**Government Polytechnic Vaishali, Bihar**
Under Department of Science, Technology and Technical Education, Bihar
Affiliated By State Board of Technical Education

# LAB MANUAL

## DC MACHINES & TRANSFORMERS

SUBJECT CODE – P2420303

**Government Polytechnic Vaishali**

# Department of Electrical Engineering

## Vision

To nurture industry-ready and ethically responsible diploma engineers in Electrical Engineering, equipped with modern technical skills, digital competence, and adaptability to support evolving industrial, infrastructural, and societal needs.

## Mission

**M1**: To provide a student-centric and outcome-based learning ecosystem that integrates classroom instruction with modern laboratories, simulation software, digital learning platforms, and hands-on practices for effective knowledge acquisition.

**M2**: To impart application-oriented technical skills in electrical machines, power distribution systems, industrial wiring, control circuits, basic automation, and testing instruments, emphasizing safety standards, quality practices, and the use of contemporary tools and technologies.

**M3**: To strengthen industry readiness, employability, entrepreneurship, and preparedness for higher education through industry–institute interaction, internships, field exposure, expert lectures, skill development programs, guidance, innovation support, and awareness of emerging trends such as energy efficiency, renewable integration, and smart electrical systems.

**M4**: To foster professional ethics, teamwork, communication skills, problem-solving ability, environmental consciousness, and lifelong learning attitude, enabling diploma holders to contribute responsibly to industry, society, and national development.

# Practical/Lab Session Outcomes (LSOs)

| S.NO | Laboratory Experiment | Lab Session Outcomes |
|---|---|---|
| 1 | Identification of parts of a DC Machine by dismantling the cut section model of a DC machine | Identify different parts of a DC machine. |
| 2 | Effect of speed and field flux on generated voltage of DC shunt generator | Interpret the effect of speed and field flux on generated voltage of DC shunt generator. |
| 3 | Load test of DC shunt Generator | Test the performance of DC shunt generator on the given load condition. |
| 4 | Load test of DC series Generator | Test the performance of DC series generator on the given load condition. |
| 5 | Starting of D. C shunt motor using 3 point /4-point starter | Use appropriate DC motor starter for starting the given DC Motor. |
| 6 | Reversal of Direction of a DC Shunt motor | Change e terminal connection of DC shunt motor and observe the direction of rotation |
| 7 | Speed control of D.C shunt motor | Control speed of DC Shunt motor using field/flux control method (Above rated speed) |
| 8 | Speed control of a D.C. Shunt motor | Control speed of DC Shunt motor using armature control method (Below rated speed). |
| 9 | Load test of D. C. shunt motor | Test performance of DC shunt motor on the given load condition. |
| 10 | Load test of D.C. series motor | Test performance of DC series motor on the given load condition. |
| 11 | Brake test of D.C. shunt motor. | Apply direct method to brake the DC shunt motor. |

| | | |
|---|---|---|
| **12** | Measurement of voltage and current ratio of a given single phase transformer. | Measure voltage and current ratio of a given single phase transformer |
| **13** | Polarity of a single-phase transformer | Test polarity of the given single phase transformer. |
| **14** | Direct load test on a single-phase transformer | Test performance of a given transformer by direct load test. |
| **15** | No load waveform of a transformer using CRO | Observe the no load waveform of a given transformer using CRO |
| **16** | Open Circuit and Short Circuit test on a single-phase transformer. | Perform Open Circuit and Short Circuit test on a single-phase transformer. |
| **17** | Parallel operation of two single phase transformers. | Perform parallel operation of two 1-phase transformer having equal and unequal KVA rating under given load. |
| **18** | Auto transformer and 1-phase two winding transformer of same rating | Test performance of an auto transformer and 1-phase two winding transformer of same rating. |
| **19** | Parallel operation of two three phase transformers for equal and unequal load sharing. | Perform parallel operation of two 3-phase transformer having equal and unequal load sharing for a given load. |
| **20** | Current ratio of a Current transformer | Measure current ratio of the given Current transformer using ammeter/clamp meter. |
| **21** | Voltage ratio of a Potential Transformer | Measure voltage ratio of the given Potential transformer using voltmeter. |

# LIST OF EXPERIMENTS

| | |
|---|---|
| **1** | Identification of parts of a DC Machine by dismantling the cut section model of a DC machine |
| **2** | Effect of speed and field flux on generated voltage of DC shunt generator |
| **3** | Load test of DC shunt Generator |
| **4** | Load test of DC series Generator |
| **5** | Starting of D. C shunt motor using 3 point /4-point starter |
| **6** | Reversal of Direction of a DC Shunt motor |
| **7** | Speed control of D.C shunt motor |
| **8** | Speed control of a D.C. Shunt motor |
| **9** | Load test of D. C. shunt motor |
| **10** | Load test of D.C. series motor |
| **11** | Brake test of D.C. shunt motor. |
| **12** | Measurement of voltage and current ratio of a given single phase transformer. |
| **13** | Polarity of a single-phase transformer |
| **14** | Direct load test on a single-phase transformer |

| | |
|---|---|
| **15** | No load waveform of a transformer using CRO |
| **16** | Open Circuit and Short Circuit test on a single-phase transformer. |
| **17** | Parallel operation of two single phase transformers. |
| **18** | Auto transformer and 1-phase two winding transformer of same rating |
| **19** | Parallel operation of two three phase transformers for equal and unequal load sharing. |
| **20** | Current ratio of a Current transformer |
| **21** | Voltage ratio of a Potential Transformer |

# PRACTICAL OUTCOMES

| CO | Statement |
|---|---|
| 1 | Test the performance of DC Generators. |
| 2 | Control the speed of DC motors as per the requirement. |
| 3 | Test the performance of Single-Phase transformers. |
| 4 | Operate two three phase transformers in parallel as per the requirement. |
| 5 | Use special purpose transformers as per the requirement. |

# PROGRAM EDUCATIONAL OBJECTIVES (PEO)

| PEO No. | Program Educational Objectives Statements |
|---|---|
| **PEO1** | To prepare diploma holders with a strong foundation in electrical engineering fundamentals and state-of-the-art technologies, enabling continuous learning, skill upgradation, and adaptability to emerging industrial and technological trends. |
| **PEO2** | To develop professionally responsible diploma holders with effective communication skills, leadership qualities, ethical values, and the ability to work efficiently as individuals and as members of multidisciplinary teams. |
| **PEO3** | To enhance employability by providing industry-oriented training, hands-on experience, and exposure through industrial visits, internships, seminars, workshops, and interaction with industry professionals and academicians. |
| **PEO4** | To enable diploma holders to apply project-based learning, modern tools, and innovative approaches to develop solutions addressing technical, socio-economic, and environmental challenges in a sustainable and socially responsible manner. |

# PROGRAM SPECIFIC OUTCOMES

PSO1: Design, Install, operate, and troubleshoot electrical systems, machines and power circuits using modern tools while adhering to safety standards and environmental consideration.

PSO2: Work effectively in multidisciplinary teams to solve real-time electrical engineering problems and communicate technical information clearly and professionally.

# PROGRAM OUTCOMES (POS)

P01: Basic and Discipline specific knowledge: Apply knowledge of basic mathematics, science and engineering fundamentals and engineering specialization to solve the engineering problems.

PO2: Problem analysis: Identify and analyse well-defined engineering problems using codified standard methods.

PO3: Design/ development of solutions: Design solutions for well-defined technical problems and assist with the design of systems components or processes to meet specified needs.

P04: Engineering Tools, Experimentation and Testing: Apply modern engineering tools and appropriate technique to conduct standard tests and measurements.

PO5: Engineering practices for society, sustainability and environment: Apply appropriate technology in context of society, sustainability, environment and ethical practices.

PO6: Project Management: Use engineering management principles individually, as a team member or a leader to manage projects and effectively communicate about well-defined engineering activities.

PO7: Life-long learning: Ability to analyze individual needs and engage in updating in the context of technological changes.

# Experiment No: 01

**Identification of Parts of a DC Machine by Dismantling the Cut-Section Model**

## 1. Aim

To identify, examine and study the function of various constructional parts of a DC machine by dismantling a cut-section (demonstration) model of a DC machine.

## 2. Theory

A DC machine (motor or generator) is broadly divided into two parts: the stationary part (stator) and the rotating part (rotor/armature). The stationary part consists of the yoke, poles, pole shoes and field winding, while the rotating part consists of the armature core, armature winding, commutator and shaft.

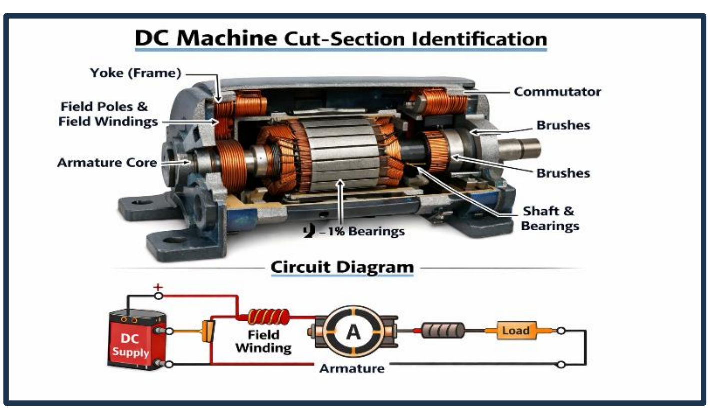
The magnetic circuit of the machine is completed through the yoke, pole core, air gap and armature core. The field winding, wound on the pole core, carries the exciting current and produces the main flux. The armature winding, placed in the slots of the laminated armature core, is where the EMF is induced (in case of a generator) as it rotates in the magnetic field, or torque is developed (in case of a motor).

The commutator, mounted on the shaft along with the armature, is made of wedge-shaped hard-drawn copper segments insulated from one another and from the shaft by mica. Along with the carbon brushes resting on it, the commutator performs the essential function of mechanical rectification — converting the alternating EMF generated in the armature conductors into unidirectional (DC) EMF at the brushes, and vice-versa in a motor.

Interpoles (commutating poles) are small auxiliary poles fixed to the yoke, midway between the main poles, and connected in series with the armature circuit. They neutralise the cross-magnetising effect of armature reaction and assist in achieving sparkless commutation.

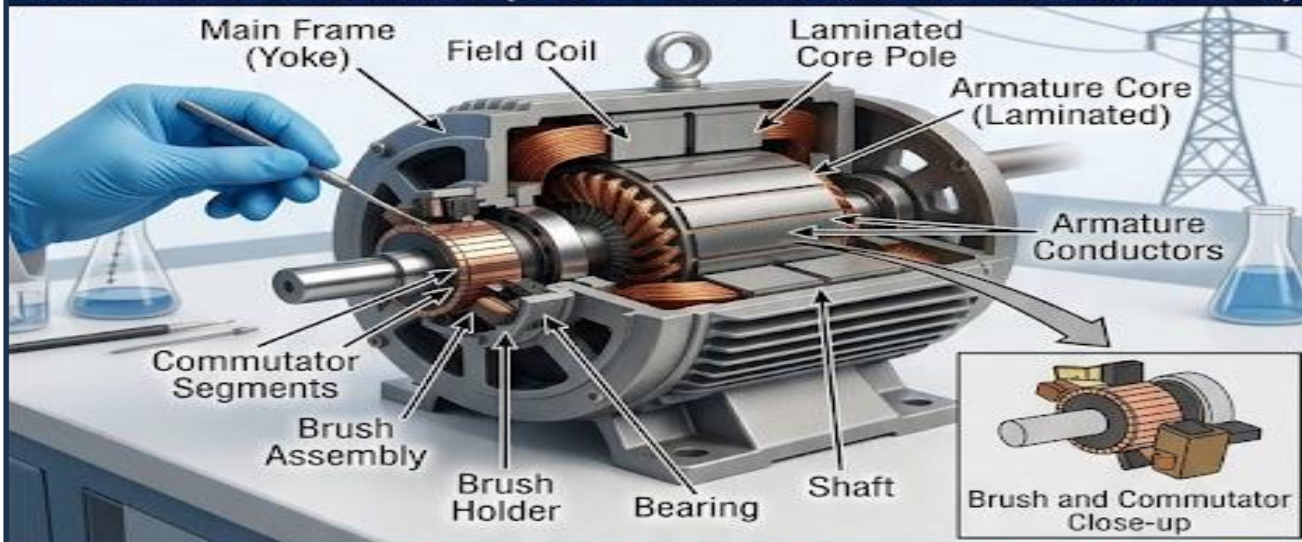
## 3. Practical Set-up / Circuit Diagram

The cut-section model of the DC machine is mounted on a base and sectioned longitudinally so that the yoke, poles, field coils, armature core, armature winding, commutator, brushes and shaft can be viewed and physically dismantled part by part. A labelled sketch of the model is drawn showing the relative position of the yoke, main poles, interpoles, field winding, armature, commutator and brush gear.

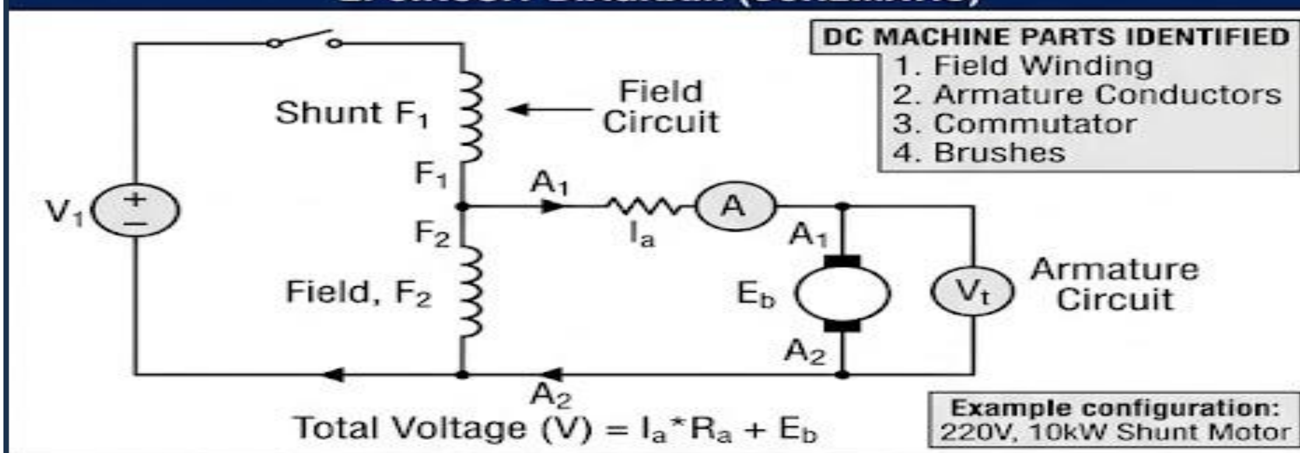


# IDENTIFICATION OF PARTS OF A DC MACHINE (DISMANTLING A CUT-SECTION MODEL)

## 1. PHYSICAL APPEARANCE (PHOTO - DISMANTLED CUT-SECTION MODEL)




## 2. CIRCUIT DIAGRAM (SCHEMATIC)




## 3. KEY PARTS & FUNCTIONS

| Part Name | Description / Function |
|---|---|
| **Stator (Yoke / Frame)** | Provides mechanical support and forms the magnetic path for field poles. |
| **Field Pole & Windings** | Creates a fixed magnetic field using DC excitation or permanent magnets. |
| **Armature (Rotor)** | Rotating assembly where torque is generated (motor) or electromotive force is induced (generator). |
| **Commutator** | Converts induced AC to DC (generator) or reverses current direction to maintain single-direction torque (motor). |
| **Brushes** | Collects current from the commutator and transfers it to the external circuit. |

***Note:** Dismantling a cut-section model is vital for understanding internal construction.*

## 4. Apparatus Required

| S.No. | Apparatus / Equipment | Quantity |
|---|---|---|
| 1 | Cut-section demonstration model of DC machine | 1 |
| 2 | Screw driver set | 1 set |
| 3 | Spanner set | 1 set |
| 4 | Marker / pointer for labelling | 1 |
| 5 | Notebook for sketching | 1 |

## 5. Precautions to be Followed

- Handle the cut-section model gently; do not apply excessive force while dismantling.
- Note the original position/orientation of each part before removing it, to facilitate correct reassembly.
- Do not touch the commutator surface and brush contact surface with bare oily hands.
- Keep all removed fasteners (nuts, bolts, screws) safely in a tray to avoid loss.
- Reassemble the model in the exact reverse order of dismantling.
- Handle mica-insulated commutator segments carefully; mica is brittle and can crack.

## 6. Procedure

1. Observe the complete assembled cut-section model and note its name-plate details, if any.
2. Sketch the general external view of the machine model.
3. Loosen and remove the end covers/end shields carefully using the screw driver/spanner set.
4. Withdraw the armature assembly (core, winding, commutator, shaft) from the yoke carefully.
5. Identify and examine the yoke, main poles, pole shoes, field winding and interpoles.
6. Identify and examine the armature core, armature winding, commutator segments and brush gear.
7. Note the material, shape and function of each part in the observation table.
8. Reassemble the machine model in the reverse sequence and verify free rotation of the shaft.

## 7. Observations and Calculations

| S.No. | Name of Part | Material Used | Function |
|---|---|---|---|
| 1 | Yoke (Frame) | Cast iron / Cast steel | Provides mechanical support, forms part of magnetic circuit, carries flux from one pole to next |
| 2 | Pole Core | Cast steel / Silicon steel laminations | Supports field winding, produces required flux |
| 3 | Pole Shoe | Cast steel laminations | Spreads flux over air gap, reduces reluctance, supports field coil |
| 4 | Field Winding | Copper wire (enamelled) | Carries excitation current, produces main magnetic flux |
| 5 | Armature Core | Silicon steel laminations | Houses armature winding, provides low-reluctance path for flux, |

| S.No. | Name of Part | Material Used | Function |
|---|---|---|---|
| | | | laminated to reduce eddy current loss |
| 6 | Armature Winding | Copper conductors | Carries load current, EMF is induced in it (generator) / develops torque (motor) |
| 7 | Commutator | Hard drawn copper segments (mica insulated) | Converts AC induced in armature to DC output (generator) / DC to AC in armature (motor) |
| 8 | Brushes | Carbon / Graphite | Collects current from commutator and delivers to external circuit |
| 9 | Brush Holder & Rocker Arm | Brass / Steel | Holds brushes in position, allows brush-shifting for sparkless commutation |
| 10 | Shaft | Mild steel | Transmits mechanical power, supports armature core and commutator |
| 11 | Bearings | Ball / Roller bearing | Support the shaft, allow free rotation with minimum friction |
| 12 | End Covers / End Shields | Cast iron | Close the machine at both ends, house bearings |
| 13 | Interpoles (Commutating poles) | Cast steel with copper winding | Neutralise armature reaction, improve commutation, connected in series with armature |

## 12. Results

The various constructional parts of the DC machine — yoke, poles, field winding, armature core, armature winding, commutator, brushes and interpoles — were successfully identified by dismantling the cut-section model, and their materials and functions were studied and recorded.

## 13. Viva Book

1. Why is the armature core laminated and not made of a solid block of steel?
2. What is the function of the commutator in a DC machine?
3. Why are brushes made of carbon and not copper?
4. What is the purpose of interpoles? Where are they connected?
5. Why is mica used between commutator segments?
6. What is the function of the yoke in a DC machine?
7. Differentiate between a lap winding and a wave winding.
8. Why is silicon steel preferred for the armature and pole laminations?

# Experiment No: 02

**Effect of Speed and Field Flux on the Generated Voltage of a DC Shunt Generator**

## 1. Aim

To study the effect of (a) armature speed (at constant field flux) and (b) field flux/field current (at constant speed) on the EMF generated by a DC shunt generator.

## 2. Theory

The EMF induced in the armature of a DC generator is given by the EMF equation: $E = (P\Phi ZN) / (60A)$ volts, where P = number of poles, $\Phi$ = flux per pole (Wb), Z = total number of armature conductors, N = speed of armature (rpm), and A = number of parallel paths.

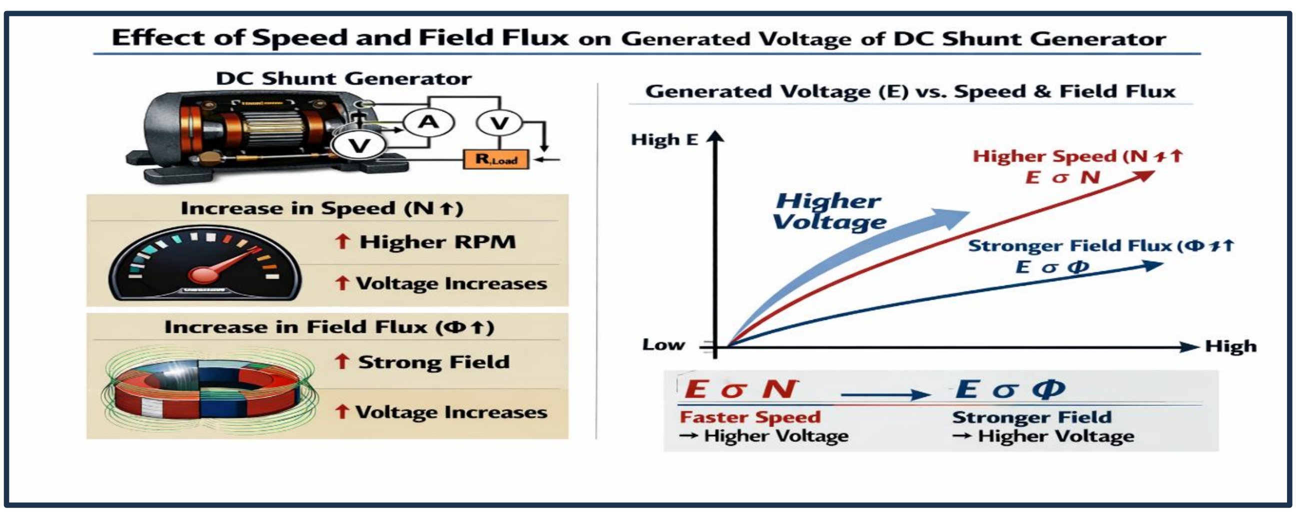
For a given machine, P, Z and A are constant. Hence the equation reduces to $E = K1\Phi N$, where $K1 = PZ/60A$ is a machine constant. This shows that the generated EMF is directly proportional to the speed N when the flux $\Phi$ (i.e. the field current) is held constant, and directly proportional to the flux $\Phi$ when the speed N is held constant.

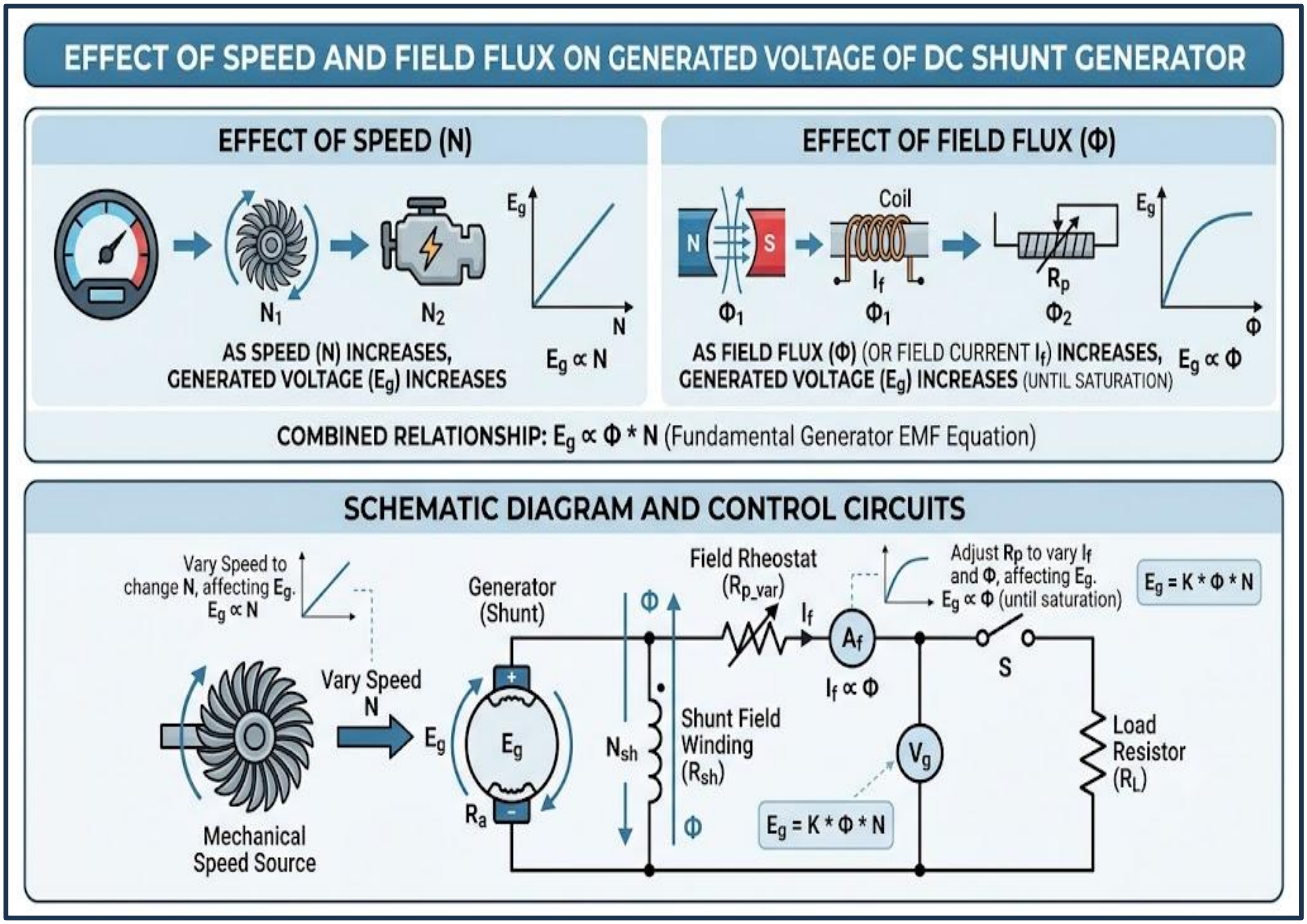
In the first part of the experiment, the field current is kept constant (using the field rheostat) and the speed of the prime mover is varied in steps; the generated EMF is noted at each speed, verifying $E \propto N$.

In the second part, the generator is run at constant speed and the field current is varied by adjusting the field rheostat; the generated EMF is noted at each value of field current, giving the open-circuit (magnetisation) characteristic, which is linear initially and bends over due to magnetic saturation of the iron at higher field currents.

## 3. Practical Set-up / Circuit Diagram

The DC shunt generator is coupled to a prime mover (DC/AC motor with speed control). The field winding is connected across the armature (through a field rheostat) to a DC exciter supply/battery for the self/separately-excited test. A voltmeter is connected across the armature terminals (on open circuit, no load), an ammeter is connected in the field circuit, and a tachometer/speed indicator is used to measure the speed of the set.






## 4. Apparatus Required

| S.No. | Apparatus / Equipment | Quantity |
|---|---|---|
| 1 | DC shunt generator | 1 |
| 2 | Prime mover with speed control (DC motor / drive) | 1 |
| 3 | Moving-coil voltmeter (0-300 V) | 1 |
| 4 | Moving-coil ammeter (0-2 A) | 1 |
| 5 | Field rheostat | 1 |
| 6 | Tachometer | 1 |
| 7 | Connecting leads | as required |

## 5. Precautions to be Followed

- Keep the field rheostat at maximum resistance position before starting the set.
- Ensure the generator is run on no-load (open circuit) throughout the test.
- Start the prime mover at low speed and increase gradually to the rated value.
- Take readings quickly to avoid heating of the field winding at low speeds.
- Ensure all meter connections are of correct range and polarity before switching on.
- Do not exceed the rated speed and rated field current of the generator.

## 6. Procedure

1. Connect the circuit as per the diagram with the generator field connected through a rheostat and a voltmeter across the armature terminals on open circuit.
2. Part A (Effect of Speed): Set the field rheostat to give a fixed, moderate field current (note and keep this value constant throughout Part A). Start the prime mover and gradually increase the speed in steps; at each speed, note the speed N and the corresponding generated EMF E, keeping If constant.
3. Part B (Effect of Field Flux): Bring the set to a fixed rated speed and maintain this speed constant using the prime mover speed control throughout Part B. Vary the field current in steps (from zero to rated value) using the field rheostat and note the corresponding generated EMF E at each step.
4. Plot the graph of E versus N (for constant Φ) and E versus If (for constant N — the magnetisation characteristic).
5. Switch off the supply and disconnect the circuit after completing observations.

## 7. Observations and Calculations

Table 1: Effect of Speed on Generated EMF (Field Current constant)

| S.No. | Speed N (rpm) | Field Current If (A) [constant] | Generated EMF E (V) |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |

Table 2: Effect of Field Current on Generated EMF (Speed constant)

| S.No. | Field Current If (A) | Speed N (rpm) [constant] | Generated EMF E (V) |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |

**Calculations:**

For Part A, plot E (Y-axis) vs N (X-axis) — a straight line passing nearly through the origin is obtained, verifying $E \propto N$. For Part B, plot E (Y-axis) vs If (X-axis) — the open-circuit characteristic (magnetisation curve) is obtained, which is linear at low If and bends over (saturates) at higher If due to magnetic saturation of the pole and yoke iron.

## 12. Results

It was verified experimentally that the EMF generated by a DC shunt generator is directly proportional to the speed of rotation when the field flux (field current) is held constant, and directly proportional to the field flux (field current) when the speed is held constant, in accordance with the EMF equation $E = K1\Phi N$.

## 13. Viva Book

1. State the EMF equation of a DC generator and explain each term.
2. Why does the open-circuit characteristic bend over at higher field currents?
3. What is residual magnetism and why is it necessary for a shunt generator to self-excite?
4. Why must the generator be run on open circuit (no-load) for this test?
5. What happens to the generated EMF if the direction of rotation is reversed?
6. Define critical field resistance and critical speed of a shunt generator.
7. Why is a tachometer used in this experiment?

# Experiment No: 03

**Load Test on DC Shunt Generator**

## 1. Aim

To conduct a load test on a DC shunt generator, to plot its internal and external (load) characteristics, and to determine its efficiency and voltage regulation.

## 2. Theory

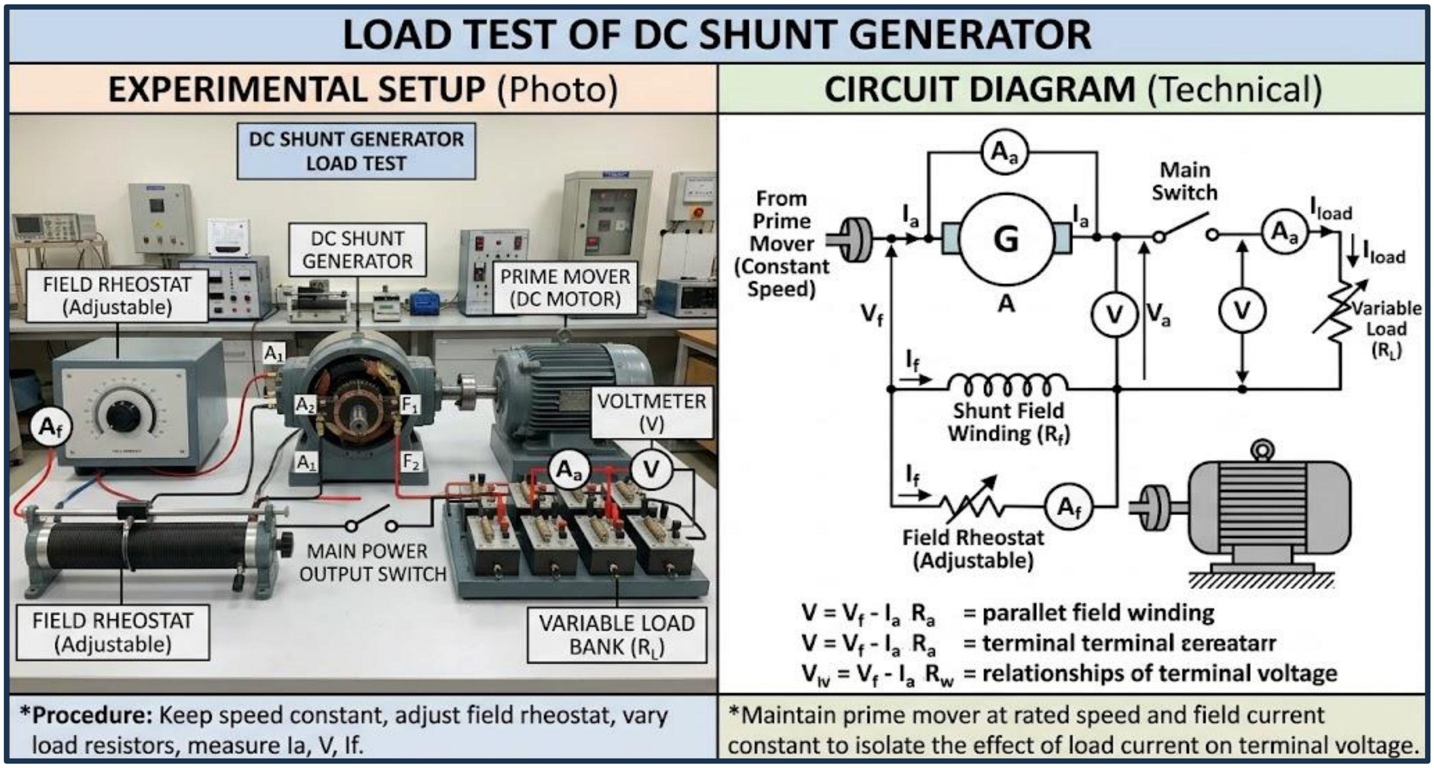
In a DC shunt generator, the field winding is connected in parallel (shunt) with the armature. As electrical load is connected across the output terminals, the load current IL flows, and the armature current is Ia = IL + Ish, where Ish is the (small, nearly constant) shunt field current.

As load is increased, the terminal voltage V decreases from its no-load value due to (i) the ohmic drop IaRa in the armature resistance, and (ii) the demagnetising effect of armature reaction which reduces the effective flux and hence the generated EMF. Because the shunt generator is self-excited, this fall in terminal voltage also reduces the field current, causing a further small drop in flux and voltage — a cumulative effect not present in a separately excited generator.

The internal (total) characteristic is the graph of generated EMF E against armature current Ia, while the external (load) characteristic is the graph of terminal voltage V against load current IL. The external characteristic droops with increasing load and is the practically useful characteristic supplied by the manufacturer.

## 3. Practical Set-up / Circuit Diagram

The DC shunt generator is driven at rated (constant) speed by a prime mover. The field winding is connected through a field rheostat across the armature. The output terminals are connected to a variable resistive load bank through a DPST switch. An ammeter is connected in the load line (IL), a voltmeter across the output terminals (V), and an ammeter in the field circuit (Ish).




## 4. Apparatus Required

| S.No. | Apparatus / Equipment | Quantity |
|---|---|---|
| 1 | DC shunt generator | 1 |
| 2 | Prime mover (with constant-speed drive) | 1 |
| 3 | Resistive load bank (lamp/rheostat load) | 1 |
| 4 | Ammeter (0-10 A) — load current | 1 |
| 5 | Ammeter (0-2 A) — field current | 1 |
| 6 | Voltmeter (0-300 V) | 1 |
| 7 | Field rheostat | 1 |
| 8 | Tachometer | 1 |

## 5. Precautions to be Followed

- Start the generator with the load switch OFF (no-load condition) and field rheostat at maximum resistance.
- Bring the generator to rated speed before applying any load, and maintain speed constant throughout.
- Apply load in small steps and note readings only after the voltmeter/ammeter readings stabilise.
- Do not exceed the rated armature current of the generator at any stage.
- Remove the entire load and switch off the field before stopping the prime mover.
- Ensure proper earthing of the machine frame.

## 6. Procedure

1. Connect the circuit as per the diagram with the load bank, ammeters and voltmeter as shown.

2. With the load switch open, start the prime mover and bring the set to rated speed; adjust the field rheostat to obtain rated no-load voltage. Note this as the no-load reading.
3. Close the load switch and apply load in convenient steps by cutting the load resistance gradually.
4. At each load step, note the load current IL, terminal voltage V and field current Ish, while maintaining the speed constant using the prime mover control.
5. Continue up to the rated full-load current of the generator.
6. Gradually remove the load in steps, switch off the field circuit, and then stop the prime mover.
7. Plot the external characteristic (V vs IL) and, after computing Ia = IL + Ish and E = V + IaRa, the internal characteristic (E vs Ia).

## 7. Observations and Calculations

| S.No. | Load Current IL (A) | Field Current Ish (A) | Armature Current Ia = IL+Ish (A) | Terminal Voltage V (V) | Generated EMF E = V+IaRa (V) |
|---|---|---|---|---|---|
| 1 | | | | | |
| 2 | | | | | |
| 3 | | | | | |
| 4 | | | | | |
| 5 | | | | | |
| 6 | | | | | |

**Calculations:**

Voltage regulation (%) = [(E0 − VFL) / VFL] × 100, where E0 is the no-load terminal voltage and VFL is the full-load terminal voltage. Efficiency (%) = [Output / (Output + Losses)] × 100 = [V·IL / (V·IL + Cu losses + Iron & friction losses)] × 100, computed at each load using the measured armature resistance Ra and the constant (rotational) losses obtained from a separate no-load test.

## 12. Results

The internal and external characteristics of the DC shunt generator were plotted. The terminal voltage was found to decrease with increasing load current due to armature resistance drop and armature reaction, and the voltage regulation and efficiency of the generator were determined.

## 13. Viva Book

1. Why does the terminal voltage of a shunt generator fall with increase in load?
2. Define voltage regulation of a generator. Is a lower value desirable?
3. What is the difference between the internal and external characteristic of a generator?
4. What is armature reaction, and how does it affect the generator's performance?
5. Why is the field current not perfectly constant as load increases in a shunt generator?
6. What is critical resistance of the field circuit?
7. How would you determine the constant (rotational) losses of the generator separately?

# Experiment No: 04

**Load Test on DC Series Generator**

## 1. Aim

To conduct a load test on a DC series generator and to plot its load characteristic (terminal voltage versus load current).

## 2. Theory

In a DC series generator, the field winding (of few turns, thick wire, low resistance) is connected in series with the armature and the external load, so that the same current flows through the field, armature and load, i.e. $I_f = I_a = I_L$.

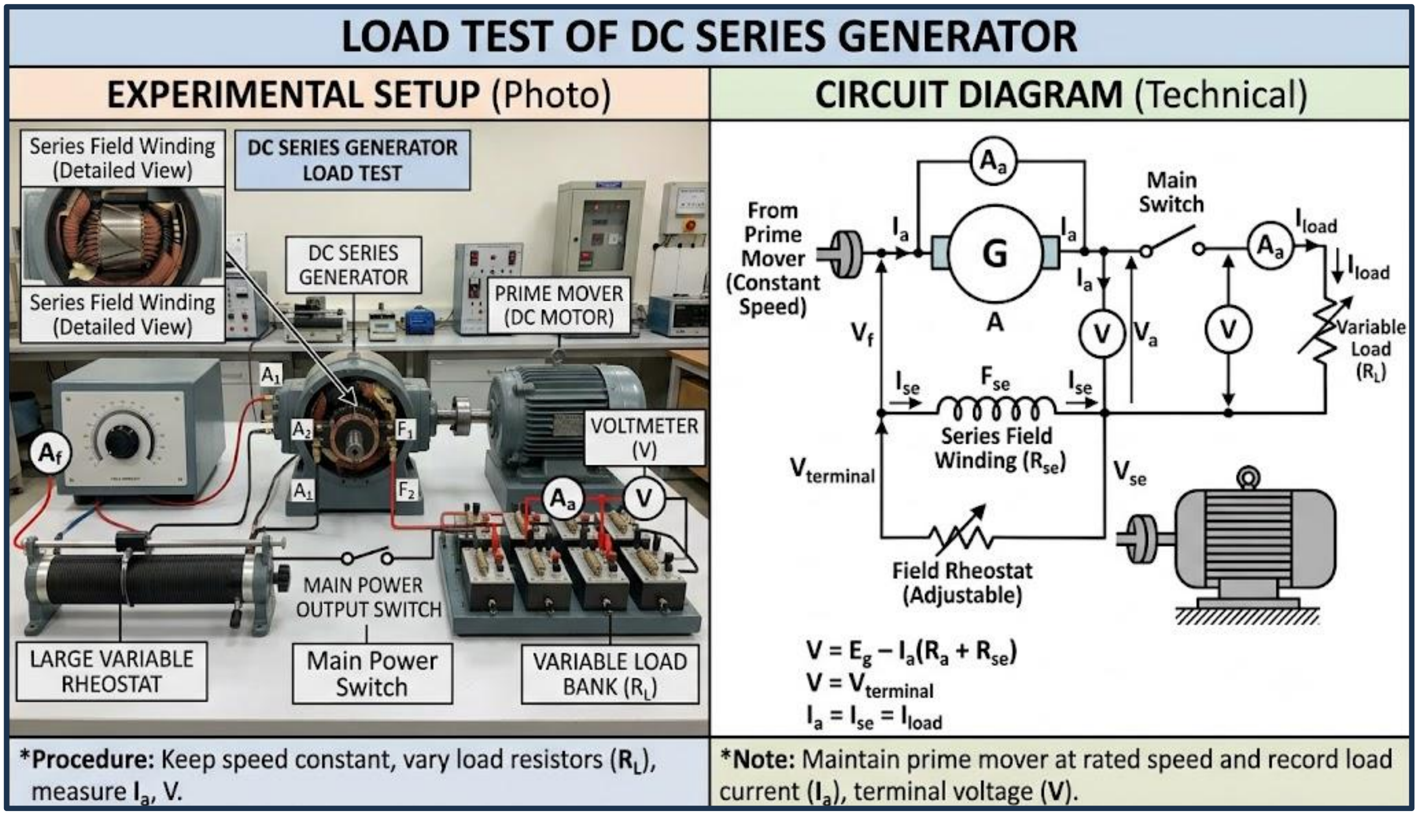
Since there is no separate field excitation, a series generator cannot build up voltage on open circuit (with no load connected) — with $I_L = 0$, no field current flows and the machine generates only the small EMF due to residual magnetism. A closed external circuit (load) is therefore essential for the machine to build up appreciable voltage.

As the load current increases from zero, the flux (and hence the generated EMF) increases nearly linearly at first, so the terminal voltage rises with load. At higher currents, the pole iron begins to saturate, and the demagnetising effect of armature reaction along with the $I_aR_a$ + series-field resistance drop become significant, causing the terminal voltage to rise more slowly, reach a maximum, and then fall at very high load currents.

Because of this rising characteristic, series generators are mainly used as boosters (to compensate for voltage drop in feeders) and are not suited for general power supply where a stiff (constant) voltage is required.

## 3. Practical Set-up / Circuit Diagram

The armature and series field winding of the generator are connected in series with the load through an ammeter. A voltmeter is connected across the output (load) terminals. The machine is driven at constant rated speed by a prime mover. A low-resistance starting/protective resistor may be used in the load circuit while building up the voltage.




## 4. Apparatus Required

| S.No. | Apparatus / Equipment | Quantity |
|---|---|---|
| 1 | DC series generator | 1 |
| 2 | Prime mover (constant-speed drive) | 1 |
| 3 | Resistive load bank | 1 |
| 4 | Ammeter (0-10 A) | 1 |
| 5 | Voltmeter (0-300 V) | 1 |
| 6 | Tachometer | 1 |

## 5. Precautions to be Followed

- Never run the series generator with the load circuit open — the machine will not build up voltage and the field will remain unexcited.
- Keep the load rheostat at its maximum resistance (minimum load current) position before starting the prime mover.
- Bring the set to rated speed before gradually reducing the load resistance to increase current.
- Maintain constant speed throughout the test using the prime mover control.
- Do not exceed the rated current of the series field/armature winding.
- Increase load current gradually in small steps and allow readings to settle before recording.

## 6. Procedure

1. Connect the armature, series field, ammeter and load rheostat in series, with the voltmeter across the load terminals, as per the circuit diagram.
2. With the load rheostat at maximum resistance, start the prime mover and bring the set to rated speed.
3. Gradually decrease the load resistance in steps to increase the load current; at each step, note the load current I and the terminal voltage V, maintaining speed constant.
4. Continue up to the rated full-load current of the generator, observing that the voltmeter reading rises with current.
5. Gradually increase the load resistance back to maximum (reducing current to a low value), then stop the prime mover.
6. Plot the load characteristic V versus I for the series generator.

## 7. Observations and Calculations

| S.No. | Load Current I (A) | Terminal Voltage V (V) |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | |
| 5 | | |
| 6 | | |
| 7 | | |

Calculations:

Efficiency (%) = [Output / (Output + Losses)] × 100 = $[V \cdot I / (V \cdot I + Ia^2(Ra+Rse) + \text{rotational losses})] \times 100$ at each load point, where Ra and Rse are the armature and series-field resistances respectively.

## 12. Results

The load characteristic of the DC series generator was obtained. The terminal voltage was found to increase with load current initially, reach a maximum, and then tend to fall at higher currents due to armature reaction and saturation, confirming the theoretical rising nature of the series generator characteristic.

## 13. Viva Book

1. Why can a series generator not build up voltage on open circuit?
2. What is the practical application of a DC series generator?
3. Why does the terminal voltage eventually fall at very high load currents in a series generator?
4. Compare the field winding of a series generator with that of a shunt generator (turns, wire size, resistance).
5. What precaution is essential before starting a series generator on load?
6. What is a 'booster' and how is a series generator used as one?

# Experiment No: 05

**Starting of a DC Shunt Motor Using a 3-Point / 4-Point Starter**

## 1. Aim

To study the construction and working of a 3-point/4-point starter, and to start, run and stop a DC shunt motor using the starter.

## 2. Theory

At the instant of starting, the back EMF (Eb) of a DC motor is zero because the armature is stationary. Since armature resistance Ra is very small, the starting armature current $Ia = (V - Eb)/Ra$ would be dangerously high (several times the rated current) if the motor were connected directly across the supply. A starter is therefore used to limit the starting current to a safe value by inserting resistance in series with the armature, which is cut out gradually in steps as the motor speeds up and back EMF builds up.

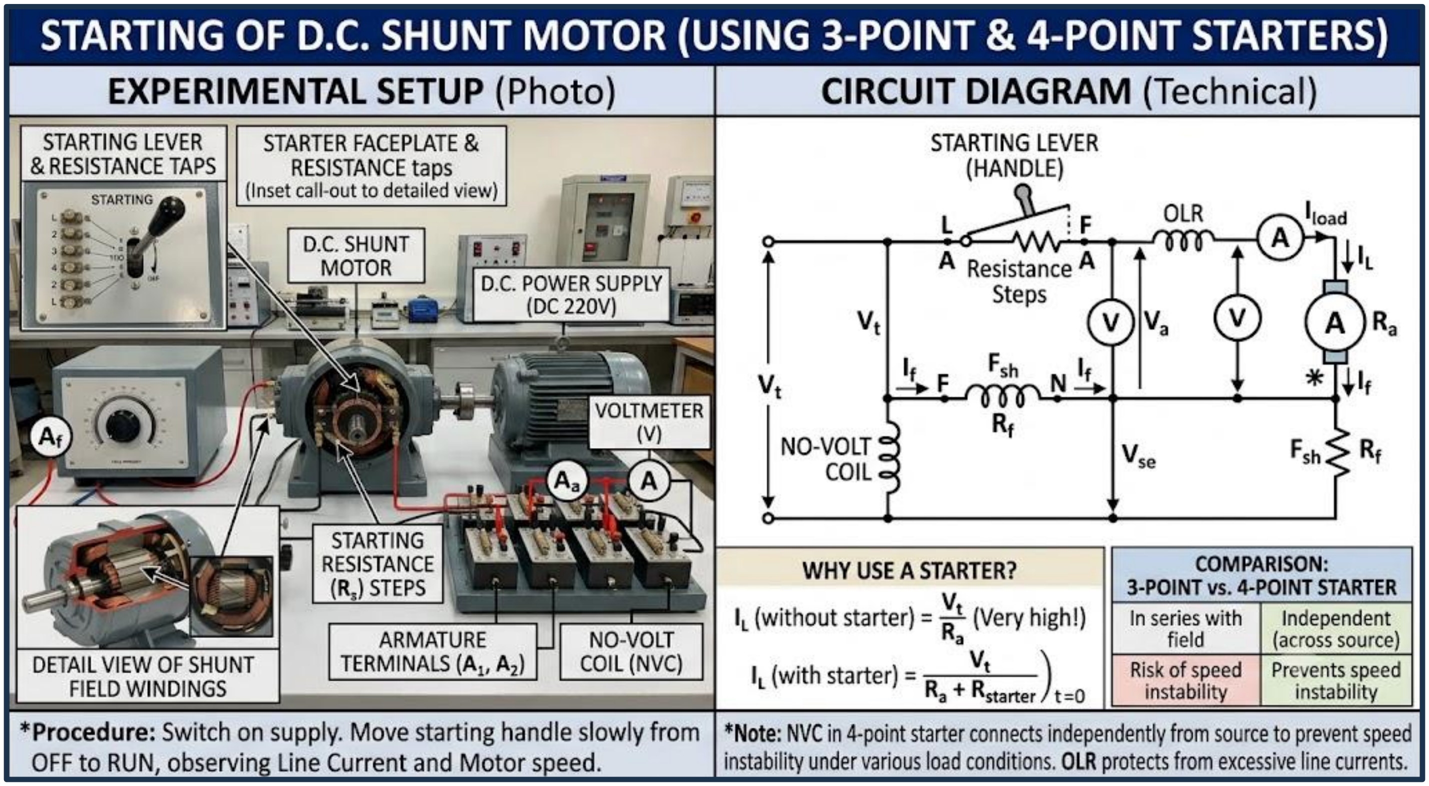
A 3-point starter has three terminals — L (Line), F (Field) and A (Armature). It consists of a resistance element divided into studs, a spring-loaded handle that moves over the studs, a No-Volt Coil (NVC) connected in series with the field circuit, and an Overload Release (OLR) coil. As the handle is moved from the OFF position stud by stud towards the RUN position, starting resistance is progressively cut out of the armature circuit. At the last stud the handle is held in the RUN position by the electromagnetic pull of the NVC (energised by the field current).

If the supply fails, or the field circuit becomes open (loss of field current), the NVC de-energises and the spring pulls the handle back to the OFF position, disconnecting the armature and thus protecting the motor from a dangerous high-speed run-away that would otherwise occur when supply is restored, or from loss of field protection. The OLR closes an auxiliary contact across the NVC terminals during a sustained overload, short-circuiting the NVC and releasing the handle to OFF.

A drawback of the 3-point starter is that the NVC is in series with the field circuit: if the field rheostat is used to increase motor speed above rated value by weakening the field (reducing field current), the reduced current may fail to hold the NVC energised, causing nuisance tripping. The 4-point starter overcomes this by connecting the NVC directly across the supply lines (through a current-limiting resistor), independent of the field circuit, so that field weakening for speed control does not affect the holding of the starter handle.

## 3. Practical Set-up / Circuit Diagram

The DC shunt motor's armature is connected through terminal 'A' of the starter, the field winding through terminal 'F', and the supply positive through terminal 'L' of the starter; the supply negative is connected directly to the armature and field. An ammeter is connected in the armature line to observe starting current, a voltmeter across the supply, a field rheostat in the field circuit for speed control, and a tachometer to measure motor speed.




## 4. Apparatus Required

| S.No. | Apparatus / Equipment | Quantity |
|---|---|---|
| 1 | DC shunt motor | 1 |
| 2 | 3-point starter (or 4-point starter) | 1 |
| 3 | Ammeter (0-10 A) | 1 |
| 4 | Voltmeter (0-300 V) | 1 |
| 5 | Field rheostat | 1 |
| 6 | Tachometer | 1 |
| 7 | DC supply / mains | 1 |

## 5. Precautions to be Followed

- Ensure the starter handle is at the OFF position before switching on the supply.
- Keep the field rheostat at zero resistance (maximum field current) at the time of starting, to limit starting speed and back EMF build-up rate.
- Move the starter handle slowly and steadily from stud to stud; do not leave it resting on an intermediate stud for long, as the starting resistance is designed for short-time duty.
- Do not move the handle rapidly to the RUN position in one motion; allow the motor to gain speed at each step.
- Check that the NVC coil circuit is intact (field circuit not open) before starting.
- In case of any abnormal sound/sparking, return the handle to OFF immediately.

## 6. Procedure

1. Connect the DC shunt motor, starter, ammeter, voltmeter, field rheostat and tachometer as per the circuit diagram for a 3-point (or 4-point) starter.
2. With the starter handle at OFF and field rheostat at zero resistance, switch on the DC supply.
3. Slowly move the starter handle from stud to stud towards the RUN position, pausing briefly at each stud, and note the armature current and speed at each stud position.
4. Observe that the handle is held at the final (RUN) stud by the No-Volt Coil.
5. Once running, use the field rheostat to vary the field current and observe the corresponding change in motor speed.
6. To test the no-volt release, momentarily switch off the supply and verify that the starter handle springs back to the OFF position automatically.
7. To stop the motor, switch off the supply (or use a stop button, if provided); the handle returns to OFF.

## 7. Observations and Calculations

| S.No. | Starter Stud Position | Armature Current Ia (A) | Speed N (rpm) |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |

Calculations:

Percentage reduction in starting current with starter, compared to the current that would flow on direct-on-line starting ($I_{a,DOL} = V/R_a$), may be calculated as: % Reduction = $[(I_{a,DOL} - I_{a,starter})/I_{a,DOL}] \times 100$.

## 12. Results

The DC shunt motor was successfully started using the 3-point/4-point starter, with the starting armature current limited to a safe value at each stud. The no-volt release and the effect of field rheostat on speed were also verified.

## 13. Viva Book

1. Why is a starter necessary for a DC shunt motor?
2. What is the function of the No-Volt Coil (NVC) in a starter?
3. What is the function of the Overload Release (OLR)?
4. What is the main drawback of a 3-point starter, and how does a 4-point starter overcome it?
5. Why should the field rheostat be kept at zero resistance while starting the motor?
6. What happens to the starter handle if the supply fails while the motor is running?
7. Why should the starter handle not be left on an intermediate stud for a long time?
8. Derive the expression for starting armature current of a DC motor without a starter.

# Experiment No: 06

**Reversal of Direction of Rotation of a DC Shunt Motor**

## 1. Aim

To reverse the direction of rotation of a DC shunt motor by (a) reversing the armature connections only, (b) reversing the field connections only, and to verify that reversing both supply leads together does not reverse the direction of rotation.

## 2. Theory

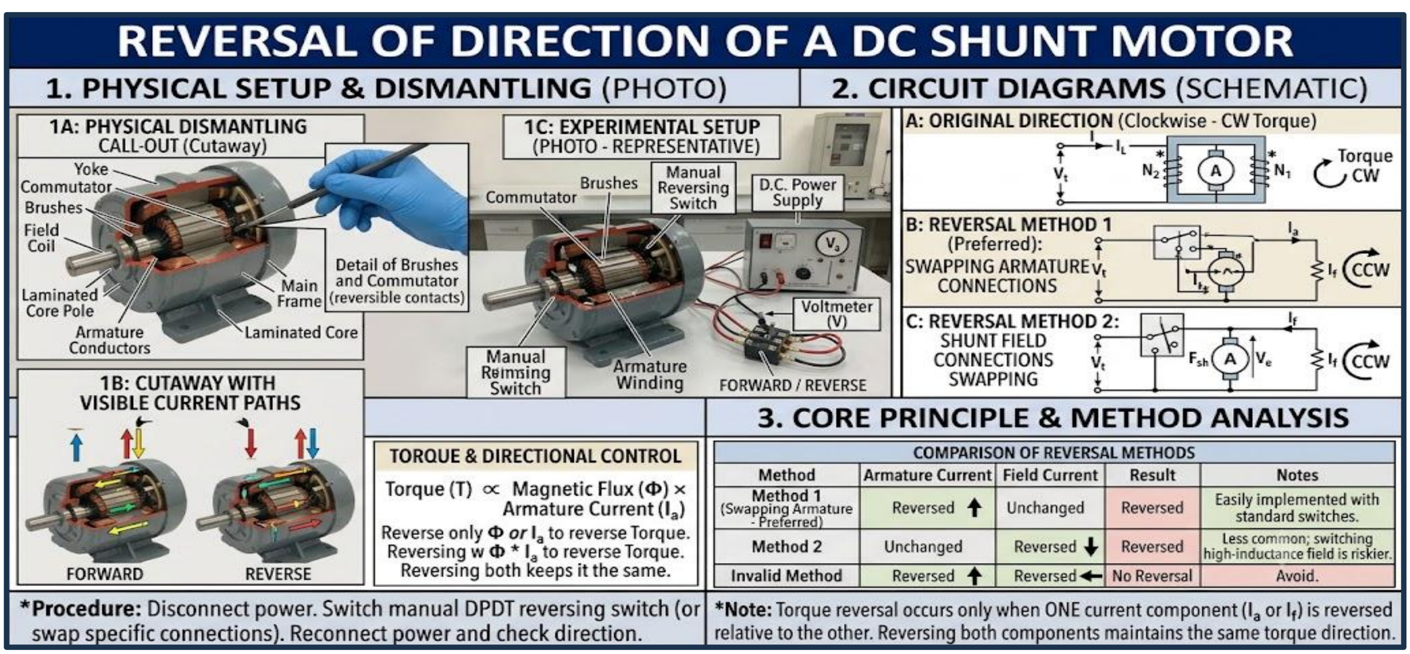
The direction of rotation of a DC motor is decided by the direction of the mechanical force F = BIL developed on the armature conductors, which in turn depends on the relative directions of the armature current and the main field flux. Reversing either the armature current alone or the field current alone reverses this relative direction and hence reverses the direction of rotation.

If, instead, both the armature and the field connections are reversed together (which is what happens when the two supply leads to the motor are simply interchanged), the direction of the armature current with respect to the field flux remains unchanged, and the motor continues to rotate in the same direction as before.

Reversal of only one circuit — armature or field — is therefore the correct method used in practice (through a double-pole double-throw reversing switch) to reverse the direction of rotation of a DC shunt motor, and this principle is used in motor-reversing starters for cranes, hoists, and reversible drives.

## 3. Practical Set-up / Circuit Diagram

The DC shunt motor is connected to the supply through a 3-point starter. A double-pole reversing switch is included in the armature circuit and another in the field circuit so that either circuit can be reversed independently while the motor is stationary. An ammeter and voltmeter are connected to monitor the armature current and supply voltage, and a reference mark/pointer on the shaft (or the pulley) is used to observe the direction of rotation.



## 4. Apparatus Required

| S.No. | Apparatus / Equipment | Quantity |
|---|---|---|
| 1 | DC shunt motor | 1 |
| 2 | 3-point starter | 1 |
| 3 | DPDT reversing switch (armature circuit) | 1 |
| 4 | DPDT reversing switch (field circuit) | 1 |
| 5 | Ammeter (0–10 A) | 1 |
| 6 | Voltmeter (0–300 V) | 1 |
| 7 | Field rheostat | 1 |

## 5. Precautions to be Followed

- Always switch off the supply and bring the starter handle to OFF before changing any connection.
- Reverse only one circuit (armature or field) at a time; never reverse both simultaneously while testing individual cases.
- Keep the field rheostat at zero resistance (maximum field current) while starting, in each trial.
- Do not leave the field circuit open at any time while the motor is running.
- Ensure firm, tight connections at the reversing switches to avoid arcing.
- Allow the motor to come to a complete stop before altering the connections for the next trial.

## 6. Procedure

1. Connect the DC shunt motor to the supply through the starter, with a reversing switch each in the armature circuit and in the field circuit, along with the ammeter, voltmeter and field rheostat.
2. With both reversing switches in the normal (forward) position, start the motor using the starter and note the direction of rotation as viewed from the non-driving end; call this the reference direction.
3. Stop the motor. Reverse the armature reversing switch only (keep the field connections unchanged), restart the motor, and note the new direction of rotation.
4. Stop the motor. Restore the armature to its original (normal) connection, reverse the field reversing switch only, restart the motor, and note the direction of rotation.
5. Stop the motor. Reverse both the armature and the field reversing switches together, restart the motor, and note the direction of rotation.
6. Tabulate the direction of rotation observed in each of the four cases and compare with the reference direction.

## 7. Observations and Calculations

| S.No. | Case | Armature Connection | Field Connection | Direction of Rotation |
|---|---|---|---|---|
| 1 | Normal (reference) | Normal | Normal | |
| 2 | Armature reversed | Reversed | Normal | |
| 3 | Field reversed | Normal | Reversed | |
| 4 | Both reversed | Reversed | Reversed | |

## 12. Results

It was observed that reversing the armature connections alone, or the field connections alone, reverses the direction of rotation of the DC shunt motor, whereas reversing both connections together restores the original direction of rotation — confirming the theoretical principle that direction of rotation depends on the relative sense of armature current and field flux.

## 13. Viva Book

1. On what factor does the direction of rotation of a DC motor depend?
2. Why does reversing the supply polarity (both leads) not reverse the direction of rotation?
3. What precaution must be taken before changing the reversing-switch connections?
4. What would happen if the field circuit were suddenly opened while the shunt motor is running?
5. Where, practically, is a reversing switch/starter used for a DC motor?
6. Why is it preferable to reverse the armature rather than the field connections in large motors?

# Experiment No: 07

**Speed Control of DC Shunt Motor by Armature Resistance (Rheostatic) Control**

## 1. Aim

To control the speed of a DC shunt motor below its normal (rated) value by the armature resistance (rheostatic) control method, and to plot the speed–armature voltage characteristic.

## 2. Theory

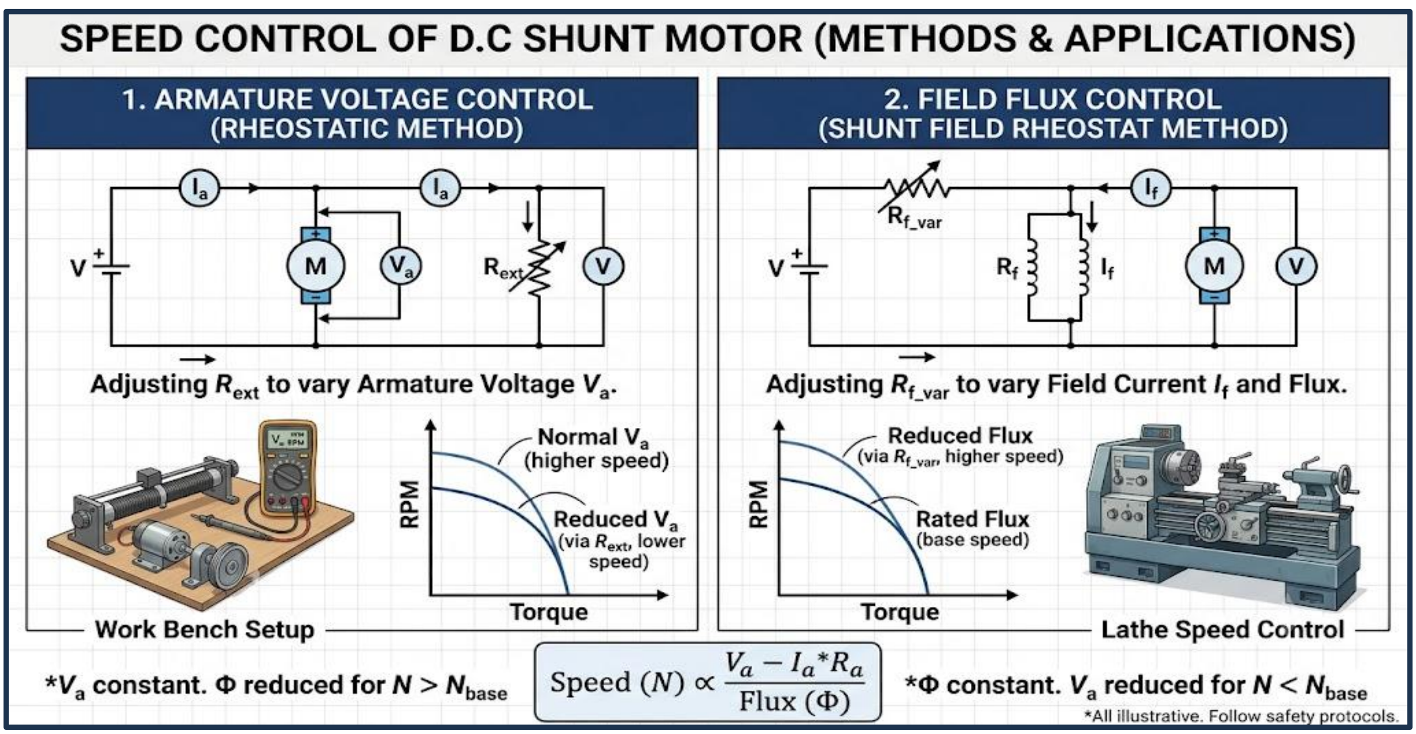
The speed of a DC shunt motor is given by $N \propto Eb/\Phi = (V - IaRa)/\Phi$, where V is the supply voltage, Ia the armature current, Ra the armature resistance and Φ the field flux. If a variable resistance Rc is inserted in series with the armature while the field is kept constant, the extra voltage drop Ia·Rc reduces the back EMF Eb required for the same current, and hence the speed falls.

This method gives speed control only below the normal rated speed. It is simple and inexpensive but inefficient, since considerable power is wasted as heat in the series rheostat, particularly at low speeds where the voltage drop (and hence the loss) is largest. Because the voltage drop Ia·Rc depends on the load current Ia, the speed at a given rheostat setting also varies with load, giving poor speed regulation.

Despite its low efficiency, armature (rheostatic) control is widely used for small motors and for applications such as cranes, hoists and traction where speed reduction is needed only occasionally and for short duration.

## 3. Practical Set-up / Circuit Diagram

A variable rheostat is connected in series with the armature of the DC shunt motor, while the field winding is connected directly across the supply through a separate field rheostat which is kept fixed throughout the test. A voltmeter is connected across the armature terminals, an ammeter in the armature line, and a tachometer is used to measure speed.



## 4. Apparatus Required

| S.No. | Apparatus / Equipment | Quantity |
|---|---|---|
| 1 | DC shunt motor | 1 |
| 2 | 3-point starter | 1 |
| 3 | Armature control rheostat (series type) | 1 |
| 4 | Field rheostat | 1 |
| 5 | Ammeter (0–10 A) | 1 |
| 6 | Voltmeter (0–300 V) | 1 |
| 7 | Tachometer | 1 |

## 5. Precautions to be Followed

- Keep the field rheostat at zero resistance (maximum field current) throughout the test.
- Keep the armature control rheostat at zero resistance at the instant of starting; introduce resistance only after the motor has picked up normal speed.
- Increase the armature resistance gradually, in small steps, and allow the speed to stabilise before recording readings.
- Do not allow the armature current to exceed the rated value at any stage.
- Keep the mechanical load on the motor constant (light and fixed) throughout the test so that readings are comparable.
- Return the armature rheostat to zero before switching off the supply.

## 6. Procedure

1. Connect the DC shunt motor with the starter, armature control rheostat, field rheostat, ammeter, voltmeter and tachometer as per the circuit diagram.
2. Start the motor using the starter with the field rheostat at zero resistance and the armature control rheostat at zero resistance.
3. Note the normal (rated) speed and the armature voltage with the armature rheostat at zero.
4. Gradually increase the resistance in the armature circuit in convenient steps; at each step, record the armature voltage, armature current and speed, keeping the load constant.
5. Continue up to the maximum safe value of armature resistance, taking about five to six sets of readings.
6. Plot the graph of speed N versus armature voltage Va (or versus resistance inserted).
7. Reduce the armature rheostat to zero and switch off the supply.

## 7. Observations and Calculations

| S.No. | Armature Voltage Va (V) | Armature Current Ia (A) | Speed N (rpm) |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

**Calculations:** Percentage reduction in speed at maximum armature resistance = $[(N0 - N)/N0] \times 100$, where N0 is the speed with zero added armature resistance and N is the speed at the corresponding rheostat setting.

## 12. Results

The speed of the DC shunt motor was found to decrease progressively as resistance was inserted in the armature circuit at constant field current, confirming that the armature (rheostatic) control method gives speed control below the normal rated speed, with the speed depending on the load current at a given rheostat setting.

## 13. Viva Book

1. Over what range of speed does the armature resistance control method operate — above or below normal?
2. Why is the efficiency of this method poor, especially at low speeds?
3. How does a change in load affect the speed at a fixed rheostat setting?
4. Why can this method not be used to obtain speeds above the rated value?
5. In what type of applications is this method commonly used despite its low efficiency?
6. How does armature control differ from the Ward-Leonard method of speed control?

# Experiment No: 08

**Speed Control of DC Shunt Motor by Field Flux (Field Weakening) Control**

## 1. Aim

To control the speed of a DC shunt motor above its normal (rated) value by the field control (flux-weakening) method, and to plot the speed–field current characteristic.

## 2. Theory

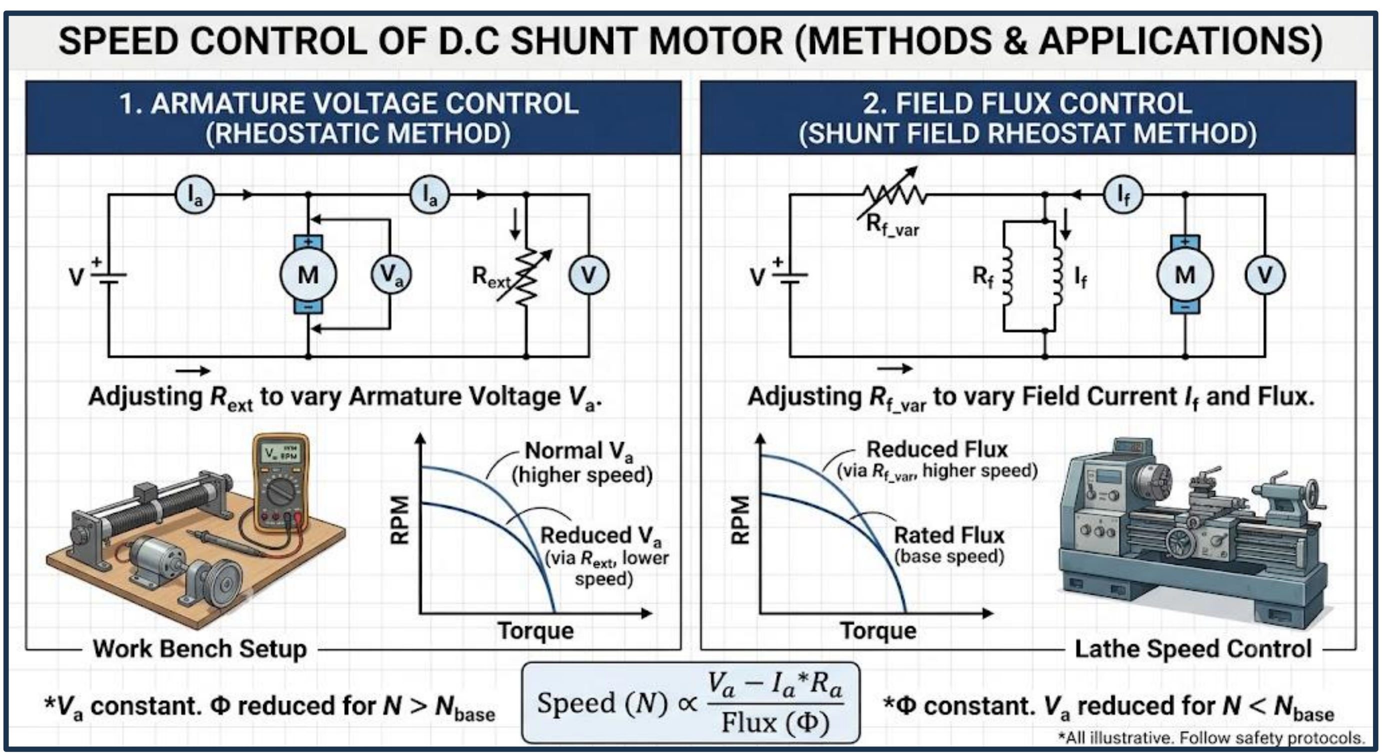
Neglecting the small armature-resistance drop, the back EMF Eb of a DC motor is approximately proportional to the supply voltage V, so that speed $N \propto Eb/\Phi \approx V/\Phi$. If a rheostat connected in series with the shunt field winding is used to reduce the field current If, the flux Φ decreases, and since Eb remains nearly constant, the speed increases inversely with the flux.

This method gives speed control above the normal rated speed and is highly efficient, since the power dissipated in the field rheostat is small (the field current itself being only a small fraction of the rated armature current). The control is smooth and stepless.

There is, however, a practical lower limit on the flux beyond which further weakening is not permissible, due to poor commutation and excessive armature reaction at very low flux. Also, since torque $T \propto \Phi \cdot Ia$, weakening the field reduces the torque the motor can develop for a given armature current — the motor above base speed behaves approximately as a constant-power (rather than constant-torque) machine.

## 3. Practical Set-up / Circuit Diagram

A variable rheostat is connected in series with the shunt field winding of the DC motor; the armature is connected directly across the supply through the starter and an ammeter. A voltmeter is connected across the supply, an ammeter in the field circuit to measure If, and a tachometer to measure speed.



## 4. Apparatus Required

| S.No. | Apparatus / Equipment | Quantity |
|---|---|---|
| 1 | DC shunt motor | 1 |
| 2 | 3-point starter | 1 |
| 3 | Field rheostat | 1 |
| 4 | Ammeter (0–2 A, field circuit) | 1 |
| 5 | Ammeter (0–10 A, armature circuit) | 1 |
| 6 | Voltmeter (0–300 V) | 1 |
| 7 | Tachometer | 1 |

## 5. Precautions to be Followed

- Never open the field circuit suddenly or completely while the motor is running — this can cause dangerous over-speeding (running away) as Φ tends to zero.
- Increase the field circuit resistance gradually, in small steps, and continuously observe the speed.
- Do not exceed the maximum safe speed specified on the motor nameplate.
- Keep the mechanical load on the motor light and constant throughout the test.
- Keep the armature supply voltage constant throughout the test.
- Return the field rheostat to zero resistance (maximum field) before switching off the motor.

## 6. Procedure

- Connect the DC shunt motor with the starter, field rheostat, field ammeter, armature ammeter, voltmeter and tachometer as per the circuit diagram.
- Start the motor with the field rheostat at zero resistance (maximum field current); note the base (rated) speed and field current.
- Gradually increase the resistance in the field circuit in small steps; at each step, record the field current If and the corresponding speed N, keeping the armature voltage and load constant.
- Continue increasing the field resistance up to the maximum permissible speed specified for the motor — do not exceed this limit.
- Plot the graph of speed N versus field current If, and observe the inverse relationship.
- Reduce the field rheostat back to zero resistance and switch off the supply.

## 7. Observations and Calculations

| S.No. | Field Current If (A) | Armature Current Ia (A) | Speed N (rpm) |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

**Calculations:** Percentage increase in speed at minimum field current = $[(N - N0)/N0] \times 100$, where N0 is the base speed at zero added field resistance and N is the speed at the corresponding weakened-field setting.

## 12. Results

The speed of the DC shunt motor was found to increase as the field current (flux) was reduced, confirming that the field control method gives speed control above the normal rated speed with high efficiency, and verifying the inverse relationship $N \propto 1/\Phi$.

## 13. Viva Book

1. Over what range of speed does the field control method operate — above or below normal?
2. Why is the field control method more efficient than the armature resistance control method?
3. What is the danger of suddenly opening the field circuit of a running shunt motor?
4. Why does the torque capability of the motor reduce as the field is weakened?
5. Is the field control method suitable for constant-torque loads? Why or why not?
6. How can armature control and field control be combined to obtain speed control both below and above normal?

# Experiment No: 09

**Load Test on DC Shunt Motor**

## 1. Aim

To conduct a load test on a DC shunt motor using a brake-drum loading arrangement, and to determine its output power, torque, speed and efficiency at various loads, and to plot the performance characteristics.

## 2. Theory

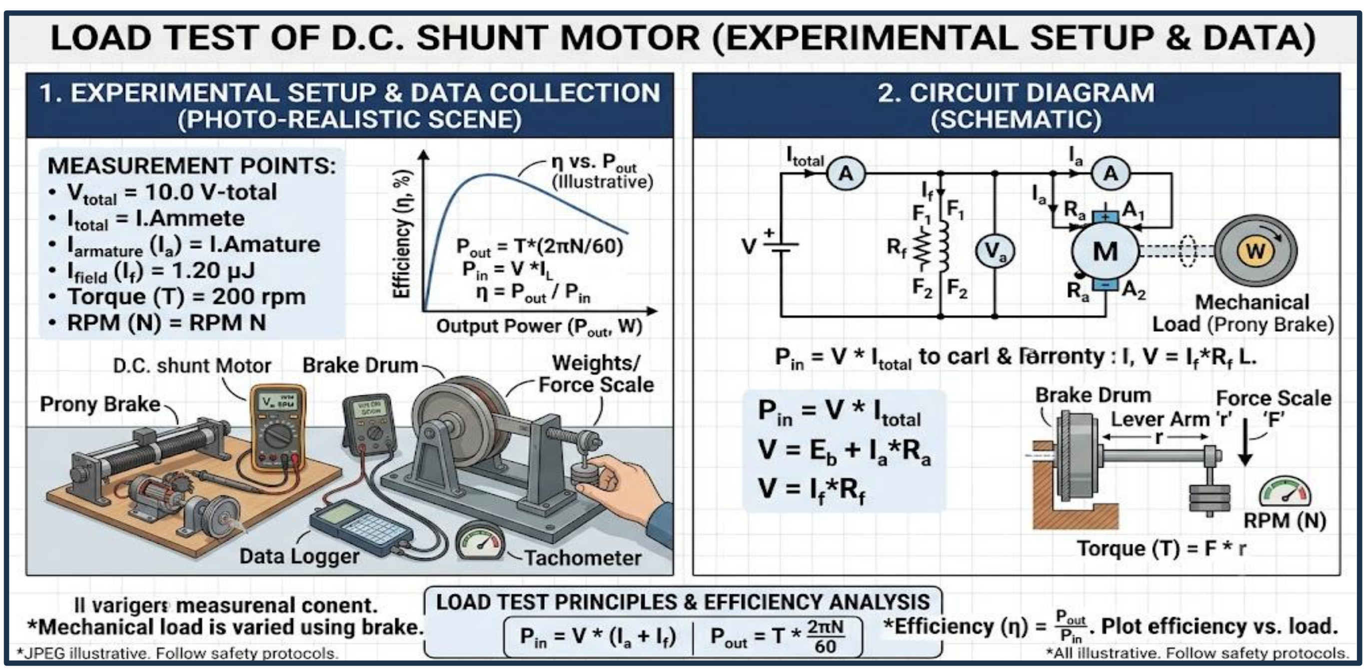
In a direct (brake-drum) load test, the mechanical output of the motor is absorbed by friction between a rope/belt wound over a pulley keyed to the motor shaft and two spring balances (or a dead-weight and a spring balance) attached to the two ends of the rope. If S1 and S2 (in kgf) are the two spring-balance readings and R is the effective radius of the pulley (drum radius plus half the rope diameter), the net braking force is (S1 − S2) kgf and the shaft torque is $T = (S1 - S2) \times 9.81 \times R$ newton-metres.

The output (mechanical) power is $Pout = 2\pi NT/60$ watts, where N is the speed in rpm. The electrical input power is $Pin = V \times IL$, where V is the supply voltage and IL the line current drawn by the motor ($IL = Ia + If$). The efficiency is $\eta = (Pout/Pin) \times 100$.

For a DC shunt motor the speed remains nearly constant with load (since flux is essentially constant), so torque rises roughly in proportion to the load current, while the efficiency curve rises with load, reaches a maximum where the variable (copper) losses equal the constant losses, and then falls off as further increase in current increases the copper loss disproportionately.

## 3. Practical Set-up / Circuit Diagram

The DC shunt motor shaft is coupled to a brake drum over which a rope or belt passes, with one end attached to a fixed support/spring balance and the other to an adjustable spring balance, allowing the band to be tightened to apply a mechanical brake load. An ammeter and voltmeter measure the electrical input, and a tachometer measures speed. Water cooling of the drum is provided to dissipate the frictional heat generated during loading.



## 4. Apparatus Required

| S.No. | Apparatus / Equipment | Quantity |
|---|---|---|
| 1 | DC shunt motor with brake-drum test rig | 1 |
| 2 | Spring balances | 2 |
| 3 | Ammeter (0–20 A) | 1 |
| 4 | Voltmeter (0–300 V) | 1 |
| 5 | Tachometer | 1 |
| 6 | 3-point starter | 1 |
| 7 | Field rheostat | 1 |

## 5. Precautions to be Followed

- Start the motor on no load with the brake band completely loose.
- Apply the brake load gradually, in small steps, allowing speed and readings to settle before recording.
- Do not exceed about 125% of the rated full-load current at any stage.
- Ensure continuous water cooling of the brake drum during loaded operation to prevent overheating and burning of the rope/band.
- Record the two spring-balance readings and the ammeter/tachometer readings simultaneously at each load step.
- Release the brake load gradually to zero before switching off the supply.

## 6. Procedure

- Note the nameplate rating of the motor (voltage, current, power, speed).
- Set up the brake-drum test rig with the rope/belt over the drum and the two spring balances connected at its ends.
- Start the motor on no load, with the brake band loose, using the starter; note the no-load current and speed.
- Gradually tighten the brake band to apply load to the motor in convenient steps.
- At each load step, record the line current IL, both spring-balance readings S1 and S2, and the speed N, ensuring the drum is being cooled with water.
- Continue loading up to about 125% of the rated full-load current.
- Gradually loosen the brake band to remove the load, then switch off the supply.
- Calculate the torque, output power, input power and efficiency at each load step, and plot η, N and T against IL.

## 7. Observations and Calculations

| S.No. | Voltage V (V) | Line Current IL (A) | S1 (kgf) | S2 (kgf) | Speed N (rpm) |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

**Calculations:** Net braking force = $(S1 - S2) \times 9.81$ N; Torque $T = (S1 - S2) \times 9.81 \times R$ N·m; Output power $P_{out} = 2\pi NT/60$ W; Input power $P_{in} = V \times IL$ W; Efficiency $\eta = (P_{out}/P_{in}) \times 100$.

## 12. Results

The performance characteristics (speed, torque and efficiency versus load current) of the DC shunt motor were obtained. The motor exhibited a nearly constant-speed characteristic, and the efficiency was found to rise with load to a maximum before falling off at higher loads.

## 13. Viva Book

1. Why does the speed of a DC shunt motor remain nearly constant as load is increased?
2. What is the purpose of using two spring balances in a brake test?
3. Why is water cooling necessary on the brake drum during the test?
4. At what condition does a DC motor operate at maximum efficiency?
5. Why should the full-load current not be applied for a prolonged period during this test?
6. What are the various losses that occur in a DC motor?

# Experiment No: 10

**Load Test on DC Series Motor**

## 1. Aim

To conduct a load test on a DC series motor using a brake-drum loading arrangement, and to determine its speed–armature current, torque–armature current and efficiency–armature current characteristics.

## 2. Theory

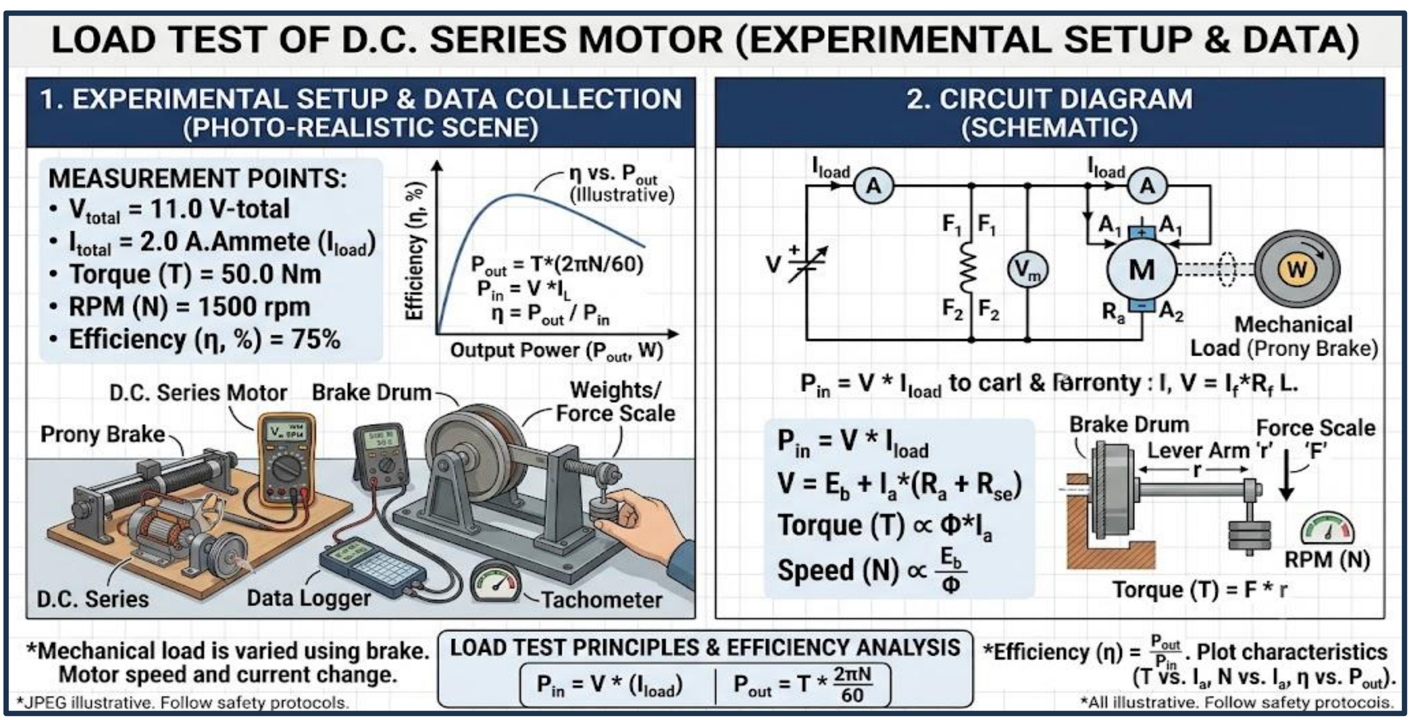
In a DC series motor, the field winding is connected in series with the armature and therefore carries the full line (armature) current Ia. Below magnetic saturation, the flux Φ is approximately proportional to Ia, so the torque $T \propto \Phi \cdot Ia \propto Ia^2$, giving the series motor a very high starting torque. As Ia increases further and the magnetic circuit saturates, Φ tends to become constant and $T \propto Ia$ approximately.

Since speed $N \propto Eb/\Phi$ and Φ increases with load, the speed of a series motor falls rapidly as load increases — giving the characteristic drooping speed–torque curve that makes the series motor well suited to traction, cranes and hoists, where high starting torque and automatic speed reduction under load are desirable.

Because flux depends on load current, a series motor must never be run with little or no mechanical load: at very low Ia the flux is very small and the speed can rise to a dangerously high (runaway) value. The motor is therefore always coupled to its load (belt, brake drum, or geared load) before it is switched on. Torque, output and efficiency are computed from brake-drum readings exactly as for the shunt motor test.

## 3. Practical Set-up / Circuit Diagram

The series motor shaft is coupled to a brake drum with a rope/belt and two spring balances as before. The line ammeter (which reads the same current as flows through the series field and the armature) is connected in the supply line, the voltmeter across the supply, and a tachometer measures speed. The motor is mechanically coupled to the brake-drum load before the supply is switched on.



## 4. Apparatus Required

| S.No. | Apparatus / Equipment | Quantity |
|---|---|---|
| 1 | DC series motor with brake-drum test rig | 1 |
| 2 | Spring balances | 2 |
| 3 | Ammeter (0–20 A) | 1 |
| 4 | Voltmeter (0–300 V) | 1 |
| 5 | Tachometer | 1 |
| 6 | Series motor starter | 1 |

## 5. Precautions to be Followed

- Never start the series motor on no load or with a slack belt — always couple it to the brake-drum load, with a light load already applied, before switching on the supply.
- Apply the load gradually starting from this safe minimum value.
- Continuously monitor the speed; if it rises abnormally, increase the load immediately or switch off the supply.
- Do not exceed the rated full-load current.
- Provide continuous water cooling of the brake drum.
- Reduce the load gradually to the safe minimum before switching off — never remove the load suddenly while the motor is running.

## 6. Procedure

- Note the nameplate rating of the series motor.
- Couple the motor firmly to the brake drum with the rope/band already engaged at a light initial load — never start the motor unloaded.
- Start the motor using the starter with this initial load applied and allow the speed to stabilise.
- Record the line current Ia (= IL), the spring-balance readings S1 and S2, and the speed N.
- Gradually increase the load in convenient steps up to the rated full-load current, recording readings at each step.
- Gradually reduce the load back to the initial safe minimum value, then switch off the supply.
- Calculate the torque, output power, input power and efficiency at each load step, and plot T, N and $\eta$ against Ia.

## 7. Observations and Calculations

| S.No. | Voltage V (V) | Armature Current Ia (A) | S1 (kgf) | S2 (kgf) | Speed N (rpm) |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

**Calculations:** Net braking force = $(S1 - S2) \times 9.81$ N; Torque $T = (S1 - S2) \times 9.81 \times R$ N·m; Output power $P_{out} = 2\pi NT/60$ W; Input power $P_{in} = V \times I_a$ W; Efficiency $\eta = (P_{out}/P_{in}) \times 100$.

## 12. Results

The DC series motor was found to have speed falling sharply and torque rising sharply with increase in load current — confirming the characteristic drooping speed–torque behaviour of a series motor. The efficiency curve rose to a maximum and then decreased, similar to the shunt motor.

## 13. Viva Book

1. Why must a DC series motor never be run without mechanical load?
2. Why is the torque of a series motor approximately proportional to the square of the armature current at low loads?
3. Name typical applications for which the series motor is particularly suited.
4. What would happen if the series field winding became open-circuited while the motor is running?
5. Compare the speed–torque characteristics of a series motor and a shunt motor.
6. Why does a series motor not normally use a field rheostat for starting?

# Experiment No: 11

**Brake Test on DC Shunt Motor**

## 1. Aim

To perform a rope-brake test on a DC shunt motor in order to directly determine the output torque, brake power and efficiency at various loads, and to plot the load characteristics up to full load.

## 2. Theory

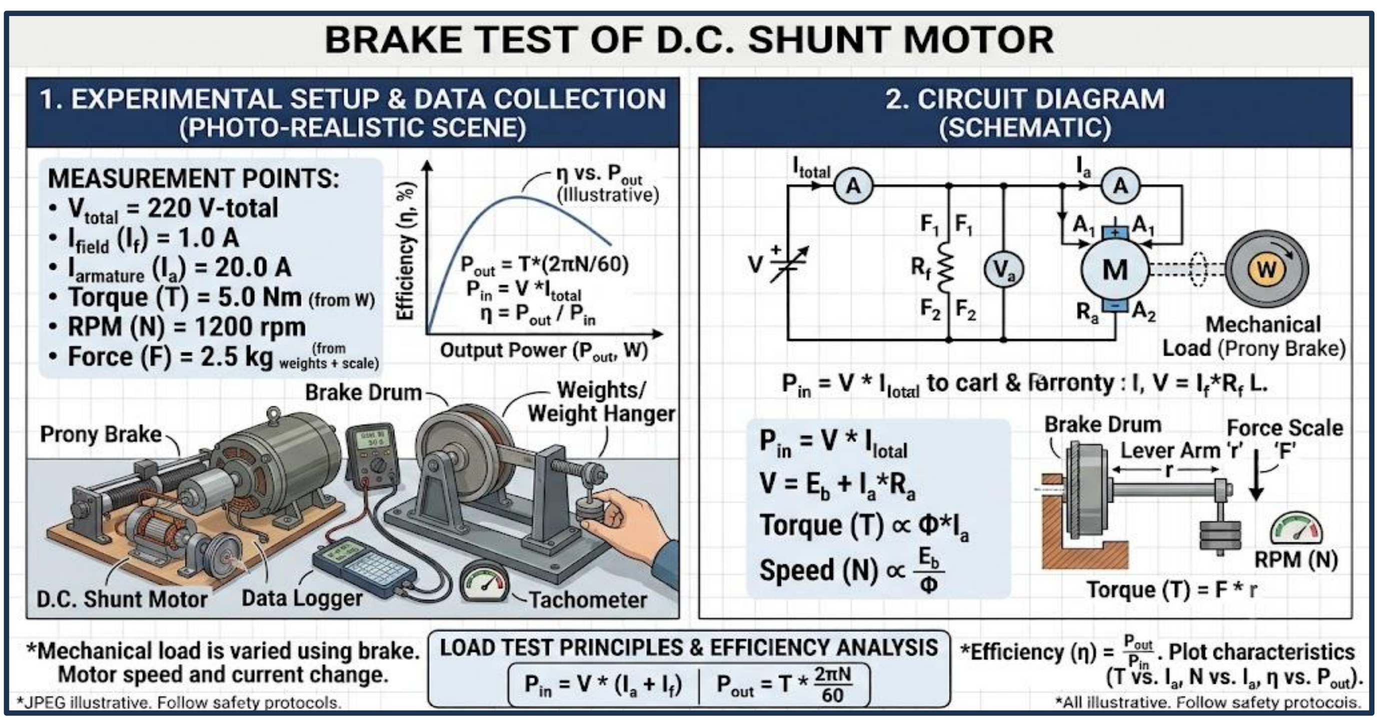
The brake (rope-brake) test is a direct-loading method in which the mechanical output of the motor is absorbed by friction between a rope wound over a pulley keyed to the shaft and a dead-weight/spring-balance arrangement at its two ends. If W (or S1) is the dead-weight (or first spring-balance reading) and S (or S2) is the spring-balance reading, both in kgf, the net braking force is $(W - S) \times 9.81$ N, and the torque is $T = (W - S) \times 9.81 \times R$, where R is the effective radius of the pulley (drum radius plus half the rope diameter).

The brake power (mechanical output) is $P_{out} = 2\pi NT/60$ watts, and comparing this with the electrical input $P_{in} = V \times I$ gives the efficiency $\eta = (P_{out}/P_{in}) \times 100$. This experiment specifically calibrates and uses the rope-brake apparatus to obtain the motor's brake-power rating directly and to locate the point of maximum efficiency, which occurs when the variable (armature copper) loss equals the constant (iron + friction + windage) loss.

Because the rope-brake dissipates the entire mechanical output as friction, considerable heat is generated at the pulley rim; continuous water cooling is essential to prevent the rope from charring and to keep readings stable.

## 3. Practical Set-up / Circuit Diagram

The rope-brake test rig is mounted on the motor shaft with a dead-weight hanger on one side of the rope and a spring balance on the other side, both passing over the pulley. An ammeter and voltmeter measure the electrical input, a tachometer measures speed, and a water can continuously wets the pulley rim to dissipate frictional heat.



## 4. Apparatus Required

| S.No. | Apparatus / Equipment | Quantity |
|---|---|---|
| 1 | DC shunt motor with rope-brake/Prony-brake test rig | 1 |
| 2 | Dead-weight hanger | 1 |
| 3 | Spring balance | 1 |
| 4 | Ammeter (0–20 A) | 1 |
| 5 | Voltmeter (0–300 V) | 1 |
| 6 | Tachometer | 1 |
| 7 | Water can / cooling arrangement | 1 |
| 8 | 3-point starter | 1 |

## 5. Precautions to be Followed

- Ensure the rope/belt is properly lubricated and runs smoothly on the pulley without slipping.
- Apply water continuously to the pulley rim throughout the loaded part of the test to dissipate frictional heat.
- Increase the load gradually and allow the speed to stabilise before taking each set of readings.
- Do not run the motor at or above rated current for a prolonged period.
- Keep hands and clothing clear of the rotating pulley and rope at all times.
- Release the brake load and switch off the supply immediately after completing the test.

## 6. Procedure

- Note the nameplate rating of the motor and measure the effective radius of the brake pulley.
- Set up the rope brake with the dead-weight hanger on one side and the spring balance on the other side of the rope over the pulley.
- Start the motor on no load with the brake loose, using the starter, keeping the field rheostat at the normal working position, and allow the speed to stabilise.
- Record the no-load readings: line current, voltage, dead-weight and spring-balance readings, and speed.
- Gradually load the motor by tightening the rope/adding weights, keeping the pulley continuously wetted with water.
- At each load step, record the line current, voltage, the dead-weight/spring-balance readings, and the speed.
- Continue up to about 125% of the rated current, then gradually reduce the load to zero and switch off the supply.
- Calculate the net braking force, torque, brake power output, input power and efficiency at each step, and plot $\eta$, T and N against the current.

## 7. Observations and Calculations

| S.No. | Voltage V (V) | Current I (A) | Dead Weight W (kgf) | Spring Balance S (kgf) | Speed N (rpm) |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

**Calculations:** Net braking force = $(W - S) \times 9.81$ N; Torque $T = (W - S) \times 9.81 \times R$ N·m; Brake (output) power = $2\pi NT/60$ W; Input power = $V \times I$ W; Efficiency $\eta = (\text{Output}/\text{Input}) \times 100$.

## 12. Results

The brake power and efficiency of the DC shunt motor were determined at various loads up to full load. The maximum efficiency was found to occur near a particular value of load current at which the variable (copper) losses equal the constant losses of the motor.

## 13. Viva Book

1. What is the essential difference in emphasis between a general load test and a rope-brake test?
2. Why is continuous water cooling necessary at the brake pulley?
3. Define brake horsepower (BHP) of a motor.
4. State the condition for maximum efficiency of a DC motor.
5. What are the possible sources of error in a rope-brake test?
6. Why is the 'effective radius' (drum radius + half rope diameter) used in the torque calculation rather than the drum radius alone?

# Experiment No: 12

**Measurement of Voltage and Current Ratio of a Given Single-Phase Transformer**

## 1. Aim

To determine the voltage transformation ratio (K = E2/E1) of a given single-phase transformer by direct measurement on open circuit, and to determine the current ratio on load, verifying that the current ratio is approximately the reciprocal of the voltage ratio.

## 2. Theory

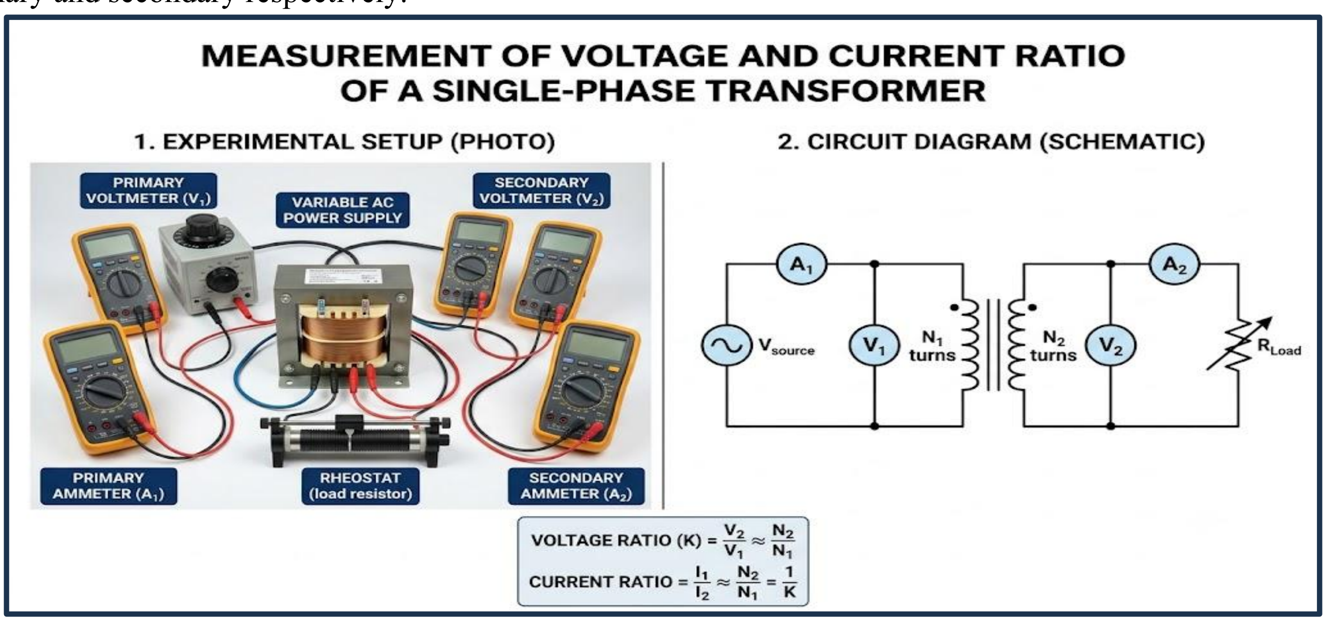
A single-phase transformer works on the principle of mutual induction: an alternating flux set up by the primary winding, when carrying an alternating current, links the secondary winding and induces an EMF in it given by E = 4.44 f Φm N, where f is the supply frequency, Φm the maximum flux and N the number of turns of the winding concerned.

For an ideal transformer, the voltage transformation ratio K = E2/E1 = N2/N1, where N1 and N2 are the number of primary and secondary turns. On load, neglecting the small no-load (magnetising and core-loss) component of the primary current, the primary and secondary currents are related by I1/I2 ≈ N2/N1 = K, i.e., the current ratio is approximately the reciprocal of the turns/voltage ratio.

In practice the measured current ratio departs slightly from the ideal value of K because the actual primary current is the phasor sum of the load component and the no-load (magnetising) component, and because of small voltage drops in the winding resistances and leakage reactances. This experiment determines K directly from open-circuit voltage measurements and verifies the current-ratio relationship by loading the secondary with a resistive load.

## 3. Practical Set-up / Circuit Diagram

For the voltage-ratio test, the primary winding is connected to a single-phase AC supply (through a variac, if provided) with a voltmeter V1 across the primary, while the secondary is kept open-circuited with a voltmeter V2 connected across it. For the current-ratio test, a resistive load bank is connected across the secondary through an ammeter A2, with an ammeter A1 retained in the primary line and voltmeters V1 and V2 across the primary and secondary respectively.



## 4. Apparatus Required

| S.No. | Apparatus / Equipment | Quantity |
|---|---|---|
| 1 | Single-phase transformer (as per nameplate rating) | 1 |
| 2 | Single-phase AC supply / variac | 1 |
| 3 | Voltmeter (0–300 V) | 2 |
| 4 | Ammeter (range as per transformer rating) | 2 |
| 5 | Resistive load bank | 1 |
| 6 | Connecting wires | As required |

## 5. Precautions to be Followed

- Note the nameplate rating of the transformer and do not exceed the rated primary voltage or rated current at any stage.
- Keep the secondary open-circuited while measuring only the voltage ratio (Part A).
- Ensure the voltmeters and ammeters used have ranges suitable for the expected primary/secondary voltages and currents.
- Apply the resistive load gradually, in small steps, while measuring the current ratio (Part B).
- Never short-circuit the secondary winding of the transformer.
- Switch off the supply before making or changing any connection.

## 6. Procedure

- Part A – Voltage ratio: Connect the transformer primary to the AC supply through voltmeter V1; keep the secondary open-circuited with voltmeter V2 connected across it.
- Switch on the supply and adjust (using the variac, if provided) to the rated primary voltage.
- Note the primary voltage V1 and the corresponding open-circuit secondary voltage V2.
- Repeat at two or three different primary voltages (at and below rated value) and tabulate the readings.
- Calculate the voltage transformation ratio K = V2/V1 at each reading and take the average value.
- Part B – Current ratio: Connect a resistive load bank to the secondary through ammeter A2, retaining ammeter A1 in the primary line and voltmeters V1, V2 as before.
- Switch on the supply at rated primary voltage with the load bank set to zero (minimum) load.
- Gradually increase the resistive load in steps up to the rated secondary current, noting I1 and I2 at each step.
- Reduce the load to zero and switch off the supply.
- Calculate the current ratio I1/I2 at each load step and compare it with the reciprocal of the average K obtained in Part A.

## 7. Observations and Calculations

**Table 1: Voltage Ratio (Secondary Open-Circuited)**

| S.No. | Primary Voltage V1 (V) | Secondary Voltage V2 (V) | K = V2/V1 |
|---|---|---|---|
| | | | |
| | | | |
| | | | |

**Table 2: Current Ratio (Secondary Loaded)**

| S.No. | Primary Voltage V1 (V) | Primary Current I1 (A) | Secondary Current I2 (A) | I1/I2 |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

**Calculations:** Average voltage ratio $K = (\Sigma V2/V1)/n$ from Table 1; reciprocal 1/K compared with the average current ratio I1/I2 from Table 2; % deviation = $[(1/K - I1/I2)/(1/K)] \times 100$.

## 12. Results

The voltage transformation ratio K of the given single-phase transformer was determined from the open-circuit test, and the current ratio I1/I2 obtained under load was found to be in close agreement with 1/K, confirming the relation E2/E1 = N2/N1 = I1/I2 for the transformer, with a small deviation attributable to the no-load (magnetising) component of the primary current.

## 13. Viva Book

1. On what principle does a transformer operate?
2. Why is the current ratio approximately the reciprocal of the voltage (turns) ratio?
3. Why is the secondary winding kept open while conducting the voltage-ratio test?
4. Why does the measured current ratio deviate slightly from the ideal value 1/K?
5. Define the voltage transformation ratio and relate it to the turns ratio of the transformer.
6. What precautions must be observed while loading a transformer during the current-ratio test?
7. Why is the no-load primary current of a transformer not in phase with the applied voltage?

# Experiment No: 13

**Polarity Test of a Single-Phase Transformer**

## 1. Aim

To determine the polarity (additive or subtractive) of a given single-phase transformer by the AC voltmeter method.

## 2. Theory

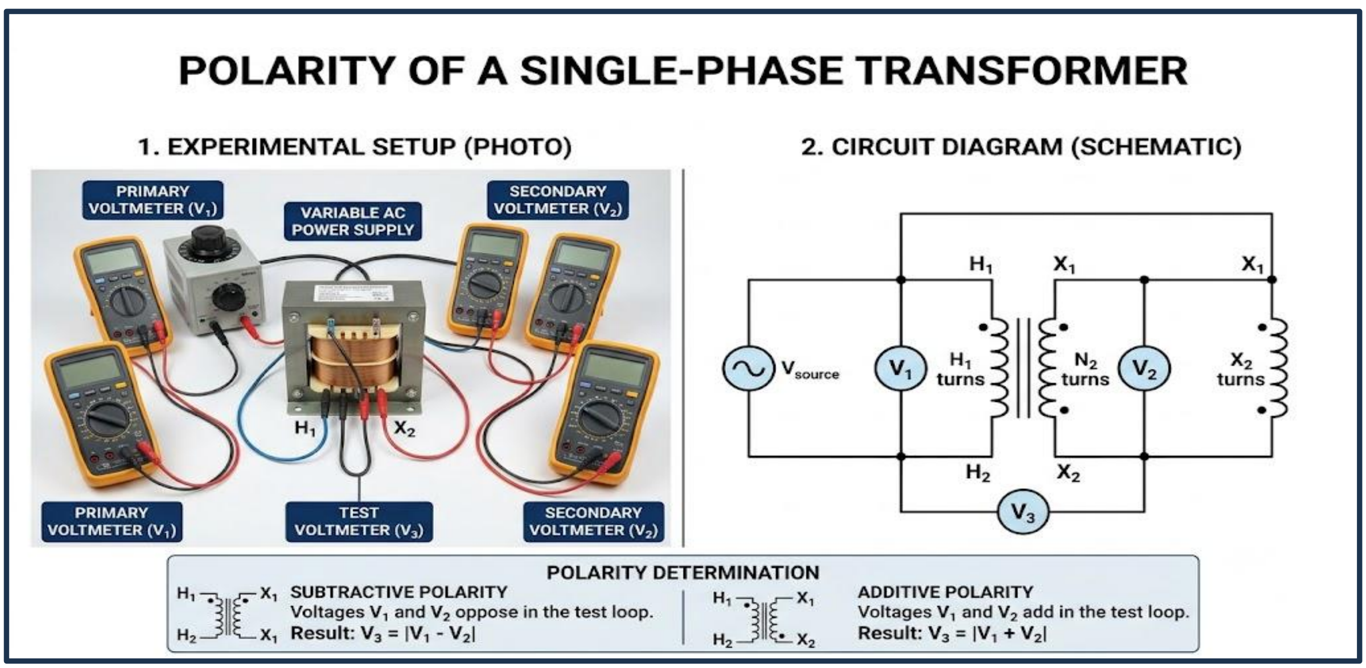
Polarity of a transformer refers to the relative instantaneous direction of the induced EMFs in the primary and secondary windings with respect to their terminal markings. Correct knowledge of polarity is essential whenever transformers are to be connected in parallel, in series (as in an auto-transformer connection), or in a three-phase bank, since a wrong polarity connection can cause a short-circuit or severe circulating current.

In the AC voltmeter method, one terminal of the high-voltage (HV) winding is temporarily jumpered to the adjacent terminal of the low-voltage (LV) winding, and a reduced voltage is applied to the HV winding through a variac. A voltmeter connected between the two remaining (free) terminals reads either the difference (V1 − V2) or the sum (V1 + V2) of the primary applied voltage V1 and the corresponding secondary induced voltage V2.

If the voltmeter reading is less than V1 (approximately V1 − V2), the transformer has subtractive polarity; if it is greater than V1 (approximately V1 + V2), the transformer has additive polarity. Distribution transformers are conventionally designed with subtractive polarity, while some small transformers may be additive.

## 3. Practical Set-up / Circuit Diagram

The HV winding is connected to a variac-controlled AC supply through a voltmeter V1. One HV terminal is temporarily jumpered to the adjacent LV terminal. A second voltmeter V3 is connected between the remaining free HV terminal and the remaining free LV terminal.



## 4. Apparatus Required

| S.No. | Apparatus / Equipment | Quantity |
|---|---|---|
| 1 | Single-phase transformer (with terminal markings) | 1 |
| 2 | Variac | 1 |
| 3 | Voltmeter (0–300 V) | 1 |
| 4 | Voltmeter (0–600 V) | 1 |
| 5 | Connecting wires / temporary jumper | As required |

## 5. Precautions to be Followed

- Note the nameplate terminal markings of the transformer carefully before starting.
- Apply only a reduced voltage (about 10–20% of rated) to the HV winding using the variac.
- Ensure the temporary jumper between the adjacent HV and LV terminals is secure before energising.
- Do not touch live terminals while the supply is on.
- Switch off the supply before removing the jumper or altering connections.
- Take the reading of voltmeter V3 promptly and confirm with a repeat trial.

## 6. Procedure

- Note the transformer's nameplate rating and terminal markings (H1, H2 for HV; X1, X2 for LV).
- Temporarily jumper terminal H2 to terminal X2 (adjacent terminals).
- Connect the variac output to the HV winding through voltmeter V1; connect voltmeter V3 between the free terminals H1 and X1.
- Switch on the supply and gradually apply a reduced voltage (about 10–20% of rated) to the HV winding using the variac.
- Record the applied voltage V1 and the voltmeter reading V3 across the free terminals.
- Compute the expected secondary voltage $V2 = K \times V1$ (K = turns ratio) and compare V3 with $(V1 - V2)$ and $(V1 + V2)$ to identify the polarity.
- Repeat once for confirmation, then switch off the supply and remove the jumper.

## 7. Observations and Calculations

| S.No. | Applied HV Voltage V1 (V) | Computed V2 (V) | Voltmeter Reading V3 (V) | Polarity |
|---|---|---|---|---|
| | | | | |
| | | | | |

**Calculations:** If $V3 \approx (V1 - V2)$, the transformer has subtractive polarity; if $V3 \approx (V1 + V2)$, the transformer has additive polarity.

## 12. Results

The polarity of the given single-phase transformer was determined by the AC voltmeter method and found to be as recorded in the observation table, consistent with its nameplate markings.

## 13. Viva Book

1. Why is knowledge of transformer polarity important?
2. Differentiate between additive and subtractive polarity.
3. Which polarity is conventionally standard for distribution transformers?
4. Describe the DC 'kick test' method of determining polarity.
5. Why is only a reduced voltage applied during the polarity test?
6. What could happen if two transformers of opposite (unverified) polarity are connected in parallel?

# Experiment No: 14

**Direct Load Test on a Single-Phase Transformer**

## 1. Aim

To conduct a direct load test on a given single-phase transformer using a resistive load bank, and to determine its efficiency and voltage regulation at various loads.

## 2. Theory

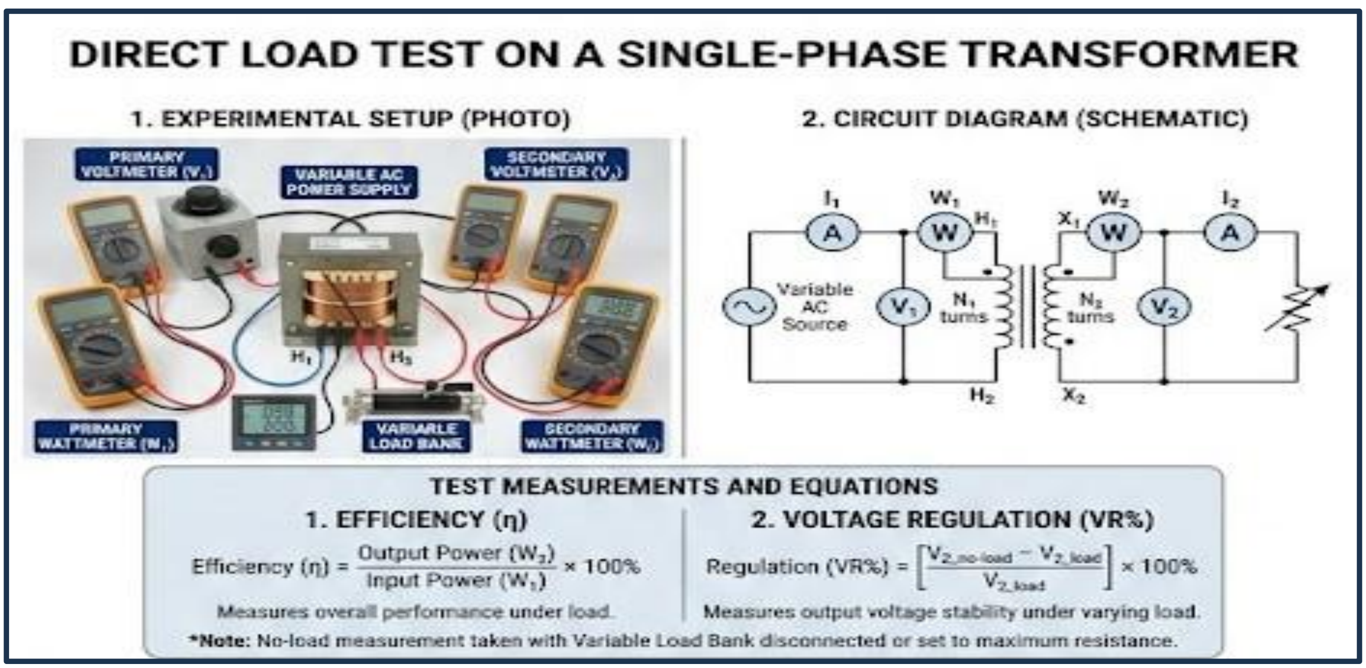
In a direct load test, the primary is energised at rated voltage and the secondary is loaded directly with a resistive (or resistive-inductive) load bank. Input power is measured on the primary side (voltmeter, ammeter, wattmeter) and output power on the secondary side, giving efficiency $\eta$ = (Output power/Input power) × 100.

Voltage regulation is obtained by comparing the no-load secondary voltage (secondary open, rated voltage applied to primary) with the secondary terminal voltage at a given load current: % Regulation = $[(E2 - V2)/V2] \times 100$, where E2 is the no-load secondary voltage and V2 is the loaded secondary terminal voltage.

The direct load test is simple and gives efficiency and regulation by actual measurement, but it requires a load bank capable of absorbing the full rated output of the transformer, which becomes impractical (wasteful of power and requires large load resistors) for transformers of large rating — for such transformers, the indirect OC and SC tests are preferred instead.

## 3. Practical Set-up / Circuit Diagram

The primary is connected to the AC supply through an ammeter, voltmeter and wattmeter. The secondary is connected to a resistive load bank through a second ammeter, voltmeter and wattmeter (or the same wattmeter switched between primary and secondary readings).



## 4. Apparatus Required

| S.No. | Apparatus / Equipment | Quantity |
|---|---|---|
| 1 | Single-phase transformer | 1 |
| 2 | AC supply / variac | 1 |
| 3 | Wattmeter (appropriate range) | 2 |
| 4 | Voltmeter (0–300 V) | 2 |
| 5 | Ammeter (as per transformer rating) | 2 |
| 6 | Resistive load bank | 1 |

## 5. Precautions to be Followed

- Apply exactly the rated voltage to the primary throughout the test.
- Keep the load bank at zero before switching on the supply.
- Increase the load gradually, in convenient steps, up to the rated secondary current.
- Ensure correct polarity connection of the current and pressure coils of each wattmeter.
- Record readings promptly at each step to minimise the effect of winding temperature rise.
- Reduce the load to zero before switching off the supply.

## 6. Procedure

- Note the nameplate rating of the transformer (V1, V2, rated current, kVA).
- Connect the primary to the supply through ammeter A1, voltmeter V1 and wattmeter W1; connect the secondary to the load bank through ammeter A2, voltmeter V2 and wattmeter W2.
- With the load bank at zero, switch on the supply at rated primary voltage and record the no-load secondary voltage E2.
- Gradually apply load in steps by adjusting the load bank, recording V1, I1, W1 (input) and V2, I2, W2 (output) at each step.
- Continue up to the rated full-load secondary current.
- Reduce the load to zero and switch off the supply.
- Calculate efficiency and voltage regulation at each load, and plot efficiency and regulation against load current.

## 7. Observations and Calculations

| S.No. | V1 (V) | I1 (A) | W1 (W) | V2 (V) | I2 (A) | W2 (W) |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

**Calculations:** Efficiency $\eta = (W2/W1) \times 100$; Voltage regulation $= [(E2 - V2)/V2] \times 100$, using the no-load secondary voltage E2 recorded before loading.

## 12. Results

The efficiency of the transformer was found to rise with load, reaching a maximum near the rated load and then declining slightly, while the voltage regulation was found to increase with load current, consistent with the expected behaviour of a small power transformer.

## 13. Viva Book

1. Define the efficiency and the voltage regulation of a transformer.
2. Why is the direct load test not preferred for large transformers?
3. What is the condition for maximum efficiency of a transformer?
4. What is meant by 'all-day efficiency', and how does it differ from ordinary (power) efficiency?
5. What are the drawbacks of the direct loading method compared with the indirect (OC/SC) method?
6. How does voltage regulation differ from efficiency as a performance measure?

# Experiment No: 15

**No-Load Waveform of a Transformer Using CRO**

## 1. Aim

To observe and sketch the no-load (exciting) current waveform of a single-phase transformer using a CRO, and to note its non-sinusoidal (peaky) nature as compared with the sinusoidal applied voltage.

## 2. Theory

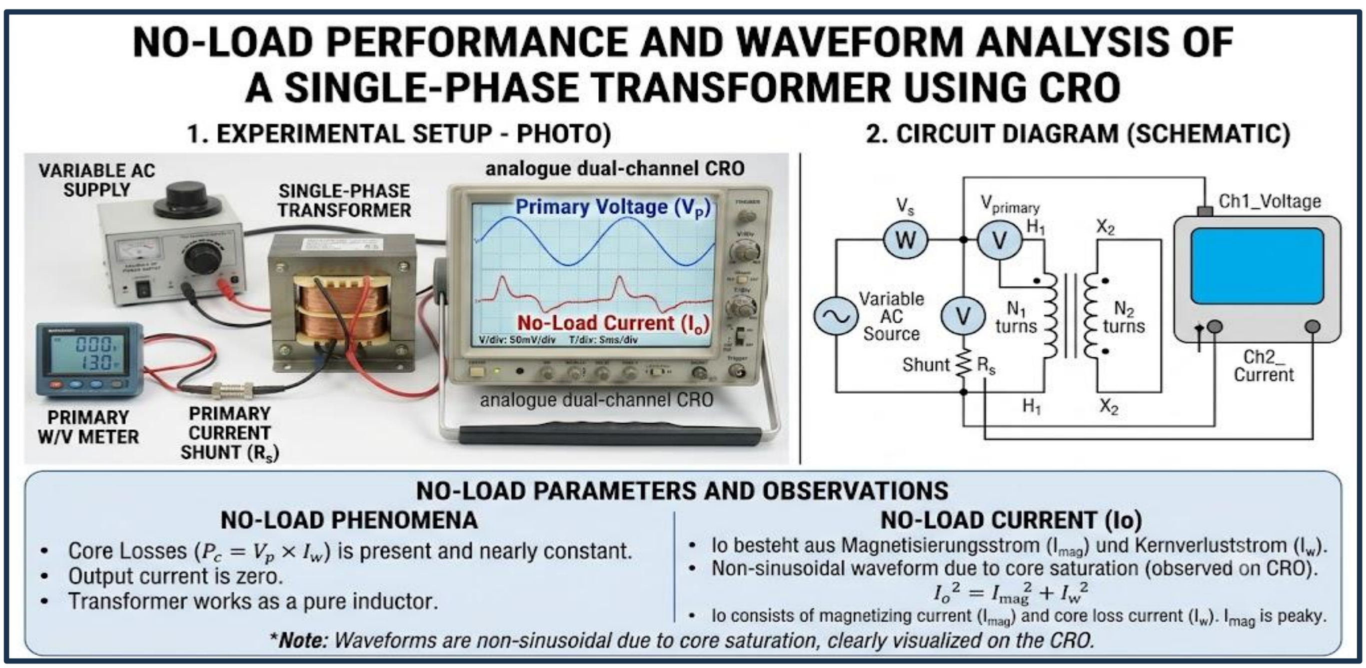
Even when the applied primary voltage is perfectly sinusoidal, the no-load (exciting) current of a transformer is not sinusoidal, because the core operates on the non-linear (saturating) part of its B–H characteristic. The exciting current can be resolved into a core-loss (working) component, nearly in phase with the induced EMF, and a magnetising component, which lags the voltage by 90° and has a markedly peaky, harmonic-rich waveform.

The distortion of the magnetising current is due to the flattening of the flux waveform at the top of the B-H loop; Fourier analysis of this peaky current shows it to be rich in odd harmonics, predominantly the third harmonic. A CRO is used to display the current waveform (sensed as a voltage drop across a small non-inductive shunt resistor) alongside the sinusoidal supply voltage waveform, on a common time axis, to visualise both the distortion and the phase relationship.

The extent of waveform distortion can be quantified approximately by the peak factor (ratio of peak value to RMS value) of the current; for a pure sine wave this equals $\sqrt{2} \approx 1.414$, while a peaky no-load current shows a peak factor noticeably greater than this value.

## 3. Practical Set-up / Circuit Diagram

The transformer primary is excited from an AC supply (through an isolation transformer, for safety, and a variac) with the secondary kept open. A small non-inductive shunt resistor is inserted in series with the primary to sense the no-load current as a voltage. CRO channel-1 is connected across this shunt (current waveform) and channel-2 across the primary supply (voltage waveform, as reference), both referenced to a common ground.



## 4. Apparatus Required

| S.No. | Apparatus / Equipment | Quantity |
|---|---|---|
| 1 | Single-phase transformer | 1 |
| 2 | Dual-trace CRO | 1 |
| 3 | Isolation transformer | 1 |
| 4 | Variac | 1 |
| 5 | Non-inductive shunt resistor (low value) | 1 |
| 6 | Connecting wires | As required |

## 5. Precautions to be Followed

- Use an isolation transformer to supply the test circuit, to avoid earthing/shock hazards to the CRO and the operator.
- Ensure the CRO probe grounds (channel-1 and channel-2) are connected to a common reference point.
- Keep the secondary of the transformer open (no load) throughout the observation.
- Do not exceed the rated voltage of the transformer.
- Use a shunt resistor of negligible value so as not to significantly disturb the primary circuit.
- Adjust the CRO time-base and volts/div carefully for a stable, clearly readable display.

## 6. Procedure

- Connect the transformer primary to the AC supply (through the isolation transformer and variac) with the secondary kept open.
- Insert the non-inductive shunt resistor in series with the primary to sense the no-load current.
- Connect CRO channel-1 across the shunt (current waveform) and channel-2 across the primary supply (voltage waveform, reference).
- Switch on the supply and apply rated primary voltage; adjust the CRO controls for a stable display of both waveforms.
- Observe and sketch the voltage waveform (sinusoidal) and the corresponding no-load current waveform (non-sinusoidal/peaky) on the same time axis.
- Note the phase relationship between the two waveforms and the extent of peaking/distortion in the current waveform.
- Switch off the supply after completing the observation.

## 7. Observations and Calculations

| S.No. | Applied Voltage V1 (V) | No-Load Current I0, rms (A) | Peak Current (from CRO) (A) | Nature of Waveform |
|---|---|---|---|---|
| | | | | |
| | | | | |

**Calculations:** Peak factor of no-load current = (Peak value read from CRO)/(RMS value read from ammeter). For a pure sinusoid, peak factor = 1.414; a value appreciably greater than 1.414 confirms a peaky, harmonic-distorted current waveform.

## 12. Results

The no-load current waveform of the transformer was observed to be non-sinusoidal (peaky) compared with the sinusoidal applied voltage waveform, with a peak factor greater than 1.414, confirming the presence of harmonics (chiefly the third) in the exciting current due to core saturation.

## 13. Viva Book

1. Why is the no-load current of a transformer not sinusoidal even though the applied voltage is sinusoidal?
2. What are the two components of the no-load current, and what are their phase relationships with the voltage?
3. Why does the no-load current contain predominantly the third harmonic?
4. What is 'peak factor', and how does it help in detecting waveform distortion?
5. Why must an isolation transformer be used when connecting a CRO to a mains-derived circuit?
6. How does core saturation influence the shape of the exciting current waveform?

# Experiment No: 16

**Open-Circuit and Short-Circuit Test on a Single-Phase Transformer**

## 1. Aim

To conduct the open-circuit (OC) and short-circuit (SC) tests on a given single-phase transformer to determine its equivalent circuit parameters, and to compute its efficiency and regulation at any load without actually loading it.

## 2. Theory

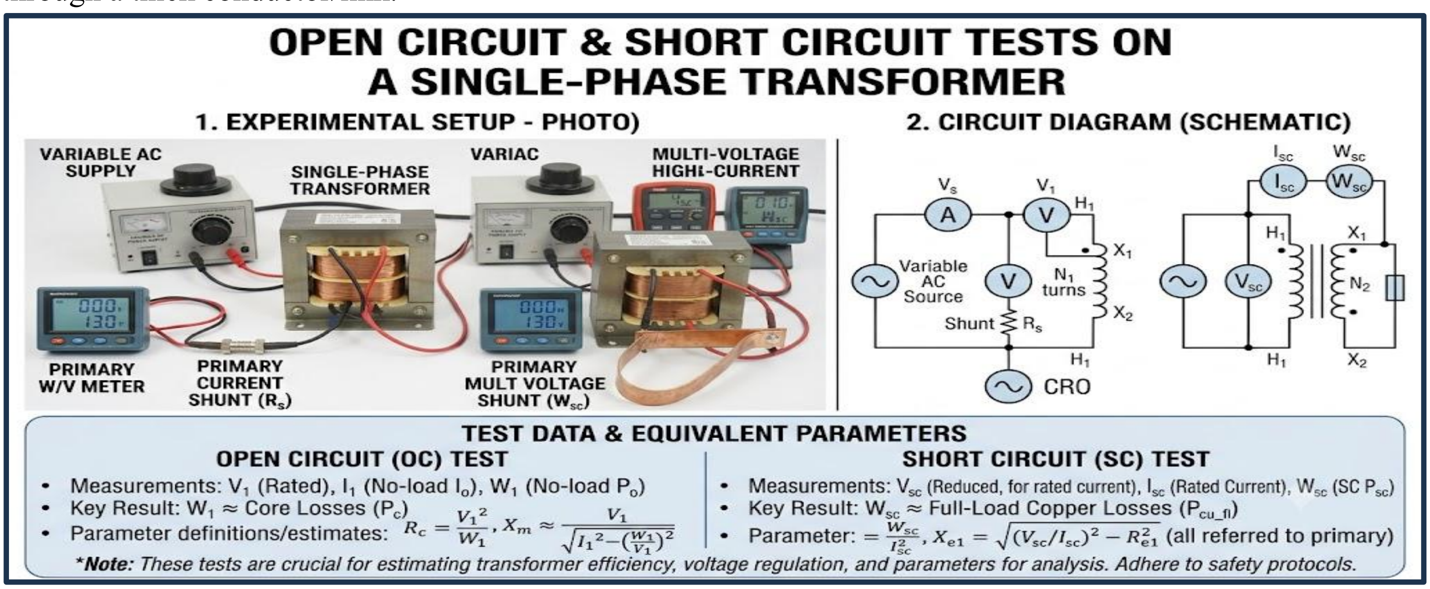
In the open-circuit test, rated voltage is applied to one winding (usually the LV winding, for convenience) with the other winding kept open. Since the no-load current I0 is small, the copper loss is negligible, so the wattmeter reading W0 represents essentially the core (iron) loss. From V0, I0 and W0: cos Φ0 = W0/(V0I0); the working (core-loss) component Iw = I0 cos Φ0 and the magnetising component Im = I0 sin Φ0 are obtained, giving the shunt-branch parameters R0 = V0/Iw and X0 = V0/Im.

In the short-circuit test, the LV (or secondary) winding is short-circuited, and a low voltage is applied to the HV (primary) winding, gradually increased until rated current flows. Since the applied voltage is low, the core loss is negligible, so the wattmeter reading Wsc represents the total copper loss at (rated) test current. From Vsc, Isc and Wsc: equivalent impedance Zeq = Vsc/Isc, equivalent resistance Req = Wsc/Isc$^2$, and equivalent reactance Xeq = $\sqrt{Zeq^2 - Req^2}$, all referred to the HV side.

These indirect tests require only a small fraction of the rated power (enough to supply the losses), making them far more economical than a direct full-load test, especially for large transformers. From the OC and SC parameters, efficiency at any fractional load x and power factor cos Φ, and the voltage regulation, can be computed without physically loading the transformer: η = (x·S·cosΦ)/(x·S·cosΦ + Pi + x$^2$Pcu) × 100, where Pi is the iron loss (from OC test) and Pcu is the full-load copper loss (from SC test).

## 3. Practical Set-up / Circuit Diagram

For the OC test, the variac supplies rated voltage to the LV winding through an ammeter, voltmeter and wattmeter, with the HV winding left open. For the SC test, the variac supplies a low, gradually-increasing voltage to the HV winding through an ammeter, voltmeter and wattmeter, with the LV winding short-circuited through a thick conductor/link.



## 4. Apparatus Required

| S.No. | Apparatus / Equipment | Quantity |
|---|---|---|
| 1 | Single-phase transformer | 1 |
| 2 | Variac | 1 |
| 3 | Voltmeter (0–300 V) | 2 |
| 4 | Ammeter (as per rating) | 2 |
| 5 | Wattmeter (LPF, appropriate range) | 2 |
| 6 | Short-circuiting link / thick conductor | 1 |

## 5. Precautions to be Followed

- In the OC test, apply exactly the rated voltage to the LV winding and keep the HV winding open.
- In the SC test, start with the variac at zero and increase gradually — never apply full/rated voltage directly across the short-circuited winding.
- Do not exceed the rated current during the SC test; take readings quickly to avoid overheating.
- Ensure correct polarity connections for the current and pressure coils of each wattmeter.
- Reduce the variac to zero before switching off the supply after each test.
- Allow the transformer to cool between the two tests, if it becomes noticeably warm.

## 6. Procedure

- Part A – OC test: Connect the variac to the LV winding through ammeter A0, voltmeter V0 and wattmeter W0; keep the HV winding open.
- Gradually increase the variac to apply rated voltage to the LV winding, and record V0, I0 and W0.
- Reduce the variac to zero and switch off the supply.
- Part B – SC test: Connect the variac to the HV winding through ammeter Isc, voltmeter Vsc and wattmeter Wsc; short-circuit the LV winding with a thick conductor/link.
- Starting from zero, gradually increase the variac voltage until rated current flows in the HV winding.
- Quickly record Vsc, Isc and Wsc.
- Reduce the variac to zero and switch off the supply immediately.
- Calculate the equivalent circuit parameters (R0, X0 from the OC test; Req, Xeq from the SC test) and hence compute the efficiency and voltage regulation at rated load for a given power factor.

## 7. Observations and Calculations

**Table 1: Open-Circuit Test**

| S.No. | V0 (V) | I0 (A) | W0 (W) |
|---|---|---|---|
| | | | |
| | | | |

**Table 2: Short-Circuit Test**

| S.No. | Vsc (V) | Isc (A) | Wsc (W) |
|---|---|---|---|
| | | | |
| | | | |

**Calculations:** $\cos \Phi_0 = W_0/(V_0 I_0)$; $I_w = I_0 \cos \Phi_0$; $I_m = I_0 \sin \Phi_0$; $R_0 = V_0/I_w$; $X_0 = V_0/I_m$. $Z_{eq} = V_{sc}/I_{sc}$; $R_{eq} = W_{sc}/I_{sc}^2$; $X_{eq} = \sqrt{(Z_{eq}^2 - R_{eq}^2)}$. Efficiency at full load, unity pf: $\eta = (S \cos\Phi)/(S \cos\Phi + W_0 + W_{sc}) \times 100$. Voltage regulation $\approx (I_{sc} R_{eq} \cos\Phi + I_{sc} X_{eq} \sin\Phi)/V \times 100$.

## 12. Results

The equivalent circuit parameters, iron loss and full-load copper loss of the transformer were determined from the OC and SC tests, and the efficiency and voltage regulation at rated load were computed without subjecting the transformer to an actual load test.

## 13. Viva Book

1. Why is the OC test generally conducted on the LV side of the transformer?
2. Why is the SC test conducted at a low (reduced) applied voltage?
3. What does the OC test primarily give, and what does the SC test primarily give?
4. Why is this indirect (OC + SC) method preferred over a direct load test for large transformers?
5. Describe the equivalent circuit of a transformer referred to one side.
6. What is the condition for maximum efficiency, and how is the load corresponding to it determined from the OC/SC data?

# Experiment No: 17

**Parallel Operation of Two Single-Phase Transformers**

## 1. Aim

To connect two single-phase transformers in parallel and to study the conditions necessary for their successful parallel operation and the sharing of load between them.

## 2. Theory

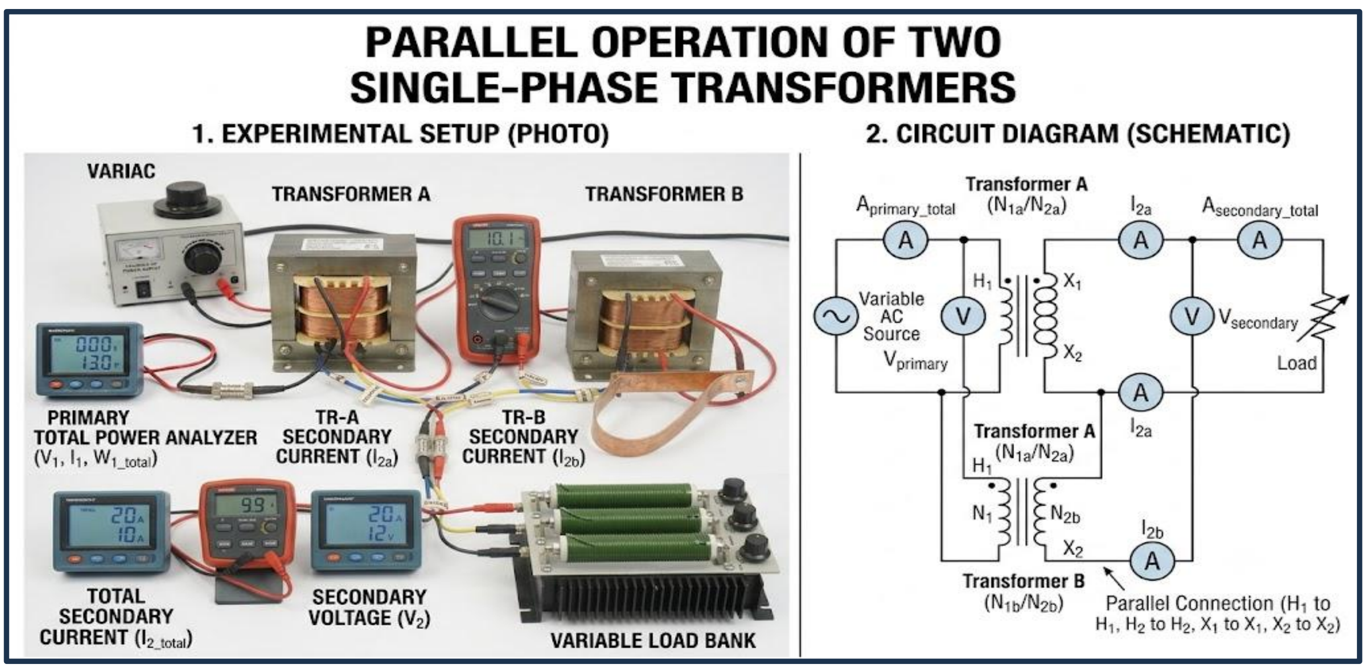
For satisfactory parallel operation of single-phase transformers, the following conditions should be met: (i) the same voltage (turns) ratio, otherwise a circulating current flows between the transformers even at no load; (ii) the same polarity, correctly connected, otherwise a short-circuit results; and (iii) the same percentage impedance (and preferably the same X/R ratio), so that the total load is shared between the two transformers in proportion to their kVA ratings.

If the voltage ratios of the two transformers differ even slightly, a circulating current flows continuously between them (even with no external load connected), causing additional copper loss and heating. When the transformers are correctly matched in polarity and voltage ratio but have unequal percentage impedances, the load is shared inversely in proportion to their impedance values (referred to the same base), which can cause one transformer to reach its rated current before the other.

Before closing the paralleling connection, it is standard practice to check that the voltage across the open switch/link joining the two secondaries reads close to zero, confirming matched voltage and correct polarity, before the two transformers are actually connected together.

## 3. Practical Set-up / Circuit Diagram

The primaries of the two transformers, T1 and T2, are connected to a common AC supply bus. Their secondaries are connected, through a paralleling switch, to a common secondary bus to which a resistive load bank is connected. Ammeters are provided in the secondary line of each transformer and in the common load line, with a voltmeter across the secondary bus.



## 4. Apparatus Required

| S.No. | Apparatus / Equipment | Quantity |
|---|---|---|
| 1 | Single-phase transformers | 2 |
| 2 | AC supply / variac | 1 |
| 3 | Voltmeter (0–300 V) | 2 |
| 4 | Ammeter (as per rating) | 3 |
| 5 | Resistive load bank | 1 |
| 6 | Paralleling switch / link | 1 |

## 5. Precautions to be Followed

- Determine and verify the polarity of both transformers (as in Experiment 13) before attempting to parallel them.
- Check that the secondary voltages of both transformers are equal before closing the paralleling switch.
- Verify that the voltage across the open paralleling switch reads close to zero before closing it.
- Apply the common load gradually, in small steps.
- Do not allow either transformer to exceed its rated current.
- Open the paralleling switch and switch off the supply before altering any connection.

## 6. Procedure

- Determine the polarity of both transformers individually and mark their terminals accordingly.
- Connect the primaries of both transformers to the common AC supply bus.
- Before closing the secondary paralleling switch, measure the voltage across it (between corresponding secondary terminals of the two transformers) — it should read close to zero.
- Close the paralleling switch to connect the two secondaries in parallel, and note any circulating current at no load.
- Connect the common resistive load bank to the paralleled secondary bus and gradually apply load in steps.
- At each load step, record the total load current and the individual currents supplied by T1 and T2, along with the common secondary voltage.
- Continue up to the rated capacity of the smaller/weaker transformer.
- Reduce the load to zero, open the paralleling switch, and switch off the supply.
- Calculate the percentage load shared by each transformer and compare it with the ratio predicted from their kVA ratings/impedances.

## 7. Observations and Calculations

| S.No. | Total Load Current IL (A) | Current from T1, I1 (A) | Current from T2, I2 (A) | Secondary Voltage (V) |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

**Calculations:** % load shared by T1 = (I1/IL) × 100; % load shared by T2 = (I2/IL) × 100. Theoretical ratio I1/I2 is compared with the inverse ratio of the percentage impedances (or with the kVA ratings, if the %impedances are equal) of the two transformers.

## 12. Results

The two single-phase transformers were successfully operated in parallel; the load was found to be shared between them approximately in accordance with their kVA ratings/impedance values, with negligible circulating current confirming matched polarity and voltage ratio.

## 13. Viva Book

1. State the conditions necessary for successful parallel operation of single-phase transformers.
2. What happens if two transformers of different voltage ratio are connected in parallel?
3. Why must polarity be verified before paralleling two transformers?
4. What causes circulating current in a parallel bank of transformers, and does it exist at no load as well as under load?
5. How is load shared between two dissimilar (unequal %impedance) transformers connected in parallel?
6. Why should the percentage impedance of paralleled transformers be nearly equal?

# Experiment No: 18

**Auto-Transformer and Single-Phase Two-Winding Transformer of the Same Rating — A Comparative Study**

## 1. Aim

To study the construction and working of an auto-transformer as compared with a two-winding (isolating) transformer of the same kVA rating, and to verify the theoretical saving of copper in the auto-transformer connection.

## 2. Theory

An auto-transformer has a single winding, part of which is common to both the primary and the secondary circuits, unlike a two-winding transformer in which the primary and secondary windings are electrically isolated from each other. For a given kVA rating and voltage ratio K (= secondary/primary voltage, for a step-down connection), part of the power is transferred directly by electrical conduction through the common winding, and only the remaining part is transferred inductively (transformer action) through mutual flux linkage.

The fraction of power conducted directly is K × (total kVA), and the fraction transformed inductively is (1 − K) × (total kVA). Because only the transformed portion of the power requires copper in the common/series windings sized for the full winding rating, an auto-transformer requires appreciably less copper than an equivalent two-winding transformer of the same output — the saving of copper, compared to an equivalent two-winding unit, is a fraction K of the copper that would be used in the two-winding transformer.

As a consequence of the reduced copper and lower leakage reactance, an auto-transformer has higher efficiency and better voltage regulation than a two-winding transformer of the same rating, particularly when K is close to 1. Its principal disadvantage is the loss of electrical isolation between the primary and secondary circuits — a serious limitation where isolation is required for safety, or where the voltage ratio is large (making the copper saving small in any case).

## 3. Practical Set-up / Circuit Diagram

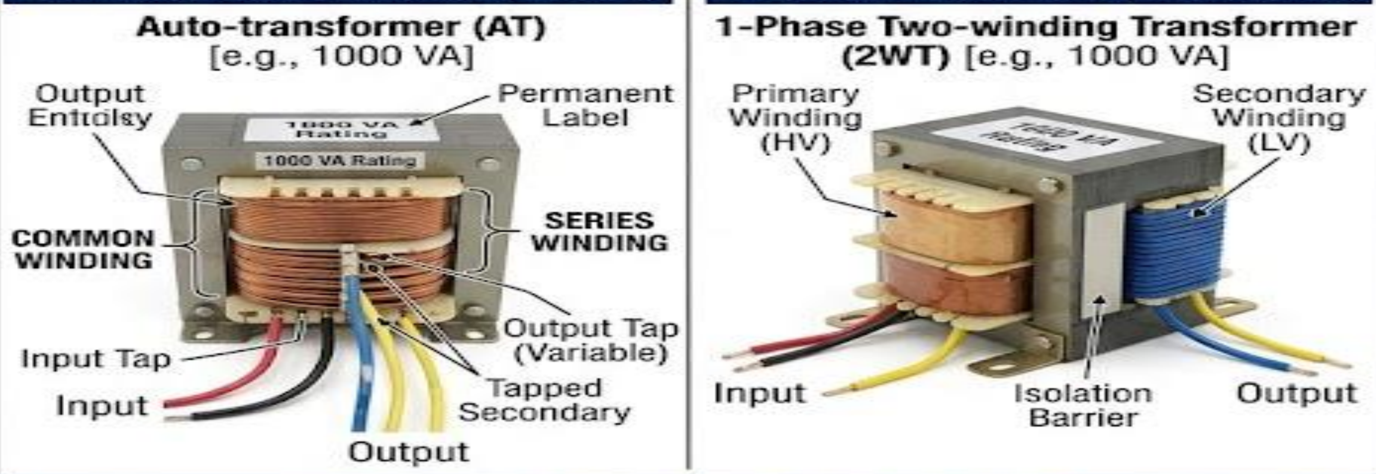
The same physical two-winding transformer is tested in two configurations for a fixed output kVA: first in its normal two-winding (isolated) connection, and then with its HV and LV windings connected in series with correct (additive) polarity to form an auto-transformer connection. Voltmeters, ammeters and a wattmeter record input/output quantities and losses in each configuration.

## 4. Apparatus Required

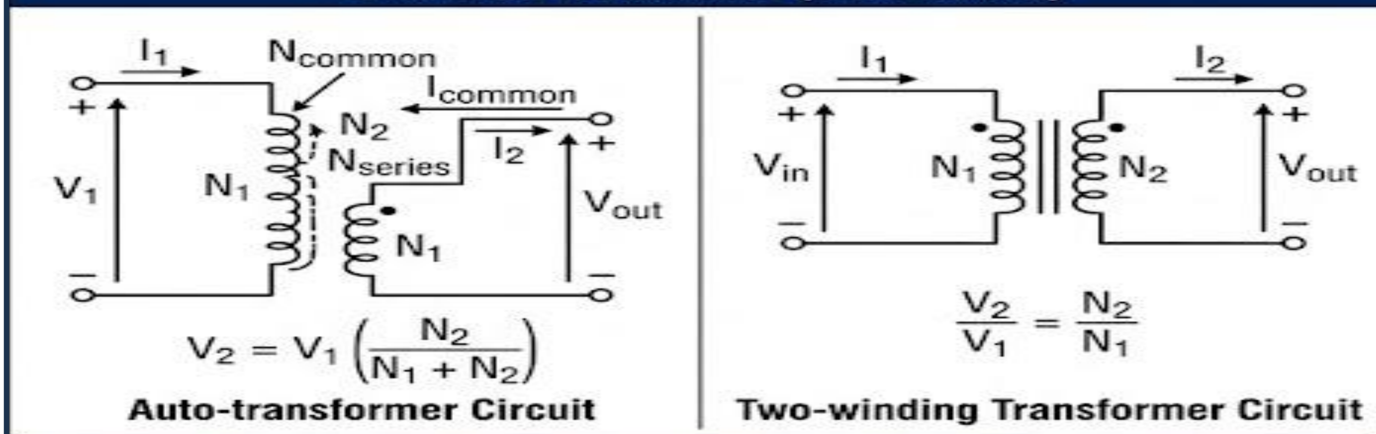
| S.No. | Apparatus / Equipment | Quantity |
|---|---|---|
| 1 | Single-phase two-winding transformer (convertible to auto-connection) | 1 |
| 2 | AC supply / variac | 1 |
| 3 | Voltmeter (0–300 V) | 2 |
| 4 | Ammeter (as per rating) | 2 |
| 5 | Wattmeter | 1 |
| 6 | Resistive load bank | 1 |

# COMPARISON: AUTO-TRANSFORMER vs. 1-PHASE TWO-WINDING TRANSFORMER (SAME RATING)

## 1. PHYSICAL APPEARANCE (PHOTO) | 2. CIRCUIT DIAGRAMS (SCHEMATIC)




## 2. CIRCUIT DIAGRAMS (SCHEMATIC)




## KEY COMPARISON: SAME POWER RATING (e.g., 1000 VA)

| Feature | Auto-transformer | Two-winding Transformer |
|---|---|---|
| Number of Windings | 1 | 2 |
| Galvanic Isolation | No | Yes |
| Copper Volume/Cost | Lower | Higher |
| Core Material/Cost | Similar | Similar |
| Size & Weight | Smaller / Lighter | Larger / Heavier |
| Full Load Efficiency | Typically Higher | Standard High |
| Output Current (at variable tap) | Higher for given core size | Standard |
| Common Applications | Good for small voltage steps, standard uses | Essential for isolation, general distribution |

*Comparison is for a fixed rating (e.g., 1000 VA). All data is representative.*

## 5. Precautions to be Followed

- Determine the polarity of the transformer's windings (Experiment 13) before making the series (auto) connection, to ensure additive polarity — a subtractive series connection can cause a short-circuit/voltage cancellation.
- Do not exceed the rated current of either winding in either connection.
- Note that, in the auto-connection, the common winding may carry the difference of the primary and secondary currents; monitor this carefully.
- Apply load gradually, in convenient steps, in both configurations.
- Switch off the supply before changing from the two-winding connection to the auto-transformer connection.
- Keep the output kVA the same in both configurations for a valid comparison.

## 6. Procedure

- Test the transformer in its normal two-winding (isolated) connection: apply rated primary voltage, load the secondary to a chosen output current, and record input/output voltage, current and losses.
- Switch off the supply, and reconnect the HV and LV windings of the same transformer in series (with verified additive polarity) to form an auto-transformer.
- Apply supply voltage to the auto-transformer connection and load it to the same output kVA as in Step 1.
- Record the input/output voltage, current and losses (or compute the copper loss) for the auto-transformer connection.
- Compare the copper ($I^2R$) loss, efficiency, and regulation obtained in the two connections for the same output.
- Calculate the theoretical copper saving using the relation for an auto-transformer, and compare it with the observed reduction in loss.
- Switch off the supply and restore the original two-winding connections.

## 7. Observations and Calculations

| S.No. | Connection | Input Voltage (V) | Input Current (A) | Output Voltage (V) | Output Current (A) | Loss (W) | Efficiency (%) |
|---|---|---|---|---|---|---|---|
| 1 | Two-winding (isolated) | | | | | | |
| 2 | Auto-transformer | | | | | | |

**Calculations:** Theoretical fraction of copper saving in the auto-transformer connection ≈ K (the voltage ratio); % saving = K × 100. Compare this with the actual observed reduction in loss: % actual saving = [(Wcu, two-winding − Wcu, auto)/Wcu, two-winding] × 100.

## 12. Results

The auto-transformer connection was found to have lower copper loss and higher efficiency than the two-winding connection for the same output kVA, with the observed copper saving found to be in reasonable agreement with the theoretical value K — at the cost of losing electrical isolation between the primary and secondary.

## 13. Viva Book

1. What is the fundamental difference between an auto-transformer and a two-winding transformer?
2. Derive the expression for the saving of copper in an auto-transformer compared with an equivalent two-winding transformer.
3. State the advantages and disadvantages of an auto-transformer as compared to a two-winding transformer.
4. Name typical applications of auto-transformers (e.g., starting of induction motors, voltage boosters/regulators, interconnecting transformers).
5. Why is the loss of isolation in an auto-transformer a safety concern in certain applications?
6. Explain the terms 'conducted power' and 'transformed power' as applied to an auto-transformer.

# Experiment No: 19

**Parallel Operation of Two Three-Phase Transformers for Equal and Unequal Load Sharing**

## 1. Aim

To connect two three-phase transformers in parallel and to study the sharing of load between them under (a) matched percentage impedance (equal load sharing) and (b) unequal percentage impedance (unequal load sharing) conditions.

## 2. Theory

In addition to the conditions applicable to single-phase transformers (same voltage ratio, correct polarity, matched percentage impedance for proportionate sharing), three-phase transformers to be paralleled must also have the same phase sequence and a compatible vector group (angular displacement between corresponding primary and secondary line voltages). Transformers of incompatible vector groups (for example, a star-star transformer and a delta-star transformer with different phase-shift) cannot generally be paralleled directly, since the resulting phase-angle difference between their secondary voltages would produce large circulating currents.

When two correctly matched three-phase transformers (same voltage ratio, vector group and phase sequence) have equal per-unit (or percentage) impedance referred to a common base, they share the total load in proportion to their kVA ratings. If their per-unit impedances are unequal, the transformer with the lower per-unit impedance draws a disproportionately larger share of the load current and may reach its rated current before the other, the approximate sharing relation being: (Load on T1)/(Load on T2) = (kVA1 × Z2%)/(kVA2 × Z1%).

This experiment verifies both cases: first with two transformers of matched percentage impedance (Part A), and then with two transformers of differing percentage impedance (Part B), comparing the observed current sharing with that predicted by the above relation.

## 3. Practical Set-up / Circuit Diagram

The primaries of the two three-phase transformers are connected to a common three-phase supply bus (after verifying matched phase sequence and vector group). Their secondaries are connected, through a paralleling switch, to a common three-phase load bus supplying a balanced resistive load bank. Ammeters record the current supplied by each transformer and a voltmeter monitors the common bus voltage.

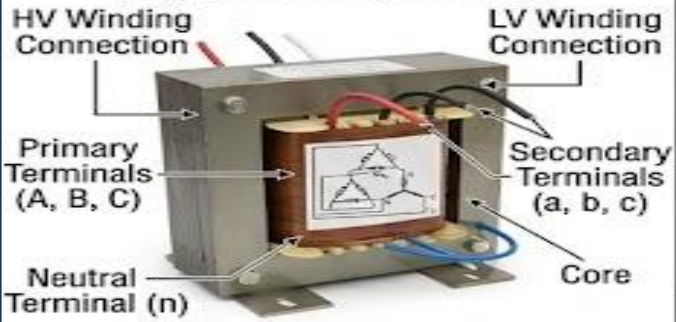
## 4. Apparatus Required

| S.No. | Apparatus / Equipment | Quantity |
|---|---|---|
| 1 | Three-phase transformers (matched %Z for Part A; differing %Z for Part B) | 2 |
| 2 | Three-phase AC supply | 1 |
| 3 | Phase-sequence indicator | 1 |
| 4 | Voltmeter | 1-2 |
| 5 | Ammeter | 3 |
| 6 | Three-phase balanced resistive load bank | 1 |

# PARALLEL OPERATION OF TWO THREE-PHASE TRANSFORMERS: EQUAL & UNEQUAL LOAD SHARING

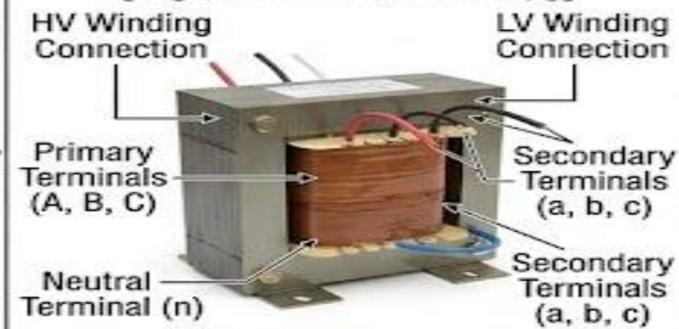
## 1. PHYSICAL APPEARANCE (PHOTO - REPRESENTATIVE)

**3-Phase Transformer A ($T_A$)**
[e.g., 500 kVA, 5% $Z_{PU}$]




**Input (Δ) / Output (Y,n)**
(e.g., Dyn11 vector group)

**3-Phase Transformer B ($T_B$)**
[e.g., 500 kVA, 10% $Z_{PU}$]

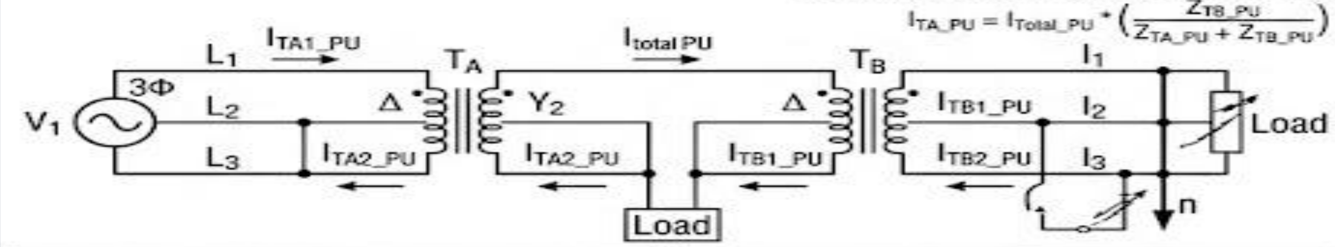



**Input (Δ) / Output (Y,n)**
(e.g., Dyn11 vector group) with higher $Z_{PU}$ higher $Z_{PU}$

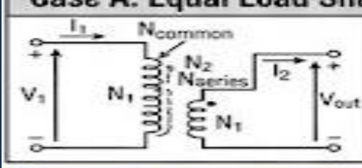
## 2. CIRCUIT DIAGRAMS (SCHEMATIC)

**PU CURRENT DIVISION RULE** (for same KVA rating):

$$I_{TA\_PU} = I_{Total\_PU} * \left(\frac{Z_{TB\_PU}}{Z_{TA\_PU} + Z_{TB\_PU}}\right)$$

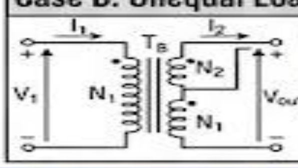



**Case A: Equal Load Sharing** (Identical $Z_{PU}$)




**Identical units:**
$S_{TA} = S_{TB} = S_{Total}/2$.
(e.g., Total load 800 kVA, shared 400 kVA each)

**Case B: Unequal Load Sharing** (Mismatch $Z_{PU}$)




**Unequal $Z_{PU}$ ($T_A$:5%, $T_B$:10%).**
**$T_A$ shares more PU load.**
(e.g., Total Load 750 kVA (1.5 PU) share is $S_{TA\_PU}$=1.0, $S_{TB\_PU}$=0.5.
$T_A$ at full load, $T_B$ at 50% load.

## KEY COMPARISON: EQUAL vs. UNEQUAL LOAD SHARING

| Feature | Case A: Equal Load Sharing (Identical $Z_{PU}$) | Case B: Unequal Load Sharing (Mismatch $Z_{PU}$) |
|---|---|---|
| Parameter condition | $Z_{TA\_PU} = Z_{TB\_PU}$ AND same rated KVA (e.g., both 500 kVA) (Note: Different KVA ratings cause: sharing) | $Z_{TA\_PU} \neq Z_{TB\_PU}$ but same rated KVA (e.g., $T_A$:5%, $T_B$:10%, both 500kVA) (Note: Different KVA ratings cause complex sharing.) |
| KVA Loading (% of total load) | Balanced ($\frac{S_{share}}{S_{rated}}$ is equal) | Imbalanced ($\frac{S_{share}}{S_{rated}}$ is different, loads based on $Z_{inv\_PU}$) |
| Division rule (PU magnitude) | Balanced $I_{TA\_PU} = I_{TB\_PU} = \frac{I_{Total\_PU}}{2}$ | Imbalanced (share based on $\frac{Z_{TB\_PU}}{(Z_{TA\_PU}+Z_{TB\_PU})}$ for PU current |
| Impact on loading | Balanced, even loading on both units | Imbalanced, one unit will load closer to its capacity, can limit total capacity or cause localized overheating |
| Cause of mismatch | Not applicable (Identical Units) | $Z_{TA\_PU}$ mismatch (e.g., due to different designs, taps, or age) |

*Important: This comparison assumes identical transformer voltage ratios. A mismatch in voltage ratios causes a circulating current and distorts the load division. Adhere to all safety protocols when paralleling high-power three-phase transformers.*

## 5. Precautions to be Followed

- Verify the phase sequence of the supply and of both transformers' secondaries before attempting to parallel them.
- Confirm that the vector groups (angular displacements) of the two transformers are compatible.
- Check that the voltage across each pole of the open paralleling switch reads close to zero on all three phases before closing it.
- Apply the balanced load gradually and equally on all three phases.
- Do not exceed the rated current of either transformer, especially the one with the lower percentage impedance.
- Open the paralleling switch and switch off the supply before altering any connection.

## 6. Procedure

- Verify the phase sequence of the supply and of both transformers' secondaries using a phase-sequence indicator, and confirm matching vector groups.
- Connect the primaries of both transformers to the common three-phase supply bus.
- Before closing the paralleling switch, check the voltage across each of its poles (should read close to zero for all three phases).
- Close the paralleling switch to connect the two secondaries in parallel, and note any circulating current at no load.
- Part A (matched impedance): with both transformers having nearly equal per-unit impedance, connect the balanced load bank and increase load gradually, recording the total load current and the current supplied by each transformer at each step.
- Part B (unequal impedance): repeat with two transformers of different (known) percentage impedances, again recording individual and total currents at each load step.
- Continue each part up to the rated current of the smaller/weaker transformer.
- Reduce load to zero, open the paralleling switch, and switch off the supply.
- Calculate the percentage load shared by each transformer in both parts, and compare with the values predicted from their kVA ratings and percentage impedances.

## 7. Observations and Calculations

**Table 1: Part A — Matched Percentage Impedance**

| S.No. | Total Load IL (A) | I1 (A) | I2 (A) | Bus Voltage (V) |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

**Table 2: Part B — Unequal Percentage Impedance**

| S.No. | Total Load IL (A) | I1 (A) | I2 (A) | Bus Voltage (V) |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

**Calculations:** % load shared by T1 = (I1/IL) × 100; % load shared by T2 = (I2/IL) × 100. Theoretical ratio I1/I2 = (kVA2 × Z1%)/(kVA1 × Z2%), compared with the observed ratio in each part.

## 12. Results

With matched per-unit impedance, the two three-phase transformers were found to share the load nearly equally (in proportion to kVA rating); with unequal per-unit impedance, the transformer of lower percentage impedance was found to take a proportionately larger share of the load, in agreement with theory.

## 13. Viva Book

1. What additional condition, beyond those for single-phase transformers, must be satisfied for paralleling three-phase transformers?
2. What is a vector group, and why must paralleled transformers have compatible vector groups?
3. What happens if two transformers of different phase sequence are connected in parallel?
4. How does a mismatch in percentage impedance affect the sharing of load between paralleled transformers?
5. Why might unequal load sharing between paralleled transformers be undesirable in practice?
6. How can a circulating current be detected in a parallel transformer bank at no load?

# Experiment No: 20

**Current Ratio of a Current Transformer (CT)**

## 1. Aim

To determine the actual current (transformation) ratio of a given current transformer (CT) and to compare it with its nameplate ratio.

## 2. Theory

A current transformer (CT) is a special-purpose instrument transformer used to step down a large primary current to a small standard secondary current (commonly 1 A or 5 A) suitable for connection to ammeters, wattmeter current coils, energy meters and protective relays, while also providing electrical isolation from the high-current primary circuit.

Ideally, the primary and secondary currents of a CT are related by $I1/I2 = N2/N1$, the nominal (nameplate) current ratio. In practice, the actual ratio departs slightly from the nominal value because the core draws a small exciting (magnetising) current, giving rise to a 'ratio error' and a 'phase-angle error' — both of which determine the accuracy class of the CT.

In this experiment, a known primary current is passed through the CT (using a low-voltage, high-current source or a loading transformer), and the corresponding secondary current is measured with an ammeter connected as the CT's burden. It is essential that the CT secondary is never left open-circuited while the primary is energised, since with no burden current to oppose it, the full primary ampere-turns act as magnetising ampere-turns, driving the core into deep saturation and producing a dangerously high peaky voltage across the open secondary.

## 3. Practical Set-up / Circuit Diagram

The primary of the CT (or the primary bus-bar/conductor passing through its window, for bar-primary CTs) is connected in series with a variable, low-voltage high-current source (through a loading transformer/variac) and a primary ammeter A1. The CT secondary is connected to a standard ammeter A2 of appropriate range, which forms its burden.

## 4. Apparatus Required

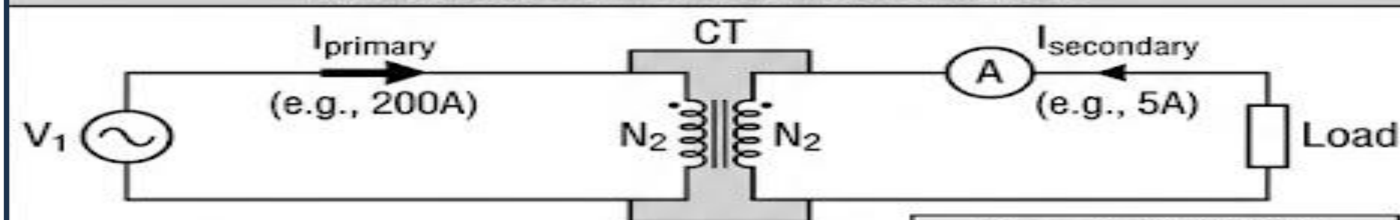
| S.No. | Apparatus / Equipment | Quantity |
|---|---|---|
| 1 | Given current transformer (known nameplate ratio, e.g., 100/5 A) | 1 |
| 2 | Loading transformer / variac (high-current, low-voltage) | 1 |
| 3 | Ammeter for primary current (as per rating) | 1 |
| 4 | Ammeter for secondary current (0–5 A / 0–1 A) | 1 |
| 5 | Connecting wires / bus-bar | As required |

# CURRENT RATIO OF A CURRENT TRANSFORMER (CT)

## 1. PHYSICAL APPEARANCE (PHOTO - REPRESENTATIVE)


## 2. CIRCUIT DIAGRAMS (SCHEMATIC)

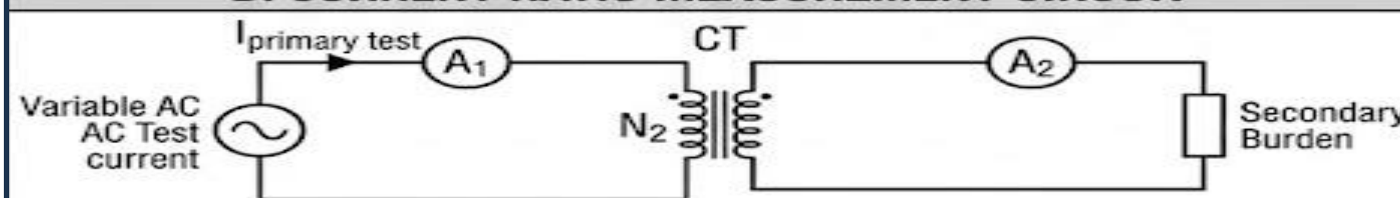
### A: BASIC CT APPLICATION CIRCUIT




$$\text{Current Ratio (K)} = \frac{I_{primary}}{I_{secondary}} \approx \frac{N_2}{N_1}$$

**Example:** 200/5 A CT.
Current Ratio is 40:1.
Turns ratio is 40:1 ($N_2$=40, $N_1$=1).

### B: CURRENT RATIO MEASUREMENT CIRCUIT




$$\text{Current Ratio (Measured)} = \frac{I_{primary}\ (A_1)}{I_{secondary}\ (A_2)}$$

## KEY DEFINITIONS & RATIO ANALYSIS

| | |
|---|---|
| **Current Ratio** (K) | Ratio of primary current to secondary current ($I_{primary}$ : . $I_{secondary}$). Scales down large current for measurement. |
| **Turns Ratio** (N) | Ratio of secondary winding turns to primary turns ($N_{secondary}$ : $N_{primary}$). $N_{primary}$ is usually 1 (the conductor). |
| **Relationship** (Ideal CT) | Current Ratio (K) ≈ Turns Ratio (N) = $\frac{I_{primary}}{I_{secondary}} = \frac{N_{secondary}}{N_{primary}}$ |

*Note: This relationship is approximate for real CTs due to core losses, saturation, and secondary burden, causing small measurement errors.*

## 5. Precautions to be Followed

- Never leave the secondary of an energised CT open-circuited — always keep an ammeter or a short-circuiting link connected across it.
- Increase the primary current gradually from zero.
- Do not exceed the rated primary current of the CT.
- Ensure the secondary ammeter used is of the correct type (AC) and adequate range.
- Reduce the primary current to zero before switching off the supply, keeping the secondary closed throughout.
- Switch off the supply and short the secondary before disconnecting the secondary ammeter.

## 6. Procedure

- Note the nameplate rating (current ratio, rated burden, accuracy class) of the given CT.
- Connect the CT primary in series with the loading transformer/variac output and the primary ammeter A1; connect the CT secondary to ammeter A2, ensuring the secondary circuit is never left open.
- With the variac at zero, switch on the supply, then gradually increase the primary current in convenient steps.
- At each step, record the primary current I1 and the corresponding secondary current I2.
- Continue up to the rated primary current of the CT.
- Gradually reduce the primary current to zero, keeping the secondary closed, and switch off the supply.
- Calculate the actual current ratio I1/I2 at each step and compare it with the nameplate (nominal) ratio.

## 7. Observations and Calculations

| S.No. | Primary Current I1 (A) | Secondary Current I2 (A) | Actual Ratio I1/I2 | Nominal Ratio |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

**Calculations:** Ratio error (%) = [(Nominal ratio − Actual ratio)/Nominal ratio] × 100, calculated at each level of primary current.

## 12. Results

The actual current ratio of the given CT was found to be close to its nameplate ratio at currents near the rated value, with the ratio error tending to increase at lower fractions of rated current, consistent with the relatively greater effect of the exciting current at light load.

## 13. Viva Book

1. Why must the secondary of a CT never be left open while the primary is energised?
2. What is meant by the ratio error and the phase-angle error of a CT?
3. On what factors does the accuracy class of a CT depend?
4. Why is the secondary of a CT normally rated at 1 A or 5 A?
5. Distinguish between a wound-primary CT and a bar-primary (window-type) CT.
6. What is meant by the 'burden' of a CT, and how does it affect its accuracy?

# Experiment No: 21

**Voltage Ratio of a Potential Transformer (PT)**

## 1. Aim

To determine the actual voltage (transformation) ratio of a given potential transformer (PT) and to compare it with its nameplate ratio.

## 2. Theory

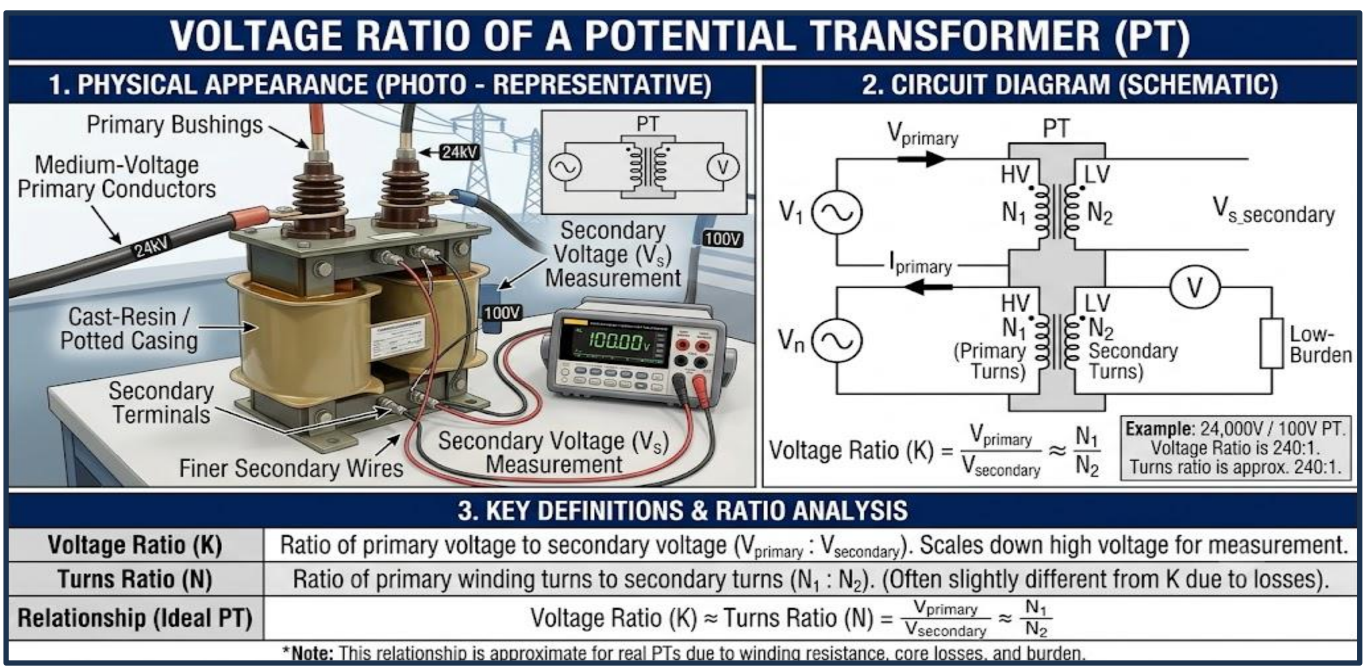
A potential transformer (PT), also called a voltage transformer (VT), is a special-purpose instrument transformer used to step down a high system voltage to a low, standard secondary voltage (commonly 110 V) suitable for connection to voltmeters, wattmeter potential coils, energy meters and protective relays, while providing electrical isolation from the high-voltage primary circuit.

Ideally, for a PT, E2/E1 = N2/N1, the nominal (nameplate) voltage ratio — similar in principle to a power transformer. However, a PT is designed to operate essentially on no load, since the voltmeters/relay coils forming its burden draw only a very small current, which keeps the ratio and phase-angle errors small. The actual voltage ratio departs slightly from the nominal value due to the small voltage drop caused by the exciting current and the burden current in the winding impedances, giving rise to a 'ratio error', which determines the accuracy class of the PT.

In this experiment, a known (safe, proportionate) primary voltage is applied through a variac and the corresponding secondary voltage is measured, so that the actual voltage ratio can be determined and compared with the nameplate value.

## 3. Practical Set-up / Circuit Diagram

The PT primary is connected to a variac-controlled AC supply through a primary voltmeter V1. The PT secondary is connected to a secondary voltmeter V2 of appropriate range, representing its normal (high-impedance) burden.



## 4. Apparatus Required

| S.No. | Apparatus / Equipment | Quantity |
|---|---|---|
| 1 | Given potential transformer (known nameplate ratio) | 1 |
| 2 | Variac | 1 |
| 3 | Voltmeter for primary V1 (as per rating) | 1 |
| 4 | Voltmeter for secondary V2 (0–150 V) | 1 |
| 5 | Connecting wires | As required |

## 5. Precautions to be Followed

- Apply only voltages within the rated primary voltage of the PT and within the safe range of the supply/variac — never exceed the rated value.
- Increase the applied voltage gradually from zero using the variac.
- Connect the PT secondary only to high-impedance instruments (voltmeters); never short-circuit the secondary of an energised PT.
- Observe standard high-voltage safety precautions if testing at an elevated voltage.
- Switch off the supply before altering any connection.
- Reduce the applied voltage to zero before switching off the supply at the end of the test.

## 6. Procedure

- Note the nameplate rating (voltage ratio, rated burden, accuracy class) of the given PT.
- Connect the PT primary to the variac output through voltmeter V1; connect the PT secondary to voltmeter V2.
- With the variac at zero, switch on the supply, then gradually increase the primary voltage in steps up to the rated primary voltage (or a suitable safe proportion, for a lab-scale test).
- At each step, record the primary voltage V1 and the corresponding secondary voltage V2.
- Reduce the applied voltage to zero and switch off the supply.
- Calculate the actual voltage ratio V1/V2 at each step and compare it with the nameplate (nominal) ratio.

## 7. Observations and Calculations

| S.No. | Primary Voltage V1 (V) | Secondary Voltage V2 (V) | Actual Ratio V1/V2 | Nominal Ratio |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

**Calculations:** Ratio error (%) = [(Nominal ratio − Actual ratio)/Nominal ratio] × 100.

## 12. Results

The actual voltage ratio of the given PT was found to be close to its nameplate ratio over the range of primary voltages tested, with a small ratio error attributable to the winding impedance drops and exciting current, consistent with the PT's specified accuracy class.

## 13. Viva Book

1. What is the essential functional difference between a CT and a PT?
2. Why is a PT designed to operate essentially on no load (high burden impedance)?
3. Why should the secondary of a PT never be short-circuited?
4. What is meant by the ratio error and the phase-angle error of a PT?
5. What accuracy classes are typically specified for PTs used in metering as compared to protection?
6. Why must a PT never be operated above its rated primary voltage?