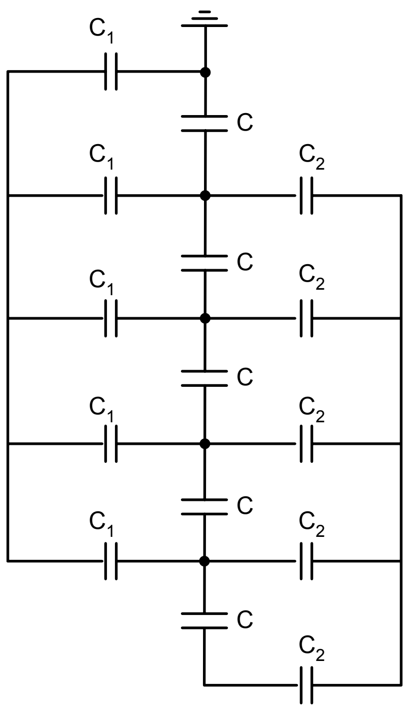

Figure 49.1

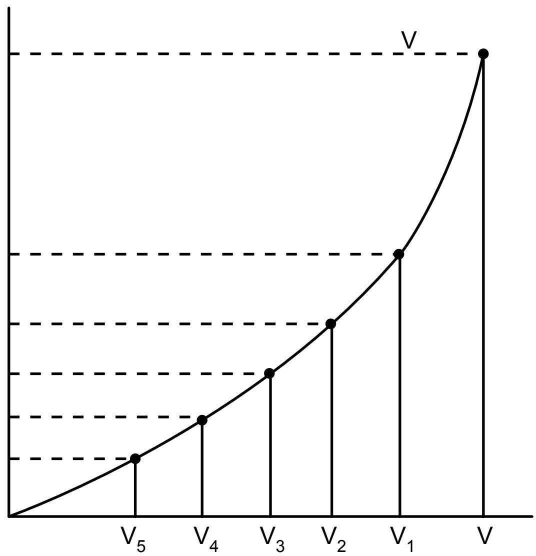

Figure 49.2

49.4 Procedure

1. Calibration of auto transformer scale. Fix the two spheres on the stand at the definite gap between the spheres, which is 0.5 cm. (The distance between the spheres must not be more than this.) Now make the switch on position and increase the voltage by an autotransformer until the breakdown voltage is obtained between the two spheres.
2. Voltage is applied across a unit nearest to the line of the first unit and the voltage at which the sphere gap fires is noted.

The sphere gap is now connected across the first, second, third . . . links while the voltage is applied across the first and fifth unit and the corresponding firing voltage is recorded.

A similar procedure is adopted by applying the voltage across the first and seventh unit.

49.5 Result

Distribution of voltage along the string is as shown in the graph.

49.6 Discussion

The procedure and presence of the capacitors C_1 and C_2 cause the non-uniform distribution of the voltage along the insulators of the string. We shall start with examining the effect of the capacitance to ground C_1 only. Evidently, due to branching of current in these capacitances, currents passing through the self-capacitance of the insulators and consequently the drop of voltage across the insulators also would be as small the farther away the insulator is located.

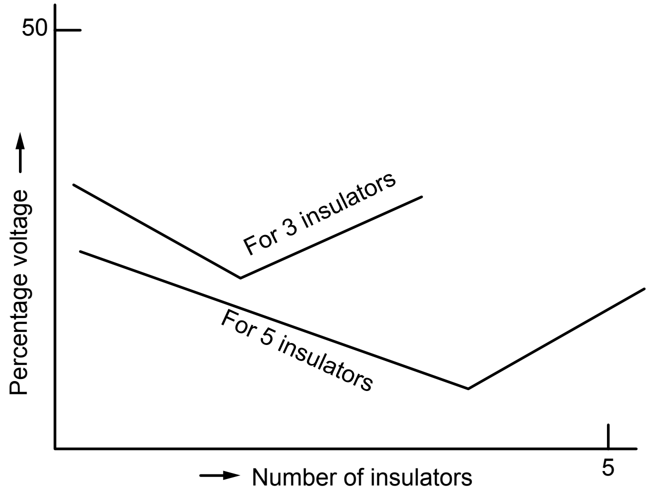

Figure 49.3

Now if we examine the effect of the capacitances relative to the conductor, only the picture will be different. Current through the capacitances C and correspondingly the drops of voltage now would be small across those insulators which are located further away from the earthed end of the string, and capacitances to ground have considerably more value than the capacitances relative to the conductor. Therefore, they exert a predominant influence on the character of the distribution of voltage along the insulators of the string. The greatest voltage lies on the insulators situated near the conductor, and the smallest on the insulators situated at the middle of the string, and somewhat more voltage comes on the insulators near the earthed end of the string. The degree of non-uniformity increases with the increase of the length of the string, because now total capacitance of the earth relative to the earth increases.

The distribution of the voltage along the string can be made uniform by means of a guard-ring.

Observations

270 division = 80 kV

Therefore: 1 division = 0.296 kV/Division.

Voltage across insulator:

= 24 division = 7.1 kV.

Strength for 3 insulators

S.N.	*No. of insulators*	*No. of Divisions*	*Voltage across insulator, kV*	*Percentage voltage across insulator*
1	1	84	24.86	28.56%
2	2	119	35.23	20.15%
3	3	140	41.44	17.13%
4	4	168	49.73	14.28%
5	5	140	41.44	17.13%

Strength for 3 insulators

S.N.	*No. of insulators*	*No. of Divisions*	*B.D. voltage insulator kV*	*Percentage voltage across insulator*
1	1	71	21.01	33.8%
2	2	82	24.03	29.2%
3	3	75	22.2	32.0%

QUESTIONS AND ANSWERS IN ELECTRICAL ENGINEERING

Q1. What is the life of an electric lamp?

Ans. The life of an electric lamp is 1000 hours of burning. A fluorescent lamp (tube light) has a life of 3000 hours of burning.

Q2. What is the resistance of human body?

Ans. The resistance of the human body in dry conditions is 10,000 ohms and 1,000 ohms in wet conditions.

Q3. Why do we connect electric equipment to earth?

Ans. A dead part of a piece of equipment is connected to earth for a safety of the human body and animals. The dead part is the part which does not have a current. When a live part (current-carrying part) unfortunately touches the dead part, a current will go to earth and the human body will be safe.

Q4. Why does the human body feel a shock when a voltage is touched to the body?

Ans. A shock is felt due to the wear and tear of the muscles. A current flows through the body. The resistance of a body is 10,000 ohms. If a voltage of 220 volts is caught by a hand, a current of 220 mA will flow. A current of 22 mA is fatal for the body. If the body is dry, a resistance will be 10,000 ohms and the current through the body will be 22 mA. A death will occur whether the body is dry or wet.

Q5. Which are more dangerous, D.C. shocks or A.C. shocks? Why?

Ans. A.C. shocks are more dangerous than D.C. shocks. This is due to more wear and tear in the body. The frequency of A.C. current damages the body more than D.C.

Q6. What is the resistivity of the earth?

Ans. The resistivity of the earth varies from 100 ohms to 10,000 ohms. The resistivity will depend on the type of soil.

Q7. A 1000-watt heater has a wire length of 50 meters. If we use a half-length of 25 meters, what will be the capacity of the heater?

Ans. The capacity will be 2000 watts when we use a half-length of wire of 25 meters.

Q8. Explain fully why the capacity of the heater is doubled when we use the half-length of wire.

Ans. The power is given by

$$W_1 = \frac{V^2}{R}$$

where V is voltage and R is resistance. The resistance will be half ($R/2$). Therefore,

$$W_2 = \frac{V^2}{\frac{R}{2}} = \frac{2V^2}{R} = 2W_1$$

If $W_1 = 1000\ W$, then $W_2 = 2 \times 1000 = 2000\ W$.

Q9. Which one electric lamp has more resistance when a 100-watt lamp and a 60-watt lamp are given?

Ans. The 60-watt lamp has more resistance than a 100-watt lamp.

Q10. What will be the resistances of a 100-watt lamp and a 60-watt lamp?

Ans. The resistance of the lamps when used for a 230-volt supply will be

$$100\ \frac{V^2}{R} = \frac{230 \times 230}{R}$$

$$R = \frac{230 \times 230}{100} = 556 \text{ ohm}$$

The resistance of a 60-watt lamp will be

$$R = \frac{230 \times 230}{60} = 826.6 \text{ ohm.}$$

Q11. Why are D.G. series motors not started at no-load?

Ans. The series motors are not started at no-load because the speed at no-load will be infinitely high. The shaft of the motor will fly away and an accident might be caused.

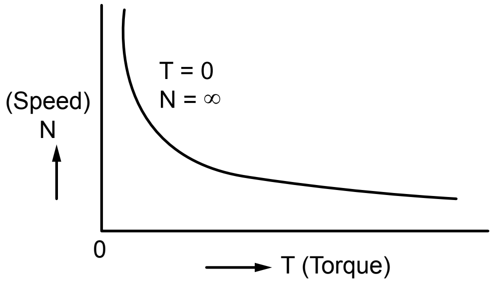

Figure 11.1

It is always advisable to load the motor before starting it.

Q12. Why is a current transformer not kept open circuited?

Ans. A current transformer is never kept open circuited when it is connected in the circuit, because the primary winding has one turn and the secondary has many number of turns. A high voltage will be induced in the large number of turns and it will cause a shock to the worker. Therefore, keep the current transformer connected with secondary winding. High current in the primary causes insulation damage.

Q13. What is a transducer?

Ans. A transducer is an energy converter; electrical machines are the transducers.

Q14. What are material transducers?

Ans. Material transducers are formed using materials such as ferro electric materials, piezoelectric materials, magnetostrictive materials, and so on. The materials convert one energy form to the other. Electro-mechanical energy conversion is possible with the help of material transducers.

Q15. Can a D.C. series motor also run on A.C. supply?

Ans. Yes, a D.C. series motor can also run on A.C. supply. The example is A.C. series motors, called universal motors.

Q16. Why is shunt field winding made of thinner wire and why does it have a large number of turns, whereas series field winding is thicker and has fewer turns?

Ans. This is made because high resistance may be obtained in the shunt winding and low resistance in the series field winding.

Q17. Why is the speed of a D.C. series motor not controlled by connecting a variable resistance in series with the armature?

Ans. The power loss will be high and power input to the armature will be very small.

Q18. Is the voltage drop in a D.C. shunt generator with load more as compared to a separately excited D.C. generator?

Ans. There is no effect on the voltage drop. The voltage drop will remain the same in both the cases.

Q19. Why is the D.C. series motor suitable for traction purposes?

Ans. The high speed in the starting and direction can be changed by reversing the current.

Q20. A rotating shunt generator is not developing voltage between its terminals. What would be a reason?

Ans. Shunt field rheostat resistance may be more than the critical resistance for the machine.

Q21. How will you obtain linear commutation in a D.C. machine? Name methods.

Ans. We use interpoles to reduce the induced voltage in the coil undergoing commutation.

The inductance of the coil should be zero, so that current cannot be retarded.

Q22. What type of power transformer at a generating station for bulk power transfer is used? Whether step up, step down, or 1:1 ratio?

Ans. Step up transformer.

Q23. Transformers are usually of what type of distribution? Whether step down, step-up, or 1:1 ratio.

Ans. Step down.

Q24. Does the efficiency of the transformer depend on load current?

Ans. Yes, the efficiency increases with load current and reaches to maximum value and then decreases with load current.

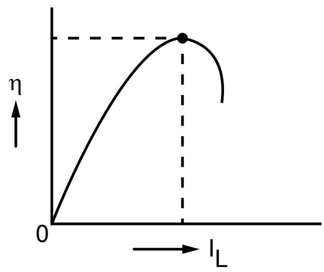

Figure 24.1

Q25. How many type of magnets are there? Which type of magnet is used for lifting load?

Ans. There are two type of magnets; one is an electromagnet and the other a permanent magnet. Permanent magnets are used for lifting the loads of iron materials.

Q26. At what speed reluctance does a motor produces average torque?

Ans. At a specific speed.

Q27. Why do we connect a lamp in the neutral wire and switch in the phase wire?

Ans. If we touch the lamp it will not give shock when connected in the neutral. If we connect the lamp in phase it will give a shock when we change it. If the switch is connected in phase, it does not give a shock because it is insulated.

Q28. Make a circuit diagram of a house wiring with three lamps and three switches.

Ans. The diagram is shown in Figure 28.1. The switch has two points and the lamp has also two points which are connected as shown in the diagram.

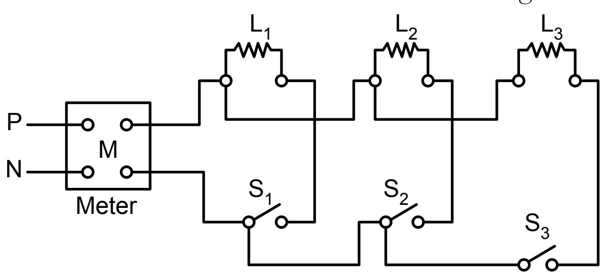

Figure 28.1

L_1, L_2, L_3 are the lamps and S_1, S_2, S_3 are switches.

Q29. Why do we prefer the magnetic field in an electromechanical energy converter over an electric field?

Ans. The production of an electrostatic field will require a large air gap as compared to the electromagnetic field. The size of the machine will be very large if the electric field is produced.

Q30. How many parallel paths are used in a wave connected armature winding?

Ans. Two parallel paths.

Q31. How many parallel paths are used in a lap connected armature winding?

Ans. Parallel paths are equal to the number of poles used in the lap winding.

Q32. What will happen to the speed of shunt motor, if the polarity of D.C. supply to its terminals is changed?

Ans. The speed will remain the same in RPM and direction. The change of polarity of the D.C. shunt motor does not affect the speed direction.

Q33. What will be the magnitude of induced voltage of a D.C. shunt generator when the shunt field resistance is decreased?

Ans. The voltage will increase in magnitude because the field current will increase:

$$E_a = Ki_f,$$

where E_a = induced voltage

K = constant and

i_f = field current.

Q34. What will happen to the speed of a series motor when the number of turns in its field winding is decreased?

Ans. The speed of the D.C. series motor will increase.

Q35. How will you connect the compensating winding? Either in parallel or in series.

Ans. In series with the armature.

Q36. What is the inductance of a magnetic circuit?

Ans. The inductance of a magnetic circuit is the rate of change of flux with respect to current.

$$L = \frac{d\phi}{di} = \frac{\phi}{i}$$

If there are N number of turns, we have

$$L = \frac{N\phi}{i} = \frac{\phi}{i}$$

$$= \frac{\text{Leakage}}{\text{Current}}.$$

Q37. What is a physical inductance? How does physical inductance differ from the effective inductance? What is the effective inductance?

Ans. The physical inductance is found from the configuration of a magnetic circuit

$$L = \frac{N^2 \mu_0 \mu_r A}{L_m}$$

where L = inductance in Henrys

N = number of turns

$\mu_0 = 4\pi \times 10^{-7}$ H/m

μ_r = relative permeability

A = area of cross-section, m^2

L_m = mean length of magnetic path.

The effective inductance is obtained from a voltage induced or current:

$$e = L\frac{di}{dt},\ L = \frac{e}{di/dt}$$

or

$$i = \frac{1}{L}\int e\,dt$$

or

$$L = \frac{\int e\,dt}{i}$$

The two inductances may differ in a slight numerical values due to measurement errors.

Q38. What is a physical resistance? What is an effective resistance? How does physical resistance differ from the effective resistance?

Ans. The physical resistance is directly proportional to the length of a wire and inversely proportional to the area of cross-section

$$R = P\frac{L}{A}$$

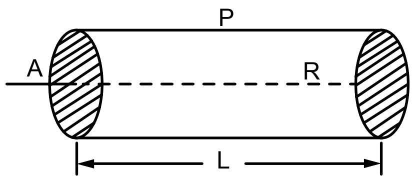

Figure 38.1

where R = resistance

P = constant of proportionality

L = length in meters and

A = area of cross-section, m^2.

The effective resistance will be given by the measurement of voltage and currrent.

$$R = V/I$$

These two may differ due to temperature and measurement errors.

Q39. What is a physical capacitance? Define effective capacitance and point out differences between these two.

Ans. Physical capacitance is determined from the physical configuration of a capacitor with its dielectric

$$C = \varepsilon_0\ \varepsilon r\frac{A}{d}$$

where C = Capacitance in Farad.

ε_0 = Permittivity of vacuum, F/m.

ε_r = Relative permittivity.

A = Area of plate.

d = Separation between the plates.

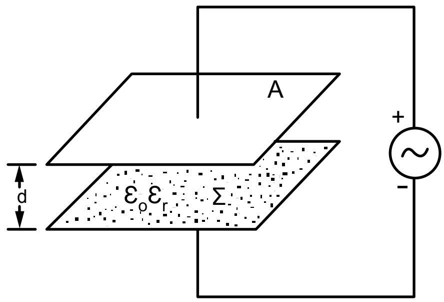

Figure 39.1

The effective capacitance is determined by the measurement of current and voltage

$$i = C\frac{de}{di}$$

$$C = \frac{i}{\frac{de}{dt}}$$

The charge on the plate will be

$$Q = CV$$

Or $$C = \frac{Q}{V}.$$

The two capacitances must be equivalent if they differ, this is due to the measurement errors.

Q40. Why we do use insulators on the poles of a telephone line and electric line?

Ans. The poles are earthed and the conductor carrying current will be in the contact to the ground, and a short-circuit will take place if there is no insulator. The insulator separates the conductor from the ground and confines the current in the conductor path. Both telephone lines and electric lines are insulated through the insulators.

Q41. Which material is used to make the line insulators?

Ans. Porcelain material is used to make the insulators.

Q42. Which material is used to make the switches of house wiring?

Ans. Bakelite material is used to make the switches used in house wire.

Q43. In what manner are electric lamps connected? (Either in series or in parallel.)

Ans. Electric lamps are connected in parallel.

Q44. Which type of lamp has a higher life?

Ans. A fluorescent lamp (tube light) has higher life than the ordinary lamp. Tube light works well up to 3000 hours while an ordinary lamp works for 1000 hours.

Q45. Why we do use a choke and starter in tube light connections?

Ans. The choke and the starter are used to start the tube light burning. The starter gives a switching action to the choke to produce a voltage of the order of 1000 volt.

$$L\frac{di}{dt} = 1000\ V.$$

The supply voltage of 230 V and 1000 V induced in the choke will start the tube light burning.

Q46. What is the direction of electromagnetic torque produced in the generator with reference to the rotation of the rotor?

Ans. Opposite direction.

Q47. Why do we install the motors and generators on a foundation base?

Ans. The action and reaction are equal and opposite. We apply an action of prime-mover force to a generator. The generator produces the internal torque on the forces. The internal forces working on the stator do not take part in the effective motion. The stator forces require the fixation of the stator body, otherwise the machine will fly away.

Q48. In a 230/110 V transformer a 230 V D.C. supply is given. Will the transformer produce 110 V D.C.?

Ans. No, the transformer will be burned due to a very high current flow. There will be no voltage induced to oppose the 230 volt D.C. The resistance of the transformer is very small of the order of 0.1 ohms. A current of 2300 A will flow, which will burn the insulation of wires and the winding.

Q49. Explain how a current in the secondary side increases when load is switched on a transformer?

Ans. The increment of current in the secondary side of a transformer is taken from the primary source of power. Its mechanism is simple. Let a demand of current be I_2 in the secondary side. This demand will disturb the steady state working of the transformer. The flux due to this current will increase the increment of flux in the primary winding. The voltage will be decreased. The source voltage will inject the equivalent current from the source of power.

Q50. Why does a transformer on a substation hum?

Ans. A transformer has humming (making a noise) due to air pockets in the core. If a core of a transformer is loose in packing, the stampings will make a noise due to vibrations. The core is formed by packing the laminations which are varnished. There is every possibility of air existence between two laminations. The magnetic stresses will act in the air to vibrate the laminations. This makes the humming in a transformer.

Q51. How will you determine the windage and friction losses in a motor working on electric supply?

Ans. The determination of friction and windage loss is a complicated problem. We may determine it with a simple method. Let the motor run at no-load. Use a shunt motor or induction motor. Do not use the series motor. Go on reducing the supply voltage slowly. The motor will stop at a certain voltage and current. Note the voltage and current. The product of voltage, V and current, I will be the power input to the motor. This input power is consumed in the windage and friction losses. Thus, we determine the windage and friction loss in the motor. This experiment may be made on both D.C. and A.C. motors.

Q52. What is iron loss?

Ans. Iron loss is a power loss in the iron core of a machine. Iron core has a resistance and a path to flow eddy currents. The hysteresis and eddy current loss of power is termed the iron loss. It is called iron loss conventionally because it is dissipated in the iron material. If we use a core of ferrite, even then the loss will be termed iron loss. Most suitable it is called core-loss. It may be energy or power, depending on the calculations.

Q53. What is no-load loss?

Ans. The no-load loss of power occurs at the zero load. This is due to the voltage of the supply available to the machine. The magnetic parts are excited at no-load and the power I^2R is dissipated in the iron parts.

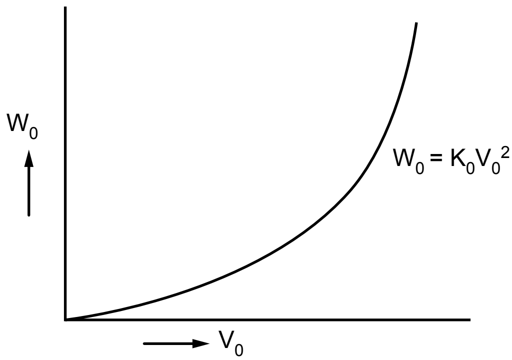

Figure 53.1

The load loss is also due to the windage and friction in the rotating machines. Therefore, the no-load will be

No-load loss = Iron loss + Friction loss + Windage loss.

The loss varies with the voltage, V as shown in Figure 53.1.

The load loss W_0 varies,

$$W_0 = K_0 V_0^2 \text{ watts.}$$

Q54. What is copper loss?

Ans. The copper loss of power is dissipated in a winding of a machine. There is a physical resistance of the winding. This will cause a loss of power I^2R watts, when current, I flows through it. This is termed copper loss conventionally because windings of copper materials are used. If we use a winding of aluminum wire, the loss of power will be called copper loss and not aluminum loss. The conventional name is well recognized. If the windings are used with a resistance wire of nickel, chromium, and iron, the loss will be still called copper loss. Most suitably this loss is called winding loss and the wires are called winding wires.

Q55. How will you recognize a D.C. fan and an A.C. fan when these are running?

Ans. The D.C. fan has a bottom part which moves with the blades of the fan. In the A.C. fan the bottom part does not move and remains fixed. If you are in a train, observe the fan. This is a D.C. shunt motor. The bottom part rotates with the blades of the fan. If you are in an office, observe the A.C. fan; it does not have a moving part in the bottom.

This is due to the commutator used in a D.C. fan.

Q56. Why do we use a starter for a motor?

Ans. A starter is used to control the input current in a motor. A high current should not be given in the motor. Back EMF in the motor develops slowly in the starting process. If we supply 230 volts suddenly to the motor, without a presence of back EMF, an enormously high current will flow. This will cause the motor to burn.

Q57. Where will you use a three-point starter? Name three points. Make a simple diagram.

Ans. We will use three-point starter for a shunt motor. The three points are *L*, *A*, *Z*, as shown in Figure 57.1.

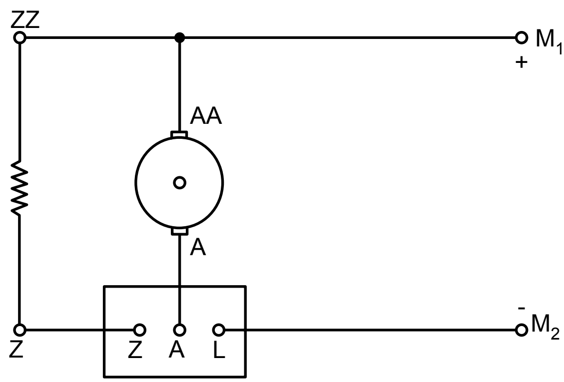

Figure 57.1

Q58. A 100 kW, 230 volt, 1200 RPM generator has a connected load of 50 kW. How much power is generated by the generator? If we connect two loads on the generator, consuming power 50 kW and 50 kW in parallel, how much power will the generator generate? If a 50 kW load is off, how much power will the generator generate? Where has the power gone?

Ans. 50 kW equal to the connected load. At 100 kW, the sum of the power of connected loads will be generated. The power cut has gone in saving the fuel at the prime mover side.

Q59. Why do we use a current transformer with a wattmeter when performing a short-circuit test on a transformer?

Ans. Wattmeter current coil capacity is about 5 amps and, therefore, more current will cause a damage to the coil. In the short-circuit test a current of more than 5 A flows. For the safety of the current coil of a wattmeter, we use a current transformer.

Q60. Make a neat diagram to connect a current transformer with a wattmeter.

Ans. Figure 60.1 represents a neat diagram of a C.T. with a wattmeter.

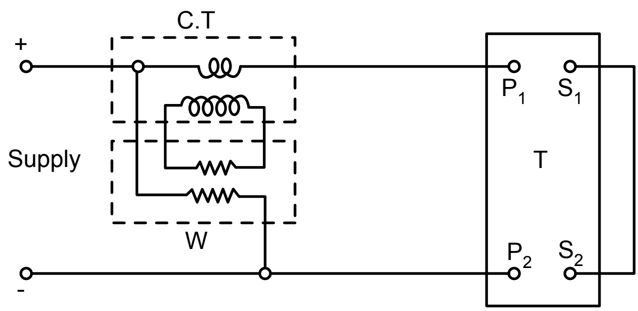

Figure 60.1

Q61. Where will you use the D.C. series motor?

Ans. D.C. series motors may be used for cranes and hoists. Digging, cutting, and punching machines have series motors. Traction motors are series motors.

Q62. Where are the shunt motors used?

Ans. D.C. fans, paper mills, cloth mills, and rolling mills have shunt motors which move the rollers. The fans in trains have shunt motors.

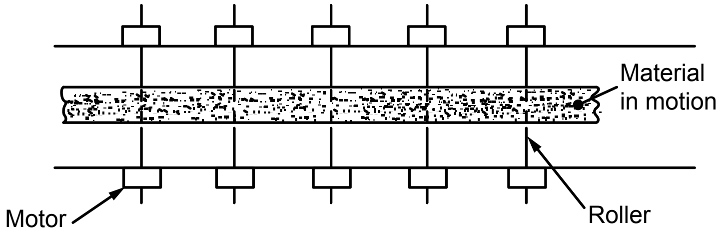

Figure 62.1

Q63. How will you perform a short-circuit test on a single-phase transformer?

Ans. We will supply a 20% approx. reduced voltage to the transformer and note the current and power input. If voltage is 230 volts, supply 46 volts or 50 volts and read current and wattage. This will be a short-circuit test.

Q64. Which type of power loss do you measure by performing a short-circuit test?

Ans. We measure copper loss.

Q65. At what current is this copper loss determined? What will be the copper loss at half the load? If the copper loss is 40 watts at 10 A of current, what will it be at 5 A?

Ans. At the full load, one quarter of the full load copper loss–10 watts.

Q66. How will you perform a no-load test on a transformer?

Ans. We will supply a full voltage and keep the other winding open and then read the current and watts in the instruments.

Q67. Which type of power loss do you measure by the open-circuit test?

Ans. We measure the iron loss at the full voltage.

Q68. At what voltage this iron loss is determined? What will be the iron loss at the half voltage? If the iron loss is 80 watts at 230 volts of supply voltage, what will it be at 115 volts?

Ans. At the full voltage, one quarter of the full voltage iron loss—20 watts.

Q69. How does copper loss vary with the current? How does iron loss vary with the voltage? Make their graphs.

Ans. The copper loss varies as the square of the current and the iron loss as the square of the voltage.

$$W_c = K_c I^2$$

and
$$W_i = K_i V_o^2$$

where W_c—copper loss; K_c—constant; I—current; W_i—iron loss; K_i—constant, and V_o—open circuit voltage.

The graphs are shown in Figures 69.1 and 69.2.

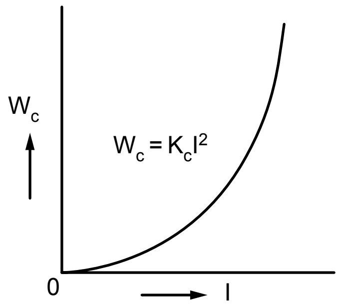

Figure 69.1

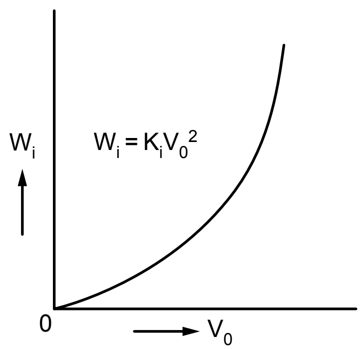

Figure 69.2

Q70. The iron loss takes place for 24 hours in a transformer, why?

Ans. The primary winding of the transformer is connected to the voltage supply for 24 hours. The secondary side may be open for a short time, but the primary winding has supply for 24 hours in a day.

Q71. We make the core of a transformer with laminations (stampings) which are varnished, why?

Ans. To reduce the iron loss the eddy current loss is reduced. The path of eddy currents is broken by the varnish insulation and thus reduces the loss.

Q72. What is a difference between a current transformer and a voltage transformer?

Ans. If the secondary of the current transformer is open, it will be working as a potential transformer. The primary of the C.T. has only one turn while there are many turns in the P.T. The primary of the C.T. is connected in series with the load, while that of the P.T. is parallel to the load. A schematic diagram is shown in Figure 72.1.

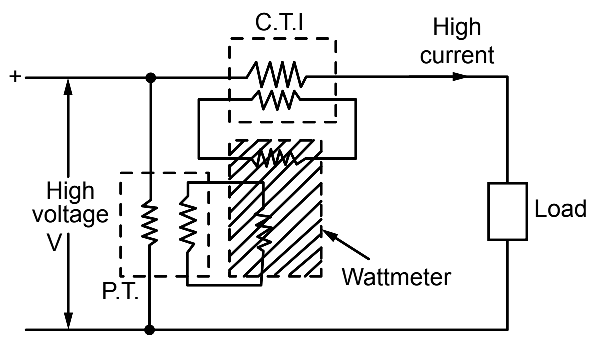

Figure 72.1

Q73. Which material is used to make a core of a current transformer and why?

Ans. Mu metal is used to make a core of the current transformer. The permeability of the Mu metal is very high of the order of tens of thousands.

Q74. Why do we use only one turn in the primary of the current transformer? Why is the turn chosen very thick?

Ans. We choose one turn winding because the induced voltage must be zero, so that the load voltage may not be reduced. A thick conductor is selected to obtain zero resistance, so that the voltage drop may be zero. One turn has another reason of current ratio. There is a large current in the primary and a small one in the secondary. The secondary turns will be smaller if we choose the primary turn.

$$\frac{N_1}{N_2} = \frac{I_2}{I_1}$$

If $I_2 = 5$, $I_1 = 100$, $N_1 = 1$, then

$$N_2 = \frac{N_1 I_1}{I_2} = \frac{1 \times 100}{5} = 20$$

If we choose $N_1 = 1$, then $N_2 = 40$.

Q75. What are the applications of a current transformer?

Ans. A current transformer is used with a relay winding to supply 5 amps of current from the line current which is very high.

A current transformer is used with a current coil of a wattmeter where a power of high current is to be measured.

A current transformer is used as a current source to generate a high current from 5 amps of current. For example, we have a C.T. of ratio 100:5. If we supply 5 amps of current in the secondary, we obtain 100 amps in the primary.

Q76. Why are current transformers and potential transformers called instrument transformers?

Ans. Because these transformers are used with instruments to extend the range. Whenever the power measurement is made in high voltage and high current lines, these C.T. and P.T. must be used with energy meters.

Q77. How will you determine the ranges of an ammeter, a voltmeter, and a wattmeter when you perform an experiment on a machine?

Ans. We read the nameplate of the machine and find the rated current, voltage, and power output. If the current rating is 20 amps, an ammeter of 0–25 amperes will be required. If the voltage is 230 volts, a voltmeter of 0–300 will be needed. If the power output rating is 4.6 kW, a wattmeter of rating 0.5 kW will be sufficient.

Q78. What is creeping error in an energy meter?

Ans. The disc of an energy meter moves when there is no load. This is due to the voltage applied on the voltage coil of the energy meter. It is not possible to disconnect the voltage coil from the supply and the creeping of the energy meter cannot be avoided. If the voltage rises due to certain reasons, the disc will move more. Sometimes it is noted that the disc is making a complete rotation in the same time period.

Q79. What are the differences between an energy meter and a wattmeter?

Ans. The energy meter has a gear system and a mechanism to record the RPM. In the wattmeter there is a spring control in the needle.

Q80. Why do we use a disc in the induction type of instrument?

Ans. Induction principle requires an interaction of two fluxes in the aluminum disc to produce a torque. Ammeter, voltmeter, wattmeter, and energy meters of an induction type are provided with an aluminum disc in which the eddy currents of two types interact to produce a moment to rotate the disc.

Q81. On what factors does the magnetizing MMF of a transformer depend?

Ans. Core dimensions, permeability, primary voltage, and number of turns.

Q82. What is a magnetizing inductance of a transformer?

Ans. The magnetizing inductance of a transformer is due to the core flux and the number of turns. The rate of change of core flux with respect to the current is called the magnetizing inductance.

Q83. What is a leakage inductance of a transformer?

Ans. The leakage inductance is due to the leakage flux. The rate of change of leakage flux with respect to current is called the leakage inductance.

Q84. Name the factors on which the efficiency of a power transformer depends.

Ans. The power factor of the load and the percentage of load.

Q85. What is a skin effect in a wire?

Ans. A current flow on the skin of a conductor is more than the current flow in the center. This is because the frequency and the inductance of the core of conductor are higher than the skin. A low reactance is offered by the skin while it is higher by the center core.

Q86. What is the proximity effect?

Ans. The effect of the current of the side by the conductor is called the proximity effect. The flux of the side by the conductor reduces the flux in one-half and increases the other half.

Q87. What is linkage? What is the relation between linkage and the voltage?

Ans. The product of flux and number of turns is called linkage. The voltage is obtained by the rate of change of linkage per second.

Q88. If there are 10 turns and 10 lines of flux, what will be the value of linkage? If the 100 lines change to 80 lines in 0.10 second, what will be the voltage induced?

Ans. The linkage $\psi = N\phi$

$$= 10 \times 10 = 100 \text{ turn.maxwell}$$

The voltage $$e = \frac{10(100 - 80)}{0.1}$$

$$= 100(20) = 2000 \text{ turn.maxwell per second.}$$

The volts will be $e = 2000 \times 10^{-8}$ volts

As 10^8 maxwell $= 1$ weber.

Q89. What is a law of induction?

Ans. The Faraday's law of induction is stated that:

The induced voltage in a coil is given by the rate of change of flux per second:

$$e = \frac{N\,d\phi}{dt} = \frac{Ldi}{dt}.$$

Q90. What is a law of interaction?

Ans. The law of interaction gives us a force produced by a current in a magnetic field. The force produced by a current in a magnetic field on a conductor will be:

$$F = BLI \sin \alpha$$

where F—Force, B—Flux density, L—length, and I—current, α—angle the axes of current and flux.

Q91. In the light of induction and interaction, state that it is impossible to generate a direct current power using electromagnetic devices.

Ans. Induction is made through $d\phi/dt$ if ϕ is constant the $d\phi/dt$ will be zero and, therefore, the D.C. voltage cannot be generated by the electromagnetic devices.

Q92. Why is the disc of an induction instrument made of non-magnetic material?

Ans. To reduce the attraction force on the disc. If we choose magnetic material disc a force of attraction will be more than the force of interaction or torque.

Q93. Why is an induction cup type structure superior to the disc type structure in relays?

Ans. Because it has a lower moment of inertia and a better magnetic circuit.

Q94. What is a power factor of an ideal dielectric material?

Ans. Ideal dielectric has a zero-power factor.

Q95. What is a power factor of an ideal choke coil?

Ans. Ideal choke coil has a zero-power factor.

Q96. What is a power factor of an electric lamp?

Ans. Electric lamp of ordinary nature has 0.98 power factor which is assumed to be unity. Tube light has 0.6 power factor.

Q97. What is the specified power factor made by M.P.E.B. Jabalpur for consumers?

Ans. 0.85 is the specified power factor by the M.P.E.B., Jabalpur for consumers.

Q98. Why do we improve the power factor?

Ans. We improve the power factor to extend the capacity of the electrical installation.

Q99. What will be the best location of a power factor improving capacitor?

Ans. At the receiving end of Figure 98.1 is a diagram for the best location of the power factor improving device (capacitor).

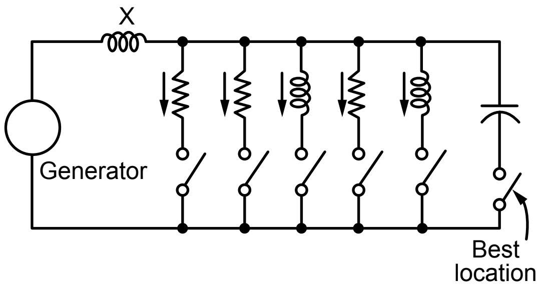

Figure 99.1

Q100. What is insulation resistance?

Ans. For an ideal dielectric, the insulation resistance will be infinite. For a lossy dielectric it will be in mega-ohms or of the order of 10^{12} Ω.

Insulation resistance is the resistance through which a small current flows through the volume and surface of an insulation. A parallel combination of volume resistance and surface resistance is called an insulation resistance.

Q101. Find the insulation resistance of the capacitor shown in Figure 101.1. The volume resistivity is $P_s = 5 \times 10^{12}\,\Omega = \text{m}$ and the surface resistivity, $P_s = 10^{18}\,\Omega$.

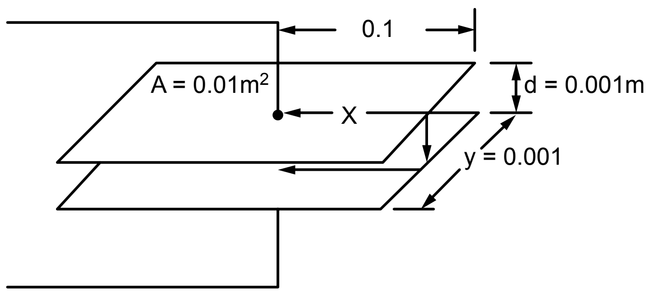

Figure 101.1

Ans. The volume resistance will be

$$R_v = \rho_v \frac{d}{A} = 5 \times 10^{12} \times \frac{0.001}{0.01} = 0.5 \times 10^{12}\ \Omega$$

The surface insulation resistance will be

$$R_s = \rho_s \frac{x}{y} = 10^{12} \times \frac{2.001}{0.001} = 2001 \times 10^{12}\ \Omega$$

$$R_t = \frac{R_v R_s}{R_v + R_s} = 0.5 \times 10^{12}\ \Omega.$$

Q102. Draw the electrical equivalent circuit of an ideal capacitor and lossy capacitor.

Ans. The electrical equivalent circuit of an ideal capacitor is shown in Figure 102.1 and that for a lossy capacitor in Figure 102.2.

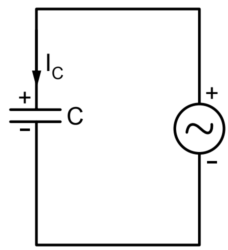

Figure 102.1

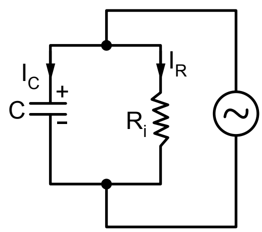

Figure 102.2

Q103. What is the name of the switch used for starting the motors?

Ans. Knife switch.

Q104. Why is the knife switch not made with one solid strip? Why do we use a spring attached supplementary strip?

Ans. To reduce the spark. If the knife switch is suddenly open or closed, a heavy spark will take place, with one strip case. The supplementary strip attached with a spring gives a time lag and the spark is reduced.

Q105. What is a hysteresis loss?

Ans. The hysteresis loss is the loss of power or energy in the form of heat when an iron specimen is given a cyclic current.

We supply a direct current to an iron specimen in the cyclic order shown in Figure 105.1.

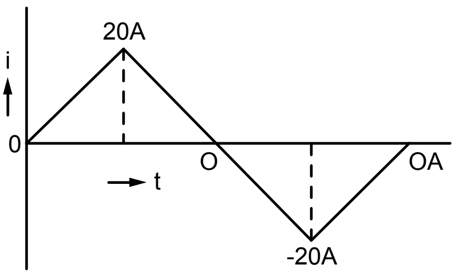

Figure 105.1

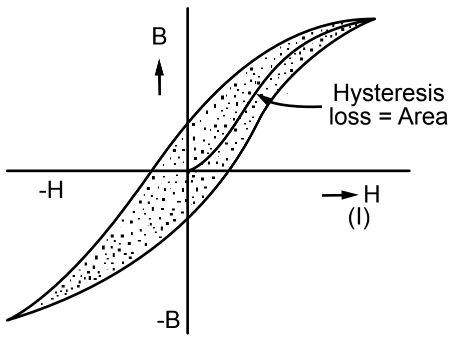

Figure 105.2

This power is absorbed in setting up the iron particles in a direction. The hysteresis loss can be found by a formula

$$W_h = K_h B^{1.6} f$$

where W_h—hysteresis loss, K_h—constant, B—Flux density, f—frequency cycles per second.

Q106. What is eddy current loss?

Ans. The eddy current loss is the power or energy in the form of heat produced in a magnetic specimen. This I^2R loss is in watts, if I is the eddy current and R, resistance to the eddy current offered by the iron path are noted.

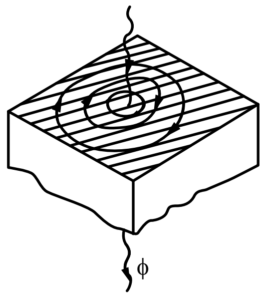

Figure 106.1

The eddy currents are due to the induced voltage which is caused by the pulsating flux.

RELAYS

Q107. What is the operating time of the instantaneous relay?

Ans. The time lapsed from the instant of energization to the instant of closing of contacts will be the operating time of the relay.

Q108. What is an order of the operating time of the instantaneous relay?

Ans. Of the order of 20 to 100 m-sec.

Q109. Why is it called instantaneous relay?

Ans. Due to a small operating time, it is called an instantaneous relay.

Q110. How does operating time depend on the energized current?

Ans. Practically independent of the value of current.

Q111. In which supply system is the instantaneous relay used?

Ans. It can be used for an A.C. supply system as well as for a D.C. supply system.

Q112. What is meant by snap action of attracted armature relay?

Ans. The process of armature getting attracted toward the magnet with a jerk is called snap action.

Q113. How can the current setting of the relay be changed without changing the number of turns on the coil?

Ans. (1) By changing the air gap lengths.

(2) By changing the tension in the spring.

Q114. Why is the reset value smaller than the pickup value?

Ans. Because at the time of resetting the length of air gap is smaller as compared to that while picking up.

Q115. For 50 c/s, A.C. supply, what will be the frequency of the vibration of the armature?

Ans. 100 c/s.

Q116. What is the practical utility of determining pickup and reset values?

Ans. This helps in determining the error between actual values and those written on the plug settings.

Q117. What is the reset value in D.C. relay?

Ans. Zero.

Q118. What arrangement is provided in the relay to save the C.T. from being open circuited when the plug setting is changed?

Ans. The upper electromagnet has a primary and secondary winding. The primary is connected to the secondary of C.T. in the line to be protected and is provided with tappings. These tappings are connected to plug setting bridge which is usually energized to give seven selections of tapping. The overcurrent range being 50 to 200% on steps of 25% of the element which tends to operate; therefore, when the pin is withdrawn to change the setting while the plug in service, the relay adopts a high setting, thus ensuring that the secondary is not open circuited while the relay operates.

Q119. Where do we use the directional overcurrent relays?

Ans. Overcurrent relays are the most widely used in the protection of electric machines, apparatus, transformers, and the transmission lines from overload.

Q120. What is setting current?

Ans. The minimum current at which the relay operates is known as the setting current.

Q121. What is a pickup value?

Ans. The pickup value is the setting current. It is expressed as a percentage of rated current of the line or apparatus protected.

Q122. What are the difficulties encountered in the differential protection of a transformer?

Ans. Different ratio C.T. are required at the primary and secondary, so as to balance the current and phase angle. This will cause difficulties in calculations. The C.T. ratio should be changed for different types of transformer connections. In tap changing, the C.T. ratio should be changed for every tapping. At the time of switching the magnetizing current of the transformer is very high, which will create unbalancing, and so the relay will operate. The C.T. and its ratio may be changed with different types of connections.

Q123. Why is the operating coil connected to the midpoint of the restraining coil?

Ans. Only then it will not operate by occurrence of any fault outside the protected zone. Because the current in the secondaries of both the transformers will be the same and no current will flow through the relay. This care must be taken under normal conditions.

Q124. In how many ways can the slope of the bias characteristic be changed?

Ans. The slope can be changed by changing the restraining factor R_f:

$$R_f = \frac{N_r}{N_0}\sqrt{\frac{K_2}{K_1}}$$

where N_r and N_o are the number of turns in the restraining coil and operating coil, respectively. It can be changed by changing N_r or N_o. The AT of the restraining coil can be changed, since the current $(I_1\text{-}I_2)$ remains constant.

Q125. Why is it preferred to take on the X-axis of the time current characteristic of the relay multiples of the pickup value instead of the actual value of the current in amps?

Ans. The time current characteristics are the inverse definite minimum time type, since the time of operation is inversely proportional to the current and tends to definite minimum time as the current increases without limit, so that the multiple of the pickup value of current is taken along the *X*-axis. The multiple of the pickup value current is preferable to the actual value of the current. The actual value gives the quantity while the current setting multiplies the number of times of the relay current.

Q126. What are the conditions which must be satisfied before the overcurrent element is operated?

Ans. The directional overcurrent relay is set to operate for the condition when the current flowing in the given direction increases above the preset value. When the current in that direction increases over the given value, the direction at the element operates first and the circuit of the overcurrent element completes and hence the overcurrent element operates. This will complete tripping the circuit breaker, and the faulty element is cut off from circuit.

Q127. What is meant by directional control?

Ans. The directional element is fitted with the overcurrent relay for directional control. The directional control wants that the relay operate for the current flow in a given direction and not in the opposite direction. This type of arrangement is called directional control and is obtained by the directional element.

Q128. How would you reverse the directional features of the relay?

Ans. The torque generated in the relay will be: $T = VI \cos \phi$ which is the power equation. The voltage, current, and power factor angle α will give us the torque. The reversal of the directional feature is that ϕ should exceed 90°. The torque will reverse.

$$T = K\,\phi_1\,\phi_2 \sin \alpha = K\,VI \sin (90 - \alpha)$$

$$= K\,VI \cos \alpha.$$

Q129. What is a relation between iron loss and copper loss at the maximum efficiency of electrical machines?

Ans. Copper loss in watts equals the iron loss in watts at the maximum efficiency.

Q130. If we use a generator at overload, what will happen?

Ans. The losses will be more and the power generated will not be economical. Excessive overloading may cause the insulation failure.

Q131. Why do we use a commutator in D.C. machines with a brush gear?

Ans. In the conductor A.C. voltage is induced. We convert A.C. voltage to D.C. voltage by the commutator and brush gear.

Q132. If the brush gear is not fixed but rotated with the speed of the armature, what type of voltage will be obtained?

Ans. We will obtain the same voltage which exists inside the armature. No commutation will take place.

Q133. If the speed of the armature and that of the brush gear is not equal, which type of voltage will be obtained?

Ans. A.C. voltage of relative speed frequency will be obtained. The difference of the two speeds will appear as the frequency of the A.C. voltage.

Q134. Why do we use a soft iron cylinder in moving coil instruments of a permanent magnet type?

Ans. The moving coil is fitted in the iron cylinder. The fitting of the coil is for one purpose. The other purpose is for magnetic shielding for the moving coil.

Q135. What arrangement of damping is provided in the moving coil permanent instruments?

Ans. Damping is made by eddy currents induced in the aluminum form upon which the moving coil is wound.

Q136. Which type of instruments are used only for D.C. measurement?

Ans. Moving coil permanent magnet voltmeters and ammeters are made to measure D.C. voltage and D.C. current.

Q137. Which type of instrument is used for A.C. measurement only?

Ans. Induction type voltmeters, ammeters, and watt meters are made for A.C. measurement only.

Q138. Name the types of instrument which are used for both A.C. and D.C. types of measurement.

Ans. Moving iron type, electrodynamometer type, electrostatic type, and hot wire type instruments can measure both the A.C. and D.C. A common scale is provided for the measurements and marked A.C./D.C.

Q139. In order that the power loss in the instrument shall be small, the ammeter resistance must be small and the voltmeter resistance large. Justify this.

Ans. The power loss in the ammeter which measures a current will be given by

$$(P)_A = I^2 R_A \text{ watts}$$

where R_A is the resistance of ammeter coil. Obviously, the R_A must small.

To measure the current I, the R_A must be small to reduce the loss of energy.

The power loss in the voltmeter which measures a voltage, V will be given by

$$(P)_V = \frac{V^2}{R_V} \text{ watts}$$

Obviously, to reduce the power loss $(P)_V$, the voltmeter resistance R_V must be large.

Q140. Name the type of error when a moving iron instrument is used for both A.C. and D.C. measurements.

Ans. (i) Hysteresis error

(*ii*) Stray magnetic fields.

(*i*) The readings are higher when descending values of current or voltage are measured than when ascending values are observed. This error may be reduced by making short iron parts.

(*ii*) Other magnetic fluxes can disturb the deflection of the needle. It can be reduced by magnetic screening by iron case or iron shield.

Q141. What is the law of resistance variation?

Ans. The law of increase of resistance of platinum with increase of temperature has been found to be:

$$R_t = R_o[1 + \alpha t + \beta t]^2$$

where R_t = resistance at temperature $t°$ C.

R_o = resistance at temperature 0° C.

alpha and β are the constants. Callender found that for pure platinum material α = 0.0037 and β = 0.00000057. A single constant α is used for the common applications and measurements

$$R_t = R_o(1 + \alpha t)$$

This law is sufficiently accurate for small temperature changes.

Q142. In the broadest sense, instruments may be divided into how many classes?

Ans. Two classes:

(*i*) Absolute instruments; and

(*ii*) Secondary instruments.

The absolute instruments measure the quantity in terms of constants of instruments and the deflection. Tangent galvanometers and Rayleigh current balances are the examples. The secondary instruments measure the quantity in terms of the deflection of the instrument.

Q143. How many types of secondary instruments are used?

Ans. There are three types secondary instruments.

(*i*) Indicating

(*ii*) Integrating

(*iii*) Recording.

A common voltmeter, ammeter, and wattmeter are the indicating instruments.

Energy meter and ampere-hour meter are the integrating instruments, and path tracing of a quantity with time is made by the recording instruments.

Q144. A consumer had a claim that his meter reads much more than what he used to consume. The meter was repaired and it was found that the bill was 10% of the original bill, in spite of the constant consumption of the house owner. The company wanted to check the consumer's activities and again the meter was checked and the bill was the same as the original bill. What had been done with the meter in between checking?

Ans. The connections of the current coil were changed. The 10% bill might be due to the voltage coil or creeping errors.

Q145. The pole of a D.C. machine is laminated and the yoke is not laminated, why?

Ans. The poles have the changing flux in the air gap, therefore, to reduce the eddy current losses the poles are laminated. The yoke has constant flux with no changes, therefore, eddy current loss is absent. We need not to make it laminated.

Q146. What is a stacking factor?

Ans. The ratio of iron content in the laminated varnished core is called the stacking factor. The factor is about 90% or 0.9. Due to stampings the net iron material is reduced to 90% and 10% will be varnish and air, etc.

Q147. What is impregnation? Why are insulating materials impregnated?

Ans. Impregnation is a process by which we fill the varnish or solidifying liquids into the pores of a material like clothes and papers. Solidifying liquids like the tung oil and linseed oils are useful for impregnation. Paraffin is the most useful impregnating liquid.

The cloths, papers, wood, and so on are impregnated to fill the pores of air. Air is a weak dielectric and it must be removed from the pin-hole. The mechanical and electrical properties of materials are improved through impregnation.

Q148. What is street main? What is consumer's main? Which main has the higher current capacity?

Ans. Street main is the electric line installed on the street. This is one type of distributor. The consumer main is the connecting wire which connects the street main to the consumer house wiring.

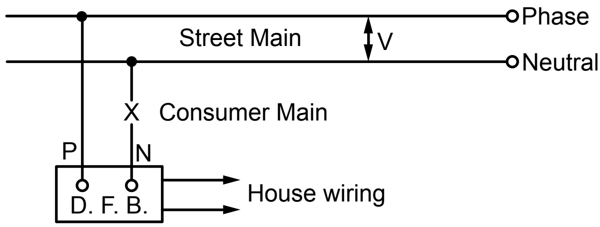

Figure 148.1

The street main has a higher capacity of current than the consumer main.

Q149. What is a feeder? What is a distributor? Which one link has higher current capacity?

Ans. A feeder is a line to feed the power from a generator to a substation transformer. It can be defined as a connecting link between a generator and the generator bus.

The distributor is a link which distributes power to the consumer. The street main may be a distributor from which the consumers take the power. Figure 149.1 will give a picture of feeders and a distributor.

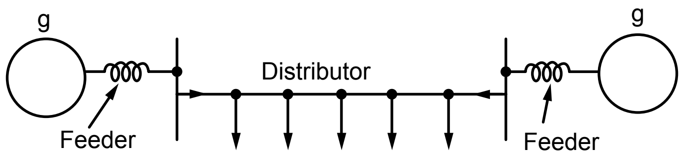

Figure 149.1

Q150. What is an infinite bus bar? Why is an alternator connected to an infinite bus-bar?

Ans. The infinite bus-bar is a very large bus-bar where an infinite number of loads are connected in parallel. The average power factor, frequency, and voltage may be assumed constant. For a practical example, the connection of millions of lamps, fans, heaters, and other domestic appliances form a nature of infinite number of loads.

The control problem of an alternator becomes simple if we connect it to the infinite bus bar. The voltage and frequency of the alternator become constant, the red power and reactive power can be controlled by controlling the coal input and excitation, respectively.

Q151. Make a block diagram of an alternator to represent the inputs and outputs. How will you control the four outputs by two inputs available in an alternator?

Ans. The block diagram of an alternator is represented in Figure 151.1. There are four output variables and two input variables.

i_f: field current.

T: torque are the inputs.

P: real power in watts.

Q: reactive power in volt-amperes.

V: voltage and

f: frequency c/s are the output variables.

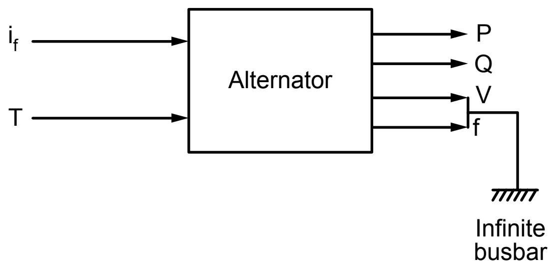

Figure 151.1

It is impossible to control four output variables with two input variables. Therefore, we must connect the voltage and frequency to the infinite bus bar where these may be kept constant.

Q152. Why do we call alternators synchronous machines?

Ans. The rotating magnetic field and the D.C. field of the rotor are in synchronism. Synchronism can be realized when the soldiers of a company make a left-right. The hands and legs are in synchronism, that is, moving without time lag.

Similarly, the field of the stator and the field of the rotor moves at one speed only. Therefore, we call it the synchronous machine. The synchronous speed is fixed by the poles and frequency:

If f = 50 and P = 8, then

$$N_s = \frac{120 \times 50}{8} = 750 \text{ RPM}$$

The rotor of the alternator must be moved at 750 RPM only to keep the machine in synchronism.

Q153. Where will you use a synchronous motor?

Ans. We use synchronous motors in paper mills and cotton mills, which require a constant speed.

Q154. A direct current cannot pass through a capacitor but alternating current can pass, why?

Ans. The capacitor offers a high impedance to the current, therefore, the current will be zero. As a matter of fact the impedance is infinite:

$$\cdot Z = j\,\frac{1}{\omega C}$$

Since $\omega = 0$ for a D.C. supply.

$$Z = \frac{1}{0} = \infty$$

If we give a supply of 50 c/s to the capacitor, the reactance will be finite and the current will flow. In the D.C. case the capacitor does not allow the current flow. The current will practically be zero, due to the open circuit.

Q155. If we supply a direct current to an A.C. network, what will happen?

Ans. The network will become a resistive network. The inductances will work as short-circuited and capacitances will be open circuited.

Q156. What is a reactance diagram? How does the reactance diagram become useful on a D.C. network analyzer?

Ans. In the case of A.C. networks, if the resistance of the systems is neglected, the reactance remains in the circuit. The circuit with the reactances only is called the reactance diagram. The reactance diagram is useful on the D.C. network analyzer to calculate the short-circuit current. We replace the reactance by the resistances on the analyzer.

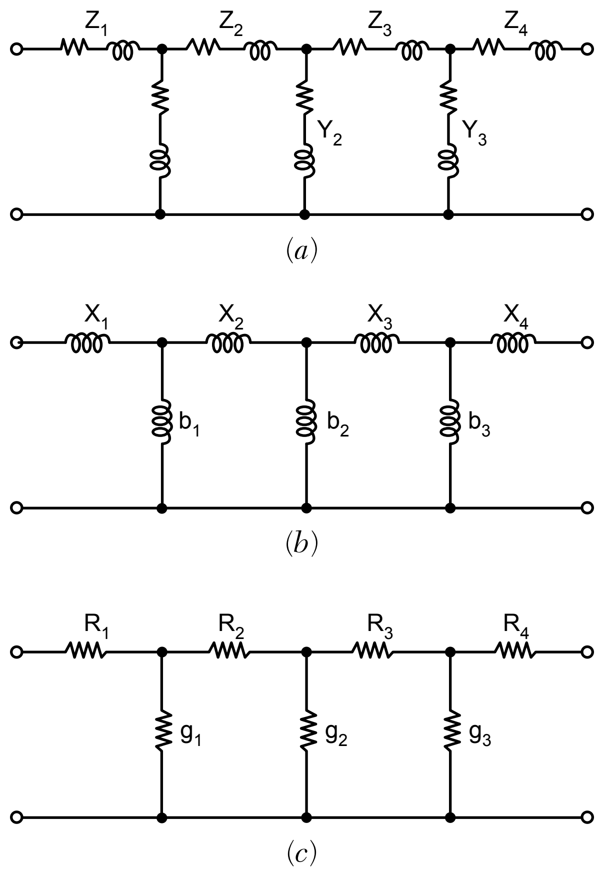

Figure 156.1

(*a*) Impedance diagram

(*b*) Reactance diagram

(*c*) D.C. network analyzer diagram.

Q157. How will you recognize a Megger and a Megger Earth tester?

Ans. A Megger has only two points while the Megger Earth tester has three points. One point of the Earth tester is connected to the earth electrode.

Q158. Why do we measure the resistance of the earth electrode by Megger Earth tester but not with the simple Megger?

Ans. The resistance of the earth electrode or earth wire is not only meaningful, but we wish to measure the resistance of the earth vicinity, up to the length of 150 feet.

The charge accumulated on the equipment must go to the earth immediately. The resistance will be a sum of $R_1 + R_2 + R_3 = R_E$. We call it the resistance of the earth connection.

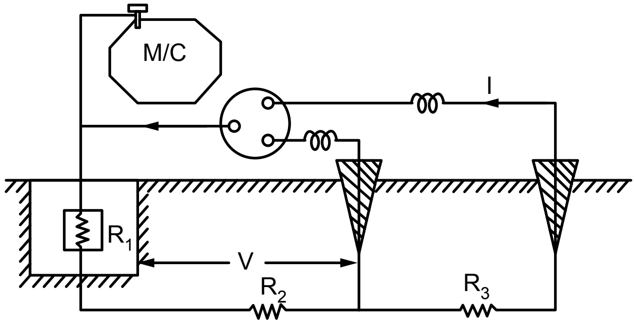

Figure 158.1

Q159. When there was no earth tester, how was earth resistance measured?

Ans. The earth resistance was measured by supplying 500 volts between the earth electrode and one peg of iron, 150 feet apart, by a generator. The current was measured by an ammeter flowing through the peg. A voltage was measured by a voltmeter between the earth electrode and a second peg at 75 feet away. The resistance calculated was

$$R_E = V/I.$$

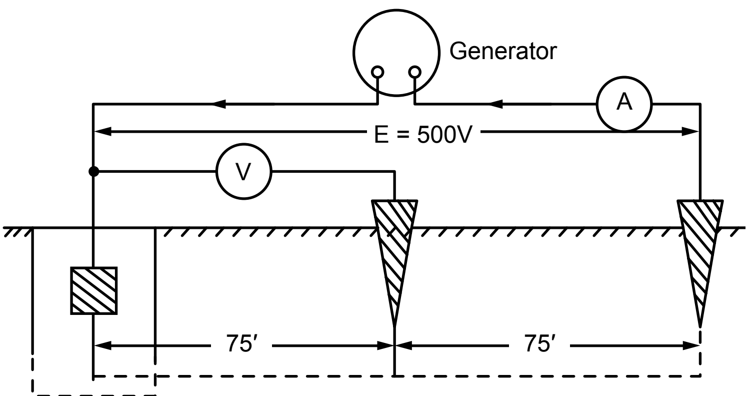

Figure 159.1

This was the primitive method to measure the earth resistance.

Q160. Why do we measure the earth resistance of an electric pole stay wire and stay peg in summer, winter, and rainy seasons?

Ans. To check the poles, whether the resistance is zero or nearly zero. If the resistance of the pole is not zero, install an earth wire and ground it by a coil. If the earth resistance of the pole is more than 1000 ohm, it must be reduced or dismantle it. The possibility of shock hazard is more if the insulator fails.

In all three seasons the earth resistance of the poles and stay wires must be recorded, for the safety of human beings and animals.

Q161. Why do we provide a plate in the bottom of an electric pole?

Ans. The plate is provided so that a proper contact of the earth may come with the pole body. The charge will go to the earth at a greater rate.

Q162. Why do we use a stay-wire with an electric pole?

Ans. This is used to support the pole against extra tension produced by a terminating line.

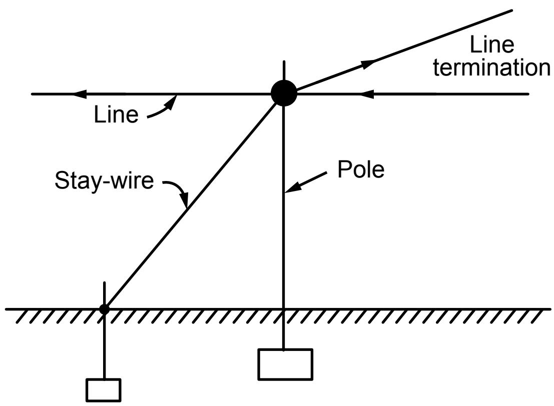

Figure 162.1

Q163. What is a thimble and where we do use it? Why do we use the thimble?

Ans. It is a M.S. oval type ring with a channel. The thimble is used for the binding of stay wire with the stay-peg through elbow. The thimble is used to save the life of the stay wire binding. By relative motion due to wind and animals, the stay wire gets friction. Its life will be reduced and may break at any time, paralyzing the electrical installation.

Q164. What is the length of a stay-peg?

Ans. About 6 feet in length for ordinary distribution.

Q165. How many types of line joints do you know?

Ans. **Splicing:** used for stranded line conductors.

Married joint: used for hard draw copper conductors

Scarf joint.

T-joint: used for terminating a line.

Q166. How many methods are used to make a house wiring?

Ans. Loop method and cut-method are the two methods generally used. In the cut method the wire is cut and in the loop method the wire is not cut into pieces, but a loop is used.

Q167. How many types of wiring do you know for installations?

Ans. Casing-capping wiring, batten wiring, cleat wiring, pipe wiring or conduit wiring, under wall wiring, etc.

Q168. Why do we provide a groove on the top of an insulator used in a telephone line or electric line?

Ans. The groove is provided to support the conductor and the binding of the conductor on the insulator is facilitated.

Q169. Why do we provide a petticoat to the insulators?

Ans. A petticoat is provided to safeguard the conducting pin short-circuited in the rainy seasons. The length of water flow stream is broken. The water will not reach the pin. The water is a good conductor and link of water stream conductor, and the link of water stream will make a short-circuit between the conductor and the pin or the pole and the earth.

Q170. Why do we keep the Carbon brushes in a magnetic neutral axis?

Ans. For a linear commutation and sparkless working of the machine is obtained. A maximum voltage is generated at this position. This also fixes the armature winding at 90° angle from the pole-axis or magnetic axis.

Q171. If we keep the brushes just under the poles or on the magnetic axis how much voltage will be generated in the armature winding?

Ans. Zero voltage will be induced in the winding as the linkage will be zero.

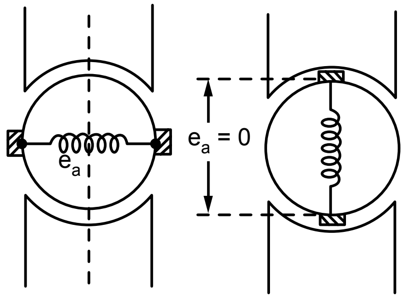

Figure 171.1

Q172. What is a commutation? What is a commutating coil?

Ans. Commutation is the process through which a current in a coil changes with time or brush length when the coil passes through the brush.

The coil which passes through the brush in a short period called the short-circuited coil or the commutating coil.

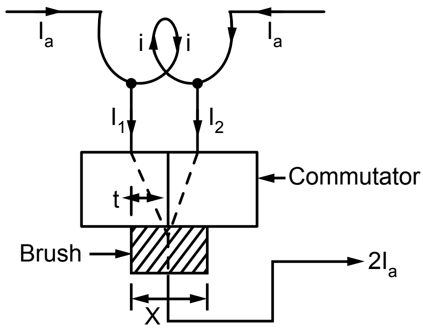

Figure 172.1

Figure 172.1 represents the short-circuited coil, C, which will be under the commutation for time period X for the brush length. The complete armature is throwing current to the brush at this state.

Q173. What is a dark commutation? Derive an equation for the dark commutating current in a simple manner.

Ans. Dark commutation is a sparkless commutation named a linear commutation. Current passes linearly in the coil under commutation and there is no chance of throwing sparks through the brushes.

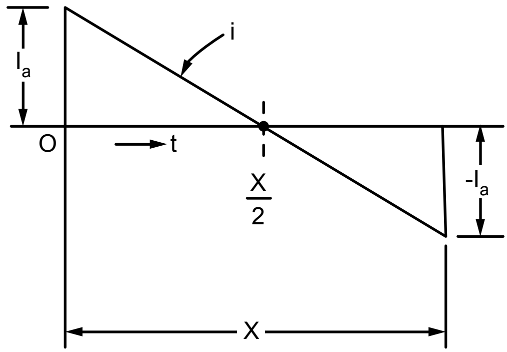

Figure 173.1

The derivation will be simple. We use Figure 173.1. The currents I_1 and I_2 will pass through the commutator segments producing uniform current density:

Or $$\frac{I_a + i}{t} = \frac{I_a - i}{X - t}$$

Or $$i = I_a\left[1 - \frac{2t}{X}\right]$$

Q174. Which type of motor is used in the fans used in trains?

Ans. D.C. shunt motors.

Q175. The speed torque curves of a D.C. shunt motor and induction motor are similar–discuss. Where would these curves be suitable?

Ans. The speed falls slowly when a load is applied; this is called the shunt characteristic.

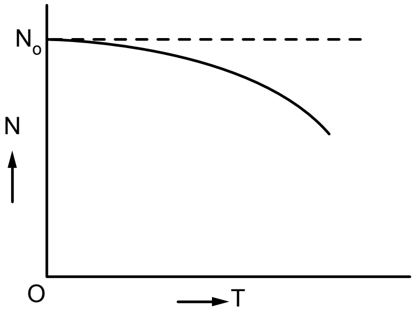

Figure 175.1

This is suitable for the centrifugal pumps, flour mills, and electric fans.

Q176. Define the magnetic flux line.

Ans. A line of magnetic flux originates from a north pole and reaches to the south pole and again to the north pole making a closed path. It is very necessary to make the closed path for the line for its existence.

Q177. Why do we use a yoke in the D.C. machine?

Ans. A yoke is used to make the path of flux complete. The flux-lines originate from the north pole and reach to the south pole through the air gap and the armature. From the south pole they reach to the north pole through the yoke.

Q178. Why do we choose diamagnetic materials as conductors?

Ans. Diamagnetic materials are such in which flux cannot enter. These repel the flux and eddy current losses are reduced.

Copper, silver, and aluminum are the diamagnetic materials. These have negative susceptibility, $-X_m$.

Q179. How can we find resistivity of mixtures?

Ans. The resistivity of mixtures is found by the logarithmic law of mixing. If the contents are specified by their resistivities, ρ_1, ρ_2 and ρ_3 and volume constants V_1, V_2 and V_3, we may find the total resistivity as follows.

$V \log_e \rho = V_1 \log_e \rho_1 + V_2 \log_e \rho_2 + V_3 \log_e \rho_3$ where V and P are the total volume and resistivity.

Q180. How will you find the permittivity of mixtures?

Ans. We may find the permittivity of mixtures by the logarithmic law of mixing. If ϵ_1, ϵ_2 and ϵ_3 are the permittivity of the contents, and V_1, V_2 and V_3 volumes, we have

$$V \log_e \epsilon = V_1 \log_e \epsilon_2 + V_2 \log_e \epsilon_2 + V_3 \log_e \epsilon_3.$$

Q181. How will you find the permeability of mixture magnetic materials?

Ans. By the logarithmic law of mixing as given above.

Q182. How will you determine the conductivity of mixtures?

Ans. The logarithmic law of mixing will be used as given above.

Q183. Which type of dielectric materials are used for the common purposes of power systems? Name some of them and mark their dielectric constant.

Ans. Paper, clothes, woods, asbestos, mica, rubber, ebonite bakelite porcelain, plastics, resins, etc., are common materials. The permittivity is between 1 and 4. The paper cloth, oils, woods, asbestos, etc., have permittivity of about 2.2.

Q184. Do you use the materials at a raw state? If you use the cloth as the insulator, will it work satisfactorily? If not, which process do you apply to the materials?

Ans. Materials are never used as dielectrics in the natural state but are impregnated by the solidifying liquids. Linseed and tung oils are commonly used vegetable oils for impregnation. Paraffin and wax are also used for the purpose.

Q185. Why do we use oil in a power transformer?

Ans. There are two main purposes for using oil in the power transformer.

(*i*) Cooling purpose, the heat is carried by the liquid in the contact to the winding up to the tank surface from where it is radiated.

(*ii*) Windings are insulated from the tank surface by the oil. The oil has a higher dielectric constant, 2.2, than air. It provides the higher capacitance.

Mineral oils are used as transformer oils, and cooling and insulating oils are called transformer oils.

Q186. What is a power oil? Do you consider transformer oil as a power oil?

Ans. Oils used in circuit breakers, switches, autotransformers, and other devices for cooling purposes and for quenching of the arc are called power oils. Transformer oil is also a type of power oil.

Q187. Why do we not use vegetable oils for the transformers?

Ans. Vegetable oils have higher viscosity and fast aging.

Q188. Why do we use a current transformer with wattmeter current coil in the short-circuit test on a transformer?

Ans. When a current coil rating is less than the current in the circuit, a current transformer of suitable ratio is used as shown in Figure 188.1.

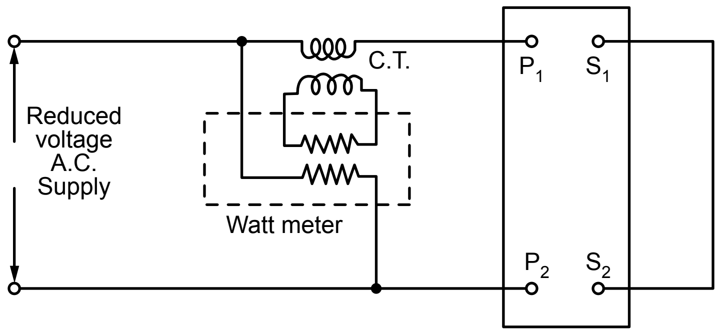

Figure 188.1

The coil of the wattmeter may be burned due to more current. It is for the safety of the instrument.

Q189. A wattmeter is used to measure the power using a current transformer. The multiplying factor of the wattmeter is 0.5 and the C.T. ratio is 20/5. Find the power taken by the circuit if the reading of the wattmeter is 120 watts.

Ans. If the multiplying factor is q and the C.T. ratio is a, then the power taken will be

$$W \times q \times a = W_a$$

$$120 \times 0.5 \times 4 = 240 \text{ watts.}$$