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Dissectible Machines System

62-005

Technology Training for tomorrow's world

Dissectible Machines System

62-005

Feedback Instruments Limited

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Notes

THE HEALTH AND SAFETY AT WORK ACT 1974

We are required under the Health and Safety at Work Act 1974, to make available to users of this equipment certain information regarding its safe use.

The equipment, when used in normal or prescribed applications within the parameters set for its mechanical and electrical performance, should not cause any danger or hazard to health or safety if normal engineering practices are observed and they are used in accordance with the instructions supplied.

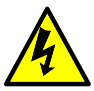
If, in specific cases, circumstances exist in which a potential hazard may be brought about by careless or improper use, these will be pointed out and the necessary precautions emphasised.

While we provide the fullest possible user information relating to the proper use of this equipment, if there is any doubt whatsoever about any aspect, the user should contact the Product Safety Officer at Feedback Instruments Limited, Crowborough.

This equipment should not be used by inexperienced users unless they are under supervision.

We are required by European Directives to indicate on our equipment panels certain areas and warnings that require attention by the user. These have been indicated in the specified way by yellow labels with black printing, the meaning of any labels that may be fixed to the instrument are shown below:

CAUTION -
RISK OF
DANGER



CAUTION -
RISK OF
ELECTRIC SHOCK

CAUTION -
ELECTROSTATIC
SENSITIVE DEVICE

Refer to accompanying documents

PRODUCT IMPROVEMENTS

We maintain a policy of continuous product improvement by incorporating the latest developments and components into our equipment, even up to the time of dispatch.

All major changes are incorporated into up-dated editions of our manuals and this manual was believed to be correct at the time of printing. However, some product changes which do not affect the instructional capability of the equipment, may not be included until it is necessary to incorporate other significant changes.

COMPONENT REPLACEMENT

Where components are of a 'Safety Critical' nature, i.e. all components involved with the supply or carrying of voltages at supply potential or higher, these must be replaced with components of equal international safety approval in order to maintain full equipment safety.

In order to maintain compliance with international directives, all replacement components should be identical to those originally supplied.

Any component may be ordered direct from Feedback or its agents by quoting the following information:

1. Equipment type	2. Component value
3. Component reference	4. Equipment serial number

Components can often be replaced by alternatives available locally, however we cannot therefore guarantee continued performance either to published specification or compliance with international standards.

OPERATING CONDITIONS

WARNING:

This equipment must not be used in conditions of condensing humidity.

This equipment is designed to operate under the following conditions:

Operating Temperature	10°C to 40°C (50°F to 104°F)
Humidity	10% to 90% (non-condensing)

CE DECLARATION CONCERNING ELECTROMAGNETIC COMPATIBILITY

Should this equipment be used outside the classroom, laboratory study area or similar such place for which it is designed and sold then Feedback Instruments Ltd hereby states that conformity with the protection requirements of the European Community Electromagnetic Compatibility Directive (89/336/EEC) may be invalidated and could lead to prosecution.

This equipment, when operated in accordance with the supplied documentation, does not cause electromagnetic disturbance outside its immediate electromagnetic environment.

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IMPORTANT NOTICE CONCERNING SAFETY

All rotating machinery is potentially dangerous, both from the electrical and mechanical points of view. Every effort has been made in the design of the system to ensure minimum risk but complete protection is neither possible nor desirable since an important part of the students' training is the acquisition of an awareness of possible hazards.

Adherence to the instructions given in this manual combined with common sense will prevent accidents.

The following DO's and DONT'S are worth noting.

DO:

1 SWITCH OFF ALL POWER BEFORE CHANGING OR HANDLING ELECTRICAL CONNECTIONS.

2 ENSURE THAT ALL PARTS ARE SECURE AND ALL SCREWS, BOLTS, ETC, ARE PROPERLY TIGHTENED BEFORE STARTING.

This applies to:

- Flexible shaft couplings
- Baseplate couplings
- Prony brake mountings (frame and brake drum)
- Centrifugal switch elements
- Commutator-to-shaft coupling
- Terminal pillars on commutator and their screws
- Pole-piece mounting on stator and rotor
- Removable end-bearing securing screws
- Brush mountings

3 ENSURE THAT THE ROTOR FLYING LEAD CONNECTIONS ARE SECURELY FIXED TO THE TERMINALS AND THAT THEY CANNOT FLY OUT UNDER CENTRIFUGAL FORCE TO TOUCH THE STATOR.

4 CHECK MANUALLY BEFORE STARTING THAT THE SHAFT IS FREE TO ROTATE.

DON'T:

1 ATTEMPT ANY ELECTRICAL OR MECHANICAL CHANGES WHEN THE MACHINE IS ENERGISED OR ROTATING

2 ALLOW HAIR OR NECKTIES TO HANG IN OR NEAR A ROTATING MACHINE.

CAUTION - HIGH VOLTAGES

HANDLE THE EQUIPMENT WITH EXTREME CARE AS **HIGH VOLTAGES** ARE PRESENT AT SOME SOCKETS AND EXPOSED TERMINALS,

PURPOSE

This manual provides practical assignments to support the use of this trainer as a teaching aid. Each assignment consists of exercises which, when performed, allow the students to discover for themselves the practical aspects of a particular subject. After results have been obtained and entered into tables and, if necessary, plotted on graph paper, they can be compared with typical answers and results given at the end of each assignment. Provided at the front of each assignment is any relevant theory pertaining to the subject and/or references to further reading.

CONTENT

This manual comprises:

- Chapter 1 System Description. Provides a description of the trainer.
- Chapter 2 Installation Checks. Provides inspection and operation information and references Utility Sheets.
- Chapter 3 Assignments. Consists of practical assignments that can be performed by the student.
- Appendices. This area provides further theoretical information to that given in each assignment.

Contents

Notes

INTRODUCTION

The Dissectible Machines System 62-005 allows approximately 60 electrical machines to be assembled or dismantled down to component parts level (shaft, coils, pole-pieces, stator, brushgear, etc). Tests can then be carried out on a complete machine to verify its characteristics.

The system comprises a Dissectible Machines Tutor 62-100 which is supported by a bench. Also located on this bench is a Variable Speed Drive Unit. Ancillary equipment, which includes power supplies and monitoring instrumentation, is mounted on a purpose-designed, bench-standing frame (System Frame). The bench supporting the Dissectible Machines Tutor should be positioned directly in front of this frame so that power lines can be connected to the tutor from equipment located in the frame (patching lines). A further frame is provide for equipment storage. Both frames allow modules to be mounted in convenient positions as they can easily be slotted in and out of the frame.

SAFETY FEATURES

It is recommended that a circuit breaker, such as the Feedback Earth Leakage Breaker Single Phase 60-140-1, be used when connecting ac supplies to the system.

The Variable ac/dc Supply 60-121 supplied with the system has a prominent power on (1)/off (0) button and is fitted with a 5 A circuit breaker.

All connections are made using shrouded plugs.

The panels are earthed using the supply earth.

WARNING:

All panels are provided with earth terminals on the front and/or back which must be connected to each other using the earth leads supplied, or personal injury might occur. The exception to this are panels such as that for virtual instrumentation which is directly supplied with power and is earthed through the supply.

System Frame Fixings

The system frame (91-200) is constructed using captive nut and bolt fixings as shown in the 'Assembly Instructions – Frame System' drawing (Figure 1-1). Ensure all bolts including the bolts securing the frame feet, as shown in the side view of Figure 1-1, are fully tightened before loading the frame with equipment.

WARNING:

If the frame system fixings are not fully tight before equipment is mounted, the frame could be unstable or collapse with consequent damage to equipment and personnel.

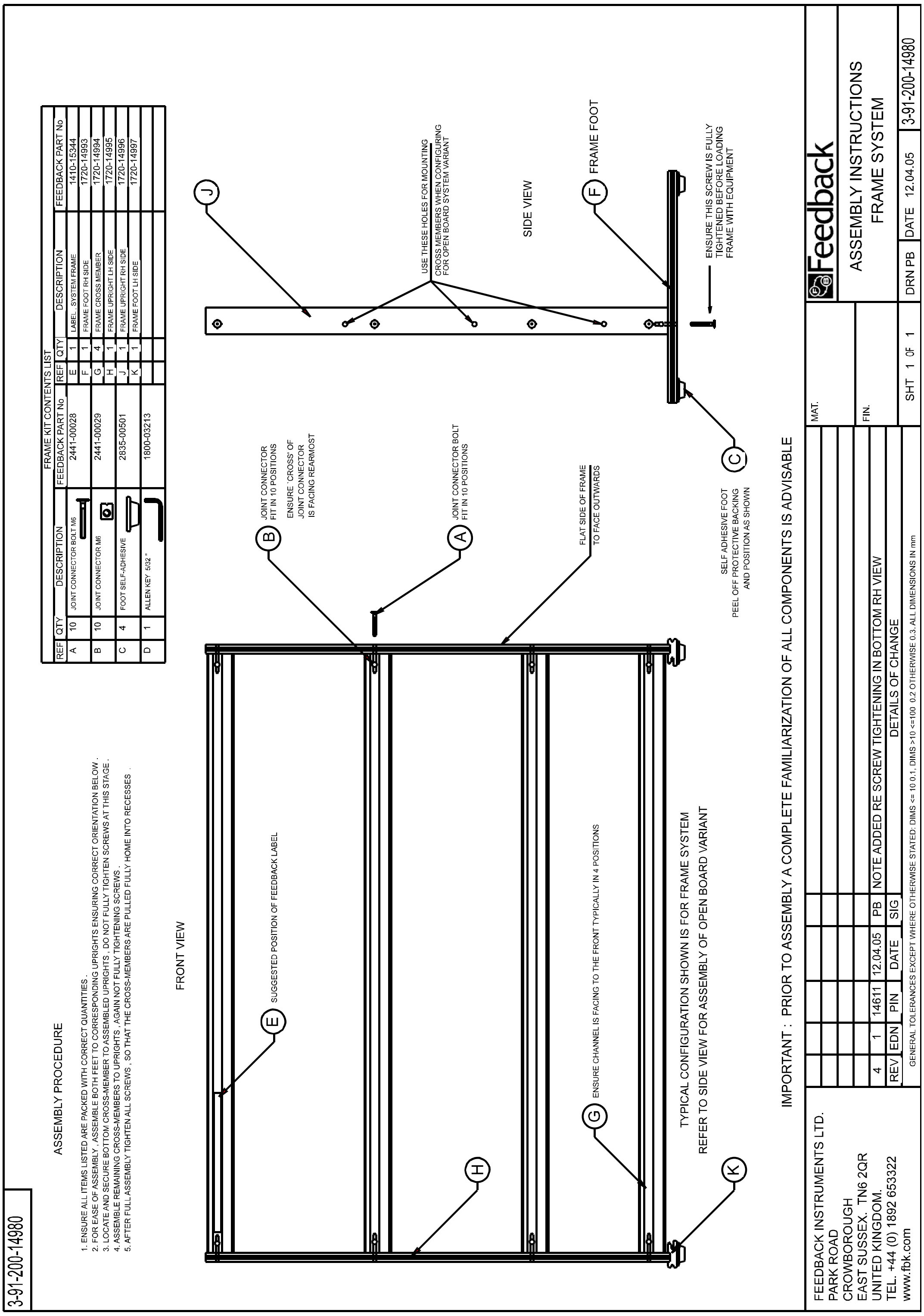

Figure 1-1: System Frame Fixings Location

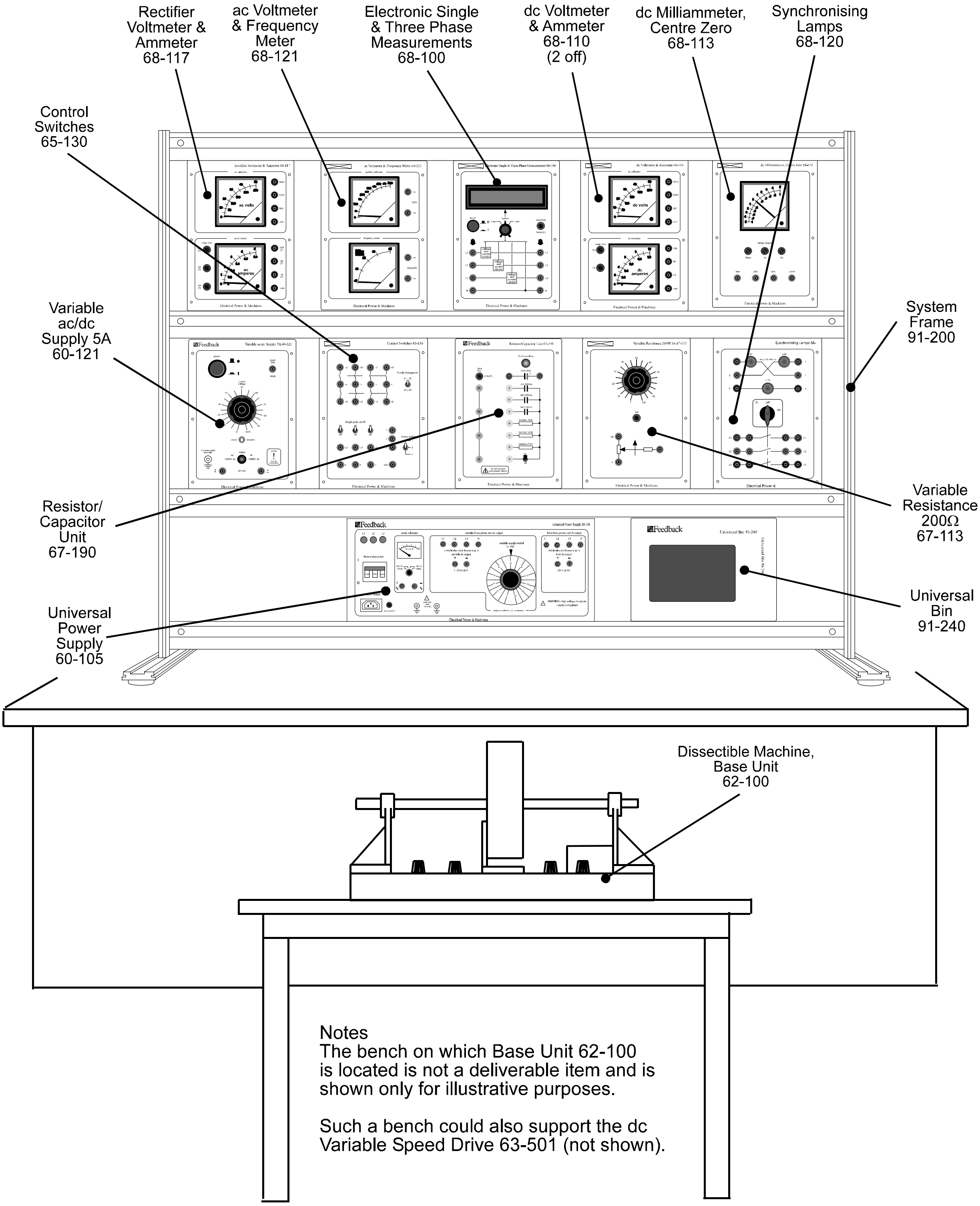

Figure 1-2: Dissectible Machines System

EQUIPMENT

The Dissectible Machines System is shown in Figure 1-2 and comprises equipment housed in a system frame, equipment supported by a bench, additional items, and storage equipment.

System Frame 91-200 Equipment:

- Universal Power Supply 60-105
- Variable ac/dc Supply 5A 60-121
- Control Switches 65-130
- Resistor/Capacitor Unit 67-190
- Variable Resistance 200Ω 3A 67-113
- Electronic Single & Three Phase Measurements 68-100
- Two dc Voltmeter & Ammeter 68-110
- dc Milliammeter, Centre Zero 68-113
- Rectifier Voltmeter & Ammeter 68-117
- Synchronising Lamps 68-120
- ac Voltmeter & Frequency Meter 68-121
- Universal Bin 91-240
- Standard Set of Patch Leads 68-800

Bench Mounted Equipment

- Dissectible Machine Basic Components 62-100
- dc Variable Speed Drive 63-501

Additional Items

- Friction (Prony) Brake 67-470
- Optical/Contact Tachometer 68-470
- Ancillary Kit

Dissectible Machines Storage System 90-100

- Dissectible Machines Storage Panel 62-101
- System Frame 91-200
- Three Universal Bins 91-240
- Lead Storage 91-245

MAIN UNITS

Brief details of the main units that constitute the system are given. For further details on individual panels, refer to the Utilities Manual.

System Frame Equipment

Universal Power Supply 60-105

The Universal Power Supply 60-105 unit receives a 400 V three phase input from a circuit breaker unit similar to the 60-140-1 and all input connections are hard wired at the rear. The presence of the supply is indicated by lamps L1, L2 and L3. After being connected to the unit via an on (1) / off (0) three pole switch, the incoming voltage can be measured using the front panel ac/dc voltmeter. Fixed or variable output voltages can be obtained from the unit.

CAUTION:

The variable power supply outputs should be restricted to 60% of maximum (ie, 138 V ac single-phase or 162 V dc). Ensure that the plastic rivet is located in the inner hole of the dial (between 0 and 100). If this is not the case, remove the rivet from the outer hole position and insert it in the inner one whilst the dial is set to the 0 position. The dial will then not be able to rotate passed the 60% position.

WARNING:

High voltages are present on front panel sockets. Ensure that only the shrouded safety connectors provided are used for all power and monitoring connections.

Variable ac/dc Supply 5A 60-121

This unit provides a continuously variable ac output of 0-240 V at 5 A The unit can also be switched to provide a rectified dc output of 0 to 220 V at 5 A. Equipped with an on (1)/off (0) switch, the output is protected with a 5 A circuit breaker. Input supplies are protected with a 6 A fuse.

WARNING:

This unit is not isolated; there are high voltages at output.

Resistor/ Capacitor Unit 67-190

This is a low power resistive/reactive component unit used for loading and starting ac motors and smoothing dc power, The required components can be patched to the common bus on the left-hand side. This allows the circuit to be controlled by an on/off switch.

The unit houses three resistors (68Ω 50 W) and three capacitors (2 μF, 4 μF, 8 μF 250 V ac) connected in parallel via a control switch. Additionally, a 10 mF 63 V dc electrolytic capacitor is provided for low voltage dc work and is reverse polarity fuse protected; an LED indicator warns of over voltage.

Variable Resistance 200Ω 3 A 67-113

This unit provides a high power variable resistance which use includes generator loading, motor starting, motor speed control and field current divider. The value of the resistance is set by the dial on the front panel.

Electronic Single & Three Phase Measurements 68-100

This unit allows parameter measurement of 3 or 4 wire, balanced, three-phase systems. The parameters include voltage, current, power factor, watts, kVA, kVAR, kWH, etc.

dc Voltmeter & Ammeter 68-110	This unit houses a dc voltmeter with ranges 0-50, 0-250 and 0-500 V, and an ammeter with ranges 0-1, 0-5 and 0-10 A
dc Milliammeter, Centre Zero 68-113	This unit houses a dc ammeter with ranges ±1 mA, ±1 A and ±5 A.
Rectifier Voltmeter & Ammeter 68-117	This unit provides voltage and current measurement with a high accuracy. The voltmeter has ranges 0-50 V, 0-250 V and 0-500 V, whilst the ammeter has ranges 0-1 A, 0-5 A and 0-10 A.
Synchronising Lamps 68-120	Basic synchronising is provided on this unit by phase indicator lamps grouped in a triangle. Synchronisation is indicated by either lamps bright of dark, and a power switch is provided to connect the systems together on synchronisation is achieved.
ac Voltmeter & Frequency Meter 68-121	This unit is used in the study of synchronous generators or for single and three-phase supply measurements. The voltmeter has a range of 0-500 V ac, whilst the frequency meter has a range of 45-65 Hz, 250 V max.
Control Switches 65-130	Heavy duty power switches are provide to allow measurement and electrical switching such as multipoint metering, component selection and changing motor speed. The items comprise one four-pole changeover switch, three single-pole On/Off switches, and one single-pole 3-way switch. All switches are rated at 240 V ac, 10 A.
Universal Bin 91-240	Provides storage for patch leads 68-800.

Bench Mounted Equipment

Dissectible Machines, Basic Components 62-100

The Dissectible Machines Components are grouped together as 62-110, which consists of the basic components 62-100, control switches 65-130 and Resistor/Capacitor Unit 67-190. Both the 65-130 and 67-190 units are described above as they are mounted on the system frame

The basic components 62-100 consist of the base unit and items shown in Figures 1-3 to 1-6.

Using the base unit and appropriate items allows various electrical machines to be assembled or dismantled down to component parts level (shaft, coils, pole-pieces, stator, brushgear, etc).

Refer to Utility Sheet 62-100 in the Utility Manual for a complete breakdown of parts that comprise this unit together with installation checks and basic assembly instructions

dc Variable Speed Drive 63-501

This unit allows the machine constructed on the Base Unit 62-100 to be driven via a coupling between the shafts of the two units. To enable this to happen, the 63-501 unit consists of a dc motor mounted on a base unit of the same height and width as the 62-100.

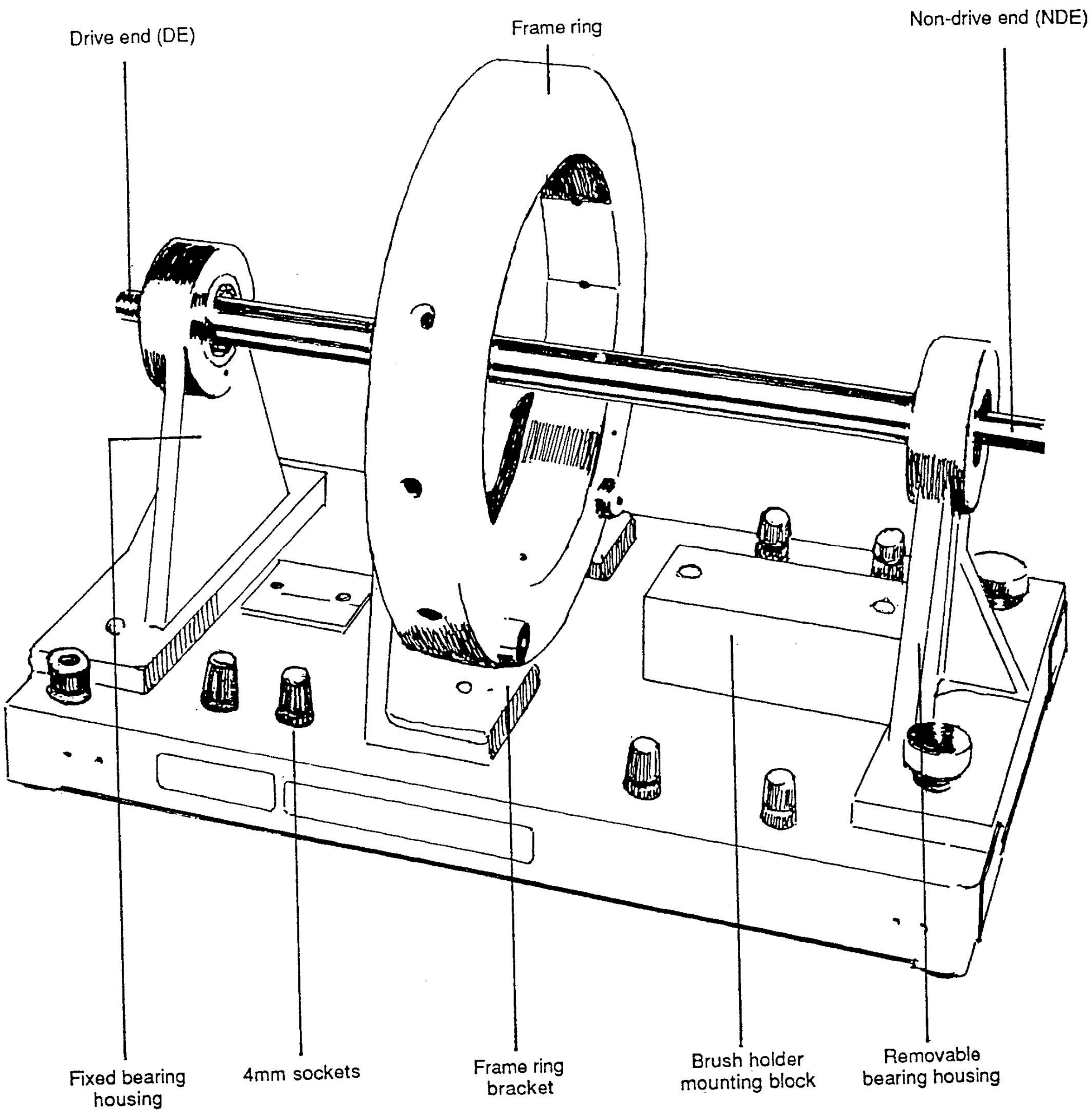

Figure 1-3: Base Unit

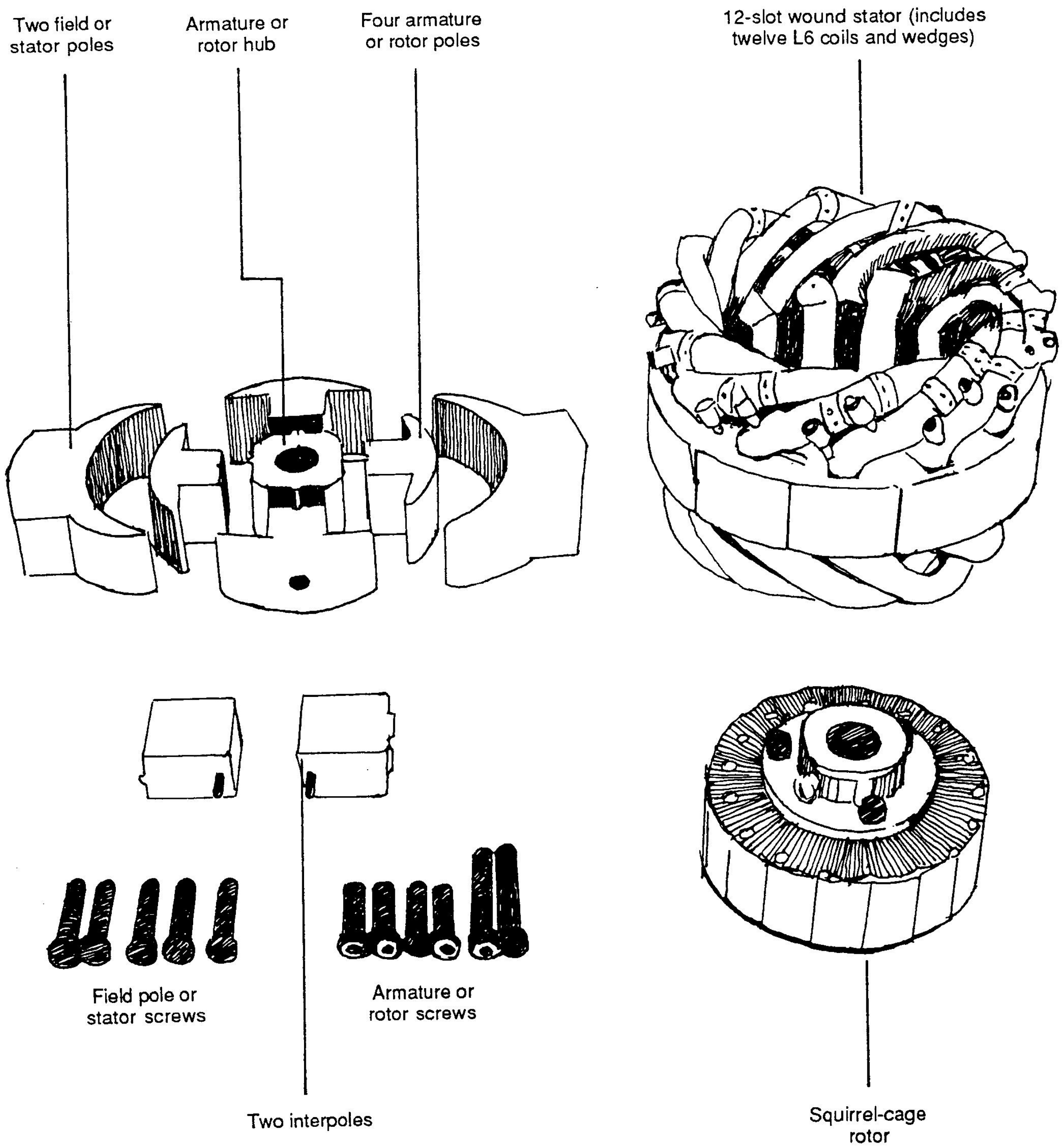

Figure 1-4: Laminated Parts

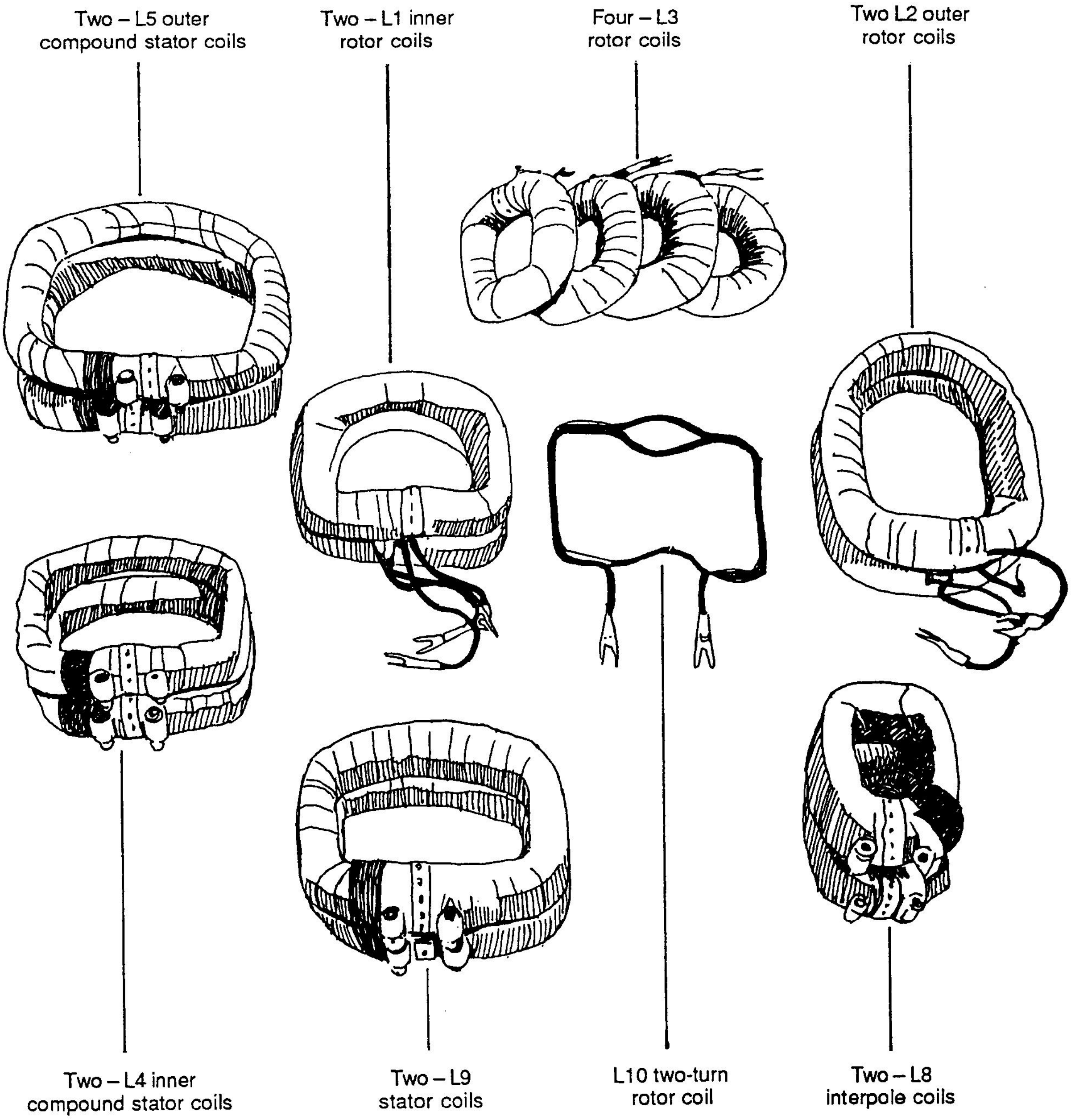

Figure 1-5: Coils

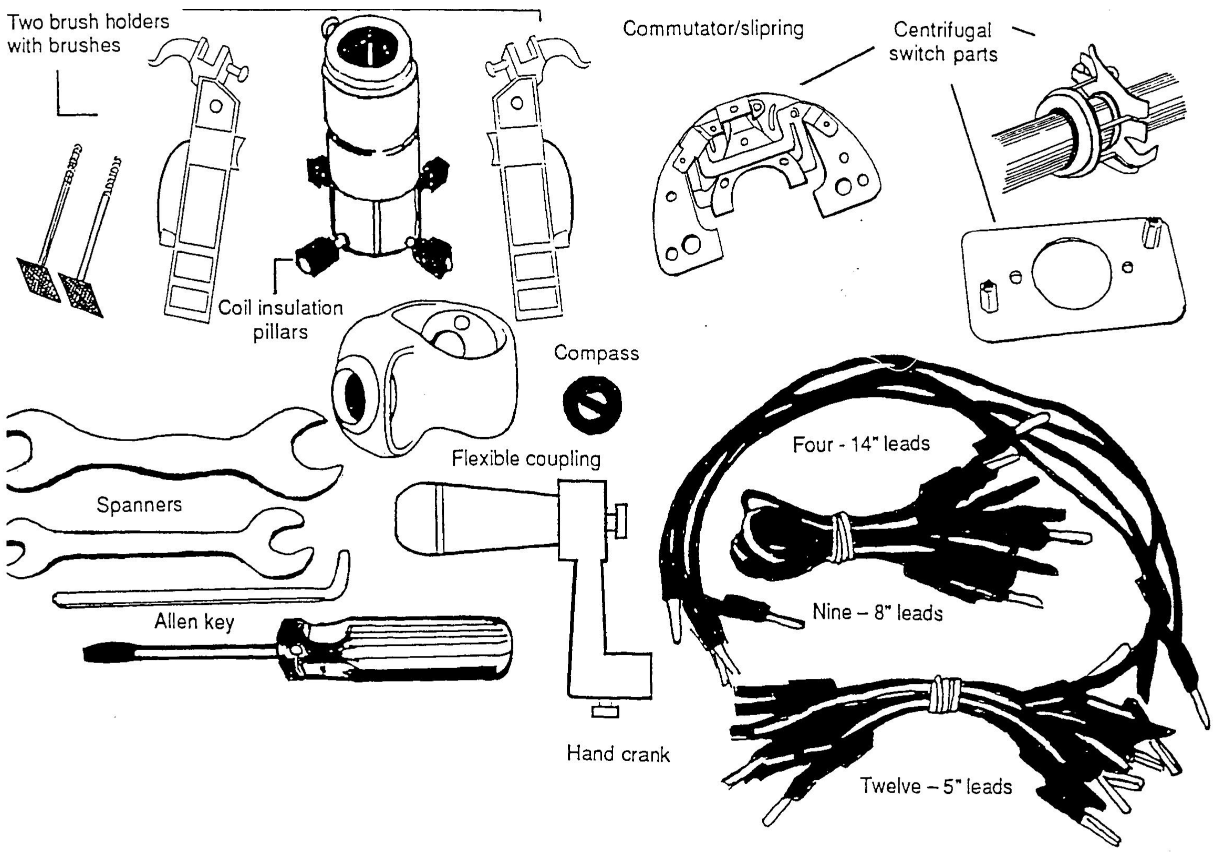

Figure 1-6: Accessories

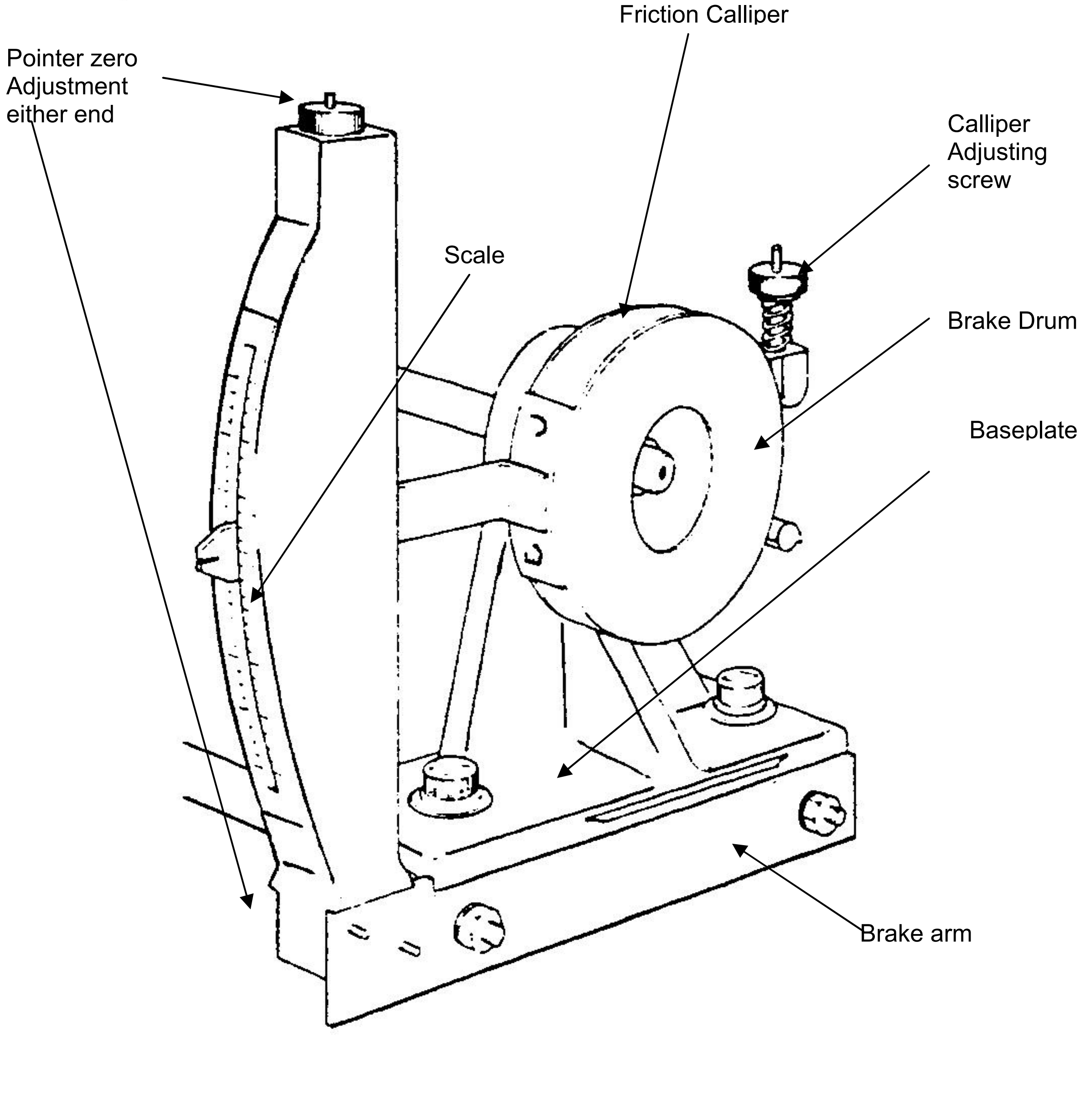

Figure 1-7: Friction (Prony) Brake 67-470

Additional Items

Friction
(Prony) Brake
67-470

The brake is shown in Figure 1-7. The assemble fits directly on to the shaft of electrical machines to allow torque to be measured. To vary frictional load, a friction calliper is tightened against the drum by use of a calliper adjusting screw. Torque is shown on a scale vertically mounted to the motor base and is indicated in either direction of shaft rotation with a maximum scale reading of ±2 Nm.

To dissipate heat generated by friction, the drum is water-cooled by a re-fillable reservoir.

CAUTION:

In continuous use, the friction drum may overheat. Care should be taken to ensure that the water reservoir is kept filled.

Optical/Contact
Tachometer
68-470

The tachometer is a small battery-powered hand-held device which is used for measuring the speed of the shaft. Digital measurement is achieved using an optical photo-sensor up to 99,999 rev/min The device can also measure speed via direct contact (conical rubber drive) but this facility is not used in this application. The tachometer is shown in Figure 1-8.

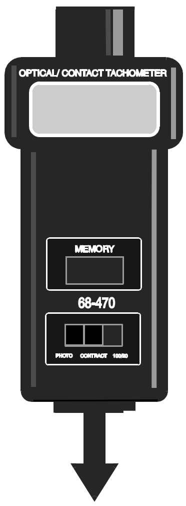

Figure 1-8: Tachometer 68-470

Ancillary Kit

The Ancillary Kit extends the scope of the Dissectible Machines System to cover:

- Stepping Motor (reluctance type)
- Shaded-Pole Induction Motor
- Split-Field Series DC Motor
- Dynamic Braking of a Shunt Motor
- Power Factor Correction of an Induction Motor
- Pole-Changing Induction Motor
- Faults occurring on a DC Shunt Motor
- Faults occurring on an Induction Motor

The kit comprises:

1 shaft

4 stepper rotor poles

1 rotor hub

1 scale plate graduated in 15° steps

1 knob with pointer disc

4 interpoles

1 link (for short-circuiting field coil?)

6 coils, L7

2 coils, L11

2 shaded field poles

1 set of patch leads

1 plastic bag containing:

2 brass contact strips

1 lead assembly, 160 mm long with spade terminals

2 2BA x 3/8 in screws with washers

41/4 in BSF x 11/4 in socket cap head screws.

The following test equipment, which is not supplied, is also required for ancillary assignments:

500 V dc insulation tester

Stop watch (0 to 60 seconds)

Storage System 90-100

The Storage System for the Dissectible Machines consists of a second system frame 91-200 on which is mounted a Dissectible Machines Storage Panel 62-101, three universal bins 91-240 and lead storage 91-245.

The Dissectible Machines Storage Panel consists of a shadow board so the location of any missing equipment can be easily ascertained. This panel comes complete with an Information Sheet which should be filed under Chapter 3 of the Utilities Manual.

Notes

Inspection

Check the units supplied for mechanical damage.

Details on Installation of the Dissectible Machines System are given in the Utility Sheet 62-100 of the Utilities Manual 91-200.

All modules should be earthed through the supply by connecting all module earth terminals (normally situated on the back of each module) to the earth terminal situated on the back of the power supply units 60-105 and 60-120, using the earth leads supplied.

Operation

Details of operation and safety aspects of the individual modules are provided in the Module Utility Sheets supplied with the equipment. These sheets should be filed under Chapter 3 of the Utilities Manual.

WARNING:
All panels are provided with earth terminals on the front and/or back which must be connected to each other using the earth leads supplied, or personal injury might occur. The exception to this are panels such as that for virtual instrumentation which is directly supplied with power and is earthed through the supply.

Notes

Assignments

This chapter comprises sub-chapters which contain assignments related to the various aspects of the Dissectible Machines System.

The assignments are divided into appropriate chapters as follows

ASSIGNMENT COMPOSITION

Most assignments comprise:

- An **Introduction**.
- **Practicals,** which contain any theory relevant to a practical, performance procedures, and exercises pertaining to the results obtained. For each practical, a patching diagram is provided.
- **Discussion** giving theory relevant to the assignment as a whole.
- **Results tables** relevant to each practical in which monitored data is recorded.
- **Typical results and answers** which provide completed tables and graphs, and answers to all questions.

SAFETY:

Before beginning any work on the Assignments, READ THE SAFETY NOTES at the front of the manual.

TERMS

Nomenclature

The terms ARMATURE and FIELD are often accepted as synonymous respectively with ROTOR and STATOR so far as they are used with reference to DIRECT CURRENT machines.

However they do not necessarily have the same meanings in general and in certain ALTERNATING CURRENT machines confusion can easily arise.

For example a three-phase induction motor usually has its power fed to the STATOR, which many authorities would regard as constituting the ARMATURE, but which also sets up a rotating FIELD.

Another example is the synchronous generator whose d.c excitation is fed to the ROTOR, setting up the FIELD and whose power output is derived from the ARMATURE windings on the STATOR.

To avoid these ambiguities this manual adopts the following practices.

DC Machines

The terms ARMATURE meaning the ROTOR and FIELD meaning the STATOR, are used throughout since no ambiguous cases arise and the terms are customary for such machines.

AC Machines

The terms FIELD and ARMATURE are used only in the initial introduction to certain machines and in titles. Elsewhere, specific references used in the experimental instructions and in the plotting of results etc, use only STATOR and ROTOR.

Hardware

For the most part, the terms STATOR and ROTOR are used when referring to actual components, although some exceptions will be found to this rule.

Note:

In the following assemblies, the coil terminations designated RED BAND in the figures should be taken to be that terminal immediately adjacent to the red band on the coil.

The twelve L6 coils fitted to the 12-slot stator are not colour coded and their individual terminals should be identified by their location and orientation.

Chapter 3-1

Introductory Assignments

This chapter contains introductory assignments as follows:

No

1) Familiarisation
2) Flux Produced by Field Coils
3) Field System of an Electrical Machine
4) Flux Levels in a Magnetic Circuit
5) Saturation
6) Induced Voltages
7) Phase Relationship in Spilt-Phase Motor
8) Rotating Fields
9) Stator Winding
10) Armature Winding
11) Interpole Flux

Notes

Assignment 1
Familiarisation

PRACTICAL	1.1	Motor Operation
EQUIPMENT REQUIRED	**Qty**	**Item**
62-100 Kit	1	Base Unit
	1	Commutator/Slipring
	2	Brushholders with Brushes
	2	L9 Coils
	2	L1 Coils
	2	L2 Coils
	2	Field Poles
	1	Rotor Hub
	4	Rotor Poles
General	1	Friction (Prony) Brake or other Dynamometer: 0-1 Nm at 1500 rev/min (eg, Feedback 67-470)
	1	1-100 V, 5 A, dc Supply (eg, Feedback 60-105)
	1	0-150 V, dc Voltmeter
	1	0–5 A dc Ammeter (eg, Feedback 68-110)
	1	Optical/Contact Tachometer (eg, Feedback 68-470

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

This assignment familiarises the student with the concept of the Dissectible Machine System. To do this, a dc series motor is constructed, run and monitored. For further study of a dc series motor, refer to Assignment 19.

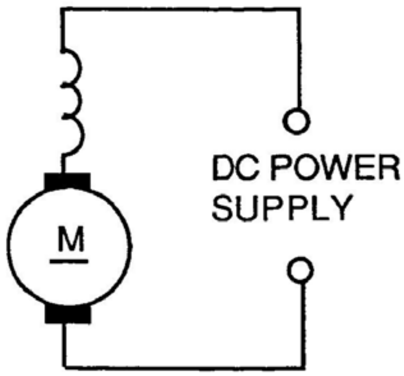

Figure A1-1: dc Series Motor Circuit Diagram

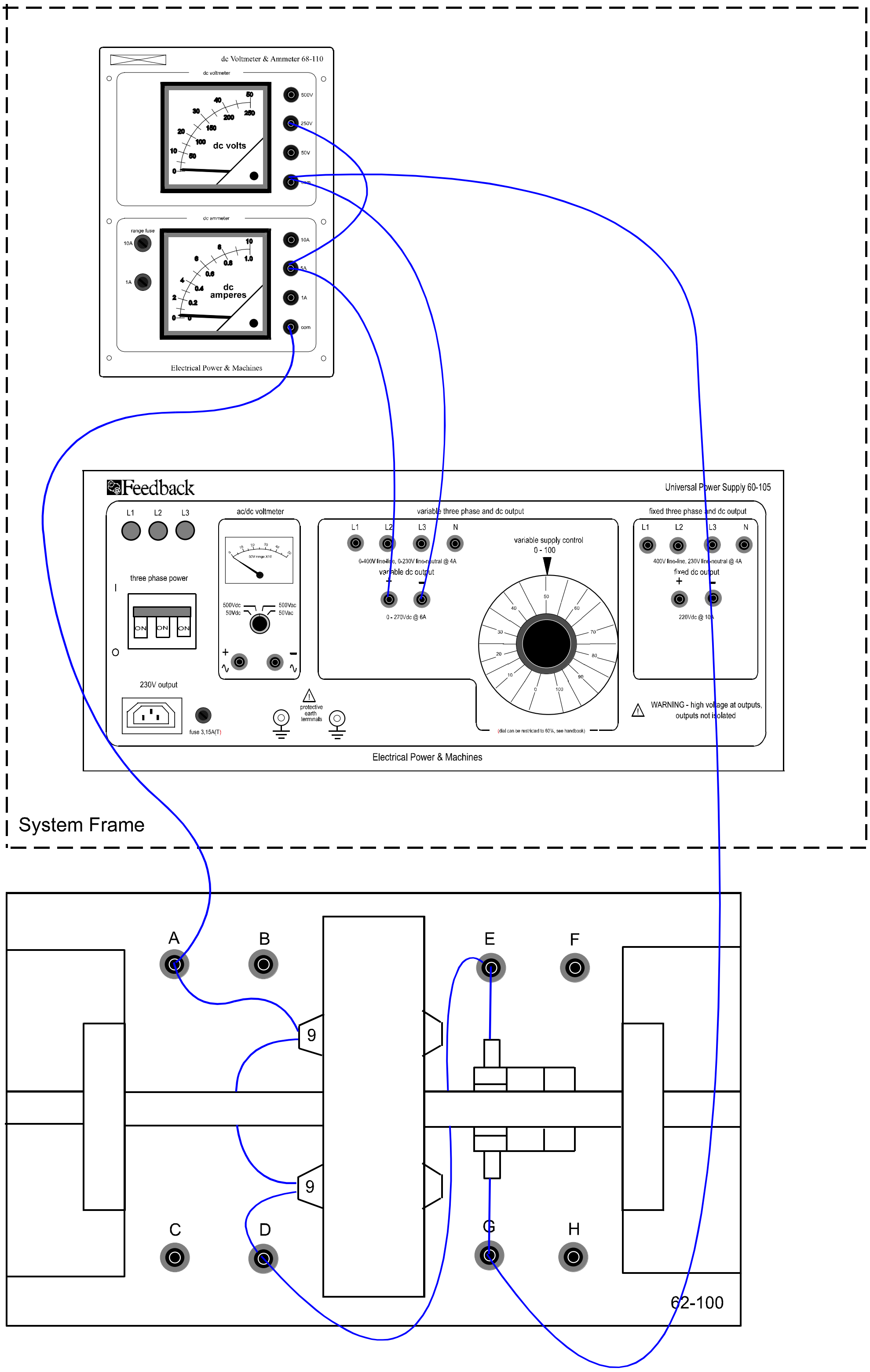

Figure A1-2: Connections for dc Series Motor

ASSEMBLY

Fix the armature and commutator to the shaft as shown in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 1 and fit the shaft into its bearings. Before finally tightening the screws holding the bearing housing to the baseplate, check that the shaft rotates freely and moves axially against the pre-loading washer.

Fit the L9 coils to the field poles and the poles to the frame ring at the 3 o'clock and 9 o'clock positions.

Fit the brushes into their holders and attach these to the mounting block positions on each side of the commutator. The brushes should move freely in their holders under the action of the brush springs.

Make the circuit shown in Figure A1-3, in accordance with the connections shown in Figure A1-2 and if the motor is to be run with no mechanical load, ensure that the supply voltage is set to less than 30 V.

If a friction (Prony) brake or other loading device is being used, fasten its frame to the baseplate and adjust it to give zero load initially. Instruction for mounting the 67-470 Prony Brake are given in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 6.

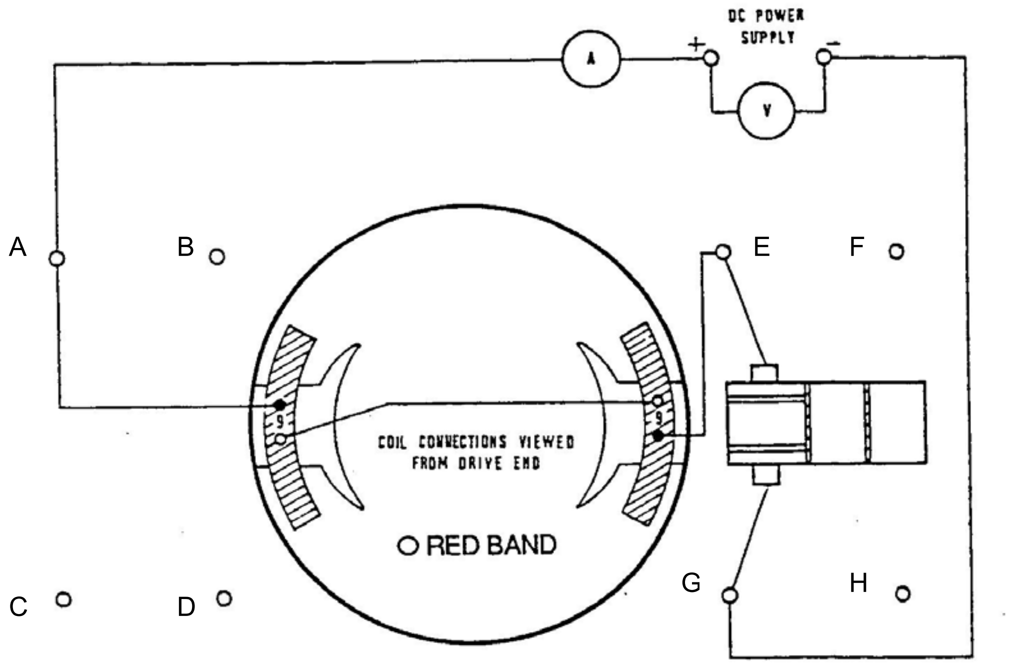

Figure A1-3: dc Series Motor Wiring Diagram

PRACTICAL 1.1

Motor Operation

On the power supply 60-105, set the 'three phase power' switch to 1 (on).

Rotate the 'variable supply output' control until the voltmeter on 68-110 indicates 15 V dc. The motor should start readily and runs at a shaft speed of approximately 500 rev/min as measured using tachometer 68-470.

On power supply 60-105, rotate the 'variable supply output' control until the voltmeter on 68-110 indicates 30 V dc.

Bring the shaft speed to approximately 1000 rev/min and the input current to 1 A as shown on the 68-110 ammeter. The motor will have no tendency to race at this voltage but since series motors on no load can reach very high speeds, do not raise the applied voltage above 30 V without shaft loading.

Apply a load to the drive shaft using the friction (Prony) brake.

Increase the applied voltage to 50 V and maintain it at this level throughout the test. Take readings of armature current and shaft speed for set values of brake load. Use these to plot the Speed/Torque and Armature current/Torque characteristics. Typical characteristic curves are given in Figure A1-4.

DISCUSSION

From these tests it is hoped that you have familiarised yourself with the Dissectible Machines System and organisation of a typical assignment. Additionally, you will also have learned a number of things about motors in general and about series dc machines in particular.

From the Torque/Speed graph that you have plotted, you will see that the series machine has a tendency to run up to dangerous speeds when it is not loaded.

This characteristic is not much of a problem in small, fractional horsepower motor because their inherent losses constitute sufficient load to restrain the maximum speed to safe limits. However, in larger machines, the inherent losses are a much smaller proportion of the total power available, therefore, certain safety precautions are required.

For further information on dc series motors, see Assignment 19.

Practical 1.1

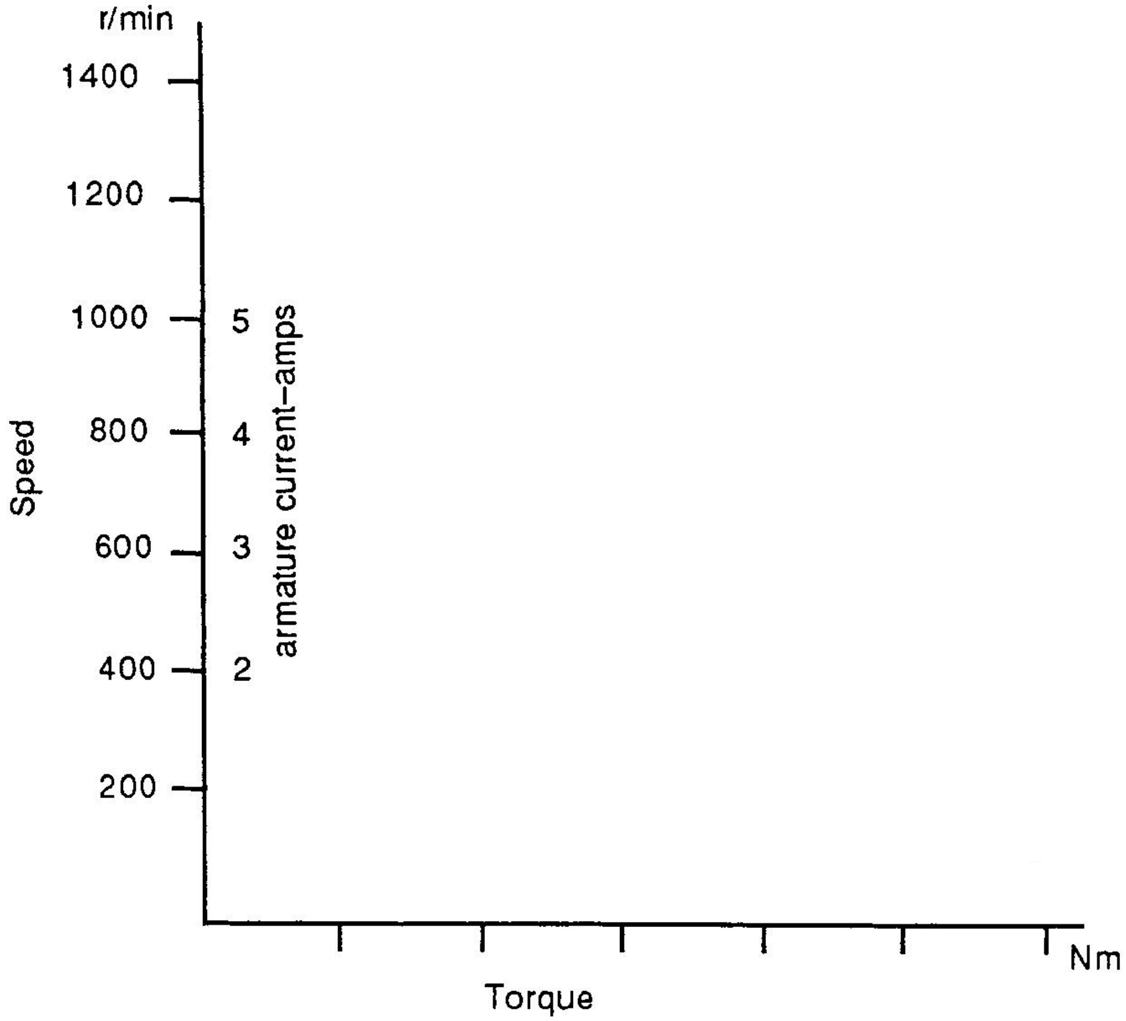

Figure A1-4 Graph Axes

Notes

Practical 1.1

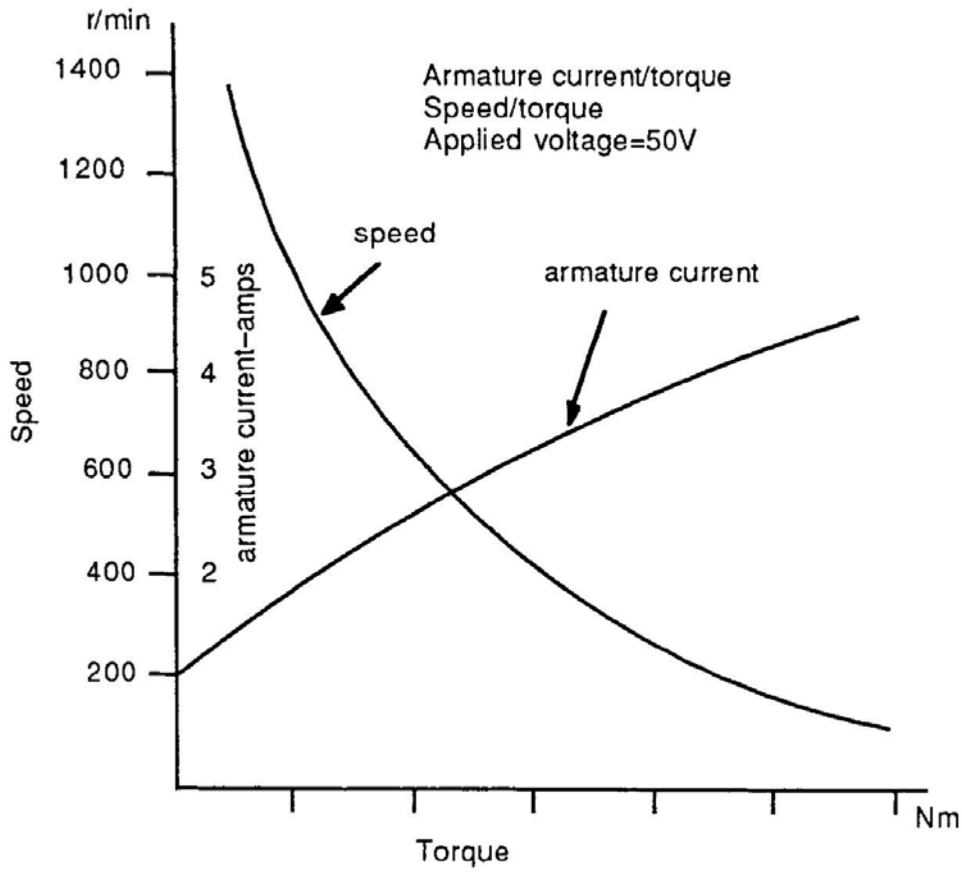

Figure A1-4: Characteristic of dc Series Motor

Notes

DISSECTIBLE

MACHINES SYSTEM

Assignment 2

Flux Produced by Field Coils

PRACTICAL	2.1	
EQUIPMENT REQUIRED	**Qty**	**Item**
62-100 Kit	1	L9 coil
	1	Field Pole
	1	Magnetic Compass
General	1	6 Volt dc Supply (eg, Feedback 60-105)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

PRACTICAL 2.1

Stand the coil vertically in front of the compass with the red band on its right-hand side and connect the dc supply to the coil, taking the positive lead to the terminal next to the red band as shown in Figure A2-1.

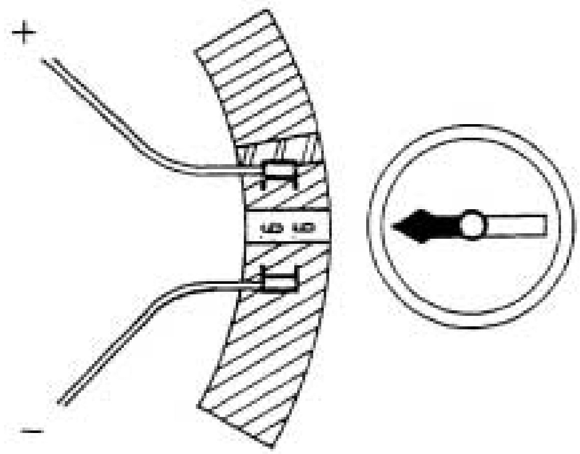

Figure A2-1

Switch on and note that the north pole of the compass needle is deflected towards the centre of the coil. By following the lines of flux through and outside the coil the pattern of its magnetic field can be determined.

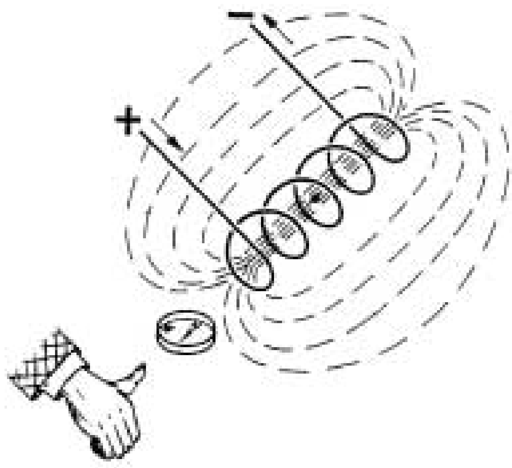

Figure A2-2

This test also shows that the direction of flux is as given by the right-hand grip rule illustrated as Figure A2-2. With the supply positive connected to the terminal next to the red band, the current flow will be clockwise round the coil when viewed with this terminal on the right. If the fingers of the right-hand are placed so as to follow the direction of current flow, the outstretched thumb gives the direction of flux through the coil.

If the coil is now fitted over a field pole and current passed through it, as before, it will be found that the direction of flux is unchanged but the field strength is increased as shown by the response of the compass at some distance from the coil.

The strength of a magnetic field is measured as flux density, B.

$$B = \frac{\Phi}{a}$$

where Φ = flux in a section of the magnetic circuit.
a = area of the section

When the dc supply is switched off it will be found that the field pole still produces a weak magnetic field. This is due to residual magnetism in the steel laminations of the pole.

Note:
In this test and in all later tests, when using the compass, do not exceed the excitation voltages recommended. This is to avoid the possibility of demagnetising or reversing the compass needle polarity.

Notes

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MACHINES SYSTEM

Assignment 3
Field System
of an Electrical Machine

PRACTICAL	3.1	
EQUIPMENT REQUIRED	**Qty**	**Item**
62-100 Kit	1	Base Unit with Shaft Removed
	2	L9 Coils
	2	Field Poles
	1	Magnetic Compass
General	1	12 V dc Supply (eg, Feedback 60-105)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

INTRODUCTION

When both field poles and their coils are fitted to the frame ring, the electrical connections to them are made so that flux will leave one pole face and enter at the other. For this reason one coil has the start terminal positive with respect to the finish (red band) terminal while in the other coil the finish (red band) terminal is positive with respect to the start terminal.

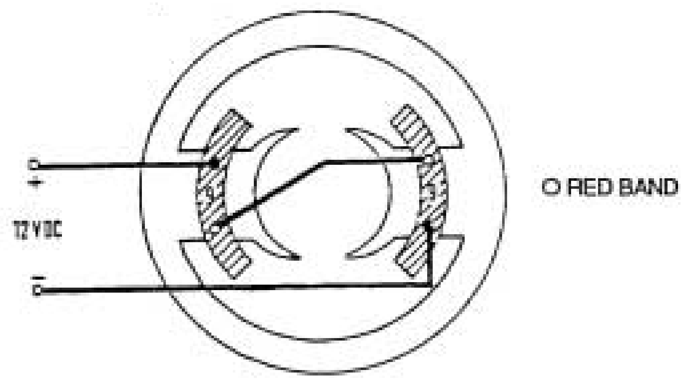

Figure A3-1

PRACTICAL 3.1

Fit the L9 coils to the field poles and attach them to the frame ring in the 3 o'clock and 9 o'clock positions. Make the coil connections shown in Figure A3-1 and switch on the dc supply.

Use a magnetic compass to identify the field poles, and with the compass between the poles note that they assist one another when the coils are correctly connected.

DISSECTIBLE

MACHINES SYSTEM

Assignment 4
Flux Levels
in a Magnetic Circuit

PRACTICAL 4.1

EQUIPMENT REQUIRED	**Qty**	**Item**
62-100 Kit	1	Base Unit with Shaft Removed
	2	L9 Coils
	2	Field Poles
	1	Squirrel-cage Rotor
General	1	6 V dc Supply (eg, Feedback 60-105)
	1	0 – 1 A dc Ammeter (eg, Feedback 68-110)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

INTRODUCTION

If the complete flux path is through magnetic steel or another ferromagnetic material, the excitation ampere-turns used in the previous assignments will produce a very considerable increase in flux through the magnetic circuit due to the lower reluctance of magnetic material as compared with air.

If a flux meter is available it can be used to measure the flux levels in the magnetic circuit at different values of excitation and to find the effect of placing a rotor between the poles. Alternatively, an approximate indication of flux in the circuit can be obtained by the use of an ammeter.

PRACTICAL 4.1

Make the connections shown in Figure A4-1.

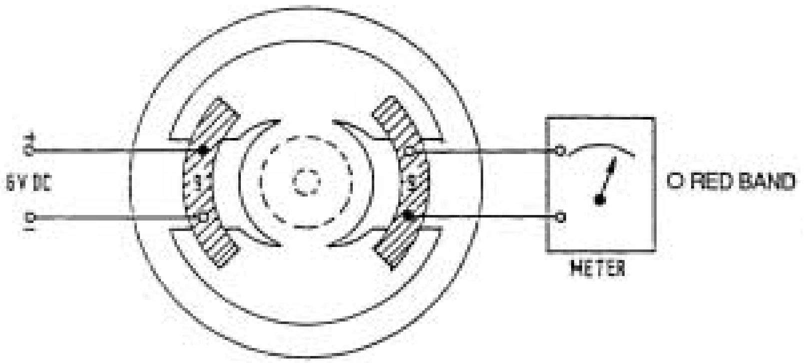

Figure A4-1

With the rotor removed from the assembly, switch the dc supply on and off: there will be a small deflection of the meter needle at each operation. Place the rotor between the poles and again switch the supply on and off: there will be a substantial increase in deflection due to the decrease in reluctance of the magnetic circuit when the rotor is in position.

It should be noted that this test does not reproduce the flux pattern which is set up when both field coils are connected to the dc supply. The leakage from the excitation pole to the frame ring is greater than it would normally be, especially with the rotor removed.

Assignment 5

Saturation

PRACTICAL 5.1

EQUIPMENT REQUIRED

	Qty	Item
62-100 Kit	1	Base Unit
	2	Field Poles
	4	Rotor Poles
	1	Rotor Hub
	2	L4 Coils
	2	L5 Coils
General	1	Variable ac Supply, 0 – 120 V (eg, Feedback 60-105)
	1	0 – 5 A ac Ammeter
	1	0 – 300 V ac Voltmeter (eg, Feedback 68-117)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

INTRODUCTION

The flux density in any part of a magnetic circuit is related t excitation by the equation:

$$F = \frac{B}{\mu}.l$$

where: F = excitation, ampere-turns
B = flux density Teslas (webers/m^2)
l = length of flux path, m
μ = absolute permeability

In ferromagnetic materials, μ is not constant. It is greatest at low flux densities, and in a typical electrical machine steel will become relatively low at flux densities above 1.5 Tesla, as the steel approaches saturation.

The effect of saturation can be shown, using the base unit and pole pieces, with two coils fitted to each main pole. Variable ac is applied to one coil of each pole and the induced voltage in the second pair of coils is read on an ac voltmeter. As the current through the excitation coils is increased in steps, the change of output voltage per step decreases due to saturation of the magnetic circuit.

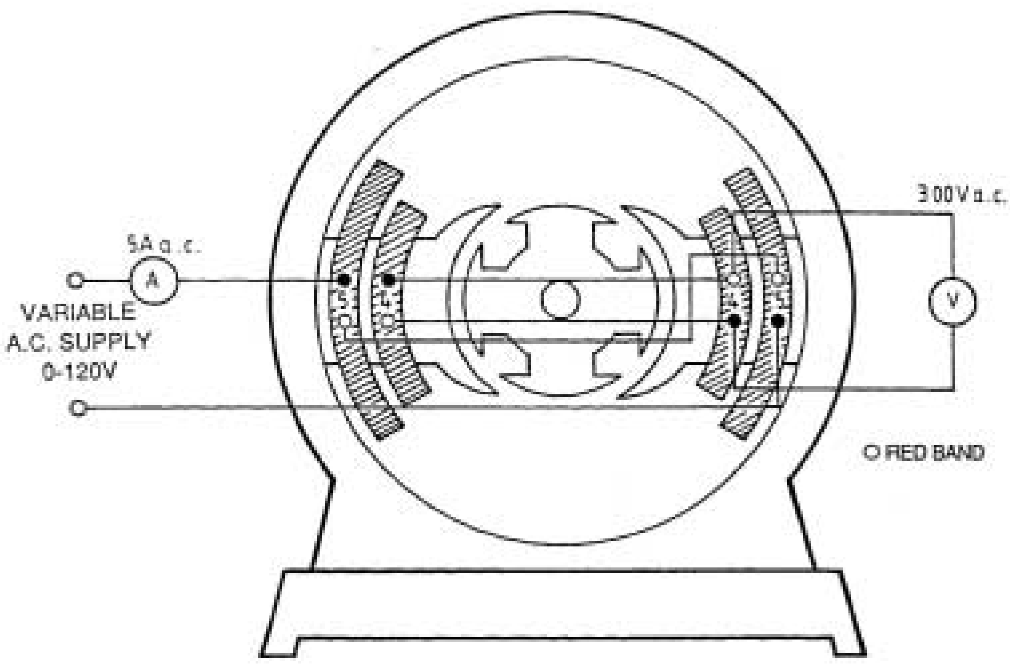

Figure A5-1: Coil Connections

PRACTICAL 5.1

Make the connection shown in Figure A5-1,

Set the variable ac supply to zero output and switch on.

Raise the current applied to the L5 coils in steps, of 0.2 A up the maximum obtainable measuring excitation current and output voltage at each step

Exercise 5.1

Plot the results to give a graph similar to that shown in Figure A5-2.

Question 5.1

At what excitation current does your graph begin to depart from the straight line?

Notes

Practical 5.1

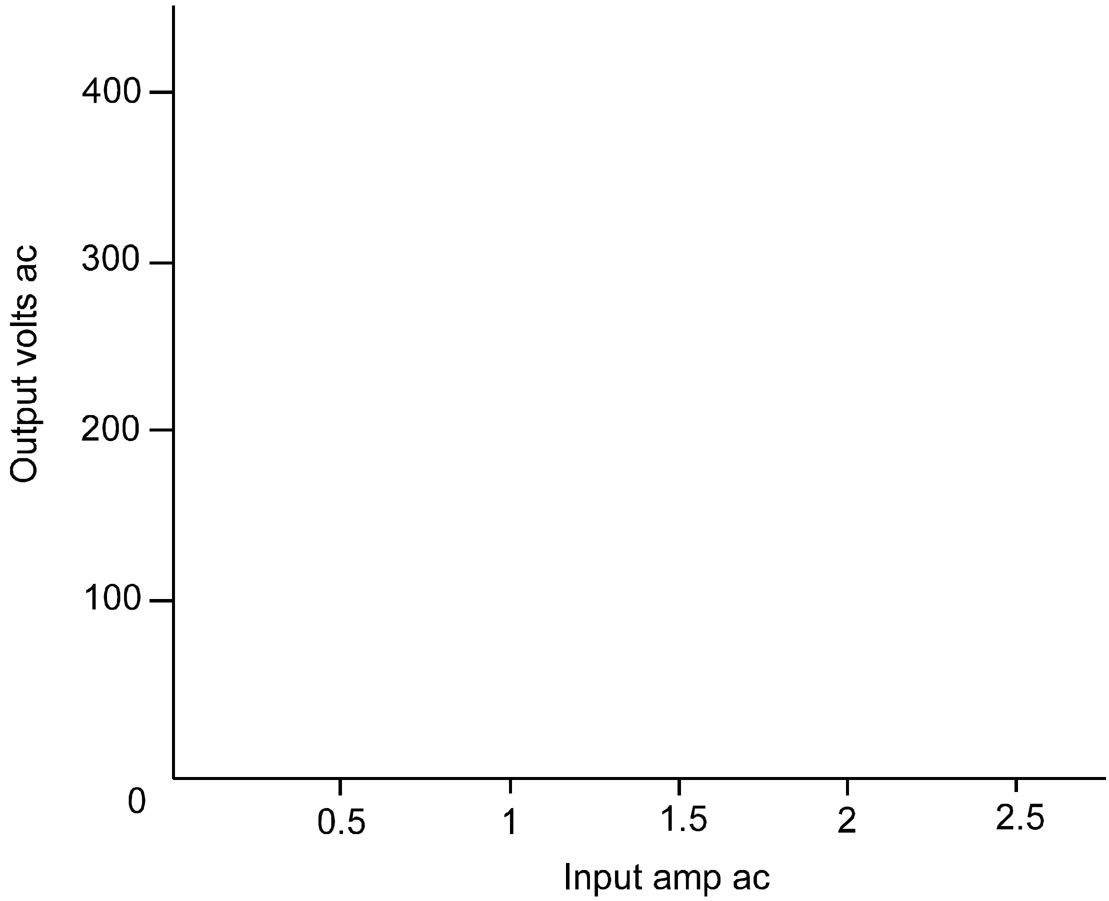

Figure A5-2 Graph Axes for Exercise 5.1

Notes

Practical 5.1

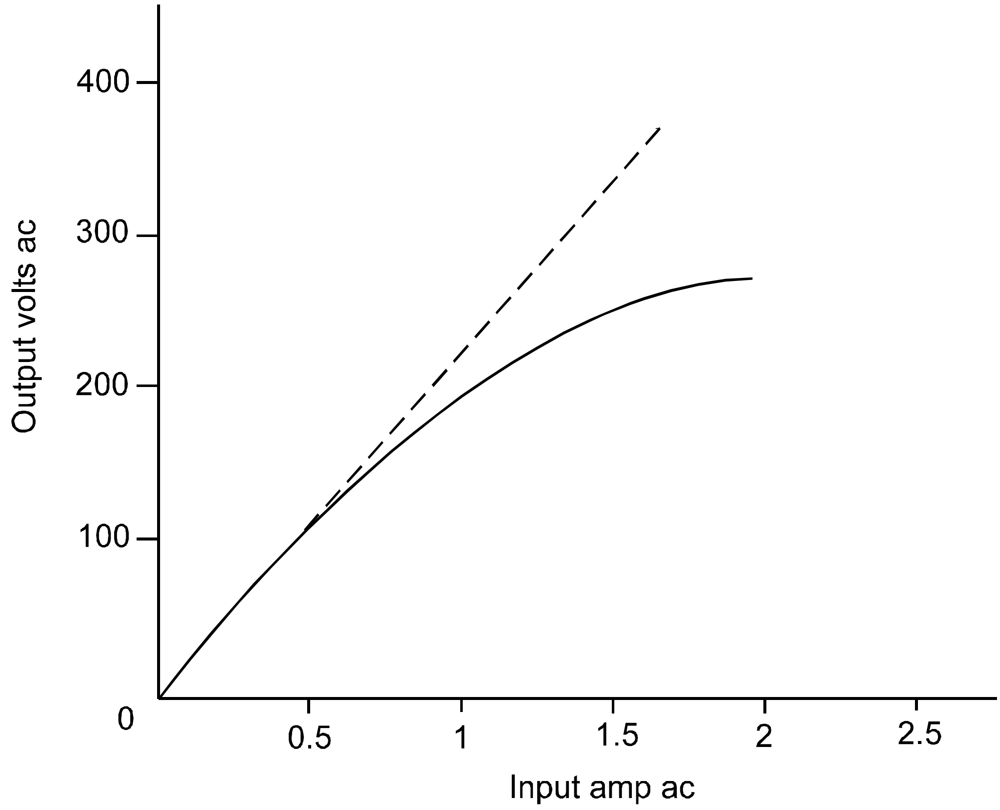

Figure A5-2: Saturation Curve

Notes

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MACHINES SYSTEM

Assignment 6

Induced Voltages

PRACTICAL 6.1

EQUIPMENT REQUIRED

	Qty	**Item**
62-100 Kit	1	Field Pole
	1	L4 Coil
	1	L5 Coil
General	1	6 V dc Supply (eg, Feedback 60-105)
	1	0 – 20 V ac Supply (eg, Feedback 60-121)
	1	0 – 25 V ac Voltmeter (eg, Feedback 68-117)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

PRACTICAL 6.1

Fit the L4 and L5 coils over the field pole and connect the dc supply to the L5 coil, positive to the terminal adjacent to the red band as shown in Figure A6-1.

Connect the multimeter to the L4 terminals, positive to the terminal adjacent to the red band, and set it to the 10O mA dc range or nearest.

Switch on the dc supply and note that the meter deflection is forward when the supply is switched on and in reverse when it is switched off. This indicates that the direction of current change in the two coils is opposite, as in Figure A6-2 (shown overleaf) and in accordance with Lenz's law. A change in the value of current flowing in coil L5 causes a corresponding change in the flux linking the two coils. An emf is therefore induced in L4 and the direction of current flow into an external load is such that the resulting flux is in opposition to the initial flux.

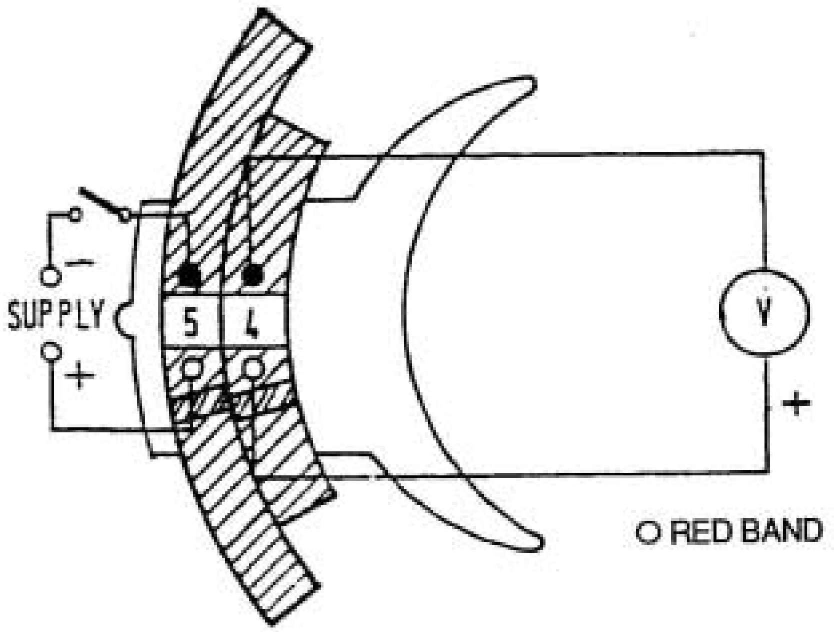

Figure A6-1

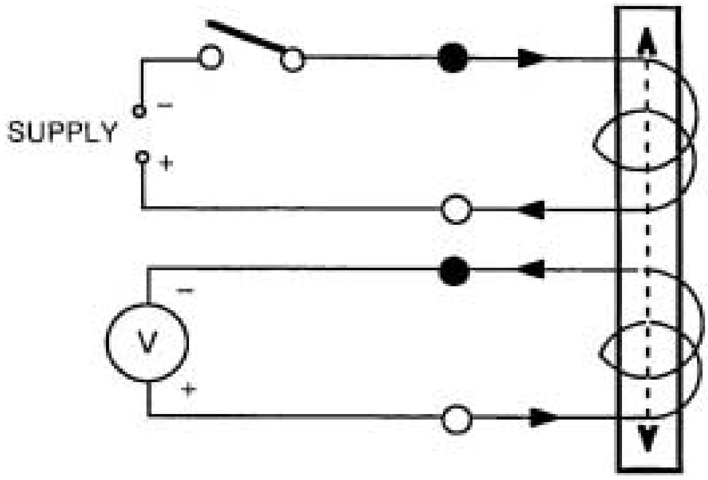

Figure A6-2

Remove the dc supply and connect a low voltage ac source to the L5 coil terminals.

Set the meter which is connected to the L4 coil, to the 25-volt ac range.

Switch on the ac supply and raise the applied voltage to 10 volts. The voltage across the L4 terminals will be approximately 15 volts; the actual value is dependent on the reluctance of the magnetic flux path. If the field pole is removed from the coils, there is a substantial reduction in the voltage induced in L4.

As in previous assignments, the voltage in the secondary coil L4 is induced by the changing flux due to the alternating current flowing in L5.

Notes

DISSECTIBLE

MACHINES SYSTEM

Assignment 7 Phase Relationship in Split-Phase Motor

PRACTICAL 7.1

EQUIPMENT REQUIRED

	Qty	Item
62-100 Kit	1	12-slot stator
	1	Squirrel-cage Rotor
General	1	Resistor/Capacitor Unit (eg, Feedback 67-190
	1	0 – 120 ac Supply (eg, Feedback 60-105)
	1	0 – 250 V ac Supply (eg, Feedback 60-121)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

INTRODUCTION

A two-phase stator winding will produce a rotating field, with the current in the two windings displaced by approximately 90°. The phase shift due to a capacitor connected in series with one winding (the 'start' winding) can be calculated from measurements of the voltage appearing across each element.

This is a static test and it is of interest to compare the results with those obtained during a running test, as shown in the phasor diagrams in Figure A7-2.

PRACTICAL 7.1

Place the stator on the bench with the coil terminals facing upwards and insert the squirrel-cage rotor in the bore, supporting it as necessary to bring the two cores to the same level.

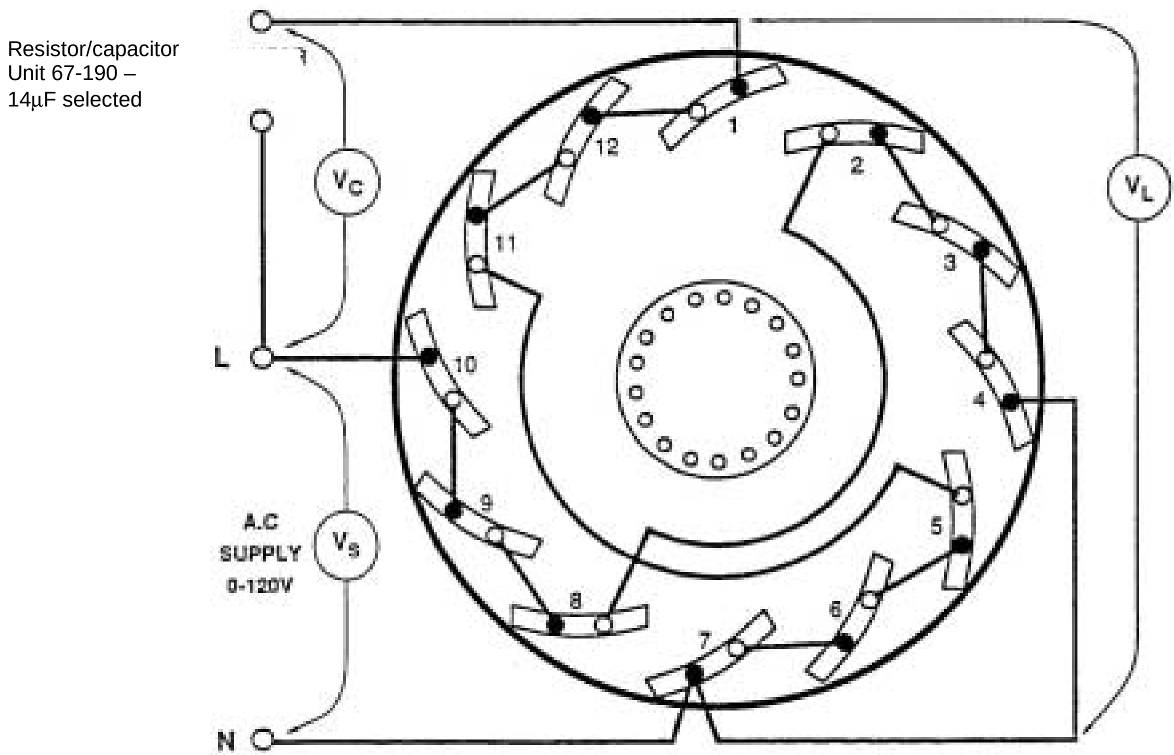

Figure A7-1: Stator Connections

Link the stator coils as shown in Figure A7-1 and connect to a supply of between 100 and 135 volts ac.

> **Note:**
> It is possible to connect directly to the 240-volt ac mains, but the stator current with the rotor stationary is higher than normal and the coils may become overheated.

Exercise 7.1

Measure the voltages:

V_S across the supply
V_C across the capacitor
V_L across the start winding

From these results, construct the phasor diagram as in Figure A7-2.

This diagram may be compared with one obtained from running test under the same conditions.

Safety Note:
Although none of the voltages are of dangerous magnitude, it is advisable to switch off whilst moving the voltmeter connections

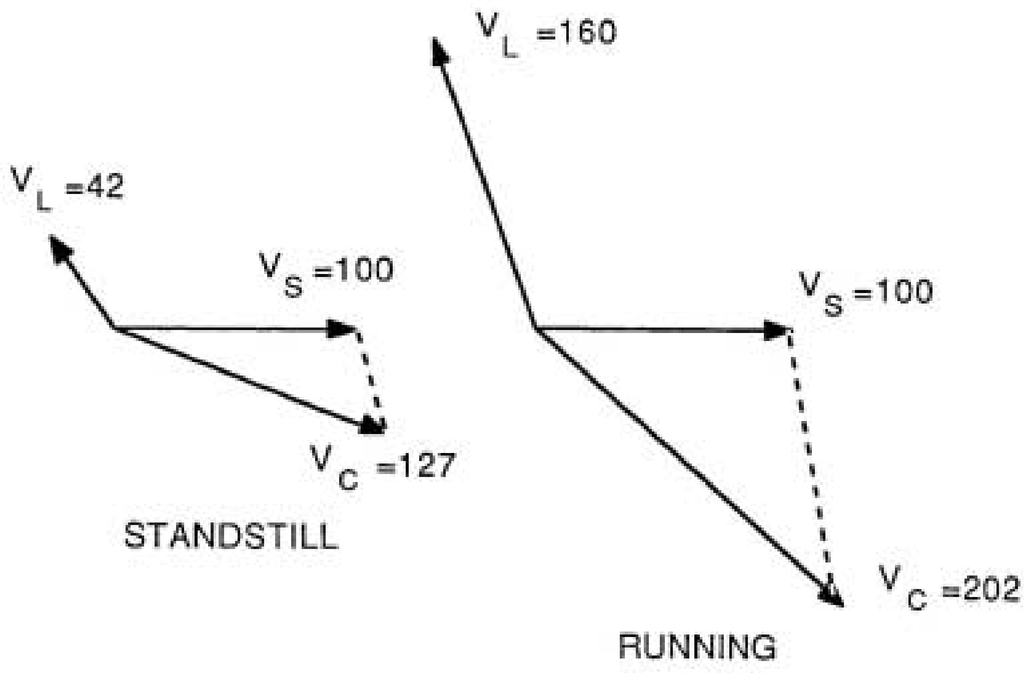

Figure A7-2: Phasor Diagrams for Split-phase Stator

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MACHINES SYSTEM

Assignment 8

Rotating Fields

PRACTICAL 8.1

EQUIPMENT REQUIRED	**Qty**	**Item**
62-100 Kit	1	12-slot stator
	1	Magnetic Compass
General	1	Resistor/Capacitor Unit (eg, Feedback 67-190)
	1	0 – 135 V ac Supply (eg, Feedback 60-105)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

INTRODUCTION

The rotating field produced by a stator wound for two or more phases can be demonstrated by a magnetic compass placed in the bore. The needle can be made to rotate in synchronism with the stator field.

PRACTICAL 8.1

Place the stator on the bench with the coil terminals upwards.

Link the stator coils as in Figure A8-1 and connect it to supply of between 100 and 135 volts ac. The voltage used is not critical and is limited by the relatively large current taken by the stator windings in the absence of a rotor.

Lower the compass slowly into the stator bore and adjust its position until the needle rotates at synchronous speed. A height of between 70 and 80 mm above the bench is recommended.

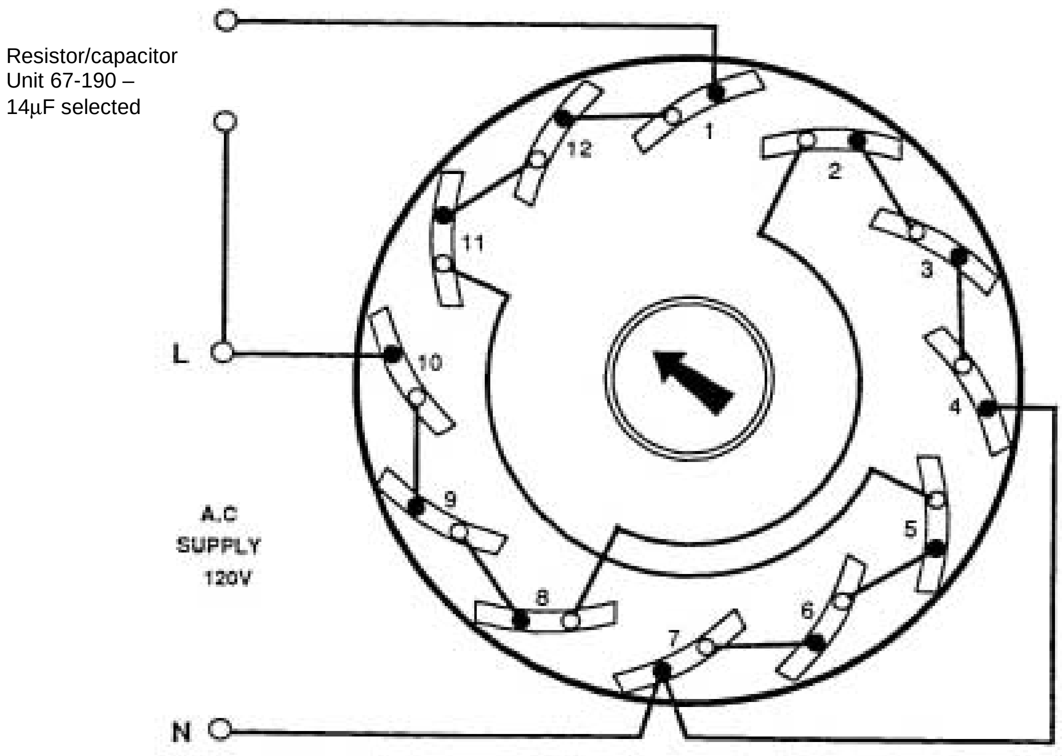

Figure A8-1: Stator Connections

Exercise 8.1

Question 8.1 *Which direction of rotation was produced in the compass needle by the connection used above?*

(Test this by withdrawing the compass when fully rotating and observing until it slows down).

Question 8.2 *Can you see how the reverse direction can be obtained?*

Practical Aspects

The magnetic field developed by the stator windings of a polyphase machine rotates at a speed given by the equation:

$$n = \frac{f}{p} \text{ x } 60$$

where: n = revolutions/minute
f = supply frequency, Hz
p = pole pairs per phase

Most polyphase electrical machines are either two-phase or three-phase, although systems with six or more phases are used. The single-phase induction motor is often started up as a two-phase machine and may run as one. In this case, one of the two stator windings is connected to the supply via a capacitor which produces a phase difference in the currents through the two windings. Alternatively, the start winding may have wire of smaller diameter than is used in the main winding so increasing its resistive component and producing the required phase shift.

In the single-phase induction motor assemblies described later in the manual, the resistor/capacitor unit components are connected in series with the start winding.

Exercise 8.1

Question 8.1	The needle rotates counter-clockwise viewed from above.
Question 8.2	If the connections to the ends of the two windings remote from N are reversed, the direction of rotation will reverse.

DISSECTIBLE

MACHINES SYSTEM

Assignment 9

Stator Windings

PRACTICAL	9.1	
EQUIPMENT REQUIRED	**Qty**	**Item**
62-100 Kit	1	12-slot Stator
General	1	0 – 5 V, 5 A dc Power Supply, (eg, Feedback 60-105)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

INTRODUCTION

Some of the different forms of winding arrangement which can be made up from the 12-slot stator are shown in Figure A9-1. If the windings are connected to a low-voltage dc source, the flux patterns produced in each case can be traced by moving a magnetic compass within the stator bore.

PRACTICAL 9.1

Link the stator coils as in any of the diagrams shown in Figure A9-1 (reproduced overleaf) and connect the input leads to the low voltage dc power supply.

Position the stator with end windings horizontal and place the magnetic compass in the bore.

Switch on the dc supply and move the compass in the vicinity of the teeth to identify the poles and trace the flux paths between poles.

For the two and three-phase connections, energize one winding at a time.

On a copy of the diagrams in Figure A9-1, sketch the principal lines of flux, showing which pole is North for a given direction of current flow.

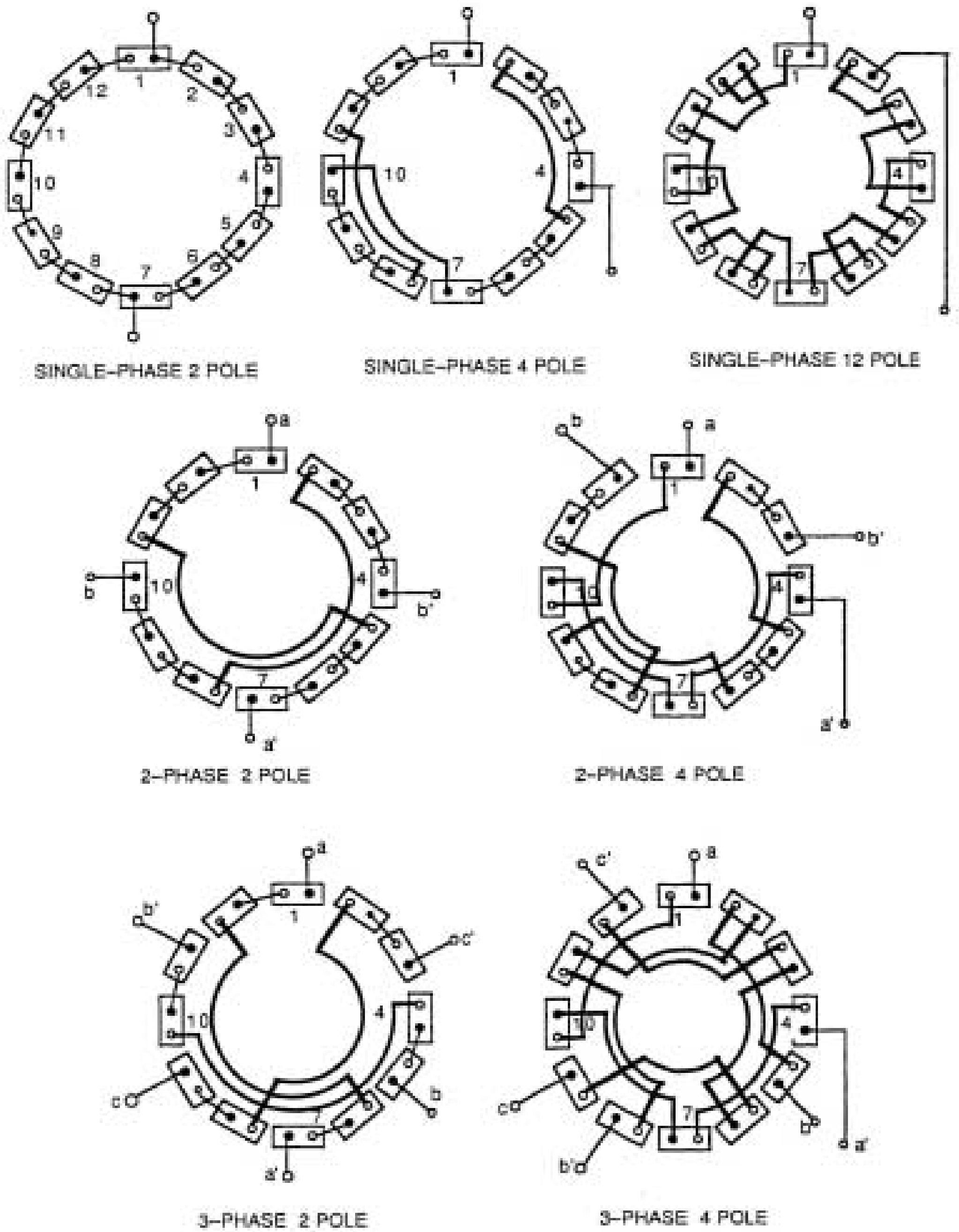
SINGLE-PHASE 2 POLE
SINGLE-PHASE 4 POLE
SINGLE-PHASE 12 POLE
2-PHASE 2 POLE
2-PHASE 4 POLE
3-PHASE 2 POLE
3-PHASE 4 POLE

Figure A9-1

Notes

Assignment 10

Armature Windings

PRACTICAL 9.1

EQUIPMENT REQUIRED	**Qty**	**Item**
62-100 Kit	1	Base Unit
	4	Rotor Poles
	1	Rotor Hub
	2	L1 Coils
	2	L2 Coils
	2	Brushholders with Brushes
General	1	0 – 12 V, 5 A dc Source, (eg, Feedback 60-105)
	1	12 V dc Voltmeter
	1	5 A dc Ammeter (eg, Feedback 68-110)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

INTRODUCTION

In the dc motors and generators with rotating armature assemblies which can be made with the 62-100, the windings are connected as in Figure A10-1 and A10-2 (overleaf). Measurements of voltage and current at the brushes for different commutator positions can be used to verify the coil connections shown.

PRACTICAL 10.1

Assemble the armature as described in Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 1 and mount the shaft in its bearings. Before finally tightening the thumb screws of the removable bearing housing, check that the shaft rotates freely and can be moved axially against the pre-loading washer. Mount the brushes in the commutator position.

Connect the low voltage dc supply to the brushes, switch on, and measure the applied voltage and current with the brushes on the centres of commutator segments and then with the brushes shorting pairs of segments. Check that the results conform with Figure A10-1. Repeat with the armature connected for repulsion motors, as in Figure A10-2 and as detailed in Basic Assembly Instruction 2.

Exercise 10.1

Question 10.1

It the voltage applied to the brushes is constant and each armature winding has the same resistance, what would you predict the relative currents to be for each of the four cases:

a) Lap winding, brushes in centre of segments
b) Lap winding, brushes bridging gaps
c) Repulsion winding brushes in centre of segments
d) Repulsion winding brushes bridging gaps?

Do your measurements agree with predictions?

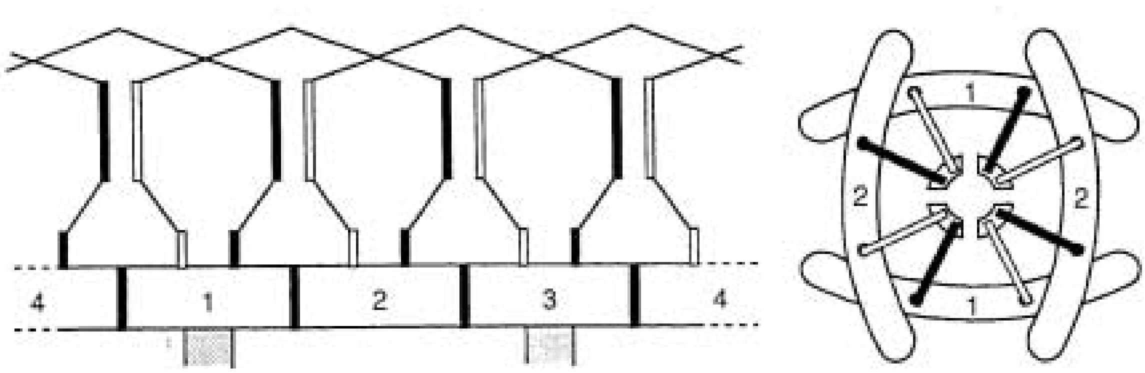

Figure A10-1: Lap Connections used in dc Motors and Generators

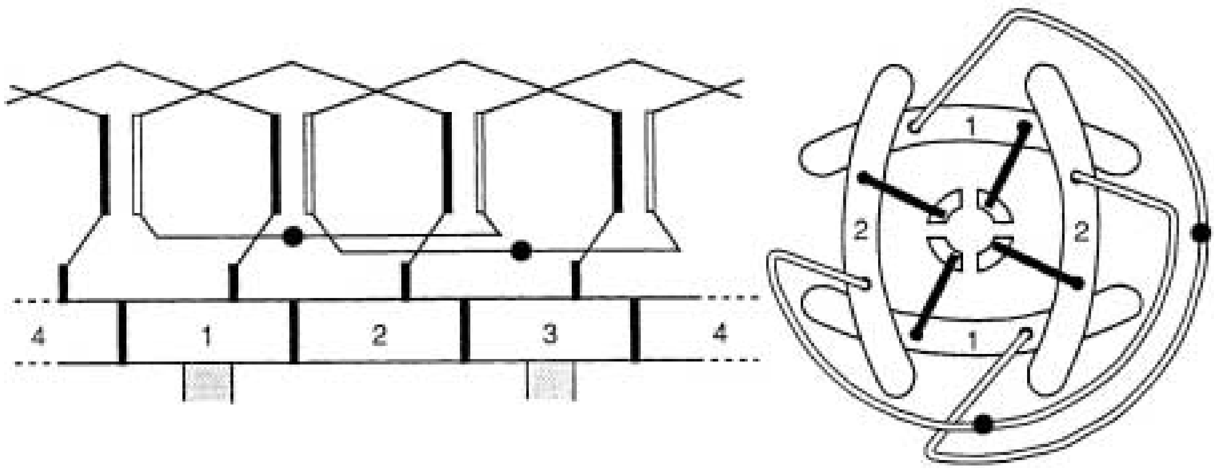

Figure A10-2: Connections used for Repulsion Motor Assembly

Exercise 10.1

Question 10.1 The ratios should be approximately:

a) 1

b) 2

c) 0.5

d) 1

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MACHINES SYSTEM

Assignment 11

Interpole Flux

PRACTICAL 11.1

EQUIPMENT REQUIRED	**Qty**	**Item**
62-100 Kit	1	Base Unit, omitting Shaft and removable Bearing Housing
	2	Field Poles
	2	Interpoles
	2	L8 Coils
	2	L9 Coils
	1	Magnetic Compass
General	1	0 – 24 V, 1 A dc Power Supply, (eg, Feedback 60-105)
	1	0 – 1A dc Ammeter (eg, Feedback 68-110)
	1	5 A, Single-pole, On-Off Switch (eg, Feedback 65-130)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

INTRODUCTION

Distortion of the main field by armature reaction may be counteracted by an interpole field acting at right angles to it. The effect of interpole flux on main-pole flux may be shown by a magnetic compass placed at the pole-arc axis. With the main field coils energised, a current equivalent to that taken by the armature on full load is applied to the interpole coils. This causes the compass needle to deflect through an angle approximating to the shift of the magnetic neutral plane due to armature reaction.

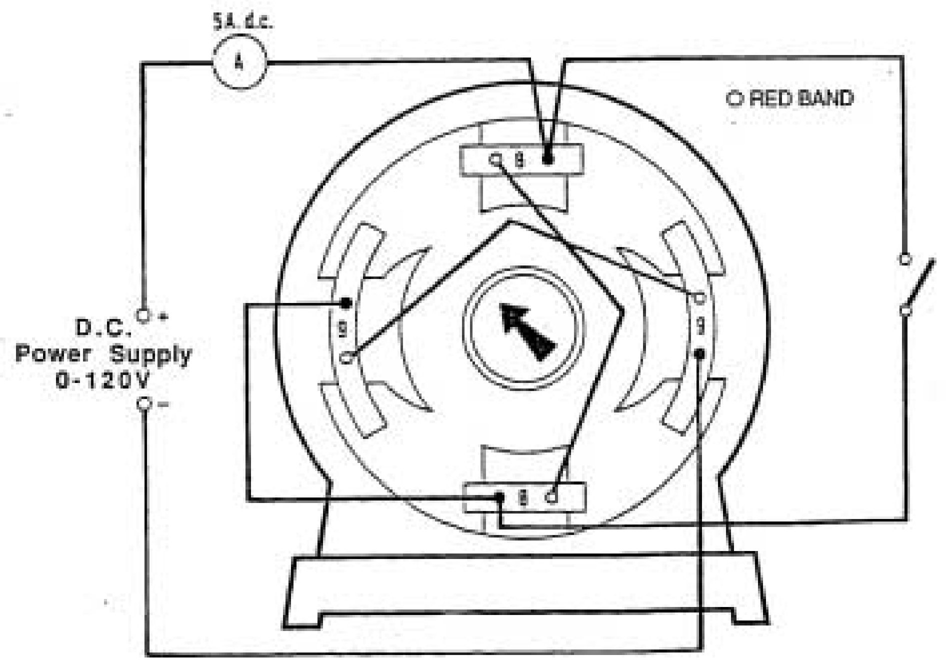

Figure A11-1

PRACTICAL 11.1

Assemble the wound poles to the frame ring and make the connections shown in Figure A11-1.

Set the base unit on end, with a suitable block placed under the fixed bearing housing.

Position the magnetic compass at the pole-arc axis, switch on the dc supply, and adjust to 0.5 amp. With the switch shorting out the interpole coils, only the main poles will be energised and the compass needle will lie in the direction of their field.

Open the switch across the interpole coils and re-adjust the supply current to 0.5 amp. Note the deflection of the compass needle due to the interaction of the main and interpole fields.

Exercise 11.1

All coils are wound in the same sense so that current flowing into the corresponding terminal of any coil produces the same field polarity. Study the connection diagram, Figure A11-1, and verity that the direction of deflection of the compass needle caused by the interpoles is what you would expect.

Notes

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MACHINES SYSTEM

Chapter 3-2 Elementary Generator Assignment

This chapter contains an assignment as follows:

No.

12) Elementary ac and dc Generator

Notes

Assignment 12

DISSECTIBLE

MACHINES SYSTEM

Elementary ac and dc Generator

PRACTICAL	12.1	ac Generator
	12.2	dc Generator
	12.3	Magnetisation Curve

EQUIPMENT REQUIRED	**Qty**	**Item**
62-100 Kit	1	Base Unit
	2	Field Poles
	2	L9 Field Coils
	1	Rotor Hub
	4	Rotor Poles
	1	L10 Two-turn Coil
	1	Commutator/Slipring
	2	Brushholders with Brushes
	1	Hand Crank
	1	Flexible Coupling
General	1	Variable Speed Motor, 1/3 hp, 0-500 rev/min (eg, Feedback 63-501)
	1	0 – 12 V dc Variable Power Supply (eg, Feedback 60-105)
	1	50-0-50 dc Millivoltmeter or
	1	1-0-1 dc Milliammeter (eg, Feedback 68-113)
	1	0-5 A dc Ammeter
	1	0 – 50 V dc Voltmeter (eg, Feedback 68-110)
	1	Single Beam Oscilloscope (optional)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

INTRODUCTION

A conductor moving through a magnetic field generates a voltage which is proportional to the length of the conductor, the speed at which it cuts the field, and the strength of the field.

In this generator, the voltage produced by rotating the two-turn coil in a magnetic field is very low but sufficient to cause deflection of a sensitive millivoltmeter connected across the coil ends. The readings obtained illustrate the action of alternating and direct current generators.

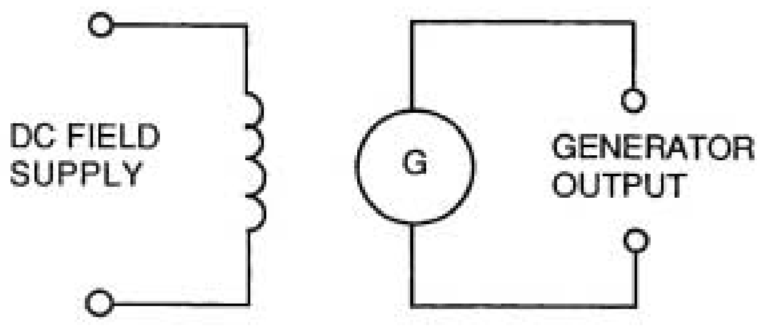


Figure A12-1: Elementary Generator – Circuit Diagram

ASSEMBLY

Armature

Attach the rotor poles B, C and D to the rotor hub using the short socket head screws.

Insert the two-turn armature coil between opposite pole gaps with the coil ends brought out for connection to the commutator, as shown in Figure A12-2.

Slip the hub and coil over the shaft and using the long socket head screw, clamp pole A to the hub; this screw engages with the tapped hole in the shaft and holds the hub and poles in position.

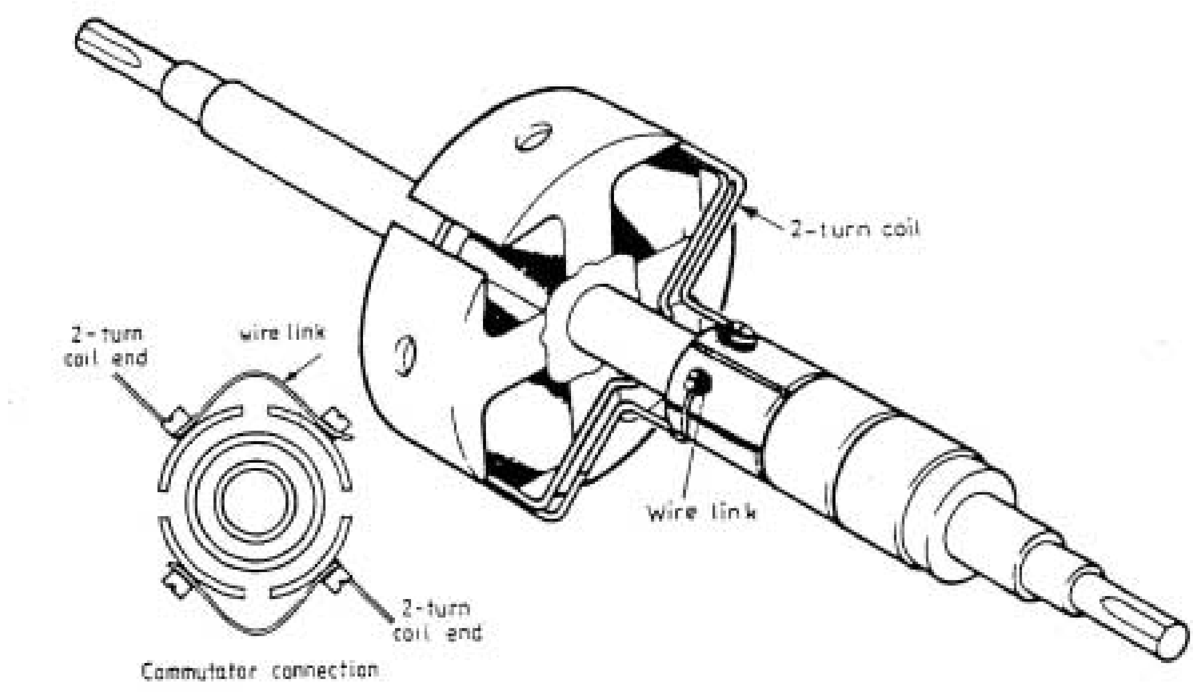


Figure A12-2

Slide the slipring/commutator over the shaft with the segments next to the armature, and adjust to bring the gaps between the segments in line with the armature pole gaps. Note that two oppositely placed commutator segments are permanently linked to sliprings. For this assembly, connect adjacent commutator segments together with short lengths of 20 swg tinned copped wire to form two pairs, giving in effect, a two-segment commutator with each segment connected to a slipring. Connect the coil ends to opposite segments and tighten the set screws.

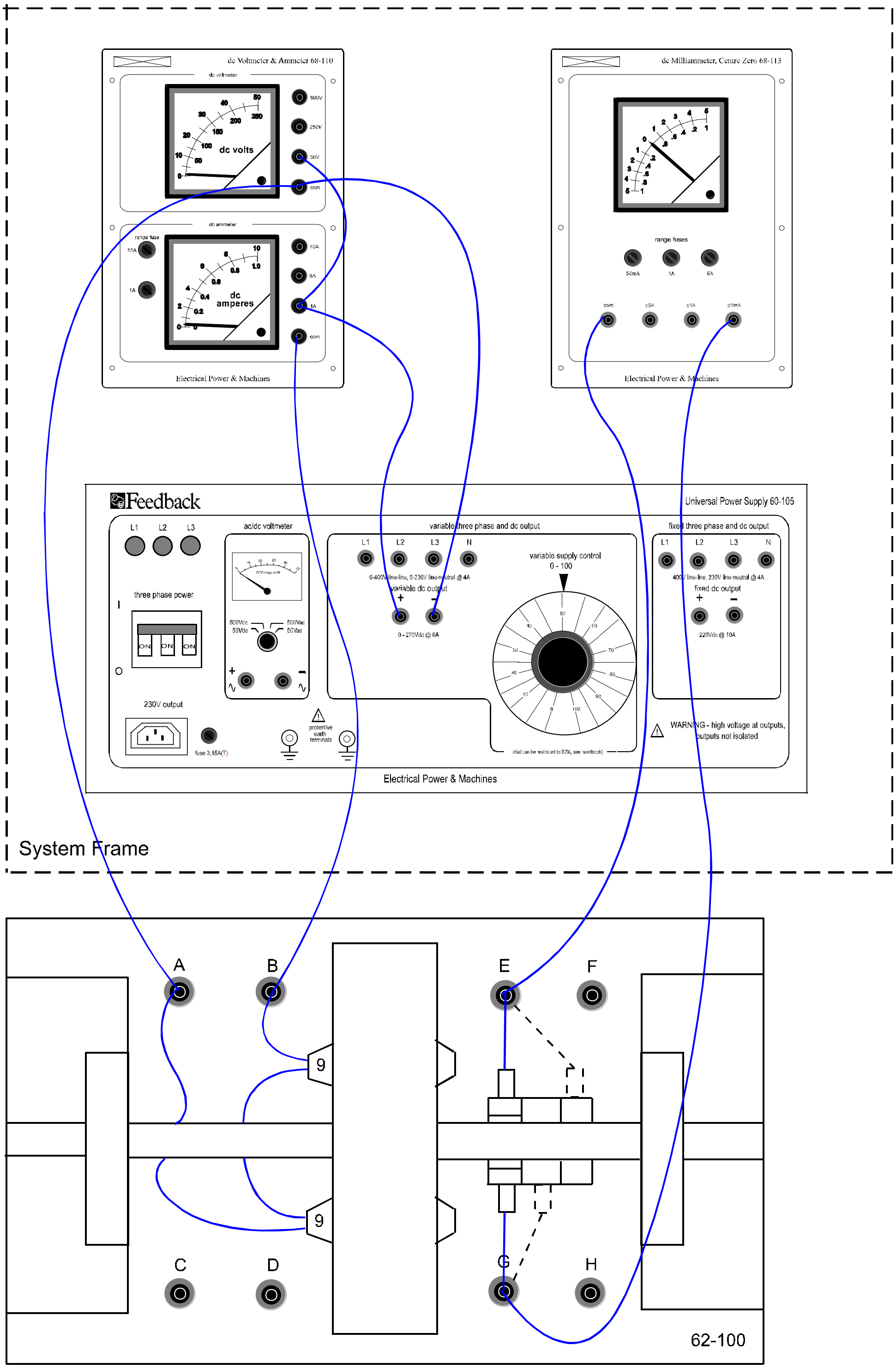


Figure A12-3: Connections-Elementary Generator

Bearings

The completed armature is now ready to be fitted into its bearings on the base unit.

Slide the drive end of the shaft through the bore of the self-aligning bearing in the fixed bearing housing and fit the commutator end of the shaft into the removable bearing housing.

Adjust the position of the removable housing, if necessary, and insert the fixing screws but, before finally tightening these, check that the shaft rotates easily and that it can be moved axially against the pre-loading washer.

Fix the hand crank to the shaft at the non-drive end.

Electrical

Place L9 coils over each field pole and fit them to the frame ring at the 3 o'clock and 9 o'clock positions with, coil ends brought out on the drive side of the machine. The 1 1/4 inch long caphead socket screws are used to fix the poles in position.

Insert the brushes into their holders and attach these to the mounting block positions opposite the sliprings. When the brushgear is in position check that the brushes move freely in their holders.

Make the circuit shown in Figure A12-.4 in accordance with the connections shown in Figure A12-3 and initially connect the output millivoltmeter to the slipring terminals. A centre zero millivoltmeter is required: Its full scale deflection is not critical but 50-0-50mV is suitable. If this is not available a 1-0-1 milliammeter may be used in its place. A typical 1 mA meter would have an internal resistance of 50n, in which case the voltage required for full scale deflection is 0.001 x 50 = 50mV.

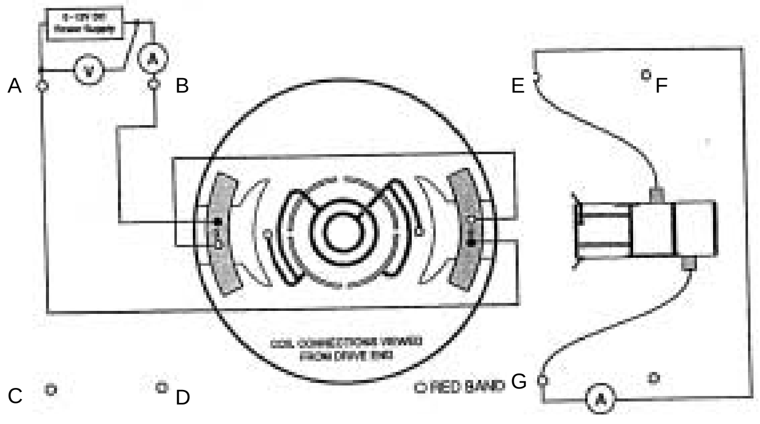


Figure A12-4: Elementary Generator Circuit Diagram

PRACTICAL 12.1

ac Generator

Switch on the power supply unit and adjust the current in the field coils to approximately 2A. The polarity of the field can be checked by a magnetic compass.

Turn the hand crank fairly slowly, and observe the millivoltmeter connected to the slipring terminals. The needle will deflect first to one side then to the other as the armature conductors pass the field poles, indicating the magnitude and polarity of the generated voltage.

Increase the speed at which the hand crank is turned and note that the meter deflection increases. It will be seen that the deflection is in one direction as one coil side moves across the N field pole, and in the opposite direction when the same coil side moves across the S field pole.

The behaviour of the meter shows that the output voltage from the elementary generator alternates from a positive value through zero to a negative value as each conductor passes through the fields produced by the two poles of opposite magnetic polarity. It will be found that rotation of the armature at the same speed as before, but in the reverse direction, again causes an alternating voltage to be produced and that the frequency of alternation and magnitude of the generated voltage are unchanged.

PRACTICAL 12.2

dc Generator

Although alternating current is generated in the armature coils of the generator, direct current can be obtained at the brushes of the machine by the use of a commutator which acts as switch between the coil ends and the brushes. As the voltage generated in a conductor is reversed its connections to the brushes are also reversed so that the output voltage is of fixed polarity though varying in magnitude.

To test the action of the commutator, transfer the brushes in their holders to a position on either side of the commutator and connect the centre-zero millivoltmeter to the commutator terminals. After fitting, check that the brushes make good contact with the commutator.

Rotate the crank clockwise and note that although the meter reading rises and fails as it did previously it now deflects in one direction only. Turn the crank anti-clockwise at the same speed as before; again the meter deflections consist of unidirectional pulses but in the opposite direction to the previous test.

Disconnect the dc supply, reverse the field connections and switch on again. With anti-clockwise shaft rotation, the meter deflections will be in the original direction.

The direct current obtained from the elementary generator is pulsating in form, failing to zero between each current peak. In commercial generators many conductors are distributed over the periphery of the armature and the output voltage takes the form of a steady value with a superimposed ripple. The diagrams in Figure A12-5 show in simplified form how the alternating voltage in an armature coil is rectified by the commutator to produce a dc output voltage. It should be noted that the voltage waveform given by a practical electrical machine will be more flat topped and with fewer disturbances than shown.

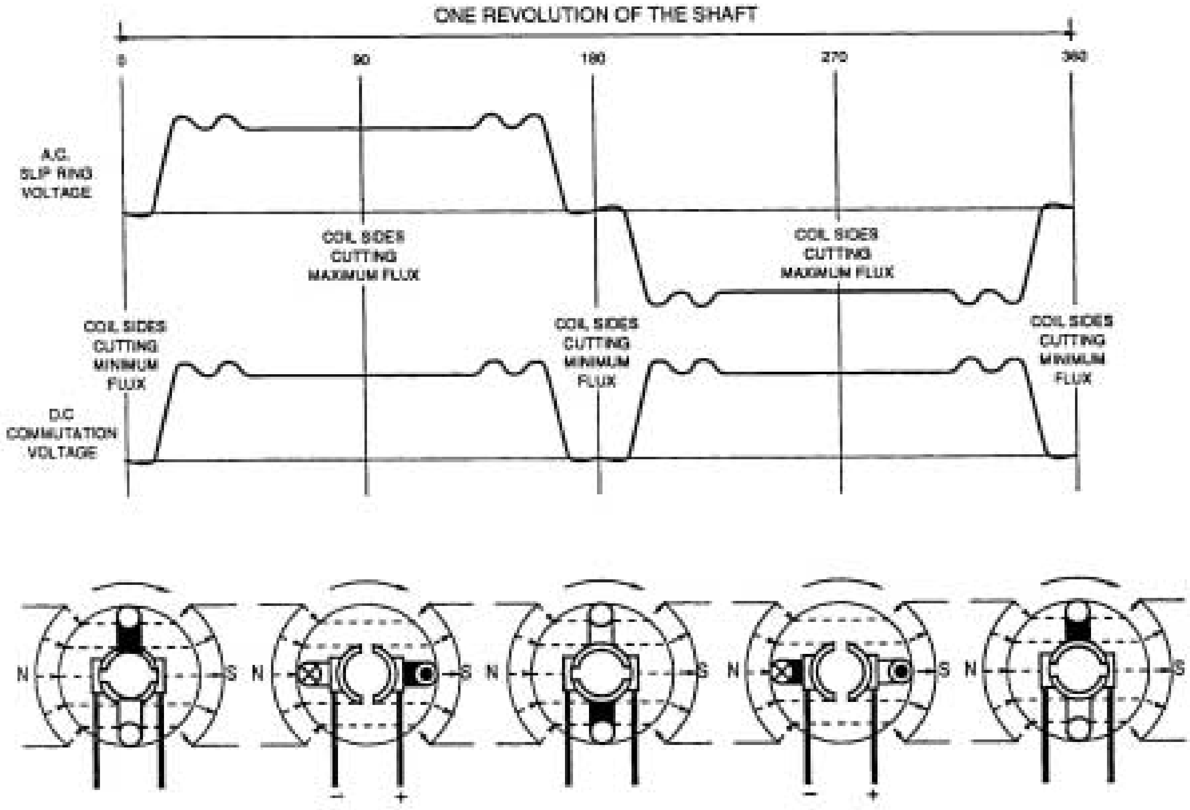


Figure A12-5: The action of the Elementary Generator

In general, the flat top comes about because the flux pattern is more or less radial from curved pole pieces as in 62-100. This is especially true when there is iron in the armature, as here. The rate of flux-cutting is thus substantially constant over the pole face, failing rapidly to zero as the coil sides move across the space between the pole faces.

The waveshape can be readily observed on an oscilloscope if a drive motor such as 63-501 is available to rotate the armature at a steady speed. See Utility Manual, Chapter 3, for details of coupling the 63-503 to the base unit. Set the speed to about 500 r/min and observe the waveforms across the brushes when they are opposite first the slip-rings and then the commutator.

PRACTICAL 12.3

Magnetising Curve

If a drive motor is available as just discussed, the generator output voltage may be varied by adjustment of the field current. With the generator connected to give an ac output, connect a multimeter in place of the centre-reading milliammeter and set it to 100 mA ac.

Set the drive motor speed to 500 rev/min, and take readings of ac milliamps for excitation currents of 0 to 3 A in 0.5 A steps. As before the milliammeter acts as a sensitive indicator of the small ac voltage generated and the readings taken can be plotted to give a magnetisation curve, similar to that shown in Figure A12-6. The actual values of generated current may vary considerably from those given, due to variability of brush/slip-ring resistance from machine to machine, but the shape should conform quite closely.

Practical 12.3

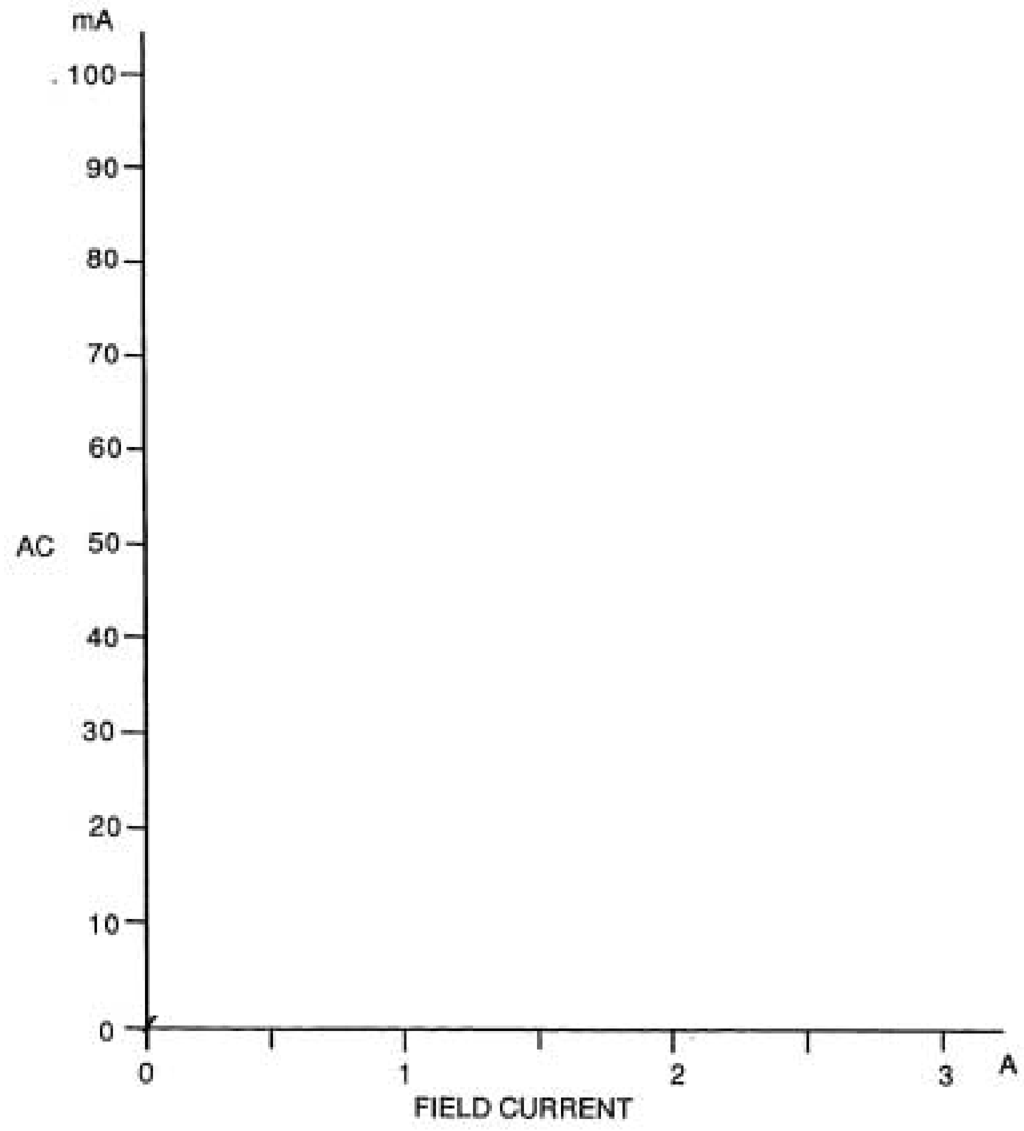


Figure A12-6 Graph Axes for Practical 12.3

Notes

Practical 12.3

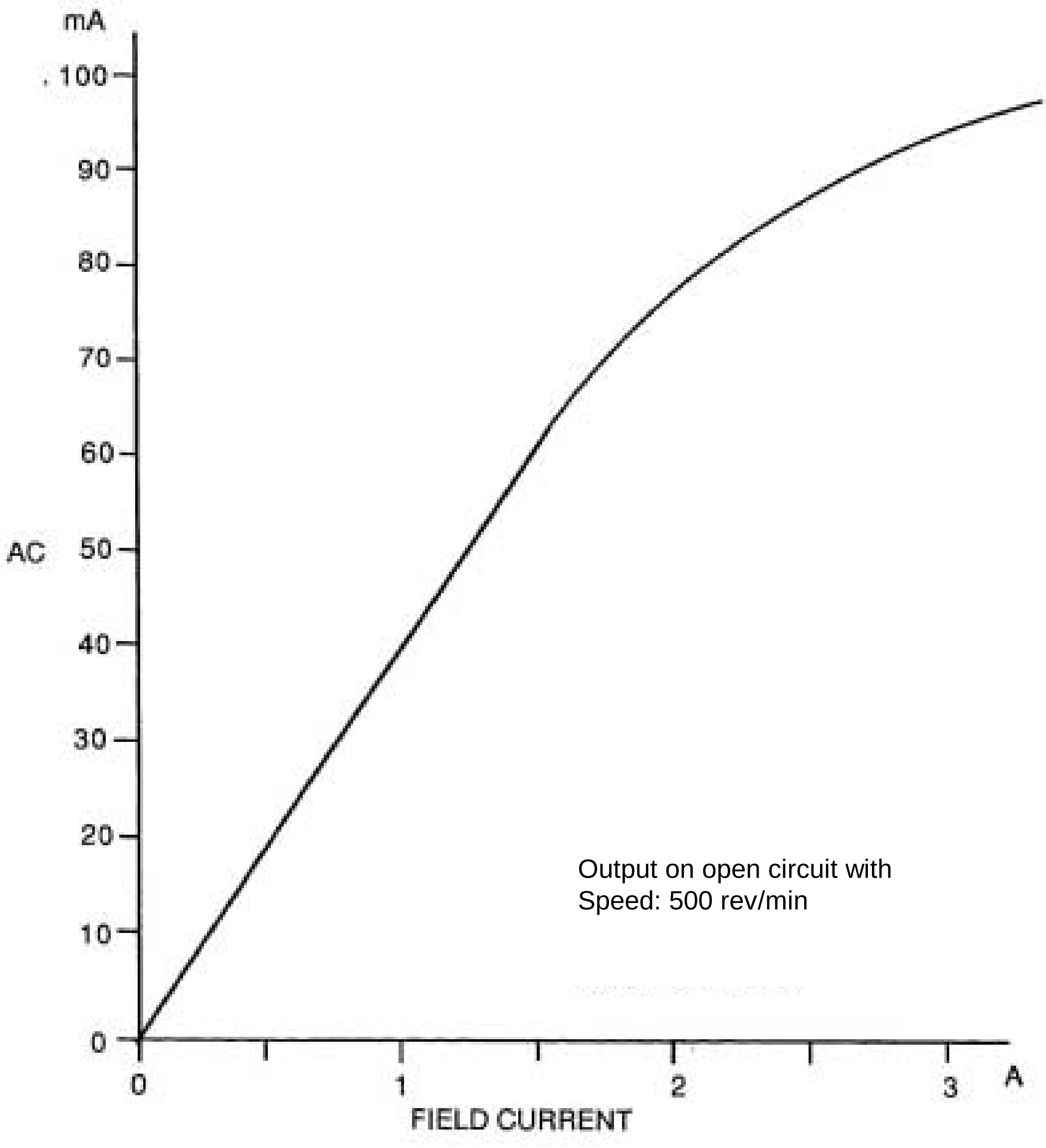


Figure A12-6: Output Characteristic of Elementary ac Generator

Notes

Chapter 3-3

DC Machine Assignments

This chapter contains ac machine assignments as follows:

No.

13) dc Shunt Motor
14) dc Shunt Motor with Interpoles
15) dc Shunt Generator
16) dc Shunt Generator with Interpoles
17) dc Separately Excited Generator
18) dc Separately Excited Generator with Interpoles
19) dc Series Motor
20) dc Series Motor with Interpoles
21) dc Series Generator
22) dc Series Generator with Interpoles
23) dc Compound-Wound Motor
24) dc Compound-Wound Motor with Interpoles
25) dc Compound Generator
26) dc Compound Generator with Interpoles

Notes

DISSECTIBLE

MACHINES SYSTEM

Assignment 13

dc Shunt Motor

PRACTICAL	13.1	Speed Control
	13.2	Motor on Load
	13.3	Direction of rotation
	13.4	Speed Control by Field Variation
EQUIPMENT REQUIRED	**Qty**	**Item**
62-100 Kit	1	Base Unit
	1	Commutator/Slipring
	2	Brushes and Brushholders
	2	L4 Coils
	2	L1 Coils
	2	L2 Coils
	2	Field Poles
	1	Rotor Hub
	4	Rotor Poles
General	1	0-70 V, 5 A, dc Supply (eg, Feedback 60-105)
	1 1	0-100 V, dc Voltmeter 0-5 A, dc Ammeter (eg, Feedback 68-110)
	1	Variable Resistor, 0-200 ohms, 2.5 A (eg, Feedback 67-113)
	1	Friction (Prony) Brake or other Dynamometer 0-1 Nm at 1500 rev/min (eg Feedback 67-470
	1	Optical/Contact Tachometer: (eg, Feedback 68-470)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

In this motor, the field coils are connected to the dc supply terminals and are in parallel with the armature circuit. As the main field excitation is independent of shaft loading conditions, it can be made virtually constant. In this case, the shunt motor can be designed to give an almost level speed/torque characteristic, the speed failing gradually at the upper end of the load range.

Because of the simplicity of its control requirements the dc shunt motor is also widely used as a variable-speed drive and in automatic speed regulation systems.

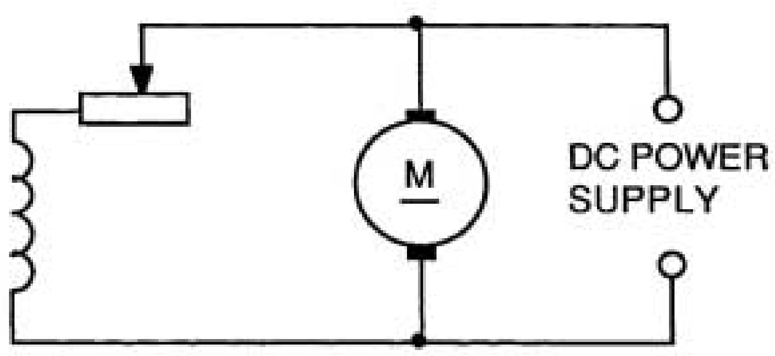


Figure A13-1: Shunt Motor – Circuit Diagram

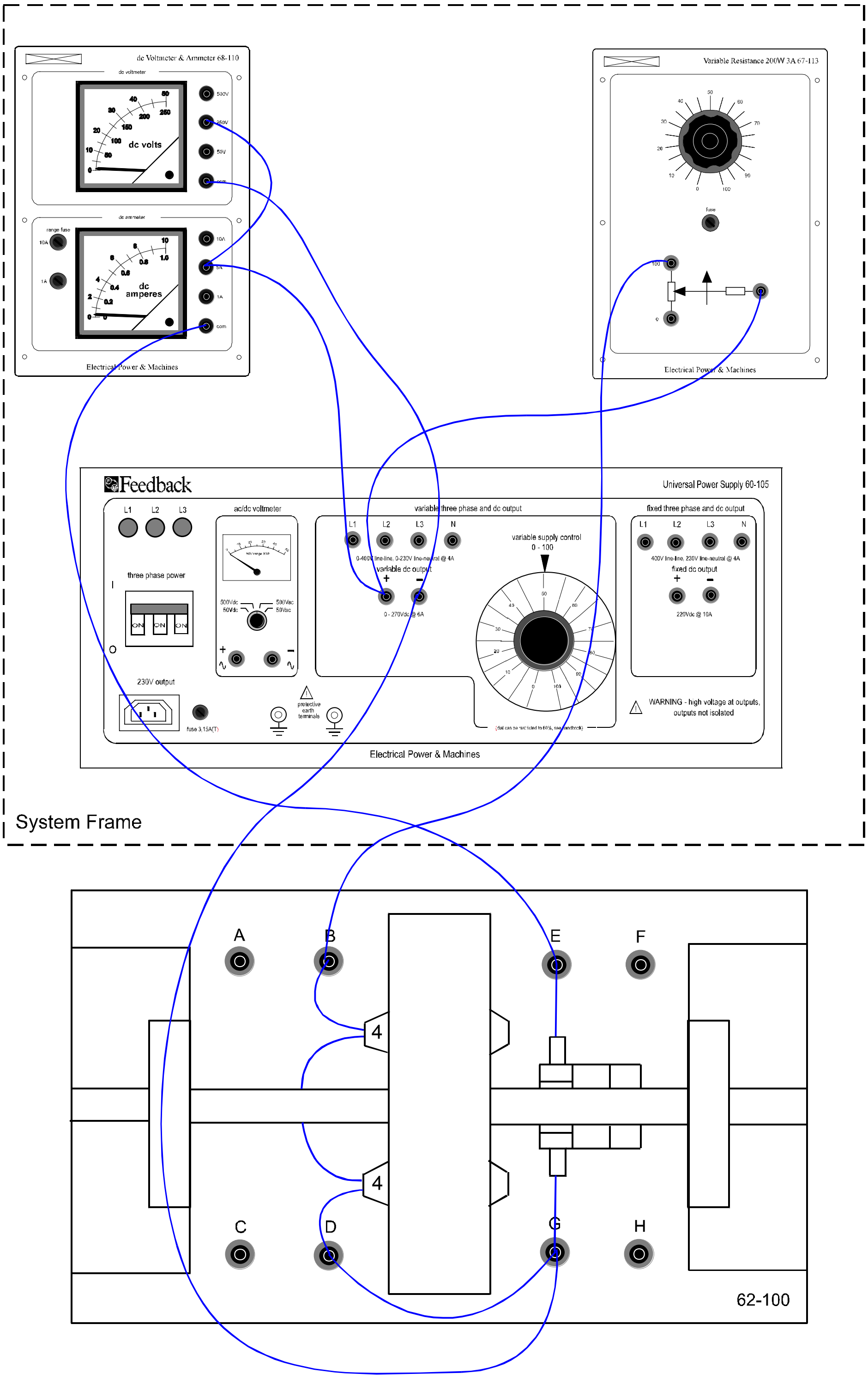


Figure A13-2: Connections for dc Shunt Motor

ASSEMBLY

Assemble the armature and commutator to the shaft as shown in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 1, and fit the shaft into its bearings. Before finally tightening the bearing housing screws in the baseplate, check that the shaft rotates freely and moves axially against the pre-loading washer.

Attach the L4 coils to the field poles, then connect these to the frame ring in the 3 o'clock and 9 o'clock positions.

Insert the brushes into their holders and fasten these to the mounting block positions on each side of the commutator. Check that the brushes move freely in their holders.

Make the circuit shown in Figure A13-3 in accordance with the connections shown in Figure A13-2. Connect the variable resistor of 67-113 as shown.

If a friction (Prony) brake or other loading device is being used, fasten its frame to the baseplate and adjust it to give up zero load initially. See Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 6 for fitting of 67-470 Prony Brake.

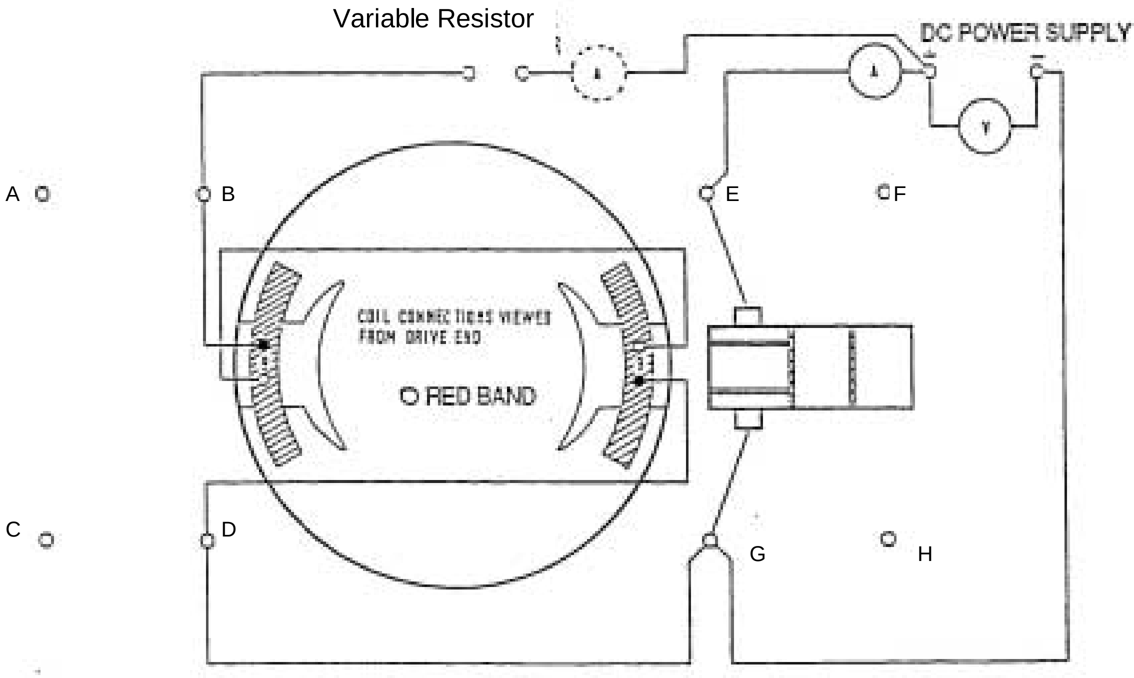


Figure A13-3: dc Shunt Motor Wiring Diagram

PRACTICAL 13.1

Speed Control

The speed of a dc shunt motor may be controlled by adjustment of the voltage applied to the armature or the current in the main field coils. Among the different methods which may be used to make these adjustments are:

- Variable resistances in series with the armature andlor the field windings,
- Separate bridge rectifiers supplying the field and armature windings from an ac source with a variable transformer in the armature circuit,
- Phase control of a diode/thyristor bridge supplying the armature winding from an ac source.

In this assembly, speed adjustments can be made by using a 200Ω, 2.5 A variable resistor located on unit 67-113.

The L4 coils have considerably less resistance than the shunt winding which would be used in a commercial machine operating at a voltage of, say, 110 volts dc. For this reason, when the supply exceeds 12 volts dc it is advisable to connect sufficient series resistance in the field circuit to limit the current.

Motor Unloaded

Switch on the dc power supply and adjust it to give 12 to 15V. With an applied voltage of 15 volts and with about 22Ω in series with the field, the motor will run at approximately 950rev/min on no load.

PRACTICAL 13.2

Motor on Load

With the field resistance set to 22Ω and with zero shaft load initially, switch on the dc power supply and adjust to a voltage within the range 40 to 50 volts. Under these conditions, the motor will run at approximately 1300 rev/min.

Increase shaft loading in steps, (eg, of 0.1 Nm) keeping the supply voltage constant throughout the test. Take readings of shaft speed and armature current at each step and use these to plot the Torque/Armature current and Speed/Armature current curves as in Figure A13-4.

The test may be repeated with a lower value of field resistance, if available, and the characteristic curves compared.

PRACTICAL 13.3

Direction of Rotation

With no shaft load, apply 12 to 15 volts to the motor and note the speed and direction of shaft rotation.

Disconnect the dc supply, reverse the connections to the motor terminals and switch on: the motor will be found to run at the same speed and in the same direction as before.

Disconnect the dc supply, reverse the polarity of the field connections leaving the armature connections unchanged. Switch on and note that the motor speed is approximately as before but that the direction of rotation has been reversed.

PRACTICAL 13.4

Speed Control by Field Variation

With a supply voltage of 40 V, maintained constant, and no shaft load, measure the speed and field current for different values of field resistance (e. 22Ω, 33Ω, 66Ω).

Repeat for a moderate shaft load of about 0.3 Nm.

Plot N against I_f for each of the two load conditions.

DISCUSSION

In Appendix A, the simplified equations for a motor were shown to be:

$$V = K_1 K_3 N I_f + I_a R_a$$

$$T = K_2 K_3 I_f I_a$$

In a shunt motor for a given resistance, I_f is constant so these become:

$$V = K N + I_a R_a$$

$$T = K^1 I_a$$

Thus we can predict that for a fixed V (armature voltage), as the load is increased so will I_a and as I_a increases, N must reduce linearly to keep V constant.

Going back to the first set of equations above, for no load when I_a is small, if I_f is reduced (field weakening) N must increase to keep V constant. But if the load torque is not zero and I_f is reduced, I_a must increase to maintain the torque. Then, since:

$$N = \frac{V - I_a R_a}{K_1 K_3 I_f}$$

N may increase, remain constant or actually decrease as I_f is reduced, according to whether ($V - I_a R_a$) or $K_1 K_3 I_f$ reduces faster.

See 'Matching the Motor to its Load' (Appendix A) for shunt motor applications.

Study your graphs of torque and speed versus armature current (load test) and those of speed versus field current (speed test) to confirm their general agreement with the predictions of the simple theory just given.

Question 13.1

Why does the graph of torque against armature current not pass through the origin?

Calculate the overall efficiency of the motor at various loads as follows:

a) For each selected load torque, note the armature current I_a and speed N from your load test results. Also note I_f for this test (this is the maximum value recorded in the speed test) and V.

b) The total input power is the sum of the power fed to the field and to the armature

Armature power	$= V I_a$
Field power	$= V I_f$
Total	$= V(I_a + I_f)$ watts

c) The output power is:

$\frac{2\pi NT}{60}$ watts when N is in rev/min and T in Newton-metre.

d) Efficiency = $\frac{\text{Output power}}{\text{Input power}} \times 100\%$

Exercise 13.1 ***Note your result for each load torque and then plot efficiency versus torque on linear graph paper.***

One reason for the low efficiency is the large proportion of input power dissipated as heat in the field winding resistance. Practical machines would have relatively much higher field resistance and thus less loss of power, but the 62-100 coils have to serve for other types of machine and are of low resistance for this reason.

Question 13.2 ***Where does the input power go when the mechanical output power is zero?***

Question 13.3 ***What is the maximum mechanical power output in horsepower? (1hp = 746W)***

Notes

Practical 13.2

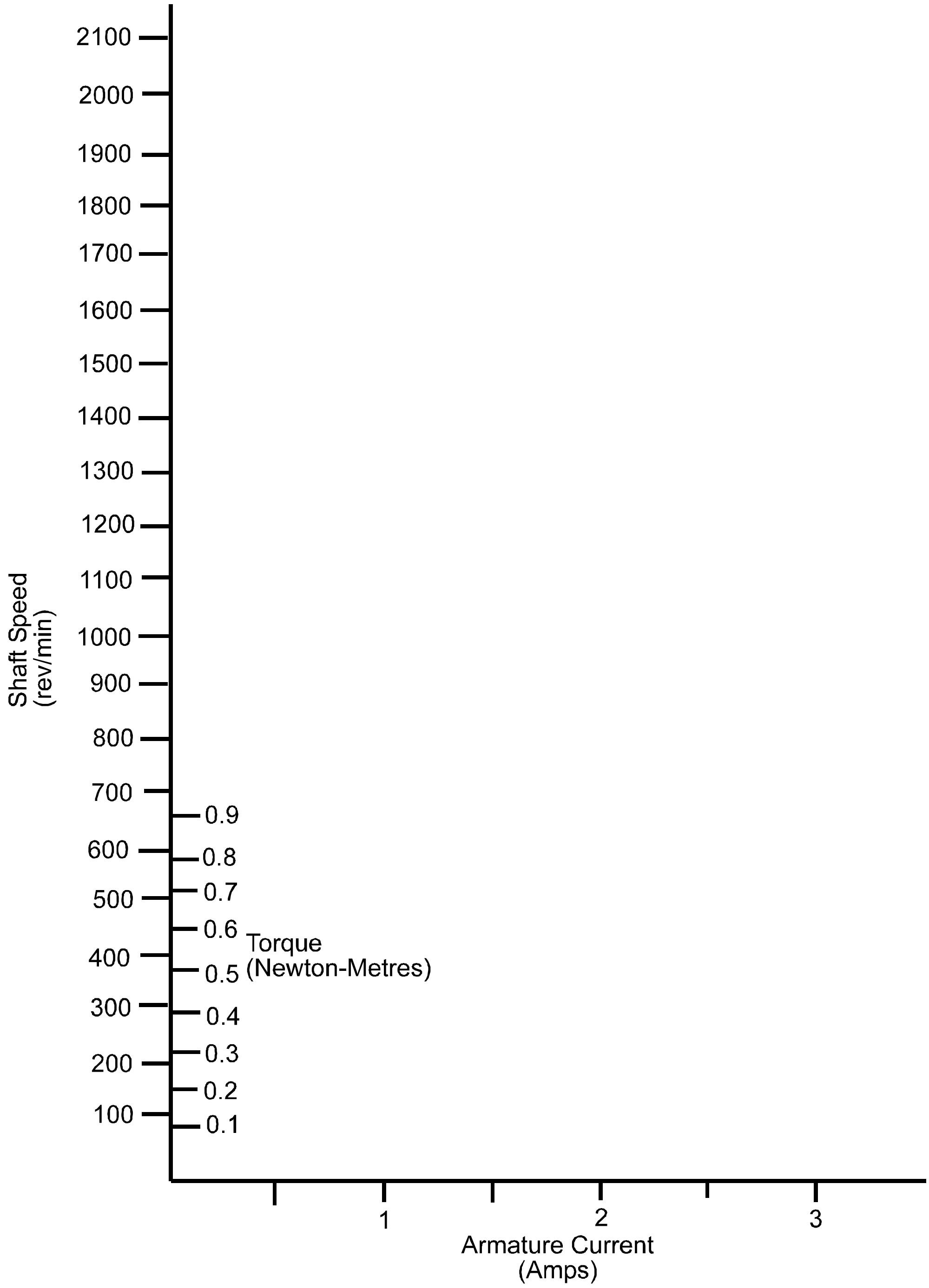


Figure A13-2 Graph Axes for Practical 13.2

Notes

Practical 13.2

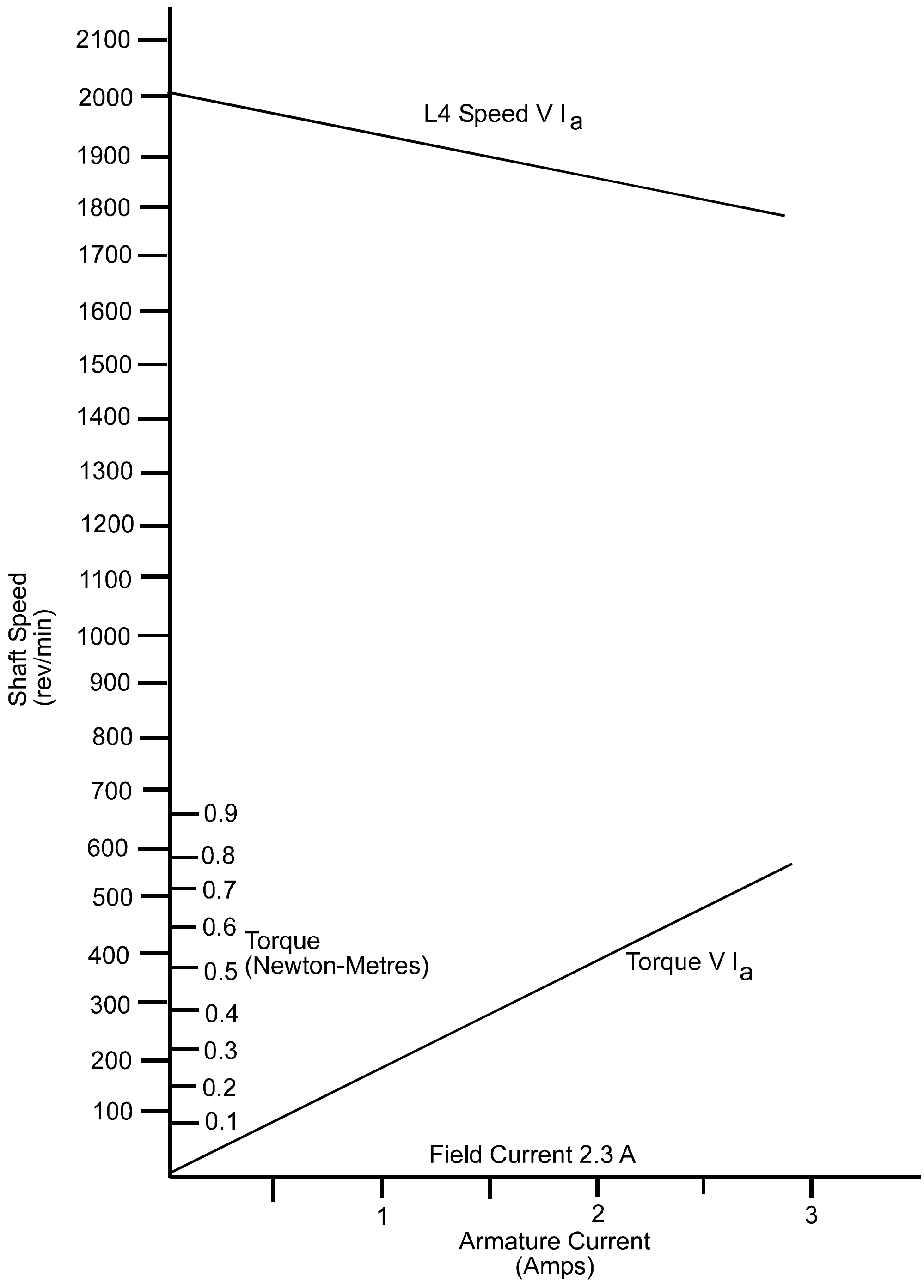


Figure A13-4: Characteristics of dc Shunt Motor

Question 13.1

Since $T = K^1 I_a$ the graph of torque versus armature current should be almost a straight line, but it will not pass through the origin because at zero load some armature current is needed to overcome bearing losses, windage, etc.

Question 13.2

When the output power is zero, the input power goes partly into heating up the field coils by resistive dissipation and partly into the armature to overcome the losses mentioned in the answer to Question 1.

Question 13.3

A typical maximum power output will be about 75W or about one tenth of a horsepower.

For a machine of its physical size, the power output is very low compared to, for instance, the motor in 63-501, which is of similar size but is rated at 1/3 hp. The open construction of 62-100 gives a magnetic circuit of lower efficiency than the normal closed construction of a commercial motor. Also, the four-segment commutator and four-coil rotor winding are not as efficient as the multiple types normally used. Commercial rotors are more compact and of smoother profile too so that less energy is lost in windage.

Assignment 14

dc Shunt Motor with Interpoles

PRACTICAL 14.1

EQUIPMENT REQUIRED

	Qty	Item
62-100 Kit	1	Base Unit
	1	Commutator/Slipring
	2	Brushes and Brushholders
	2	L4 Coils
	2	L1 Coils
	2	L2 Coils
	2	Field Poles
	1	Rotor Hub
	4	Rotor Poles
	2	L8 Coils
	2	Interpoles
General	1	0-70 V, 5 A, dc Supply (eg, Feedback 60-105)
	1 1	0-100 V, dc Voltmeter 0-5 A, dc Ammeter (eg, Feedback 68-110)
	1	Variable Resistor, 0-200 ohms, 2.5 A (eg, Feedback 67-113)
	1	Friction (Prony) Brake or other Dynamometer 0-1 Nm at 1500 rev/min (eg Feedback 67-470)
	1	Optical/Contact Tachometer (eg, Feedback 68-470)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

INTRODUCTION

Interpoles are used in dc machines to improve commutation by providing a flux to compensate for the distortion of the main field which occurs as the motor or generator is loaded. In this motor interpoles have been added to the dc shunt machines of Assignment 13

The polarity of each interpole in a dc motor is opposite to that of the next main pole with respect to direction of rotation.

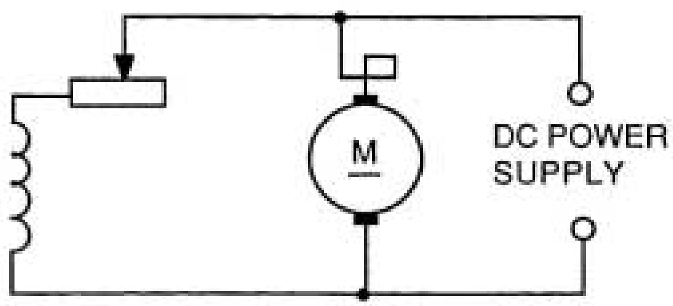


Figure A14-1: dc Shunt Motor with Interpoles – Circuit Diagram

ASSEMBLY

Follow the assembly instructions for Assignment 13, then attach the interpoles with their coils to the frame ring in the 6 o'clock and 12 o'clock positions.

Connect the coils as shown in Figure A14-2. Make the connections shown in Figure A14-3, between the motor and the supply.

Set the commutator so that the slots between segments are in line with the armature pole gaps. This is quite critical for this particular assembly and should be carefully set.

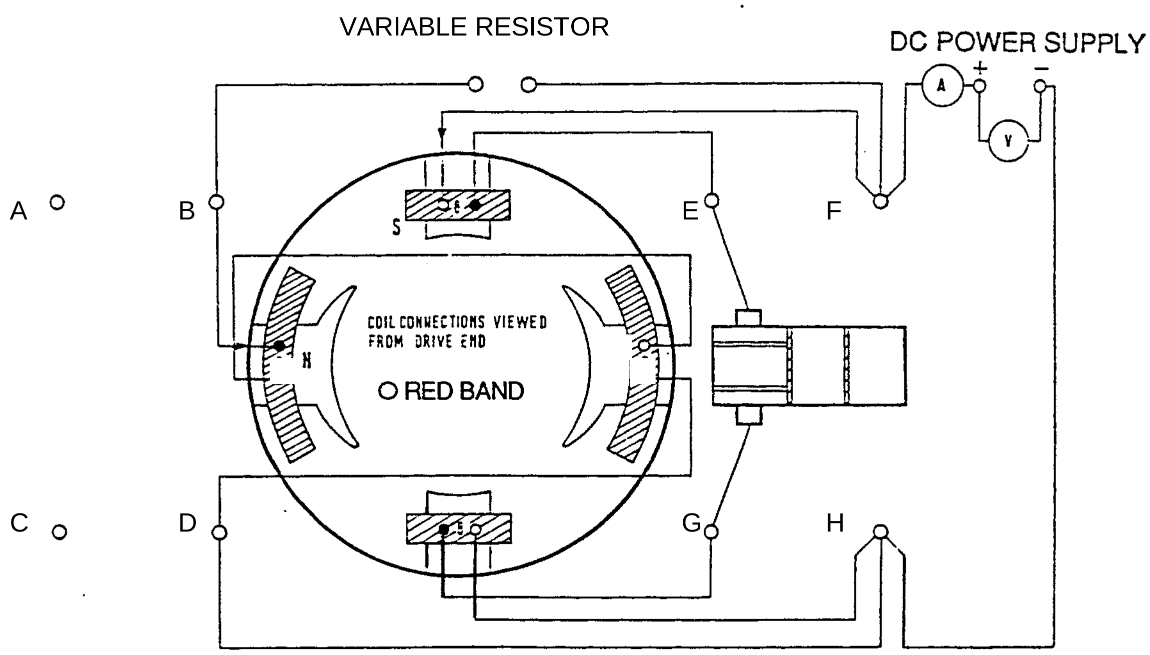


Figure A14-2: dc Shunt Motor with Interpoles Wiring Diagram

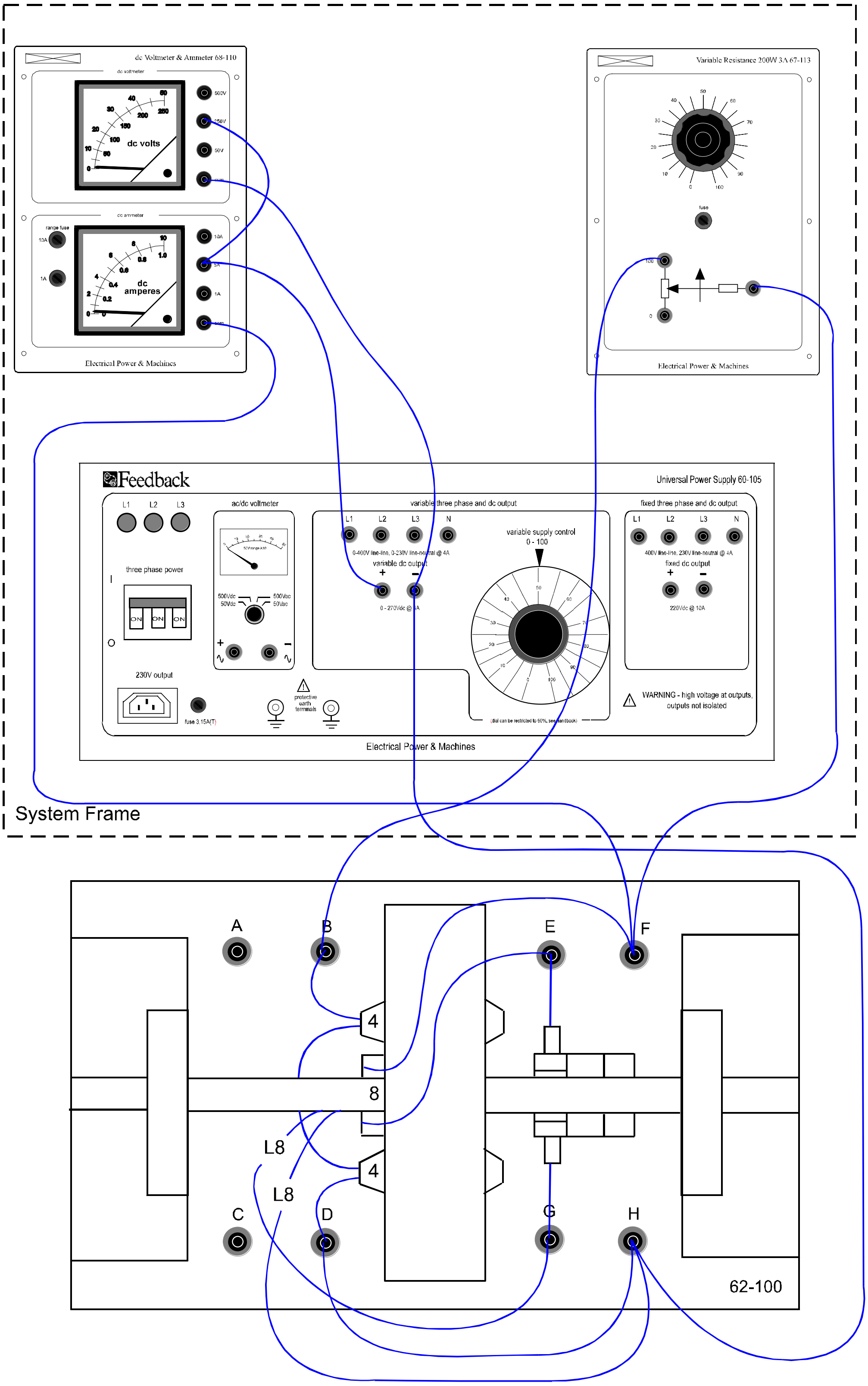


Figure A14-3: Connections for dc motor with Interpoles

PRACTICAL 14.1

Starting up and loading the motor are carried out as with Assignment 13. The improvement in commutation brought about by the use of interpoles is noticeable when the motor is running on load.

To demonstrate the effect of interpoles, connect. shorting links across the terminals of each L8 coil.

Run the motor on load and observe the level of sparking at the brushes.

Remove the links and note the marked reduction in sparking which results.

Now carry out a load test exactly similar to that in Assignment 13 to allow you to find the efficiency at different loads, setting the supply to 50 V and using the ammeter in Figure A14-2 to read the total current I_a and I_f. Note also the speed and increment the torque in 0.1 Nm steps.

Exercise 14.1

As in Assignment 13, calculate the output power for each load as:

$$\frac{2\pi N T}{60}$$

and the input power as $V(I_a + I_f)$ watts and hence find the efficiency as:

$$\frac{\text{Power out}}{\text{Power in}}$$

Plot efficiency versus load, preferably on the same sheet as used in Assignment 13.

Question 14.1

What do you notice about the efficiency of the motor with interpoles as compared with that without interpoles? Can you explain the difference qualitatively?

Question 14.2

Study the wiring diagram (Figure A14-2) and note the directions of rotation and current flow in the main and interpole windings. Are the interpoles following the main poles in the direction of rotation of the same or opposite polarity?

DISCUSSION

The distortion of the stator field mentioned earlier is caused by the magnetic field set up by the armature current and is called armature reaction'. This is detailed in Appendix A of this manual under the heading of Commutation and the following notes are supplementary to those, leading to the use of Interpoles (or Commutating poles) to reduce the effect. Figure A14-4 illustrates armature reaction in a motor.

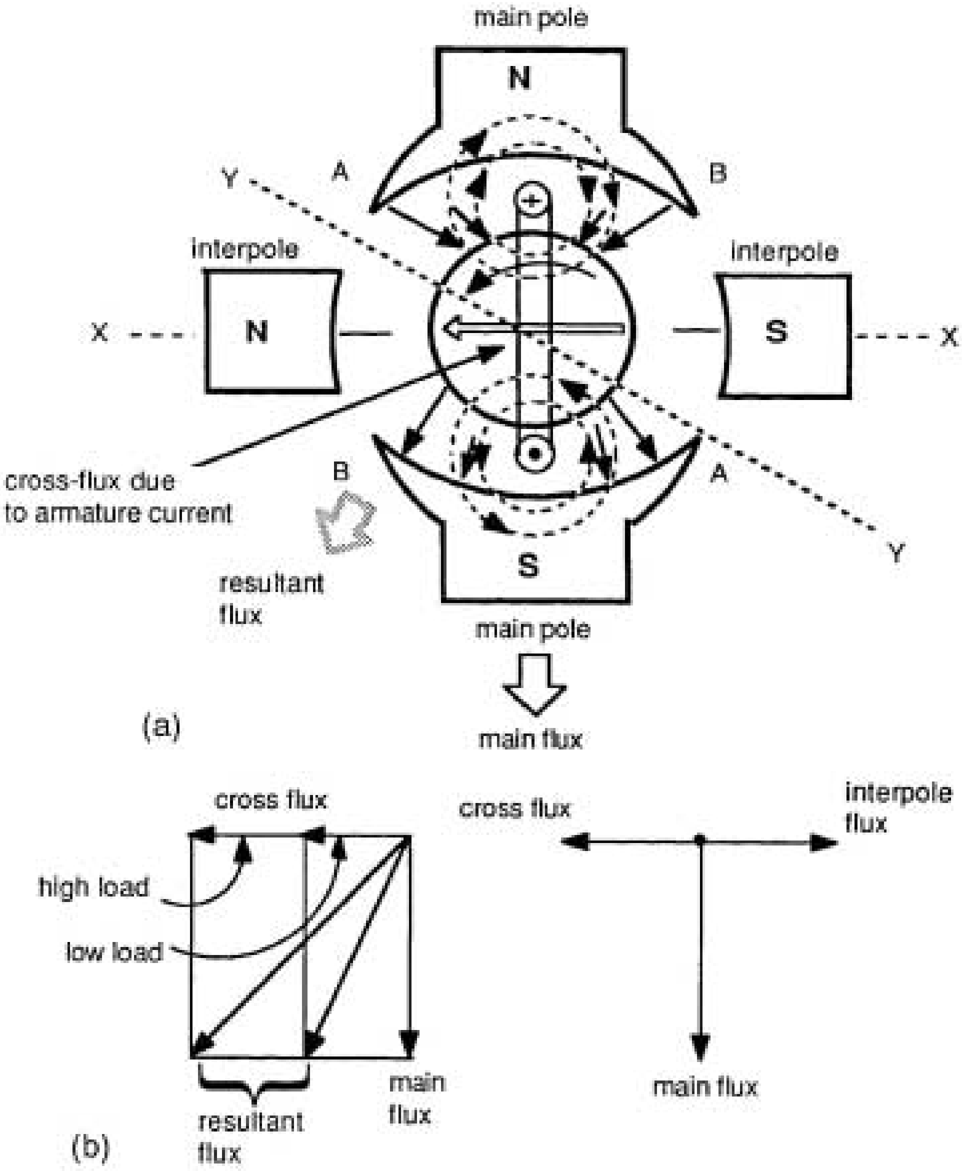


Figure A14-4

With the direction of current shown in the armature coil the motion is as indicated; check this by reference to Appendix A. The armature current sets up fields illustrated by the circular paths and these can be seen to have the effect of weakening the main field in the region of A and reinforcing in the region of B. Due to the effects of saturation at pole tips A and B, the reduction of field strength at A is greater than the increase at B so that there is a net reduction of total flux. The field due to the armature acts at right angles to the main field as shown in Figure A14-4 (a) and marked cross-flux.

Without the secondary field the position at which the armature coil has a zero of flux-cutting is represented by axis XX but the distortion of the field caused by the armature currents shifts this backwards to an axis such as YY. The exact position of this axis depends, amongst other things, upon how much armature current flows and hence upon how much load is applied to the motor. This is clearly shown by the vector diagrams of flux in Figure A14-4 (b)

Ideally, commutation should occur at the point where the instantaneous armature current is zero. This corresponds roughly (but not exactly because of armature inductance) to the point at which the generated back-emf is zero; that is, at the magnetic neutral plane (MNP). One way of arranging this is to rotate the brushes against the direction of armature rotation until they are in the MNP. This can be done if rotating brushgear RB185 is available -see Additional Assignment 50. However, because the MNP position varies with armature current it is not possible to find a single brush angle to give good commutation for all load conditions.

The alternative method, illustrated by this assignment, is to pass the armature current through interpole coils in such a sense as to generate pole as indicated in Figure A14-4 (a). These set up a field opposing the cross-flux, see Figure A14-4 (b), thus restoring the MNP to axis XX and restoring the total flux to its original value. Since the strength of the interpoles increases with armature current, a degree of automatic compensation for load changes is achieved although this will not be perfect.

Brush arcing is undesirable not only because of energy loss, but also because it causes destructive erosion of the copper commutator and carbon brushes.

Notes

Question 14.1	You should find that your graph of efficiency versus load is of similar shape to that obtained without interpoles but rises to greater values of efficiency at the higher load values. The difference will not be great but is partly due to the reduction in the loss of energy represented by arcing at the brushes and partly to the restoration of total flux to its no-load value effected by the interpoles.
Question 14.2	You should find that a main pole and the next interpole in the direction of rotation are similar as illustrated in Figure A14-4.

Notes

DISSECTIBLE

MACHINES SYSTEM

Assignment 15

dc Shunt Generator

PRACTICAL	15.1	Generator Unloaded
	15.2	Generator Loaded

EQUIPMENT REQUIRED

	Qty	Item
62-100 Kit	1	Base Unit
	1	Commutator/Slipring
	2	Brushes and Brushholders
	2	L4 Coils
	2	L1 Coils
	2	L2 Coils
	2	Field Poles
	1	Rotor Hub
	4	Rotor Poles
	1	Flexible Coupling
General	1	Variable Speed Motor: 1/3 hp, 1200 rev/min, (eg, Feedback 63-501)
	1	0-100 V, dc Voltmeter (eg, Feedback 68-110)
	1 1	0–5 A ac Ammeter 0 – 300 V ac Voltmeter (eg, Feedback 68-117)
	1	Variable Resistor, 0-200 ohms, 2.5 A (eg, Feedback 67-113)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

The shunt generator is self-excited and therefore relies on some residual flux being present in the magnetic circuit to initiate voltage generation. In a new machine the field may have to be momentarily energised from an external dc source.

Over its working load range the curve of terminal voltage against load current will have a failing characteristic resembling that of a separately excited generator but more pronounced, since the drop in terminal voltage is accentuated by a progressive reduction in shunt field excitation. Eventually further reduction of load resistance causes a decrease in output current.

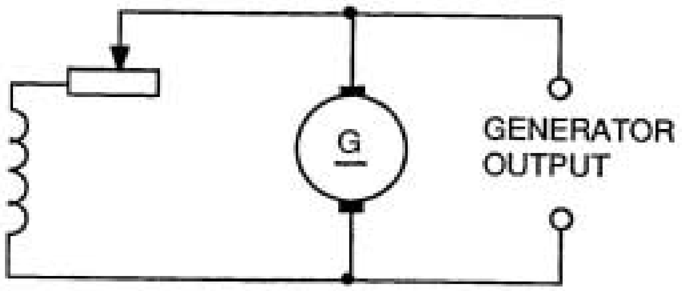


Figure A15-1: dc Shunt Generator Circuit Diagram

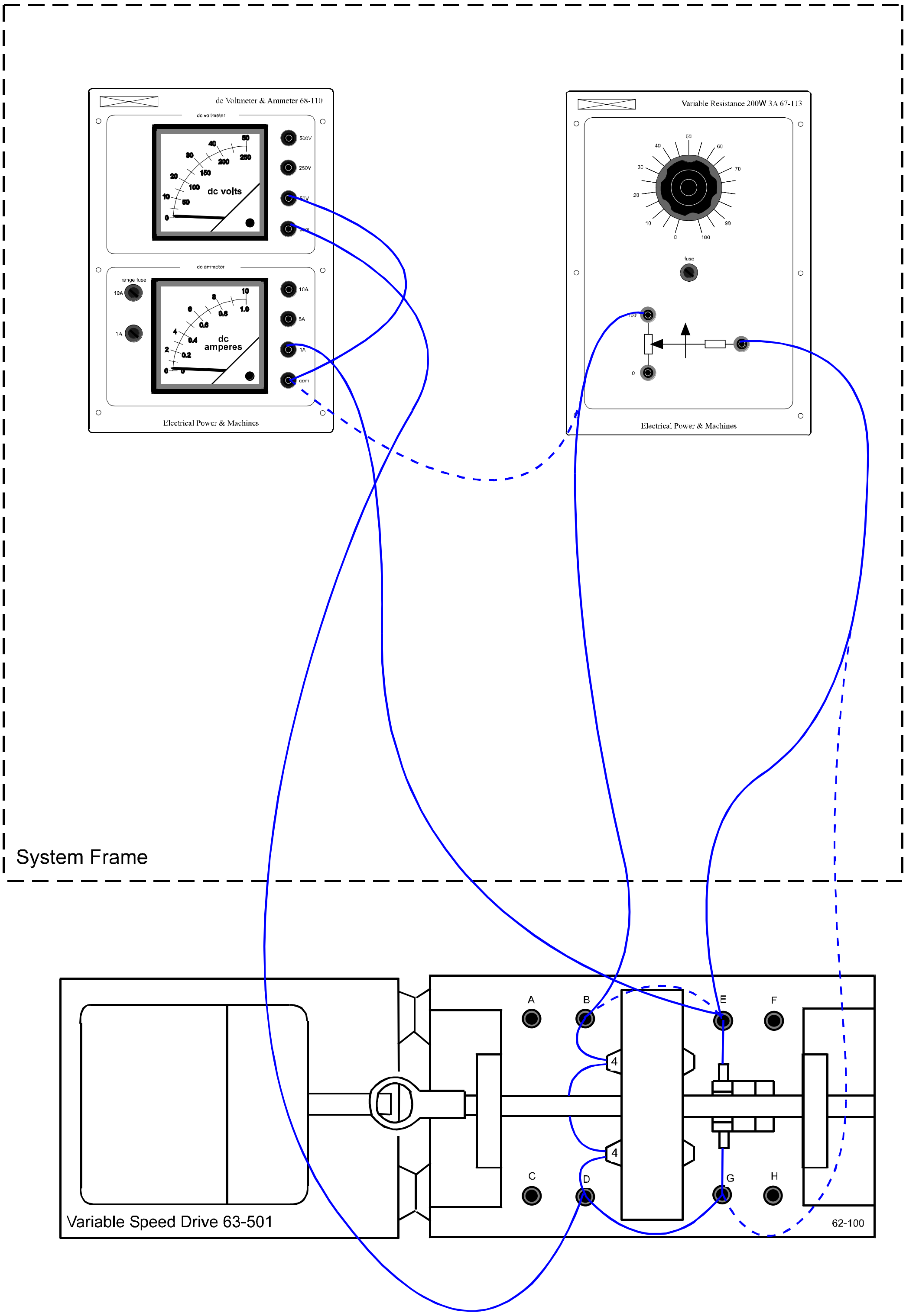


Figure A15-2: Connections for dc Shunt Generator

ASSEMBLY

Fix the armature and commutator to the shaft as shown in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 1, and fit the shaft into its bearings. Before finally tightening the screws holding the bearing housing to the base, check that the shaft rotates freely and moves axially against the preloading washer.

Fit the L4 coils to the field poles then fix the poles to the frame ring at the 3 o'clock and 9 o'clock positions.

Fit the brushes into their holders, attach the holders to the housings on each side of the commutator and check that the brushes move freely in their holders.

Make the circuit shown in Figure A15-3 in accordance with the connections shown in Figure A15-2 and set the external field resistance to its maximum value.

See Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 7 for details of coupling the Variable Speed Drive 63-501 to the 62-100 base.

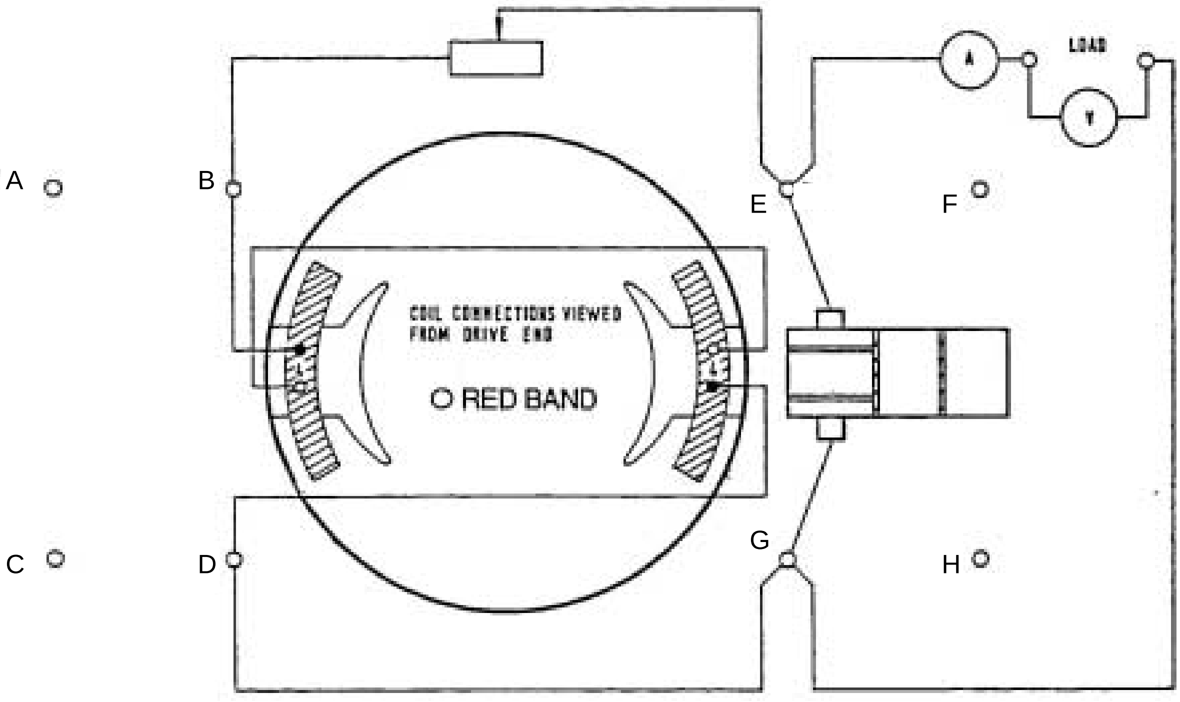


Figure A15-3: dc Shunt Generator Wiring Diagram

PRACTICAL 15.1

Generator Unloaded

With the generator field disconnected, start the drive motor and set it to run at approximately 1200 rev/min. A voltmeter connected across the output terminals should give a small indication due to the residual magnetism of the magnetic circuit. (in a new machine the residual flux may be negligibly small - in this case the field circuit should be momentarily 'excited' by connecting 12 V dc across the field for about 30 seconds).

Connect the generator field and gradually decrease the field resistance. The voltmeter reading will increase if the coils are connected so that the excitation flux assist the residual flux. As the field resistance is decreased, a critical value is reached at which a rapid increase in generated volts occurs for only a small change in resistance. With the field resistance set to zero, the voltage generated will be approximately 40 V on no-load.

PRACTICAL 15.2

Generator Load

Set the resistor to its maximum resistance.

Transfer the leads from the variable resistor to terminals B and E in Figure A15-2, to the positions shown by the broken lines.

Connect terminal B to E.

Bring the drive motor speed to 1200 rev/min and maintain it at this level throughout the test.

Adjust the load resistance in steps from maximum to minimum resistance, taking readings of terminal voltage and load current at each step.

Plot terminal voltage against load current, as in Figure A15-4, and repeat the test at another value of shaft speed.

DISCUSSION

The unloaded terminal voltage of a shunt generator is somewhat indeterminate because the field strength and terminal voltage are mutually dependent. Thus if a small reduction occurs in the reactance of the field magnetic circuit, for example, an increased field strength results which in turn causes an increase in terminal voltage. This further increases the field strength and so on.

A limit to the cumulative effect of small changes of this sort is set by the onset of saturation of the magnetic circuit but nevertheless the terminal voltage for a given speed may vary widely from machine to machine, as also may the maximum load current capability. Thus you should not expect your graph to agree very closely with the typical results of Figure A15-4.

The Shunt Generator's rapidly failing output characteristic make it unsuitable for general purpose dc generation although special applications do exist.

Question 15.1

When you were taking readings for your graph of voltage against load current you probably noticed that as you increased the load current the generator speed increased slightly and had to be reduced by adjusting the drive motor control in order to maintain a constant speed. Can you suggest why this should happen?

If you cannot answer this question, or even if you can, carry out the following exercise, which will explain or confirm the reason for the speed increase.

Exercise 15.1

For one generator speed only, calculate the field current for each reading of terminal voltage from the expression:

$$I = \frac{V_t}{R_f}$$

where R_f = total field resistance = 32 ohms (two L4 coils in series). Then, for each reading, find the total armature current $I + I_f = I_t$ and hence the total output power $I_t V_t$ watts.

Question 15.2

How does the output power vary as the load current increases?

Notes

Practical 15.2

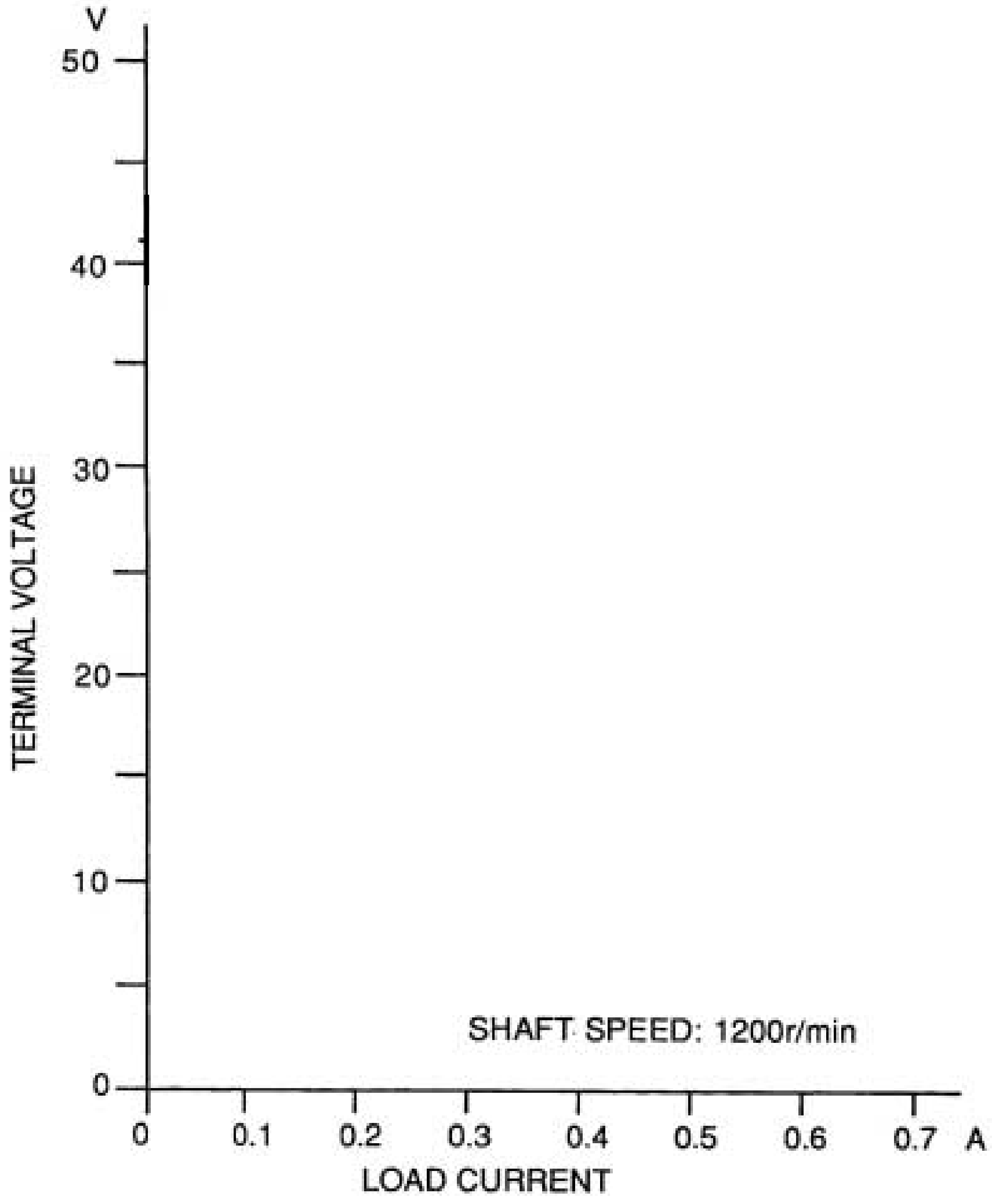


Figure A15-4 Graph Axes

Notes

Practical 15.2

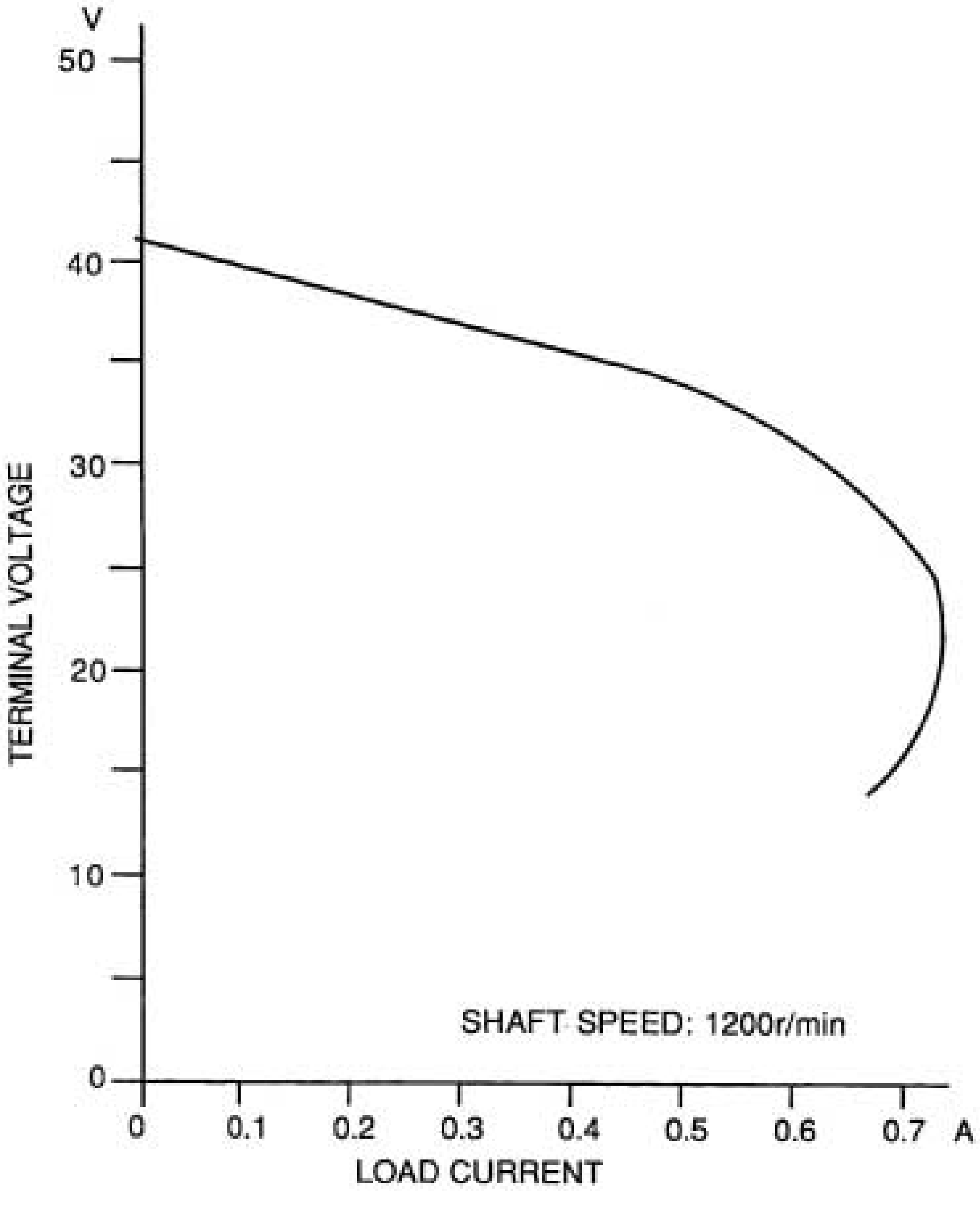


Figure A15-2: Characteristic of dc Shunt Generator

Question 15.1 & 15.2

As load is applied to generator the terminal voltage fails at a greater rate than the total armature current (including field current) increases, so that the output power reduces. This places a reducing mechanical load upon the drive motor, whose speed therefore tends to increase.

DISSECTIBLE MACHINES SYSTEM

Assignment 16

dc Shunt Generator with Interpoles

PRACTICAL	16.1	No Load Test
	16.2	Comparison with Assignment 15

EQUIPMENT REQUIRED	**Qty**	**Item**
62-100 Kit	1	Base Unit
	1	Commutator/Slipring
	2	Brushes and Brushholders
	2	L4 Coils
	2	L1 Coils
	2	L2 Coils
	2	Field Poles
	1	Rotor Hub
	4	Rotor Poles
	2	L8 Coils
	2	Interpoles
	1	Flexible Coupling
General	1	Variable Speed Motor: 1/3 hp, 1200 rev/min, (eg, Feedback 63-501)
	1	0-100 V, dc Voltmeter (eg, Feedback 68-110)
	1	0–5 A ac Ammeter
	1	0 – 300 V ac Voltmeter (eg, Feedback 68-117)
	1	Variable Resistor, 0-200 ohms, 2.5 A (eg, Feedback 67-113)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

Interpoles are used in the shunt generator to improve commutation and, as with any dc generator, the polarity of each interpole is the same as that of the next main pole with respect to direction of rotation.

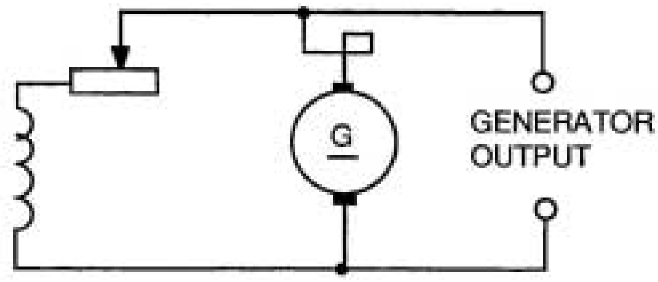


Figure A16-1: dc Shunt Generator with Interpoles Circuit Diagram

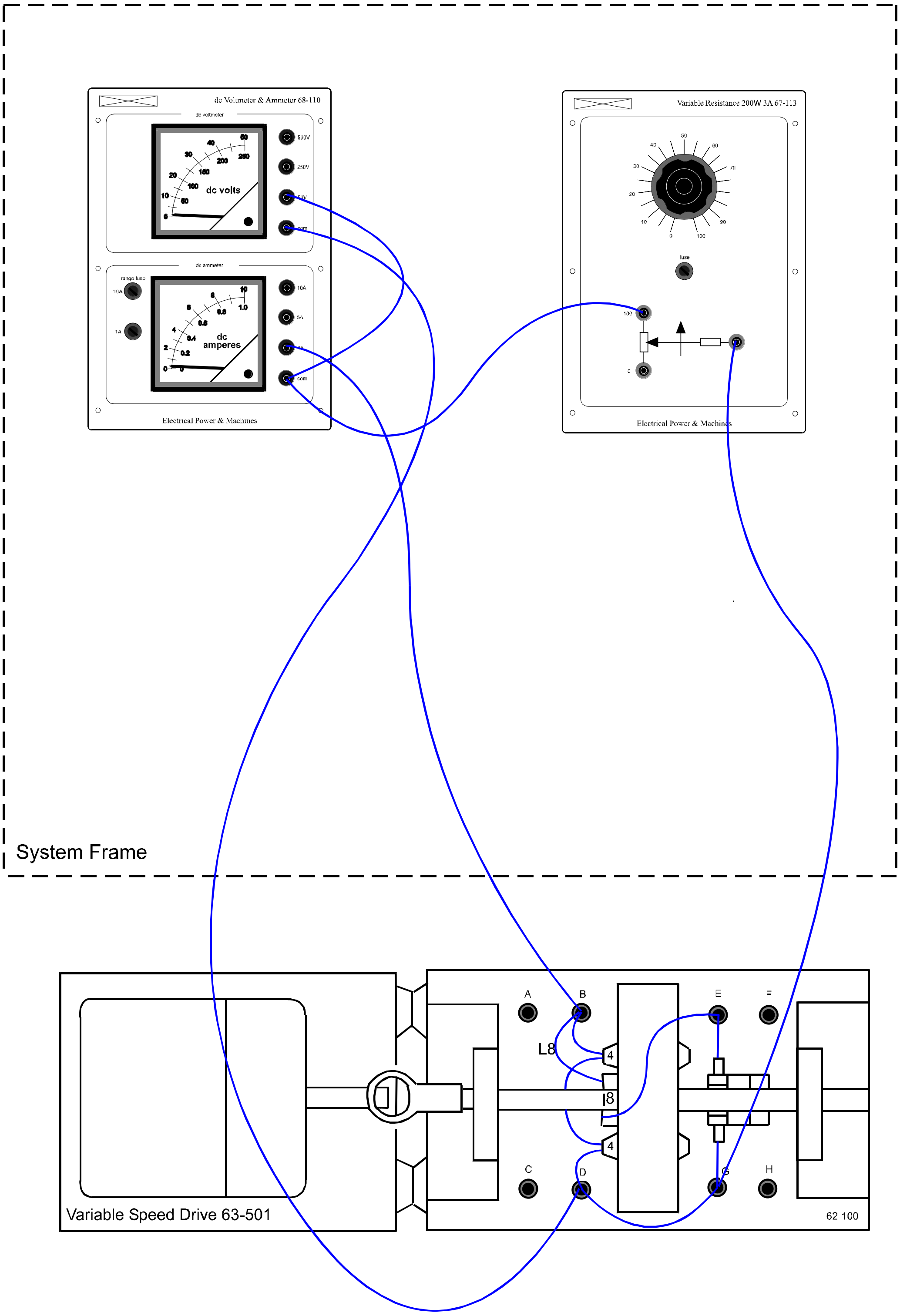


Figure A16-2: Connections for dc Shunt Generator with Interpoles

ASSEMBLY

Follow the instructions for Assignment15, then attach interpoles with their coils to the frame ring in the 6 o'clock and 12 o'clock positions. Make the circuit shown in Figure A16-3 in accordance with the connections shown in Figure A16-2 and set the commutator so that the slots between segments are in line with armature pole gaps. This is quite critical for this assembly and should be carefully set.

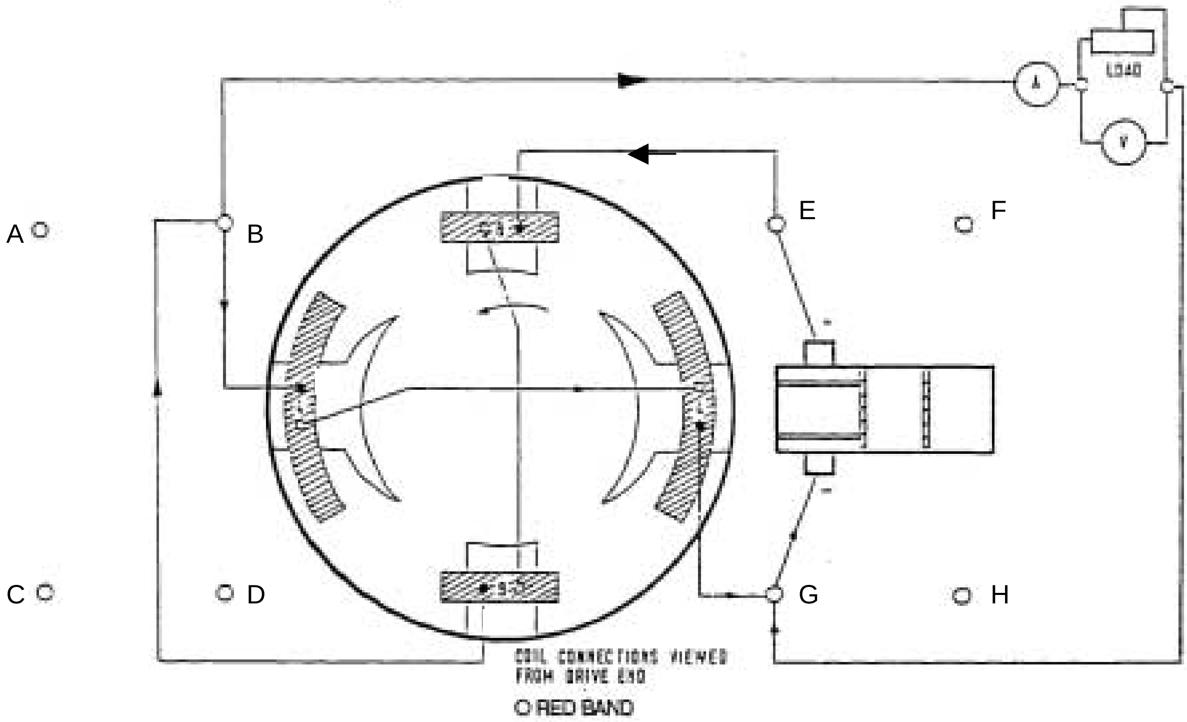


Figure A16-3: dc Shunt Generator with Interpoles Wiring Diagram

PRACTICAL 16.1

The improvement in commutation brought about by the use of interpoles is apparent when the generator is on load. To demonstrate their effect, connect shorting links across the terminals of each L8 coil and drive the generator at sufficient speed to give 30 volts across a 33Q load.

With the interpoles shorted out sparking at the brushes will be quite heavy, but when the shorting links are removed and the drive speed re-adjusted to give the same output load, a marked reduction in sparking level will be observed.

No Load Test

With no applied load, raise the shaft speed in steps from 0 to 1500 rev/min. At around 700 rev/min, a sudden rise in voltage should occur. Take readings of terminal voltage and shaft speed at each step and plot the voltage/speed curve as in Figure A16-4.

PRACTICAL 16.2

Comparison with Assignment 16

Replace the shorting link across the interpoles and set the speed to 1200 rev/min.

Adjust the load resistor to give a load current of about 0.3A, adjusting the speed if necessary to maintain 1200 rev/min.

Record terminal voltage and load current.

Remove the shorting link, reset speed to 1200 rev/min and record new terminal voltage and load current.

DISCUSSION

First refer back to the Discussion of Assignment 14, where the action of interpoles was briefly explained as applied to a motor and was illustrated by Figure A14-3 of that assembly.

For a given field polarity and direction of armature rotation, the armature current in a generator is opposite in direction to that in a motor so the armature reaction effect is also reversed. Thus the magnetic neutral plane is shifted with the direction of rotation instead of against it.

In turn this means that the interpole following the main pole in the direction of rotation must be of opposite polarity instead of similar as shown in Figure14-3 of Assignment 14.

As before the variation of interpole field strength with armature current gives a degree of automatic compensation for the variation in angle of shift of the MNP.

Question 16.1

Study the wiring diagram in Figure A16-3 and mark on it the directions of rotation and of current flow in the main and interpole windings. Are the polarities of a main pole and its adjacent interpole in the direction of rotation opposite or equal?

Exercise 16.1

Take the results of your comparison test with and without interpoles and for each case calculate the field current as:

$$I_f = \frac{V_t}{R_f}$$

total field resistance = 32 ohms (two L4 in series).

Then find the total power output $V_t\,(I + I_f)$ for each case.

Question 16.2

For a given speed is the power output greater or less with interpoles in use? How do you account for any difference?

Notes

Practical 16.1

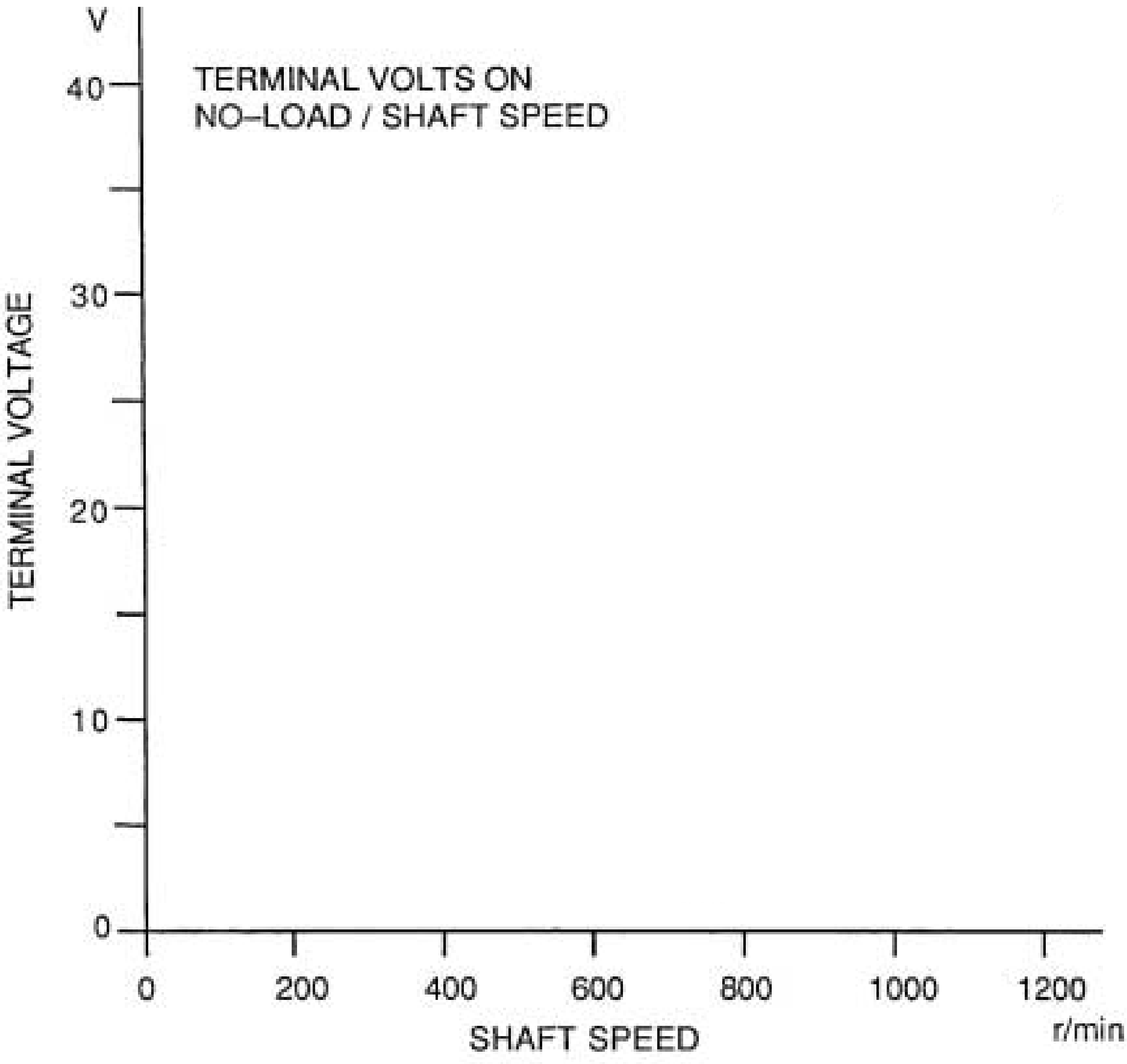


Figure A16-4 Graph Axes

Notes

Practical 16.1

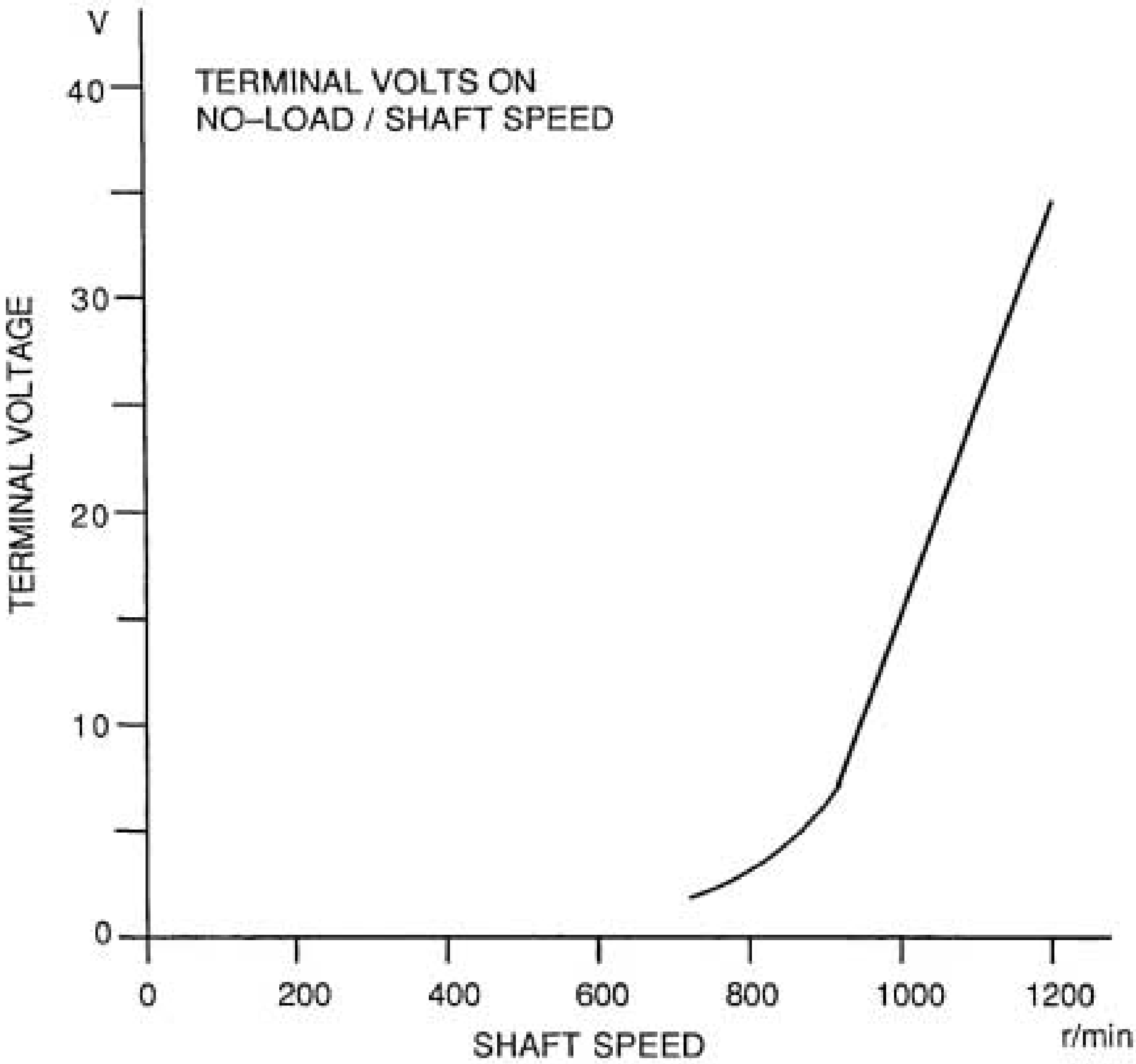


Figure A16-4: Characteristic of dc Shunt Generator

Question 16.1	The polarities should be opposite, that is the reverse of those shown in Figure 14-3 (b) of Assignment 14.
Question 16.2	The power output with interpoles is typically about 30% greater than without. This is partly due to the saving of arcing energy and partly to the restoration of total flux to its no-load value brought about by the interpole field. (see Assignment 14 Discussion for explanation of flux drop due to armature reaction).

DISSECTIBLE

MACHINES SYSTEM

Assignment 17

dc Separately Excited Generator

PRACTICAL	17.1	Open Circuit Test
	17.2	Generator On Load

EQUIPMENT REQUIRED	**Qty**	**Item**
62-100 Kit	1	Base Unit
	1	Commutator/Slipring
	2	L1 Coils
	2	L2 Coils
	2	L9 Coils
	2	Field Poles
	1	Rotor Hub
	4	Rotor Poles
	2	Brushholders with Brushes
	1	Flexible Coupling
General	1	Variable Speed Motor: 1/3 hp, 1000 rev/min, (eg, Feedback 63-501)
	1	0-20 V, 5 A dc Power Supply (eg, Feedback 60-105)
	1 1	0-50 V, dc Voltmeter 0–5 A dc Ammeter (eg, Feedback 68-110)
	1	5-0-5 A Centre-Zero dc Ammeter (eg, Feedback 68-113)
	1	Variable Resistor, 0-200 ohms, 2.5 A (eg, Feedback 67-113)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

In this generator, the field coils are not connected in series or parallel with the armature, as in self-excited machines, but are taken to an independent dc source. Adjustment of field current provides sensitive control of output power making the separately excited generator particularly suitable for automatic control systems.

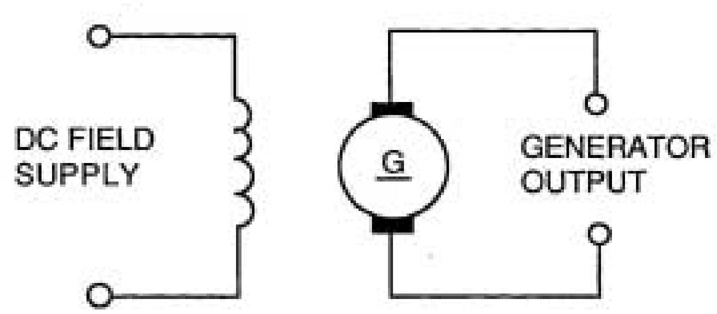


Figure A17-1: dc Separately Excited Generator Circuit Diagram

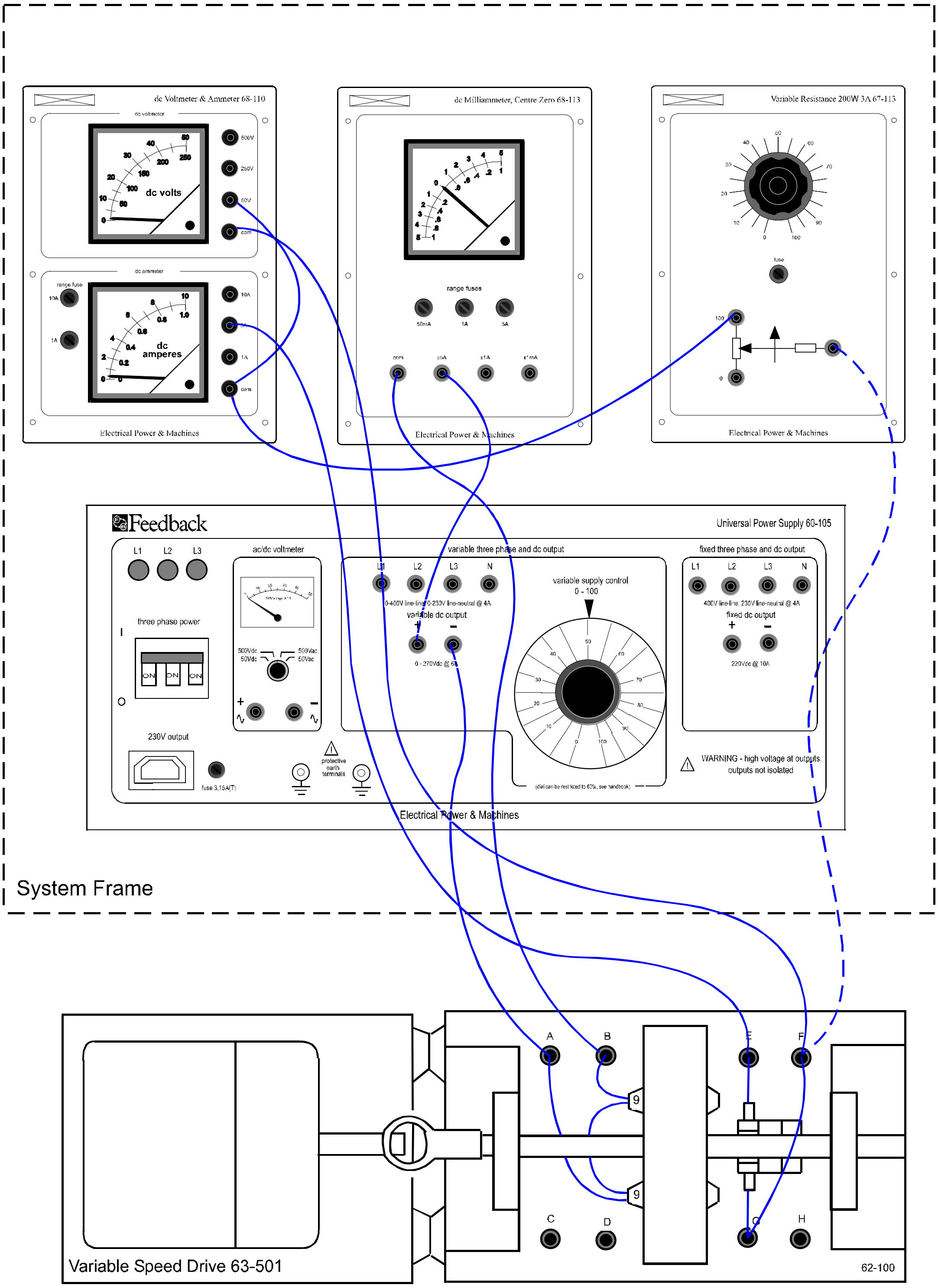


Figure A17-2: Connections for dc Separately Excited Generator

ASSEMBLY

Fit the armature and commutator to the shaft as shown in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 1 positioning the commutator so that the slots between the segments are in line with the armature pole gaps. Fit the shaft into its bearings but before finally tightening the bearing housing screws, check that the shaft rotates freely and can move axially against the pre-loading washer.

Fit the L9 coils and the field poles and fix the poles to the frame ring at the 3 o'clock and 9 o'clock positions.

Fit the brushes into their holders, attach them to the housing on either side of the commutator and check that the brushes move freely in their holders.

Make the circuit shown in Figure A17-3 in accordance with the connections shown in Figure A17-2 but do not make the broken line connection at this stage.

Attach the drive motor baseplate to that of the base unit, align the two shafts and connect them by a flexible coupling as explained in the Utility Manual, Sheet 62-100, Chapter 3, Basic Instruction 7.

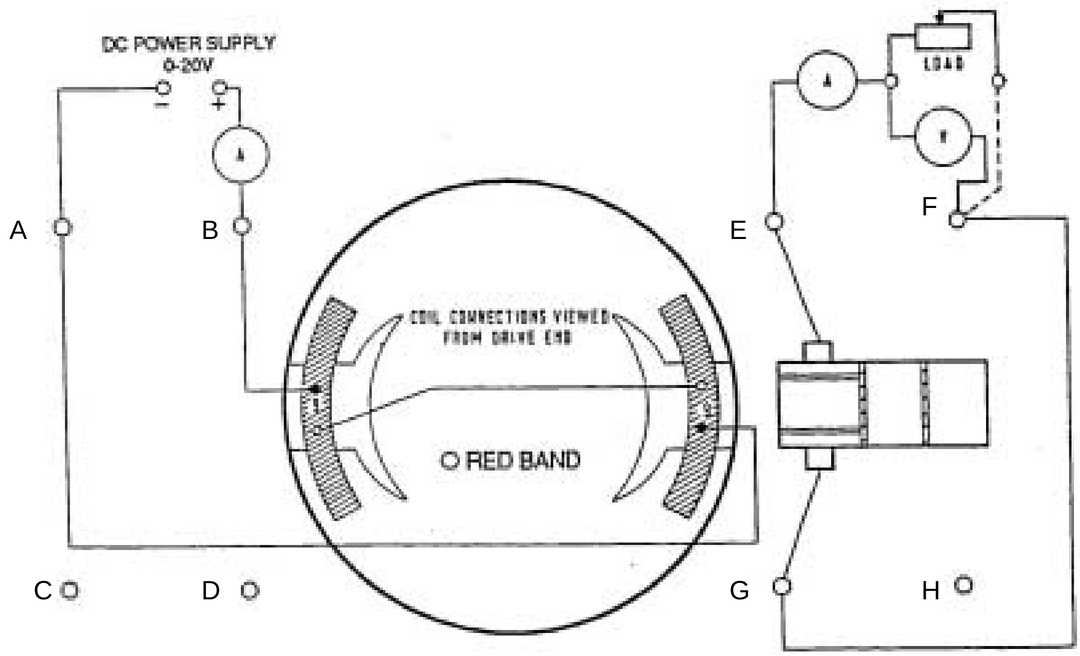


Figure A17-3: dc Separately Excited Generator Wiring Diagram

PRACTICAL 17.1

Open Circuit Test

With the field power supply switched off, bring the drive motor speed up to 1000 rev/min and read the small output voltage generated by residual magnetism in the field circuit.

Switch on the field power supply and increase the current in steps from zero up to 3A, taking readings of field current and terminal voltage at each step while maintaining the shaft speed constant at 1000r/min. The results when plotted should give a graph similar to that of Figure A17-4.

PRACTICAL 17.2

Generator On Load

In this test the speed is maintained constant at 1000 rev/min and the field current at 1.5 amp.

Make the connection shown as a broken line in Figure A17-2 and A17-3.

Vary the value of the load resistor in steps from 100Ω down to approximately 15Ω, taking readings of load current and terminal voltage at each step. Repeat at a field current of 2.5 amp and plot graphs of terminal voltage against load current as in Figure A17-5.

DISCUSSION

Because the field of a separately excited generator is independent, apart from the effects of armature reaction, of the terminal voltage and load current; the rapidly falling characteristic of the shunt machine is replaced by a slowly falling one in which the current steadily increases and at no stage decreases as the load resistance is reduced. It is thus more practical as a general-purpose generator but has the disadvantage of needing a separate field supply. See the Discussion of Assignments14 and 16 for an explanation of the effects of armature reaction in a generator.

Question 17.1

Why does the terminal voltage on no-load show a steady fall in its rate of increase as the field current is increased?

Practical 17.1

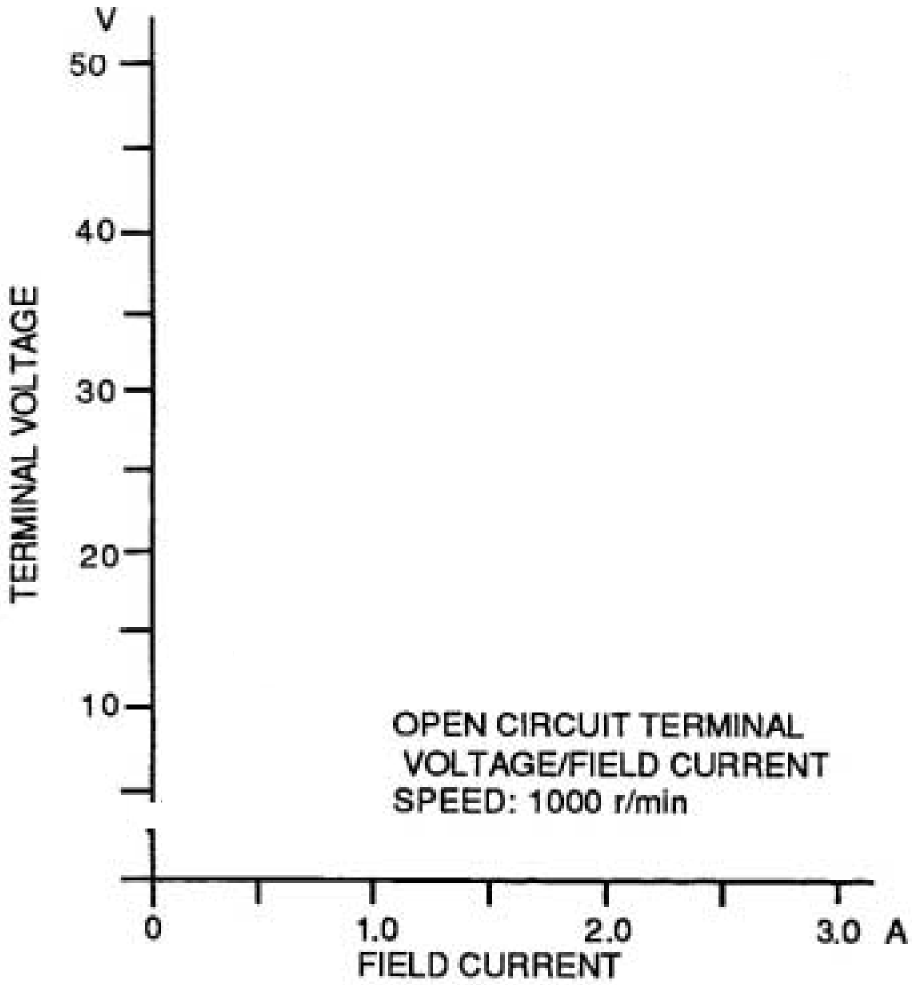


Figure A17-4 Graph Axes

Practical 17.2

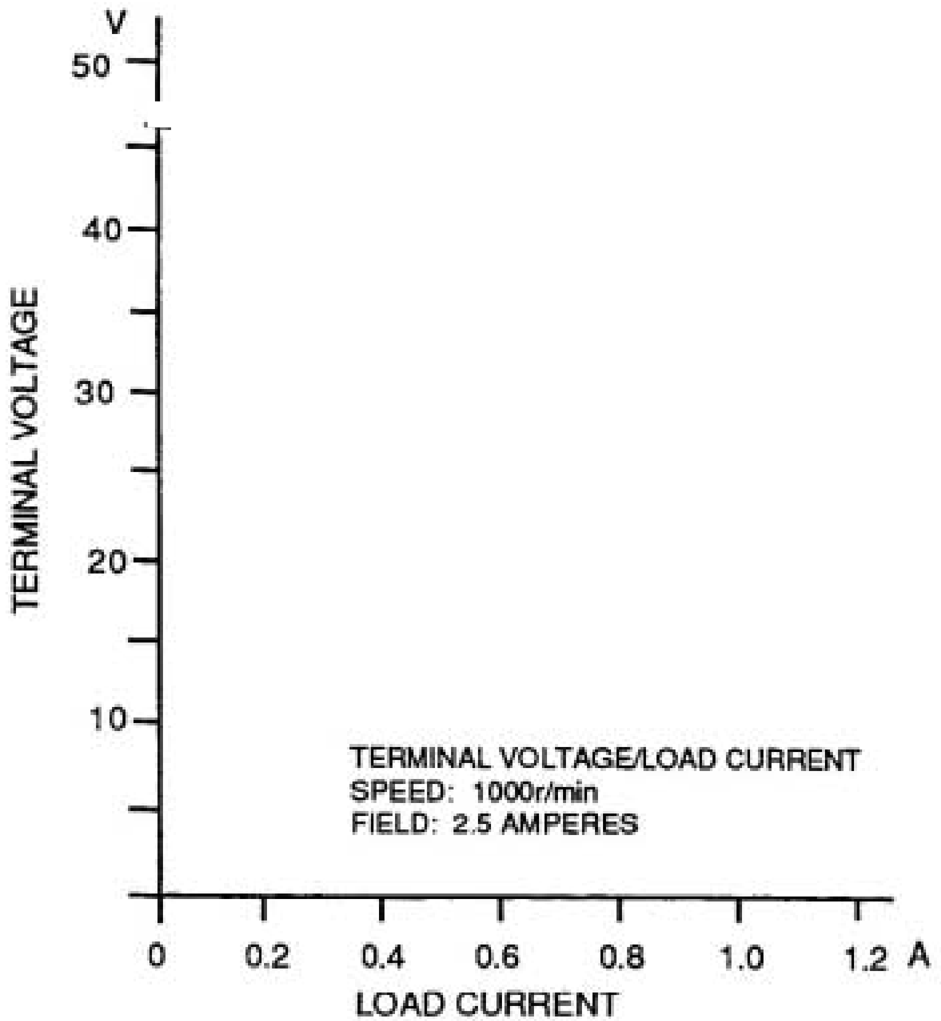


Figure A17-5 Graph Axes

Practical 17.1

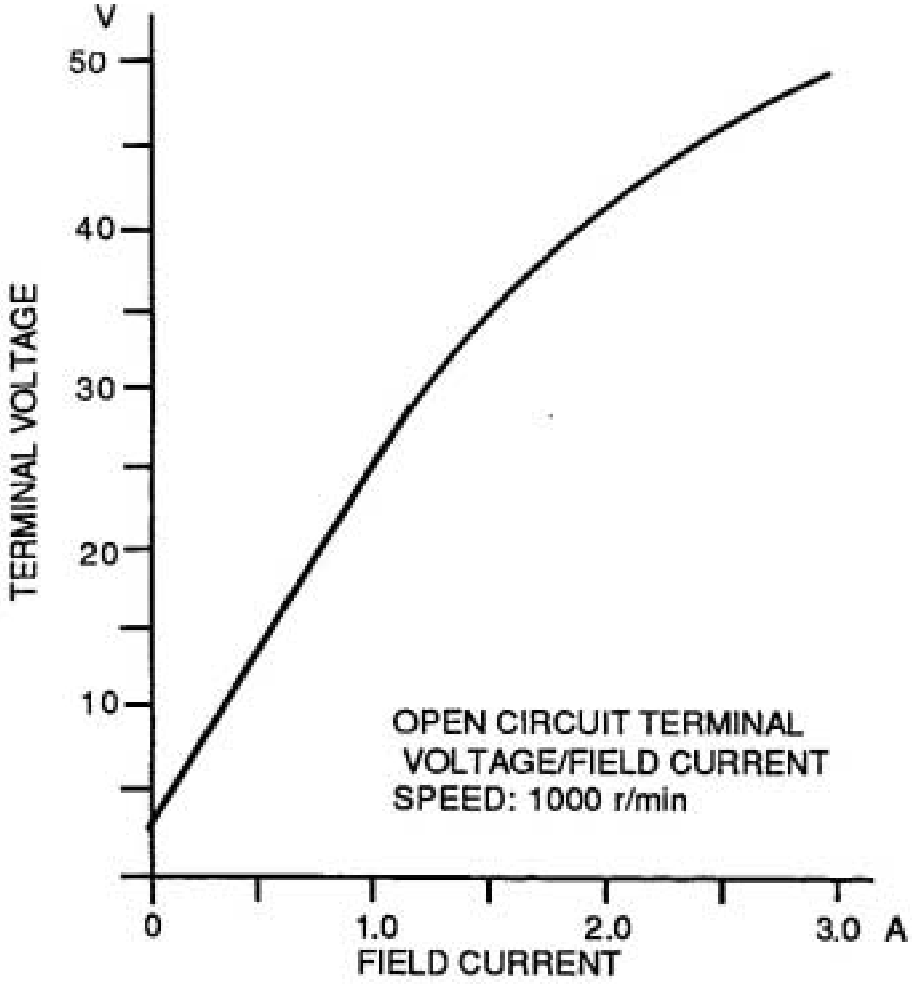


Figure A17-4: Characteristic of dc Separately Excited Generator

Practical 17.2

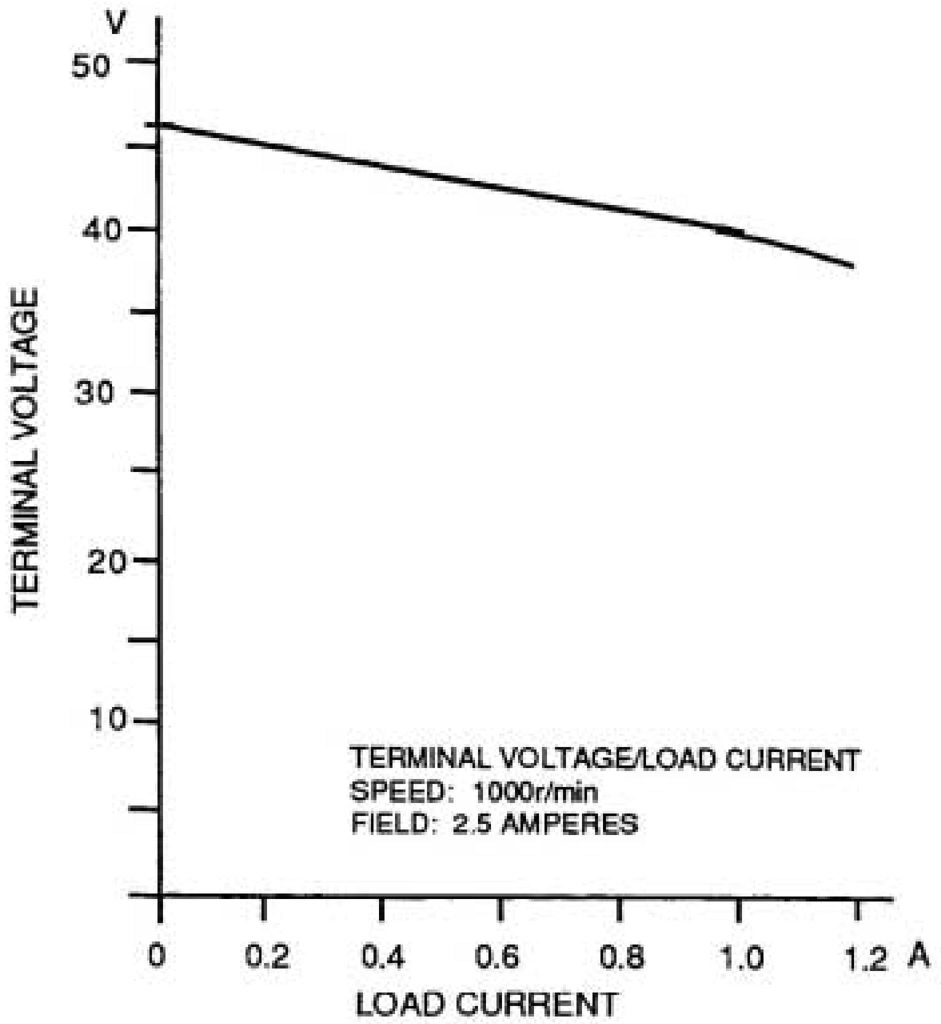


Figure A17-5 Characteristic for dc Separately Excited Generator

Question 17.1 This is due to the magnetic circuit beginning to saturate as field current is increased.

DISSECTIBLE

MACHINES SYSTEM

Assignment 18
dc Separately Excited Generator with Interpoles

PRACTICAL 18.1

EQUIPMENT REQUIRED

	Qty	Item
62-100 Kit	1	Base Unit
	1	Commutator/Slipring
	2	L1 Coils
	2	L2 Coils
	2	L9 Coils
	2	Field Poles
	1	Rotor Hub
	4	Rotor Poles
	2	L8 Coils
	2	Interpoles
	2	Brushholders with Brushes
	1	Flexible Coupling
General	1	Variable Speed Motor: 1/3 hp, 1420 rev/min, (eg, Feedback 63-501)
	1	0-20 V, 5 A dc Power Supply (eg, Feedback 60-105)
	1 1	0-50 V, dc Voltmeter 0–5 A dc Ammeter (eg, Feedback 68-110)
	1	5-0-5 A Centre-Zero dc Ammeter ((eg, Feedback 68-113)
	1	Variable Resistor, 0-200 ohms, 2.5 A (eg, Feedback 67-113)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

Again interpoles are used to improve commutation on load. They are here connected so that the polarity of each interpole is the same as that of the next main pole with respect to direction of rotation.

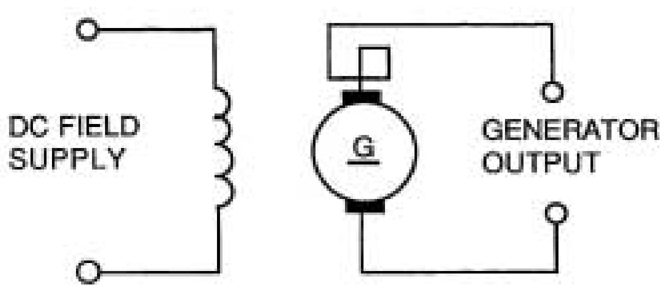


Figure A18-1: dc Separately Excited Generator with Interpoles Circuit Diagram

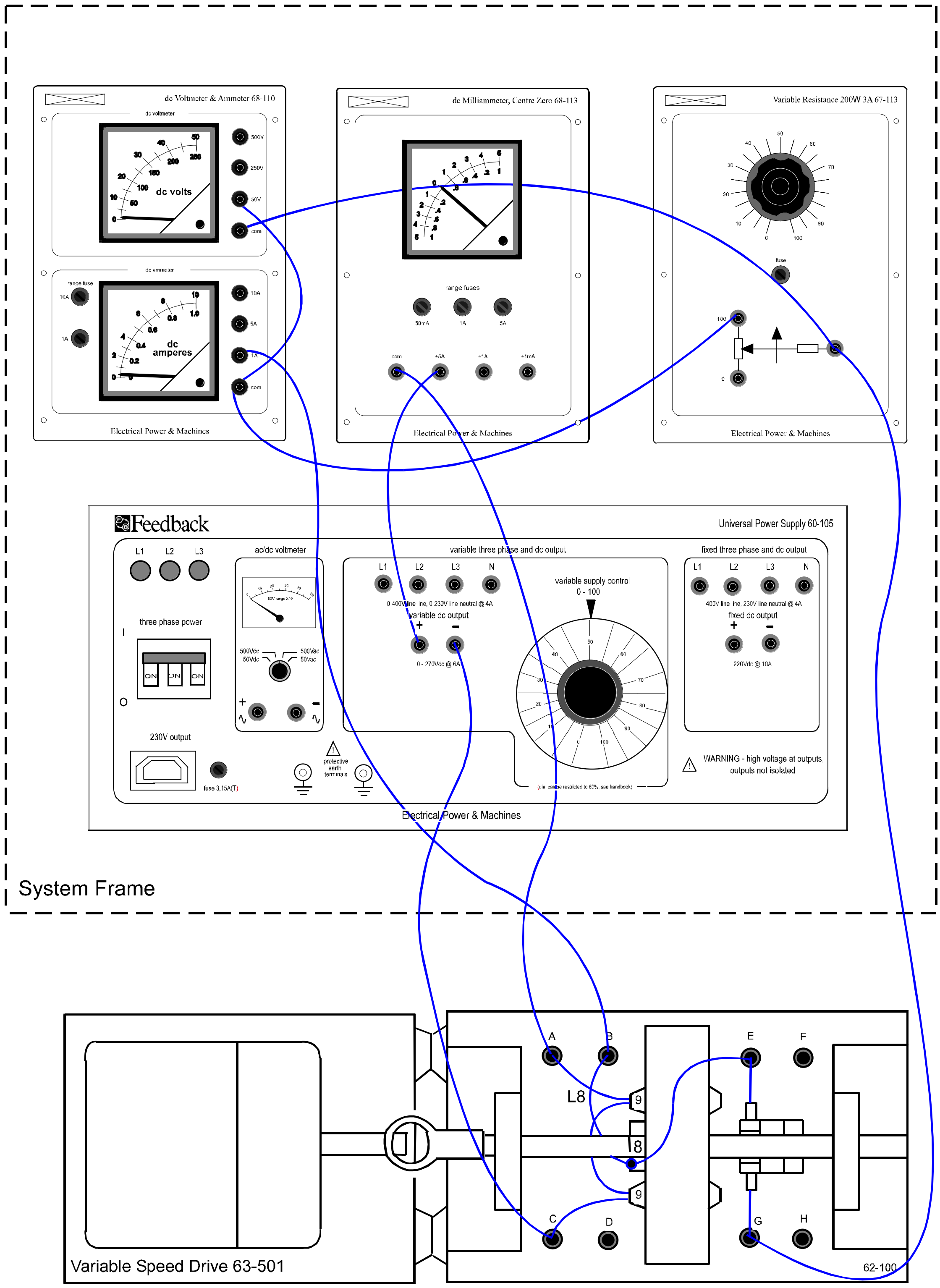


Figure A18-2: Connections for dc Separately Excited Generator with Interpoles

ASSEMBLY

Follow the instructions for Assignment 17, then attach the interpoles with their coils to the frame ring in the 6 o'clock and 12 o'clock positions and connect as shown in the wiring diagram Figure A18-2. and A18-3. Set the commutator so that the slots between segments are in line with the armature pole gaps.

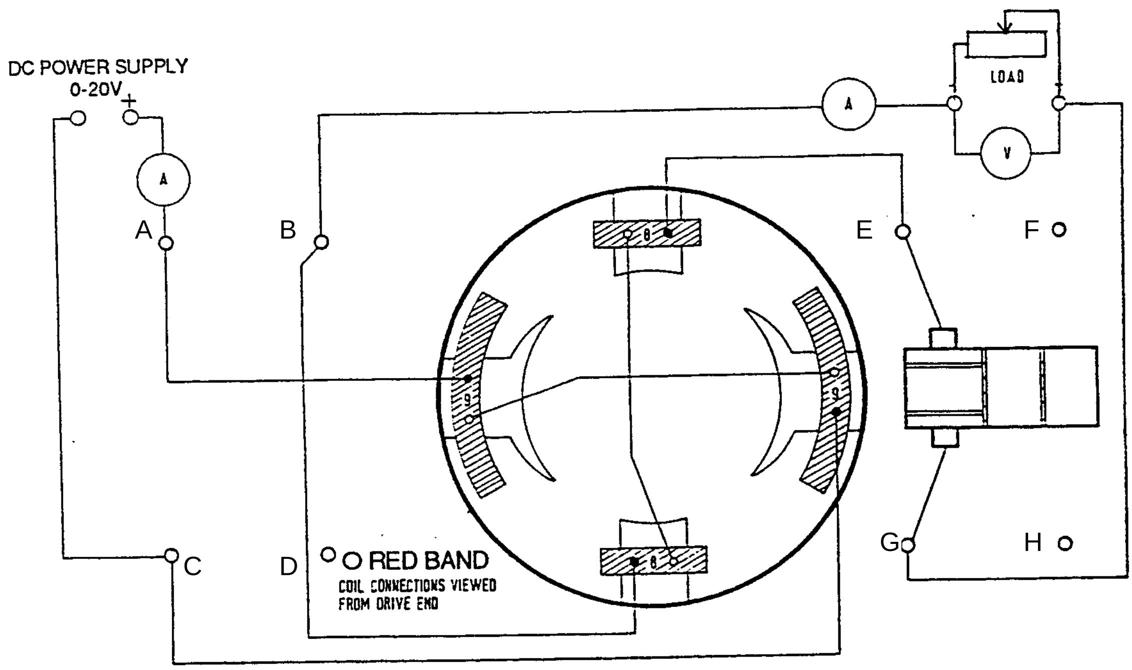


Figure A18-3: dc Separately Excited Generator with Interpoles Wiring Diagram

PRACTICAL 18.1

The improvement in commutation which results from the use of interpoles may be demonstrated with the machine on load.

Connect shorting links across each interpole coil and with the generator running at 1000 rev/min, apply sufficient field current to produce an output from the generator of 1 A into a 22Ω load. With the interpoles shorted, quite pronounced sparking will occur at the brushes.

Remove the shorting links and re-adjust speed and excitation to give the same loading as before. There will be a noticeable reduction in the sparking level.

DISCUSSION

The effects of armature reaction and its counteraction by use of interpole windings have already been explained for motors in Assignment 14 and generators in Assignment16.

Refer to the Discussion in those assignments if you have not yet performed them.

DISSECTIBLE

MACHINES SYSTEM

Assignment 19

dc Series Motor

PRACTICAL	19.1	Motor Unloaded/Loaded
EQUIPMENT REQUIRED	**Qty**	**Item**
62-100 Kit	1	Base Unit
	1	Commutator/Slipring
	2	Brushholders with Brushes
	2	L9 Coils
	2	L1 Coils
	2	L2 Coils
	2	Field Poles
	1	Rotor Hub
	4	Rotor Poles
General	1	1-100 V, 5 A, dc Supply (eg, Feedback 60-105)
	1 1	0-150 V, dc Voltmeter 0–5 A dc Ammeter (eg, Feedback 68-110)
	1	Friction (Prony) Brake or other Dynamometer: 0-1 Nm at 1500 rev/min (eg, Feedback 67-470)
	1	Optical/Contact Tachometer (eg, Feedback 68-470)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

The series motor has a high starting torque making it suitable for traction motors, cranes, etc. Its speed can be controlled by adjustment of the applied voltage but it is also dependent on loading. A heavy shaft load will cause the armature current to increase and will also produce an increase in field strength since the field coils are in series with the armature. Torque is proportional to the product of flux per pole and armature current while shaft speed is inversely proportional to flux per pole. The effect of load is therefore to increase available torque and reduce shaft speed.

If full voltage is applied with no load the speed of the series motor may rise to a run-away condition. This assembly gives a motor which can operate safely at no load with applied voltages of up to 30 V.

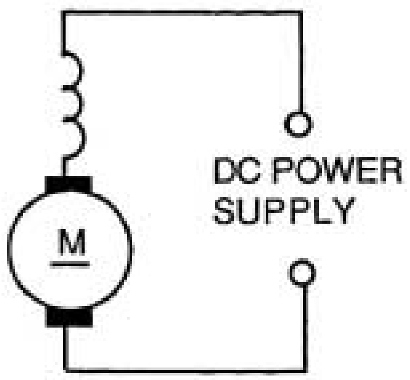


Figure A19-1: dc Series Motor Circuit Diagram

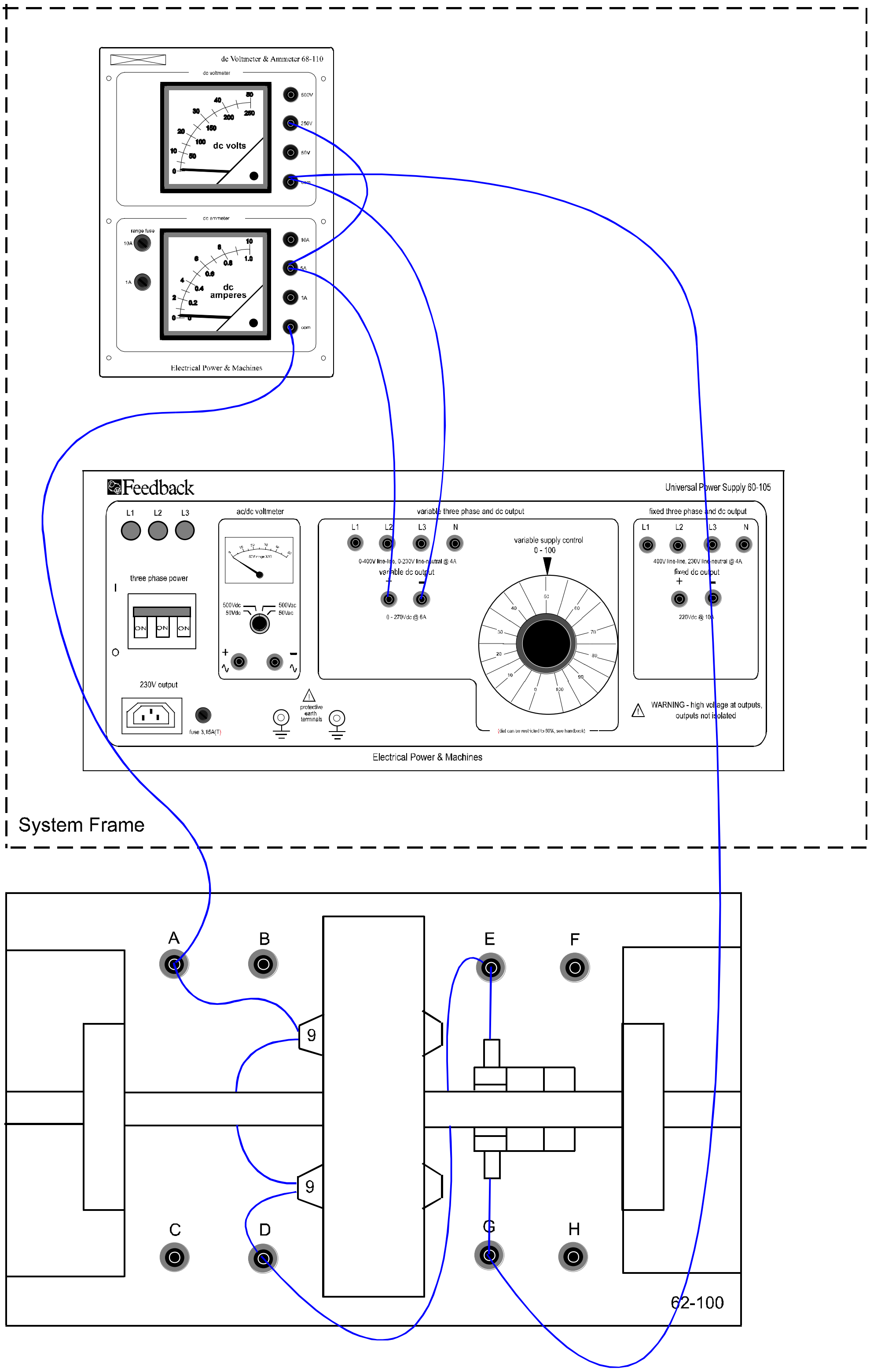


Figure A19-2: Connections for dc Series Motor

ASSEMBLY

Fix the armature and commutator to the shaft as shown in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 1 and fit the shaft into its bearings. Before finally tightening the screws holding the bearing housing to the baseplate, check that the shaft rotates freely and moves axially against the pre-loading washer.

Fit the L9 coils to the field poles and the poles to the frame ring at the 3 o'clock and 9 o'clock positions.

Fit the brushes into their holders and attach these to the mounting block positions on each side of the commutator. The brushes should move freely in their holders under the action of the brush springs.

Make the circuit shown in Figure A19-3, in accordance with the connections shown in Figure A19-2 and if the motor is to be run with no mechanical load, ensure that the supply voltage is set to less than 30 V.

If a friction (Prony) brake or other loading device is being used, fasten its frame to the baseplate and adjust it to give zero load initially. Instruction for mounting the 67-470 Prony Brake are given in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 6.

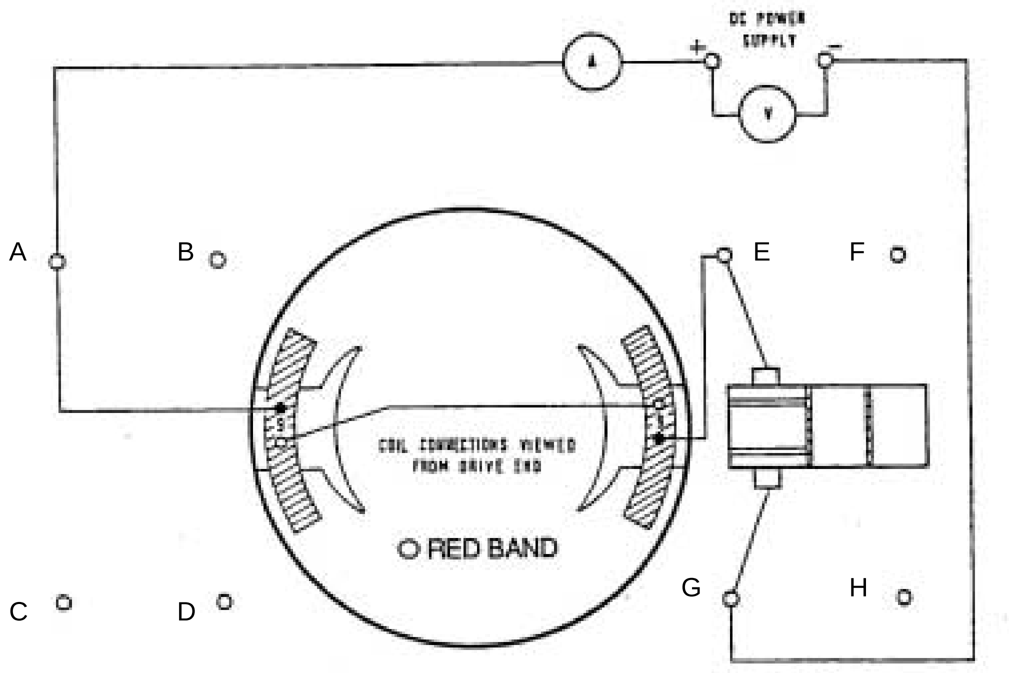


Figure A19-3: dc Series Motor Wiring Diagram

PRACTICAL 19.1

Motor Unloaded

Switch on the dc power supply. With an applied voltage of 15 V, the shaft speed on no-load will be approximately 500 rev/min and the input current 0.6 A.

Motor On Load

With no shaft load applied switch on the power supply to the motor and adjust to 30 volts. The motor will have no tendency to race at this voltage, but before making any further increase, apply a load to the drive shaft.

Increase the applied voltage to 50 V and maintain it at this level throughout the test. Take readings of armature current and shaft speed for set values of brake load. Use these to plot the Speed/Torque and Armature current/Torque characteristics. Typical characteristic curves are given in Figure A19-4.

Question 19.1

Why is it necessary to keep the supply voltage constant at 50 V during the test?

Exercise 19.1

For each value of torque in your results, calculate the output power as:

$$\frac{2\pi N T}{60} \text{ watts}$$

and the output power as VI_a watts.

Hence find the efficiency:

$$\frac{\text{Power out}}{\text{Power in}} \times 100\%$$

Plot power out and efficiency versus torque on your graph.

Question 19.2

What is the maximum output horsepower (1 hp = 746 W) and at what armature current does it occur?

Question 19.3

a) What is the maximum efficiency achieved?

If you have studied the shunt motor in Assignment 13, compare the maximum efficiencies of the two.

b) Which is greater?

c) Can you explain the difference qualitatively?

Question 18.4

At what speed would you expect the motor to run if ALL

load were removed?

DISCUSSION

From these tests we hope you have learned a number of things about motors in general and about series dc machines in particular.

In assembling the machine you will have observed that the only current path through the machine is through the armature and field in series. This means that in the series machine, the field coils have to be able to carry the large armature currents of the loaded machine. In general practice, this means that the field coils of series machines are generally wound of relatively few turns of large diameter wire. If you open up a machine and find the field coils to have many turns of fine wire, you can be fairly sure it is not a series machine.

You have been conducting Load Tests on the assembled motor at a specified supply voltage. If you repeated these tests at different supply voltages, you would obtain a family of curves.

From the Torque/Speed graph that you have plotted, you will see that the series machine has a tendency to run up to dangerous speeds when it is not loaded.

This characteristic is not much of a problem in small, fractional horsepower motor because their inherent losses constitute sufficient load to restrain the maximum speed to safe limits. However, in larger machines, the inherent losses are a much smaller proportion of the total power available, therefore, certain safety precautions are required.

Larger series motors are always directly coupled to their load. Belt drives should not be used because the machine would 'run away' if the belt broke. Also some form of starting control box is generally used.

Obviously, when the motor is starting up from rest it can pass a very large current because the armature is not producing a back-emf and the field coils are low resistance. It is shown in the following paragraphs that the torque of a series motor is proportional to the square of armature current so that the motor produces a very high starting torque.

This makes the series motor suitable for applications where large masses have to be moved from rest. These include railway cars, elevators, cranes, and automotive starter motors.

You should have found that at maximum horse-power the efficiency of the machine you tested was about 35% - 40%.

However, this machine is an educational machine and it has been specially built with regard to making it safe to operate and for 'opening up' the machine so that you can see the principles of its construction.

A commercial machine would have less field resistance and would be built in a more compact way with smaller air gaps and a smaller armature - giving less windage loss. The machine you have just tested produced 0.075 hp = 1/13 hp - you probably know that the ¼ hp motors for electric hand-drills are much smaller that this.

The combined effects of lower resistance, closer magnetic coupling and less windage significantly improves the efficiency of commercial machines. The actual efficiency of small motors below 1 hp is quite variable, however, and they would quite likely be in the 60% - 70% range.

Above 1 hp, they become more precisely predictable with average values:

1 hp	75% efficient
50 hp	89% efficient
500 hp	93% efficient
5000 hp	97% efficient

In theory, the torque generated by a series motor should be proportional to the square of the armature current.

$$T \propto I^2{}_a$$

This is because Torque ($\propto$ (flux) X (I_a) and in the case of a series motor the flux is itself proportional to I_a. A study of your graph of torque versus current will soon reveal that it is far more like a straight line that the parabolic shape characteristic of a square law.

The reason is partly that at high current, armature reaction and magnetic saturation limit the flux increases with current, and partly that your curve shows only the useful shaft torque and omits the effects of static friction and windage. The former is fairly constant but the latter increases roughly as the square of speed. Thus at low armature currents, when the speed is high, the hidden torque is also high and as the armature current increase with fall of speed the hidden torque reduces to a nearly constant value. Such a curve is shown superimposed on the shaft load curve in Figure A19-5, which also shows the sum of the two representing the total generated torque. This graph has a shape similar to the one anticipated, in which torque increases as the square of the current.

For further information on the uses of series motors, see 'Matching the Motor to its Load' in Appendix A of this manual. Also see the Discussion of Assignment 14 for an explanation of armature reaction effects in a motor.

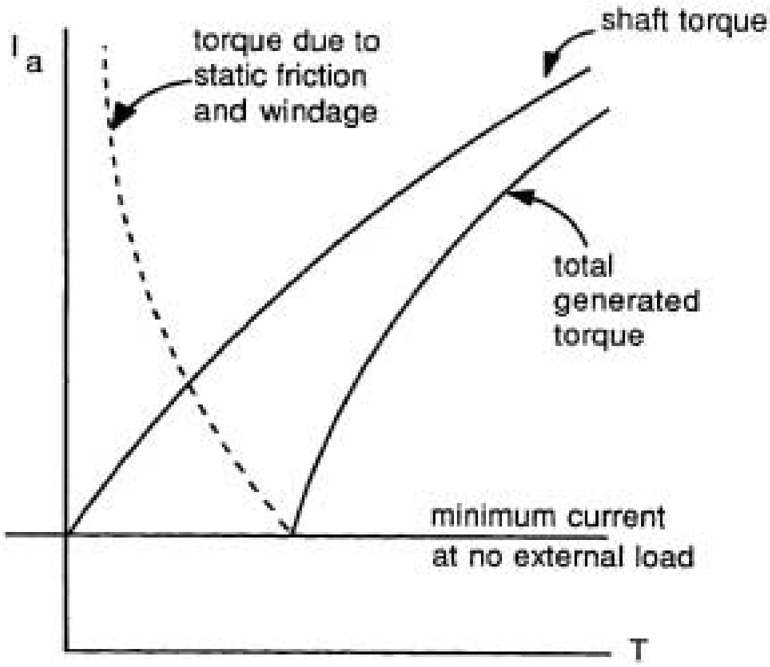


Figure A19-5

Notes

Practical 19.1

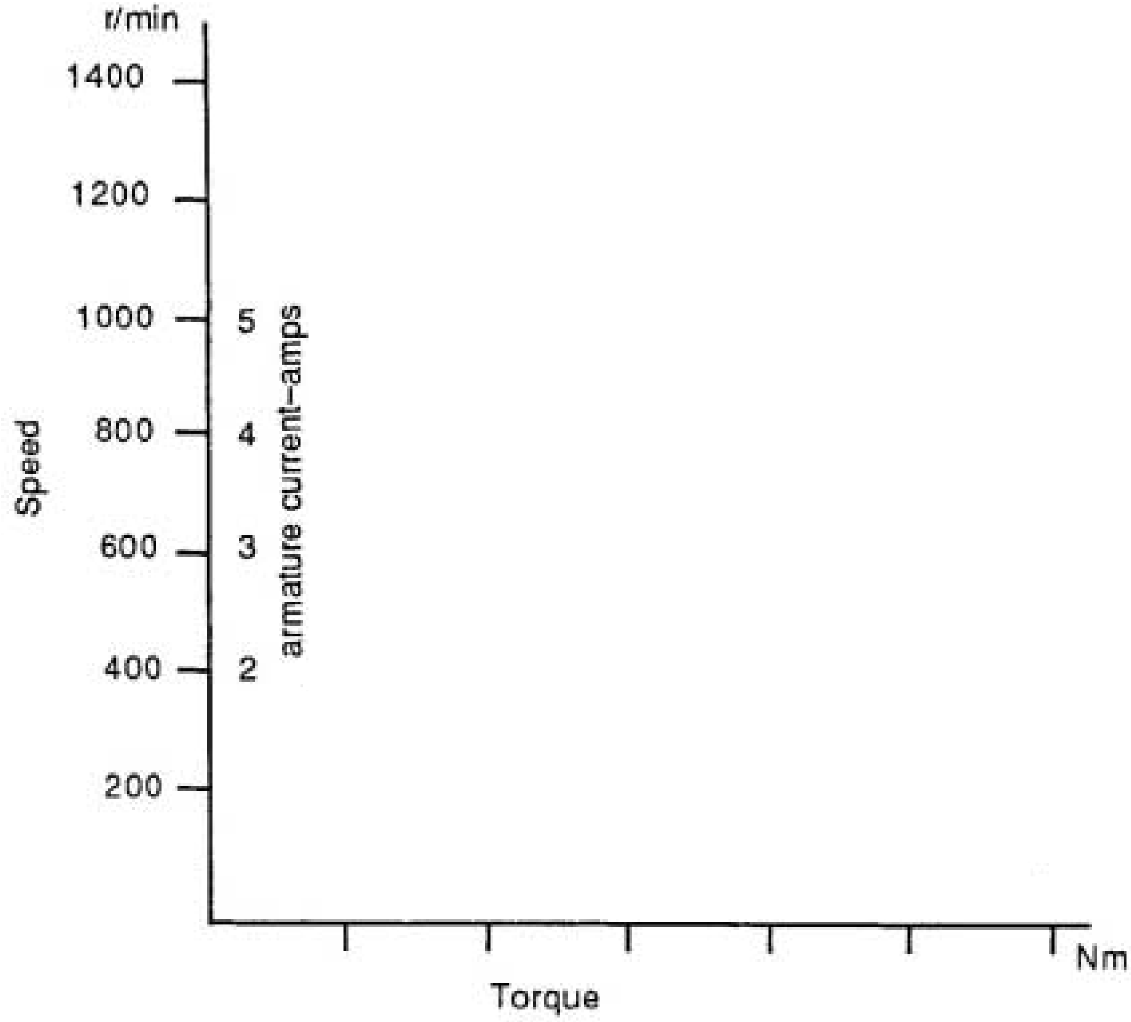


Figure A19-4 Graph Axes

Notes

Practical 19.1

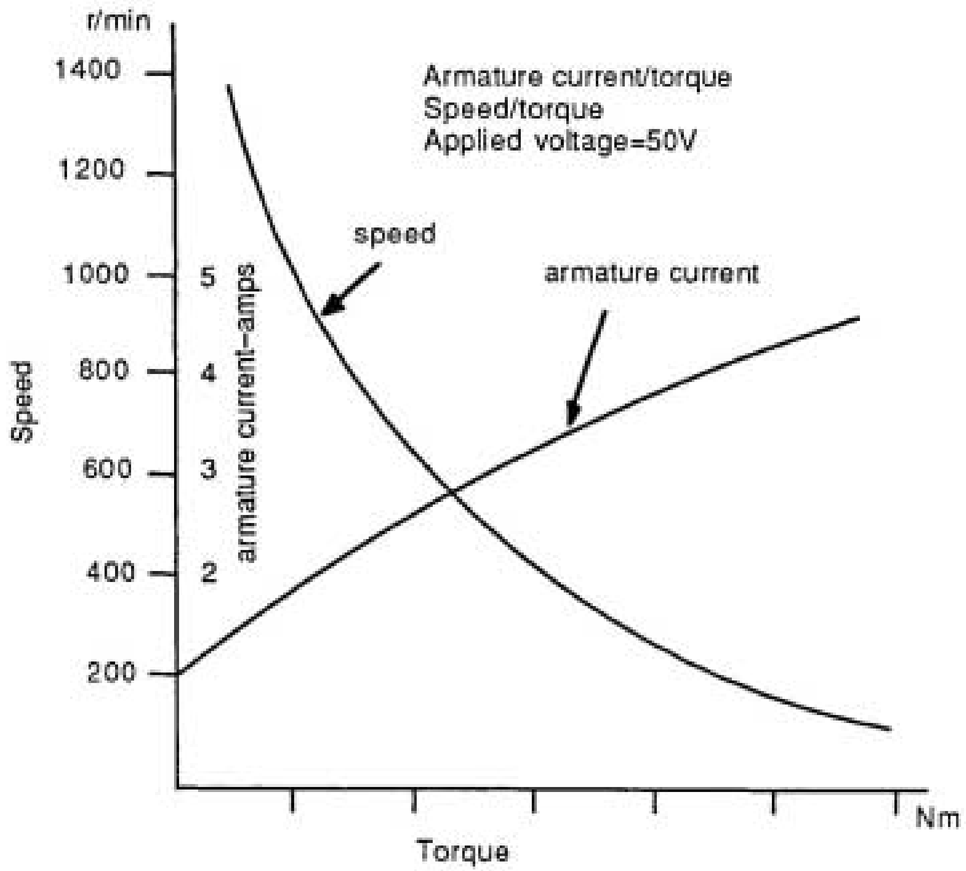


Figure A19-4: Characteristic of dc Series Motor

Question 19.1

The supply voltage is kept constant to eliminate this as a factor in the test. As armature current increases, the terminal voltage may fall due to internal resistance in the supply and must be adjusted.

Question 19.2

A typical maximum horsepower is 0.07 hp at 3 A armature current.

Question 19.3

a) Maximum efficiency is typically about 40%.

b) This the greater than for the shunt motor (about 30%).

c) The shunt motor dissipates a nearly constant amount of power as heat in the shunt field coils. On average, this is lower in the series motor, and particularly so at the higher speeds.

Question 19.4

If all external loads were removed, the motor would run up to an indeterminate speed governed by friction and windage. This could be dangerously high.

DISSECTIBLE

MACHINES SYSTEM

Assignment 20

dc Series Motor with Interpoles

PRACTICAL 20.1

EQUIPMENT REQUIRED	**Qty**	**Item**
62-100 Kit	1	Base Unit
	1	Commutator/Slipring
	2	Brushholders with Brushes
	2	L9 Coils
	2	L1 Coils
	2	L2 Coils
	2	Field Poles
	1	Rotor Hub
	4	Rotor Poles
	2	L8 Coils
	2	Interpoles
General	1	1-100 V, 5 A, dc Supply (eg, Feedback 60-105)
	1 1	0-150 V, dc Voltmeter 0–5 A dc Ammeter (eg, Feedback 60-105)
	1	Friction (Prony) Brake or other Dynamometer: 0-1 Nm at 1500 rev/min (eg, Feedback 67-470)
	1	Optical/Contact Tachometer (eg, Feedback 68-470)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

The addition of interpoles to the series motor improves commutation particularly under loaded conditions. The polarity of each interpole in a dc motor is opposite to that of the next main pole with respect to direction of rotation.

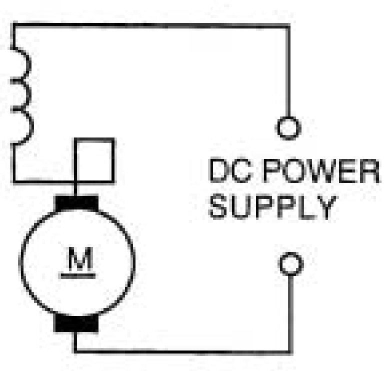


Figure A20-1: dc Series Motor with Interpoles Circuit Diagram

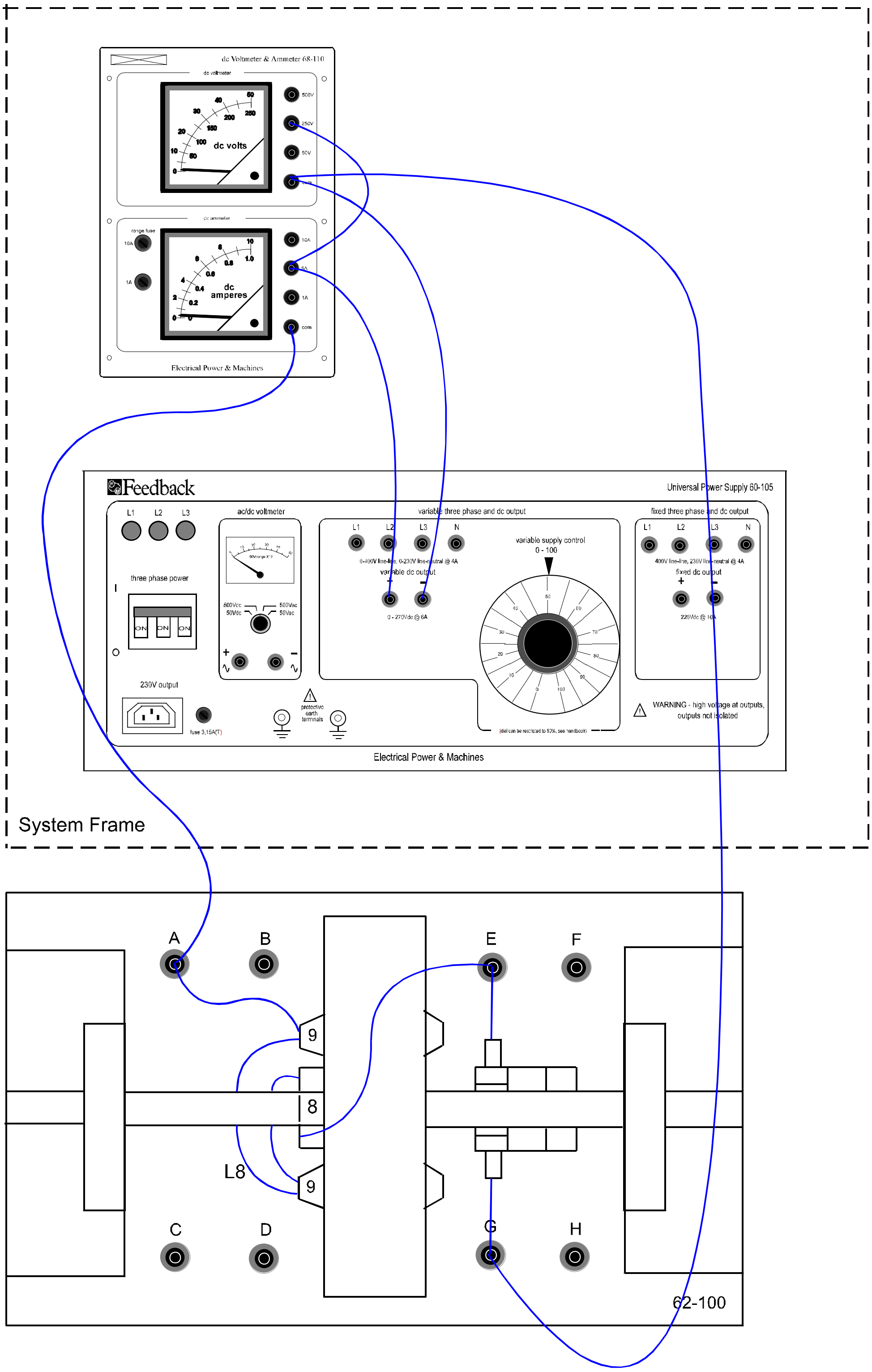


Figure A20-2: Connections for dc Series Motor with Interpoles

ASSEMBLY

Follow the instructions for Assignment 19 then attach the interpoles with their coils to the frame ring in the 6 o'clock and 12 o'clock positions.

Connect as shown in Figures A20-2 and A20-3.

Set the commutator so that the slots between segments are in line with armature pole gaps.

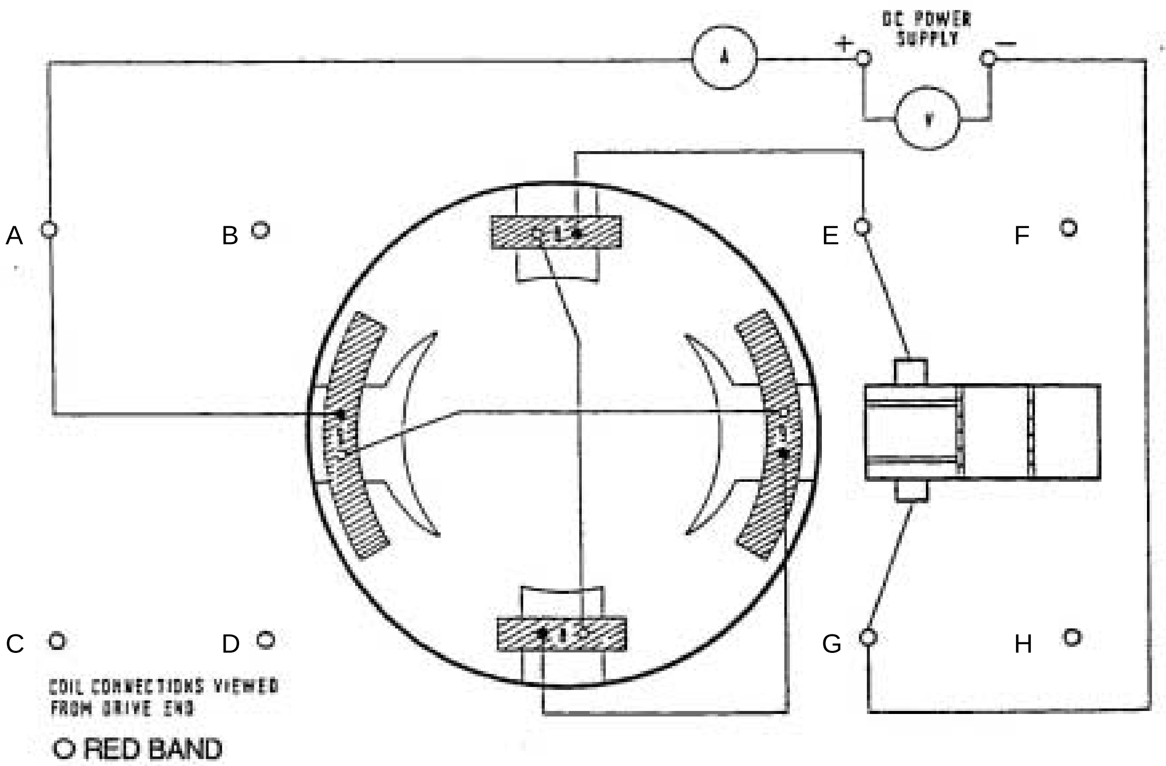


Figure A20-3: dc Series Motor with Interpoles Wiring Diagram

PRACTICAL 20.1

Connect shorting links across the interpole terminals and with the motor running on load, observe the level of sparking at the brushes when the interpoles are not energised. Disconnect the shorting links and with the motor operating on the same load as before the note ' the reduction in sparking which results. Do not operate the motor on no-load with an applied voltage in excess of 30 V.

Exercise 20.1

If you have previously tested Assignment 19, you will have found the load torque at which maximum efficiency occurred. Make a spot check at this load of speed and armature current for the series motor with interpoles at 50V supply. Then calculate the efficiency for comparison with your previous result.

Question 20.1

Can you account for any difference?

Exercise 20.2

Establish on Figure A20.3 the direction of current flow in main and interpole windings and that of armature rotation. Decide whether the polarity of an interpole is equal or opposite that of the main pole that precedes it in respect of the direction of rotation.

Question 20.2

Is it equal or opposite?

DISCUSSION

The effect of armature reaction in a motor and its reduction by the use of interpoles is described in the Discussion of Assignment 14. Please refer to it.

Question 20.1	A typical result is an efficiency of 53% compared with 41% without interpoles. The main reason is the restoration of the total flux, previously reduced by armature reaction, to its design value.
Question 20.2	The interpole should be of similar polarity to that of the preceding main pole.

Notes

DISSECTIBLE

MACHINES SYSTEM

Assignment 21

dc Series Generator

PRACTICAL	21.1	
EQUIPMENT REQUIRED	**Qty**	**Item**
62-100 Kit	1	Base Unit
	1	Commutator/Slipring
	2	Brushes and Brushholders
	2	L9 Coils
	2	L1 Coils
	2	L2 Coils
	2	Field Poles
	1	Rotor Hub
	4	Rotor Poles
	1	Flexible Coupling
General	1	Variable Speed Motor: 1/3 hp, 1200 rev/min, (eg, Feedback 63-501)
	1	0-50 V, dc Voltmeter
	1	0–5 A dc Ammeter (eg, Feedback 68-110)
	1	Variable Resistor, 0-200 ohms, 2.5 A (eg, Feedback 67-113)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

In this generator the armature, field coils and load are all connected in series, so that initially an increase in load current will increase flux per pole and produce a rise in terminal voltage. If load current is further increased, however, the effects of saturation, armature reaction and internal voltage drops will cause the terminal voltage to fall again.

The series generator may be used as a booster, with a main generator controlling the load current or as a constant current generator operating over the failing part of the voltage-current curve.

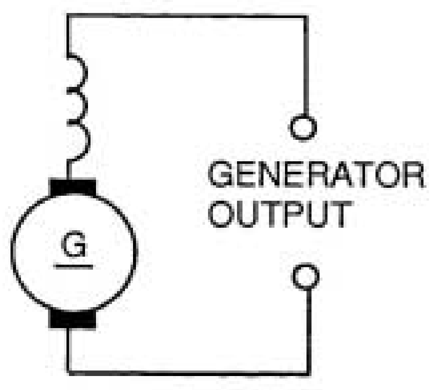


Figure A21-1: dc Series Generator Circuit Diagram

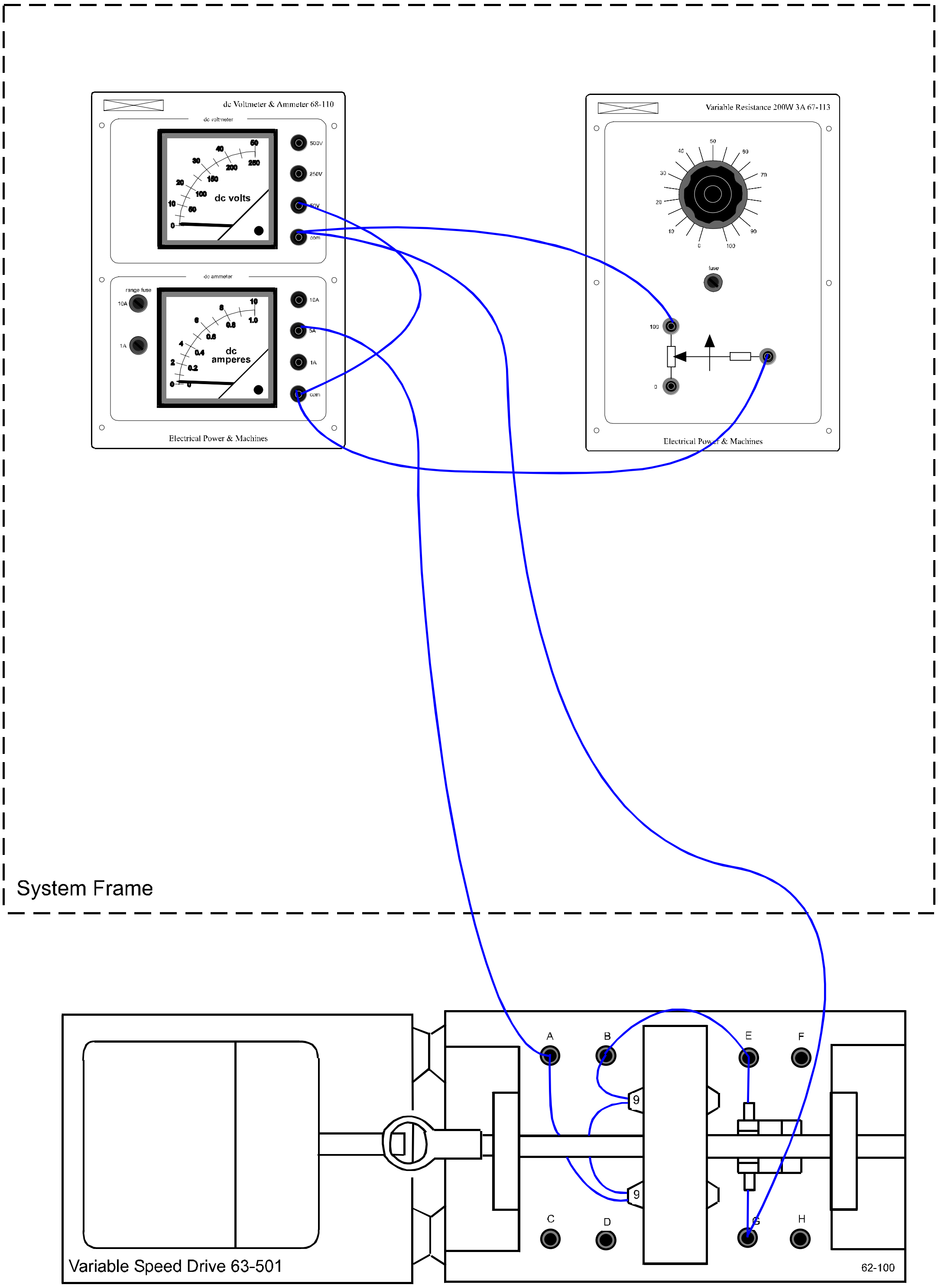


Figure A21-2: Connections for dc Series Generator

ASSEMBLY

Fix the armature and commutator to the shaft as shown in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 1 and fit the shaft into its bearings. Before finally tightening the screws that hold the bearing housing to the baseplate, check that the shaft rotates freely and moves axially against the preloading washer.

Fit the field poles with their L9 coils to the frame ring at the 3 o'clock and 9 o'clock positions.

Place the brushes in their holders and attach these to the mounting block positions on each side of the commutator. Check that the brushes move freely in their holders.

Make the circuit shown in Figure A21-3 in accordance with the connections shown in Figure A21-2, and set the load resistor to its highest value. Attach the drive motor baseplate to that of the base unit, align the two shafts and connect them by a flexible coupling as explained in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 7.

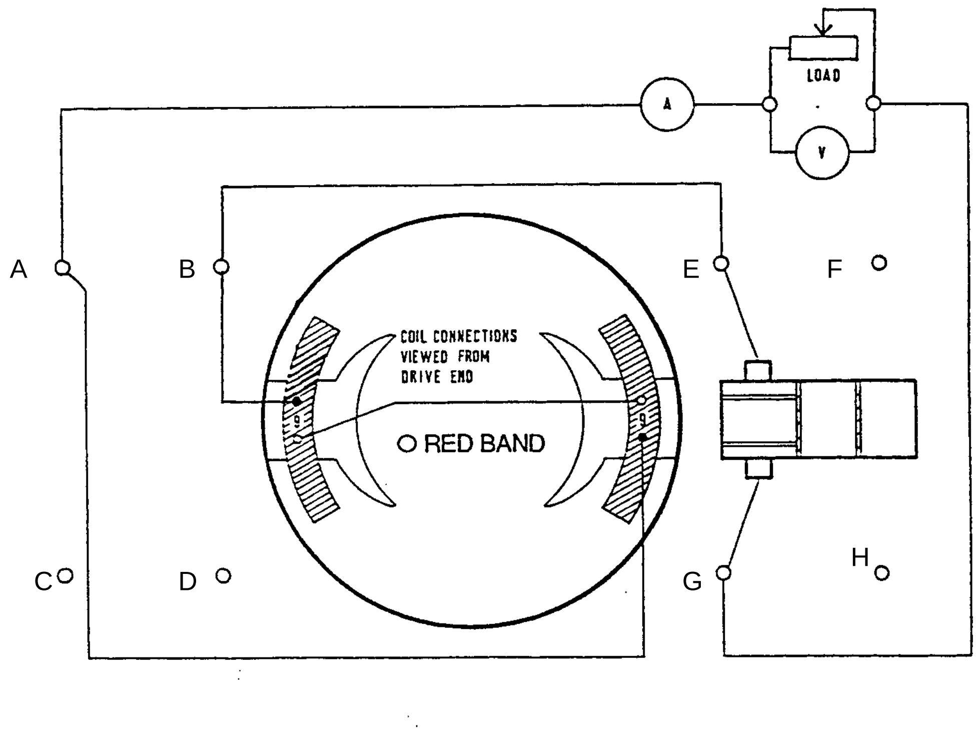


Figure A21-3: dc Series Generator Wiring Diagram

PRACTICAL 21.1

As with any self-excited generator the initial build up of voltage is dependent on the residual magnetism present in the magnetic circuit. In a new machine this may be insufficient and it will then be necessary to momentarily 'excite' the field coils from a low voltage dc source.

With the shaft speed set to 1500 rev/min throughout the test, increase the load resistance in steps from 10Ω to approximately 50Ω. Measure the load current and terminal voltage at each step. Plot terminal voltage versus load current on linear graph paper.

Question 21.1

What shape do you find for the terminal voltage/load current characteristic? How do you explain it?

Exercise 21.1

Calculate the output power for each load current at $V_t\ I_l$ watts and plot against I_l on your graph.

Question 21.2

What is the maximum power output in watts?

DISCUSSION

In Appendix A, the general equation for a generator was found to be:

$$V_t = K_1 N\Phi - I_a R_a$$

where
V_t = terminal voltage
K_1 = constant
N = speed
Φ = total flux
I_a = armature current
R_a = armature resistance

In this series generator, neglecting the effects of armature reaction and saturation, Φ is proportional to I_a and also $I_a = I_l$ the load current. Also the series field resistance R_f must be added to R_a. Thus, for a constant speed we obtain:

$$V_t = K_2 I_l - I_l (R_a + R_f) = (K_2 – R_a + R_f) I_l$$

or

$$V_t \propto I_l$$

Thus an ideal series generator produces a voltage proportional to its load current and so its practical applications are limited to situations where the load current is known and constant. However, this rising voltage characteristic can be combined with the failing one of a shunt generator as demonstrated in Assignment 25.

In practice, both saturation and armature reaction occur as the load current increases so that the straight line graph of V_t versus I_l, predicted actually rounds off to a peak and eventually the voltage reduces with current increase, once the flux can increase no more. Please see the Discussion of Assignments 14 and 16 for an explanation of the effect of armature reaction in a generator.

Notes

Practical 21.1

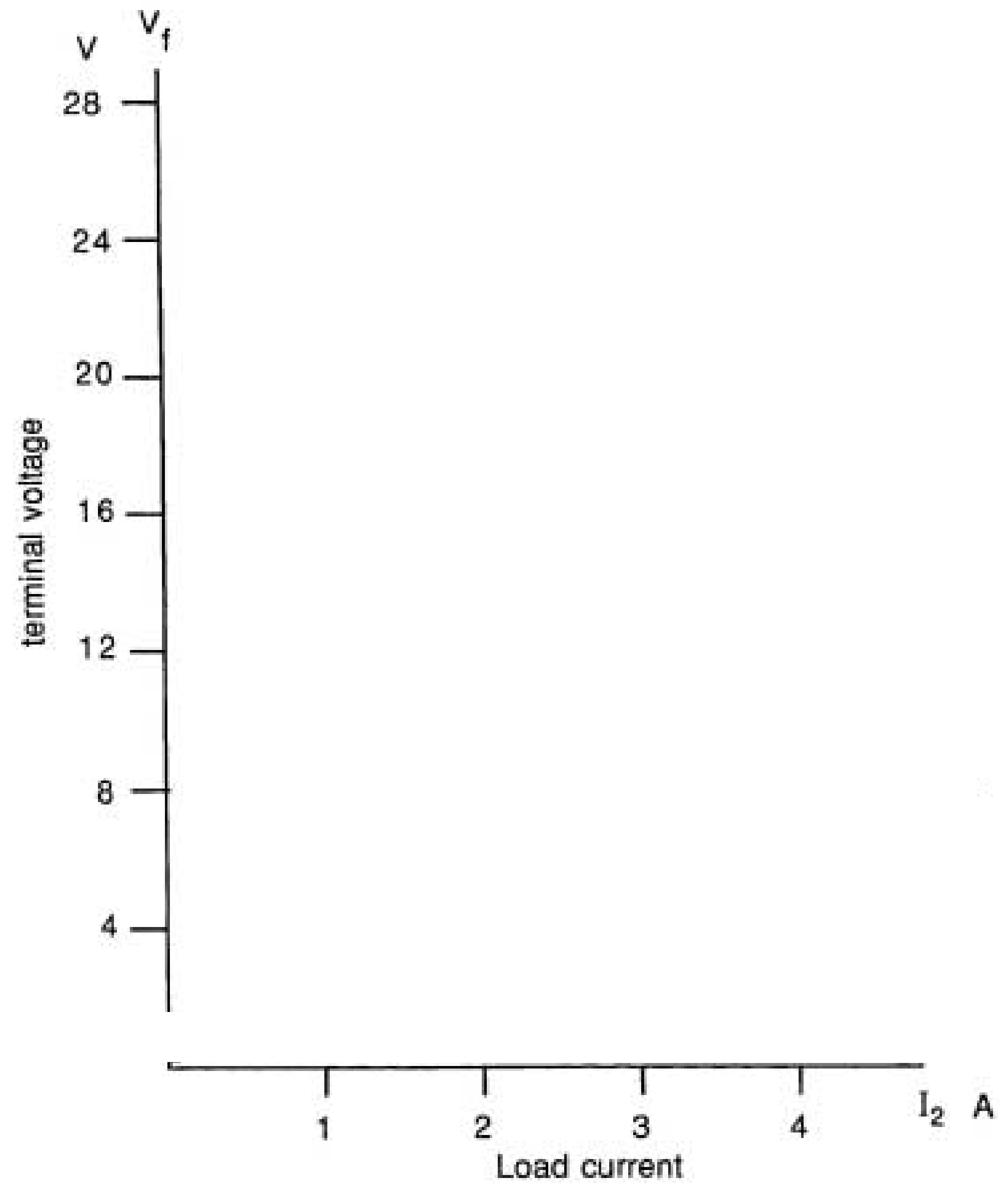


Figure A21-4 Graph Axes

Notes

Question 21.1 — Figure A21-4 shows a typical characteristic, displaying the initial linear rise in voltage with load current followed by rounding and finally dropping as saturation and armature reaction set in.

Question 21.2 — Typically, the maximum power will be around 80W. Figure A21-4 shows a representative plot of power versus I_l over the lower part of the curve, since $V_t \propto I_l$ then the power $P \propto I_l^2$ and a square-law curve results. As saturation occurs, however, this becomes more nearly a straight line.

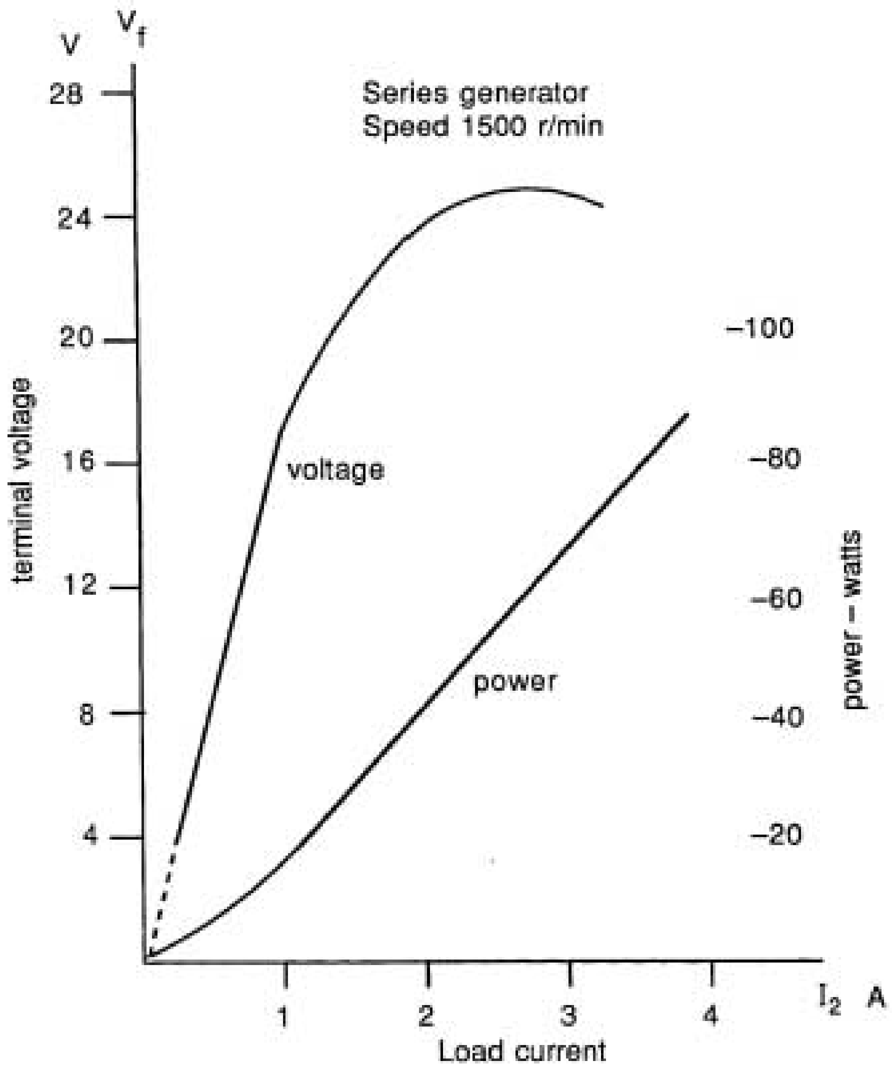


Figure A21-4: Characteristic of dc Series Generator

Notes

DISSECTIBLE MACHINES SYSTEM

Assignment 22

dc Series Generator with Interpoles

PRACTICAL 22.1 Load Test/Speed Test

EQUIPMENT REQUIRED

	Qty	Item
62-100 Kit	1	Base Unit
	1	Commutator/Slipring
	2	Brushes and Brushholders
	2	L9 Coils
	2	L1 Coils
	2	L2 Coils
	2	Field Poles
	1	Rotor Hub
	4	Rotor Poles
	2	L8 Coils
	2	Interpoles
	1	Flexible Coupling
General	1	Variable Speed Motor: 1/3 hp, 1200 rev/min, (eg, Feedback 63-501)
	1	0-50 V, dc Voltmeter
	1	0–5 A dc Ammeter (eg, Feedback 68-110)
	1	Variable Resistor, 0-200 ohms, 2.5 A (eg, Feedback 67-113)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

The effect of interpoles in the series generator is to improve commutation over the load range of the machine. The polarity of each interpole in a dc generator is the same as that of the next main pole with respect to direction of rotation.

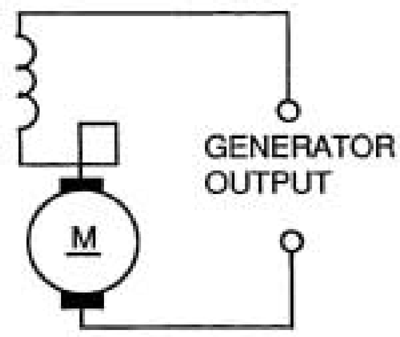


Figure A22-1: dc Series Generator with Interpoles Circuit Diagram

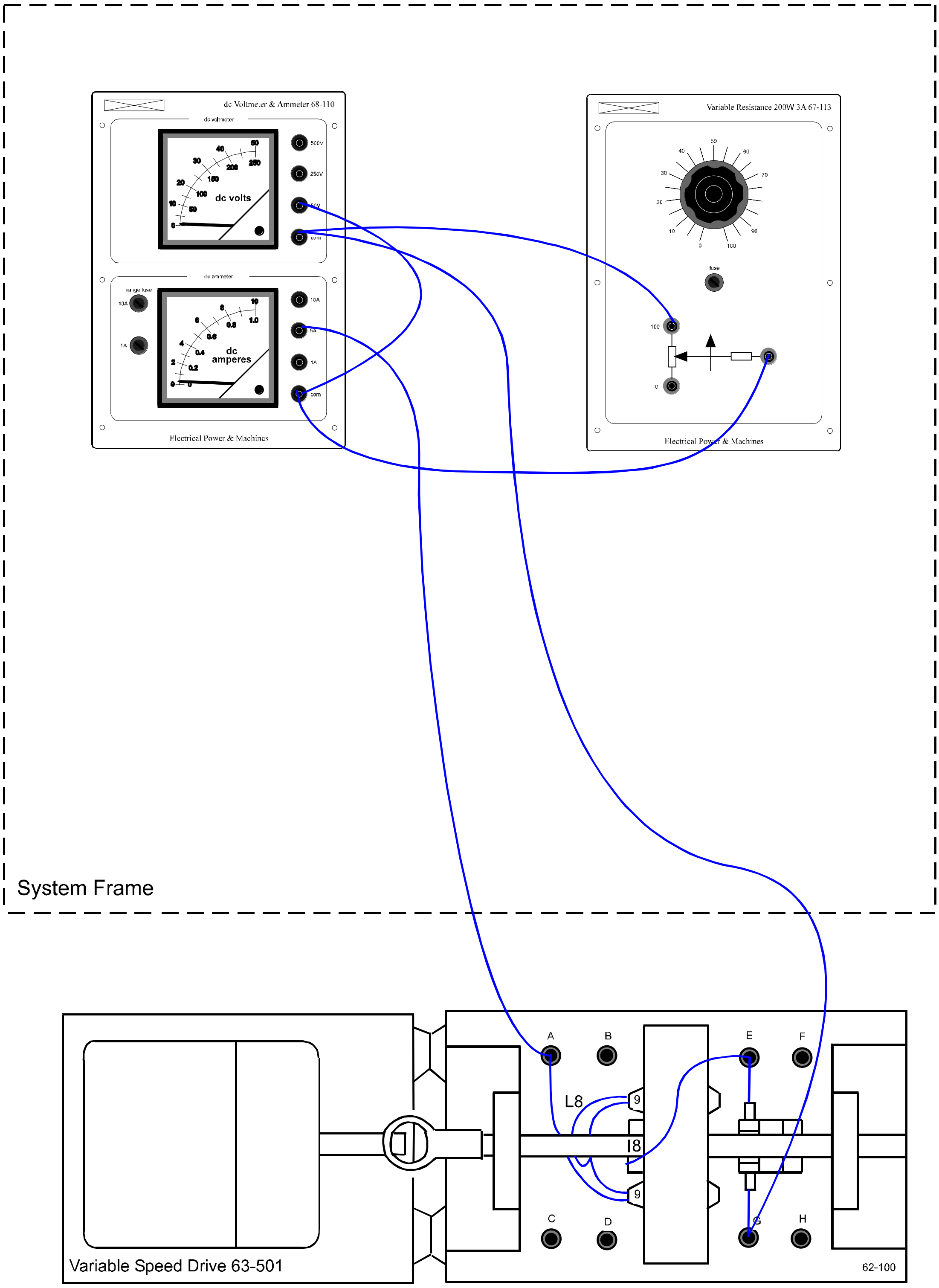


Figure A22-2: Connections for dc Series Generator with Interpoles

ASSEMBLY

Follow the instructions in Assignment 21, then attach the interpoles with their coils to the frame ring in the 6 o'clock and 12 o'clock positions. Connect as shown in Figures A22-2 and A22-3 and set the commutator so that the slots between segments are in line with the armature pole gaps.

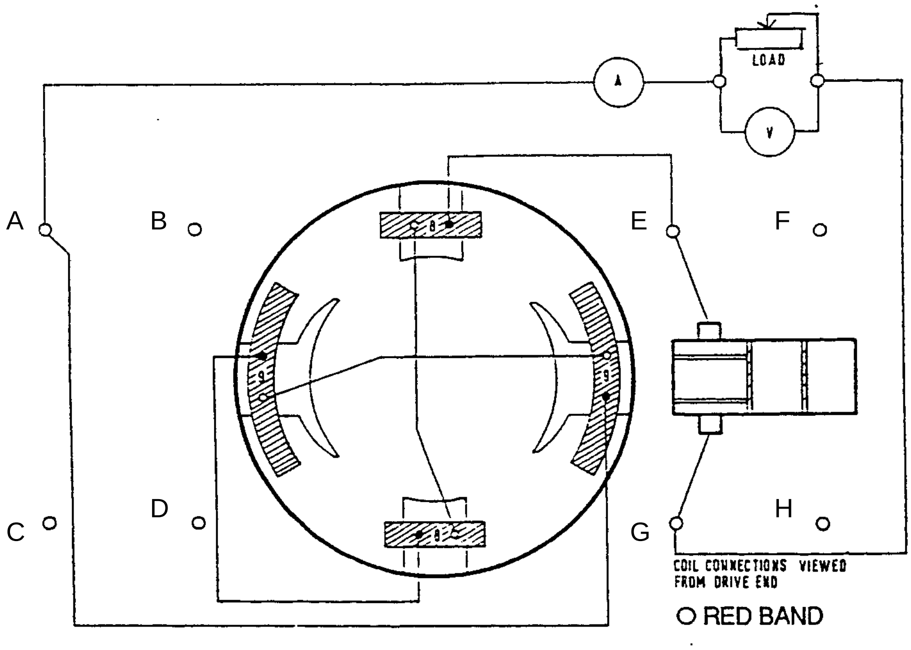


Figure A22-3: dc Series Generator with Interpoles Wiring Diagram

PRACTICAL 22.1

To demonstrate the action of interpoles, place shorting links across both interpole coil terminals. Load the generator to 1 A at 1200 rev/min and note the sparking which occurs at the brushes.

Remove the shorting links and re-adjust the output to 1 A. Note that when the interpoles are energised, there is a marked improvement as shown by the decrease in sparking to near pinpoint level.

Load Test

With shaft speed maintained constant at 1500 rev/min, increase the load resistance in steps from 10Ω to approximately 50Ω. Measure load current and terminal voltage at each step. The characteristic obtained should resemble that of Figure A22-4.

Speed Test

Set the drive to give a speed of about 500 rev/min and adjust the load resistor to give a load current of about 0.5 A. Note the speed and terminal voltage. Now increase the speed in steps up to about 1500 rev/min, each time adjusting the load resistor for 0.5 A current and noting speed and terminal voltage.

Question 22.1

Comparing your graph of the load test with that obtained for Assignment 21 without interpoles, what do you find and why?

The total resistance of the armature, main and interpole windings, ie, the total series resistance, is about 10Ω so that the voltage drop due to a load current I_l is 10 x I_l volts.

In the speed test, the current was constant at 0.5 A so the voltage drop should also be constant at 10 x 0.5 = 5 volts.

Exercise 22.1

For each result of the speed test calculate $V_t + 5 = E$ which should be the generated emf, and plot E against N, the speed.

Question 22.2

Is your plot of E versus N what you would expect from the simple generator equation? Explain your answer.

DISCUSSION

Please see the Discussion of Assignments14 and 16 for an explanation of the effect of armature reaction in a generator and its reduction by the use of interpoles.

Practical 22.1

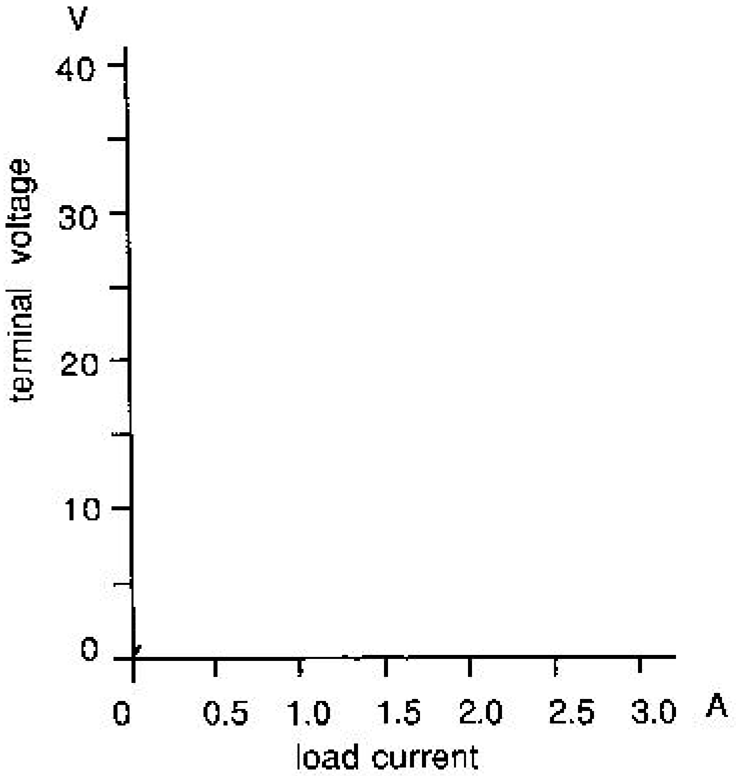


Figure A22-4 Graph Axes

Notes

Practical 22.1

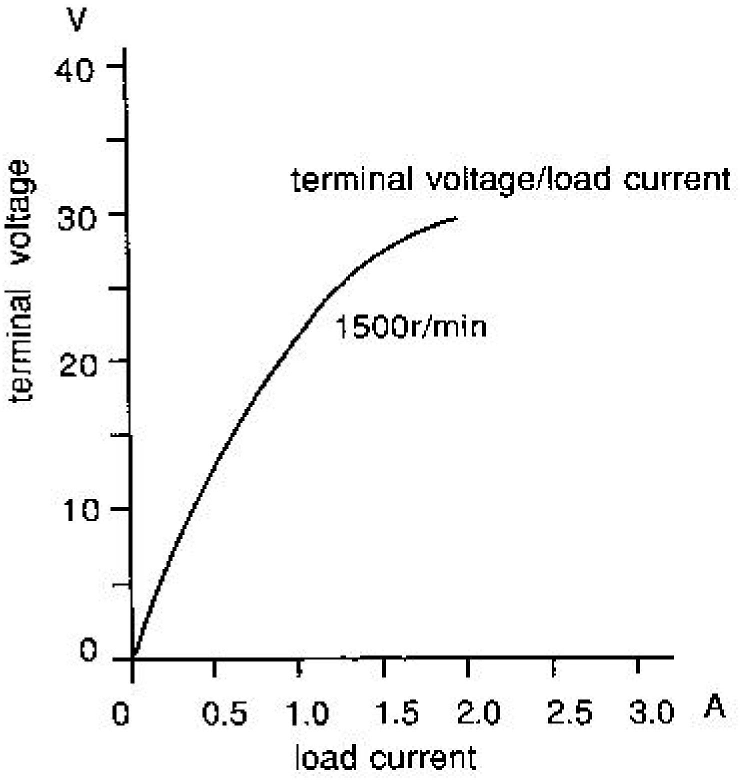


Figure A22-4: Characteristic of dc Series Generator with Interpoles

Question 22.1

You should find that the terminal voltage for a given load current is appreciably greater than before (eg, 23V against 17V for a 1 A load current). This is due to the elimination by the interpoles of the flux reduction caused by armature reaction. However the graph still curves over, peaking at about the same load current of 2.5A; this is where saturation commences.

Question 22.2

Your graph of E versus N should be a good straight line passing through, or very close to, the origin. This is what you would expect by the following reasoning.

$$V_t = E - I_l R_t$$

where E = generated emf = $K_1 N \Phi$
I_l = load current = 0.5 A
R_t = total series resistance = 10Ω

Since Φ is constant for a given load current, this is equivalent to:

$$V_t + I_l R_t \alpha N$$

or

$$V_t + 5 \alpha N$$

This represents a straight line through the origin.

DISSECTIBLE

MACHINES SYSTEM

Assignment 23

dc Compound Wound Motor

PRACTICAL

PRACTICAL	23.1	Cumulative Compound Motor
	23.2	Differential Compound Motor

EQUIPMENT REQUIRED

	Qty	Item
62-100 Kit	1	Base Unit
	1	Commutator/Slipring
	2	Brushes and Brushholders
	2	L1 Coils
	2	L2 Coils
	2	L4 Coils
	2	L5 Coils
	2	Field Poles
	1	Rotor Hub
	4	Rotor Poles
General	1	0-50 V, 5A, dc Supply (eg, Feedback 60-105)
	1	0-50 V, dc Voltmeter
	1	0–5 A dc Ammeter (eg, Feedback 68-110)
	1	Friction (Prony) Brake or other Dynamometer: 0-1 Nm at 1500 rev/min (eg, Feedback 67-470)
	1	Optical/Contact Tachometer (eg, Feedback 68-470)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

Compound motors have both series and shunt windings which may be connected to assist - cumulative compound, or oppose - differential compound.

Cumulative compound motors have characteristics resembling those of a series motor but have no tendency to race when the load is removed as the no-load speed is fixed by the shunt field. Applications include lift motors, rolling mill drives, etc.

In the differential case, increasing armature current causes a decrease in net flux which tends to maintain constant shaft speed. However, heavy starting currents or overloads may allow the series field to predominate, causing excessive armature current or even reversal of rotation.

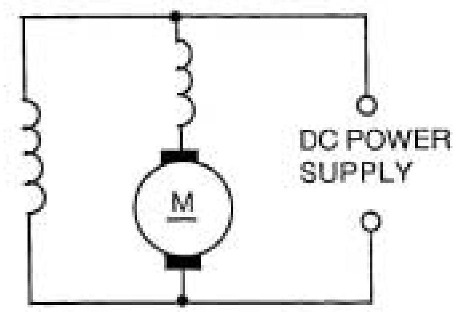


Figure A23-1: dc Compound Motor, Long Shunt Circuit Diagram

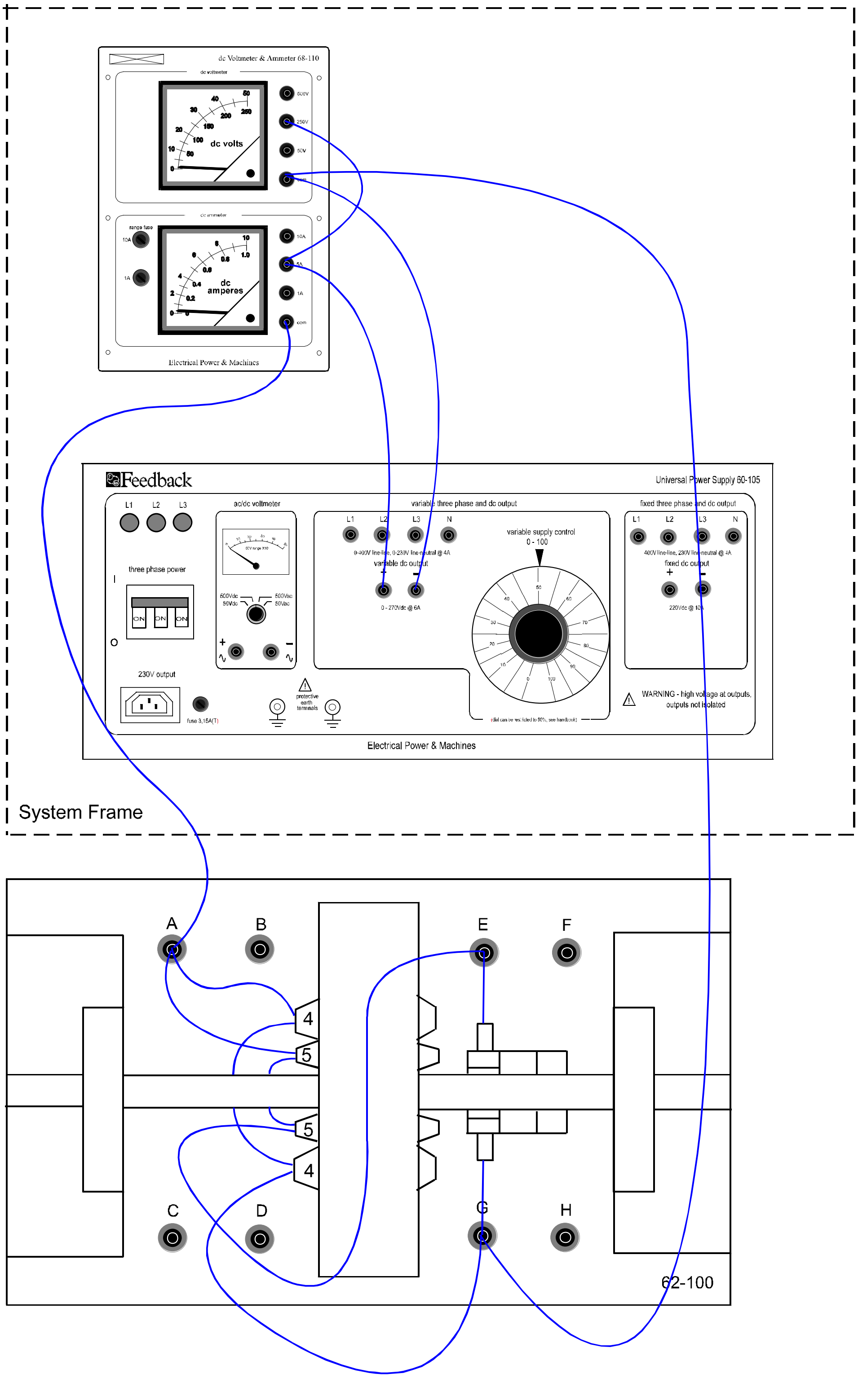


Figure A23-2: Connections for dc Compound Motor Cumulative Connection

ASSEMBLY

Fix the armature and commutator to the shaft as shown in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 1 and fit the shaft into its bearings. Before finally tightening the bearing housing screws into the baseplate, check that the shaft rotates freely and moves axially against the pre-loading washer.

Fit coils L4 and L5 to each field pole and fix these to the frame ring in the 3 o'clock and 9 o'clock positions using the long socket-head screws.

Place the brushes in their holders and screw these into position on each side of the commutator. Cheek that the brushes move freely in their holders.

Make the circuit shown in the wiring diagram Figure A23-3 in accordance with the connections shown in Figure A23-2, which is for the cumulative compound version of the motor with long shunt (ie, the shunt winding is across the supply and not across the armature, which would be a short shunt).

Fasten the band brake to the baseplate and adjust for zero load initially. Instructions for mounting the Friction (Prony) Brake 67-470 are given in Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 6.

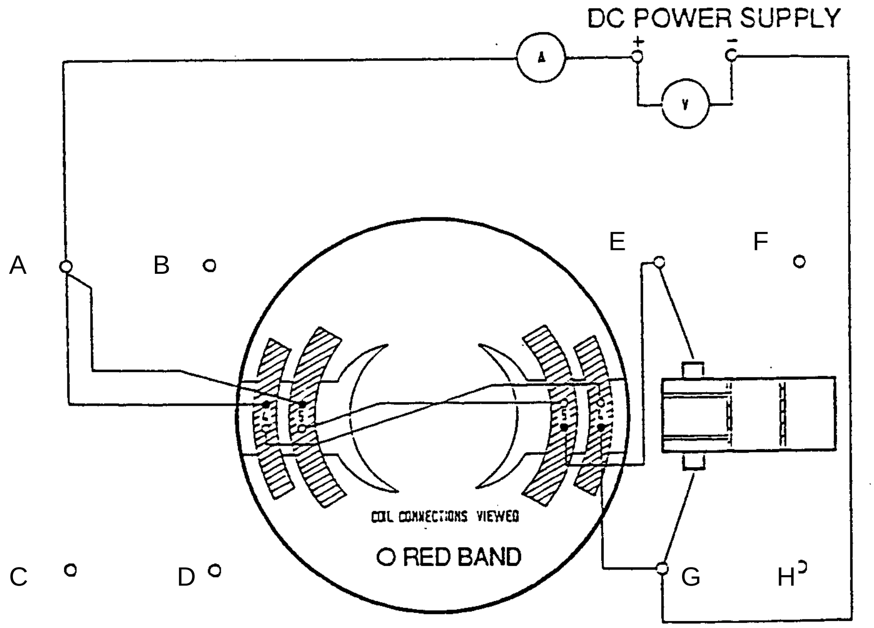


Figure A23-3: dc Compound Motor Cumulative Connection Wiring Diagram

PRACTICAL 22.1

Cumulative Compound Motor

Switch on the power supply, adjust to 40 V and maintain at this level throughout the test. Take readings of speed and supply current for increasing steps of brake loading.

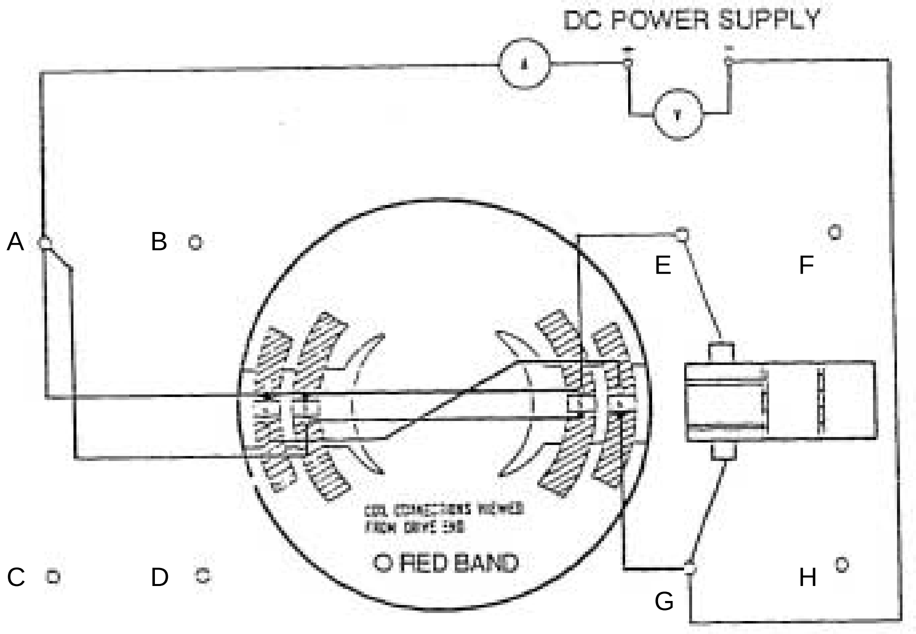


Figure A23-3: dc Compound Motor Differential Connection Wiring Diagram

Differential Compound Motor

Connect the series field coils in parallel with one another and in reverse polarity to the previous test, as shown in Figure A23-4. Switch on the power supply and note that as the applied voltage is increased, the motor will tend to start in reverse due to the flux set up by the series field. To overcome this, short-circuit the series field at starting.

With the motor running with the same rotation as in the cumulative compound case, raise the voltage to 40 V and again read the speed, current and torque for different shaft loadings and constant terminal voltage.

> NOTE:
>
> If the applied load is too great, the series field may overcome the main field and reverse the direction of rotation.

Exercise 23.1

The resistance of the shunt field windings is about 40 ohms so at 40 V supply, they absorb 1 A of the total supply current. Deduct this amount from each of your current readings for both machines to find the true armature current and then plot both it and the speed against torque.

Your curves should resemble those given in Figure A23-5 and A23-6.

Exercise 23.1

For the cumulative connection only, calculate the output power as:

$$\frac{2\pi N T}{60}$$

and the input power as the products of supply voltage and current (includes shunt power) and hence find the efficiency s:

$$\frac{\text{Power out}}{\text{Power in}} \times 100\%$$

Plot this against torque on Figure A23-5.

Question 23.1 ***Can you explain qualitatively the shape of the speed/torque graph for cumulative connection?***

Question 23.2 ***At what speed does the cumulative compound motor run when unloaded?***

Question 23.3 ***What is the maximum efficiency of the cumulative compound motor?***

Question 23.4 ***Why does the differential compound motor tend to stall and then run in reverse when the load reaches a certain value, and at what value does this happen from you results?***

Question 23.5 ***On Figures A23-3 and A23-4, mark the direction of current flow in the various windings to satisfy yourself that they do give cumulative and differential action respectively.***

Notes

Exercise 23.1

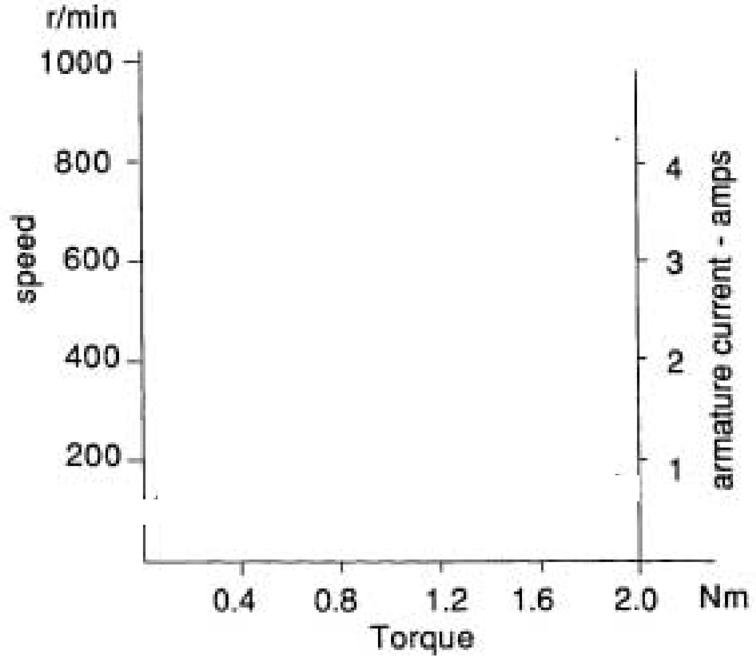


Figure A23-5 Graph Axes

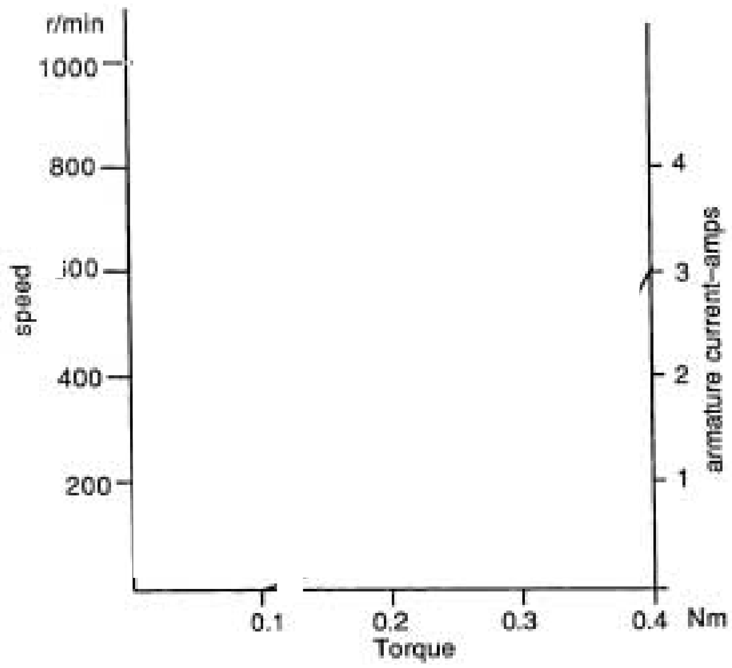


Figure A23-6 Graph Axes

Notes

Exercise 23.1

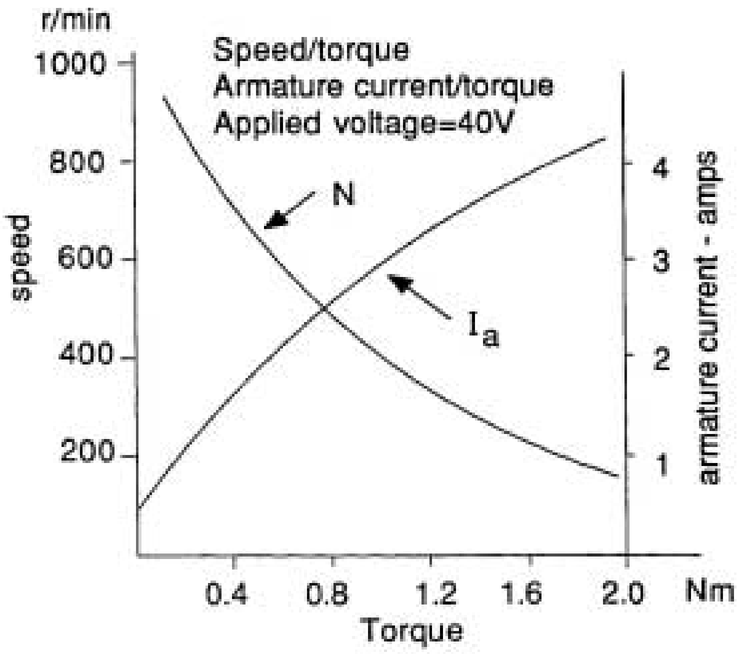


Figure A23-5: Characteristic of dc Compound Motor, Long Shunt Cumulative

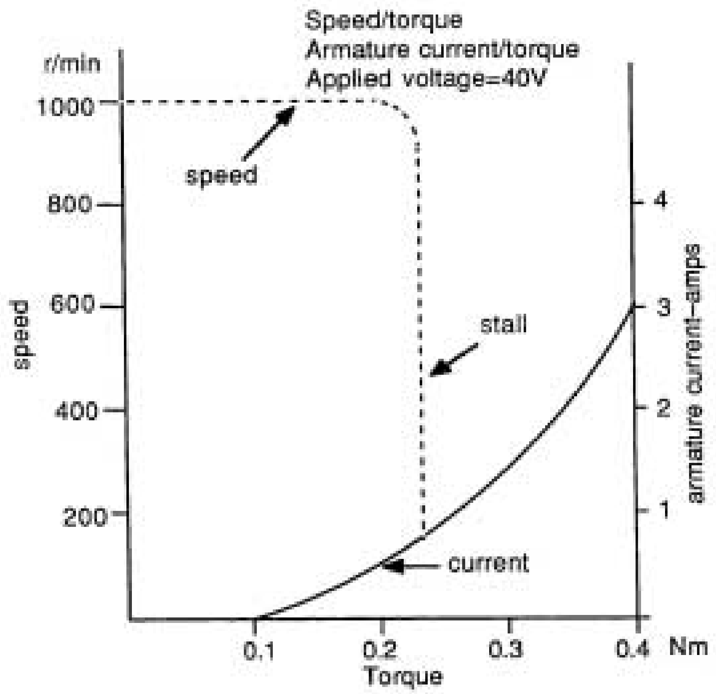


Figure A23-6: Characteristic of dc Compound Motor, Long Shunt Differential

Question 23.1

The series field gives the cumulative compound motor the general characteristic of a series machine since, at high loads and hence at high armature current, this field predominates. Thus, a high-starting torque is obtained. At low loads, the series field is negligible and the shunt field gives a defined no-load speed.

Question 23.2

The cumulative compound motor, instead of running to a high speed at no load, runs at about 900 rev/min.

Question 23.3

The maximum efficiency of the cumulative compound motor is about 30%.

Question 23.4

The differential compound motor tends to stall because as the armature current rises the increasing series field opposes the steady shunt field and soon reduces the net field to a value insufficient to supply the load torque. As stalling commences the armature current rises due to the drop in speed and thus in back-emf so the available torque reduces still further.

The effect is thus cumulative and the motor stalls out of control. The series field is now completely predominant and, being oppositely polarized, causes the motor to run in reverse.

Stall occurs at quite a low value of load torque typically 0.2 to 0.3 Nm. However, over the useful load range, the speed is virtually constant.

See 'Matching the Motor to its Load' in Appendix A of this manual for further notes on compound machine applications.

DISSECTIBLE

MACHINES SYSTEM

Assignment 24
dc Compound Wound Motor with Interpoles

PRACTICAL 24.1

EQUIPMENT REQUIRED	**Qty**	**Item**
62-100 Kit	1	Base Unit
	1	Commutator/Slipring
	2	Brushholders with Brushes
	2	L1 Coils
	2	L2 Coils
	2	L4 Coils
	2	L5 Coils
	2	Field Poles
	1	Rotor Hub
	4	Rotor Poles
	2	L8 Coils
	2	Interpoles
General	1	1-50 V, 5 A, dc Supply (eg, Feedback 60-105)
	1 1	0-50 V, dc Voltmeter 0–5 A dc Ammeter (eg, Feedback 68-110)
	1	Friction (Prony) Brake or other Dynamometer: 0-1 Nm at 1500 rev/min (eg, Feedback 67-470)
	1	Optical/Contact Tachometer (eg, Feedback 68-470)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

Interpoles are added to the compound motor to improve commutation on load. The polarity of each interpole in a dc motor is opposite to that of the next main pole with respect to direction of rotation.

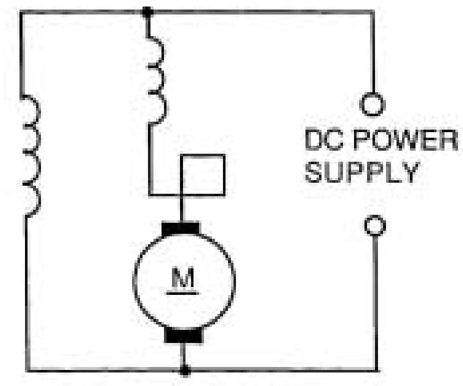


Figure A24-1: dc Compound Motor (Long Shunt) with Interpoles Circuit Diagram

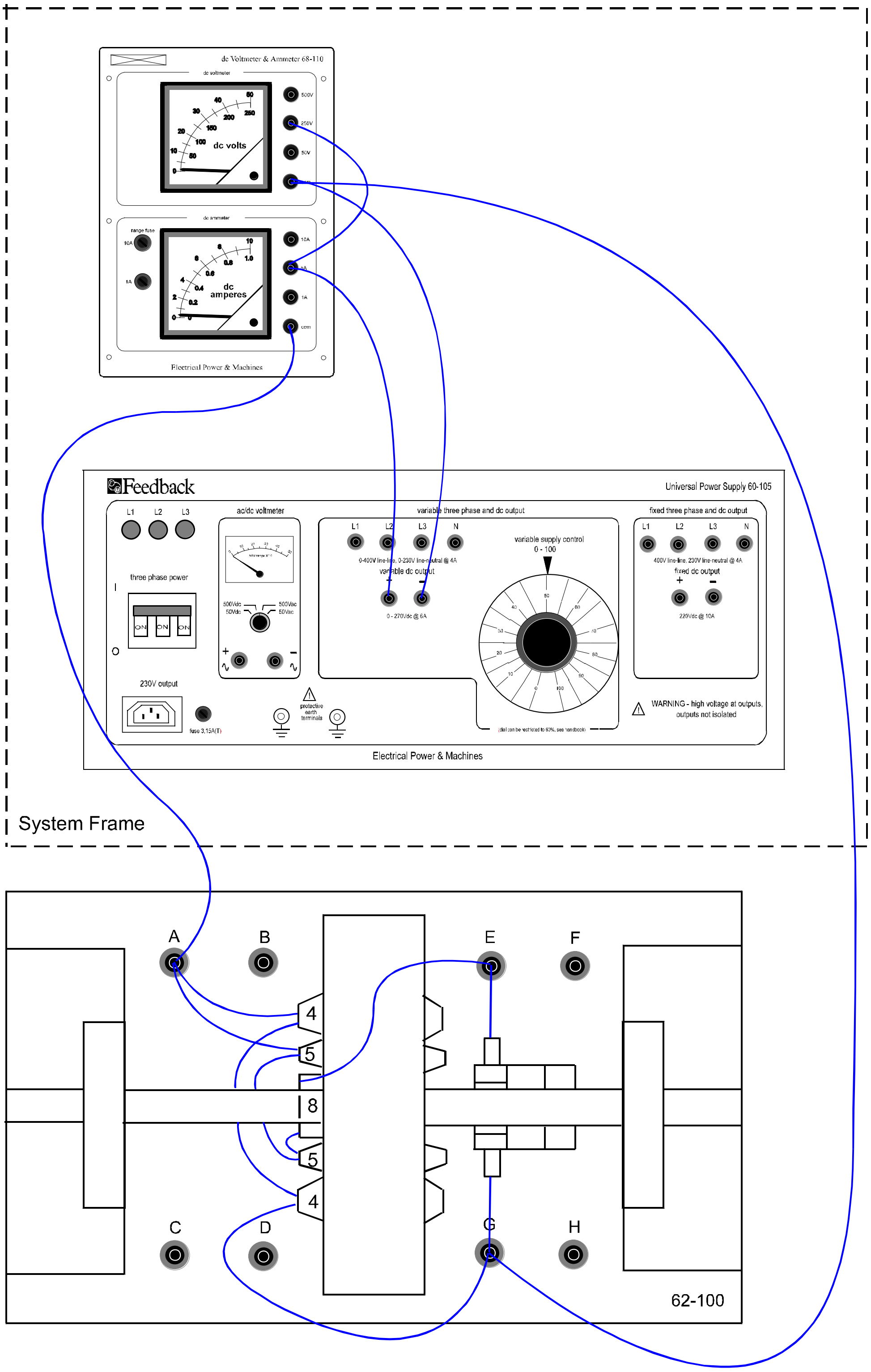


Figure A24-2: Connections for dc Cumulative Compound Motor with Interpoles

ASSEMBLY

Follow the instructions for Assignment 23 then attach the interpoles with their coils to the frame ring in the 6 o'clock and 12 o'clock positions. Connect as shown in Figures A24-3 and A24-2 and set the commutator so that the slots between segments are in line with the armature pole gaps.

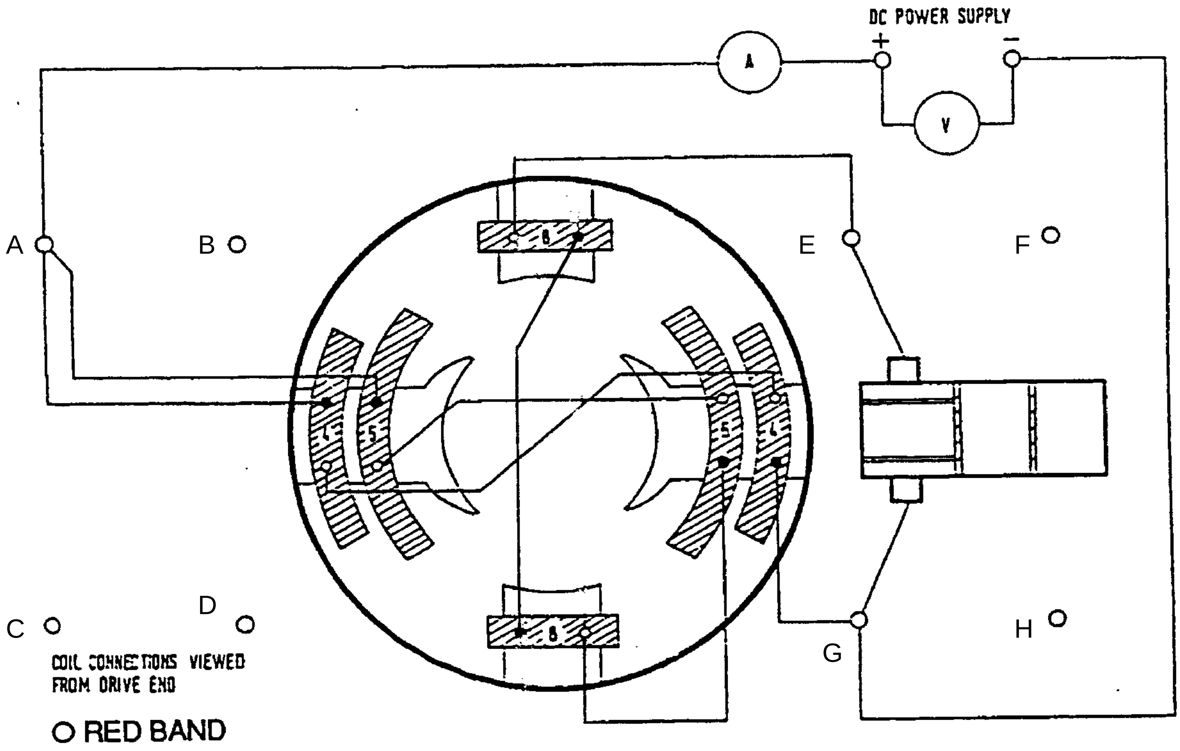


Figure A24-3: dc Cumulative Compound Motor with Interpoles Wiring Diagram

PRACTICAL 24.1

Connect shorting links across the interpole coil terminals and with the motor running on-load observe the level of sparking at the brushes. Disconnect the shorting links and note the reduction in sparking which results.

Exercise 24.1

On Figure A24-3, establish the direction of current flow in all windings and also the direction of rotation, thus satisfying yourself that the interpoles are opposite in polarity to the next main pole in the direction of rotation.

DISCUSSION

Please see the Discussion of Assignment14 for an explanation of the effect of armature reaction in a motor and its reduction by the use of interpoles.

DISSECTIBLE

MACHINES SYSTEM

Assignment 25

dc Compound Generator

PRACTICAL 25.1

25.2

EQUIPMENT REQUIRED

	Qty	**Item**
62-100 Kit	1	Base Unit
	1	Commutator/Slipring
	2	Brushes and Brushholders
	2	L1 Coils
	2	L2 Coils
	2	L4 Coils
	2	L5 Coils
	2	Field Poles
	1	Rotor Hub
	4	Rotor Poles
	1	Flexible Coupling
General	1	Variable Speed Motor: 1/3 hp, 1200 rev/min, (eg, Feedback 63-501)
	1	0-100 V, dc Voltmeter
	1	0–5 A dc Ammeter (eg, Feedback 68-110)
	1	Variable Resistor, 0-200 ohms, 2.5 A (eg, Feedback 67-113)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

The compound generator utilises both series and shunt field windings connected to assist one another. On load the series winding produces an additional flux which compensates for the effects of armature reaction and internal resistance drops. The terminal voltage can therefore be held at an almost constant level over the load range of the generator. The shunt field may be connected across the output terminals, termed long shunt, or more usually across the armature, termed short shunt.

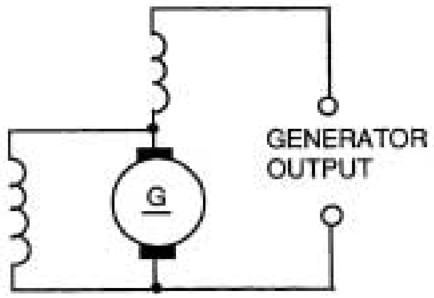


Figure A25-1: dc Cumulative Compound Generator, Short Shunt Circuit Diagram

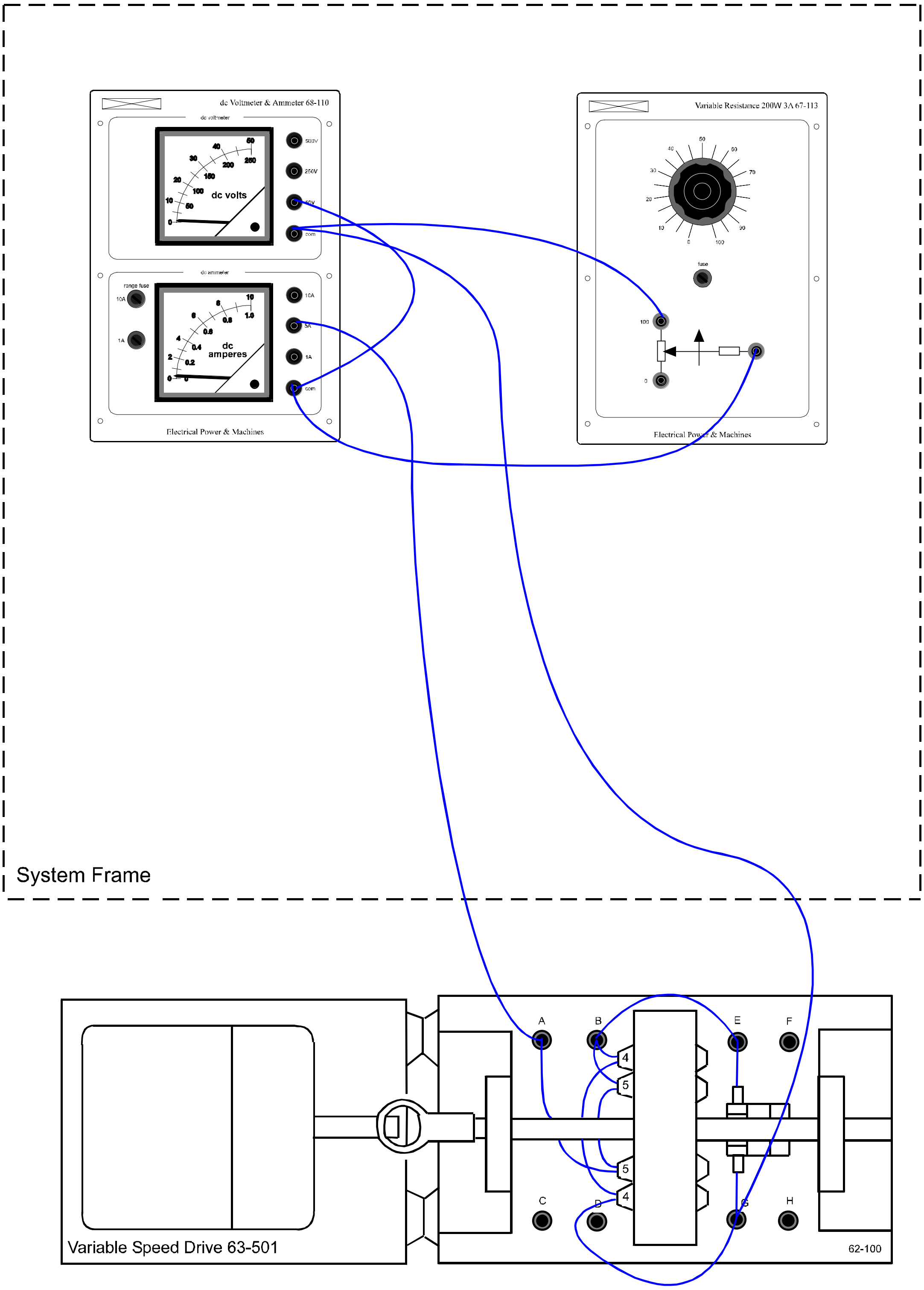


Figure A25-2: Connections for dc Cumulative Compound Generator, Short Shunt

ASSEMBLY

Fix the armature and commutator to the shaft as shown in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 1 and fit the shaft into its bearings. Before finally tightening the bearing housing screws in the baseplate, check that the shaft rotates freely and moves axially against the pre-loading washer.

Fit the field poles with their L4 and L5 coils to the frame ring at the 3 o'clock and 9 o'clock positions.

Place the brushes in their holders and attach the holder to the mounting block positions on each side of the commutator, check that the brushes move freely in their holders.

Make the circuit shown in Figure A25-3 in accordance with the connections shown in Figure A25-2. These are the same as for the cumulative compound motor except that the series field connections have been reversed. Attach the drive motor baseplate to that of the base unit, align the shafts and connect them by a flexible coupling as explained in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 7.

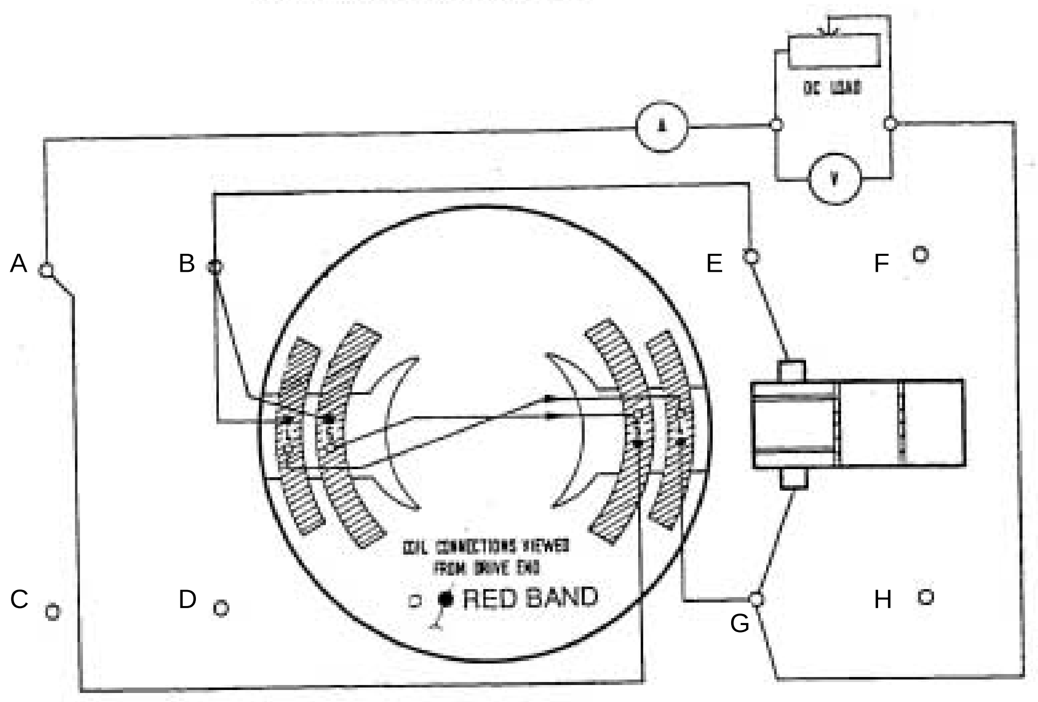


Figure A25-3: dc Cumulative Compound Generator, Short Shunt Wiring Diagram

PRACTICAL 25.1

In any self-excited generator, the initial build-up of voltage is dependent on some residual magnetism being present in the field circuit. This may be negligibly small in a new machine and it will then be necessary to momentarily 'excite' the field coils from a low-voltage dc source.

With a shaft speed of 1000 rev/min, the terminal voltage on no-load should be approximately 24 V. Increase the loading in steps and take readings of terminal voltage and load current at each step, maintaining the shaft speed constant. The graph of Figure A25-4 shows the characteristic curves obtained at different speeds.

PRACTICAL 25.2

Comparison with the Shunt Generator

The cumulative compound generator uses the same (L4) shunt windings as are used by the shunt generator of Assignment 15. If you have not yet tested Assignment15, you can make a quick comparison as follows.

Set the compound generator drive speed to 1200 rev/min and adjust the load resistor to give a load current of about 0.5 A. Reset the speed if necessary and note the terminal voltage and load current.

Now short out the series windings L5 by a link, reset the speed to 1200 rev/min, and again note the terminal voltage and load current.

Exercise 25.1

Calculate the electrical power delivered to the load by each of the compound and shunt generators.

Question 25.1

Which generator gives the greater power into a fixed load at a fixed speed?

Question 25.2

Why did the speed tend to rise when the short-circuit was placed across the series windings?

Practical 25.1

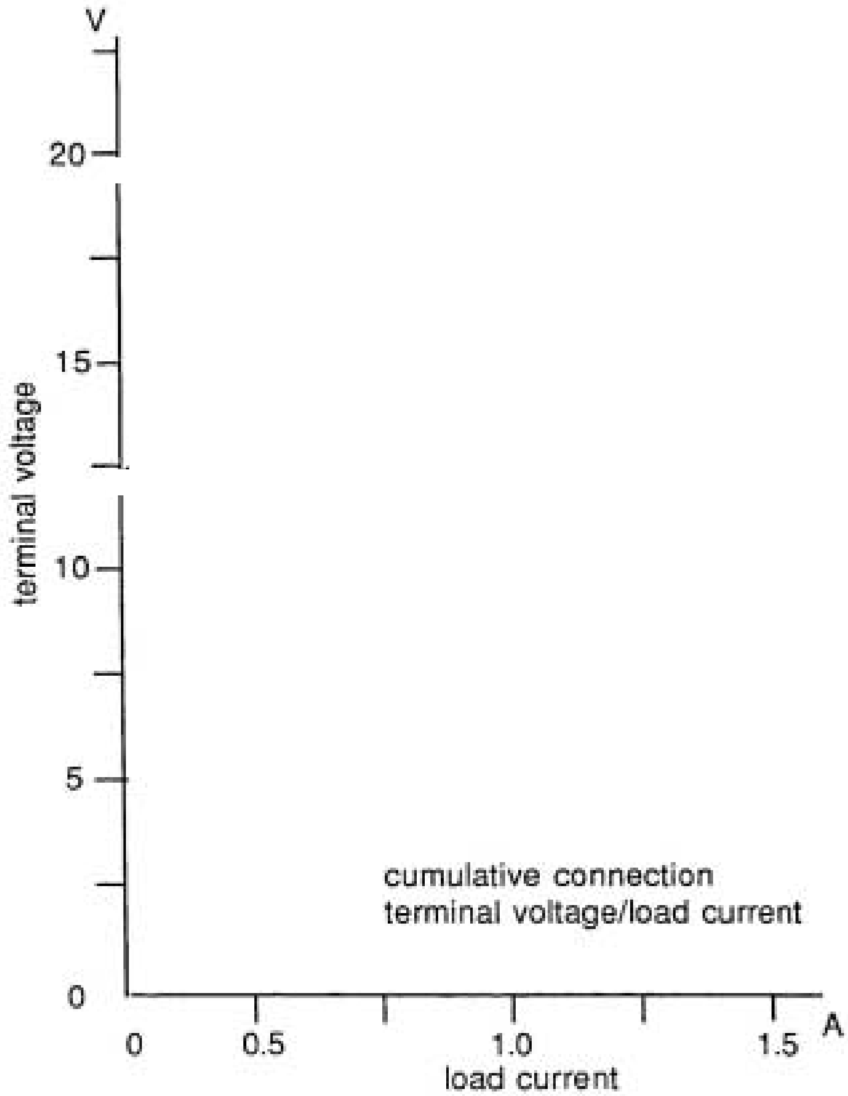


Figure A25-4 Graph Axes

Notes

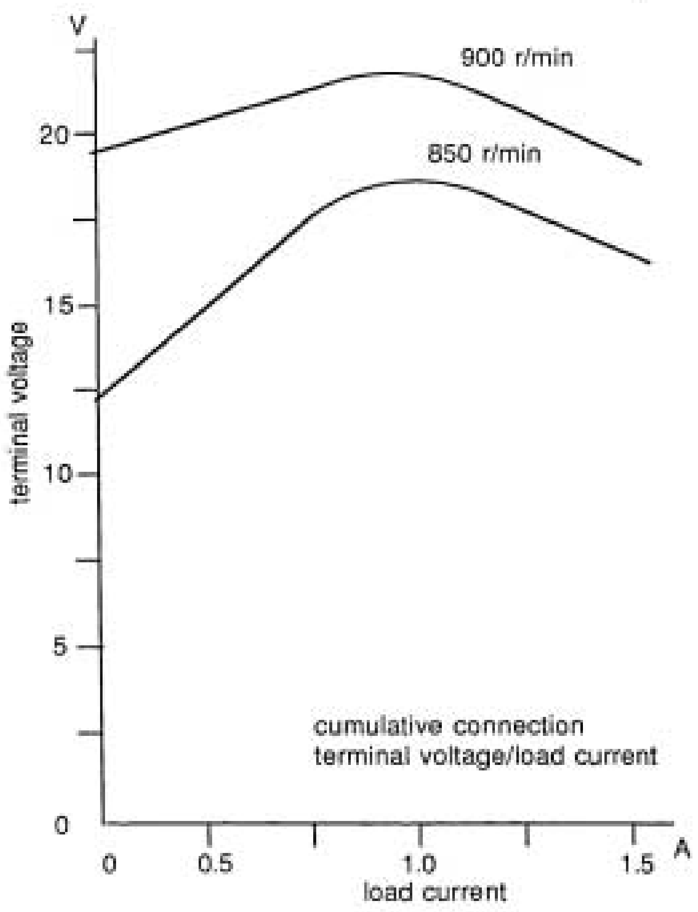


Figure A25-4: Characteristic for dc Cumulative Compound Generator, Short Shunt

Question 25.1 The compound generator gives the greater power, typically 9W compared with 3.5W for the shunt generator at the same speed.

Question 25.2 When the series winding is short-circuited, the field due to the load current vanishes so that the terminal voltage fails and with it the load current. The power delivered thus falls considerably, demanding a smaller input power from the drive motor whose speed therefore rises slightly.

Notes

DISSECTIBLE

MACHINES SYSTEM

Assignment 26
dc Compound Wound Generator with Interpoles

PRACTICAL 26.1

26.2

EQUIPMENT REQUIRED	**Qty**	**Item**
62-100 Kit	1	Base Unit
	1	Commutator/Slipring
	2	Brushes and Brushholders
	2	L1 Coils
	2	L2 Coils
	2	L4 Coils
	2	L5 Coils
	2	Field Poles
	1	Rotor Hub
	4	Rotor Poles
	2	L8 Coils
	2	Interpoles
	1	Flexible Coupling
General	1	Variable Speed Motor: 1/3 hp, 1200 rev/min, (eg, Feedback 63-501)
	1	0-100 V, dc Voltmeter
	1	0–5 A dc Ammeter (eg, Feedback 68-110)
	1	Variable Resistor, 0-200 ohms, 2.5 A (eg, Feedback 67-113)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

The addition of interpoles to the compound generator improves commutation when the machine is on load. The polarity of each interpole in a dc generator is the same as that of the next main pole with respect to direction of rotation.

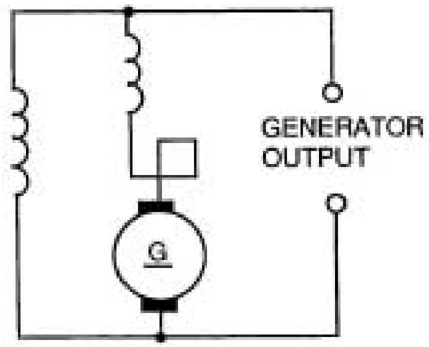


Figure A26-1: dc Cumulative Compound Generator, Long Shunt with Interpoles Circuit Diagram

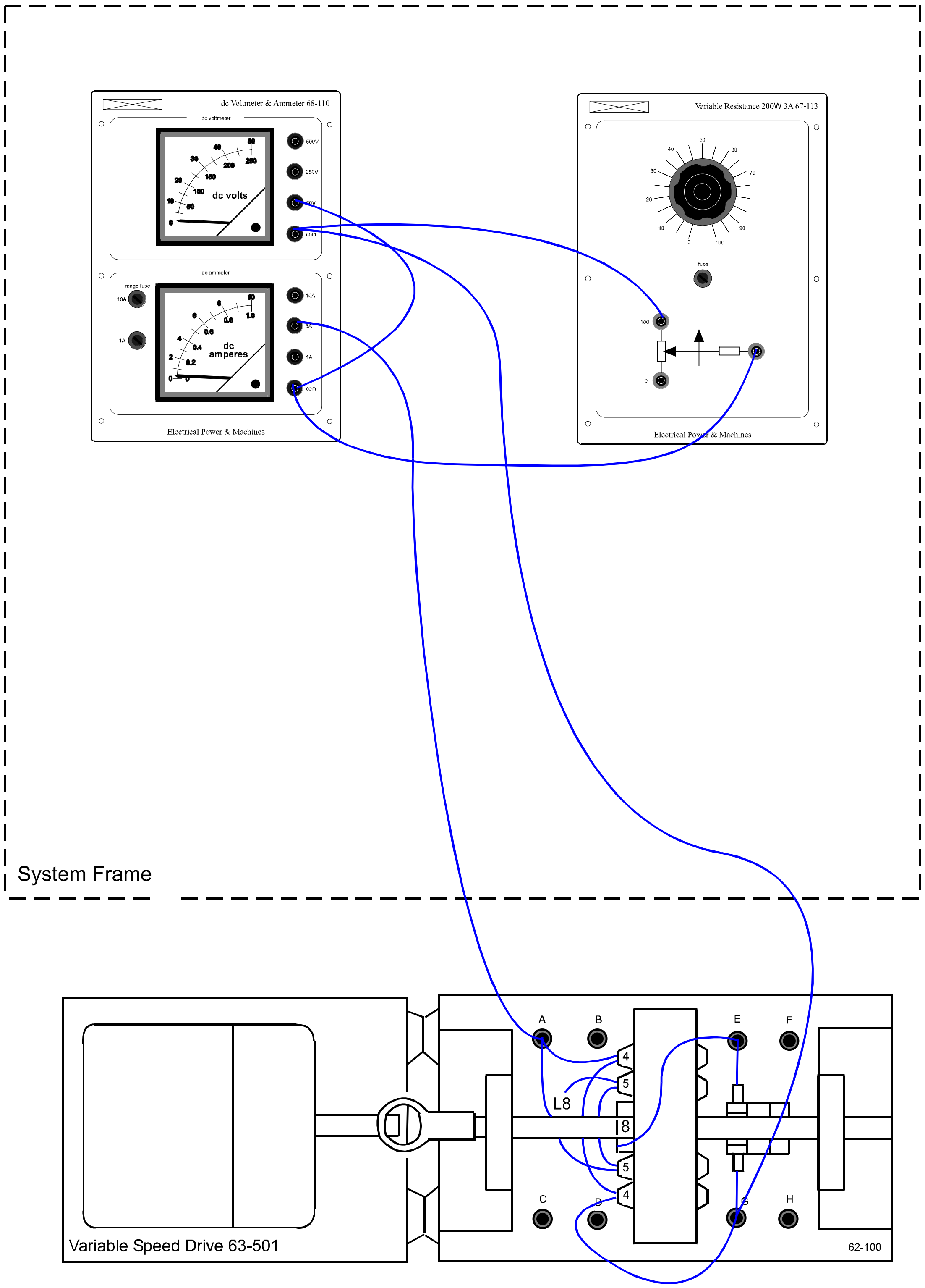


Figure A26-2: Connections for dc Cumulative Compound Generator, Long Shunt with Interpoles

ASSEMBLY

Follow the instructions for Assignment 25 then attach the interpoles with their coils to the frame ring in the 6 o'clock and 12 o'clock positions. Connect as shown in Figure A26-3 and A26-2. Note that for this test a 'long shunt' connection is used. Set the commutator so that the slots between segments are in line with the armature pole gaps.

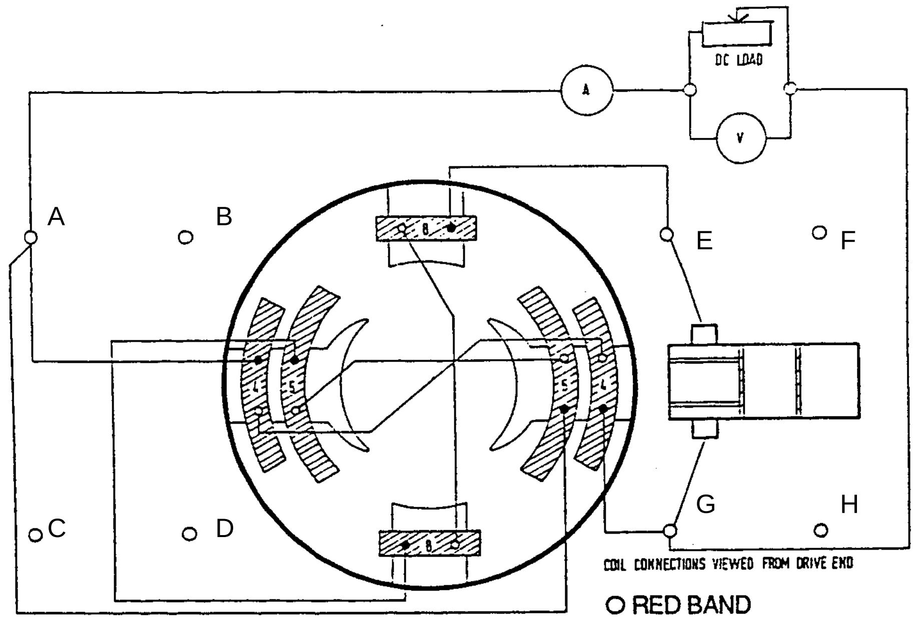


Figure A26-3: dc Cumulative Compound Generator, Long Shunt with Interpoles Wiring Diagram

PRACTICAL 26.1

Run the generator on load but with the interpoles made ineffective by shorting links connected across the interpole coil terminals.

Observe the level of sparking at the brushes, then remove the shorting links and re-adjust the speed to give the same loading as before. There will be a marked improvement in commutation as shown by the reduction of sparking to pin-point level.

PRACTICAL 26.2

Comparison with the Short Shunt

Short out the interpole windings and take readings of terminal voltage and load current for different load resistances, keeping the speed at 1000 rev/min throughout.

Exercise 26.1

Establish on Figure A26-3 the direction of all winding currents and the direction of rotation. Satisfy yourself that an interpole and the next main pole in the direction of rotation are of the same polarity, as they should be for a generator.

Exercise 26.2

Plot terminal voltage against load current preferably on the same sheet of graph paper you used for Assignment 25.

DISCUSSION

This assignment, as well as demonstrating the effect of the interpoles, also illustrates the long shunt arrangement. In this the current drawn by the shunt winding flows in the series winding so that even at zero external load the series winding has the effect of raising the terminal voltage. Your plot of Exercise 26.2 should show this but will also show that the terminal voltage falls more steeply with increase of load current than it did for the short shunt connection.

The reason for the steeper slope can be seen by reference to Figure A26-4.

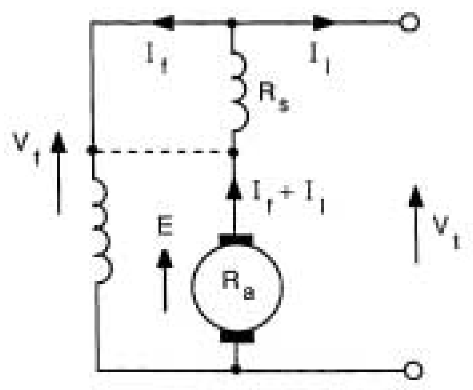


Figure A26-4

At no load flux, say Φ_0, gives a generated emf E so that:

$$V_t = E - I_f (R_a + R_s)$$

As I_l increases, Φ_0 tends to increase due to the additional current on the field winding and this increase helps to offset the reduction of V_t caused by the voltage drop due to the extra current in (R_a + R_s). This is how either form of compound generator works.

In the long shunt arrangement, the voltage across the shunt winding, V_f, is subject to a restive drop of I_l (R_s+R_a) for every increase in the load current. This is greater than the drop due to the same increase in current in the short shunt connection (shown dotted in Figure A26-4), which is only $I_l R_a$. Thus the shunt excitation current falls more rapidly in the long shunt than in the short, and the generated emf does the same. The effect of resistive drops on the terminal voltage due to an increase in I_l is the same in both cases so the net effect is that the terminal voltage fails more quickly in the long shunt connection.

For an explanation of the effect of armature reaction in a generator and its reduction by the use of interpoles, please refer to the discussion of Assignments 14 and 16.

Notes

Chapter 3-4

AC Machine Assignments

This chapter contains ac machine assignments as follows:

No.	
27/28)	ac Single-phase, 4-pole, Squirrel-cage Induction Motor, Capacitor Start and Run, Resistor Start
29/30)	ac Single-phase, 2-pole, Squirrel-cage Induction Motor, Capacitor Start and Run, Resistor Start
31/32)	ac Single-phase Series or 'Universal' Motor. Concentrated and Distributed Field
33/34)	ac Single-phase Repulsion Motor. Fixed and Variable Brush Angle
35)	ac Single-phase, 2-pole, Synchronous Motor, Rotating Field, Distributed Stator Winding
36)	ac Single-phase, 4-pole, Synchronous Motor, Rotating Field, Distributed Stator Winding
37/38)	ac Single-phase Generator, Rotating Field. Concentrated and Distributed Stator Winding
39)	ac Single-phase Generator, Rotating Armature
40)	ac 3-phase, 4-pole, Squirrel-cage Induction Motor. 4-pole Distributed Stator Winding
41)	ac 3-phase, 2-pole, Squirrel-cage Induction Motor. 2-pole Distributed Stator Winding
42)	ac 3-phase, Synchronous Motor 2-pole, Rotating Field, Distributed Stator Winding
43)	ac 3-phase, Synchronous Generator 2-pole, Rotating Field, Distributed Stator Winding
44)	ac Brushless Generator
45/46)	Synchro Position-indicator and Synchro Control Transformer (two 62-100's required)
47)	Variable Ratio Transformer
48)	Motor-generator Set

Notes

DISSECTIBLE

MACHINES SYSTEM

Assignment 27/28
ac Single-Phase, 4-Pole Squirrel-Cage Induction Motor

PRACTICAL

PRACTICAL	27.1	No Load
	27.2	Load Tests
	27.3	Stall Test
	27.4	Supply Voltage Test

EQUIPMENT REQUIRED

	Qty	**Item**
62-100 Kit	1	Base Unit
	1	Centrifugal Switch
	1	12-slot Wound Stator
	1	Squirrel-Cage Rotor
General	1	0-135 V, Single-Phase ac Supply (eg, Feedback 60-121)
	1	0-200 V, ac Voltmeter
	1	0-5 A, ac Ammeter (eg, Feedback 68-117)
	1	Resistor/Capacitor Unit (eg, Feedback 67-190)
	1	Friction (Prony) Brake or other Dynamometer: 0-1 Nm, 1500 rev/min (eg, Feedback 67-470)
	1	Optical/Contact Tachometer (eg, Feedback 68-470)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

The widespread use of the single-phase induction motor is due mainly to its low cost and simplicity coupled with the ready availability of single-phase ac supplies. It is not inherently self starting because the flux produced by a single-phase winding merely alternates in polarity. To obtain the required rotating field, the stator must be wound for two or more phases.

Most motors of this type are wound as two-phase machines with the main and starting circuits initially in parallel across the single-phase supply but designed so that the currents in the two windings differ in phase. The necessary phase shift can be made by connecting a capacitor in series with the starting winding or alternatively winding it with fewer turns of smaller diameter wire than is used in the main winding so that its resistive component is increased. As the motor approaches its operating speed, this winding can be switched off, although in some motors it is left connected to the supply with a reduced value of series capacitance. In either case, a centrifugal switch is used which operates at approximately 80% of the normal running speed.

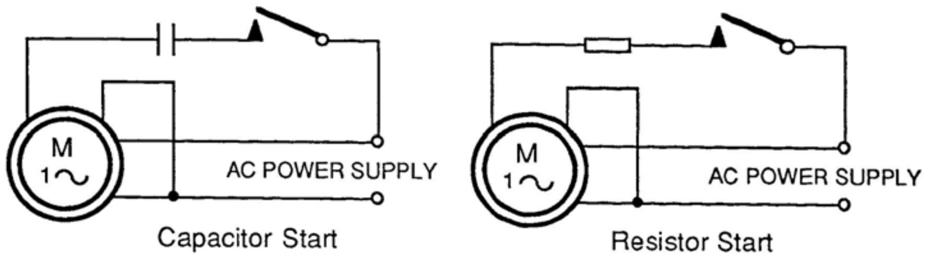


Figure A27-1: ac Single-Phase Induction Motor Circuit Diagram

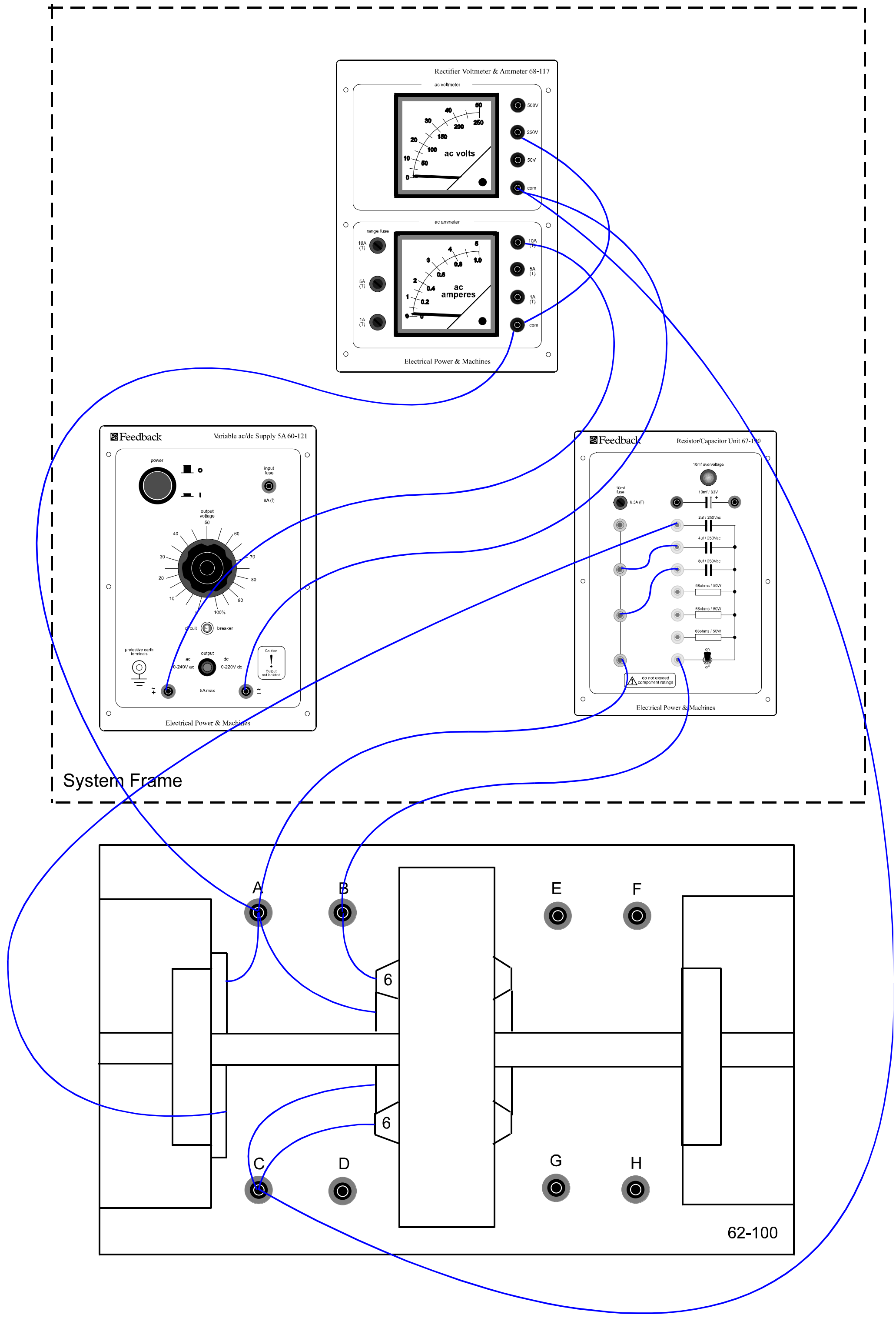


Figure A27-2: 4-Pole, Single-Phase, Induction Motor, Capacitor Start & Run Connections

ASSEMBLY

Mount the stator in the frame ring, with coil No 1 at the top, fixing it in position by three 1 3/8" long cap-head socket screws at the 12, 4 and 8 o'clock positions. Attach the fixed element of the centrifugal switch to the drive-end bearing housing using the screws as described in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 4.

Fit the squirrel-cage rotor to the shaft, locating the hub set screw in the conical recess on the non-drive side of the shaft. Attach the rotating element of the centrifugal switch to the drive-end of the shaft adjacent to the rotor. Fit the shaft into its bearing and screw the removable bearing housing to the baseplate, but before finally tightening down check that the shaft rotates freely and moves axially against the pre-loading washer.

Fasten the friction brake to the baseplate as described in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 6. Adjust the brake for zero load initially.

Make the circuit shown in Figure A27-3 in accordance with the connections shown in Figure A27-2 and Figure A27-4(a). The resistor/capacitor unit is connected in series with the start winding and connected to give capacitor start initially.

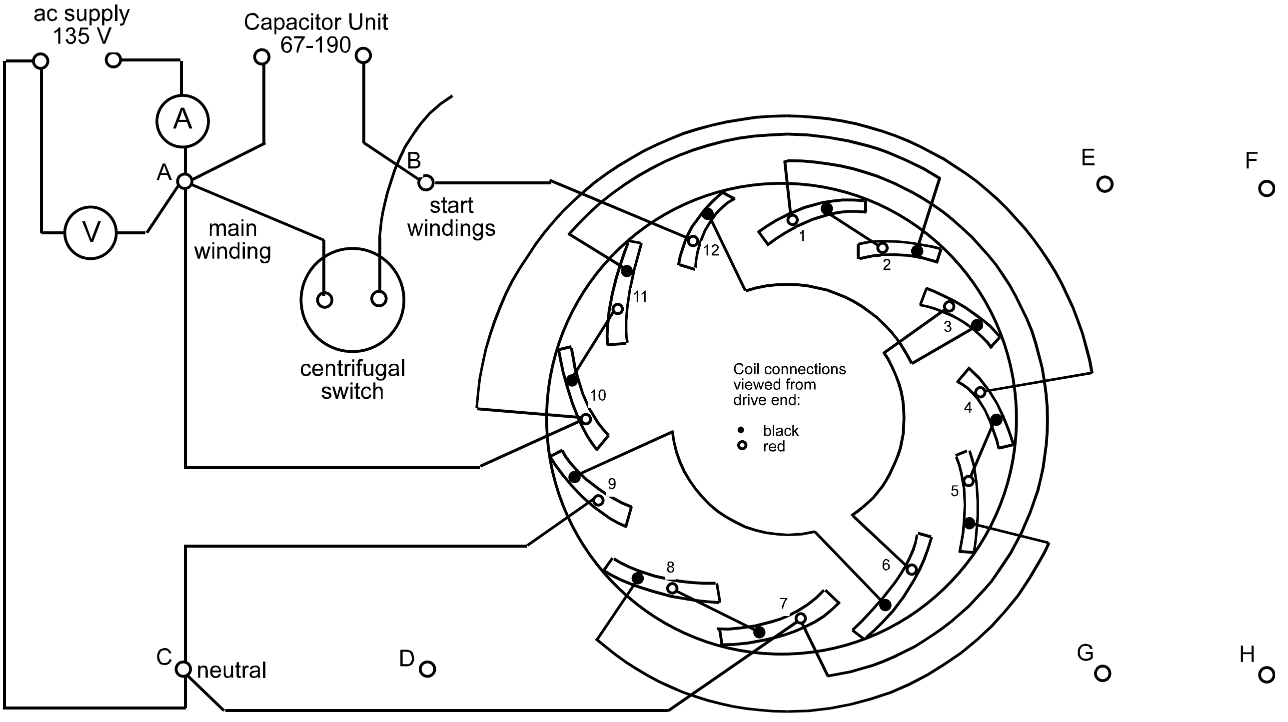
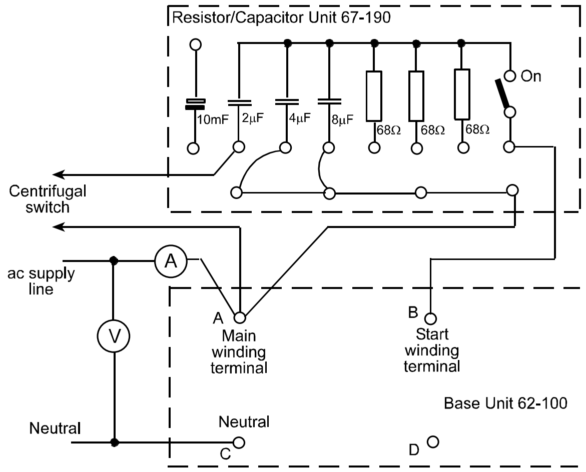
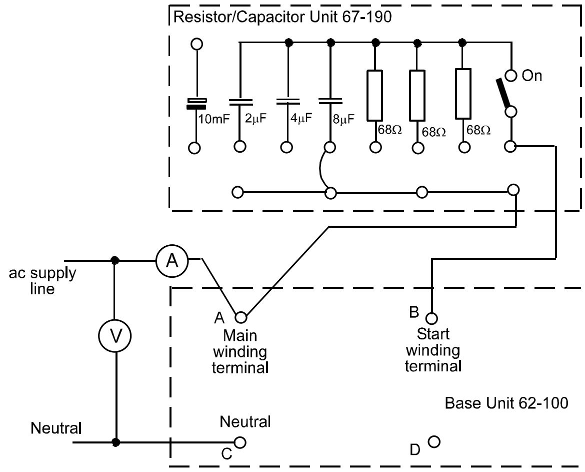


Figure A27-3: 4-Pole, Single-Phase, Squirrel –Cage, Induction Motor – Capacitor or Resistor Start Wiring Diagram



(a) Connections for Capacitor-Start/Run Motor



(b) Connections for Capacitor-Run Load Test

Figure A27-3

PRACTICAL 27.1

An induction motor runs at a speed n, which is dependent on the supply frequency f, pole pairs p, and fractional slip s. In this four-pole assembly, p = 2 and taking s = 0.05

$$n = \frac{60}{p} f(1 - s) = \frac{60}{2} x\, 50(1 - 0.05)$$

$\therefore$ operating speed = 1425 rev/min

for the same slip and supply frequency 60 Hz, the speed would be 1710 rev/min.

As the slip varies with load, this equation is only true at one particular value of load.

No Load

Set the value of starting capacitance to 8 μF and switch on the 135 V ac supply to the motor. When the shaft speed reaches approximately 1150 rev/min, the centrifugal switch will operate and cut out the starting circuit or, if the centrifugal switch is not fitted, this can be done manually using the on-off switch on the Resistor/Capacitor Unit. The motor will then run up to its no-load speed of approximately 1470 rev/min.

The effectiveness of different values of starting capacitance can be investigated and the switching arrangements can be altered to permit capacitor start and run operation, using the connections given in Figure A27-4(b). For resistor start

operation, it is only necessary to connect resistors in place of capacitors to give 22 ohm in series with the start winding.

PRACTICAL 27.2

Make the connections required for capacitor-start/run operation, Figure A27-4(a), and switch on the 135 V ac supply to the motor. With the supply voltage constant, increase the brake load in steps measuring shaft speed and stator current at each step.

Reconnect for capacitor-run operation, Figure A27-4(b), with 12μF in circuit and repeat the previous test increasing the load in steps from zero to approximately 0.8 Nm. Plot shaft speed against torque to give curves similar to those of Figure A27-5.

PRACTICAL 27.3

Stall Test

For the capacitor-run connection, gradually increase the load torque until the motor decelerates and stalls, trying to get the best estimate you can of the torque and speed at which this occurs. Also note the torque developed when the rotor is stationary and the supply current in this condition.

PRACTICAL 27.4

Supply Voltage Test

Use the Capacitor-run connection. Apply a small load of about 0.2 Nm and note the speed and the applied stator voltage. Now reduce the applied voltage in steps of 10 V and for each value, note the speed. Do not alter the load torque and continue until the motor stalls.

Question 27.1 ***Over what range of load torque is your capacitor-run motor useful?***

Question 27.2 ***What do you notice about the supply current during acceleration from stand-still?***

Question 27.3 ***Is the starting torque of an induction motor high or low?***

Exercise 27.2

If the slips = $\dfrac{\text{synchronous speed - actual speed}}{\text{synchronous speed}}$

find s for each value of applied voltage in the supply voltage tests and plot V against s
(synchronous speed = 1500 rev/min for 50 Hz and 1800 rev/min for 60 Hz)

Question 27.4 ***What sort of graph do you obtain – linear or not?***

Exercise 27.7 Study Figure A27-3 and satisfy yourself that it produces a four-pole machine by locating N and S against the main windings according to the relevant direction of current flow in them.

DISCUSSION

A full analysis of the principle of single-phase induction motors is beyond the scope of this manual, being appreciably more complex in detail than that of the three-phase machine. Single-phase motors have no starting torque although, as we have seen in this assignment, they can be made to start by the addition of a second, capacitor-fed, stator winding having the effect of producing a component of the field which rotates like that of a three-phase machine. See Appendix A for notes on rotating field production.

However, if the capacitor-start winding is disconnected when the motor is running, it continues to run, proving that torque is now being generated. Although a proper explanation of this is lengthy, it turns out that the resulting performance equations are similar to those for the three-phase motor with a true rotating field, which we will now examine as briefly as possible consistent with obtaining an understanding of this very important type of motor.

The rotating field produced by three-phase alternating currents in a suitably wound stator may be thought of as being physically the same as a constant, unidirectional field (like that of a dc machine) which is mechanically rotated at the synchronous speed N_s where:

$$N_s = \frac{60f}{p} \text{ rev/min}$$

where f = supply frequency in Hz
p = no. of pairs of poles.

This moving field induces emf's in the rotor coils, which in the squirrel -cage type comprise copper rods embedded in an iron frame and short-circuited at the ends by copper plates, by virtue of the motion, just as in a dc generator. These emf's cause currents in the low-resistance rotor coils and the currents react with the field to produce a force on the rotor tending to move it in the direction of rotation of the field. This may be explained by Lenz's Law in that the motion produced will be in a direction such as to reduce the induced currents causing the force.

If the rotor is prevented from moving, the emf and current will be of a frequency corresponding to the rate of field rotation. For example, a four-pole machine at 50 Hz supply has an effective stator field rotation speed of 50/2 rev/sec so that the frequency of rotor emf is 25 Hz. We can call the field rotation frequency, f_s so that:

$$f_s = \frac{f}{p}$$

If the rotor is allowed to rotate and does so at a speed of N_r rev/min, then the speed of the field relative to that of the rotor is $N_s - N_r$ and this is usually expressed as a fraction s of the synchronous speed N_s and is called the slip speed.

Thus slip speed $= s\,N_s = N_s - N_r$

and slip $= s = \dfrac{N_s - N_r}{N_s}$

that is, s = 1 at standstill and 0 at synchronous speed.

Obviously, an induction motor cannot reach synchronous speed since, were it to do so, there would be no relative motion of field and rotor (slip speed zero), no induced emf, no current and hence no torque. Since there will always be friction and other losses, some slip must always occur.

The frequency of the emf and current induced in the rotor at rotor speed N_r is clearly proportional to N_s-N_r so that if f_r is the rotor frequency:

$$f_r = s\,f_s$$

Now that we have seen the broad principle of torque generation, let us determine quantitatively the torque on one pair of opposite conductors in the rotor, forming a rotor coil as shown in Figure A27-6.

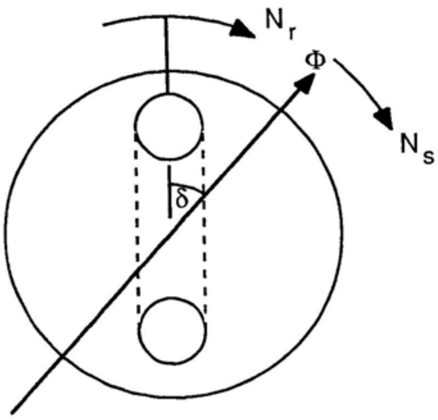


Figure A27-6

In Figure A27-6, δ is the instantaneous angle between the field Φ and the plane of the coil and is increasing with time at the slip speed so that:

$$\delta = 2\pi\ s\ f_s\ t = s\ \omega_s\ t$$

where $\omega_s = 2\pi\ f_s$

The flux linked with the rotor coil is:

$$\Phi \sin \delta = \Phi \sin s\ \omega_s\ t$$

and the emf induced in the coil is proportional to the time differential of the flux or:

$$\frac{d}{dt}\ \Phi \sin s\ \omega_s t = s\omega_s \cos s\omega_s\, t$$

This gives rise to a current:

$$i = \frac{s\,\omega_s \Phi}{\sqrt{R^2 + (sX)^2}} \cos\,(s\omega_s t - \theta)$$

where R = rotor coil resistance

X = rotor coil inductive reactance at standstill (so that at Slip s, it is sX

$\theta = \arc\tan \frac{sX}{R}$, which is the angle by which the current in the rotor lags the induced emf.

The instantaneous torque on the coil, carrying current i, due to the field Φ at an instantaneous angle δ is proportional to:

$$\Phi \text{ i} \cos \delta = \Phi \text{ i} \cos s\,\omega_s t$$

$$= \frac{s\omega_s \Phi^2}{\sqrt{R^2 + (sX)^2}} \cos(s\omega_s t - \theta)$$

$$= \frac{s\omega_s \Phi^2}{\sqrt{R^2 + (sX)^2}} \left[\frac{\cos\theta + \cos(2s\omega_s t - \theta}{2} \right]$$

This expression has two parts: one steady or mean part (the $\cos\theta$ term) and the other a cosine term at twice the slip frequency. The mean value of the latter part is zero so the mean value of the whole is simply the first part.

Thus mean torque $T \alpha \dfrac{s\omega_s \Phi^2}{\sqrt{R^2 + (sX)^2}} \cos\theta$

But $\cos\theta = \dfrac{R}{\sqrt{R^2 + (sX)^2}}$ and $R\ \omega_s\ \alpha\ N_s$

So that finally:

$$T\ \alpha\ -\frac{sN_s \Phi^2 R}{R^2 + (sX)^2}\ \alpha\ \frac{s\Phi^2 R}{R^2 + (sX)^2}$$

for a given supply frequency.

At standstill, s = 1 and $T\ \alpha\ \dfrac{R}{R^2 + X^2}$

for a given stator flux F; this can be shown by differentiation with respect to X to be maximum when R=X, but in practice R is usually less than X so that for a high starting torque R must be increased. This demands a wound rotor with slip-rings connected to an externally adjusted resistor and adds greatly to the cost.

Under normal running conditions, $T \alpha \dfrac{R}{R^2 + X^2}$

which is a maximum with respect to speed when:

$s = \dfrac{R}{X}$ and if we put this value into the equation we get:

$T_{max} \alpha \dfrac{1}{X}$ which is independent of R.

Thus we have found that for high starting torque, R and X should be equal but for high maximum running torque, X should be small.

At no-load, s is very small (near synchronous speed) so the term $(sX)^2$ is negligible compared with R^2. Then we have:

$$T \alpha \frac{s\Phi^2}{R}$$

This equation tells us three things:

- First that at speeds near synchronism the torque is proportional to the slip. This means that, since the torque can never be zero (due to friction and windage), the speed must always be less than synchronous.
- Secondly, the torque is proportional to the square of the flux, but since the latter is proportional to the applied stator voltage V, then we have:

  $T \alpha sV^2$ so that $s \alpha \dfrac{T}{V^2}$

- Thirdly, the torque is inversely proportional to R for a given stator voltage and slip, so that a high R value suitable for starting would not be suitable for running,

The equation $T \alpha \dfrac{sR}{R^2 + s^2X^2}$ is applicable for a given supply

Voltage and frequency and if T is plotted against s for different values of rotor resistance R, a family of curves is obtained as in Figure A27-7.

Note:
The maximum torque is independent of R as expected and that the starting torque (slip = 1) is high for a high R.

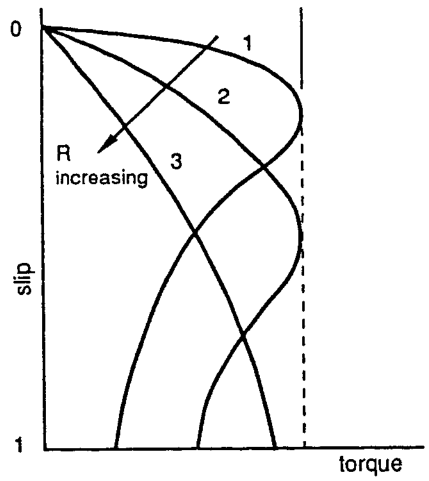


Figure A27-7

All motors whose torque/slip characteristics reach a maximum before standstill will stall if the load exceeds this value and will not restart if the load is then reduced slightly. Motor 3 in Figure A27-7 would, however, restart under the same conditions.

Because of the stalling behaviour of most induction motors, special methods have to be used to plot out their full torque/slip characteristics. For more information on induction motor applications, refer to 'Matching the motor to its Load' in Appendix A of this manual.

Notes

Practical 27.2

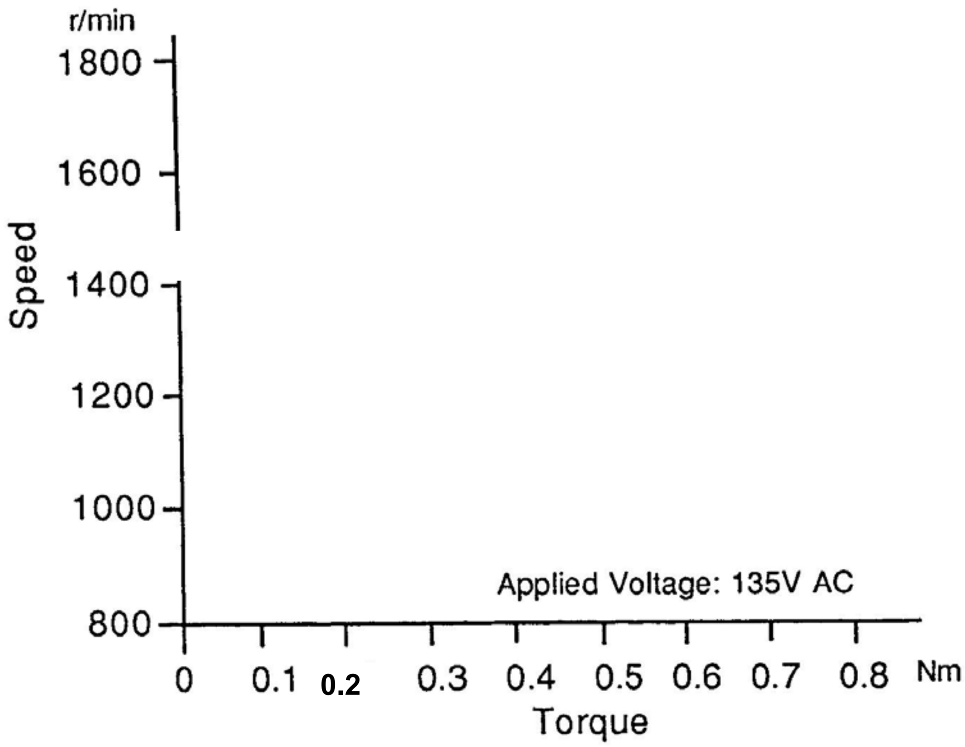


Figure A27-5 Graph Axes

Exercise 27.2

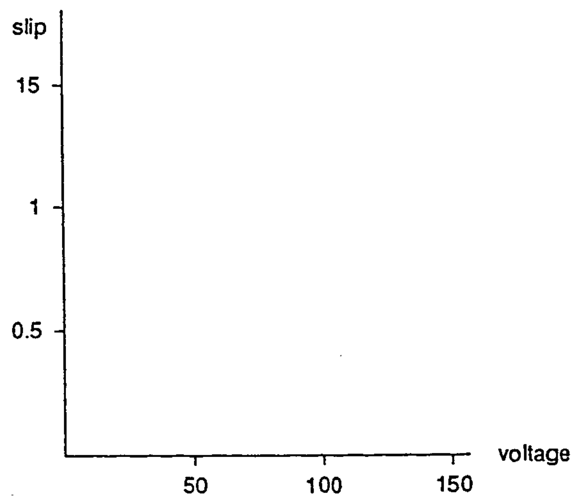


Figure A27-8 Graph Axes

Notes

Practical 27.2

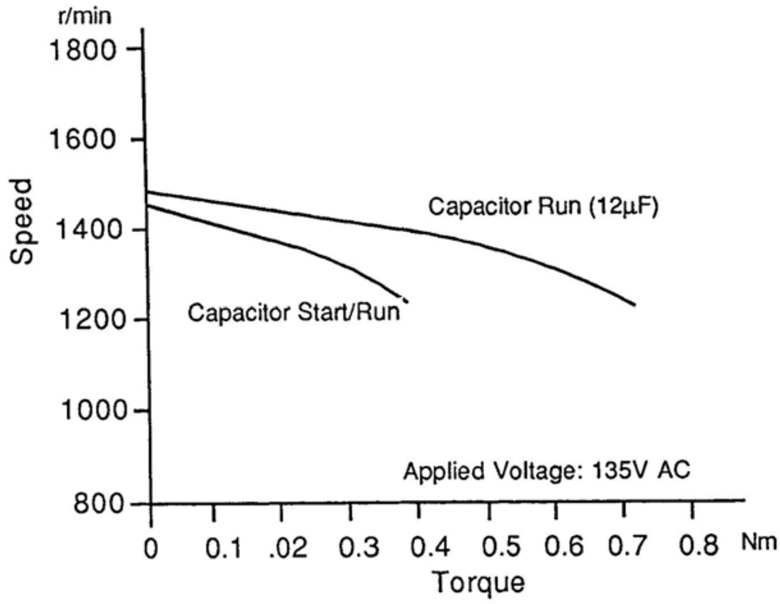


Figure A27-5: Characteristics for 4-Pole Squirrel-Cage Motor

Exercise27.2

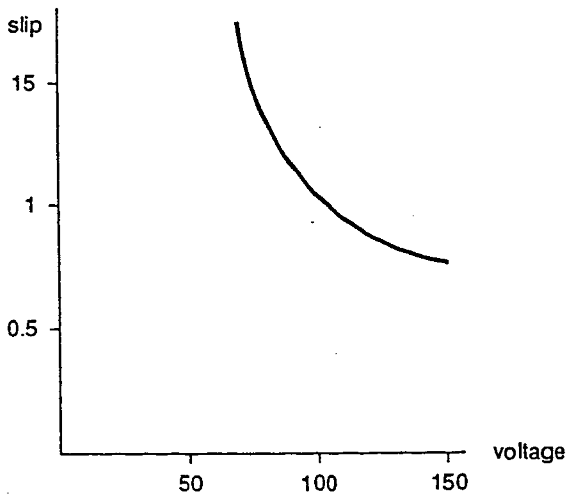


Figure A27-8

Question 27.1	The capacitor run motor stalls at a load of about 0.9 Nm and a speed of about 1200 rev/min so the useful range is up to about 0.8 Nm.
Question 27.2	During acceleration, the supply current is high but drops to its working value as the normal running speed is reached. When the motor is stationary, it behaves very much like a short-circuited secondary winding of a transformer whose primary is the stator winding. Thus a large current flows as the rotor accelerates, the secondary currents become smaller because the frequency in the motor is reducing and thus the generated emf. Hence the primary current also reduces.
Question 27.3	The starting torque is generally low unless special arrangements are made to increase the rotor resistance. Thus an induction motor cannot be started against its full-load torque. Sometimes a centrifugal clutch is used to couple up the load when full-speed has been reached.
Question 27.4	Your graph of slip versus supply voltage should appear as in Figure A27-8. This corresponds with the inverse square law predicted from theory as indicated in the Discussion.

DISSECTIBLE

MACHINES SYSTEM

Assignment 29/30
ac Single-Phase, 2-Pole Squirrel-Cage Induction Motor

PRACTICAL 29.1

29.2

29.3

EQUIPMENT REQUIRED

	Qty	**Item**
62-100 Kit	1	Base Unit
	1	12-slot Wound Stator
	1	Squirrel-Cage Rotor
	1	Centrifugal Switch
General	1	0-135 V, Single-Phase ac Supply (eg, Feedback 60-121)
	1 1	0-200 V, ac Voltmeter 0-5 A, ac Ammeter (eg, Feedback 68-117)
	1	Resistor/Capacitor Unit (eg, Feedback 67-190)
	1	Wattmeter: 200 V, 5 A (eg, Feedback 68-201 – optional)
	1	Friction (Prony) Brake or other Dynamometer: 0-1 Nm, 1500 rev/min (eg, Feedback 67-470)
	1	Optical/Contact Tachometer (eg, Feedback 68-470)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

In assembly and operation, this motor is similar to the 4-pole squirrel-cage versions of Assignment 27/28. In this case, however, the stator is connected to give a 2-pole winding and since operating speed is inversely proportional to the number of poles, it is increased from 1420 rev/min to 2850 rev/min.

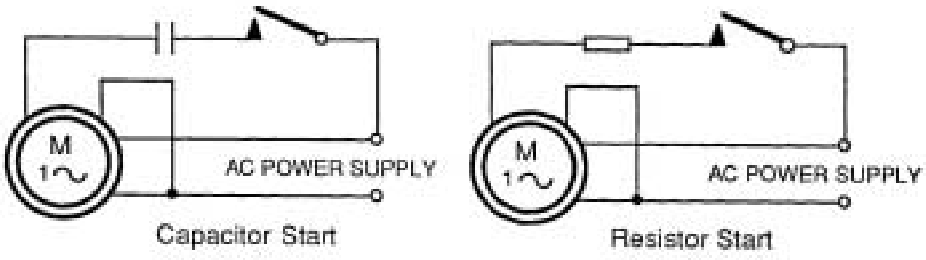


Figure A29-1: ac Single-Phase Induction Motor Circuit Diagram

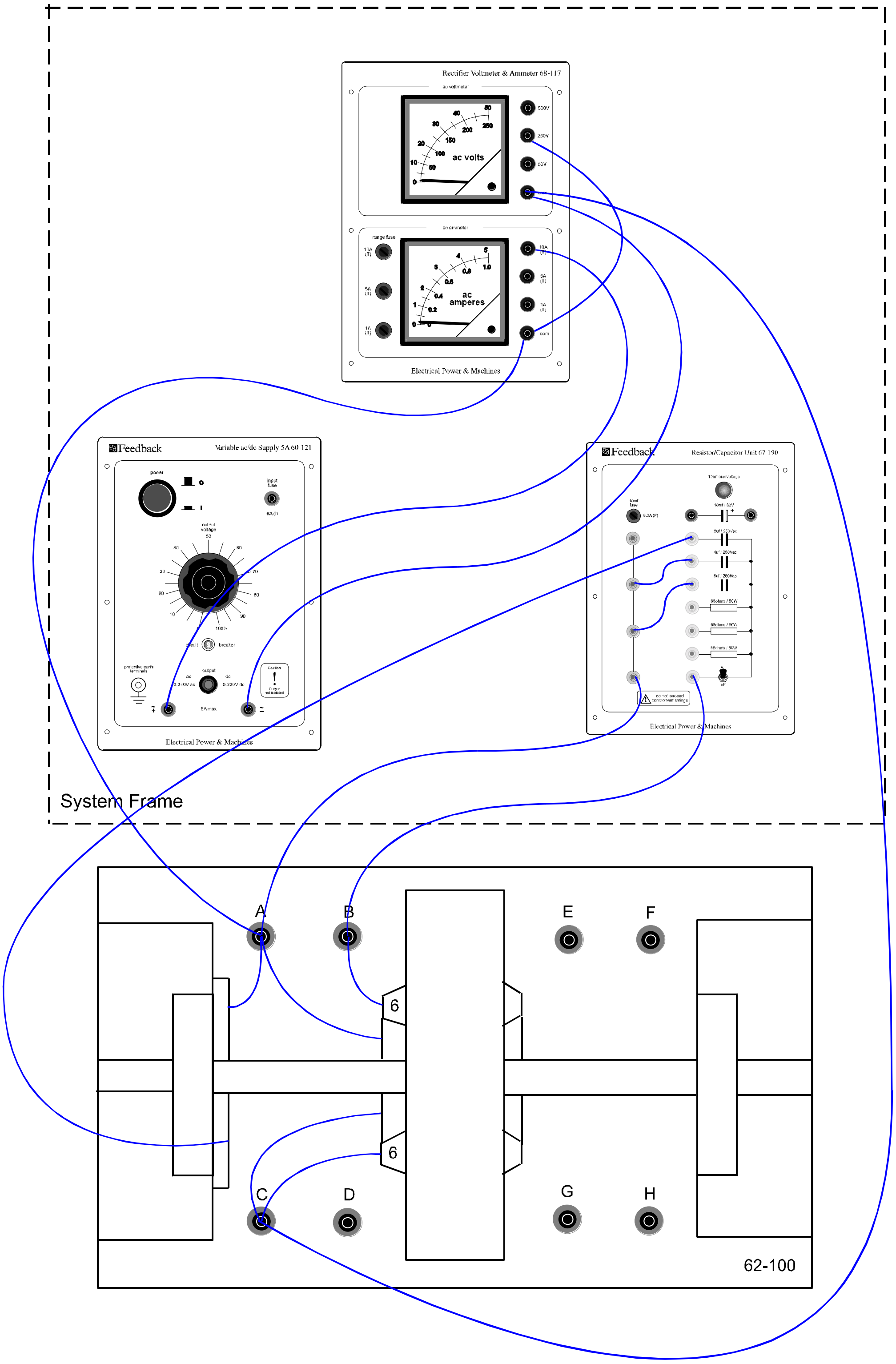


Figure A29-2: 2-Pole, Single-Phase, Induction Motor, Capacitor Start & Run Connections

ASSEMBLY

Mount the stator in the frame ring, with coil No 1 at the top, fixing it in position by three 1 3/8" long cap-head socket screws at the 12, 4 and 8 o'clock positions. Attach the fixed element of the centrifugal switch to the drive-end bearing housing using the screws as described in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 4.

Fit the squirrel-cage rotor to the shaft, locating the hub set screw in the conical recess on the non-drive side of the shaft. Attach the rotating element of the centrifugal switch to the drive-end of the shaft adjacent to the rotor. Fit the shaft into its bearing and screw the removable bearing housing to the baseplate, but before finally tightening down check that the shaft rotates freely and moves axially against the pre-loading washer.

Fasten the friction brake to the baseplate as described in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 6. Adjust the brake for zero load initially.

Make the circuit shown in Figure A29-3 in accordance with the connections shown in Figure A29-2 and Figure A29-4(a). The resistor/capacitor unit is connected in series with the start winding and connected to give capacitor start initially.

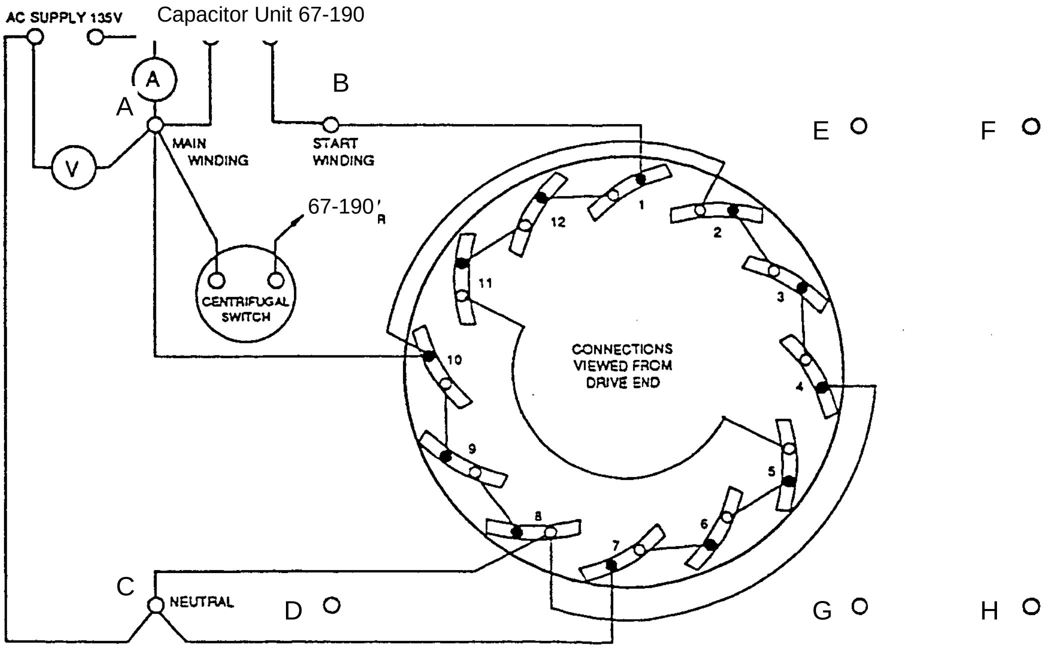


Figure A29-3: 2-Pole, Single-Phase, Squirrel –Cage, Induction Motor – Capacitor or Resistor Start Wiring Diagram

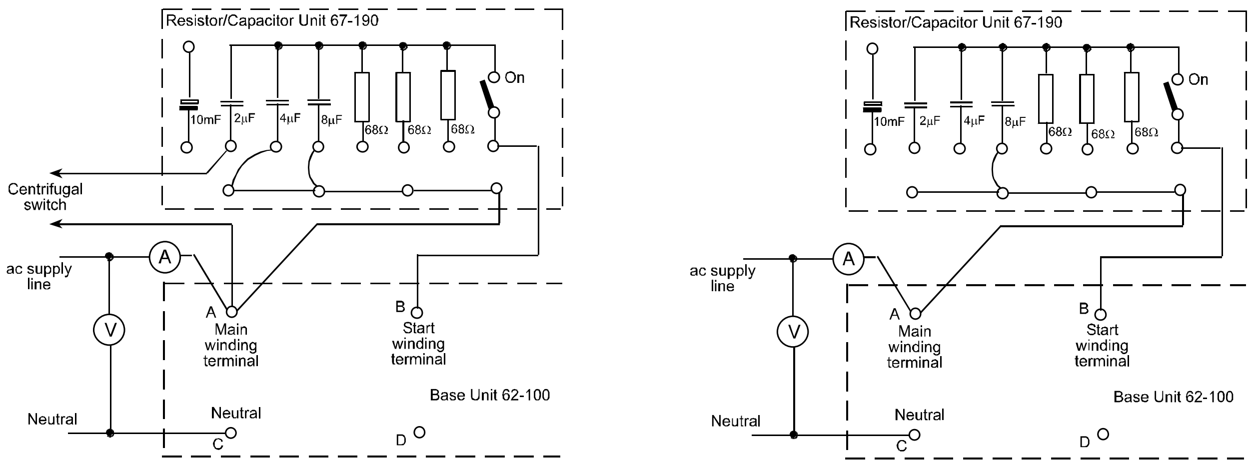
PRACTICAL 29.1

The centrifugal switch is intended for operation on 4-pole machines and cuts out at approximately 1150 rev/min, which is much lower than the normal cut-out speed for a 2-pole motor. However, the centrifugal switch can be used on the motors of these assemblies, although the time taken to reach normal running speed will be longer than with a centrifugal switch operating at, say, 2300 rev/min.

No Load

Set the value of starting capacitance to 8 μF and switch on the 135 V ac supply to the motor. When the shaft speed reaches approximately 1150 rev/min, the centrifugal switch will operate and cut out the starting circuit or, if the centrifugal switch is not fitted, this can be done manually using the on-off switch on the Resistor/Capacitor Unit. The motor will then run up to its no-load speed of approximately 2950 rev/min for 50 Hz or 3450 rev/min for 60 Hz supply.

The effectiveness of different values of starting capacitance can be investigated and the switching arrangements can be altered to permit capacitor start and run operation, using the connections given in Figure A29-4(b). For resistor start operation, it is only necessary to connect resistors in place of capacitors to give 22 ohm in series with the start winding.



(a) Capacitor – Start/Run Motor Connections **(b) Capacitor – Run Load Test Connections**

Figure A29-4

PRACTICAL 29.2

Load Tests

Make the connections required for capacitor-start/run operation, Figure A29-4(a), and switch on the 135 V ac supply to the motor. With the supply voltage constant, increase the brake load in steps measuring shaft speed and stator current at each step.

Reconnect for capacitor-run operation, Figure A29-4(b), with 14µF in circuit and repeat the previous test increasing the load in steps from zero to approximately 1 Nm. Plot shaft speed against torque to give curves similar to those of Figure A29-5.

PRACTICAL 29.3

To measure the power taken by the motor when loaded, connect a wattmeter in the circuit as shown in Figure A29-4(b). Carry out a load test on the motor, taking readings on input watts, input current, brake load and shaft speed at constant voltages. For one value of load only, say 0.4 Nm, switch out the start winding and record the altered values of power, current and speed. Enter your results in the columns of a table similar to Table A29-1.

Exercise 29.1

From the results of your load test, calculate the following and enter them in the remaining columns of Table 29.1.

VA Input

This is the product of the supply voltage and the supply current, taking account of relative phases.

Output Power and Horsepower

This is $\frac{2\pi NT}{60}$ watts

where N = speed rev/min

T = torque Nm

Divide by 746 (watts in one hp) to obtain horsepower.

Efficiency

This is $\frac{\text{output power}}{\text{input power}} \times 100\%$

Power Factor

For a supply voltage V and current I, the stator input power is:

$VI \cos \Phi = W$

Where W = measured input power
Φ = phase angle between V and I
$\cos \Phi$ = power factor

Therefore $\cos \Phi = \frac{W}{VI} = \frac{\text{input power}}{\text{input VA}}$

The power factor cannot be greater than unity but due to errors in the three measuring instruments used, you may well find that it appears to be so when you work out your results. Also, most ac voltmeters and ammeters use full-wave rectification followed by mean reading so that rms values are correct only if the waveforms are sinusoidal. If you suspect such errors you could try your meters on a resistive load and obtain a correction factor to apply to your other readings.

For example, if on a resistive load you found:

V = 140 V
I = 1 A
W = 145 W

the voltmeter is reading too high or the other meters too low by a factor:

$$\frac{145}{140} = 1.036$$

and all you wattmeter readings should be divided by this factor. This will give better power factor estimates and will not affect other measurements appreciably.

When you have calculated all the results, plot efficiency against output horsepower as in Figure A29.6.

Question 29.1 ***What maximum efficiency do you find?***

Question 29.2 ***What change occurred to the input current and power factor when you switched out the start winding? Can you explain the result you observed?***

Exercise 29.2 Establish the relative directions of currents in the main windings on Figure A29.3 and satisfy yourself that they produce one pair of poles only.

DISCUSSION

The only difference of importance between this assembly and the previous one is in the number of poles it has, resulting in a different operating speed. However, the start winding uses six coils instead of four and this gives a greater rotating component to the field and improves starting torque. The measurements of power input on this machine enable an idea to be gained of the kind of power factor to be expected of an induction motor. All induction motors take a lagging current and an industrial machine on full load will usually have a power factor of the order 0.8.

Notes

Practical 29.2

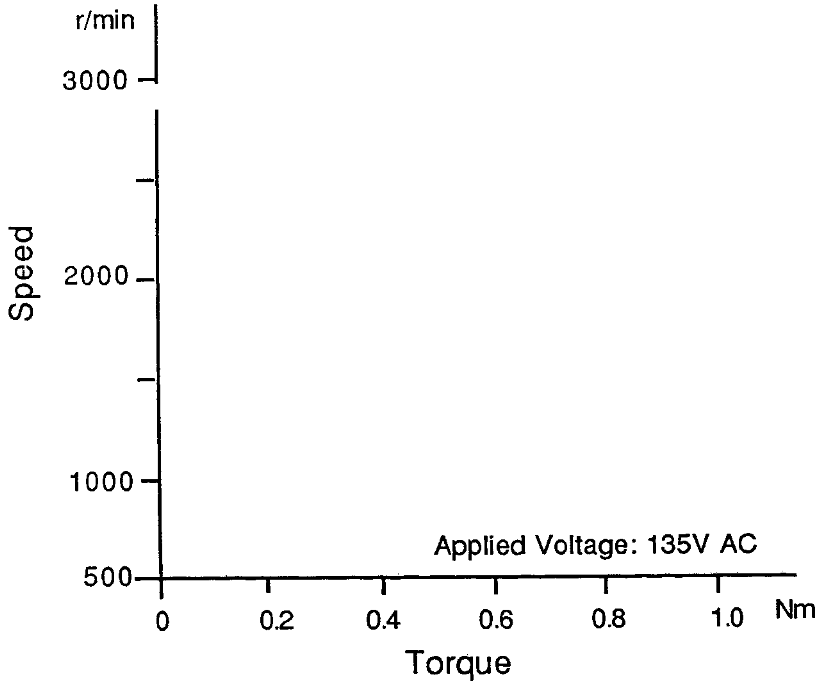


Figure A29-5 Graph Axes

Practical 29.3

Torque (Nm)	Speed (rev/min)	Current (amps)	Input Power (watts)	VA Input	Output Power (watts)	Output Power (HP)	Efficiency (%)	Power Factor
0								
0.2								
0.4								
0.6								
0.8								
1.0								
1.2								
0.4								

Note: Figures in last row are for Main Winding only.

Exercise 29.1

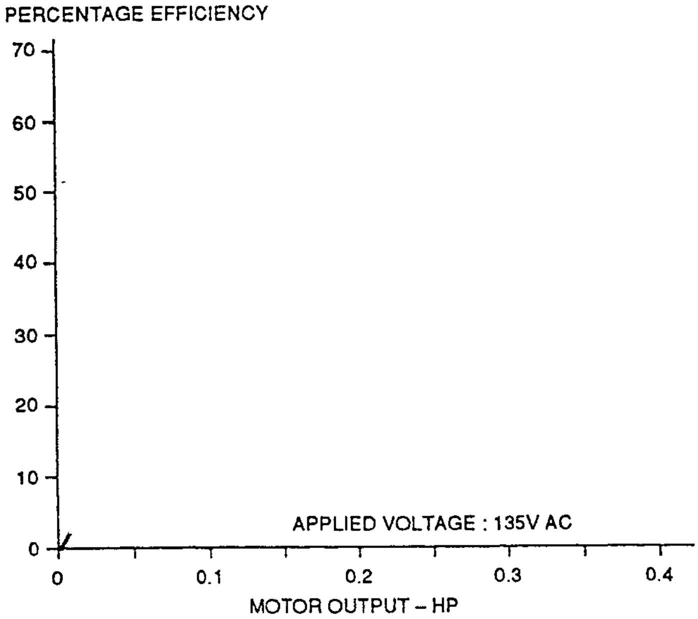


Figure A29-8 Graph Axes

Practical 29.2

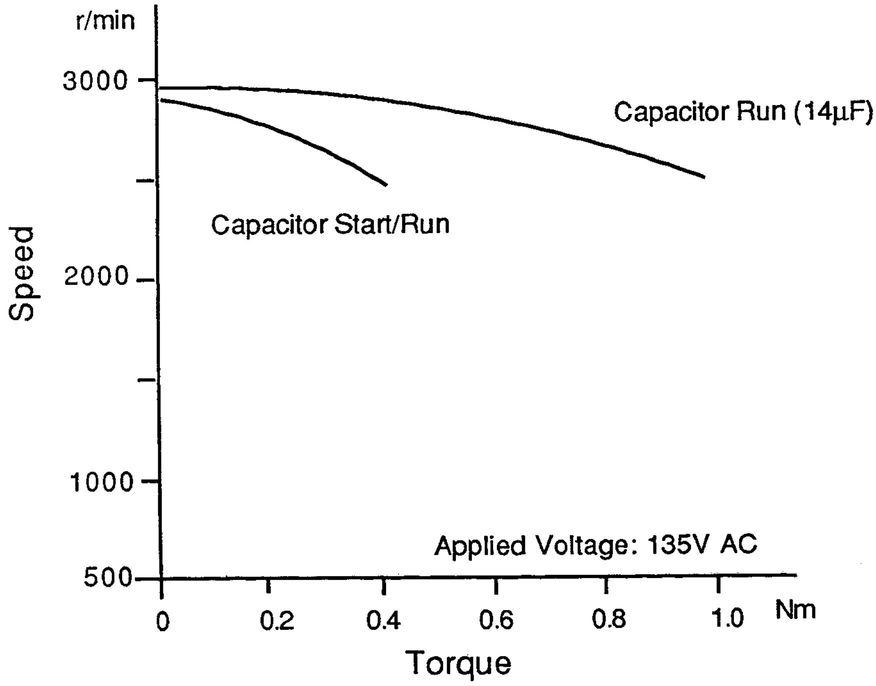


Figure A29-5: Characteristics for 2-Pole Squirrel-Cage Motor, Capacitor Start/Run

Exercise29.1

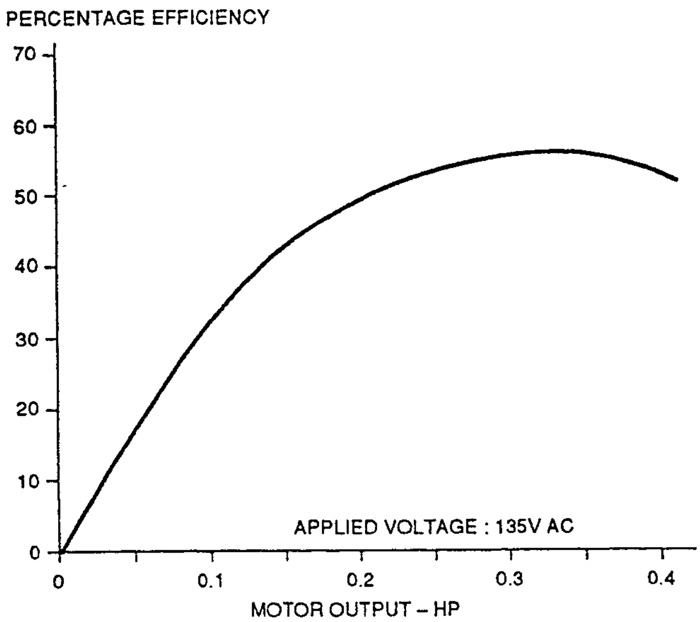


Figure A29-6

Question 29.1 Maximum efficiency is typically 60%.

Question 29.2 When the start winding is switched out, the current *increases* even though the start winding is no longer across the supply. Thus the calculated power factor reduces. Although the effect of removing the start winding is quite complicated, the resulting current increase is largely explained by the removal of the leading current drawn by the start winding in series with the capacitor. Figure A29-7 shows this in phasor form. In (a), the power factor angle θ_1 is less than θ_2 in (b) due to the leading start winding current. For the same power in each case, I_m must be less than I_t since $\cos\theta_2$ is than $\cos\theta_1$.

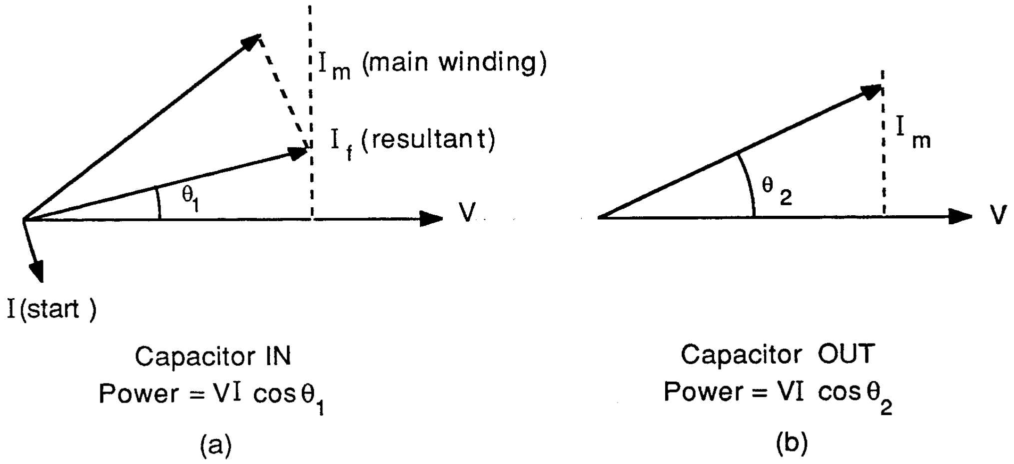


Figure A29-7

DISSECTIBLE

MACHINES SYSTEM

Assignment 31/32

ac Single-Phase, Series Motor

PRACTICAL 31.1
32.2

EQUIPMENT REQUIRED	**Qty**	**Item**
62-100 Kit	1	Base Unit
	1	Commutator/Slipring
	2	Brushes and Brushholders
	2	L1 Coils
	2	L2 Coils
	2	L9 Coils
	1	12-slot Wound Stator
	2	Field Poles
	1	Rotor Hub
	4	Rotor Poles
General	1	0-135 V, Single-Phase ac Supply (eg, Feedback 60-121)
	1	0-200 V, ac Voltmeter
	1	10-5 A, ac Ammeter (eg, Feedback 68-117)
	1	Friction (Prony) Brake or other Dynamometer: 0-1 Nm, 1500 rev/min (eg, Feedback 67-470)
	1	Optical/Contact Tachometer (eg, Feedback 68-470)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

Although there are important differences in the design and construction of the ac series motor and its dc counterpart, the two machines are basically alike and have similar characteristics.

The ac series motor has good low-speed torque and can be used at high shaft speeds and in variable-speed applications. It has the advantage that it can operate directly from a single-phase supply, but as both the field and the armature coils carry alternating current it requires a completely laminated magnetic circuit. Although commutation is inherently poor, special techniques can be used to improve this. Fractional horsepower versions are used in blowers, fans, machine tools, vacuum cleaners, sewing machines, etc.

Special forms of series motor known as Universal motors can be designed to operate on either ac or dc. Their efficiency is low, however, and they are only made in the smaller sizes.

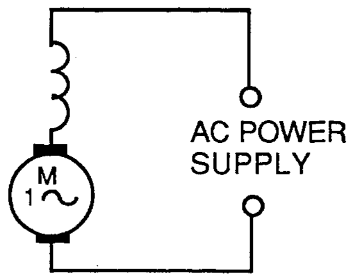


Figure A31-1: ac Single-Phase Series Motor Circuit Diagram

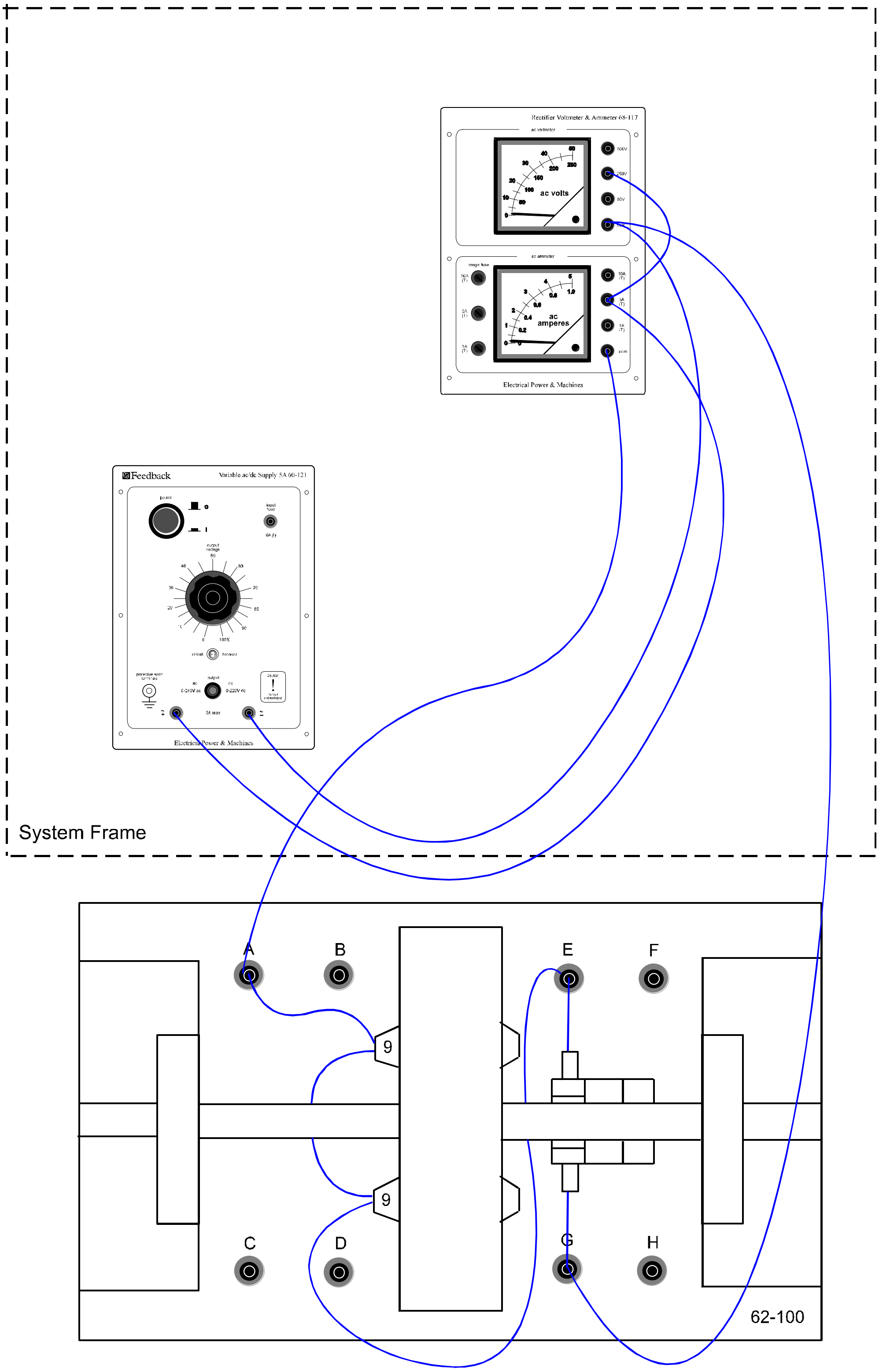


Figure A31-2: ac Series Motor Connections

ASSEMBLY

You need only test one type of field connection. For the concentrated field assembly, fit L9 coils over the field poles and attach these to the frame ring at the 3 o'clock and 9 o'clock positions. For the distributed field assembly, connect six L6 coils as shown in the wiring diagram, Figure A31-3, and fit the wound stator into the frame ring so that pole centres are in the 3 o'clock and 9 o'clock positions. Fasten to the frame using three $1^3/_8$" cap-head screws in the 12, 4 and 8 o'clock positions.

Assemble the rotor and commutator and attach to the shaft as shown in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 1. Fit the shaft into its bearings and screw the bearing housings to the base plate. Before finally tightening, check that the shaft rotates.

Fasten the friction brake to the baseplate as described in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 6. Adjust the brake for zero load initially.

Attach the Brushholders with their brushes to the mounting block positions on each side of the commutator and check that the brushes move freely in their holders against the action of the brush spring. Make the circuit in accordance with the connections shown in Figure A31-2 and A31-3 for concentrated windings and Figure A31-4 for distributed windings.

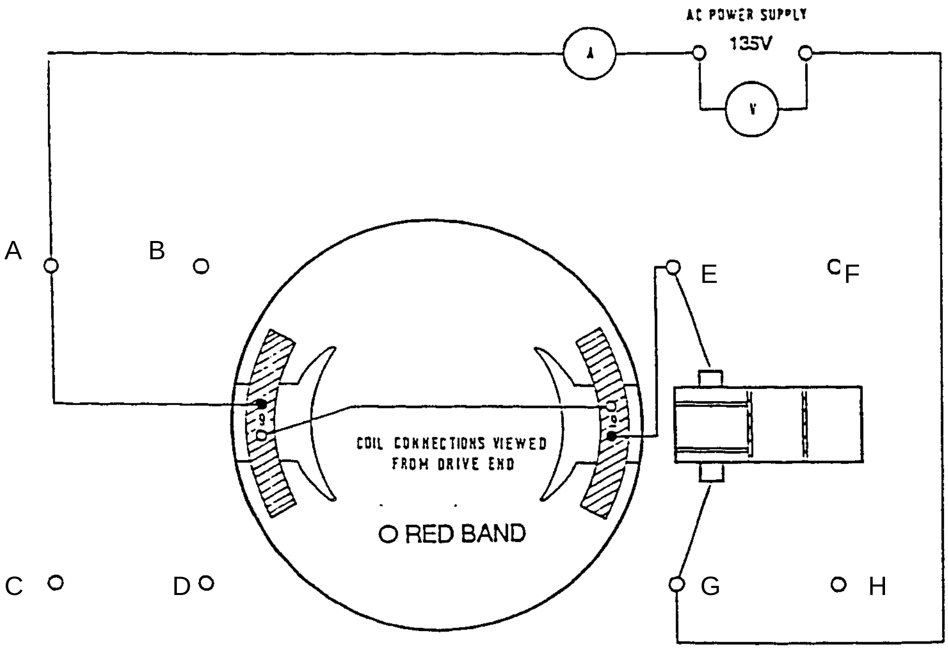


Figure A31-3: ac Series Motor, Concentrated Windings Wiring Diagram

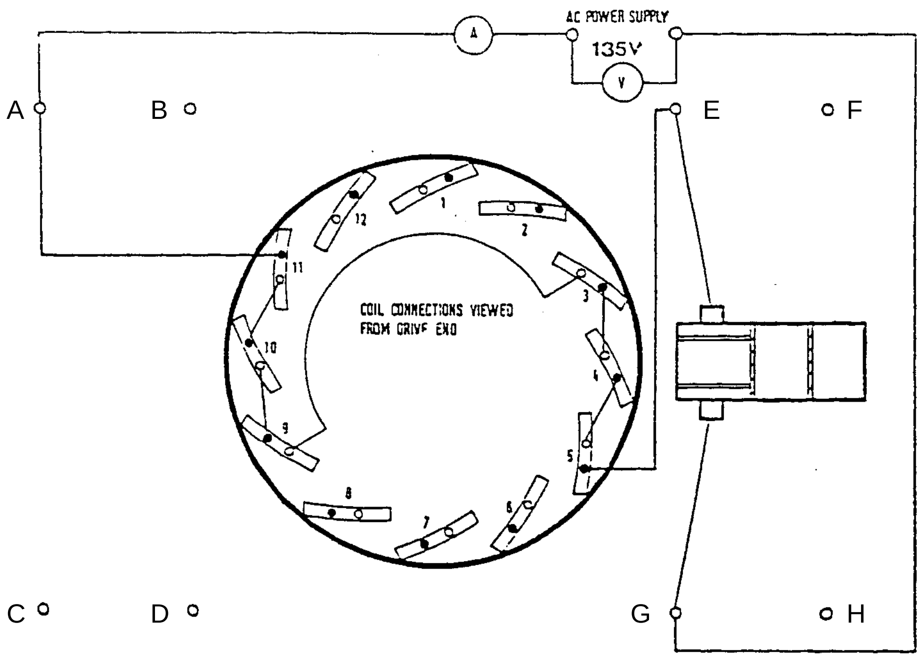


Figure A31-4: ac Series Motor, Distributed Windings Wiring Diagram

PRACTICAL 31.1

Switch on the 135 V ac power supply and when the shaft speed has reached its stead value, measure input current and speed. Typical no load values are given in Table 31-1.

Although in construction this motor is the same as the dc version of Assignment 19, its performances is considerably affected by ac operation.

There are two main reasons for this:

- emf's induced by transformer action in the coils undergoing commutation cause sparking at the brushes which cannot be corrected by interpoles,
- leakage reactance n the stator and rotor coils causes the ac impedance of the motor windings to be much greater than their dc resistance and the electrical power input is consequently reduced.

PRACTICAL 31.2

Load Test

Try applying a small load torque to either of the two motor configurations and note the effect on speed.

Question 31.1

Do you find the ac series motor to have a high or low output power?

Question 31.2

Compare the results of your tests with those obtained for the dc series motor (Assignment 19).

DISCUSSION

As already mentioned in the Introduction, the ac series motor finds wide applications in fractional hp form. Apart from the examples given, you may also note that most hand-held power drills employ this type of motor. Some of these provide quite a high output in a small space compared with the assembly just tested, which has very poor characteristics.

The difference is, of course, that the windings of the hand-drill are specially designed for efficiency and have the correct impedance for the job. Also a multi-segment commutator is fitted and this too gives greater efficiency and smoother running.

Notes

Practical 31.1

Applied Voltage (ac)	Input Current (Amps)	Shaft Speed (rev/min)	

Table A31-1

Notes

Practical 31.1

Applied Voltage (ac)	Input Current (Amps)	Shaft Speed (rev/min)	
135	0.6	2200	Concentrated field
135	0.55	1250	Distributed field

Table A31-1

Practical 31.2

Question 31.1

Even a small load torque is sufficient to bring the motor to rest and there is no tendency for it to race on no-load. The output power is clearly low.

Notes

DISSECTIBLE

MACHINES SYSTEM

Assignment 33/34

ac Single-Phase, Repulsion Motor

PRACTICAL	33.1	Fixed Brush Angle
	33.2	Variable Brush Angle

EQUIPMENT REQUIRED	**Qty**	**Item**
6-100 Kit	1	Base Unit
	1	Commutator/Slipring
	2	Brushes and Brushholders
	2	L1 Coils
	2	L2 Coils
	2	L9 Coils
	1	Crank Handle
	2	Field Poles
	1	Rotor Hub
	4	Rotor Poles
	1	Rotatable Brushgear RB185 (Assignment 34)
General	1	0-135 V, Single-Phase ac Supply (eg, Feedback 60-121)
	1	0-200 V, ac Voltmeter
	1	0-5 A, ac Ammeter (eg, Feedback 68-117)
	1	Friction (Prony) Brake or other Dynamometer: 0-1 Nm, 1500 rev/min (eg, Feedback 67-470)
	1	Optical/Contact Tachometer (eg, Feedback 68-470)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

The essential components of a repulsion motor are similar to those of ac series motor, but the interconnections and operating principles are different. The ac supply is connected only to field windings, which may be concentrated or distributed in a slotted stator. The rotor is conventional but the brushes are shorted to one another and have no external connections.

However, the angle of the brush axis relative to that of the field poles has to be different from the normal in order for torque to be generated. As the Rotatable Brushgear RB185 may not be available, two assemblies are described. The first uses a modified form of rotor winding, which will give torque with the standard brush angle. The second uses normal rotor windings and employs the rotating brushgear.

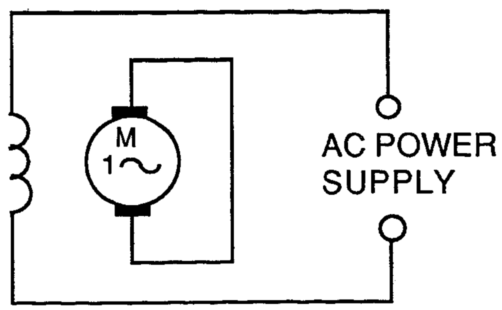


Figure A33-1: ac Single-Phase Repulsion Motor Circuit Diagram

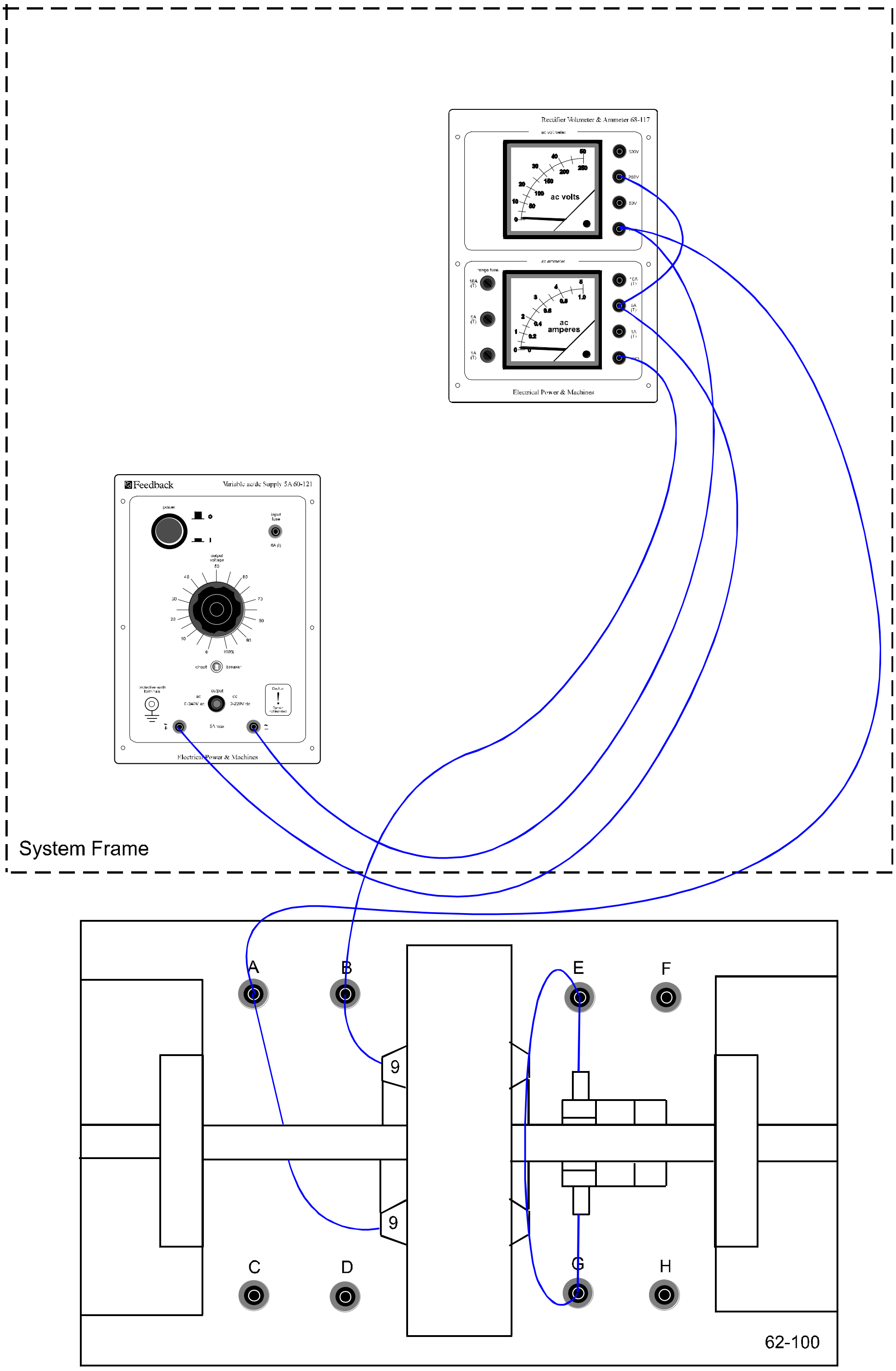


Figure A33-2: ac Repulsion Motor Connections

ASSEMBLY

Both Assemblies

Stator

Fit L9 coils over the field poles and attach these to the frame ring at the 3 o'clock and 9 o'clock positions.

Assignment 33

Rotor Fixed Brush Angle

Assemble the rotor and commutator and attach to the shaft as shown in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 1 but make the connections given in Figure A33-3.

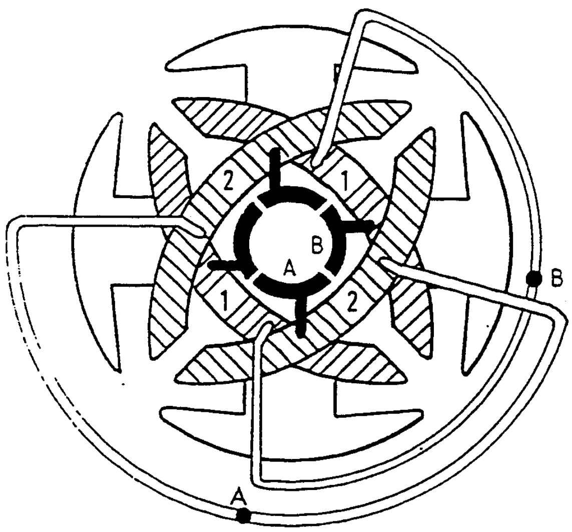


Figure A33-3: Armature Connections for Repulsion-Motors, Fixed Brush Angle

This assignment requires for use two insulating pillars in the positions marked A and B in Figure A33-3. See Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 3. Connect the black leads from the coils to the commutator segments as shown in Figure A33-3. Connect the red leads from the coils L1 together by securing them under the top screw of pillar B. Connect the red leads of the coils L2 by securing them under the top screw of pillar A.

Make sure that the pillars and all screws are securely tightened (without using excessive force).

Brushes

Attach the Brushholders with their brushes to the mounting block positions on each side of the commutator and check that the brushes move freely in their holders against the action of the brush springs.

Assignment 34

Variable Brush Angle Rotor

Assemble the rotor and commutator and attach to the shaft as shown in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 1 and connect up as shown there.

Fit the shaft into its bearing and screw the removable bearing housing to the baseplate but, before finally tightening, check that the shaft rotates freely and moves axially against the pre-loading washer.

Brushes

Fit the Rotatable Brushgear RB185 to the removable bearing housing as shown in Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 5.

Make the circuit shown in Figure A33-4 in accordance with the connections shown in Figure A33-2.

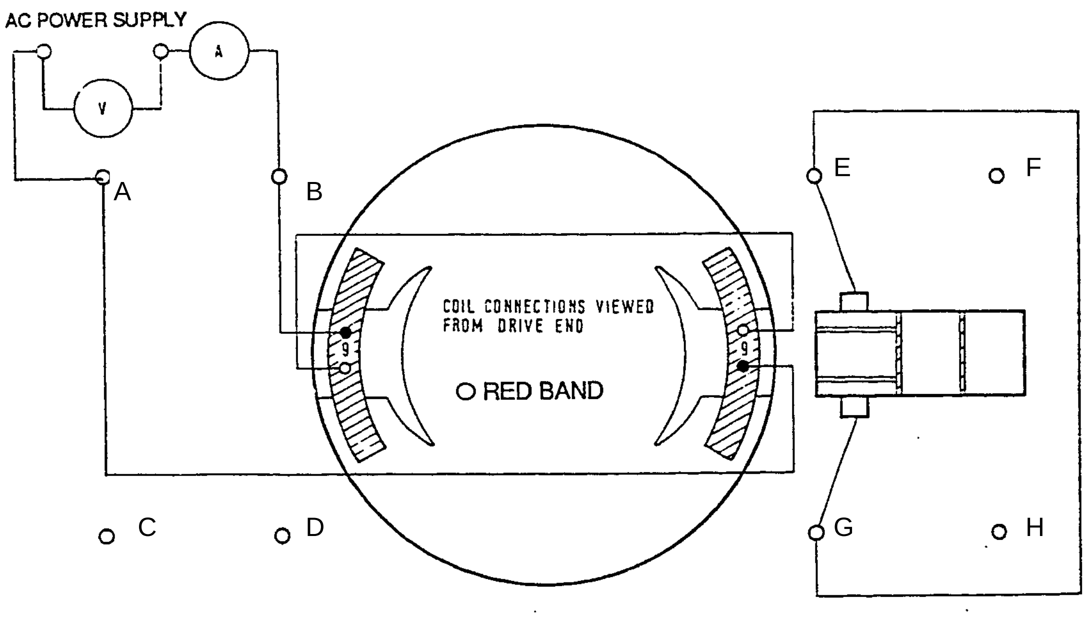


Figure A33-4: ac Single-Phase Repulsion Motor Wiring Diagram

PRACTICAL 33.1

Fixed Brush Angle

With the rotation brushgear set to 55° (ie, with the thumbscrew at the 2 o'clock position) and with no load on the shaft, apply 130 V ac to the stator winding. The motor should start and accelerate to about 700 rev/min in an anti-clockwise direction as seen from the drive end. If the motor does not start, move the rotor by hand a quarter of a turn.

Now switch off the supply and allow the motor to come to rest. Fit the crank handle to one end of the shaft and hold it firmly while you re-apply power at a *reduced* voltage of about 100 V ac. Now turn the crank slowly and note how the torque varies over one revolution. You should find that it rises from zero to a unidirectional maximum every 90° of rotation. Switch off and remove the crank.

Question 33.1

Can you suggest how the reverse direction of rotation could be achieved? Try out your answer.

PRACTICAL 33.2

Variable Brush Angle

With the rotatable brushgear set to 0° (normal position), fit the crack handle to the shaft and switch on full power. Rotate the shaft by hand and note how the torque varies. You should find that a rather low torque is generated when the shaft is moved about 45° from its equilibrium position and that this torque is positive or negative according to which direction the shaft is moved. In other words, there is no net torque in either direction and the motor will not start.

Switch off and rotate the brushes to 90° (ie, with the thumbscrew at the 9 o'clock position). Switch on and repeat the test – the result should be similar.

Switch off and remove the crank handle. Switch on again and rotate the brushgear slowly from the 90° position towards 0°. At about 80°, the motor should show a tendency to rotate, but a little manual assistance may be needed. When running, continue to adjust the brush angle until maximum speed is obtained. This should occur at about 70°.

Continue to rotate the brushes back to 0°, in a smooth continuous motion, and then further. The motor should reverse direction at about 0° and achieve maximum speed in the reverse direction.

DISCUSSION

The repulsion motor is a form of induction motor but it has different torque-speed characteristics which, combined with the ability to control speed and direction merely by rotating the brushes, make it useful in certain applications.

Why is the name repulsion used? Consider Figure A33-5, which shows at (a) a simple coil, energised by an external ac source and at (b) another, short-circuited. Both coils are placed in a uniform but alternating magnetic field.

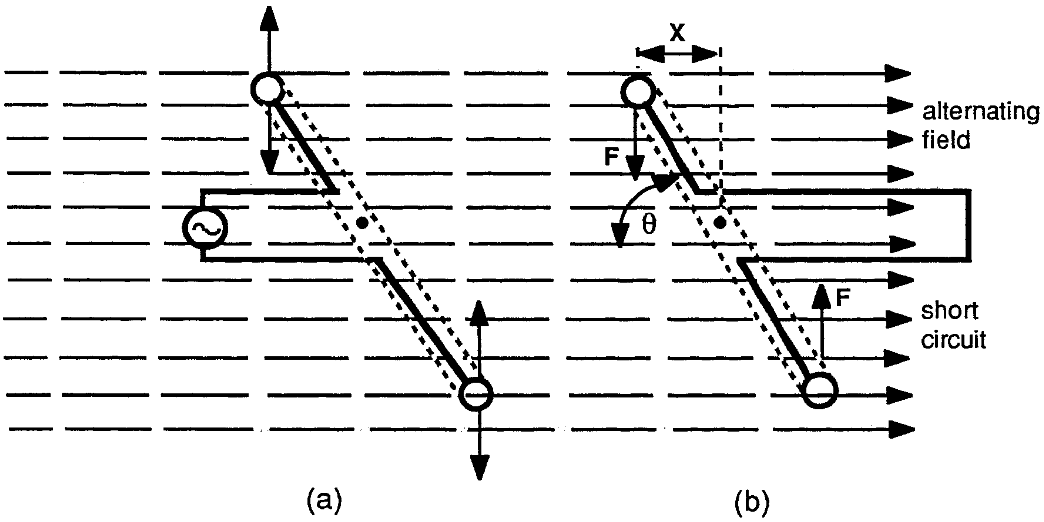


Figure A33-5

In Figure A33-5(a), the current produced by the external supply causes a force to be applied to the coils sides in one of the directions shown, depending on the relative phases of the field and coil supply alternations. Whichever this happens to be, the coils will rotate until the emf induced in the coil by the alternating field opposes that of the external source to the maximum possible degree (conservation of energy). This occurs when the coil lies at right angle to the field and its magnetic axis is aligned with that of the field. The field and coil poles could be said to have been attracted.

In Figure A33-5(b), the induced emf in the coil give rise to a current which causes a force on the coil sides as shown and (again by conservation of energy) the coil moves so as to minimize the induced emf and the resultant current. The coil thus ends up aligned with the field and the magnetic axes at right angles. The two magnetic poles can then be said to have repelled one another. In this sense, all induction motors are repulsion motors but the name is used only for commutator types.

Incidentally, the variation of the torque on a single coil in the motors of these assemblies can be seen from Figure A33-5(b). The emf generated and hence the current and hence F, depends on the total flux encompassed by the coil and this varies as sinθ, being maximum when the coil is at 90° to the field. The torque is FX and X varies as cosθ. Thus the torque varies as sinθ cosθ or as sin 2θ. Thus the torque is maximum at about 45° and zero at 0° and 90°. In practice, the field is not uniform as assumed and the torque tends to maximise at about 65° and then reduce rapidly up to 90°.

We can now consider how the two motors of Assignments 33 and 34 produce a net torque in one direction.

Figure A33-6 illustrates the emf's, currents and resultant torque in the rotor of Assignment 33 for different positions of the motor.

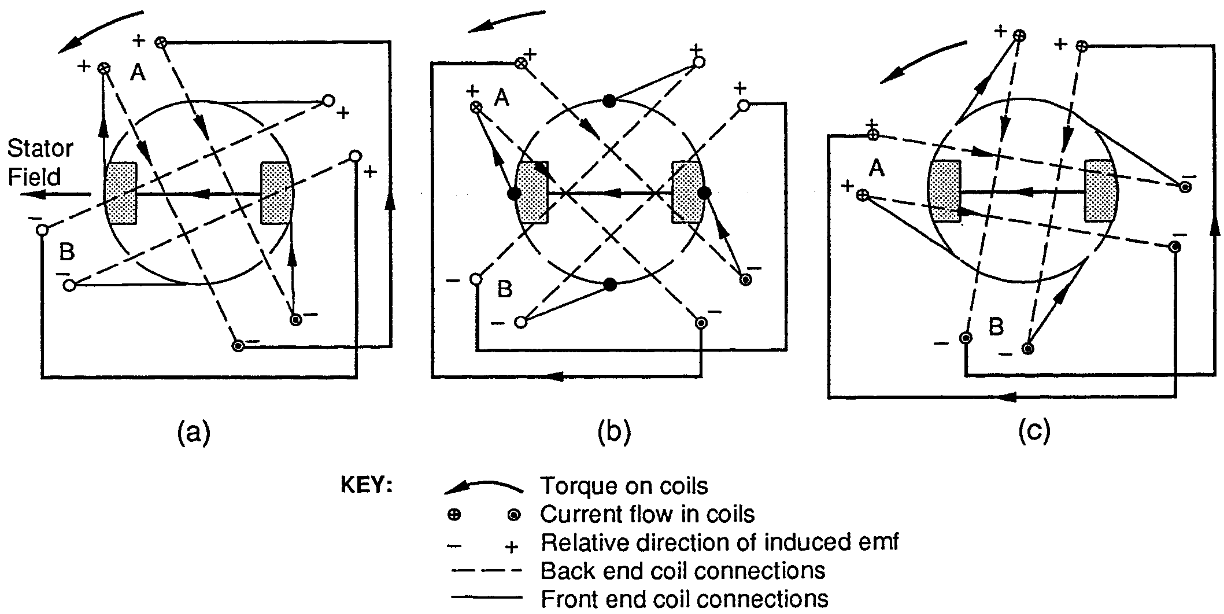


Figure A33-6

In (a), coils B have no circuit and no current flows in spite of the emf's induced. But coils A carry current as indicated by arrows and a near-maximum anti-clockwise torque is developed on them.

In (b), the same conditions occur but the induced emf's in coils A are less. An anti-clockwise torque still exists but is smaller.

In (c), the brushes have just bridged the commutator segments.

Coils A have now a small emf and coils B a larger one. Current flows in both coils but more in B than in A. Coils A produce a clockwise torque but not a large one as the coils are near the 90° position. Coils B produce a small anti-clockwise torque and the resultant torque is substantially zero and remains so until coils B reach the position of coils A in Figure A33-6(a) when the same cycle recommences. There is thus a net anti-clockwise torque producing continuous rotation, although the torque pulsates four times each revolution. In a practical multi-segment rotor, these pulsations would be negligible.

Figure A33-7 shows two rotor positions for each of three brush angles in Assignment 34.

In (a), each potential current path has equal and opposite emf's induced in it by coils A and B so no current flows and no torque is generated. Rotating each way from this angle generates a restoring torque tending to this position as equilibrium. For example, if clockwise rotation occurs, coils A have greater emf and coils B less, resulting in a current such that both A and B experience anti-clockwise torque.

In (b), coils A have zero emf but coils B carry current – however, because coils B are at 90° no torque results. There is thus no net starting torque and the motor does not run.

In (c), with brushes at 90°, both coils A and B both carry equal currents as indicated and both experience torque, but in opposite directions so net torque is zero. As before, this is an equilibrium position and rotation either way produces a restoring torque.

In (d), only coils B carry current but no torque is generated as explained for (b).

With the brushes at an intermediate angle in (e), the emf's and current in coils B are greater than coils A so that the clockwise torque on B exceeds the anti-clockwise one on A. A net clockwise torque results. In (f), coils A and B are in series in pairs and although their emf's oppose each other, that in A is greater and the currents indicated result. Both coils A and B now experience clockwise torque. There is thus a more or less continuous torque in one direction and the motor starts. Moving the brushes to the other side of 90° clearly gives an opposite torque.

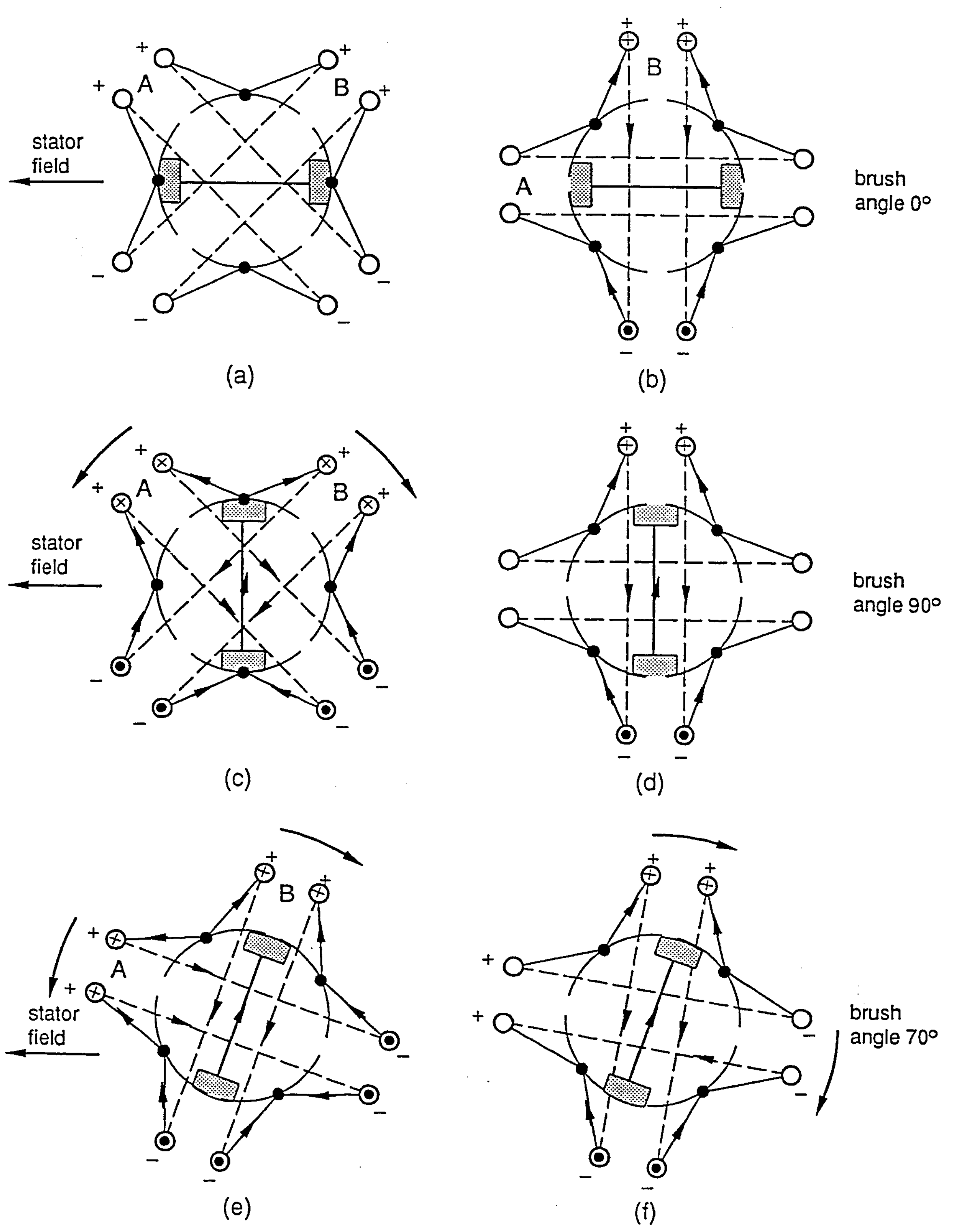

stator
field
A
B
(a)
brush
angle 0°
(b)
(c)
brush
angle 90°
(d)
(e)
brush
angle 70°
(f)

Figure A33-7

When a repulsion motor accelerates, similar effects occur to those explained in Assignment 27/28.

SUMMARY

Practical repulsion motors have a high starting torque and a lower running torque, a characteristic complementary to that of an induction motor and also they give a starting torque on a single-phase supply. For this reason, combined repulsion/induction motors have been designed in which the shorted brushes are used for starting and the whole commutator is shorted by a centrifugal device when near synchronous speed, when normal induction running occurs. However, the motors are expensive due to the need for a wound rotor, commutator and centrifugal switch.

Exercise 33.1

Although the connection of Assignment 33 gives rise to a self-starting motor without the need for brush angle change, this does not mean that such a change will not give a better torque. If you have RB185 available, try using it with the rotor of Assignment 33 and also try extending the diagrams of Figure A33-6 to explain your observations.

Question 33.1

The motor of Assignment 33 may be reversed by altering the connections between rotor coils and commutator to connect the red leads to the commutator and coupling the black leads in pairs.

Notes

DISSECTIBLE MACHINES SYSTEM

Assignment 35
ac Single-Phase, 2-Pole Synchronous Motor, Rotating Field

PRACTICAL

35.1

35.2 Variable Excitation Test

EQUIPMENT REQUIRED

	Qty	Item
62-100 Kit	1	Base Unit
	2	L1 Coils
	1	12-slot Wound Stator
	1	Rotor Hub
	4	Rotor Poles
	1	Commutator/Slipring
	2	Brushes and Brushholders
	1	Flexible Coupling
General	1	Variable Speed Motor: 1/3 hp, 1200 rev/min, (eg, Feedback 63-501)
	1	ac supply; 135 V, 5 A single-phase (eg, Feedback 60-121)
	1	dc supply; 0-20 V, 5 A (eg, Feedback 60-105)
	1 1	0 – 200 V ac Voltmeter 0–5 A ac Ammeter (eg, Feedback 68-117)
	1 1	0-50 V, dc Voltmeter 0-5 A dc Ammeter (eg, Feedback 68-110)
	1	Friction (Prony) Brake or other Dynamometer 0-1 Nm at 1500 rev/min (eg, Feedback 67-470)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

The single-phase synchronous motor has a field which is supplied from a dc source and an armature supplied from an ac source. It is usual, as in this assembly, to have a rotating field and stationary armature, although this arrangement can be reversed.

Synchronous motors are not self-starting and the method used to bring them to running speed depends on the size of the motor. To avoid using a separate drive machine, some motors have a low resistance squirrel-cage winding embedded in the rotor poles and are brought up to near synchronous speed as an induction motor. Smaller motors may be spun by hand to a speed above synchronism and will pull into step as the shaft speed fails.

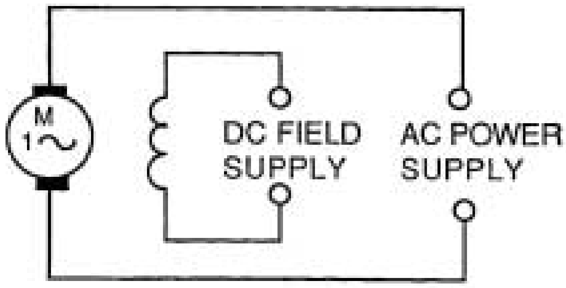


Figure A35-1: ac Single-Phase Synchronous Motor Circuit Diagram

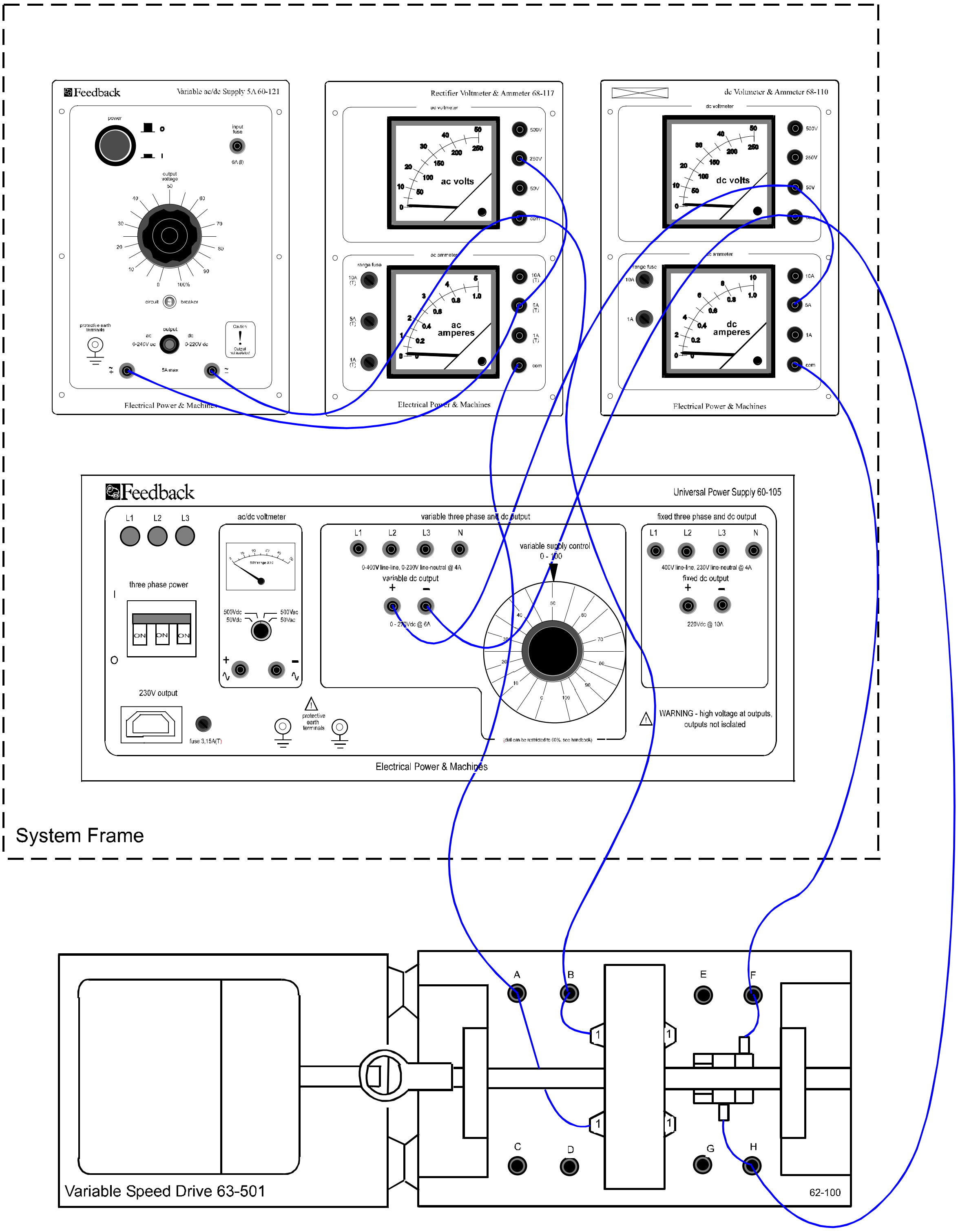


Figure A35-2: Connections for Synchronous Motor

ASSEMBLY

Mount the wound stator in the frame ring, fixing it in position with three $1^3/_8$" long cap head screws in the 12, 4 and 8 o'clock positions, with coil no.1 at the top.

Assemble the two-pole rotor as shown in the wiring diagram Figure A35-3, and as follows:

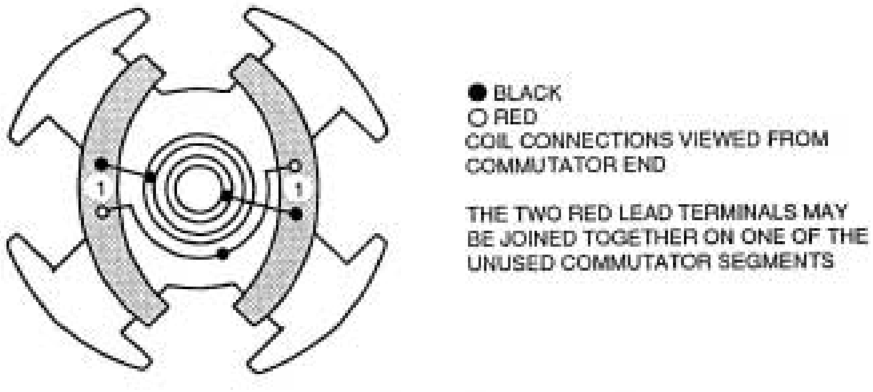


Figure A35-3: Rotor Wiring Diagram

Place two L1 coils round the rotor hub and fasten poles, B, C and D to it, using the three 1" long cap head screws and arranging the coils so that two coils sides are held in the space between poles B and C. Insert the shaft through the hub to bring the non-drive end on the same side as the coil terminals. Insert pole A and clamp the rotor to the shaft by the $1^3/_4$" long caphead screw which engages with the threaded hole in the shaft.

Slide the commutator/slipring over the shaft, make the connections shown in the wiring diagram, and tighten the set screw which holds the sliprings to the shaft - the final position can be adjusted when the rotor is mounted in its bearings. Join one coil lead to each slipring via a commutator segment.

If required, the two-salient-pole rotor described in Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 2 may be used instead of the above in this assembly.

The rotor shaft may now be fitted into the bearing housings and the removable housing screwed to the baseplate. Before finally tightening down, check that the shaft rotates freely and moves axially against the pre-loading washer. Attach the drive motor baseplate to that of the base unit, align the two shafts and connect them by a flexible coupling as explained in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 8.

Fasten the friction (Prony) brake to the baseplate as described in Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 6. Adjust the brake for zero load initially.

Make the circuit shown in wiring diagram Figure A35-4 in accordance with the connections shown in Figure A35-2.

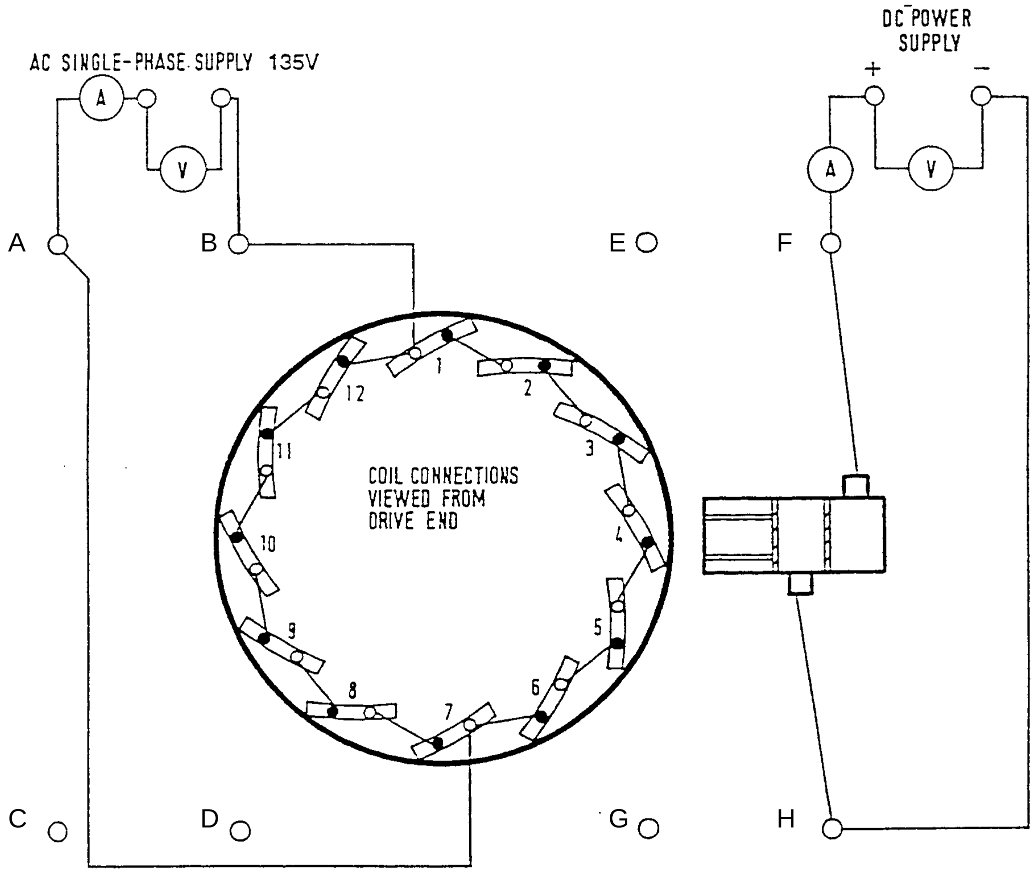


Figure A35-4: Wiring Diagram for ac Single-Phase Synchronous Motor, Rotating Field Distributed Stator Winding

PRACTICAL 35.1

The operating speed n of a synchronous motor is dependent on supply frequency f and the number of poles p:

$$n = \frac{60f}{p}$$

In this two-pole assembly, p = 1 and f = 50 Hz or 60 Hz.

$$\therefore = \frac{60 \times 50}{1} = 3000 \text{ rev/min}$$

$$\text{or } \frac{60 \times 60}{1} = 3600 \text{ rev/min.}$$

To start the motor, switch on the drive machine, bring the shaft speed to 3000 rev/min or 3600 rev/min then switch on the 135 V single-phase supply. Switch on the synchronous motor rotor dc supply and adjust the current to 2.5A dc. The motor should pull in and run steadily at its synchronous speed. The drive machine can now be switched off, but as the shaft remains coupled to the synchronous motor, it will now be driven by it.

Readings taken in a no-load test on this assembly are as given in Table A35-1 (see Typical Results and Answers section).

PRACTICAL 35.2

Variable Excitation Test

With no shaft load, vary the dc supply voltage to the rotor and observe the variation of the ac supply current to the stator. Exact measurement may not be possible due to 'hunting' of the motor, but sufficiently good indication should be obtained to allow you to sketch the shape of the curve relating supply current to excitation current on Figure A35-5 (see Results section).

Now apply a small shaft load and repeat the test, plotting a second curve. Repeat again for a greater shaft load. Finally set excitation to 2.5 A and increase the shaft load until the motor stalls. Note the torque at which this occurs.

Question 35.1 ***What shape do your curves have?***

Question 35.2 ***Did the motor speed vary up to the point where stall occurred?***

Question 35.3 ***What was the pull-out torque?***

DISCUSSION

A single-phase synchronous motor does not have a rotating stator field as does a three-phase machine and yet the rotor locks in at synchronous speed when accelerated to that speed in either direction. If you used the variable speed drive 63-501 to run your motor up, you can confirm this by repeating a run-up after reversing the armature plug on the 63-501. The single-phase stator field can be regarded as the sum of two contra-rotating fields, each of half the strength of the actual field, and the rotor can then be thought of as locking in on one of these two The other stator field, rotating in opposite sense to the rotor has the effect of varying the motor torque cyclically as it is first aiding and then opposing the locking torque. The instantaneous torque thus varies roughly sinusoidally over the revolution as shown in Figure A35-6, reaching minimum and maximum twice per revolution.

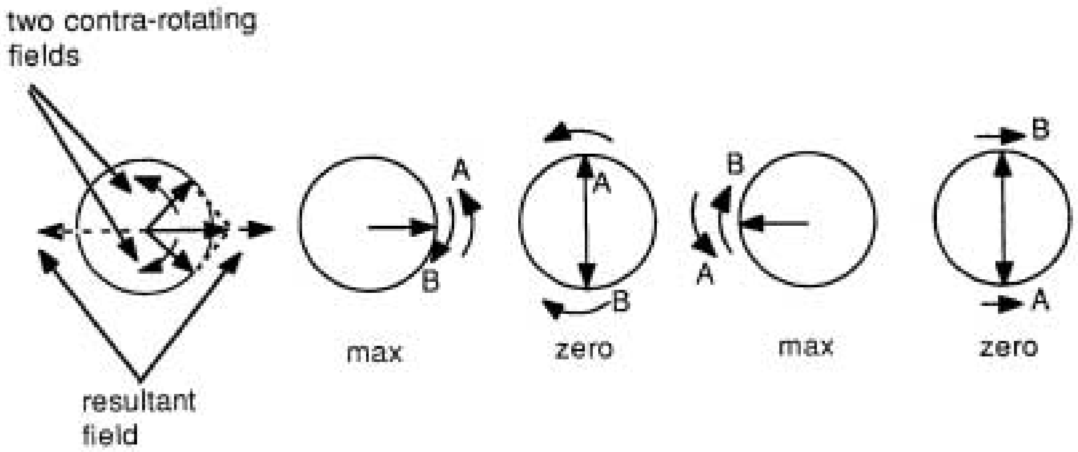


Figure A35-6

A synchronous motor may be represented by the simplified equivalent circuit of Figure A35-7.

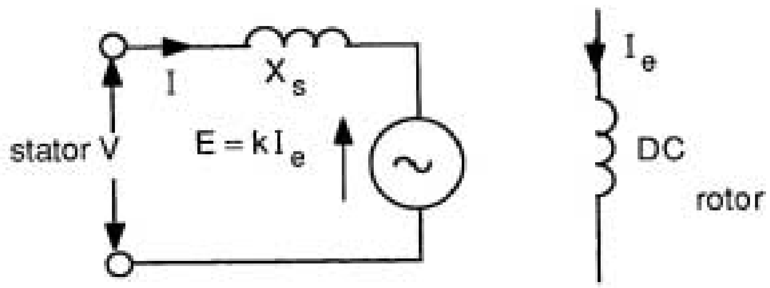


Figure A35-7

In this I_e is the rotor excitation direct current, V is the alternating applied voltage of the stator, I is the stator current, E the back-emf generated in the stator windings by the rotation of the rotor field, and X_s the stator synchronous reactance of the machine. The last item represents the combined effects of armature reaction and leakage flux and is usually large compared with the stator resistance, which may be neglected.

$$V = E + j\,I\,X_s$$

and this is represented by the phasor diagrams of Figure A35-8 (a), (b) and (c). In these, the value of E is varied by changing I_e and it is assumed that there is no shaft load.

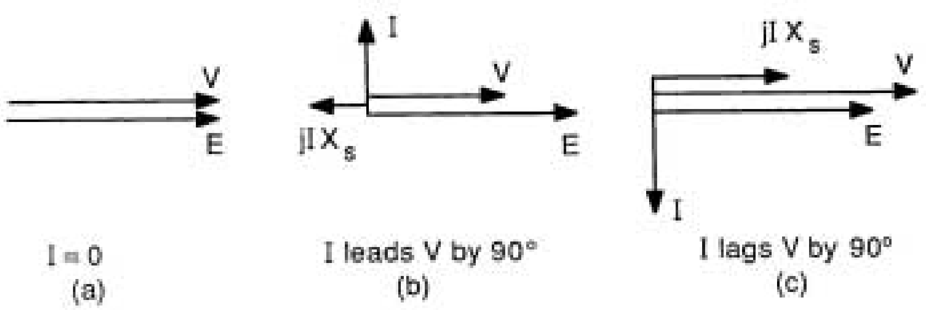


Figure A35-8

Evidently, as E is varied up or down relative to V, the current increases. However, when it is increased (over-excitation), the motor takes a leading current and when decreased (under excitation), a lagging one.

The ability of a synchronous motor to take a leading current is sometimes used to perform power factor improvement in a large installation.

When a shaft load is applied, the rotor slips back behind the rotating field by an angle called the 'torque angle'. The effect is that V and E are no longer in phase but differ by this same angle. The rotor still runs at synchronous speed but, as the load increases, the torque angle increases in order to increase the tangential component of the attractive force between the stator and rotor magnetic poles as in Figure A35-9.

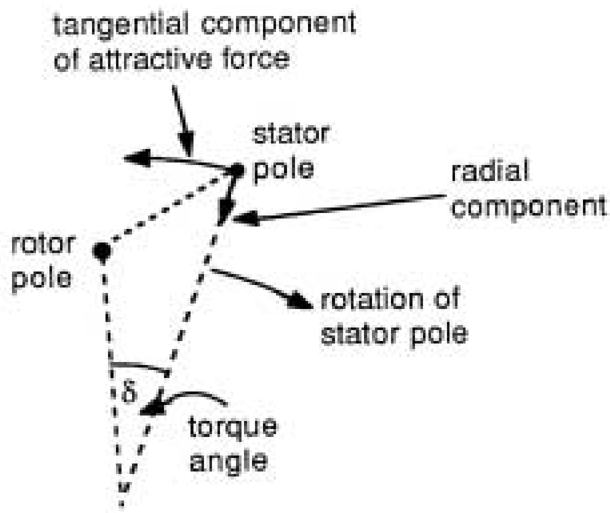


Figure A35-9

Figure A35-10 shows approximate phasor diagrams for three different values of excitation at a given value of load angle. In these diagrams, δ is the load angle between applied voltage V and stator back-emf E and the stator voltage drop j IX_s is equal to the phasor difference between V and E. Stator current I lags 90° behind j IX_s and the angle θ between it and V is the stator power factor angle. For a given shaft load and assuming that the internal losses do not vary (not strictly true), then the input power V I cos θ must be constant for different excitations. This is represented by the constant power line perpendicular to V.

In Figure A35-10 (a), a small lag angle is produced but if E is made considerably greater than V by over excitation as in Figure A35-10 (b), θ becomes quite large and leading. Obviously the magnitude of I occurs in Figure A35-10 (c) where E is just a little greater than V to make j I X_s perpendicular to V. This is often called 'Normal' excitation. If E were made less than V by under excitation, θ would be a large lagging angle and I would again increase (you could sketch the phasor diagram as an exercise).

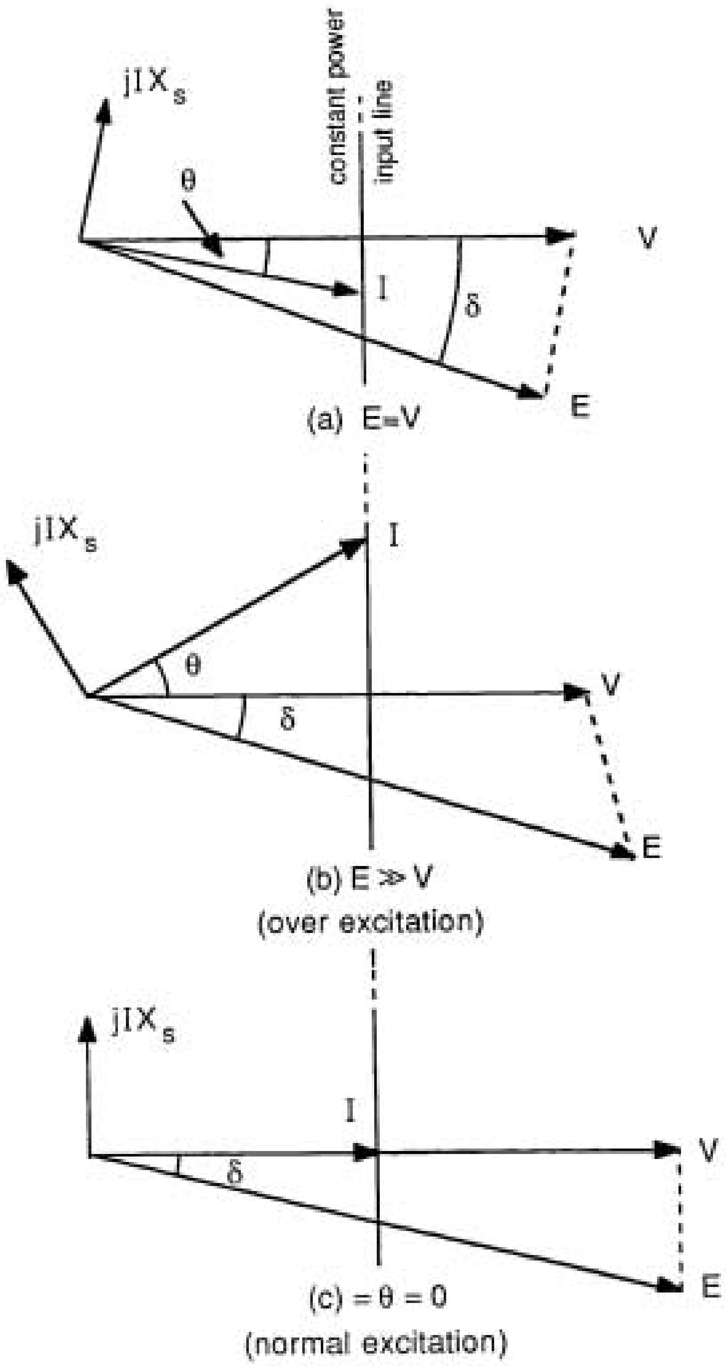


Figure A35-10

For a given excitation, if the load is increased, θ also increases and so does the magnitude and lag angle of I. Figure A35-11 shows this situation for the case of E = V only.

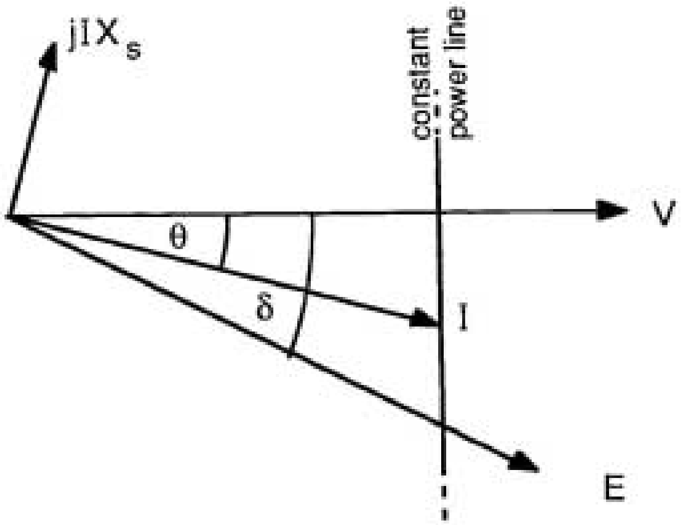


Figure A35-11

It should be evident that as the load increases, the percentage over-excitation needed to bring I back into phase with V (θ = 0) also increases. If we now plot I against excitation for different loads, we obtain the curves of Figure A35-12, known as the V-curves, in which, for each load, a certain excitation leads to minimum current. The value of this 'Normal' excitation increases slightly with load.

You may have noticed from Figure A35-10 or A35-11 that the minimum value of the phasor difference V - E must always occur when V and E are equal in magnitude and this would seem to suggest that j IX_s and therefore I should also be minimum at this point. Power considerations, however, show that I is minimum where θ is zero as in Figure A35-10 (c). This apparent anomaly is due to the approximate nature of the phasor diagram used. This neglects several significant secondary effects such as the changes in power loss in the stator resistance as I varies and the contribution made by I to the total machine flux (armature reaction). In practice, however, if power loss variations are relatively small the constant power principle is nearly correct and the curves of Figure A35-12 will be obtained.

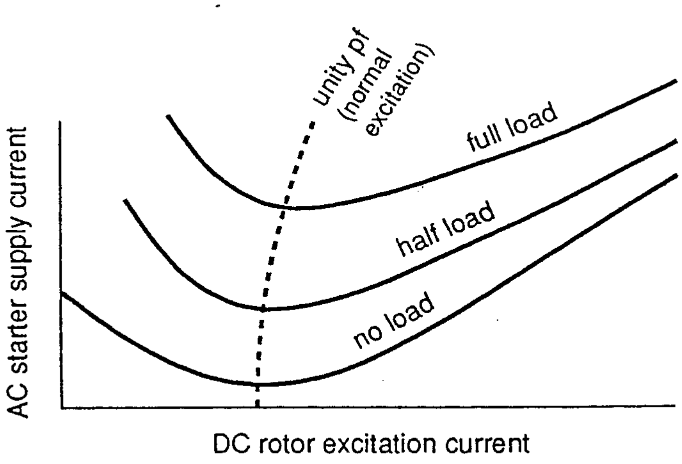


Figure A35-12

Notes

Practical 35.1

Stator		Rotor		Shaft Speed (50/60 Hz)
Volts ac	Amps ac	Volts dc	Amps dc	Rev/min

Table A35-1

Practical 35.2

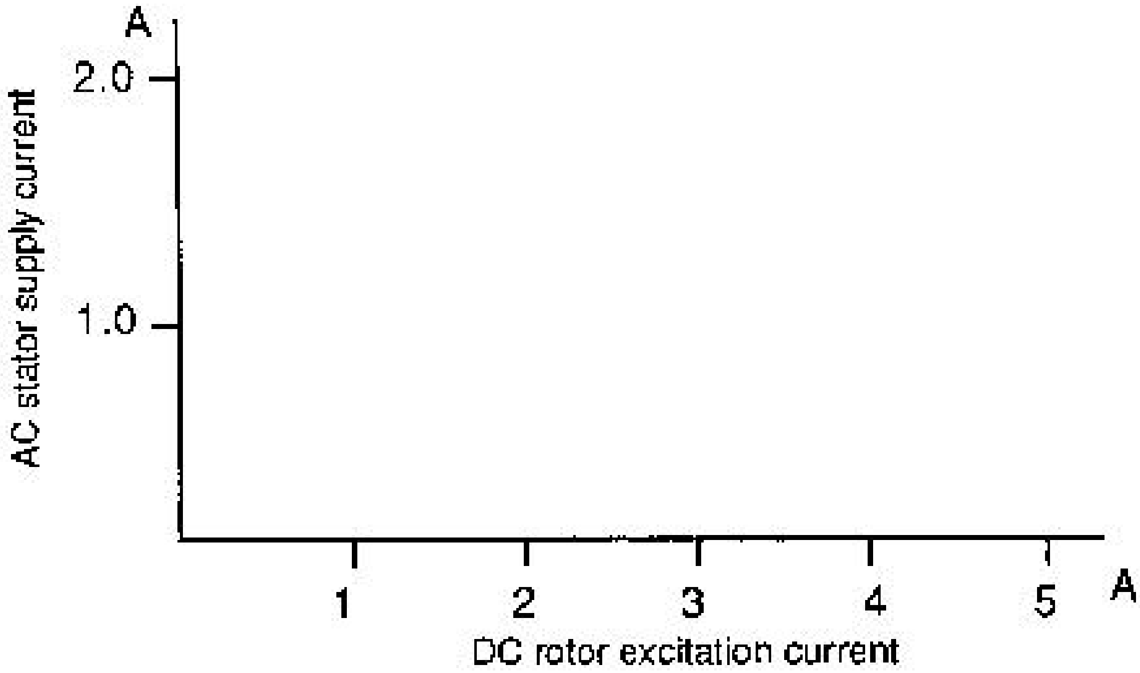


Figure A35-5 Graph Axes

Notes

Practical 35.1

Stator		Rotor		Shaft Speed (50/60 Hz)
Volts ac	Amps ac	Volts dc	Amps dc	Rev/min
135	0.88	10.2	2.5	3000/3600

Table A35-1

Practical 35.2

Question 35.1 The curves resulting from the variable excitation test are the well-known V curves and should typically be as shown in Figure A35-12 and as explained in the Discussion.

Question 35.2 The motor speed remained constant until pull-out torque was reached but the torque angle increased. This can be observed, using a synchronized stroboscope, as a fall back in rotor position as load is increased.

Question 35.3 The pull-out torque should be about 0.6 Nm.

See 'Matching the Motor to its Load' in Appendix A for further information on synchronous motor applications.

Notes

DISSECTIBLE MACHINES SYSTEM

Assignment 36
ac Single-Phase, 4-Pole Synchronous Motor, Rotating Field

PRACTICAL

36.1

36.2 Variable Excitation Test

EQUIPMENT REQUIRED

	Qty	Item
62-100 Kit	1	Base Unit
	4	L3 Coils
	1	12-slot Wound Stator
	1	Rotor Hub
	4	Rotor Poles
	1	Commutator/Slipring
	2	Brushes and Brushholders
	1	Flexible Coupling
General	1	Variable Speed Motor: 1/3 hp, 1200 rev/min, (eg, Feedback 63-501)
	1	ac supply; 135 V, 5 A single-phase (eg, Feedback 60-121)
	1	dc supply; 0-20 V, 5 A (eg, Feedback 60-105)
	1 1	0 – 200 V ac Voltmeter 0–5 A ac Ammeter (eg, Feedback 68-117)
	1 1	0-50 V, dc Voltmeter 0-5 A dc Ammeter (eg, Feedback 68-110)
	1	Friction (Prony) Brake or other Dynamometer 0-1 Nm at 1500 rev/min (eg, Feedback 67-470)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

The single-phase synchronous motor has a field which is supplied from a dc source and an armature supplied from an ac source. It is usual, as in this assembly, to have a rotating field and stationary armature, although this arrangement can be reversed.

Synchronous motors are not self-starting and the method used to bring them to running speed depends on the size of the motor. To avoid using a separate drive machine, some motors have a low resistance squirrel-cage winding embedded in the rotor poles and are brought up to near synchronous speed as an induction motor. Smaller motors may be spun by hand to a speed above synchronism and will pull into step as the shaft speed fails.

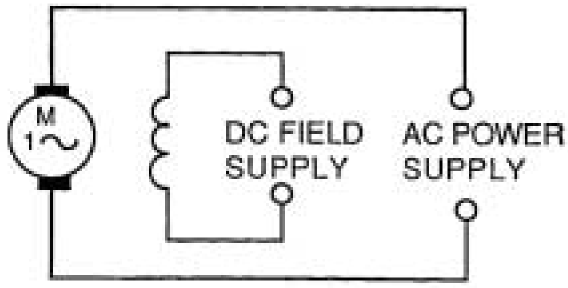


Figure A36-1: ac Single-Phase Synchronous Motor Circuit Diagram

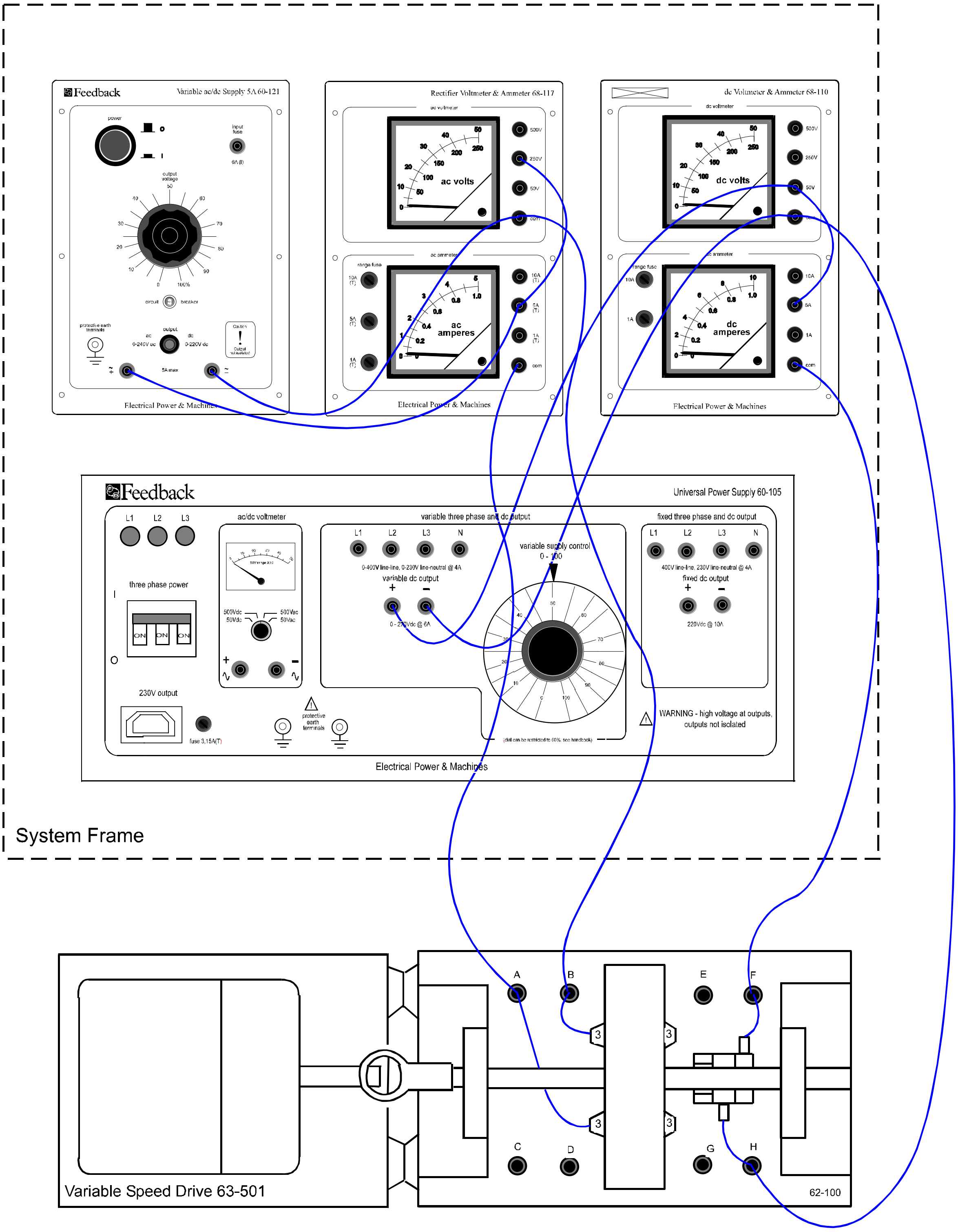


Figure A36-2: Connections for Synchronous Motor

ASSEMBLY

Mount the wound stator in the frame ring, fixing it in position with three $1^3/_8$" long cap head screws in the 12, 4 and 8 o'clock positions, with coil no.3 at the top.

Assemble the four-pole rotor as shown in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 2 and connect it to the slip-rings as shown there (also in Figure A36-4).

Slide the sliprings over the shaft, make the connections shown in wiring diagram (Figure A36-3) and tighten the set screw which holds the sliprings to the shaft - the final position can be adjusted when the rotor is mounted in its bearings. Join one coil lead to each slipring via a commutator segment.

The rotor shaft may now be fitted into the bearing housings and the removable housing screwed to the baseplate. Before finally tightening down, cheek that the shaft rotates freely and moves axially against the pre-loading washer. Attach the drive motor baseplate to that of the base unit 62-100, align the two shafts and connect them by a flexible coupling as explained in Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 7.

Fasten the friction (Prony) brake to the baseplate as described in Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 6.

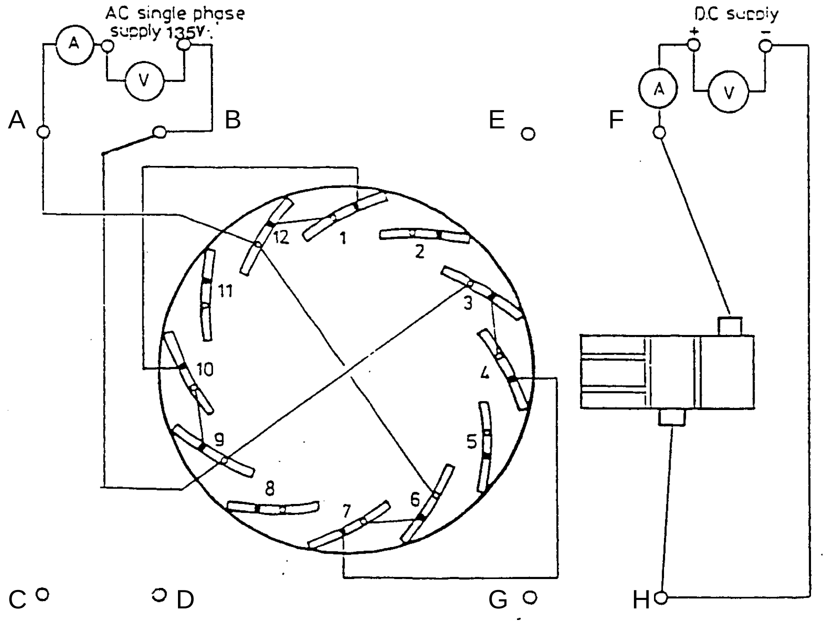


Figure A36-3: Wiring Diagram for ac Single-Phase, 4-Pole, Synchronous Motor, Rotating Field Distributed Stator Winding

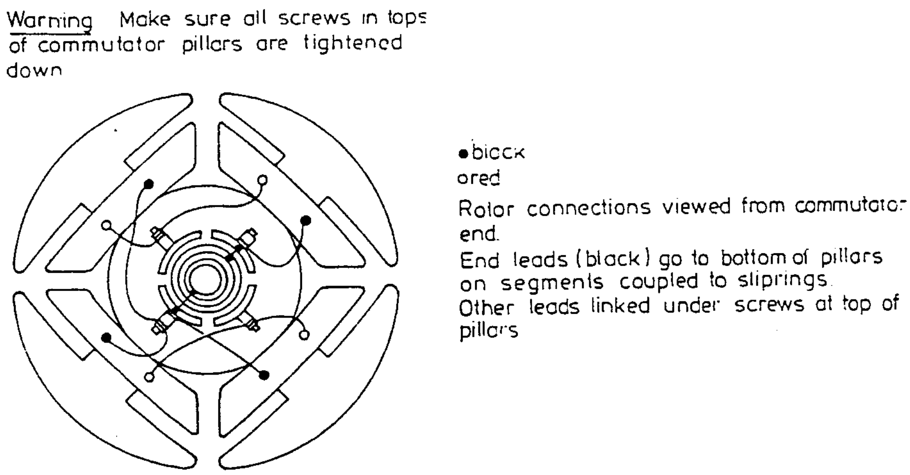


Figure A36-4: 4-pole Rotor Wiring Diagram

Make the circuit shown in Figure A36-3 in accordance with the connections given in Figure A36-2.

PRACTICAL 36.1

The operating speed n of a synchronous motor is dependent on supply frequency f and the number of poles p:

$$n = \frac{60f}{p}$$

In this four-pole assembly, p = 2 and f = 50 Hz or 60 Hz.

$$\therefore = \frac{60 \times 50}{2} = 1500 \text{ rev/min}$$

$$\text{or } \frac{60 \times 60}{2} = 1800 \text{ rev/min.}$$

To start the motor, switch on the drive machine, bring the shaft speed to 1500 rev/min or 1800 rev/min then switch on the 135 V single-phase supply. Switch on the synchronous motor rotor dc supply and adjust the current to 2.5A dc. The motor should pull in and run steadily at its synchronous speed. The drive machine can now be switched off, but as the shaft remains coupled to the synchronous motor, it will now be driven by it.

Readings taken in a no-load test on this assembly are as given in Table A36-1 (see Typical Results and Answers section).

PRACTICAL 36.2

Variable Excitation Test

With no shaft load, vary the dc supply voltage to the rotor and observe the variation of the ac supply current to the stator. Exact measurement may not be possible due to 'hunting' of the motor, but sufficiently good indication should be obtained to allow you to sketch the shape of the curve relating supply current to excitation current on Figure A36-5 (see Results section).

Now apply a small shaft load (0.3Nm) and repeat the test, plotting a second curve. Repeat again for a load around 0.6Nm. Finally set excitation to 2 A and increase the load until stall occurs, noting the load torque when it does so.

Question 36.1 ***What shape do your curves have?***

Question 36.2 ***Did the motor speed vary up to the stall point?***

Question 36.3 ***What was the pull-out torque?***

Question 36.4 ***Why must both rotor and stator be provided with four poles?***

DISCUSSION

Apart from the doubled number of poles and consequent halving of the synchronous speed, this motor is exactly the same as that of Assignment 35 and the Discussion of that should be read now if you have not already done so. This will explain the shapes of curve obtained in the excitation test.

The rotor of this assembly is a salient-pole type having alternate North and South Poles; its construction makes is a more efficient electromagnetic and hence the pull-out torque is somewhat greater than for the two-pole machine of Assignment 35.

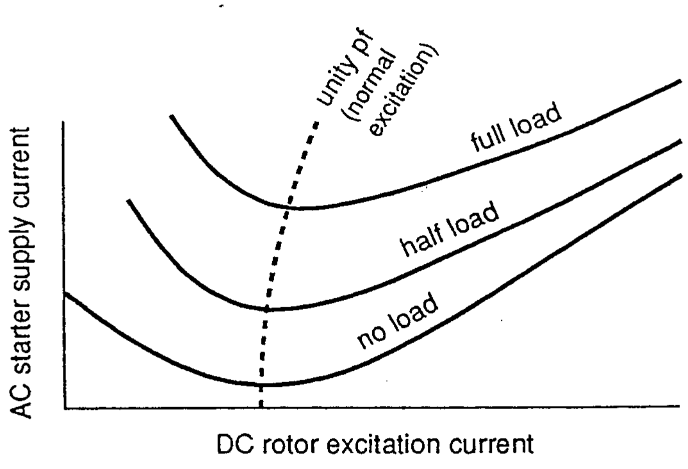


Figure A35-12

Practical 36.1

Stator		Rotor		Shaft Speed (50/60 Hz)
Volts ac	Amps ac	Volts dc	Amps dc	Rev/min

Table A36-1

Practical 36.2

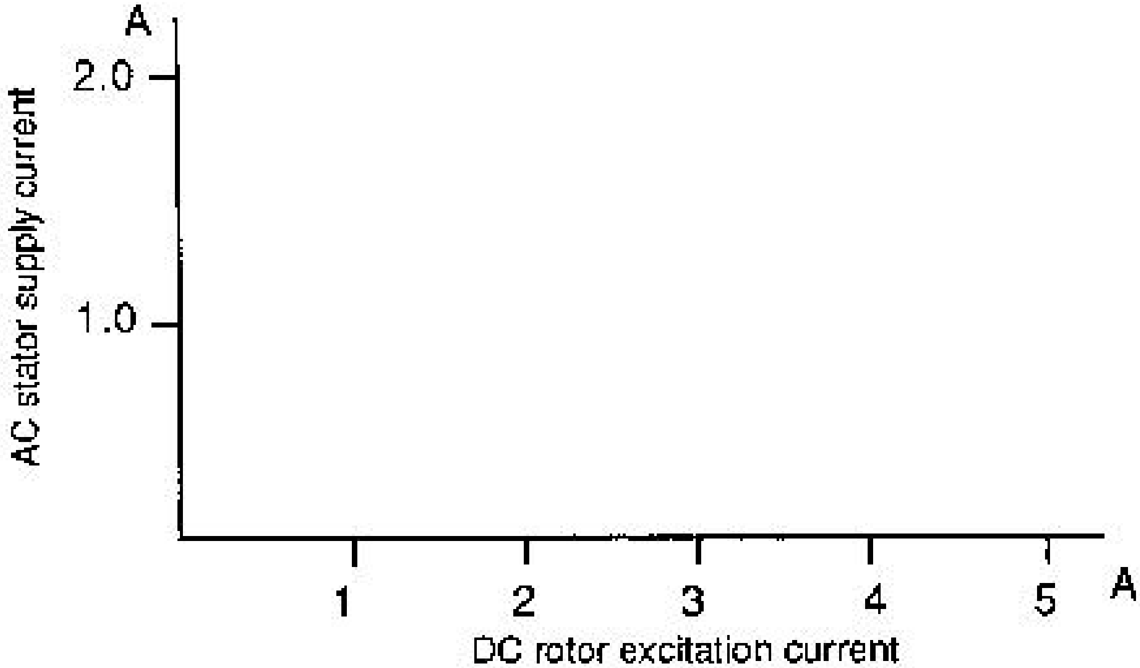


Figure A36-5 Graph Axes

Notes

Practical 35.1

Stator		Rotor		Shaft Speed (50/60 Hz)
Volts ac	Amps ac	Volts dc	Amps dc	Rev/min
135	0.5	17	2.5	1500/1800

Table A35-1

Practical 35.2

Question 35.1 The curves obtained are the well-known V-curves and should be similar to those in Figure A36-5

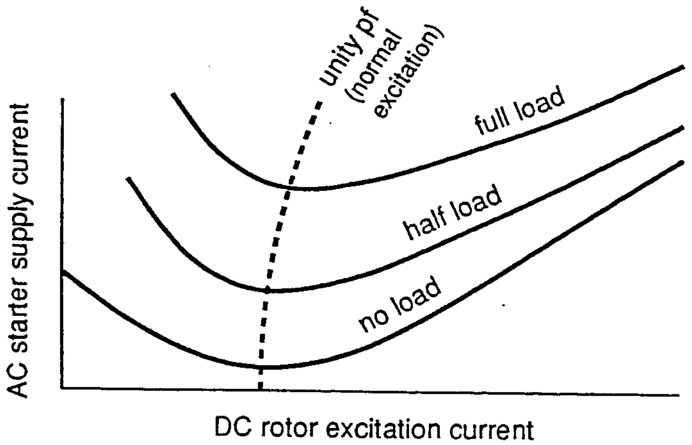


Figure A36-5

These curves are consistent with the explanation given in Assignment 35, Discussion, with over-excitation corresponding to a leading power factor and under-excitation to a lagging one. This is strictly true only at no-load and the locus of unity power factor follows the line indicated in Figure A36-5.

Question 35.2 The motor speed is constant up to pull-out but, as torque is increased, the rotor falls back relative to the rotating stator field by the 'torque angle'. This can be observed if a stroboscope is used to view the rotor and its frequency either synchronised to the supply frequency or set carefully to give a stationary rotor image.

Question 35.3 Pull-out torque should be about 1.2 Nm.

Question 36.4

Since the stator has four poles, at a given time the rotating field due to the stator must have poles separated by 90° as in Figure A36-6. For the rotor to be able to lock onto this rotation, it must have corresponding but opposite poles and must therefore also have four poles.

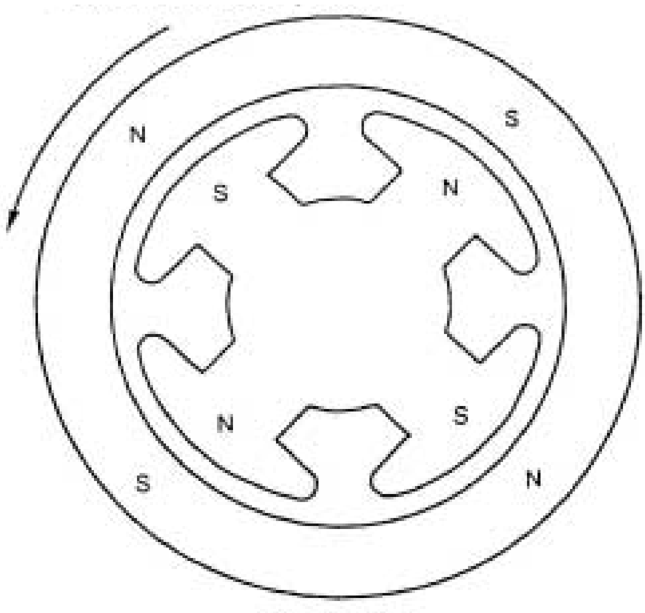


Figure A36-6

For further information on synchronous motor applications, see 'Matching the Motor to its Load' in Appendix A, and also Additional Assignment 53.

DISSECTIBLE

MACHINES SYSTEM

Assignment 37/38
ac Single-Phase Generator, Rotating Field

PRACTICAL	37.1	Open Circuit Test
	37.2	Load Characteristic
	37.3	Short Circuit Test
	37.4	Capacitive Load

EQUIPMENT REQUIRED

	Qty	**Item**
62-100 Kit	1	Base Unit
	2	L1 Coils
	2	L9 Coils
	1	12-slot Wound Stator
	2	Stator Poles
	1	Rotor Hub
	4	Rotor Poles
	1	Commutator/Slipring
	2	Brushes and Brushholders
	1	Flexible Coupling
General	1	Variable Speed Motor: 1/3 hp, 1200 rev/min, (eg, Feedback 63-501)
	1	dc supply; 0-20 V, 5 A (eg, Feedback 60-105)
	1 1	0-50 V, dc Voltmeter 0-5 A dc Ammeter (eg, Feedback 68-110)
	1 1	0 – 200 V ac Voltmeter 0–5 A ac Ammeter (eg, Feedback 68-117)
	1	Variable Resistor, 0-200 ohms, 2.5 A (eg, Feedback 67-113
	1	Control Switches (eg, Feedback 65-130)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

INTRODUCTION

In these assemblies, the armature winding is stationary and is connected directly to the load. The field system rotates and is supplied through sliprings from a low-voltage dc source.

There are two main categories of ac generator designated by the type of rotor employed, cylindrical or salient-pole. Cylindrical rotors are used in large high-speed steam turbine generators and have a two- or four-pole field winding distributed in slots on the face of the rotor. Salient-pole rotors are generally used in low-speed applications and have radial poles bolted to a central hub, with a coil fitted to each pole. The coils are joined in series or parallel and connected to a pair of sliprings.

The stator has the same general form in each case. It will usually have distributed windings, connected to give a single-phase or multi-phase output. The large turbine generators in power station are always three-phase, while the small generators used for auxiliary supplies or vehicle supplies may be single-phase.

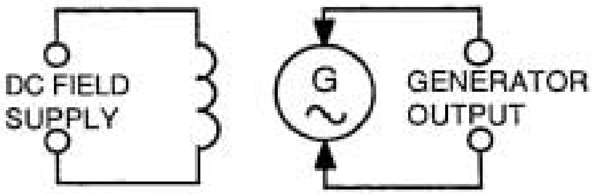


Figure A37-1: ac Single-Phase Generator, Rotating Field Circuit Diagram

ASSEMBLY

For the concentrated stator winding, fit the L9 coils to the two stator poles, then fix the poles to the frame ring at the 3 o'clock and 9 o'clock positions using the 1 ½" long cap head screws. For the distributed stator winding, mount the wound stator in the frame ring and fix in position with three 1 ¼" long cap head screws in the 12, 4 and 8 o'clock positions, with coil No.1 at the top.

Assemble the two-pole rotor as shown in the wiring diagram Figure A37-2, and as follows.

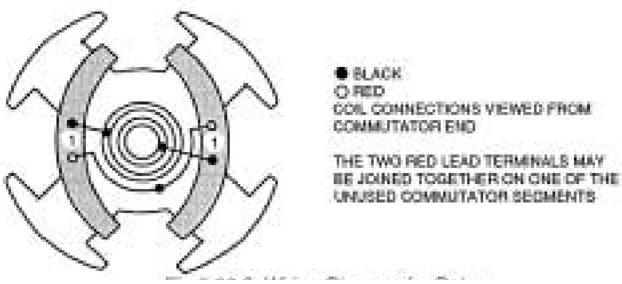


Figure A37-2: Rotor Wiring Diagram

Place two L1 coils round the rotor hub and fasten poles B, C and D to it using the three 1” long cap-head screws, and arranging the coils so that two coils sides are held in the space between poles B and C. Insert the shaft through the hub to bring the non-drive end on the same side as the coil terminals. Insert pole A and clamp the rotor to the shaft by the 1 ¾" long caphead screw which engages with the threaded hole in the shaft.

Slide the sliprings over the shaft, make the connections shown in the wiring diagram, and tighten the set screw which holds the sliprings to the shaft -the final position can be adjusted when the rotor is mounted in its bearings. Join one coil lead to each slipring via a commutator segment.

If desired, the two-salient-pole rotor described in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 2, may be used instead for this assignment.

The rotor shaft may now be fitted into the bearing housings and the removable housing screwed to the baseplate. Before finally tightening down, check that the shaft rotates freely and moves axially against the pre-loading washer. Attach the drive motor baseplate to that of the 61-100, align the two shafts and connect them together by a flexible coupling as described in. the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 7.

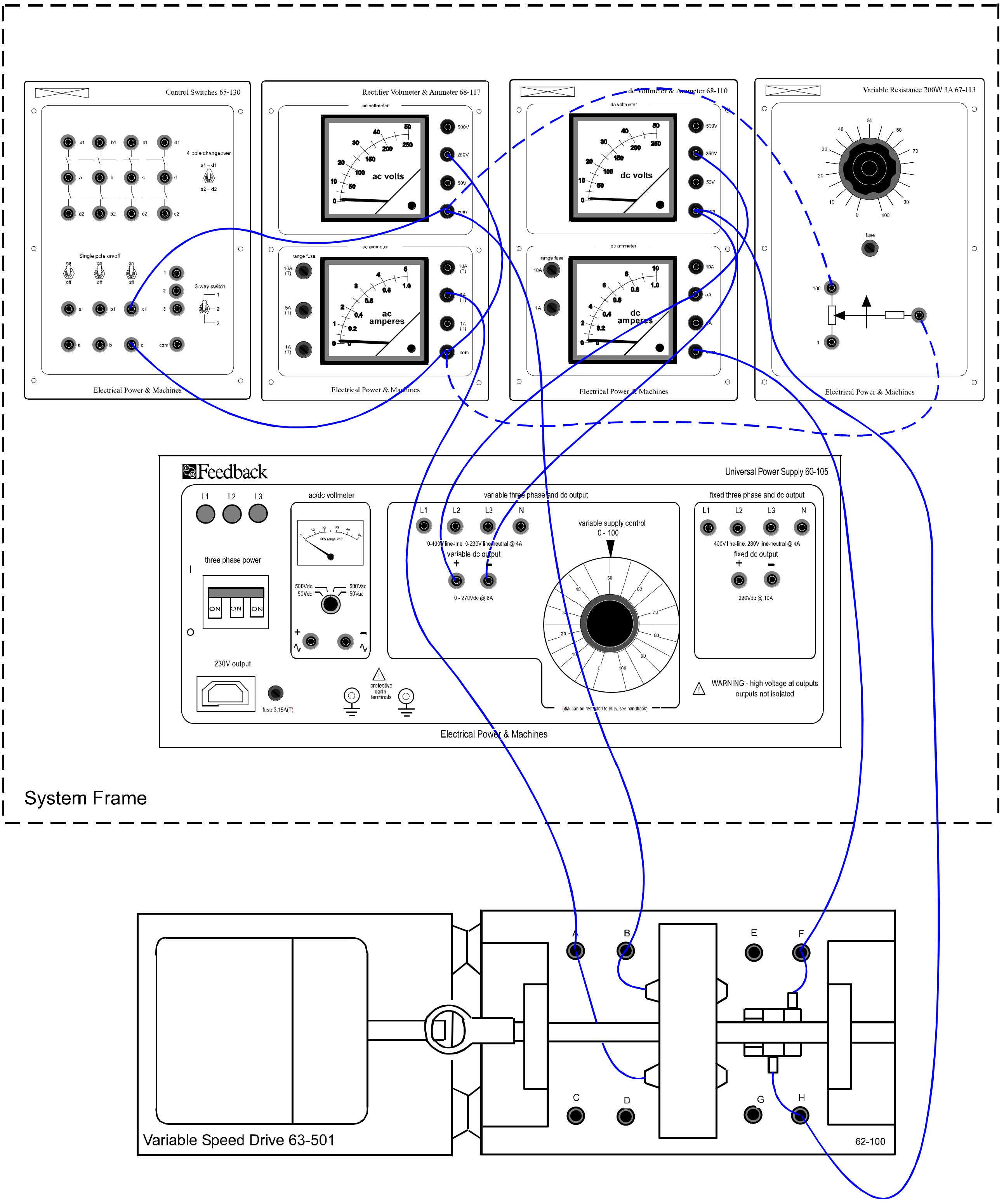


Figure A37-3: ac Single-Phase Generator, Rotating Field Connections

Make the circuit shown in Figure A37-4 for concentrated windings and Figure A37-5 for distributed windings in accordance with the connections shown in Figure A37-3.

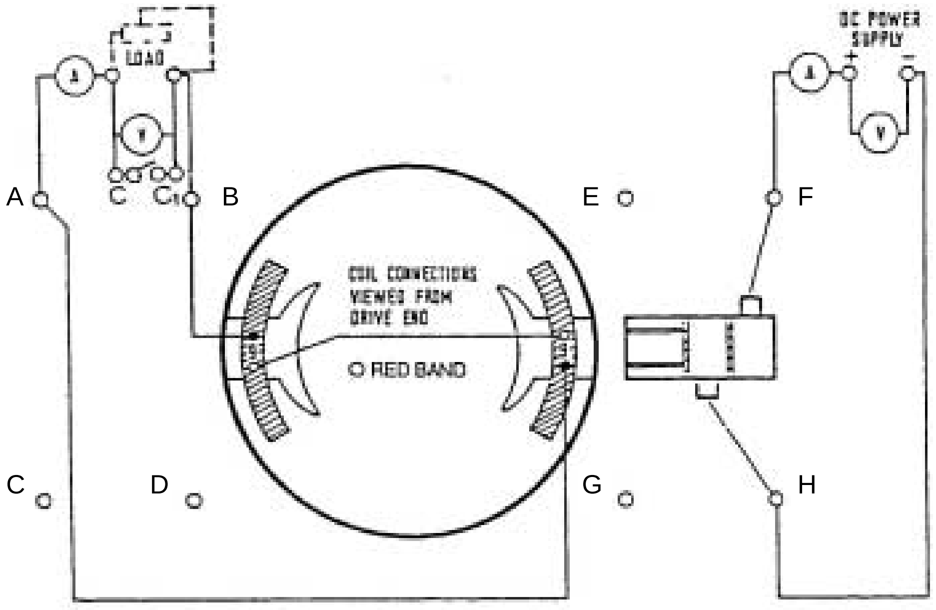


Figure A37-4: 4-ac Single-Phase Generator, Rotating Field Concentrated Stator Winding

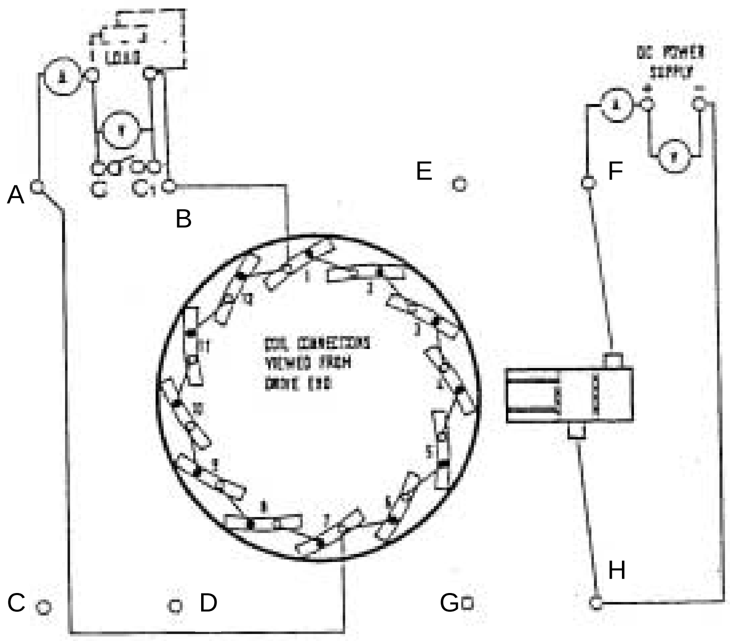


Figure A37-4: 5-ac Single-Phase Generator, Rotating Field Distributed Stator Winding

PRACTICAL 37.1

The frequency of the alternating voltage generated in the stator windings is proportional to p the number of pole pairs in the rotor field, and n the speed of shaft rotation

$$f = \frac{pn}{60}$$

In this assignment, there is one pair of rotor poles, therefore:

$$f = \frac{\text{shaft speed}}{60}$$

and with a shaft speed of 3000 rev/min, the generator frequency will be 50 Hz.

Similarly, a shaft speed of 1500 rev/min will give a frequency of 25 Hz.

Open Circuit Test

The purpose of this test is to obtain a relationship between field excitation and generated voltage with no applied load. The results when plotted give the open-circuit or magnetisation curve.

Start the drive motor, adjust its speed to either 3000 rev/min or 1500 rev/min and maintain at the set value throughout the test. If available, a low reading voltmeter can be temporarily connected across the output terminals to read the small voltage generated at zero field current due to residual magnetism. Switch on the dc supply to the rotor and adjust the current in steps from 0 to 5 A, taking readings of terminal voltage and rotor current at each step. The results when plotted (see Results Tables) should give a graph similar to that of Figure A37-6 for concentrated windings, or Figure A37-7 for distributed windings(see Typical Results and Answers).

PRACTICAL 37.2

Load Characteristic

Connect a 100Ω, 3 A variable resistor to the output terminals of the generator. Set the shaft speed to 3000 or 1500 rev/min and maintain at that value throughout the test. Vary the load resistance from maximum down to approximately 10Ω in steps, with the terminal voltage held at, say, 30 volts by adjustment of rotor current. Take readings of load current and rotor current at each step and plot the results (see Results Tables) to give a graph similar to that of Figure A37-8 (see Typical Results and Answers).

PRACTICAL 37.3

Short Circuit Test

The short circuit characteristic relates generator output current on short circuit to rotor excitation. It is a measure of stator reactance and is useful as a test of performance from which regulation, etc can be calculated.

Before running the generator, short the output terminals together through a 5 A ac ammeter by setting switch C-C1 'on' and set the rotor current to its minimum value. Bring the shaft speed up to the value used in the previous tests and increase the rotor current in steps from 0 to 4 A, taking readings of short-circuit current and rotor current at each step.

Plot the results on a graph (see Results Tables) similar to Figure A37-9 (see Typical Results and Answers).

Now vary the shaft speed over a fairly wide range, say 500 – 2500 rev/min.

It will be found that quite large changes in speed have little effect on short-circuit current. The stator reactance, which is considerably greater than the resistance, is proportional to frequency and hence to rotor speed. The internal emf generated is also proportional to speed so the short-circuited current is in this case given approximately by the ratio:

$$\frac{\text{stator emf}}{\text{stator reactance}}$$

and is not greatly affected by changes in shaft speed.

PRACTICAL 37.4
Capacitive Load

With the speed at 1500 rev/min and an unloaded terminal voltage of 50 V, connect a 14 μF load across the terminals and note the new terminal voltage and the load current.

Exercise 37.1

Assuming that the generator has an overall efficiency of 50%, calculate the drive torque needed to maintain a speed of 1500rev/min when the generator is supplying a 30W load.

Question 37.1 ***Are the voltage and current in the capacitive load test what you would expect for a 14 μF load?***

Question 37.2 ***What happens to the terminal voltage when the capacitive load is connected and why?***

DISCUSSION

The elements of this generator are exactly the same as those of a synchronous motor as studied in Assignment 35. Before continuing and if you have not already done so, read the Discussion of Assignment 35.

The simplified equivalent circuit and phasor diagrams for the generator are thus similar to those for the motor but the direction of power flow is reversed. Figure A37-10 is the equivalent circuit and in it I_e is the rotor excitation current, E is the generated emf for a constant speed, X_s is the stator reactance, I is the load current and V the terminal voltage.

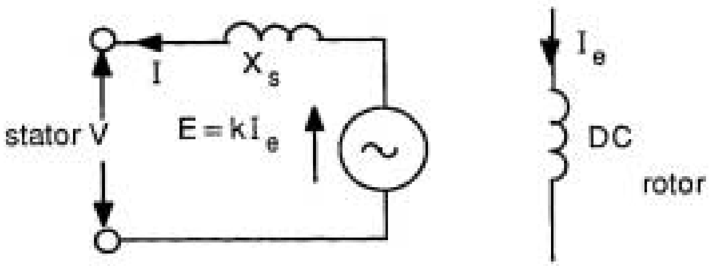


Figure A37-10

Since the current flows into the load, the equation represented by Figure A37-10 is:

$$V = E - j\,I\,X_s$$

$$\text{or } E = V + j\,I\,X_s$$

The corresponding phasor diagram is dependent upon the power factor of the load, that is upon the phase angle between the terminal voltage V and the load current I. Figure A37-11 shows the three cases for resistive (unity p.f) inductive (lagging p.f) and capacitive (leading p.f) loads.

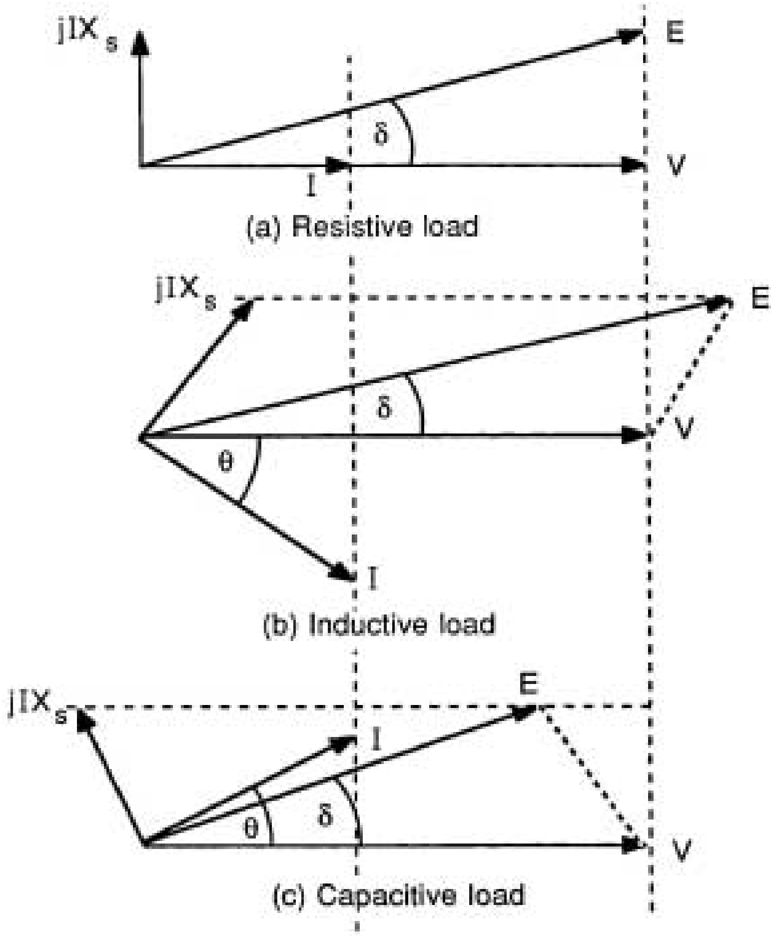


Figure A37-11

These diagrams assume a constant power to the load VI cos θ at a constant terminal voltage and show that the required value of E is greater for an inductive load and less for a capacitive one. Conversely, for constant generated emf E (constant speed and excitation current) V will increase for a capacitive load and reduce for an inductive one.

Notes

Practical 37.1

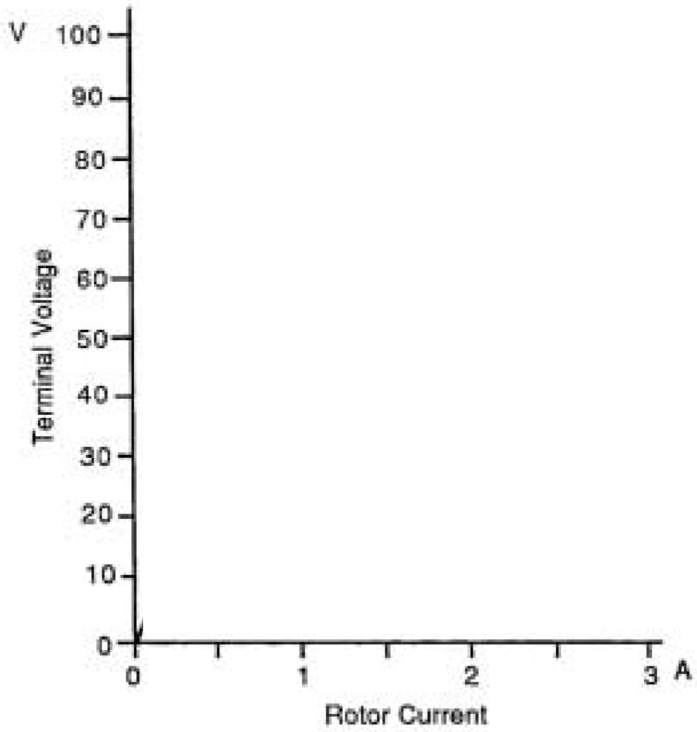


Figure A37-6 Graph Axes

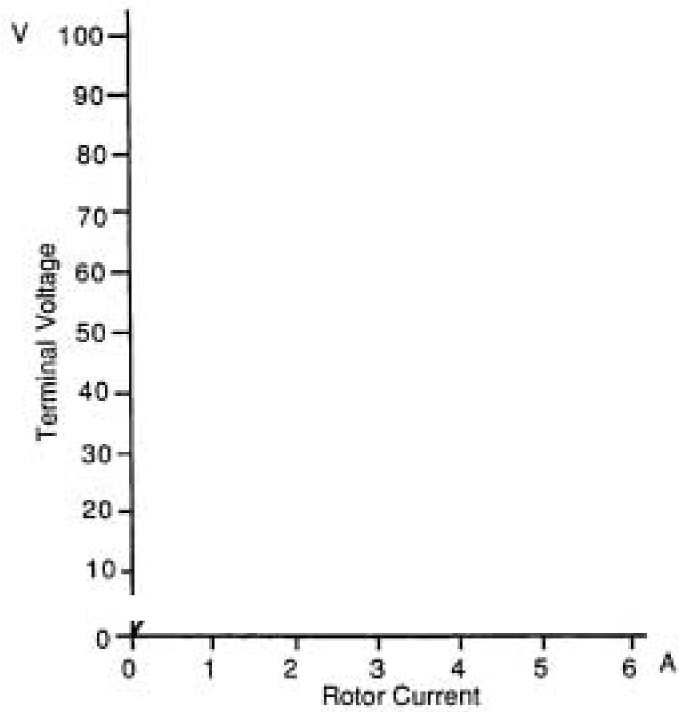


Figure A37-7 Graph Axes

Practical 37.2

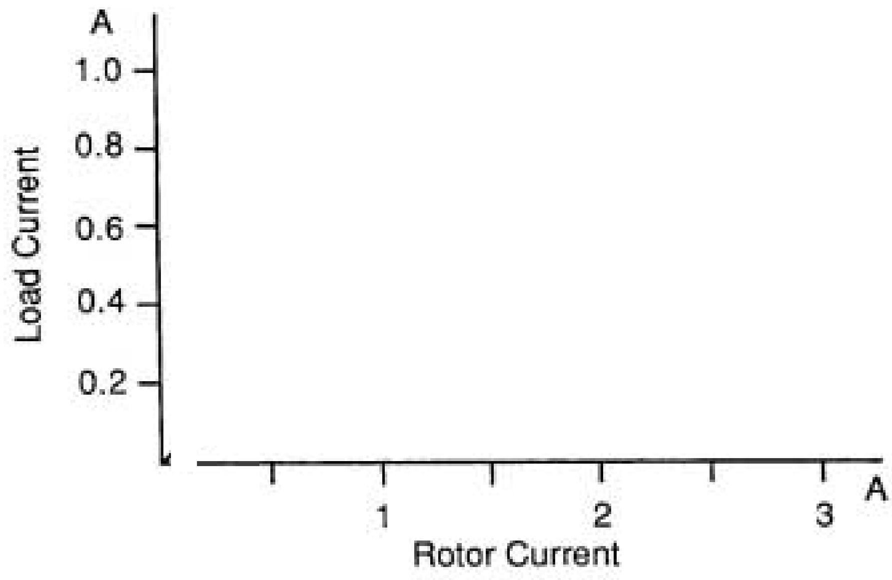


Figure A37-8 Graph Axes

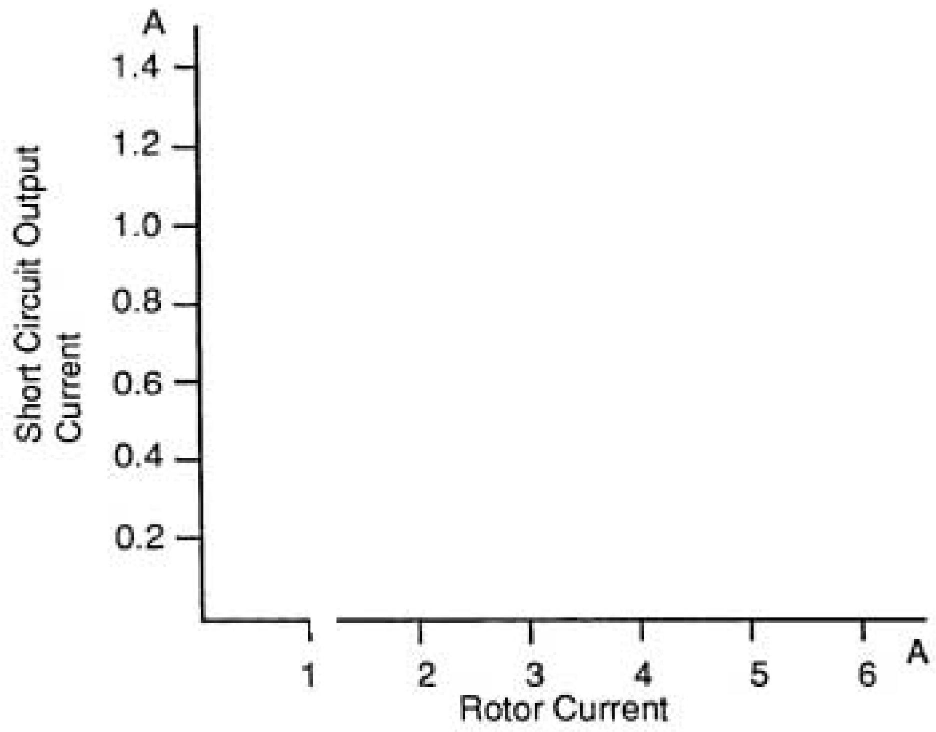


Figure A37-9 Graph Axes

Practical 37.1

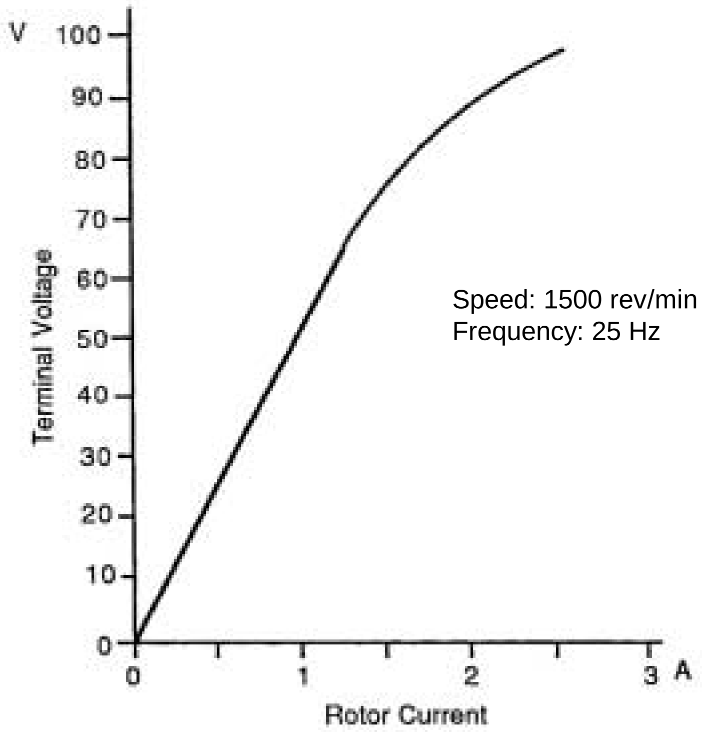


Figure A37-6: Open-Circuit Test, Concentrated Winding

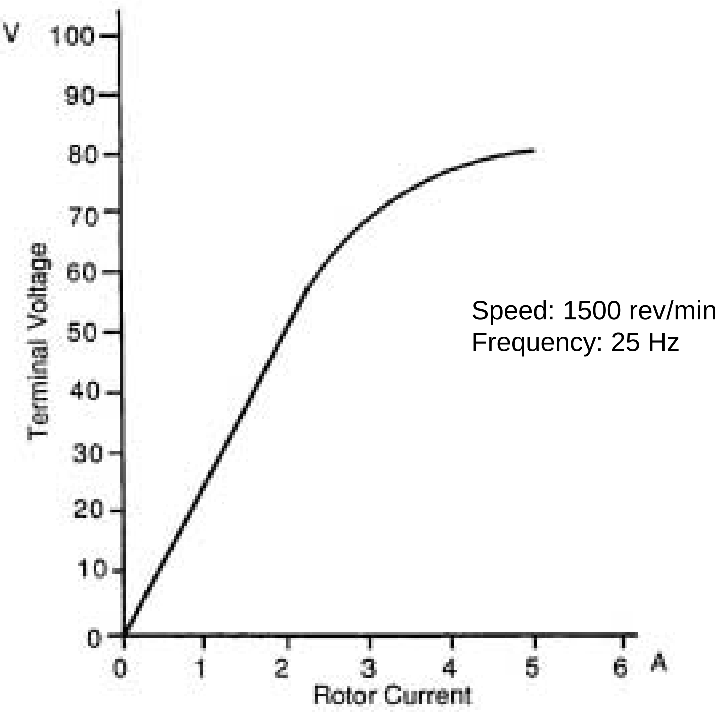


Figure A37-7: Open-Circuit Test, Distributed Winding

Practical 37.2

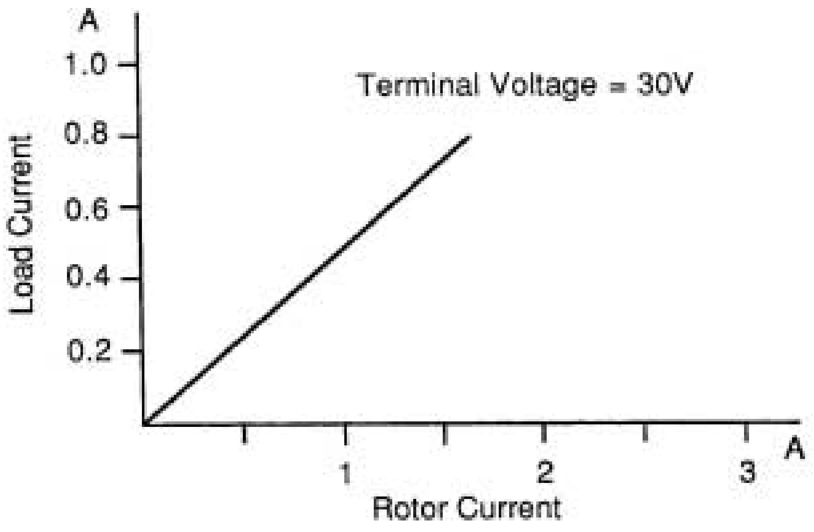


Figure A37-8: Load Characteristic

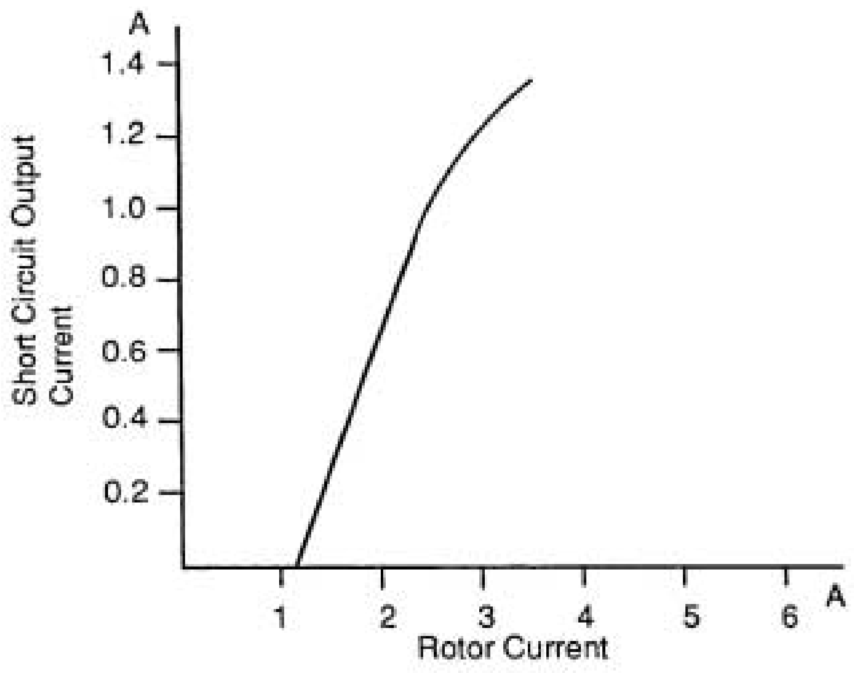


Figure A37-9: Short Circuit Test, Concentrated Winding

Exercise 37.1

Output power = 30 W

Input power = $\frac{30}{50}$ x 100 = 60 W

$= \frac{2\pi NT}{60}$ where T = torque (Nm)

N = speed (rev/min)

Thus at N = 1500

$T = \frac{60 \times 60}{2\pi \times 1500} = 0.36$ Nm

Question 37.1

At 1500 rev/min, the generated frequency for a 2-pole machine is:

$\frac{1500}{60} = 25$ Hz

The current at 54 V should be:

$I = \frac{V}{X_c}$

$= V \times 2\pi fC$

$= 54 \times 2\pi \times 25 \times 14 \times 10^{-6}$

Typical values for V and I in the capacitive load test are 54 V and 0.25 A.

The agreement is only fair, the discrepancy being explained primarily by the non-sinusoidal waveform of the generator affecting voltage and current readings on rectifier-type instruments. Also there are considerable harmonic currents drawn by the capacitive load which increases the current measured.

Question 37.2

The terminal voltage increases when a capacitive load is applied and this is explained by Figure A37-11 in the Discussion.

Notes

DISSECTIBLE MACHINES SYSTEM

Assignment 39
ac Single-Phase Generator, Rotating Armature

PRACTICAL	39.1	Open Circuit Test
	39.2	Short Circuit Test
	39.3	Capacitive Load Test

EQUIPMENT REQUIRED

	Qty	Item
62-100 Kit	1	Base Unit
	1	Commutator/Slipring
	2	L1 Coils
	2	L9 Coils
	2	Field Poles
	1	Rotor Hub
	4	Rotor Poles
	2	Brushes and Brushholders
	1	Flexible Coupling
General	1	Variable Speed Motor: 1/3 hp, 1200 rev/min, (eg, Feedback 63-501)
	1	dc supply; 0-20 V, 5 A (eg, Feedback 60-105)
	1 1	0-50 V, dc Voltmeter 0-5 A dc Ammeter (eg, Feedback 68-110)
	1 1	0 – 200 V ac Voltmeter 0–5 A ac Ammeter (eg, Feedback 68-117)
	1	Variable Resistor, 0-200 ohms, 2.5 A (eg, Feedback 67-113
	1	Control Switches (eg, Feedback 65-130)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

INTRODUCTION

This assignment reverses the conventional arrangement for ac generators in that the field windings are stationary while the armature windings rotate and-are connected to the load through sliprings and brushes.

This construction is employed in one form of brushless ac generator where a rotating armature machine is used as an exciter supplying the field of the main generator. The exciter armature connections are taken directly to a bank of shaft mounted rectifiers and the dc output from these is connected to the rotating field windings of the main generator.

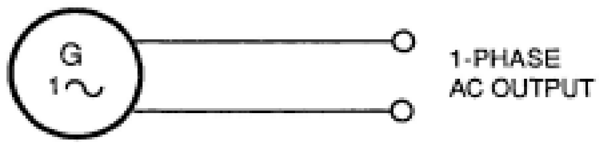


Figure A39-1: ac Single-Phase Generator, Rotating Armature Circuit Diagram

ASSEMBLY

Fit the L9 coils to the stator poles then attach these poles to the frame at the 3 o'clock and 9 o'clock positions using the 1 $^1/_2$" long cap-head screws.

Assemble the 2-pole rotor as shown in Figure A39-2 and in the following notes:

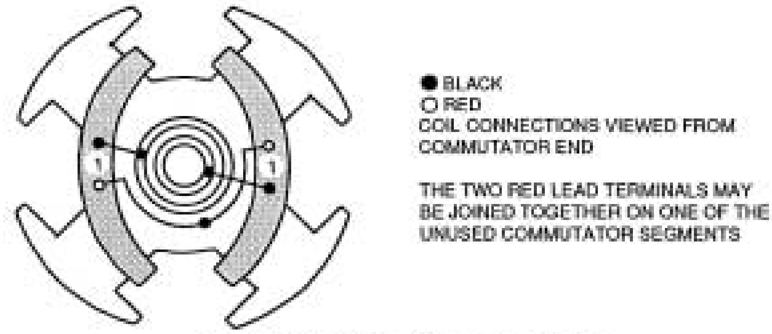


Figure A39-2: Rotor Wiring Diagram

Place two L1 coils round the rotor hub and fasten poles B, C and D to it using the three 1 ¼" long cap-head screws, and arranging the coils so that two coils sides are held in the space between poles B and C. Insert the shaft through the hubs to bring the non-drive end on the same side as the coil terminals. Insert pole A and clamp the rotor to the shaft by the 1 ¾" long cap-head screw which engages with the threaded hole in the shaft.

Slide the commutator over the shaft, make the connections shown in the wiring diagram and tighten the set screw which holds the commutator to the shaft - the final position can be adjusted when the rotor is mounted in its bearings.

If desired, the two-salient-pole rotor described in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 2, may be used instead for this assignment.

The rotor shaft may now be fitted into the bearing housings and the removable housing screwed to the baseplate. Before finally tightening down, check that the shaft rotates freely and moves axially against the pre-loading washer.

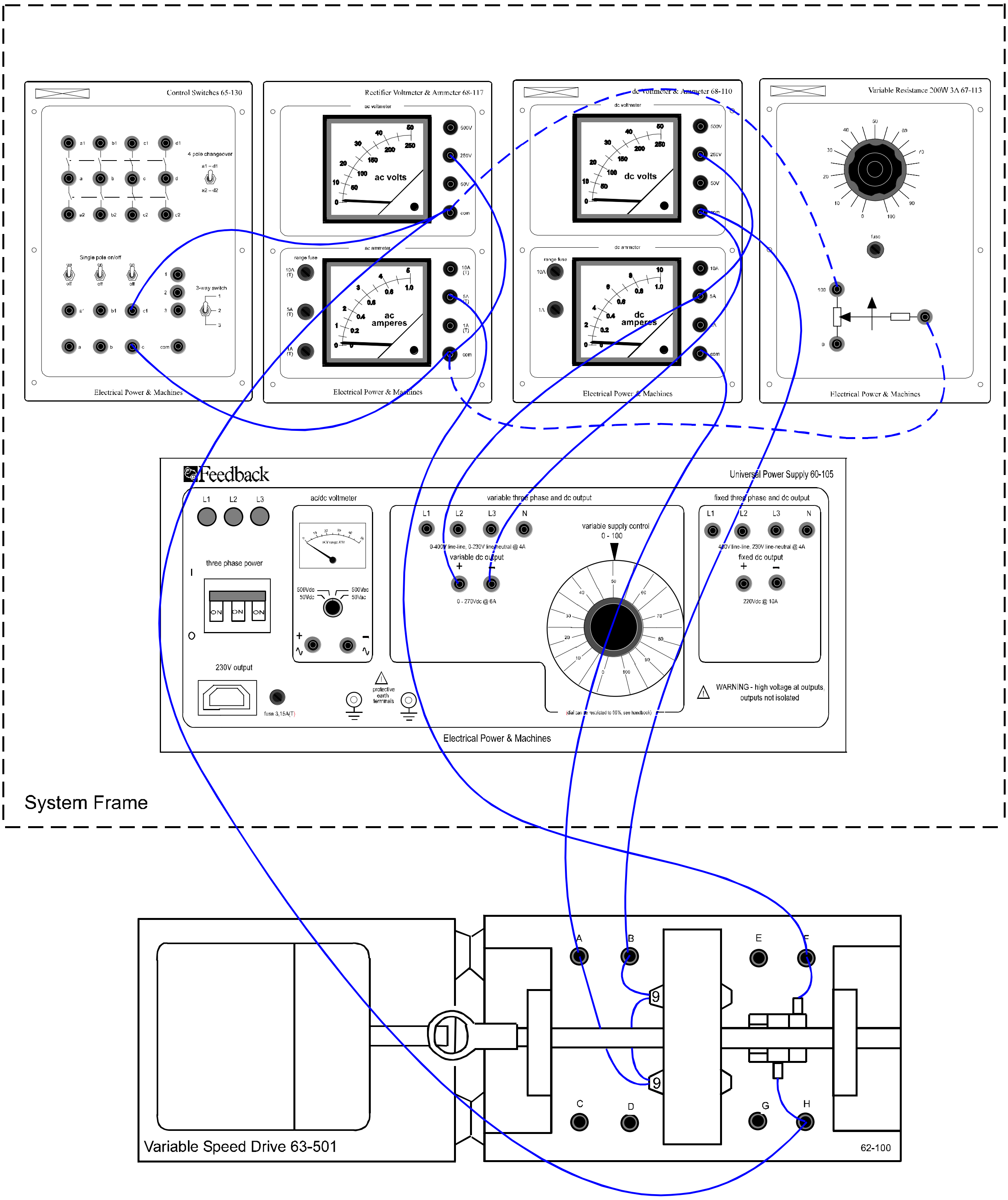


Figure A39-3: ac Single-Phase Generator, Rotating Armature Connections

Make the circuit shown in Figure A39-4 for concentrated windings in accordance with the connections shown in Figure A39-3.

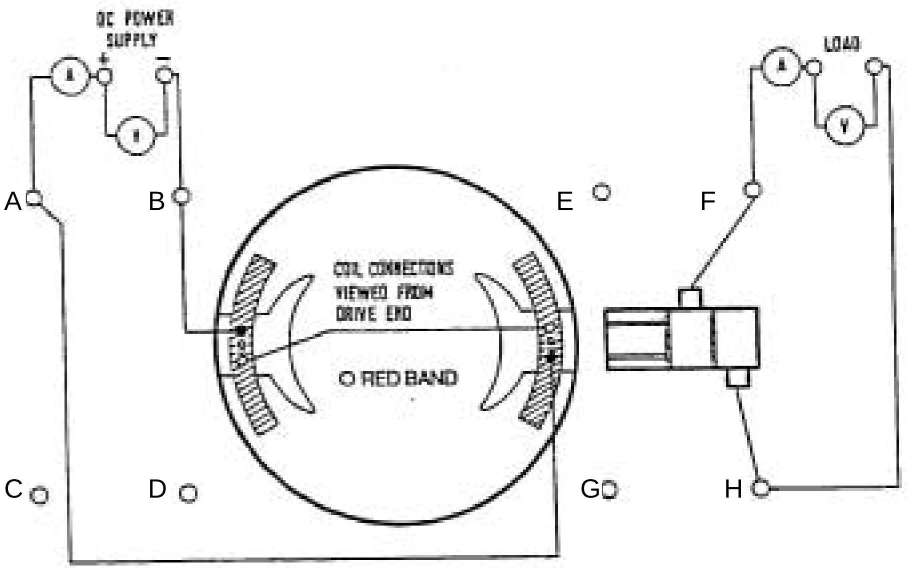


Figure A39-4: 4-ac Single-Phase Generator, Rotating Armature

Attach the drive motor baseplate to that of 62-100 base unit, align the two shafts and connect them together by a flexible coupling as explained in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 7.

PRACTICAL 39.1

The frequency of the alternating voltage generated in the rotor is equal of the number the number of pole pairs which the rotor coils traverse per second.

Therefore: $f = \frac{pn}{60}$

Where p = pole pairs,
n = shaft rev/min

In this assignment, there is one pair of poles fitted to the frame, and:

$$f = \frac{\text{shaft speed}}{60}$$

Therefore, with a shaft speed of 1500 rev/min. the generator frequency will be 25 Hz.

Open Circuit Test

From the results of this test, the relationship between stator current and no-load output voltage is obtained.

Start the drive motor, adjust its speed to 1500 rev/min and maintain it at this value throughout the test. Switch on the dc stator supply and raise the current in steps from 0 to 3 A, taking readings of terminal voltage and stator current at each step. The results may be plotted (see Results Tables) to give a characteristic similar to Figure A37-5 (see Typical Results and Answers).

PRACTICAL 39.2

Short Circuit Test

This test gives the relationship between stator current and output current on short circuit.

Short the generator output terminals together through a 5A AC ammeter by setting switch C-C1 'on' and set the stator current to its minimum value. Bring the shaft speed up to 1500 rev/min and increase the stator current in steps from 0 to 2 A, taking readings of short-circuit current and stator current at each step and plotting the result (see Results Table). A typical characteristic is given in Figure A39-6 (see Typical Results and Answers).

PRACTICAL 39.3

Capacitive Load Test

With the speed set to 1500 rev/min and the excitation adjusted for 50 V terminal voltage, connect 14 µF across the terminals and note the current and the new terminal voltage.

Question 39.1

Are the current and voltage in the capacitive load test what you would expect form theory?

If not, can you suggest why not?

Question 39.2

What happens to the terminal voltage when the capacitor is connected and why?

DISCUSSION

This generator is essentially the same as that of Assignment 37/38. Read the Discussion of Assignment 35 (synchronous motor) and that of Assignment 37/38 for an understanding of the effects of different types of load on the generator.

The stator magnetic field strength in the configuration used here is substantially constant over the whole of the pole face so that the waveform generated in the rotor is similar to that illustrated in Figure A12-5 of Assignment 12 - Elementary Generator. This is far from sinusoidal and contains many high-order odd harmonic terms.

Notes

Practical 39.1

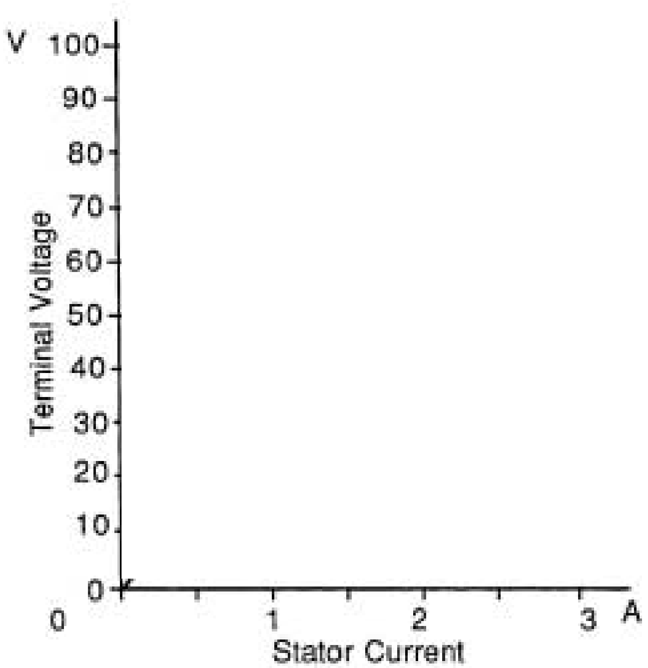


Figure A39-5 Graph Axes

Practical 39.2

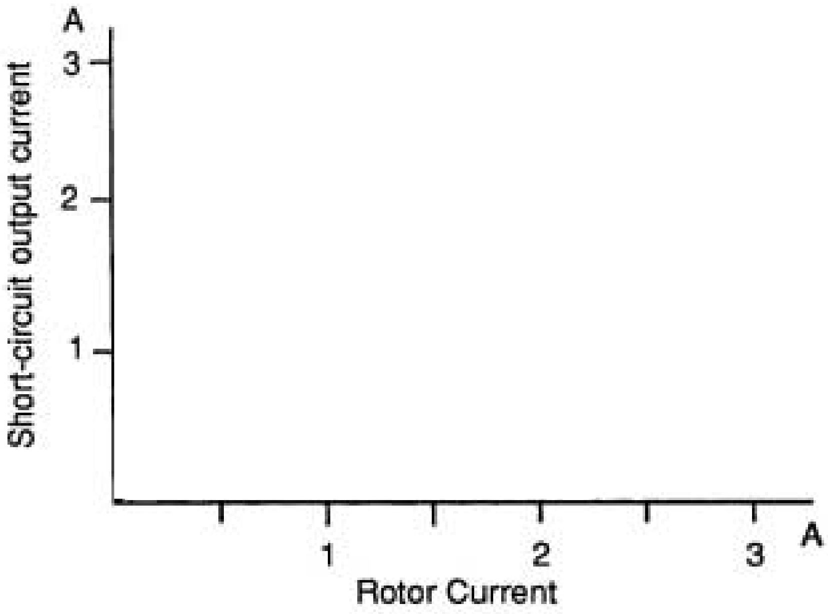


Figure A39-6 Graph Axes

Notes

Practical 39.1

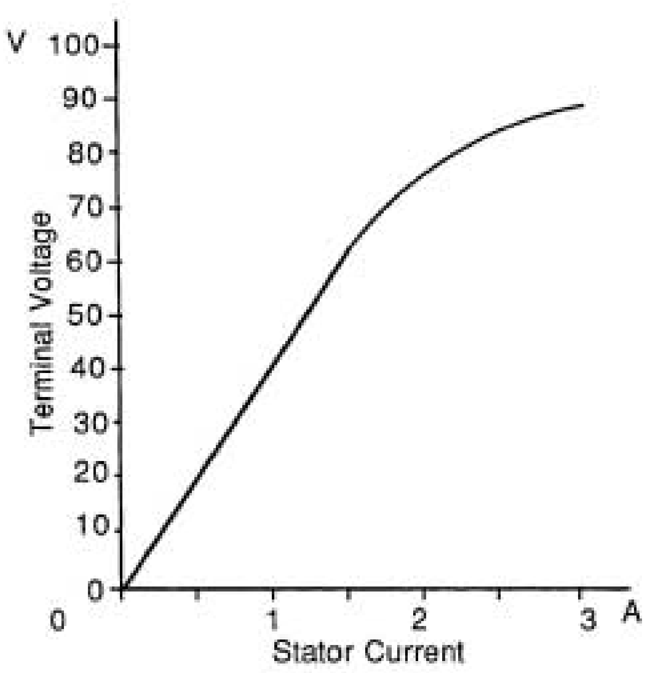


Figure A39-5: Single-Phase ac Generator, Rotating Armature Open Circuit Test

Practical 39.2

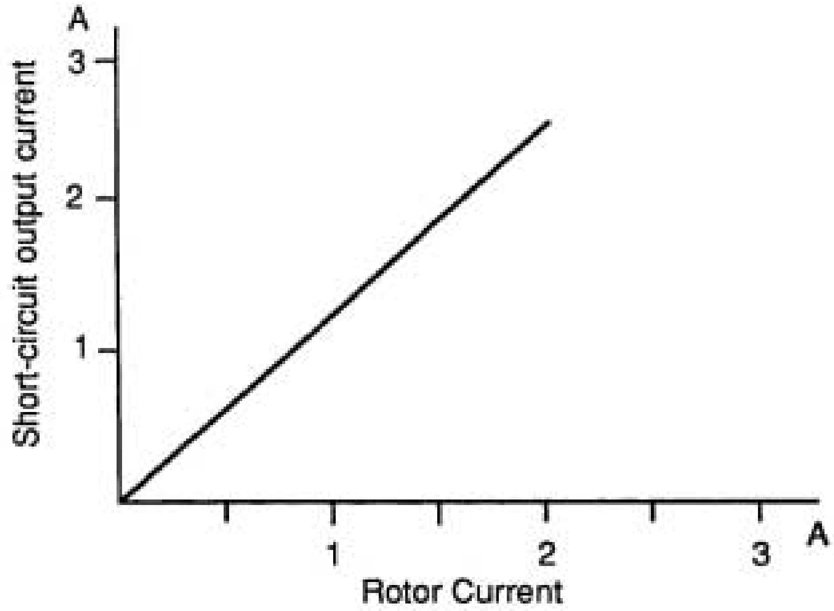


Figure A39-6: Single-Phase ac Generator, Rotating Armature Short Circuit Test

Question 39.1

The frequency at 1500 rev/min is 25 Hz.

Typical measured values are voltage 54 V, current 0.3 A.

Theoretically at 25 Hz and 54 V, a 14 μF load should draw a current of:

$$54 \times 2\pi \times 14 \times 10^{-6} = 0.12 \text{ A}$$

The increased current is due largely to the high harmonic content of the generated waveform but, in addition, the voltmeter and ammeter now have different, non-sinusoidal, waveforms and thus (if they are mean-reading rectifier instruments), do not accurately show the relationship between voltage and current.

Question 39.2

The increase in terminal voltage caused by a capacitive load is explained in the Discussion of Assignment 37/38, although that is much simplified and does not take into account the non-sinusoidal waveform actually existing.

DISSECTIBLE

MACHINES SYSTEM

Assignment 40
ac 3-Phase, 4-Pole, Squirrel-Cage Induction Motor

PRACTICAL 40.1 Load Test

EQUIPMENT REQUIRED	**Qty**	**Item**
62-100 Kit	1	Base Unit
	1	12-Slot Wound Stator
	1	Squirrel-Cage Rotor
General	1	3-Phase Power Supply (eg, Feedback 60-105)
	1 1	0-500 V, ac Voltmeter 0–5 A ac Ammeter (eg, Feedback 68-117)
	1	Control Switches (eg, Feedback 65-130)
	1	Wattmeter, 500 V, 5 A (eg, Feedback 68-201 – optional)
	1	Friction (Prony) Brake or other Dynamometer: 0-1 Nm at 1500 rev/min (eg, Feedback 67-470)
	1	Optical/Contact Tachometer (eg, Feedback 68-470)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

In this motor, the stator coils are arranged to form either a star or delta winding and are connected directly to a three-phase supply. The rotor has no external connections but consists of a cage of copper bars embedded in a laminated steel core and joined together by a copper ring at each end. The three-phase stator produces a rotating magnetic field and the motor is self starting. It runs at a speed a little below synchronous.

Three-phase, squirrel-cage motors are widely used in industry. They require little maintenance, having no brushgear or centrifugal switch, are robust and relatively inexpensive. Starting torque is not great, though it can be increased by forming the rotor cage from a metal with a higher resistivity than copper. Cast aluminium cage rotors are quite frequently used.

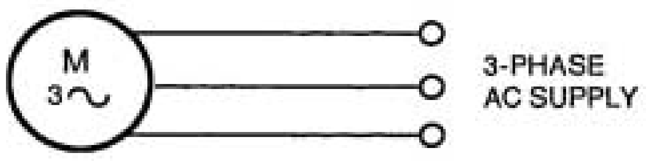


Figure A40-1: ac 3-Phase Squirrel-Cage Induction Motor Circuit Diagram

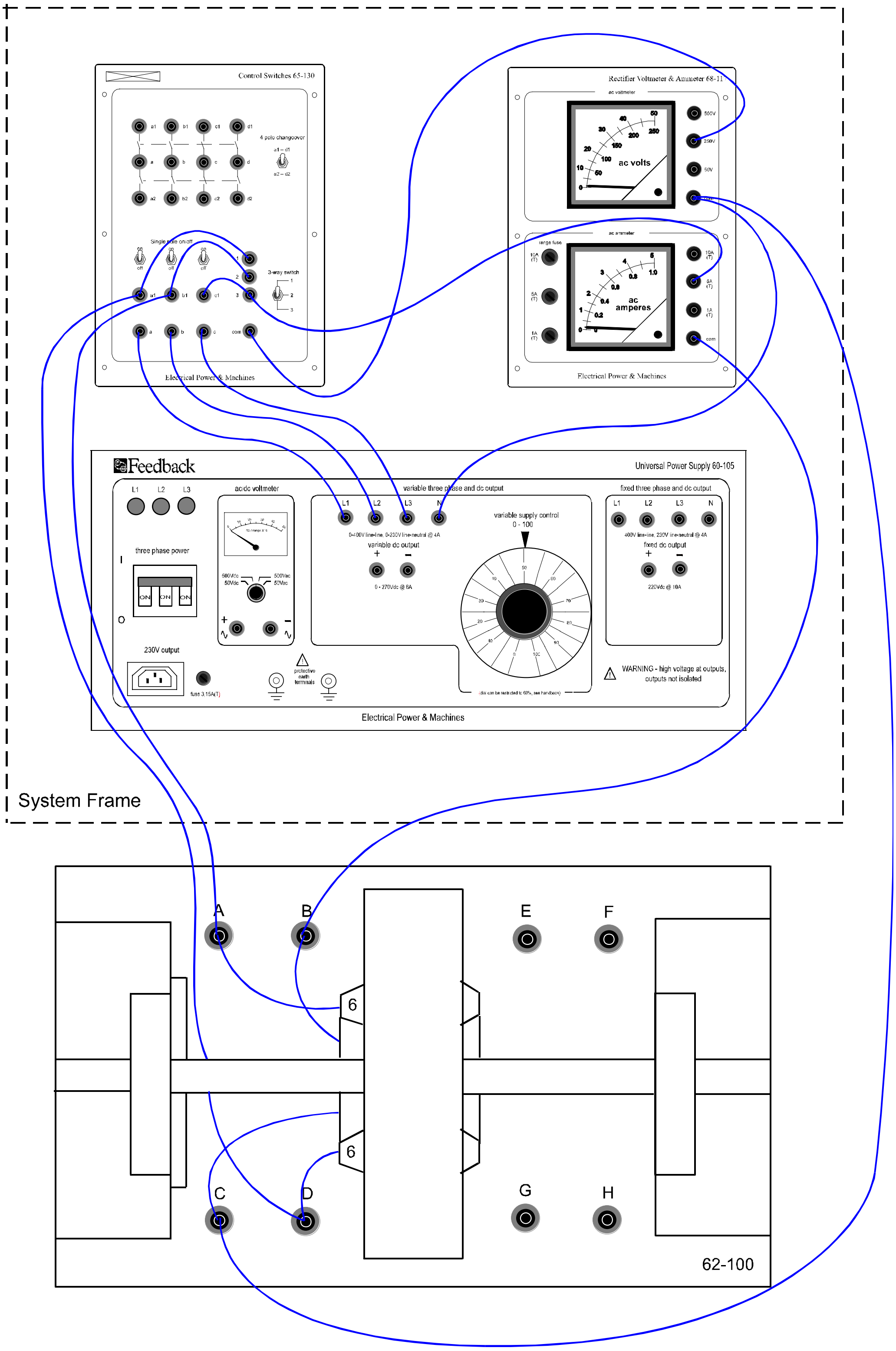


Figure A40-2: Connections for 3-Phase, 4-Pole, Induction Motor, Star Connected

ASSEMBLY

Mount the wound stator in the frame ring, fixing it in position with three 1 3/8" long cap head screws in the 12, 4 and 8 o'clock positions, with coil No. 1 at the top.

Fit the squirrel-cage rotor to the shaft, locating the hub set screw in the conical recess on the non-drive side of the shaft. Fit the shaft into the bearing housings and screw the removable housing to the baseplate, but before finally tightening down check that the shaft rotates freely and moves axially against the pre-loading washer.

Fasten the friction (Prony) brake to the baseplate. Instructions for mounting the 67-470 Prony Brake are given in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 6. Adjust the brake for zero load initially.

Make the circuits shown for 3-phase star or delta stator windings, Figure A40-3 and A40-4 as required. Suitable connections for the star-connected stator are shown in Figure A40-2.

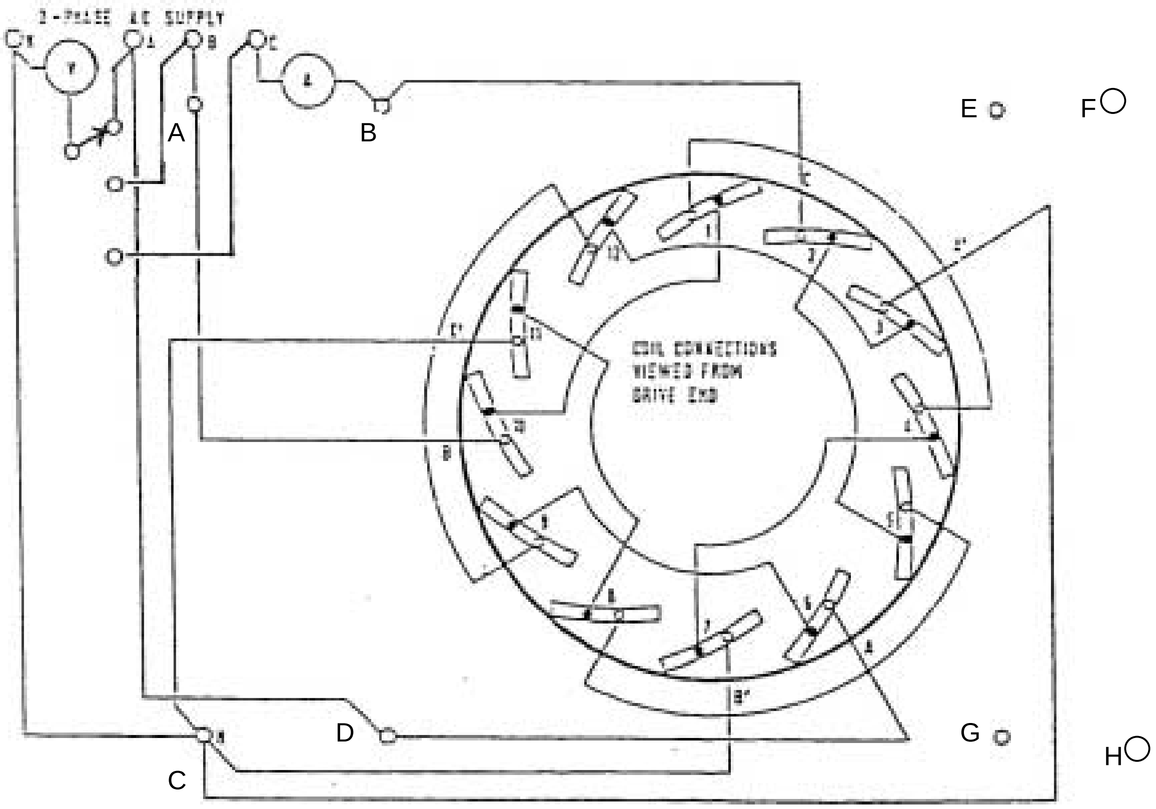


Figure A40-3: ac 3-Phase, 4-Pole, Squirrel-Cage Induction Motor, Star Connection Wiring Diagram

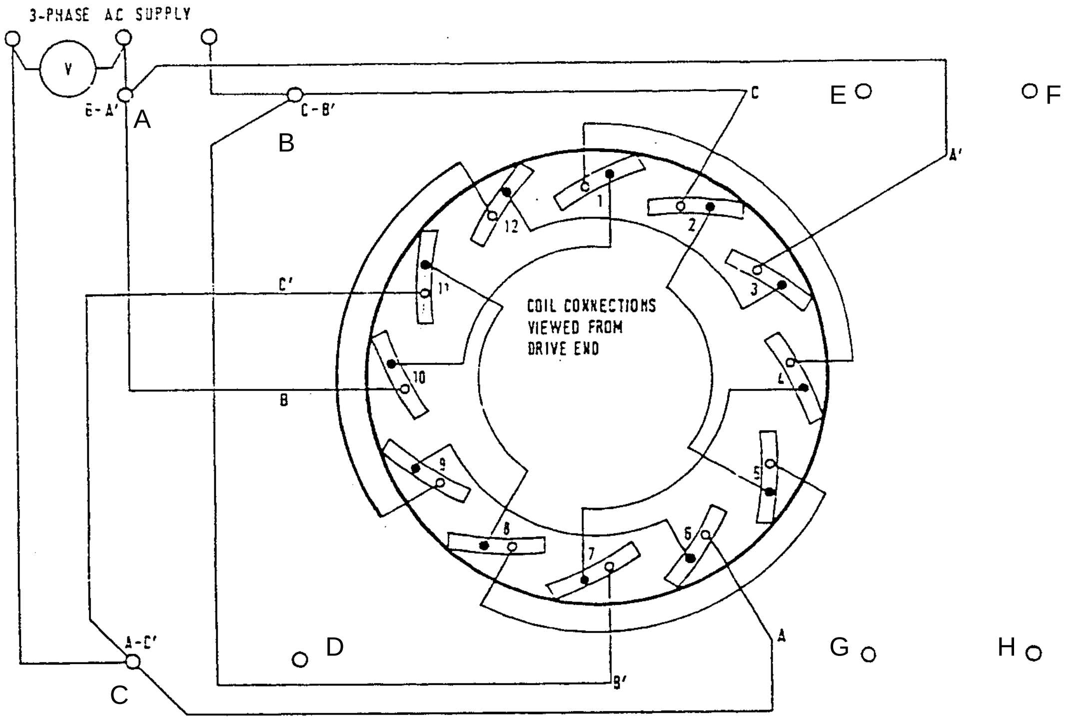


Figure A40-4: ac 3-Phase, 4-Pole, Squirrel-Cage Induction Motor, Delta Connection Wiring Diagram

PRACTICAL 40.1

When the stator windings are energised they set up a magnetic field which rotates at synchronous speed n_s, as given by the equation:

$$n_s = \frac{60 \text{ x frequency in Hz}}{\text{pole pairs per phase}}$$

This revolving field cuts the conductors forming the rotor cage, causing induced currents to flow in them. By applying Fleming's rules, the directions of induced current and then the direction of force acting on the rotor cage can be found. The rotor will revolve in the same direction as the stator field but not at the same speed, as there would then be no induced current and hence no rotor torque.

The difference in speed between the rotating stator field and the rotor can be expressed as s- the fractional slip.

$$s = \frac{n_s - n}{n_s}$$

where n_s = synchronous speed
n = rotor speed

A typical value of s for an induction motor on load would be 0.05.

The operating speed of the motor in rev/min is given by the equation:

$$n = \frac{60f}{p}(1-s)$$

In this assignment, the frequency f is 50 or 60 Hz, the pole pairs per phase p is 2, and slip s is take as 0.05.

Therefore:

$$n = \frac{60 \times 50}{2} \times 0.95 = 1425 \text{ rev/min}$$

Note:
Although the rated supply voltage for this motor is 240 V line/135V per phase it can, if required, be operated from a 415V line/240V per phase supply. The stator should in this case be star connected to give 240 volts across each phase.

Load Test

Switch on the three-phase supply to the motor and when the shaft speed has reached its steady value, measure line current, line voltage and shaft speed. Increase the brake load in steps and with a constant applied voltage, take readings of shaft speed and line current for each value of applied load. If two wattmeters are available, they may be used to measure the input power to the motor as shown in Figure A40-5(a). Otherwise a single wattmeter may be used as shown in Figure A40-5(b).

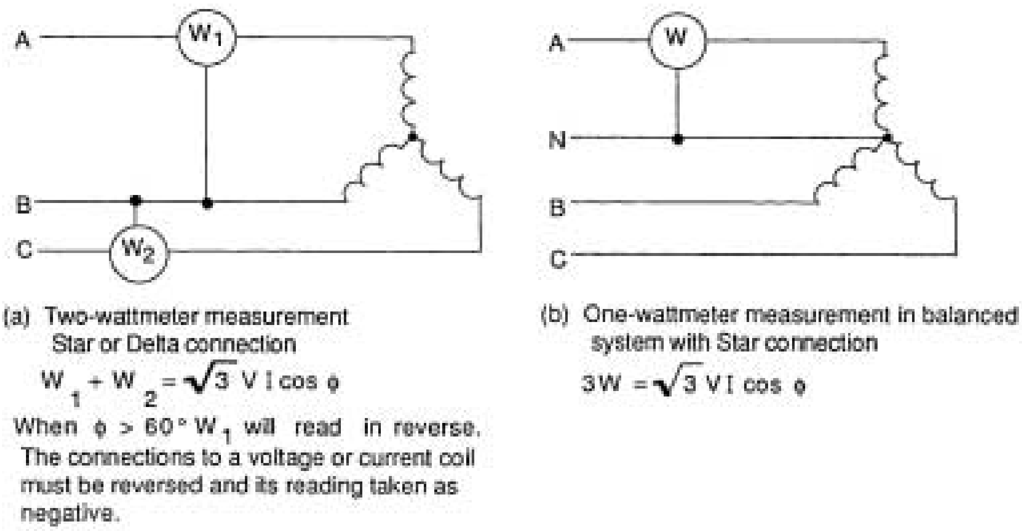


Figure A40-5: Power Measurement

From the above measurements, the efficiency and power factor of the motor can be calculated.

DISCUSSION

The three-phase induction motor operates on a basically similar principle to that of the single-phase motor as described in the Discussion of Assignment 27, which you should now read if you have not already done so.

The principal difference lies in the fact that three-phase energisation gives rise to a true rotating field, that is to say a steady field whose axis of maximum intensity advances by two pole pitches for every cycle of the supply frequency. Thus in a two-pole machine, it executes one full revolution in one cycle. The single-phase machine, on the other hand, can be considered as having two contra-rotating field components and only operates when the motor is already running at near the synchronous speed of one of these components (ie in either direction). The other component imposes a fluctuation of torque on the rotor.

We thus have the following basic comparison:

	1-Phase	3-Phase
Self-starting	No	Yes
Constant Torque	No	Yes
Reversible	Yes	Yes, but needs wiring change

Obviously, when the motor is starting up from rest it can pass a very large current because the armature is not producing a back-emf and the field coils are low resistance. It is shown in the following paragraphs that the torque of a series motor is proportional to the s

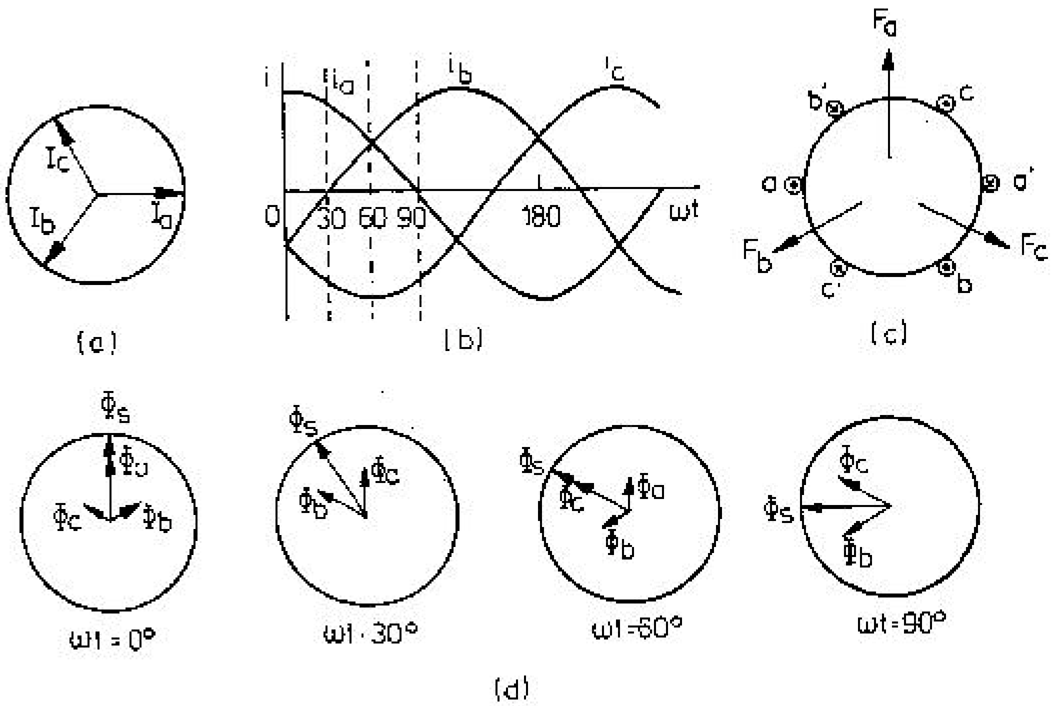


Figure A40-6: Production of Rotating Field

The production of a rotating field is illustrated in Figure A40-6, where (a) shows the relative phases of a three-phase supply and (b) the waveforms on a time base. (c) shows diagrammatically the directions of maximum field set up by currents in the concentrated windings of a two-pole stator for the directions of current indicated.

Figure A40-6 (d) shows the instantaneous field strengths due to each of the three windings at instants corresponding to 0,30,60 and 900. The resultant of the three fields is also shown and it can be seen that this is of constant strength (ie is steady, not alternating) but rotates in an anticlockwise direction by the same angle as the supply. It is thus equivalent to rotating the poles of a permanent magnet round the rotor. The direction of rotation is reversed by switching the supply to any two of the windings, eg by connecting i_a to winding 'b' and i_b to winding 'a'.

Although single-phase motors are much used in small sizes, they are far less efficient then three-phase motors in the larger sizes.

See 'Matching the Motor to its Load' in Appendix A for further application information.

See also 'Rotating Fields' in Basic Electrical Machine Theory (Appendix A).

Exercise 40.1 Satisfy yourself that changing over two of the three windings reverses the direction of field rotation.

Question 40.1 ***Would the same effect be achieved by reversing the connections to one winding? If not, explain.***

Exercise 40.1	The supply phases reach their maxima in the order a - b - c and this is the anti-clockwise ordering of the windings in Figure A40-6 (c). Interchanging any two gives a clockwise ordering of the windings and since the supply order is unchanged the direction of field rotation must reverse also.
Exercise 40.2	Reversing one winding, eg 'a', would cause ϕa to be reversed, destroying the symmetry of Figure A40-6 (c). Thus the same effect is not achieved.

Notes

DISSECTIBLE

MACHINES SYSTEM

Assignment 41
ac 3-Phase, 2-Pole, Squirrel-Cage Induction Motor

PRACTICAL	41.1	Load Test

EQUIPMENT REQUIRED	**Qty**	**Item**
62-100 Kit	1	Base Unit
	1	12-Slot Wound Stator
	1	Squirrel-Cage Rotor
General	1	3-Phase Power Supply (eg, Feedback 60-105)
	1 1	0-500 V, ac Voltmeter 0–5 A ac Ammeter (eg, Feedback 68-117)
	1	Control Switches (eg, Feedback 65-130)
	1	Wattmeter, 500 V, 5 A (eg, Feedback 68-201 – optional)
	1	Friction (Prony) Brake or other Dynamometer: 0-1 Nm at 1500 rev/min (eg, Feedback 67-470)
	1	Optical/Contact Tachometer (eg, Feedback 68-470)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

The stator coils are here connected to give a star or delta three-phase two-pole winding. The motor is self starting and will run a little below the synchronous speed of 3000 rev/min.

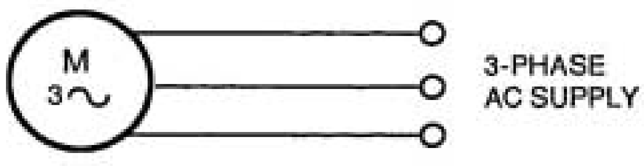


Figure A41-1: ac 3-Phase Squirrel-Cage Induction Motor Circuit Diagram

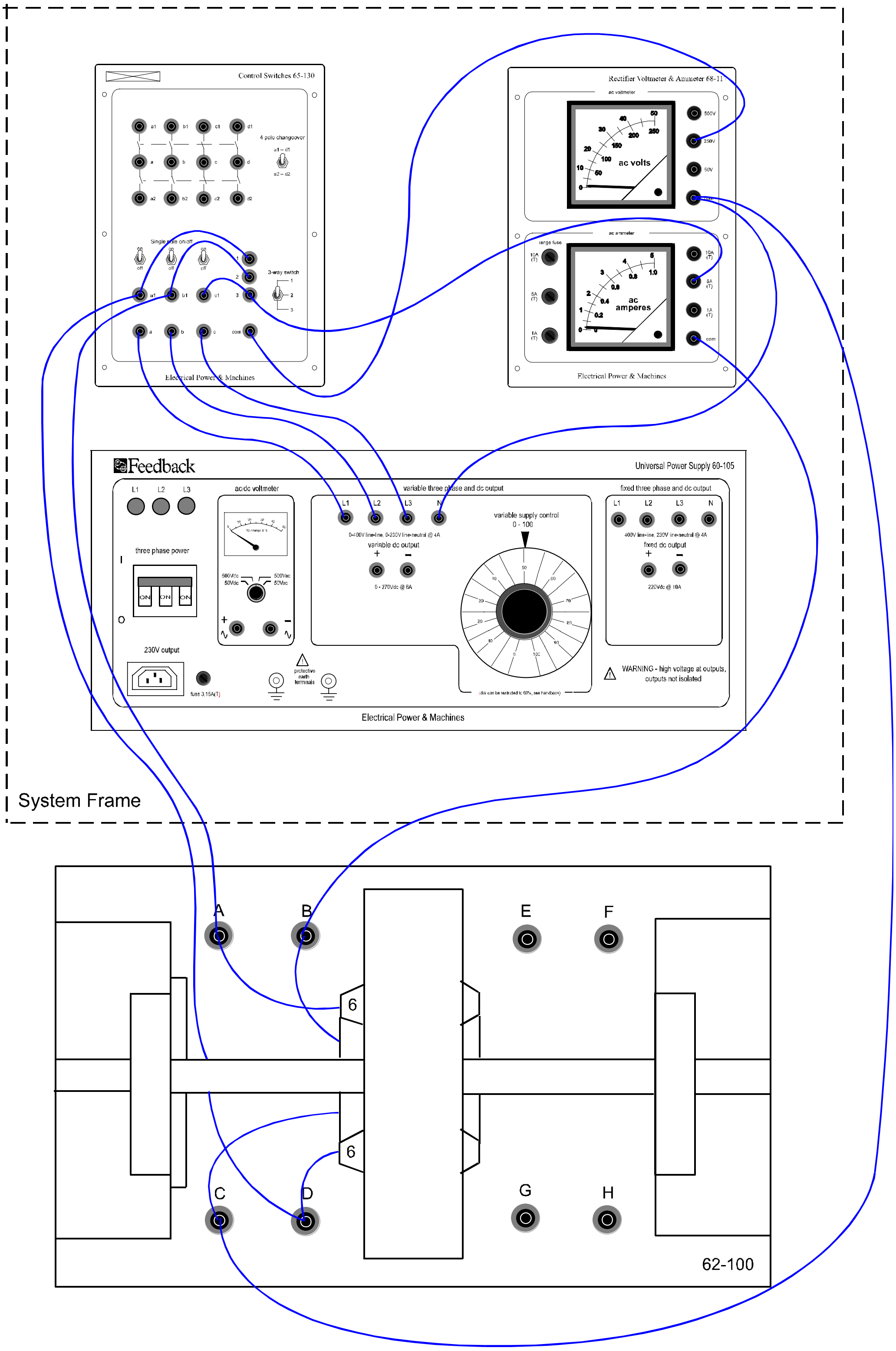


Figure A41-2: Connections for 3-Phase, 2-Pole, Induction Motor, Star Connected

ASSEMBLY

Mount the wound stator in the frame ring, fixing it in position with three $1^3/_8$" long cap head screws in the 12, 4 and 8 o'clock positions, with coil No. 1 at the top.

Fit the squirrel-cage rotor to the shaft, locating the hub set screw in the conical recess on the non-drive side of the shaft. Fit the shaft into the bearing housings and screw the removable housing to the baseplate, but before finally tightening down check that the shaft rotates freely and moves axially against the pre-loading washer.

Fasten the friction (Prony) brake to the baseplate. Instructions for mounting the 67-470 Prony Brake are given in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 6. Adjust the brake for zero load initially.

Make the circuits shown for 3-phase star or delta stator windings, Figure A41-3 and A41-4 as required. Suitable connections for the star-connected stator are shown in Figure A41-2.

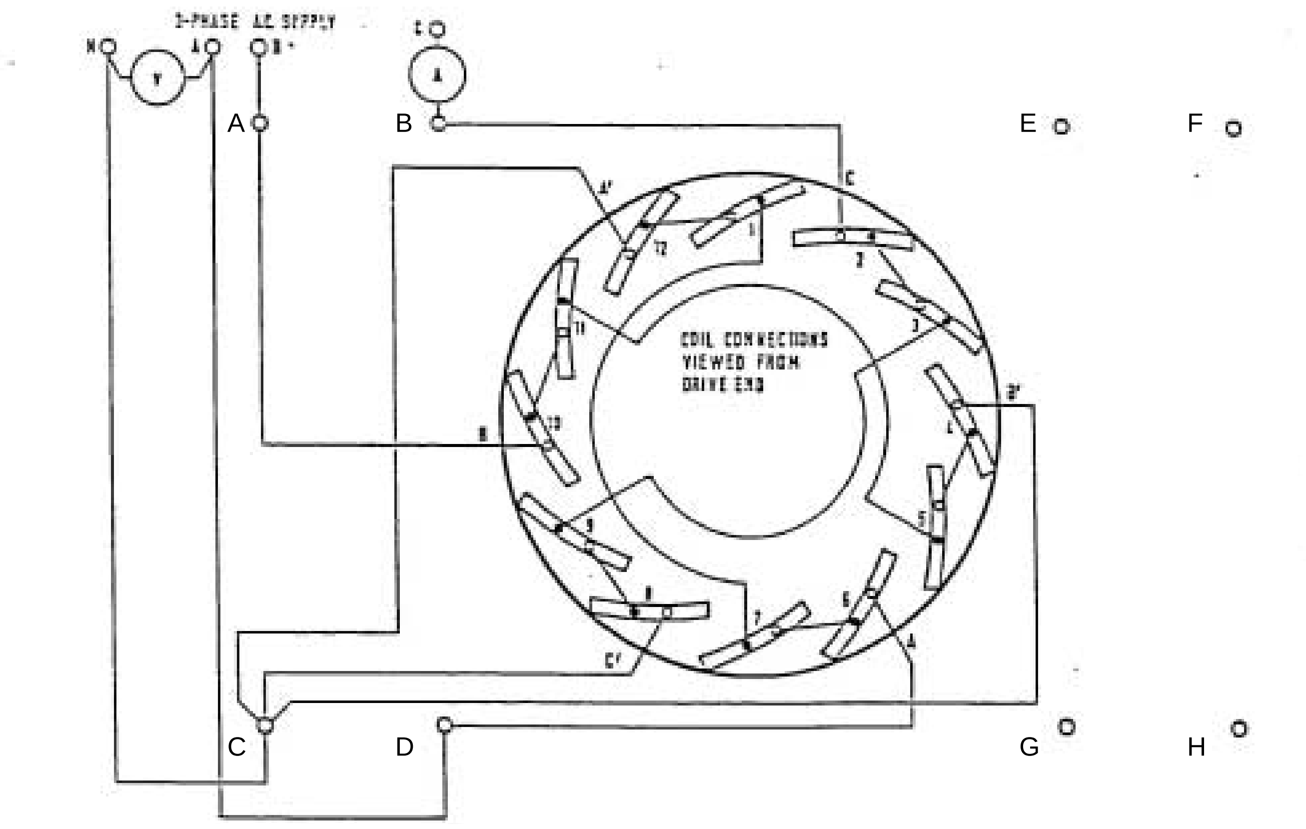


Figure A41-3: ac 3-Phase, 2-Pole, Squirrel-Cage Induction Motor, Star Connection Wiring Diagram

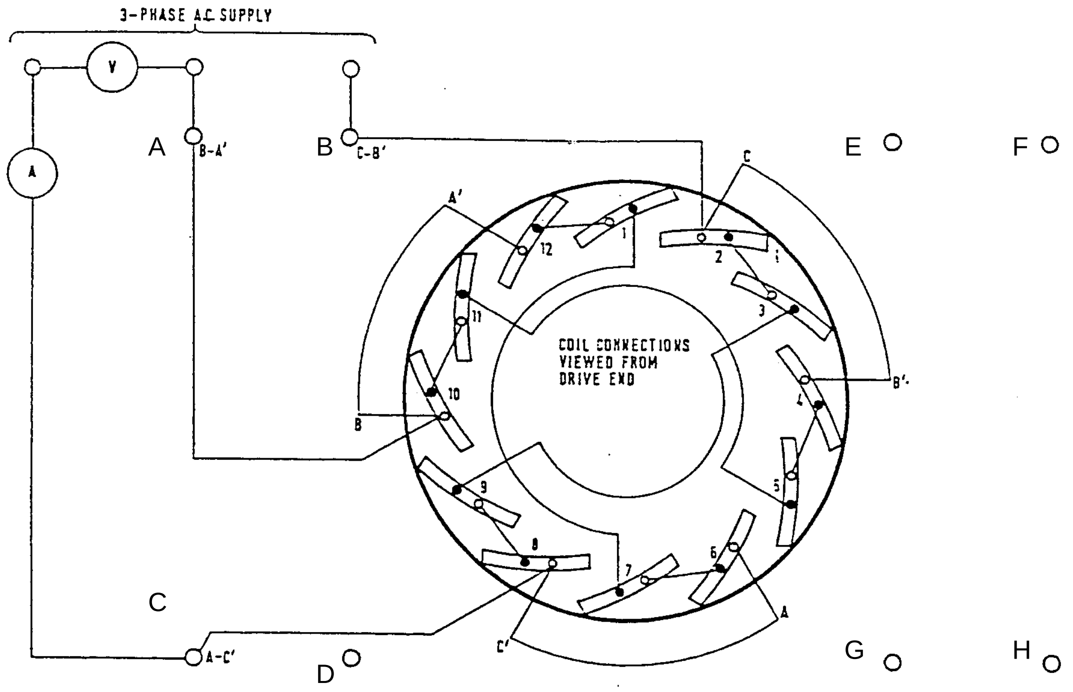


Figure A41-4: ac 3-Phase, 2-Pole, Squirrel-Cage Induction Motor, Delta Connection Wiring Diagram

PRACTICAL 41.1

The operating speed of the motor n, is given by the equation:

$$n = \frac{60}{p} f(1 - s)$$

where p = pole pairs per phase = 1
f = frequency (Hz) = 50 or 60
s = fractional slip, say 0.05

Therefore:

$$n = \frac{60}{1} \times 50(1 - 0.05) = 2850 \text{ rev/min}$$

at this particular value of slip and 50 Hz supply.

Note:
Although the rated supply voltage for this motor is 240 V line/135V per phase it can, if required, be operated from a 415V line/240V per phase supply. In this case, the stator should be star connected to give 240 volts across each phase. As there will then be 415 volts between exposed terminals only a few inches apart, special care is needed when this ac supply is used.

Load Test

Switch on the three-phase supply to the motor and when the shaft speed has reached its steady value, measure line current, line voltage and shaft speed. Increase the brake load in steps and with a constant applied voltage, take readings of shaft speed and line current for each value of applied load. If two wattmeters are available, they may be used to measure the input power to the motor as shown in Figure A41-5(a).

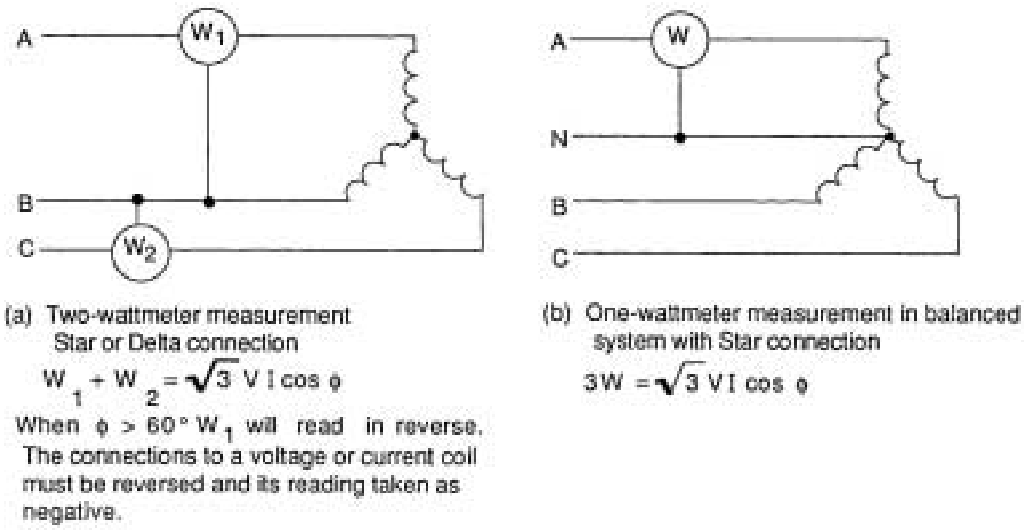


Figure A41-5: Power Measurement

From the above measurements, the efficiency and power factor of the motor can be calculated. Graphs for the plots are shown in the Results Table. Typical plots are given in Typical Results and Answers, Figure A41-6 and A41-7 which show speed/torque and efficiency/load characteristics for this assembly.

DISCUSSION

This motor differs from Assignment 40 only in having one pair of poles per phase instead of two.

Even if you have been unable to make the measurements yourself to find the efficiency, the curve of Figure A40-7 will indicate that at best it is quite good for this motor, in spite of unrepresentative dimensions of the 60-100 parts compared with those of a commercial machine.

If you have not already done so, read the Discussions of Assignments 27 and 40 for a background to single and three-phase induction motors.

Notes

Practical 41.1

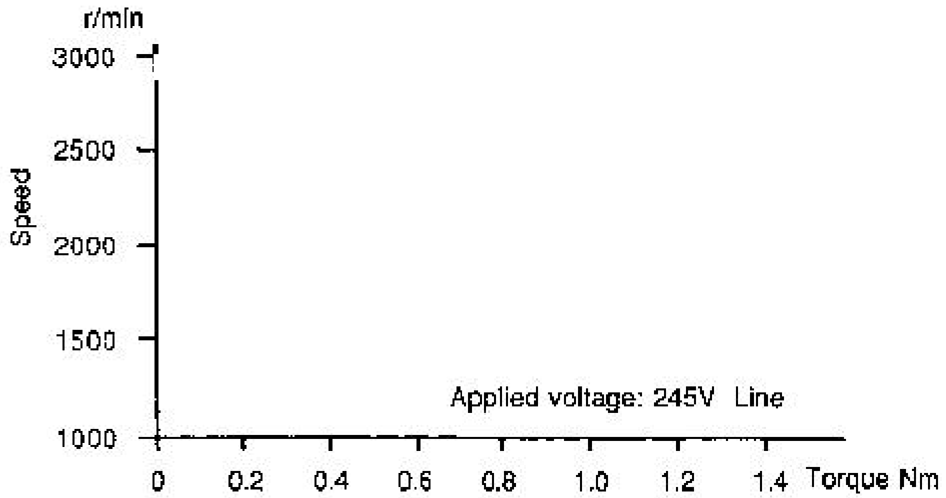


Figure A41-6: Graph Axes

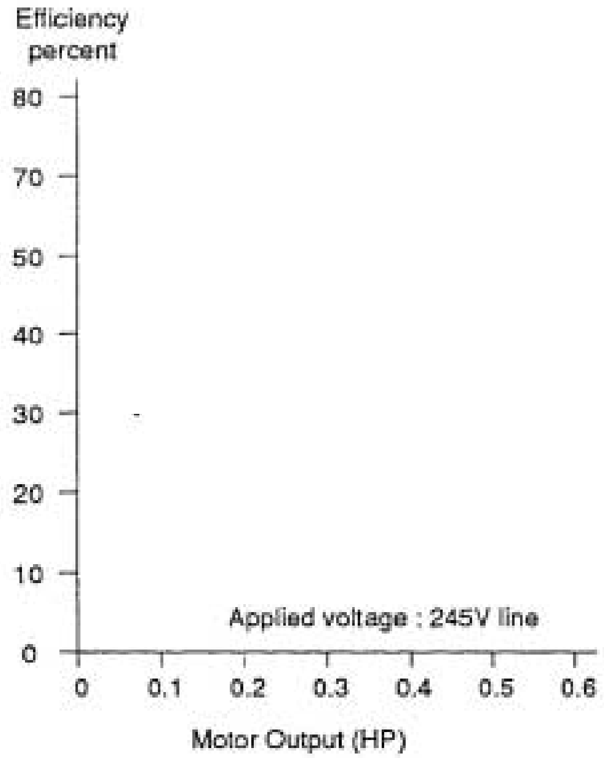


Figure A41-7: Graph Axes

Notes

Practical 41.1

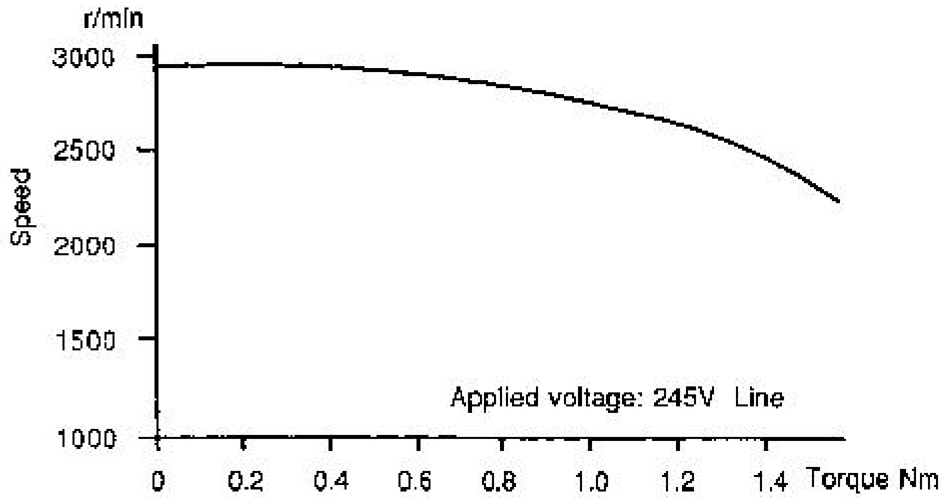


Figure A41-6: Speed-Torque Characteristic for 3-Phase, Squirrel-Cage Motor 2-Pole Delta Connection

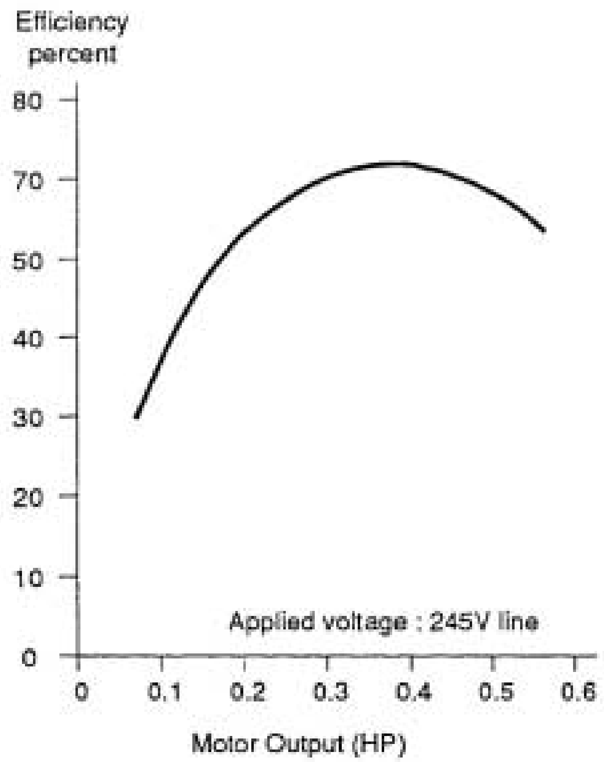


Figure A41-7: Efficiency-Load Characteristic for 3-Phase, Squirrel-Cage Motor 2-Pole Delta Connection

Notes

DISSECTIBLE MACHINES SYSTEM

Assignment 42
ac 3-Phase, 2-Pole, Synchronous Motor, Rotating Field

PRACTICAL	42.1	
	42.2	Load Test

EQUIPMENT REQUIRED	**Qty**	**Item**
62-100 Kit	1	Base Unit
	1	Commutator/Slipring
	2	Brushholders with Brushes
	1	12-Slot Wound Stator
	1	Rotor Hub
	4	Rotor Poles
	2	L1 Coils
	1	Flexible Coupling
General	1	Variable Speed Motor: 1/3 hp, 1200 rev/min (eg, Feedback 63-501)
	1	Friction (Prony) Brake or other Dynamometer: 0-1 Nm at 1500 rev/min (eg, Feedback 67-470)
	1	3-Phase Power Supply
	1	0-20 V, 5 A, dc Supply (eg, Feedback 60-105)
	1	0-300 V, ac Voltmeter
	1	0–5 A ac Ammeter (eg, Feedback 68-117)
	1	0-50 V, dc Voltmeter
	1	0-5 A, dc Ammeter (eg, Feedback 68-110)
	1	Control Switches (eg, Feedback 65-130)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

INTRODUCTION

The stator of a synchronous motor has the same general form as that of an equivalent induction motor or ac generator . The windings, usually distributed, are arranged either in star or in delta and are connected directly to the ac supply. The rotating field consists of one or more pairs of poles with concentrated or distributed windings supplied through sliprings and brushes from a dc source.

The synchronous motor has zero starting torque and must be run up to operating speed by an external drive. When the rotor poles are almost in synchronism with the rotating field produced by the stator, they pull into step and the rotor then runs at synchronous speed. If a squirrel-cage windings is embedded in the poles faces, the machine will start as an induction motor then lock in and run as a synchronous motor.

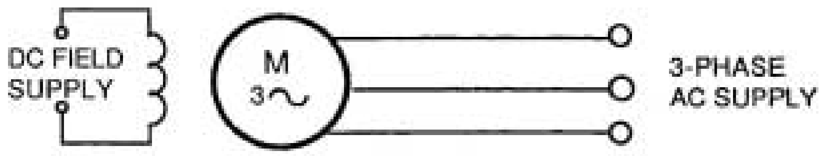


Figure A42-1: ac 3-Phase Synchronous Motor, Rotating Field Circuit Diagram

ASSEMBLY

Mount the wound stator in the frame ring, and fit it in position with three $1^3/_8$" long cap head screws in the 12, 4 and 8 o'clock positions, with coil No.1 at the top.

Assemble the 2-pole rotor as shown in Figure A42-2, and as follows.

Place two L1 coils round the rotor hub and fasten poles, B, C and D to it using the three 1” long cap-head screws and arranging the coils so that two coils sides are held in the space between poles B and C. Insert the shaft through the hub to bring the non-drive end on the same side as the coil terminals. Insert pole A and clamp the rotor to the shaft by the $1^3/_4$" long cap-head screw which engages with the threaded hole in the shaft.

Slide the sliprings over the shaft, make the connections shown in the wiring diagram, and tighten the set screw which holds the sliprings to the shaft - the final positions can be adjusted when the rotor is mounted in its bearings. Join one coils lead to each slipring via a commutator segment.

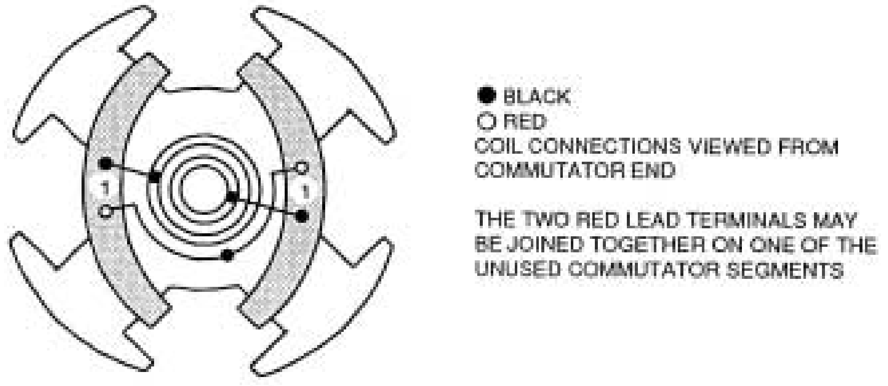


Figure A42-2: Rotor Wiring Diagram

If desired, the two-salient-pole rotor described in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 2, may be used instead of the above.

The rotor shaft may now be fitted into the bearing housings and the removable housing screwed to the baseplate. Before finally tightening down check that the shaft rotates freely and moves axially against the pre-loading washer.

Fasten the friction (Prony) brake to the baseplate. Instructions for mounting the 67-470 Prony Brake are given in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 6. Adjust the brake for zero load initially.

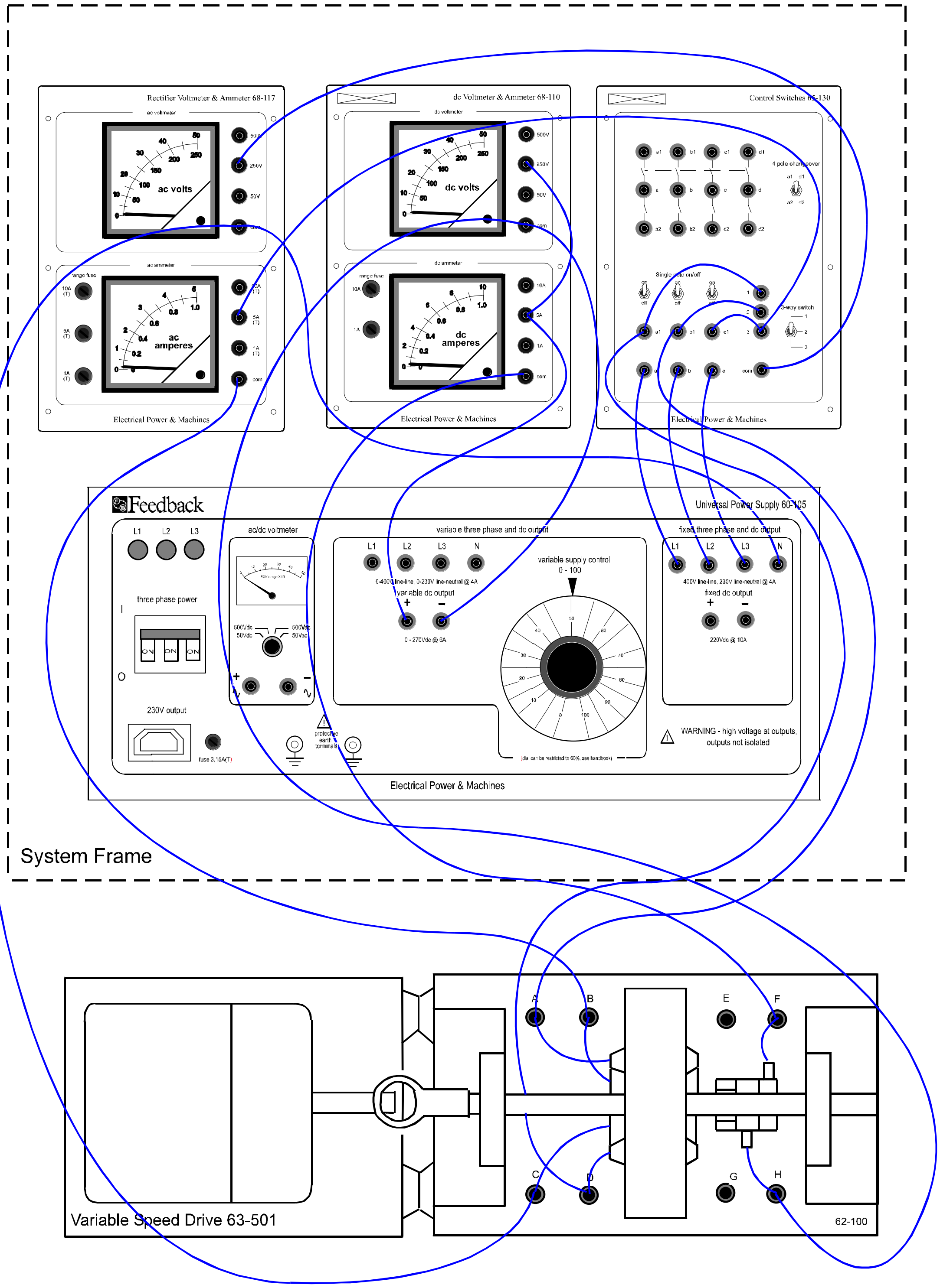


Figure A42-3: Connections for ac 3-Phase, 2-Pole, Synchronous Motor, Rotating Field Star Connection

Attach the drive motor baseplate to that of the 62-100, align the two shafts and connect them by a flexible coupling as explained in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 7.

Make the circuits shown for 3-phase star or delta stator windings, Figure A42-4 and A42-5, as required. Suitable connections for the star-connected stator are shown in Figure A42-3.

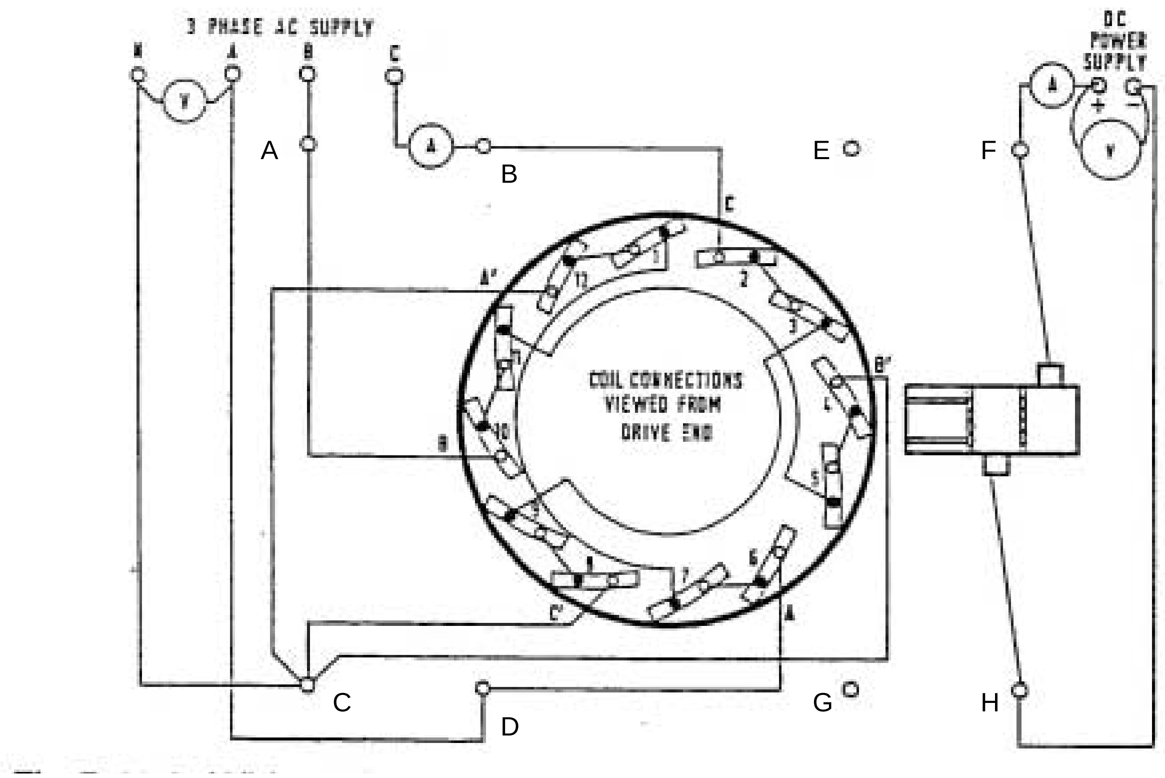


Figure A42-4: ac 3-Phase, 2-Pole, Synchronous Motor, Rotating Field Star Connection

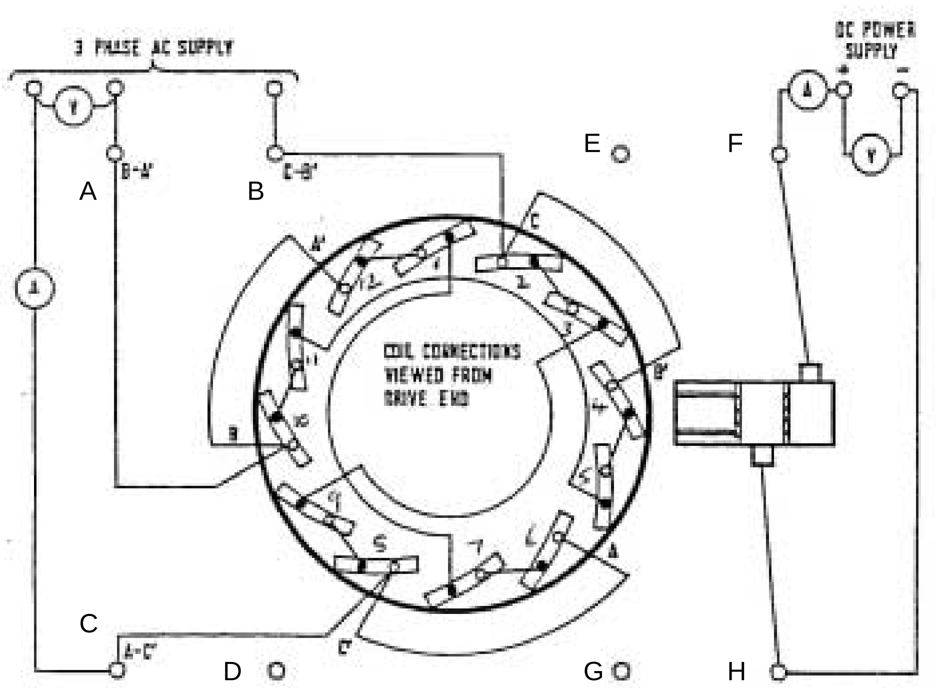


Figure A42-5: ac 3-Phase, 2-Pole, Synchronous Motor, Rotating Field Delta Connection

Note:
Although the rated supply voltage for this motor is 240 V line/135V per phase it can, if required, be operated from a 415V line/240V per phase supply. In this case, the stator should be star connected to give 240 volts across each phase. As there will then be 415 volts between exposed terminals only a few inches apart, special care is needed when this ac supply is used.

PRACTICAL 42.1

The motor operates at synchronous speed n_s, as given by the equation:

$$n_s = \frac{60f}{p} \text{ rev/min}$$

where f = supply frequency Hz
p = pole pairs per phase

There are two poles per phase, so p = 1, and with a supply frequency of 50 Hz, the motor speed is:

$$n_s = \frac{60 \times 50}{1} = 3000 \text{ rev/min}$$

To start the motor, switch on the dc rotor supply and adjust to approximately 2.5 A but leave the 3-phase ac supply to the stator switched off. Start the drive motor, adjust its speed to approximately 3000 rev/min and switch on the 3-phase supply. The Synchronous Motor should pull into synchronism and run steadily at 3000 rev/min as determined by the supply frequency. The drive machine may now be switched off: it will continue to rotate, however, driven by the synchronous motor. If a dc motor is used as a drive machine, it may be possible to operate it as a generator when it is being driven. It can then serve as a load for the synchronous motor.

PRACTICAL 42.2

Load Test

With the rotor current set to 2.5 A, apply a shaft load and note the speed and the stator line current in one phase. Repeat for various loads up to the point where pull-out occurs.

Exercise 42.1

Calculate the output horsepower and plot stator current and hp against load torque as in Figures A42-6, A42-7, A42-8 and A42-9. Graph axes are given in the Results Tables and typical plots in Typical Results and Answers.

Question 42.1

Why is the shaft horsepower linearly related to the load torque?

Exercise 42.2

Referring back to Assignment 35 (single-phase synchronous motor) if necessary, make measurements on the three-phase motor to allow you to plot the excitation curves (V-curves).

DISCUSSION

You should preferably have constructed and tested Assignment 35 (single-phase synchronous motor) and read its Discussion before testing this assignment.

The three-phase motor is generally more stable (less liable to 'hunting') than the single-phase motor because there is no pulsating component to the rotating field.

See 'Matching the Motor to its Load' in Appendix A, for applications information.

Notes

Practical 42.2

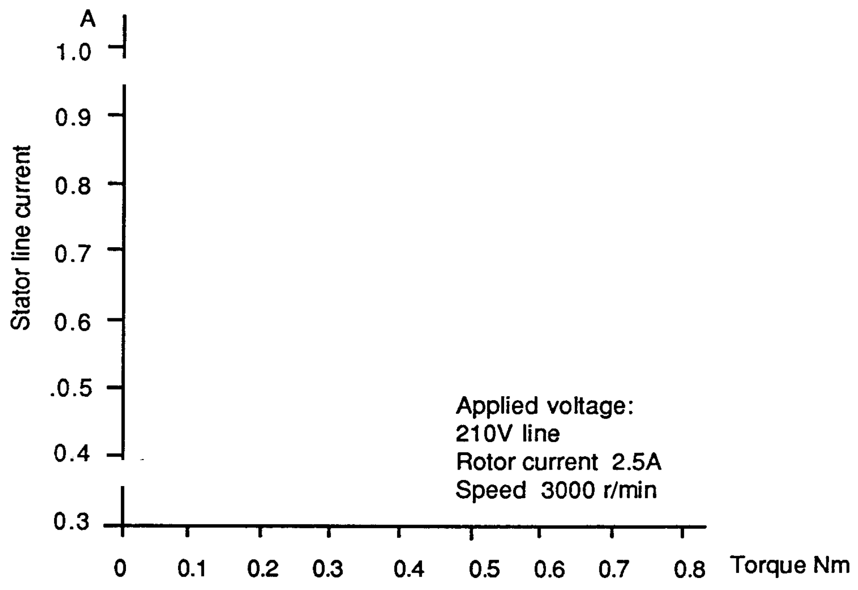


Figure A42-6: Graph Axes

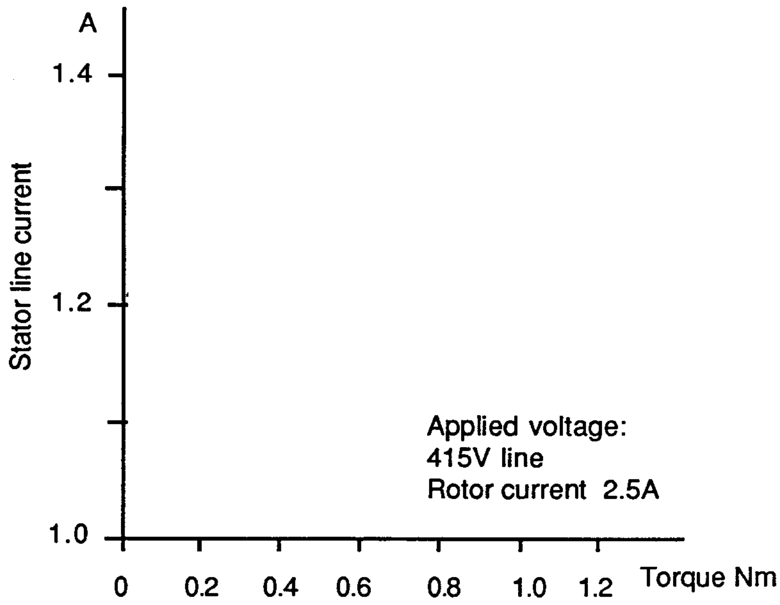


Figure A42-7: Graph Axes

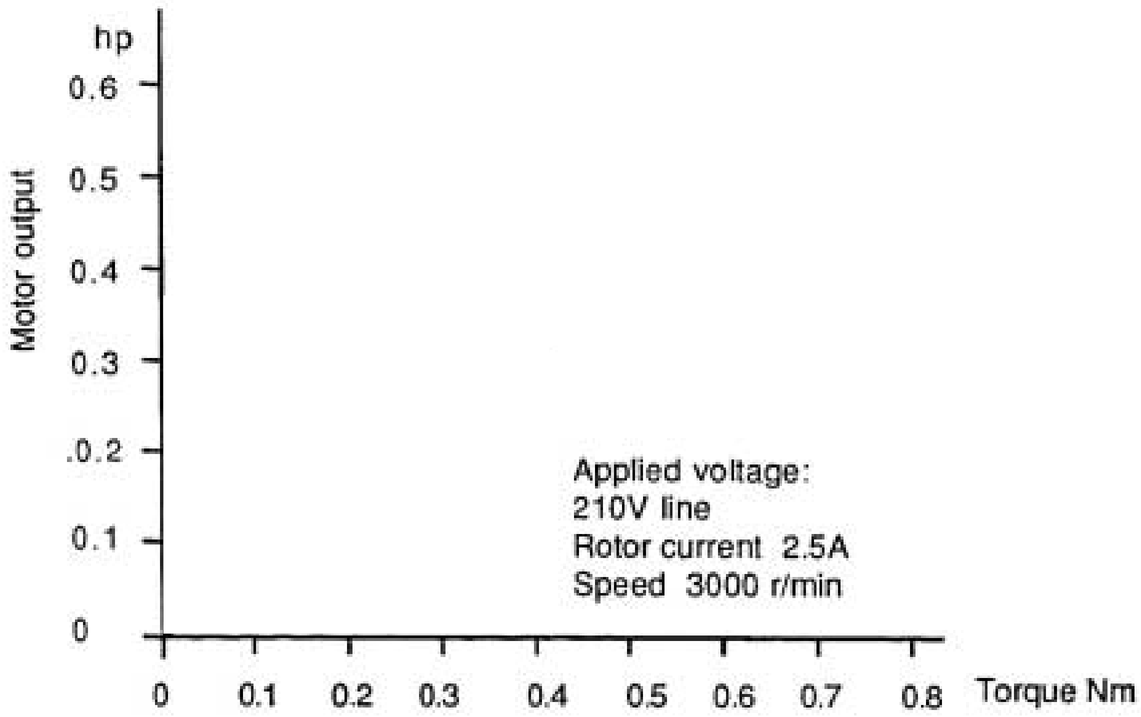


Figure A42-8: Graph Axes

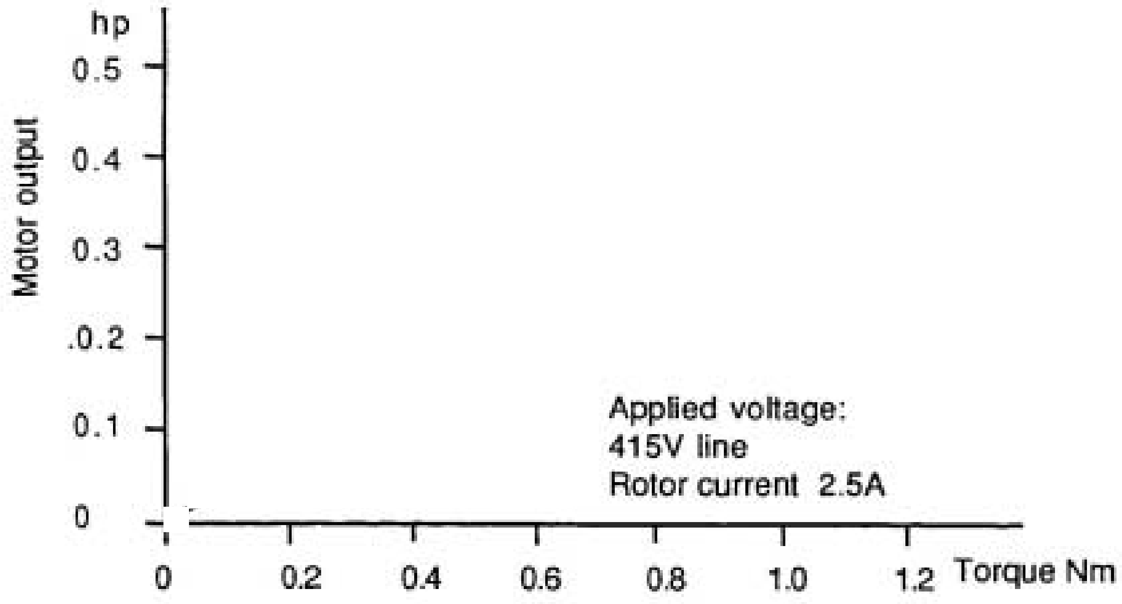


Figure A42-9: Graph Axes

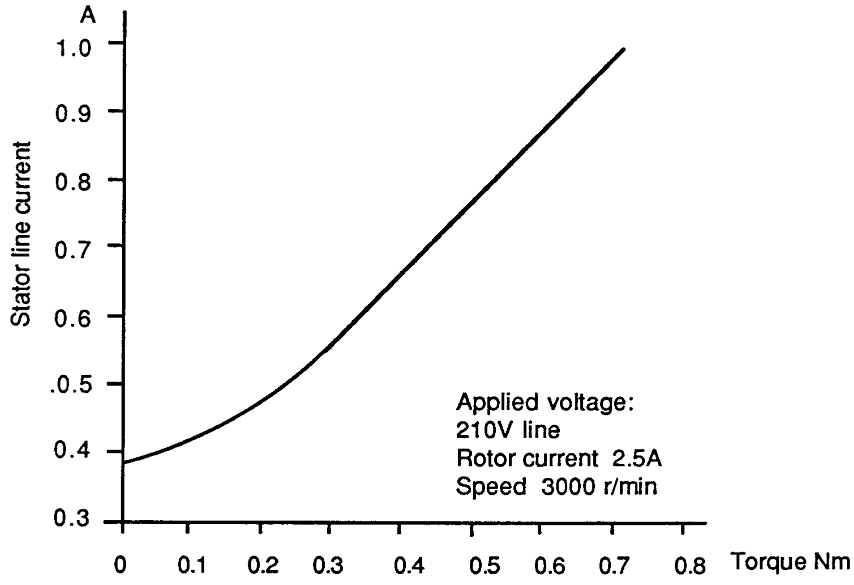


Figure A42-6

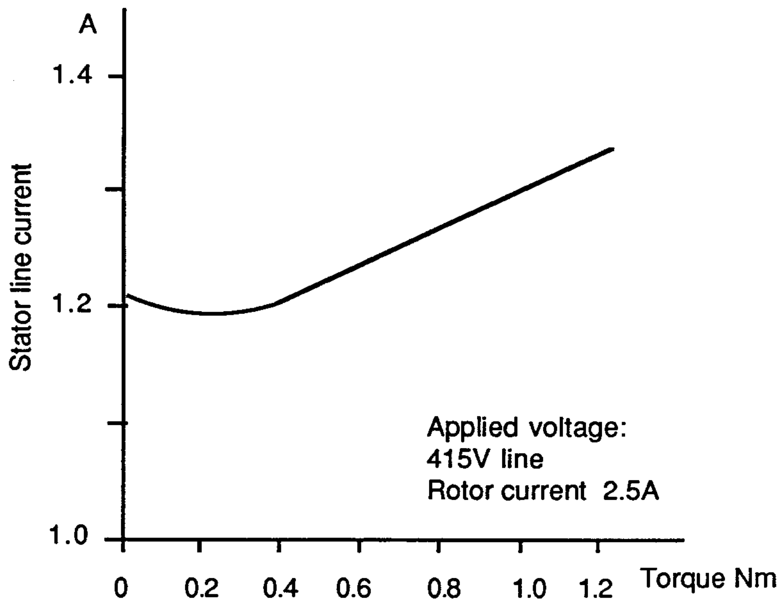


Figure A42-7

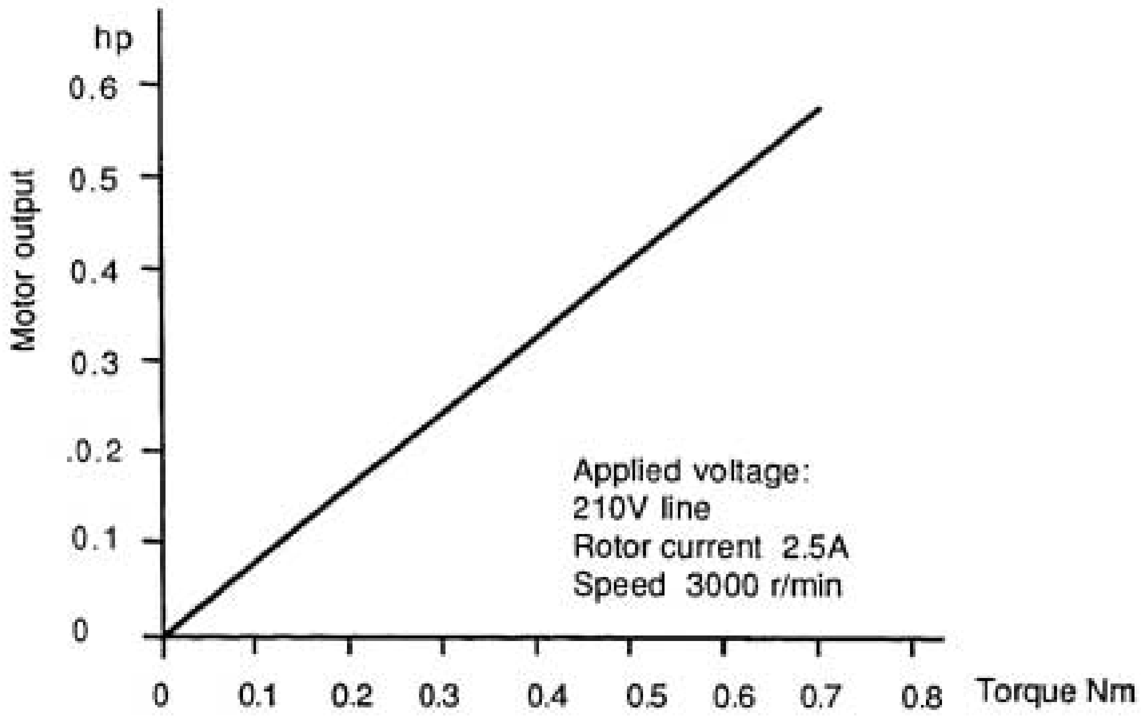


Figure A42-8

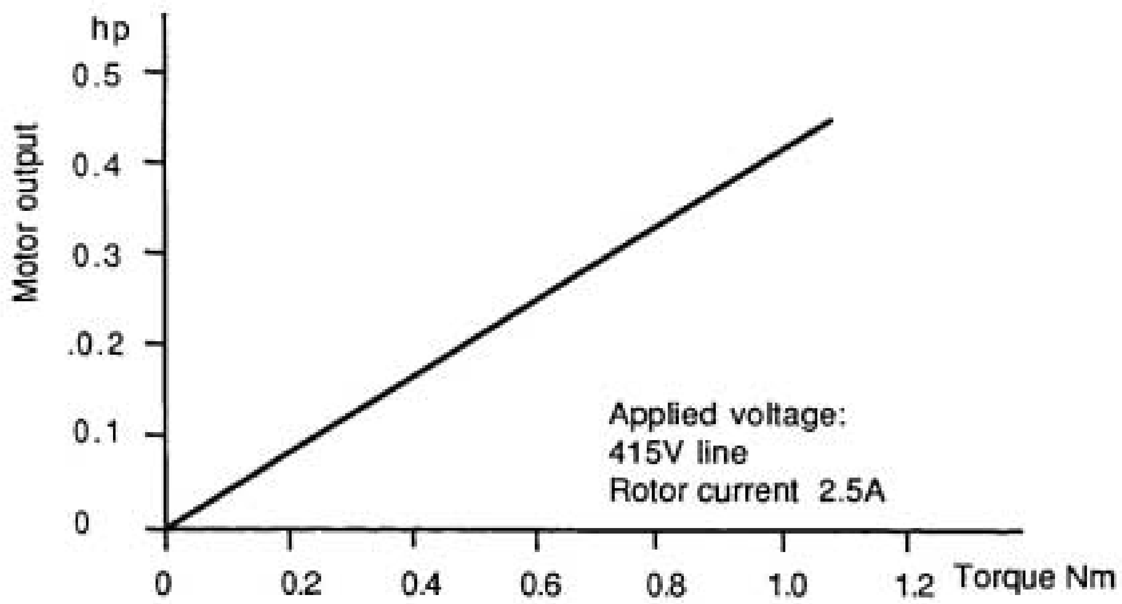


Figure A42-9

Exercise 42.1 — Figures A42-6 to A42-9 show typical results to be expected.

Question 42.1 — Since the speed up to pull-out is constant, the shaft power is proportional to torque, resulting in a straight line graph.

Exercise 42.2 — The V-curves for a synchronous motor have the general form of Figure A42-10.

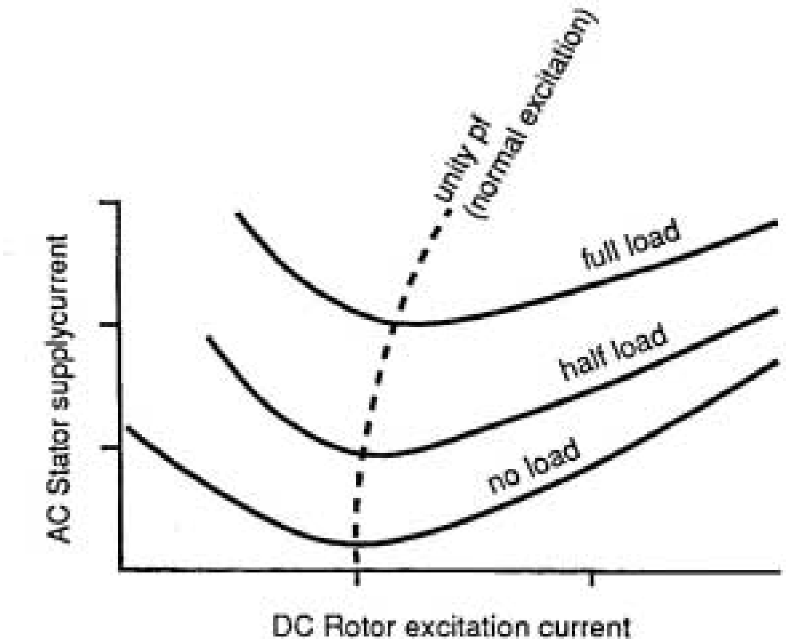


Figure A42-10

In general, over-excitation causes a leading stator current to be drawn and under-excitation a lagging one, but the locus of unity power factor actually follows the dotted line indicated. For an explanation of this, see Assignment 35 Discussion.

Notes

DISSECTIBLE MACHINES SYSTEM

Assignment 43
ac 3-Phase, 2-Pole, Synchronous Generator, Rotating Field

PRACTICAL	43.1	Open-Circuit Characteristic
	42.2	Short-Circuit Characteristics
	42.3	Load Characteristics

EQUIPMENT REQUIRED	**Qty**	**Item**
62-100 Kit	1	Base Unit
	1	Commutator/Slipring
	2	Brushholders with Brushes
	1	12-Slot Wound Stator
	1	Rotor Hub
	4	Rotor Poles
	2	L1 Coils
	1	Flexible Coupling
General	1	Variable Speed Motor: 1/3 hp, 1200 rev/min (eg, Feedback 63-501)
	1	0-20 V, 5 A, dc supply (eg, Feedback 60-105)
	1 1	0-300 V, ac Voltmeter 0–5 A ac Ammeter (eg, Feedback 68-117)
	1 1	0-50 V, dc Voltmeter 0-5 A, dc Ammeter (eg, Feedback 68-110)
	1	Control Switches (eg, Feedback 65-130)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

INTRODUCTION

Most of the world's electrical energy is produced by two types of three-phase ac generator - the steam-turbine-driven generator operating at 3000 or 3600 rev/min with a two-pole cylindrical rotor field, and the water-wheel generator in hydro-electric stations rotating at speeds around 300 rev/min with 20 or 24 salient poles, depending on supply frequency.

Although advanced techniques are used in the electrical, thermal and mechanical design of these generators, the basic components -windings, magnetic system, bearing arrangement, etc, are similar to those of much smaller machines. There is a family resemblance between a 750 MVA, 3-phase turbine-generator and the machine constructed in this assignment.

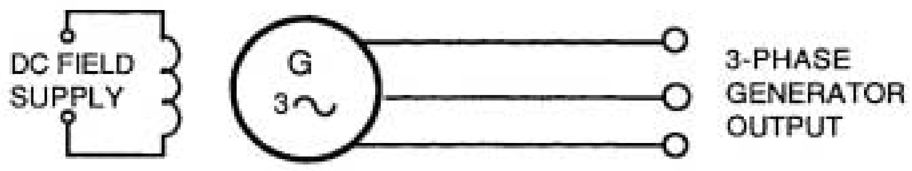


Figure A43-1: ac 3-Phase Synchronous Generator, Rotating Field Circuit Diagram

ASSEMBLY

Mount the wound stator in the frame ring, and fit it in position with three $1^3/_8$" long cap head screws in the 12, 4 and 8 o'clock positions, with coil No.1 at the top.

Assemble the 2-pole rotor as shown in Figure A42-2, and as follows.

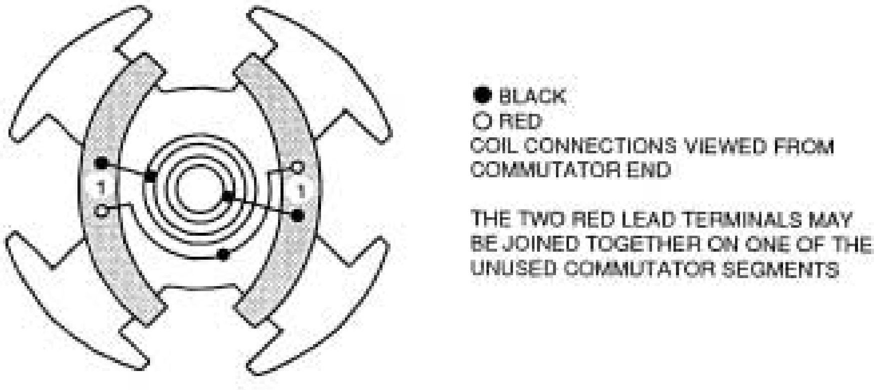


Figure A43-2: Rotor Wiring Diagram

Place two L1 coils round the rotor hub and fasten poles, B, C and D to it using the three $1^1/_4$" long cap-head screws and arranging the coils so that two coils sides are held in the space between poles B and C. Insert the shaft through the hub to bring the non-drive end on the same side as the coil terminals. Insert pole A and clamp the rotor to the shaft by the $1^3/_4$" long cap-head screw which engages with the threaded hole in the shaft.

Slide the sliprings over the shaft, make the connections shown in the wiring diagram, and tighten the set screw which holds the sliprings to the shaft - the final positions can be adjusted when the rotor is mounted in its bearings. Join one coil lead to each slipring via a commutator segment. If desired, the two-salient-pole rotor described in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 2, may be used instead of the above.

The rotor shaft may now be fitted into the bearing housings and the removable housing screwed to the baseplate. Before finally tightening down, check that the shaft rotates freely and moves axially against the pre-loading washer. Attach the drive motor baseplate to that of the 62-100, align the two shafts and connect them by a flexible coupling, as explained in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 7.

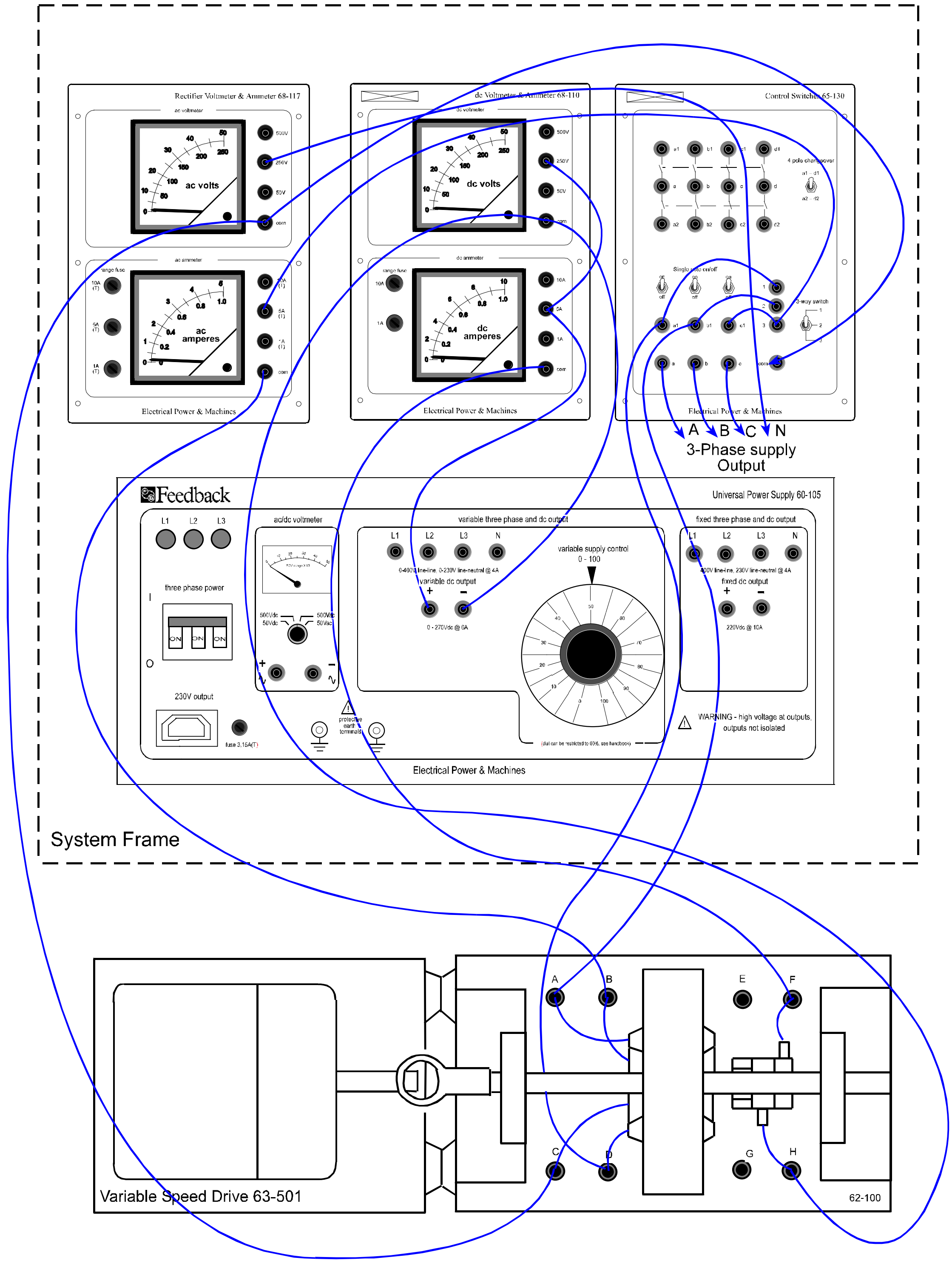


Figure A43-3: Connections for ac 3-Phase, 2-Pole, Synchronous Generator, Star Connection

Make the circuits shown for 3-phase star or delta stator windings, Figure A43-4 and A43-5, as required. Suitable connections for the star-connected stator are shown in Figure A43-3.

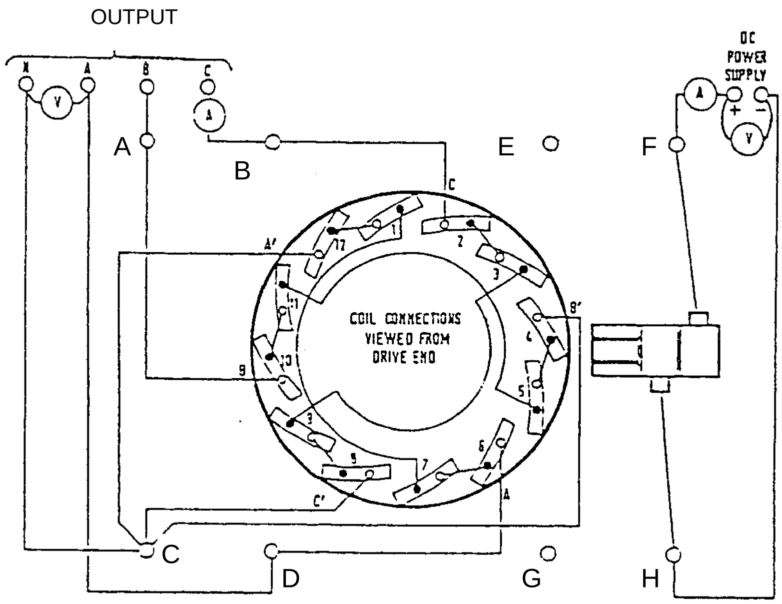


Figure A43-4: ac 3-Phase, 2-Pole, Synchronous Motor, Rotating Field Star Connection

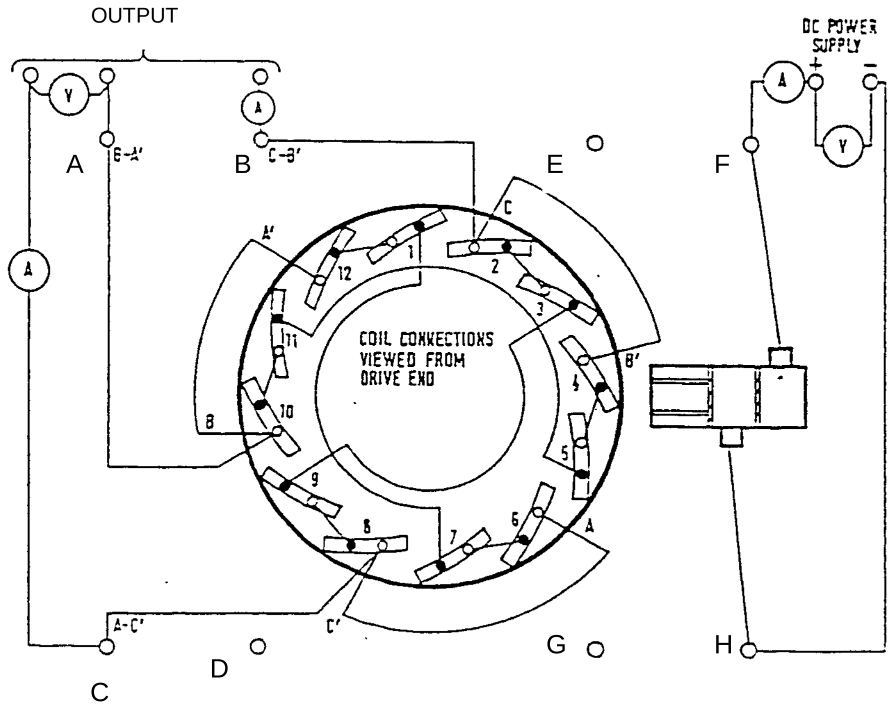


Figure A43-5: ac 3-Phase, 2-Pole, Synchronous Motor, Rotating Field Delta Connection

PRACTICAL 43.1

The frequency of the generated voltage is determined by the number of complete reversal of magnetic polarity which occur per second under each stator coils. This is equal to the number of pole pairs in the rotor field multiplied by the shaft revolutions per second.

$$f = \frac{pn}{60}$$

where p = pole pairs
n = shaft speed rev/min

In this assignment, p = 1 and

$$f = \frac{3600}{60} = 50 \text{ Hz at } 3000 \text{ rev/min}$$

or $$f = \frac{1500}{60} = 25 \text{ Hz at } 1500 \text{ rev/min}$$

Open-Cir Characteristic

This test is carried out with no external load applied to the generator. It is assumed that the three phases are symmetrical. This can be checked during the test by setting the three-position switch on the Control Switches unit 65-130 to measure each phase voltage in turn.

Switch on the drive motor, bring its speed up to 1500 rev/min and maintain at this value throughout the test. Switch on the dc rotor supply and increase the current from zero to 5A in steps, taking readings of ac phase voltage and rotor current at each step and recording them on Graph axes (Figure A43-6) given in the Results Table. Typical test results are shown in the Typical Results and Answers section (Figure A43-6).

PRACTICAL 43.2

Short-Circuit Characteristic

In this test, the three line terminals are shorted together either directly or through the ac ammeter.

With the drive speed maintained at 1500 rev/min, switch on the dc rotor supply and increase the current in steps from zero to 5 A, taking readings of output current on short circuit and rotor current at each step. The graph of short-circuit current against field excitation should be a straight line passing through the origin.

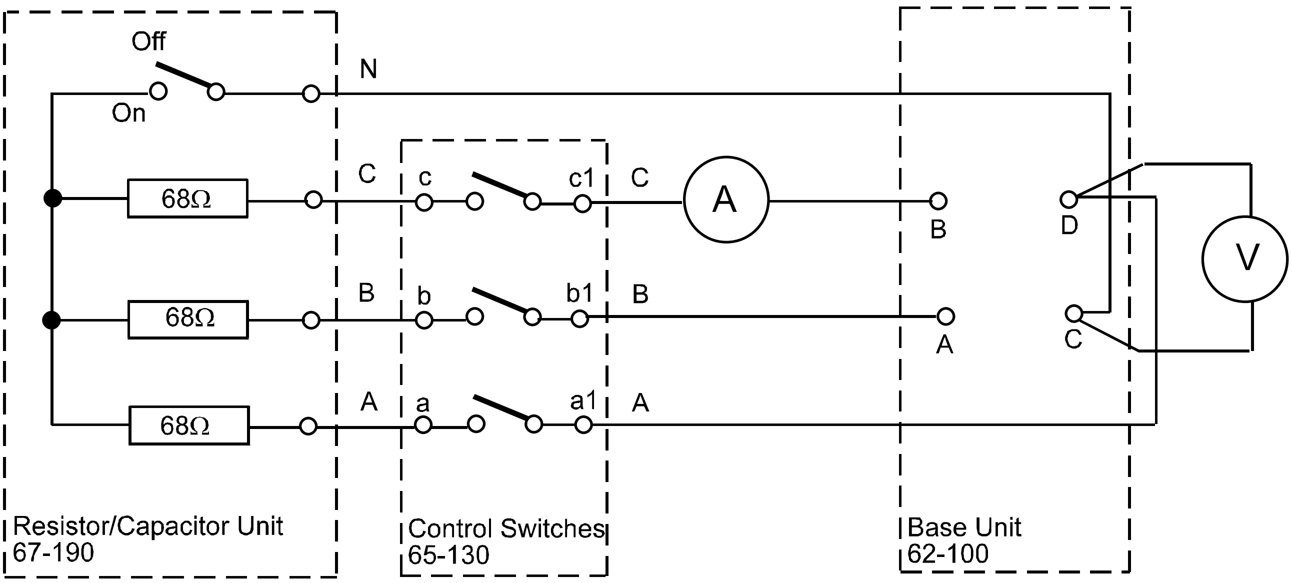
If the drive speed is allowed to vary during the test it will be found to have little effect on short-circuit current. At constant excitation the internally generated voltage is proportional to shaft speed and stator reactance, which forms the major part of the short-circuit impedance, is proportional to frequency and hence also to shaft speed. The ratio of the two, which determines short-circuit current, is therefore almost independent of rotational speed.

PRACTICAL 43.3

Load Characteristics

In this test, the generator is again driven at constant speed and load is plotted against rotor current for constant terminal voltage.

Connect the resistors on the resistor/capacitor unit 67-190 to the generator terminals as shown in Figure A43-7 to provide a three-phase load. Start the drive motor and maintain its speed constant at 1500 rev/min during the test. Switch on the dc supply to the rotor and set the current to a value which will give, say, 35 volts per phase across the load resistors. Measure phase voltage, phase current and rotor current at this load.



Three-phase fixed load connection

Figure A43-7: Connections between 62-100 and Resistor/Capacitor Unit

Question 43.1 ***What is the total power delivered to the load for your test results?***

DISCUSSION

Read the Discussion of Assignments 37/38 if you have not already done so.

This three-phase generator is identical in principle to the single-phase machine studied in Assignment 38 (distributed winding) and differs only in the form in which the generated power appears.

Practical 43.1

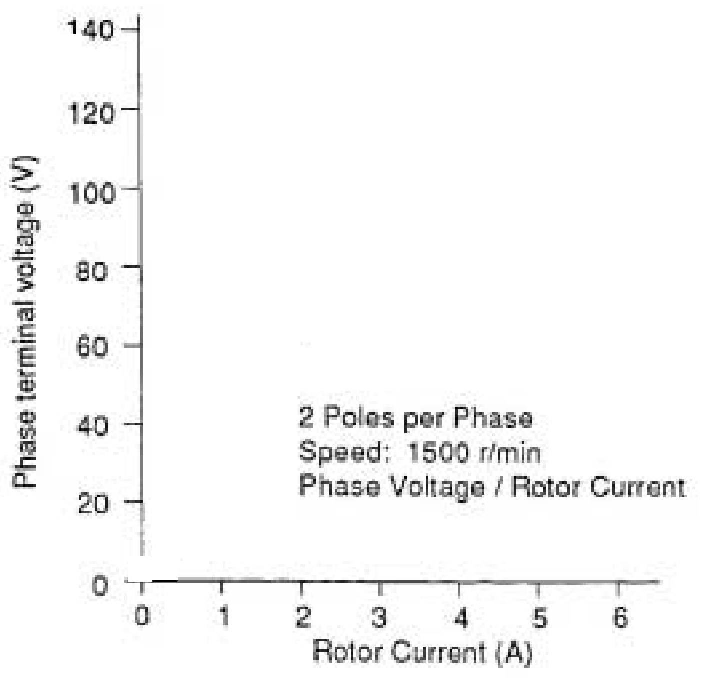


Figure A43-6: Graph Axes

Question 43.1

A table to enter fixed three-phase resistive load test results is given below:

Speed (Rev/min)	Vrotor (Volts)	Iphase (Amps)	Vphase (Amps)	Iphase (Amps)	Resistance/phase (Ohms)

Notes

Practical 43.1

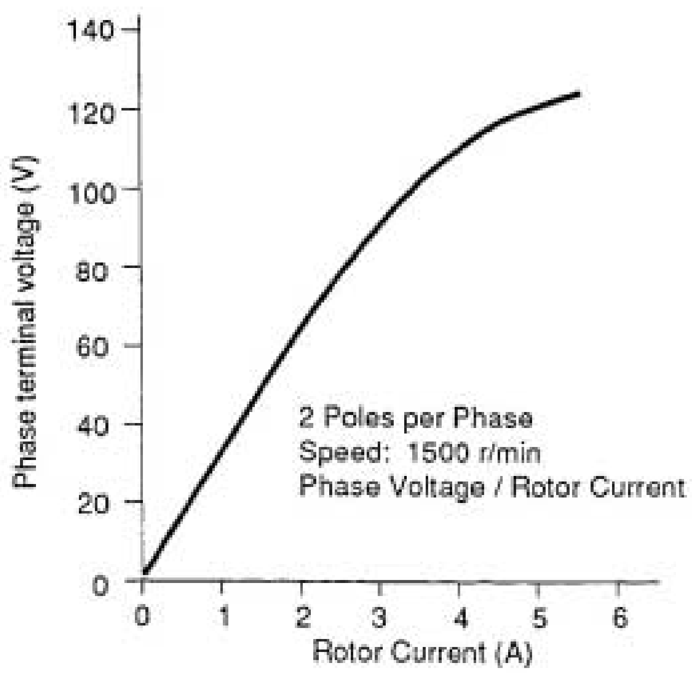


Figure A43-6

Question 43.1

Power per phase = volts/phase x current/phase

for a resistive load = 38 x 0.58 = 22.04 W

Thus total power = 3 x 22.04 = 66.12 W

Typical test results for fixed three-phase resistive load are given below:

Speed (Rev/min)	Vrotor (Volts)	Iphase (Amps)	Vphase (Amps)	Iphase (Amps)	Resistance/phase (Ohms)
1500	10.5	2.5	38	0.58	66

Notes

Assignment 44

ac Brushless Generator

PRACTICAL	44.1	Excitation and Speed Test – No Load
	44.2	Load Test
EQUIPMENT REQUIRED	**Qty**	**Item**
62-100 Kit	1	Base Unit
	2	Rotor Poles
	1	Rotor Hub
	2	Field Poles
	2	L4 Coils
	2	L5 Coils
	1	Flexible Coupling
General	1	Variable Speed Motor: 1/3 hp, 1200 rev/min, (eg, Feedback 63-501)
	1	0-20 V, 5 A, dc Power Supply (eg, Feedback 60-105)
	1 1	0-50 V, dc Voltmeter 5 A, dc ammeter (eg, Feedback 68-110)
	1	0–10 V, ac Voltmeter (eg, Feedback 68-117)
	1	Variable Resistor, 0-200 ohms, 2.5 A (eg, Feedback 67-113)
	1	Resistor/Capacitor Unit (eg, Feedback 67-190)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

The 'inductor alternator' is one form of brushless generator which may be used to produce relatively high frequency alternating current. It also has applications in environments where a virtually solid rotor with no sliding contacts or field windings is desirable.

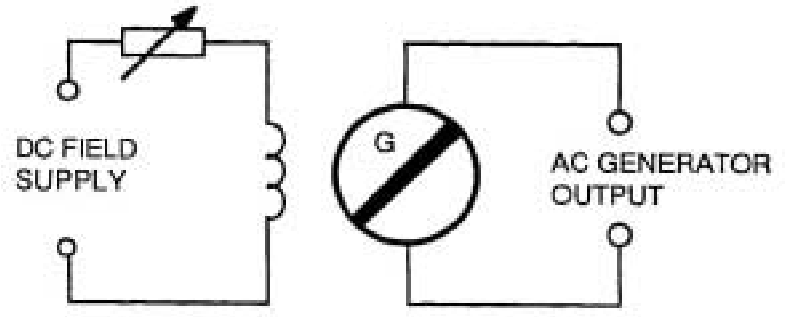


Figure A44-1: ac Brushless Generator Circuit Diagram

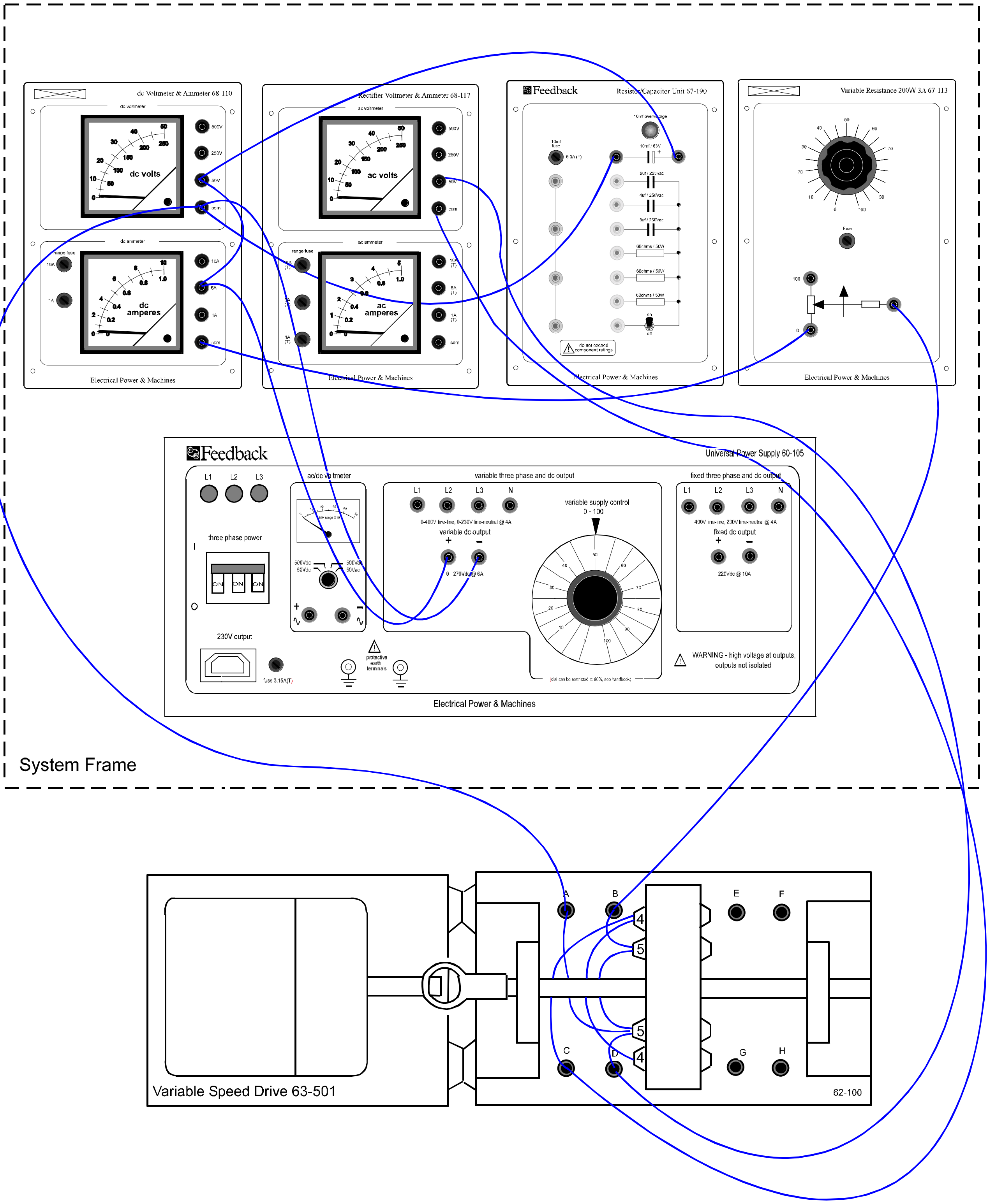


Figure A44-2: Connections for ac Brushless Generator

ASSEMBLY

Make the circuit shown in Figure A44-3 in accordance with the connections shown in Figure A44-2. Connect the drive motor baseplate to that of the 62-100 and connect them by flexible coupling as explained in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 7.

The electrolytic capacitor across the dc power supply is necessary when the supply used is unsmoothed or unregulated.

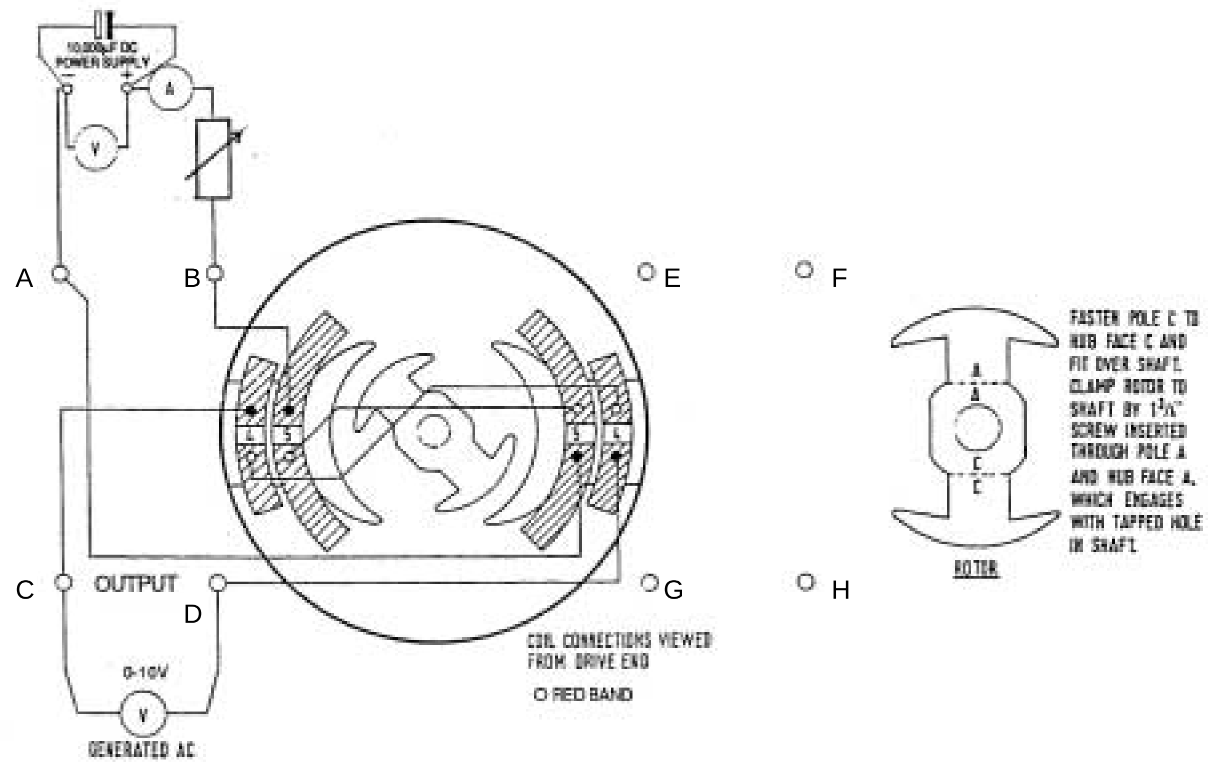


Figure A44-3: ac Brushless Generator Wiring Diagram

Question 44.1 ***Why must the dc supply by substantially free from ripple in this assignment?***

PRACTICAL 44.1

Excitation and Speed Test – No Load

Switch on the dc supply, set the variable resistor to zero and adjust the voltage to give an excitation current of 0.5 A.

Start the drive motor and increase its speed in steps of 200rev/min up to about 2400 rev/min, noting the value of the ac output at each step.

Stop the drive, adjust the series resistor to about 15 ohms and reset the direct excitation current to 0.5 A by adjustment of the dc voltage. Repeat the speed test as before.

Repeat for series resistor values of 35 and 75 ohms. The L5 coils in series have a resistance of 5 ohms so you now have data for four graphs of output versus speed at R = 5, 20, 40 and 80 ohms. Plot these graphs on linear paper with R as the parameter.

If you have an oscilloscope available it is interesting to observe the output voltage waveform on it,

PRACTICAL 44.2

Load Test

With the series resistor at 35 ohms, direct current 0.5 A and speed 1500 rev/min, apply loads of 68 ohms, 34 ohms and 23 ohms using the Resistor/Capacitor Unit 67-190 across the output. Note the terminal voltage and measure or calculate the load current. Calculate the power dissipated in the load for each reading.

Question 44.2 ***What is the fundamental frequency of the generated output of a speed of 1500 rev/min?***

Question 44.3 ***Does the output voltage vary with speed when the series resistor is a zero?***

Question 44.4 ***Can you infer from your graphs of output versus speed how the output would vary with speed if R were infinite (constant current source)?***

DISCUSSION

In the inductor alternator, the field set up by the dc excitation is varied about its mean value by the change in reluctance of the magnetic circuit as the rotor poles are rotated. Figure A44-4 shows the positions of maximum and minimum field.

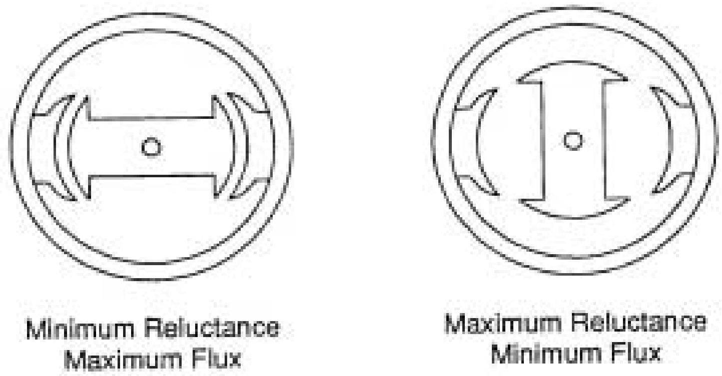


Figure A44-4

In addition, the direction of the field around the stator poles varies when the rotor poles are approaching and leaving the stator poles, causing further variations in the amount of flux linked with the windings. The combined effects of these changes in flux linkages cause generation of emf in both the output and excitation windings. Notice that the field never actually reverses but merely varies about a mean value. This variation is only a small fraction of the static field in this assembly so only a small output is produced and the machine is of low efficiency.

Since the same magnetic conditions occur twice per revolution, the fundamental frequency generated is twice the shaft speed. The complex form of the flux variation, however, means that the emf's are not truly sinusoidal. Figure A44-5, shows a typical emf waveform.

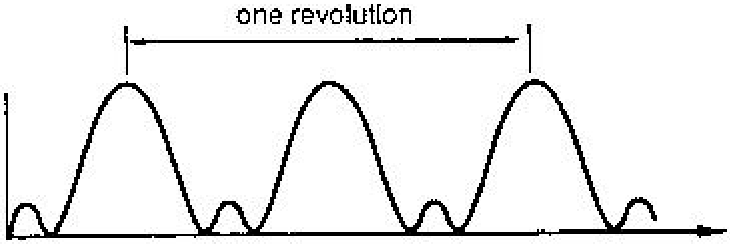


Figure A44-5

The shape of this waveform is virtually constant over a wide range of shaft speeds. The constancy of shape is to be expected since this is determined solely by the changes in field geometry over one half of a revolution.

The variation in amplitude for different speeds and values of excitation winding resistance is more difficult to explain but can be predicted with the aid of the simplified equivalent circuit and phasor diagram of Figure A44-6.

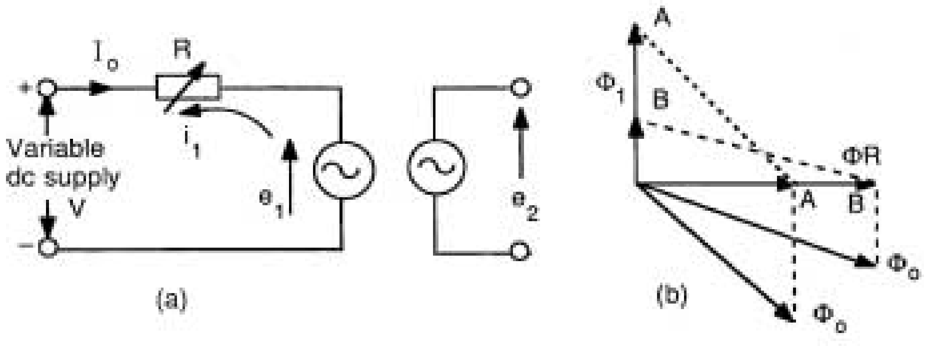


Figure A44-6

In Figure A44-6, I_o is the steady direct current established by supply V across total resistance of the excitation winding R. This is assumed to be kept constant together with the motion of the rotor and gives rise to a constant fundamental component of alternating field Φo. This is the variation of flux caused simply by the change in reluctance of the magnetic circuit.

Any ac currents flowing in either winding will set up secondary fields which combine with Φ_o to give a resultant field Φ_R. The emf's generated in both windings will be functions of this resultant field . If we consider the non-load conditions, no current flows in the output winding, but a current i_1 will flow in the excitation winding and its power supply, and is superimposed on I_o, the direct current.

Current i_1 is caused by emf acting across R. It has been assumed that at all frequencies of interest R is large compared with the inductive reactance, which is true in this machine.

Now $e_1 \propto \frac{d\Phi_R}{dt}$ and $\Phi_R = |\Phi_R| \sin\omega t$

Where ω = fundamental periodicity

$|\Phi_R|$ = peak value of Φ_R

Thus $e_1 \propto \omega |\Phi_R| \cos \omega t$

and $i_1 \propto \frac{\omega|\Phi_R|\cos \omega t}{R}$

This current sets up an alternating flux Φ_1

$$\Phi_1 \propto \frac{\omega|\Phi_R|\cos \omega t}{R}$$

and this is represented in Figure A44-6 by a phasor 90° in advance of Φ_R. Remembering that Φ_o is constant and that Φ_R is the resultant of Φ_o and Φ_1, the construction shown can be completed. Cases A and B are illustrated for two values of ω/R and this shows that as ω/R changes, Φ_o changes in relative phase.

From Figure A44-6 (b), we can easily deduce the equation:

$$\Phi_1^2 + \Phi_R^2 = \Phi_o^2$$

where these symbols now represent rms amplitudes.

Substituting for $\Phi_1 = K\Phi_R \dfrac{\omega}{R}$

K = a constant

we obtain $\Phi_R = \dfrac{\Phi_o}{\sqrt{1+(\frac{K\omega}{R})^2}}$

We can now find:

$$e_2 \propto \frac{d\Phi_R}{dt} \propto \omega\Phi_R$$

$$e_2 \propto \frac{\omega}{\sqrt{1+(\frac{K\omega}{R})^2}}$$

When $\frac{K\omega}{R}$ is very large, this becomes $e_2 \propto R$.

When $\frac{K\omega}{R}$ is small compared with 1, it becomes $e_2 \propto \omega$

If e_2 is plotted against speed:

($\omega = \frac{2\pi N}{60}$ x 2 for speed N rev/min)

for different values of R, the curves of Figure A44-7 are obtained. The constants of proportionality for these curves so that they represent the actual machine for $I_o = 0.5$ A.

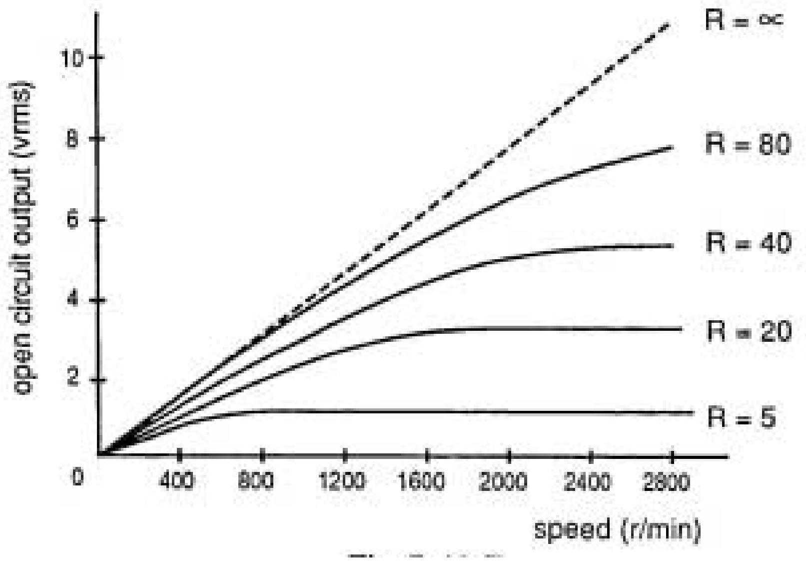


Figure A44-7

The effect of load currents drawn by resistive, capacitive and inductive loads can also be predicted from the phasor diagram of Figure A44-6(b). Resistive loads have exactly the same effect as variation of excitation resistance R. Capacitive loads cause a component of Φ_1 in opposite phase to Φ_R and hence in e_2. Inductive loads cause a component of Φ_1 in phase with Φ_R and tend to offset the reduction of e_2.

Practical generators of this type would have multiple poles and are used, for example, in aircraft for generation of 400 or 1000 Hz supplies and where the absence of brushes reduces interference with radio and other electronic equipment.

Question 44.1	If the dc supply is not smooth, the ripple is transferred from the excitation winding to the output winding by transformer action and obscures the true generated emf.
Question 44.2	At 1500 rev/min, the fundamental frequency generated is: $\frac{1500}{60} \text{ x } 2 = 50\,\text{Hz}$
Question 44.3	When the series resistor is zero, this output is constant for all speeds above about 400 rev/min as shown by the graph of Figure A44-7 for R = 5Ω.
Question 44.4	If R were infinite, the open circuit voltage would be proportional to speed. This is the dotted straight line in Figure A44-7 to which all other curves are asymptotic.
Question 44.5	The load current is virtually constant.

Notes

DISSECTIBLE

MACHINES SYSTEM

Assignment 45/46
Synchro Position-Indicator
Synchro Control Transformer

PRACTICAL	45.1	Position Indicator
	45.2	Control Transformer

EQUIPMENT REQUIRED	**Qty**	**Item**
62-100 Kit	2	Base Units
	1	Hand Crank
	2	Commutator/Sliprings
	4	Brushholders with Brushes
	2	12-Slot Wound Stator
	2	Rotor Hubs
	8	Rotor Poles
	4	L1 Coils
General	1	0-135 V, 5 A, ac supply (eg, Feedback 60-121)
	1	0-150 V, ac Voltmeter
	1	0-5 A, ac Ammeter (eg, Feedback 68-117)

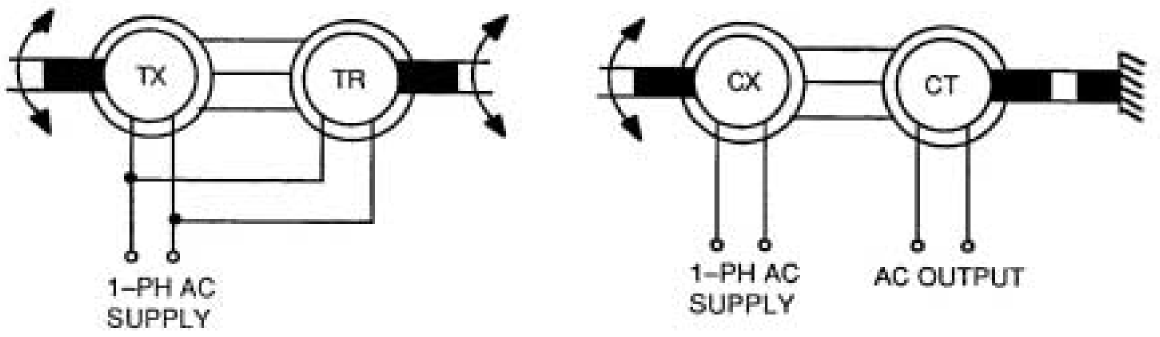
KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

Synchros are servo devices used for the transmission of data, in which rotary motion at a control point produces either a corresponding mechanical rotation or electrical output at a receiving point with no intervening mechanical link. A synchro resembles a 3-phase synchronous machine in appearance, having a stator with three distributed windings spaced 120° apart and a wound rotor with sliprings. Two 62-100's, connected as synchros, are used in each of these assignments.



(a) Synchro Position Indicator Circuit **(b) Synchro Control Transformer Circuit**

Figure A45-1

ASSEMBLY

Assemble both 62-100's as shown in Figures A45-2, A45-3 and A45-4, joining the corresponding stator terminals, A-A, B-B, C-C. Join the rotor windings in parallel and connect to the ac power supply unit.

PRACTICAL 45.1
Position Indicator

The synchro position indicator, Figure A45-1 (a), uses two synchros. One transmits an electrical signal which is dependent on shaft position, to the receiver synchro which develops sufficient torque to bring its shaft to a position corresponding to that of the transmitter synchro.

Switch on the supply and adjust the rotor current to 3 A. Attach the hand crank to one synchro. It will be found that rotation of the control synchro rotor produces a corresponding rotation in the receive synchro. Test the effect of different values of rotor current and of series connection on synchro response.

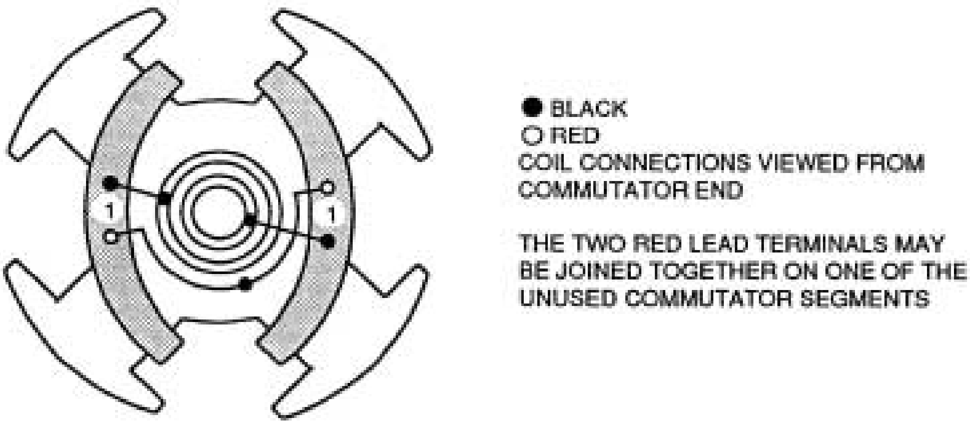


Figure A45-2: Rotor Wiring Diagram

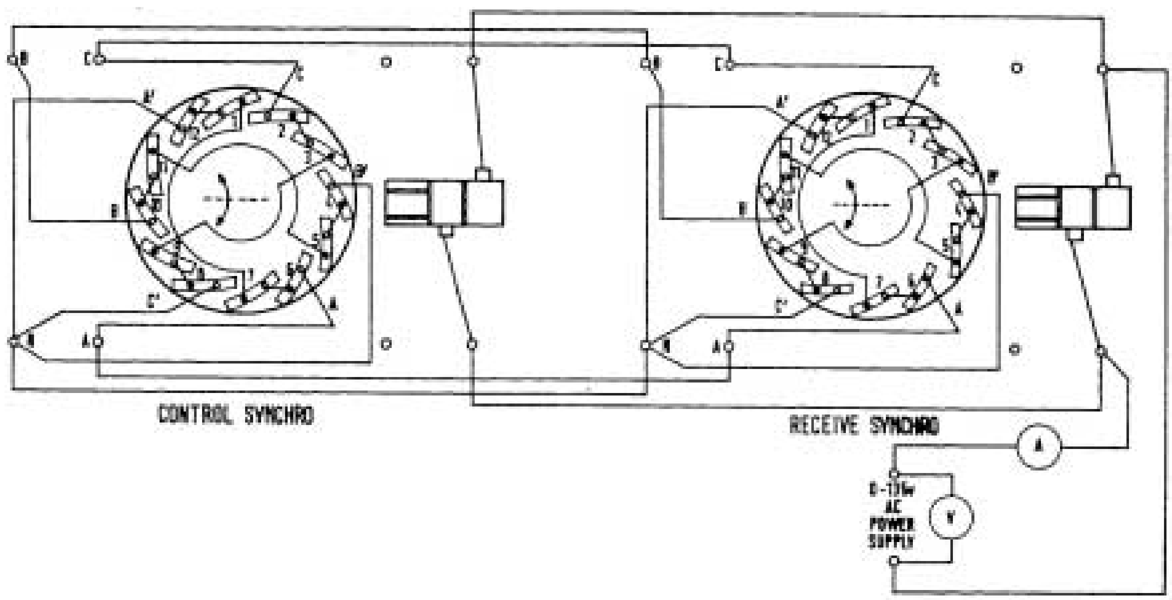


Figure A45-3: Synchro Position Indicator Wiring Diagram

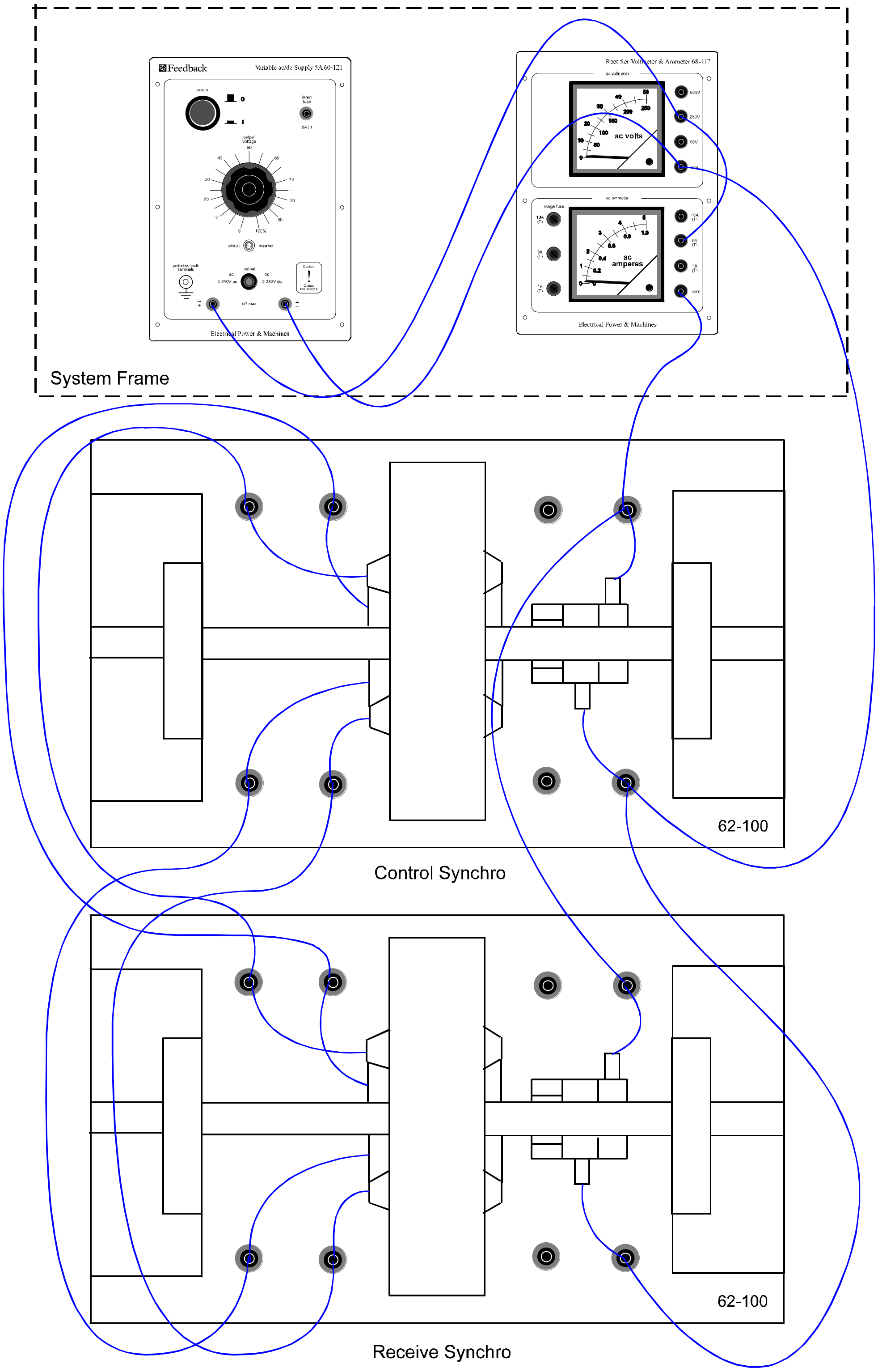


Figure A45-4: Connections for Synchro Position Indicator

PRACTICAL 45.2

Control Transformer

The synchro control transformer, Figure A44-1(b), also uses two synchros - one transmits an electrical signal depending on its shaft position, to the transformer synchro, whose rotor then supplies a voltage proportional to the difference between its angular position and that of the transmitter synchro.

Assemble as in the previous test but, in this case, connect the ac supply to the control synchro rotor winding only as shown in Figures A45-5 and A45-6. Connect a 0-150 V ac voltmeter across the slipring terminals of the control transformer. Switch on the ac supply and rotate the transmitter synchro shaft, using the crank provided. Note that the control transformer output voltage reaches a maximum twice in each revolution of the transmitter synchro shaft. These correspond to positions in which the two rotor windings are in-phase or anti-phase. The control transformer therefore acts as an indicator of the alignment between two shafts, or of the magnitude and direction of misalignment between them.

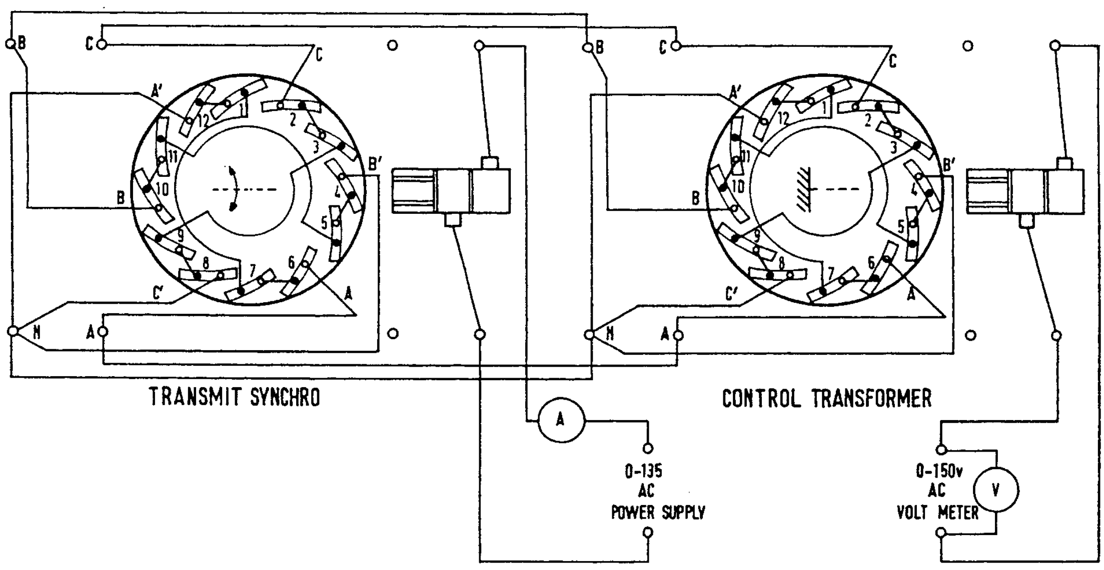


Figure A45-5: Synchro Control Transformer Wiring Diagram

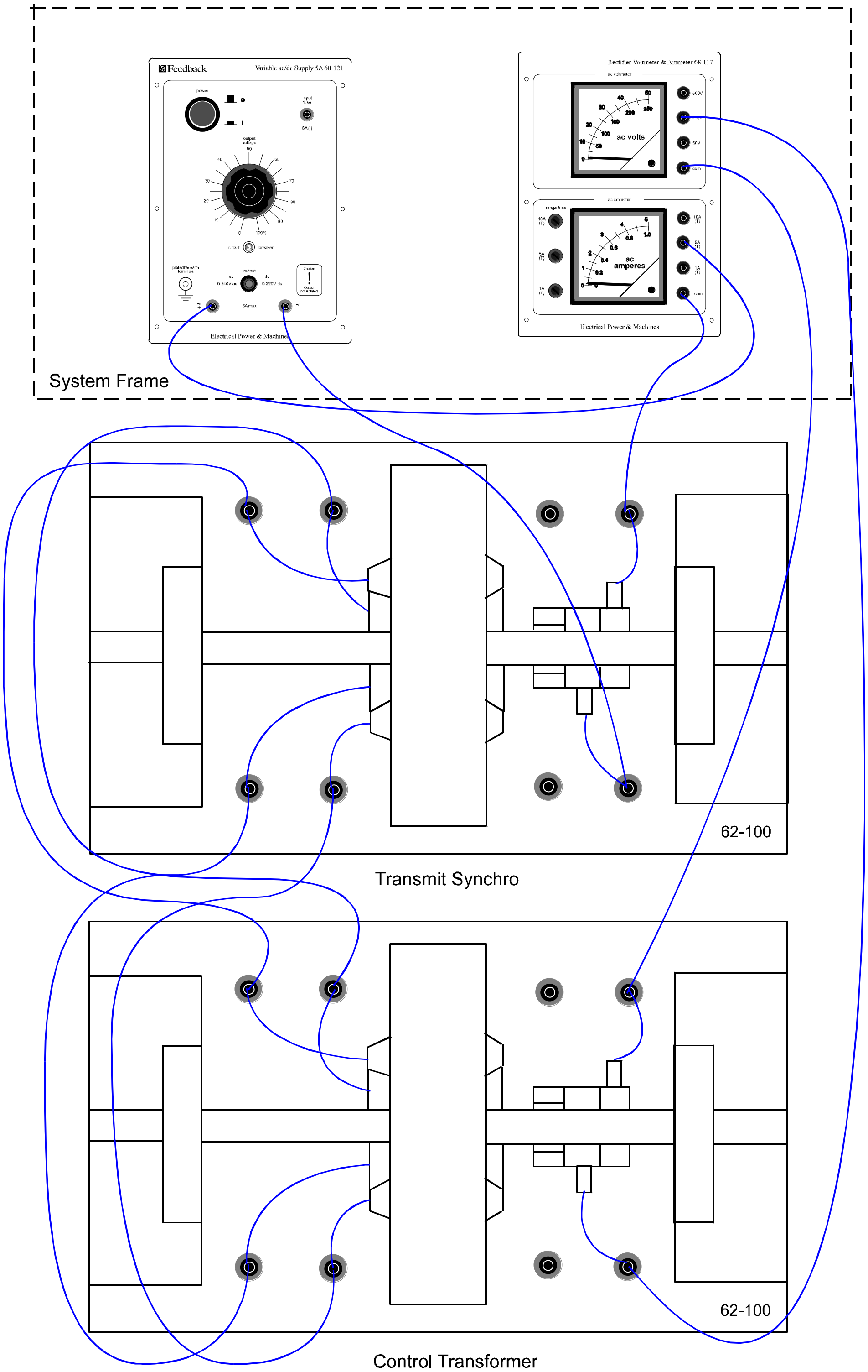


Figure A45-6: Connections for Synchro Control Transformer

DISCUSSION

In a synchro the relationship between stator and rotor positions is defined by the relative amplitudes of alternating emf's or currents in three windings positioned at 120° intervals. All three emf's or currents have the same basic phase so the situation is quite different from that in a three-phase system. However, any one signal may be of positive or negative polarity depending upon the angle to be represented. Figure A45-7 shows some typical values for various angles.

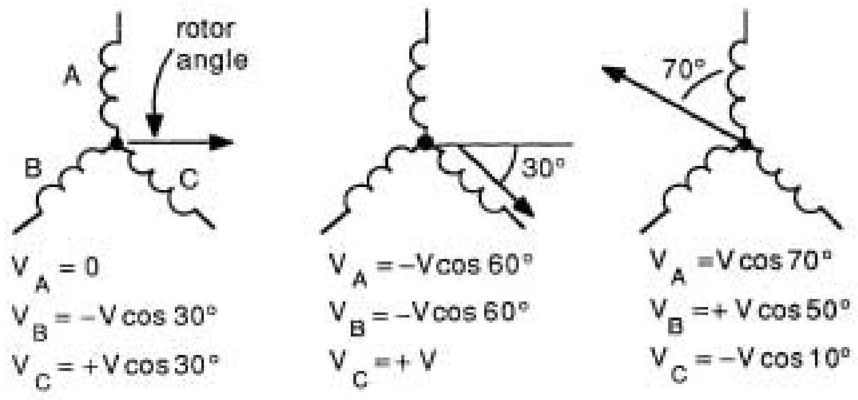


Figure A45-7: Typical Synchro Voltages

DISSECTIBLE

MACHINES SYSTEM

Assignment 47

Variable Ration Transformer

PRACTICAL 47.1

EQUIPMENT REQUIRED

	Qty	Item
62-100 Kit	1	Base Unit
	1	Commutator/Slipring
	2	Brushholders with Brushes
	2	L1 Coils
	2	L9 Coils
	2	Field Poles
	1	Rotor Hub
	4	Rotor Poles
	1	Hand Crank
General	1	1-135 V, 5 A, ac Supply (eg, Feedback 60-121)
	1	0-150 V, ac Voltmeter
	1	0–5 A ac Ammeter (eg, Feedback 68-117)
	1	Variable Resistance, 200Ω (eg, Feedback 67-113)
	1	Control Switches (eg, Feedback 65-130)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

Variable ratio transformers provide a variable output voltage in accordance with the alignment of rotor and stator coils. When the coils are aligned, maximum voltage is obtained. Minimum voltage is obtained when the coils are in quadrature.

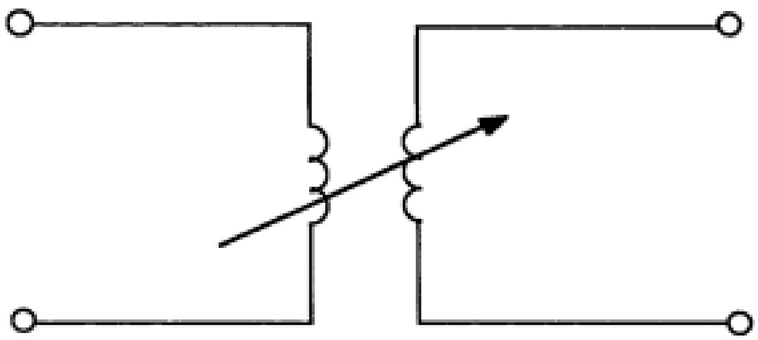


Figure A47-1: Variable-Ratio Transformer Circuit Diagram

ASSEMBLY

Fit L1 coils between opposite pairs of rotor poles as shown in Figure A47-2, and secure the rotor and commutator/slipring to the shaft. Connect the L1 coils in series and take one lead from each coil to a slipring via the appropriate commutator segments. Fit the shaft into its bearings and check that it rotates freely before finally tightening the thumb screws which hold the removable bearing pedestal to the base unit. Attach the hand crank to the drive-end shaft extension. Place the L9 coils over the stator field poles, fix these to the frame ring in the 3 o'clock and 9 o'clock positions. Make the circuit shown in Figure A47-3 in accordance with the connections shown in Figure A47-4. Attach the brushholders with their brushes to the mounting block so that each brush is in contact with a slipring.

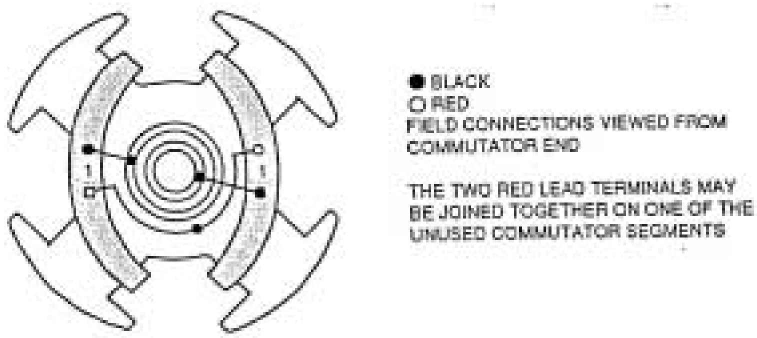


Figure A47-2: Rotor Wiring Diagram

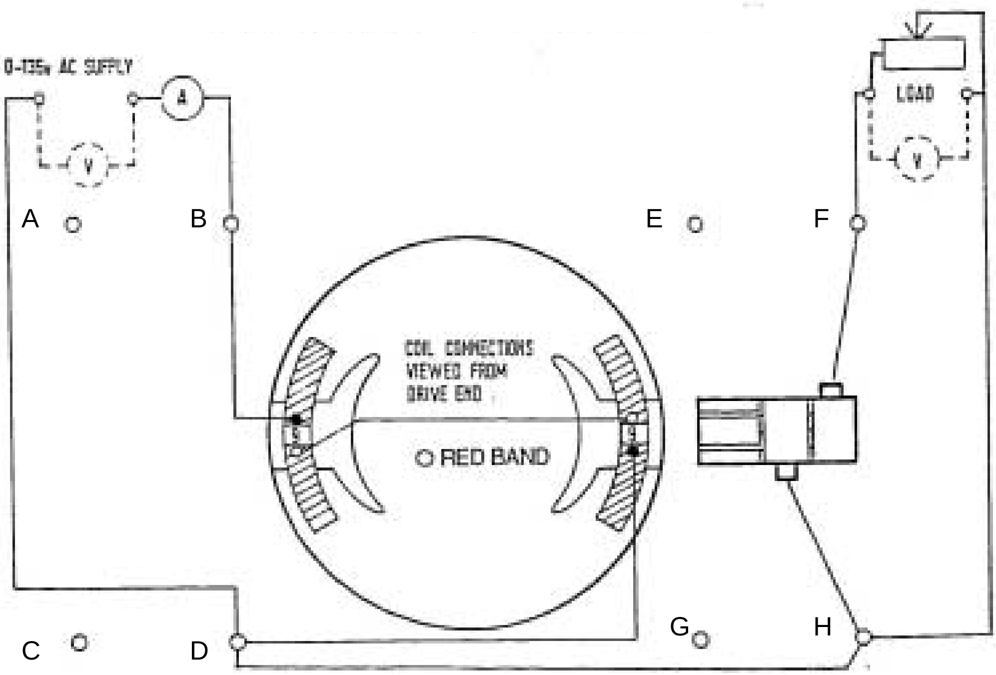


Figure A47-3: Variable-Ratio Transformer Wiring Diagram

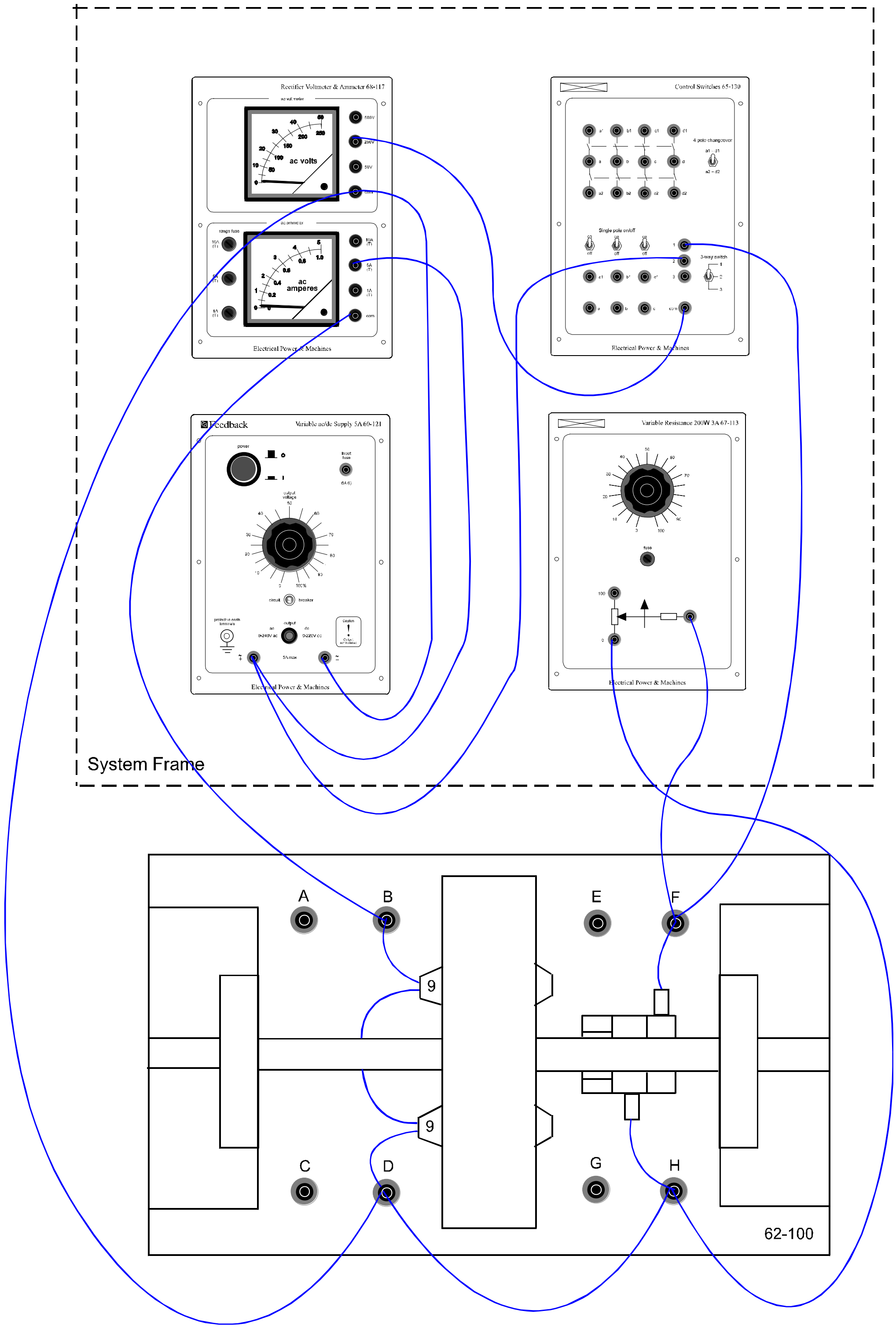


Figure A47-4: Connections for Variable-Ratio Transformer

PRACTICAL 47.1

Switch on the ac supply and turn the rotor slowly through a full revolution. Note that the output voltage is a maximum when the axis of the rotor coils is in line with that of the stator coils and a minimum when the two axes are in quadrature.

Use the three-position panel switch to monitor supply and output voltages, as required.

DISSECTIBLE

MACHINES SYSTEM

Assignment 48

Motor-Generator Set

PRACTICAL 48.1

EQUIPMENT REQUIRED	**Qty**	**Item**
62-100 Kit	2	Base Units
	2	Commutator/Slipring
	4	Brushholders with Brushes
	4	L1 Coils
	2	L2 Coils
	4	L9 Coils
	4	Field Poles
	2	Rotor Hubs
	8	Rotor Poles
	1	Flexible Coupling
General	1	0-120 V, 5 A, dc power supply (eg, Feedback 60-105)
	1	0-20 V, 5 A, dc power supply (eg, Feedback 60-121)
	1 1	0-5 A, dc ammeter 0-150 V, dc voltmeter (eg, Feedback 68-110)
	1	5-0-5 mA Centre-Zero, dc ammeter (eg, Feedback 68-113)
	1 1	0–2 A ac Ammeter 0-150 V, ac Voltmeter (eg, Feedback 68-117)
	1	Variable Resistance, 200Ω (eg, Feedback 67-113)
	1	Optical/Contact Tachometer (eg, Feedback 68-470)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

The motor-generator set comprises a dc series motor driving a rotating field, single-phase ac generator but many of the motors and generators described earlier in the manual can be used as alternatives.

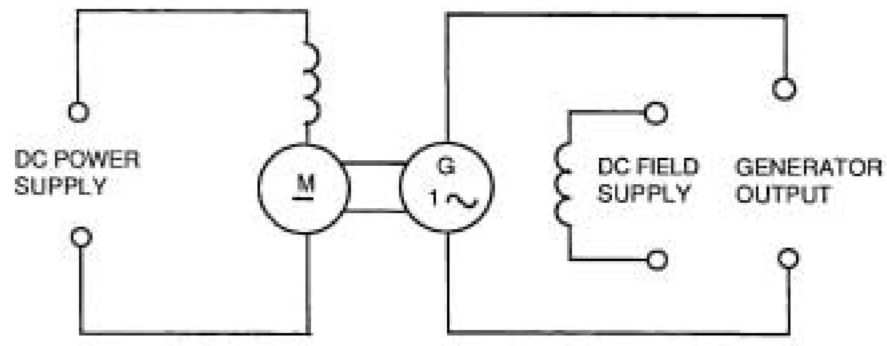


Figure A48-1: Motor-Generator Set Circuit Diagram

ASSEMBLY

Make up the dc armature and the ac rotor as shown in Figures A48-2 and A48-3. Fit the shafts into their bearings and check that each rotates freely before finally tightening down the thumbscrews in the removable bearing pedestal. Place the two sets of L9 coils over their poles, attach these to their respective frame rings in the 3. o'clock and 9 o'clock positions in each case, and make the circuits shown in Figure A48-4 in accordance with the connections shown in Figure A48-5. Attach the brushholders with their brushes to the mounting block to contact the commutator of the dc series motor or the sliprings of the ac generator. Couple the two base units together as explained in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 7.

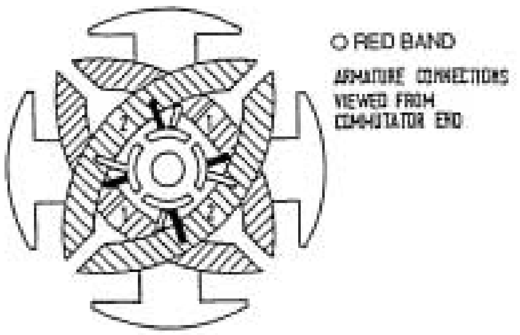


Figure A48-2: dc Armature Wiring Diagram

Figure A48-3: ac Rotor Wiring Diagram

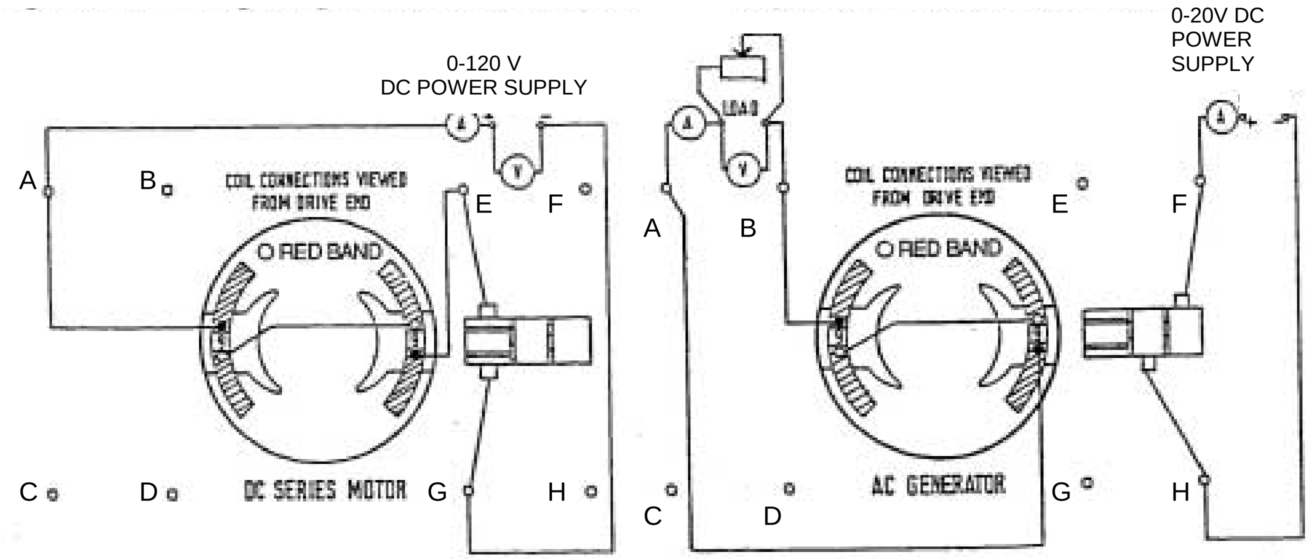


Figure A48-4: Motor-Generator Set Wiring Diagram

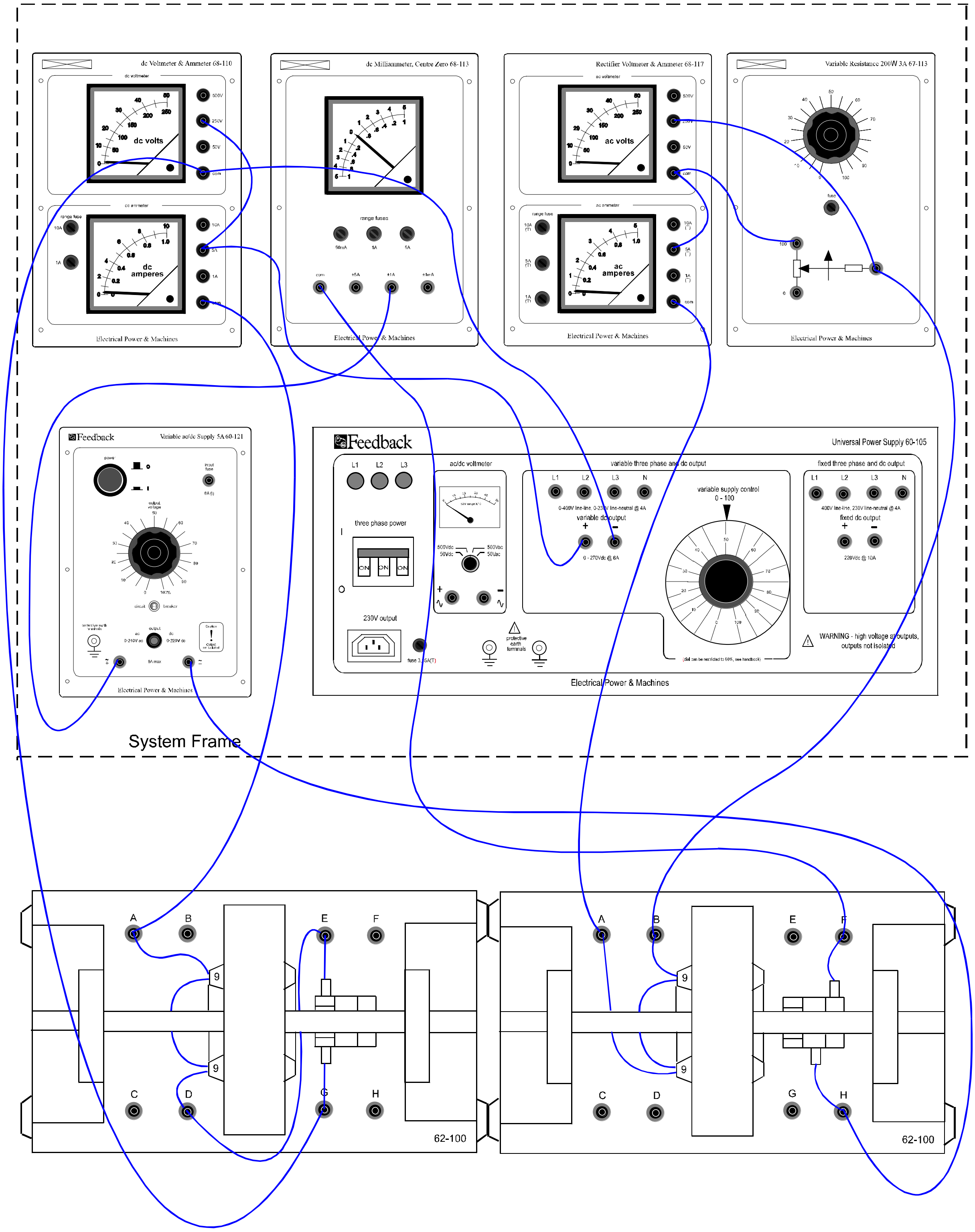


Figure A48-5: Connections for Motor-Generator Set

PRACTICAL 48.1

Check that the two shafts rotate smoothly and switch on the dc power supply to the series motor. Raise the shaft speed to 1500 rev/min, switch on the dc supply to the generator field and correct the shaft speed as necessary. Open-circuit, load tests, etc can be carried out, taking measurements of input power to the motor and output volt-amperes of the ac generator. You can thus determine the overall efficiency of the motor-generator set.

DISSECTIBLE

MACHINES SYSTEM

Chapter 3-5

Additional Assignments

This chapter contains additional assignments as follows:

No.

49) Effect of Brush Angle on Commutation in dc Motors and Generators

50) Variable Speed Drive Unit 63-501 coupled to 62-100 dc Generators – Terminal Voltage/Load Current Curves and Efficiency

51) ac Generator synchronized with the Mains Supply

52) Synchronous Motor Characteristics

53) Induction Motor with Wound Rotor

54) Rotor Assemblies for 62-100

55) Stepping Motors

56) Shaded-Pole Induction Motor

57) Split-Field Series dc Motor

58) Dynamic Braking of a dc Motor

59) Power Factor Correction of Induction Motors

60) Pole-changing Induction Motor

61) Fault Occurring on a dc Shunt Motor

62) Faults Occurring on a 4-pole Induction Motor

Notes

DISSECTIBLE MACHINES SYSTEM

Assignment 49
Effect of Brush Angle on Commutation in dc Motors and Generators

PRACTICAL	49.1	62-100 Shunt Motor
	49.2	62-100 Series Generator
EQUIPMENT REQUIRED	**Qty**	**Item**
62-100 Kit	1	Base Unit
	1	Commutator/Slipring
	2	Field Poles
	1	Rotor Hub
	4	Rotor Poles
	2	L1 Coils
	2	L2 Coils
	2	L4 Coils
	1	Flexible Coupling
General	1	Variable Speed Motor: 1/3 hp, 1200 rev/min (eg, Feedback 63-501)
	1	Rotatable Brushgear (eg, Feedback RB185)
	1	0-135 V, 5 A, dc Power Supply (eg, Feedback 60-105)
	1 1	50 V/250 V, dc Voltmeter 1 A/5 A, dc Ammeter (eg, Feedback 68-110)
	1	Variable Resistance 200Ω, 3 A (eg, Feedback 67-113)
	1	Friction (Prony) Brake or other Dynamometer 0-1 Nm at 1500 rev/min (eg, Feedback 67-470)
	1	Optical/Contact Tachometer (eg, Feedback 68-470)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

INTRODUCTION

In the elementary dc generator shown below, each armature coil side is moved alternately under North and South field poles, so generating an emf whose polarity changes correspondingly from positive to negative. To produce a uni-directional output at terminals of the generator, a commutator is used to reverse the connections to the coil when the emf induced in it passes through zero. This occurs when the coil sides are in the magnetic neutral plane, as shown in Figure A49-1.

Figure A49-2 shows the graphs of generated voltage against armature rotation, for a single coil and also for two coils positioned at right angles to one another. The effect of additional coils is to decrease the ripple content of the output voltage waveform.

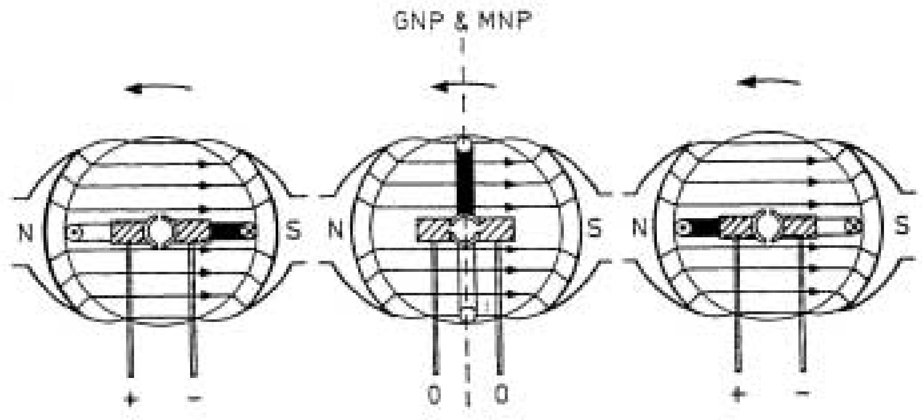


Figure A49-1:

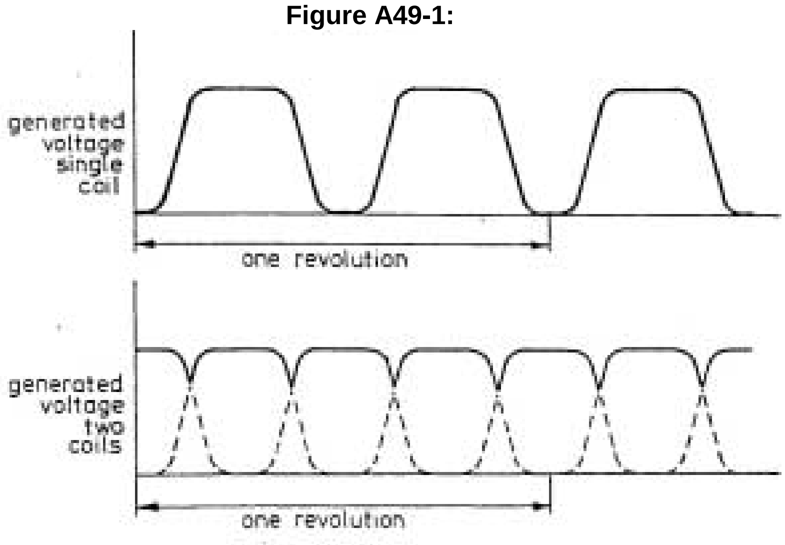


Figure A49-2

In a multi-coil armature, the main field is distorted by a flux due to load current flowing in the armature coils causing the magnetic neutral plane (MNP) to be shifted away from the geometric neutral plane (GNP) by an amount which is dependent on the strength of the armature current, as shown in Figure A49-3. To obtain good commutation, it is necessary either to move the brushes so that commutation again occurs in the magnetic neutral plane or to produce an additional magnetic flux to compensate for that due to armature reaction.

Interpoles may be used to produce a flux which will act in opposition to that produced by armature reaction and will have an intensity which is dependent on armature current. Interpoles are positioned between each pair of main poles and the interpole coils are connected in series with the armature. Wound interpoles are provided as part of the 62-100 and their application is described in the assemblies for each dc motor or generator.

Brush-shifting may be used to improve commutation as an alternative or in addition to interpoles. As the shift in the magnetic neutral plane is related to armature current there is no single setting which will give correction over the load range of the machine, and a compromise setting is often used.

For improvement of commutation in motors and generators the following rules apply:

dc Motors Shift brushes opposite to the direction of armature rotation.

dc Generators Shift brushes in the directions of armature rotation.

ASSEMBLY

Fit the armature and commutator to the shaft as shown in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 1, positioning the back face of the slipring/commutator approximately 12 mm (½”) from the bearing seating shoulder.

Fit the Rotatable Brushgear RB185 as described in Basic Assembly Instruction 5.

Make the circuits for the motor or generator assemblies, as shown in Figures A49-4 and A49-5 as required, in accordance with the connections shown in Figures A49-6 and A49-7 respectively. Use 8 in or 12 in leads to connect from the baseplate terminals to the brushbox terminals to allow for rotation of the brushgear.

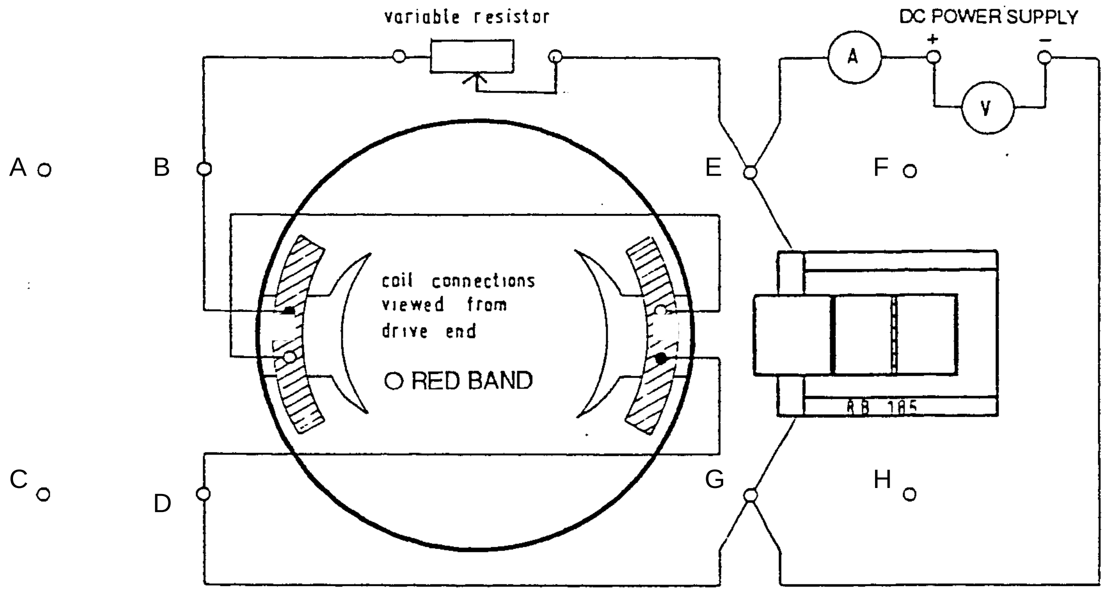


Figure A49-4: dc Shunt Motor Wiring Diagram

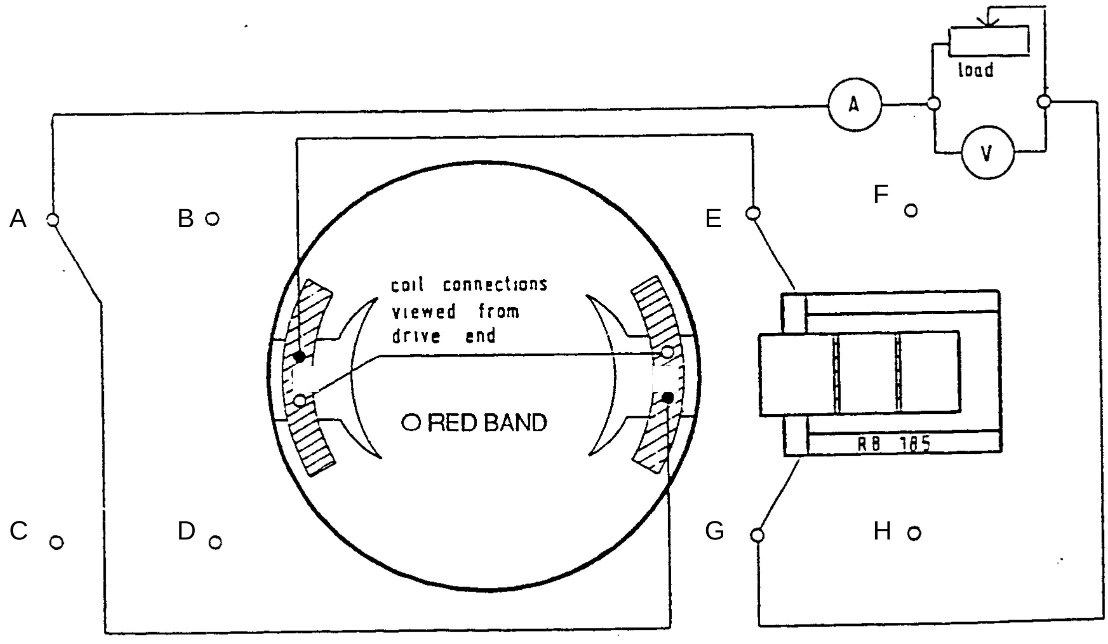


Figure A49-5: Series Generator Wiring Diagram

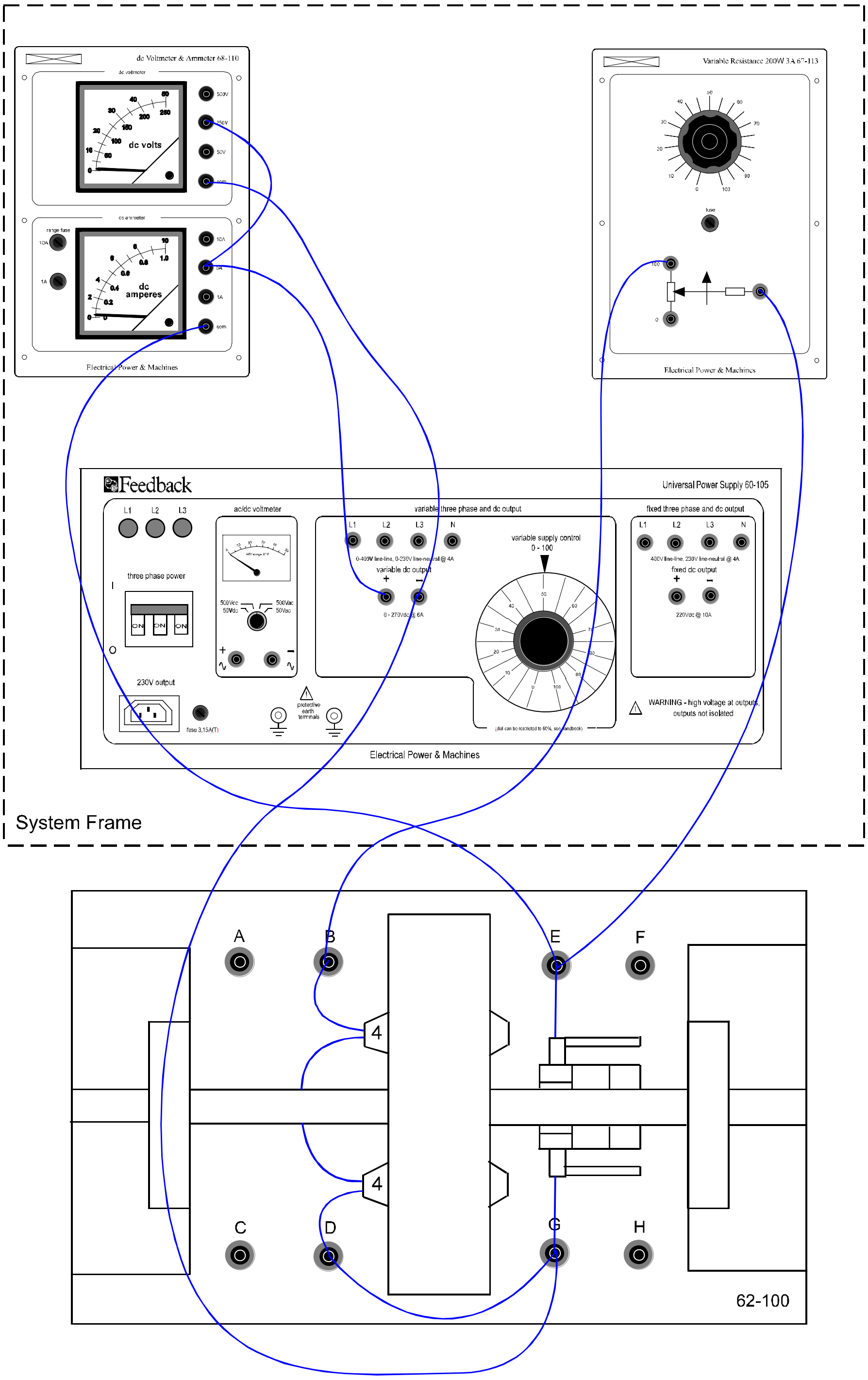


Figure A49-6: Connections for dc Shunt Motor

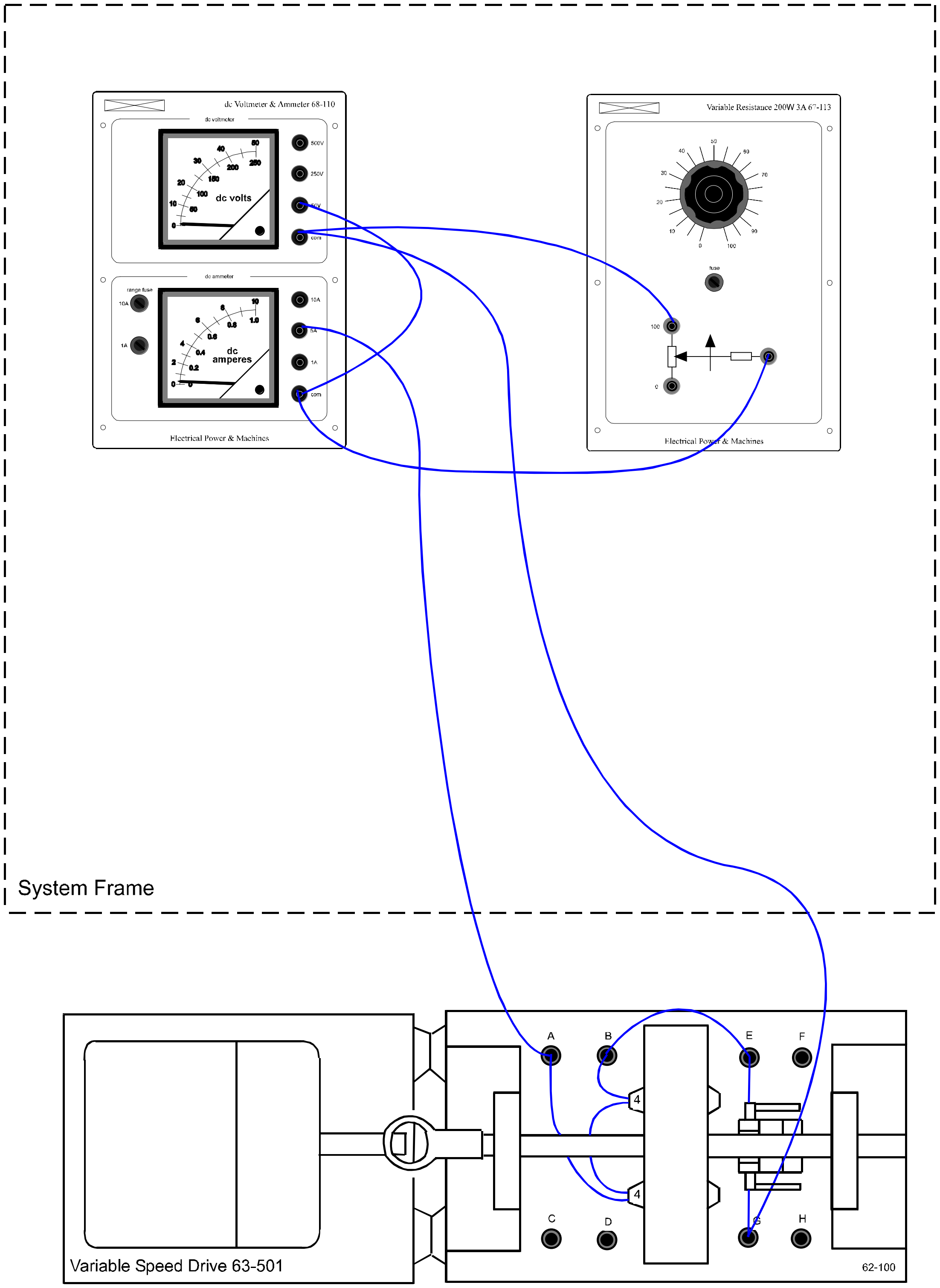


Figure A49-7: Connections for dc Series Generator

Motors

Fasten the band brake to the baseplate. Adjust the brake for zero load initially. Instructions for mounting the Friction (Prony) Brake are given in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 6.

Generators

Connect the drive motor baseplate to that of the 62-100, aligning the two shafts and connect them by a flexible coupling as explained in Basic Assembly Instruction 7.

PRACTICAL 49.1

Before switching on the power supply, ensure the voltage control dial is set to zero.

Shunt Motor

Slacken off the friction (Prony) brake adjustment screw to give zero torque initially.

Switch on the control panel main switch.

Set the variable resistor in series with the field to approximately 50 ohms.

Switch on the power supply and raise the output voltage to approximately 20 V to start the motor, and adjust to obtain the required speed of 1500, rev/min.

To demonstrate the improvement on commutation brought about by shifting the brushes, the motor is first run at 1500rev/min on no load. It will be found that brush position has less effect on sparking level. Return the brushes to the zero position and apply load by tightening the adjusting screw on the brake to the required value of torque, as read on the gauge. For the dc shunt motor, when supplied from a 50 V source, a load of 0.6 Newton-metres (0.44 pound-feet) is suitable. Maintain constant shaft speed through-out the test by adjustment of the dc supply to the motor.

As the load is increased, it will be noticed that sparking at the brushes increases considerably. Slacken off the brushgear thumbscrew and move the brushes opposite to the direction of rotation, noting the effect on commutation. At an angle of approximately 20°, there will be a marked reduction in sparking level.

PRACTICAL 49.2

Series Generator

Set the variable load resistor to maximum (200 ohms)

Switch on the variable speed drive 63-501, raise the shaft speed to 1500 rev/min and maintain at this speed. Set the brush angle to zero.

Reduce the load resistor setting to 20 ohms - the generator should give an output of approximately 20 V at 1 A. If self-excitation does not occur, reverse either the direction of shaft rotation or the field coil polarity so as to assist the build up of residual voltage.

With the machine supplying an electrical load, commutation is observed first with the brushes in the geometric neutral position and then when advanced in the direction of armature rotation.

With the brush angle set to zero and the shaft speed maintained at 1500 rev/min, reduce the variable load resistor to approximately 15 ohms and adjust as necessary to produce a load current of 2 A. Observe the level of sparking at the brushes, then advance the brushes in the direction of armature rotation and determine the brush angle which gives minimum sparking. Adjust the variable load resistor during this operation to maintain constant load current.

DISSECTIBLE MACHINES SYSTEM

Assignment 50
Drive Motor Coupled to 62-100 dc Generators – Characteristic Curves

PRACTICAL

50.1 Separately Excited Generator

50.2 Series Generator

EQUIPMENT REQUIRED

	Qty	Item
62-100 Kit	1	Base Unit
	2	Field Poles
	1	Rotor Hub
	4	Rotor Poles
	2	L1 Coils
	2	L2 Coils
	2	L4 Coils
	1	Slipring/Commutator
	2	Brushholders with Brushes
	1	Flexible Coupling
General	1	Rotatable Brushgear (eg, Feedback RB185)
	1	Variable Speed Motor: 1/3 hp, 1200 rev/min (eg, Feedback 63-501)
	1	0-135 V, 5 A, dc Power Supply (eg, Feedback 60-105)
	1	1-0-1 mA Centre-Zero dc Ammeter (eg, Feedback 68-113)
	1 1	1 A/5 A dc Ammeter 50 V/250 V, dc Voltmeter (eg, Feedback 68-110)
	1	Variable Resistance 200Ω (eg, Feedback 67-113)
	1	Friction (Prony) Brake or other Dynamometer 0-1 Nm at 1500 rev/min (eg, Feedback 67-470)
	1	Control Switches (eg, Feedback 65-130)
	1	Optical/Contact Tachometer (eg, Feedback 68-470)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

A drive motor and controller may be coupled directly to the 62-100 and used to supply torque to any of the dc generator assemblies at speeds from 300 rev/min to over 3000 rev/min. If the input current to the drive unit is measured for a range of generator loadings, the input power supplied to the generator can be derived and the efficiency calculated. Details are given of load tests on the two dc generators shown in Figure A50-1.

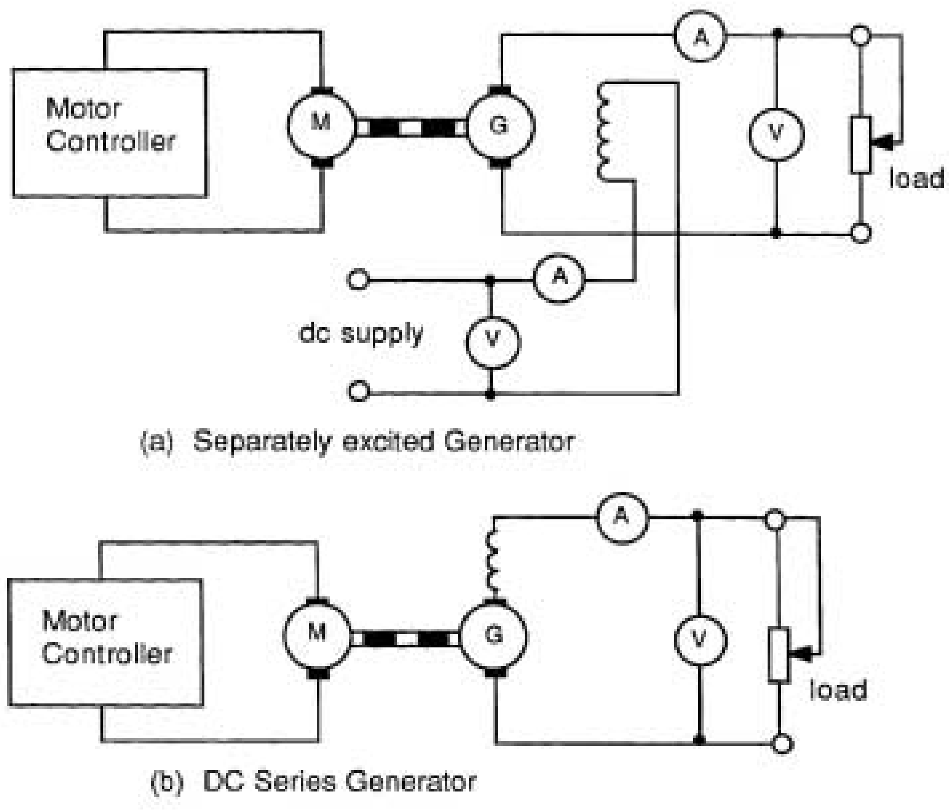


Figure A50-1: Circuit Diagrams

ASSEMBLY

Construct either the series or separately excited generators as described in Assignments 21 and 17 respectively, but fit the Rotatable Brushgear RB185 as described in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 5.

Couple the drive motor to the 62-100 base unit according to the instructions given in Basic Assembly Instruction 7.

Make the circuits shown in Figures A50.2 and A50.3 for the separately excited generator, and Figures A50.4 and A50.5 for the series generator. Set the brush angle initially 20° back for motors and 20° forward for generators, with respect to the direction of rotation

Connect the drive motor to the dc supply and connect an ammeter to measure external line current.

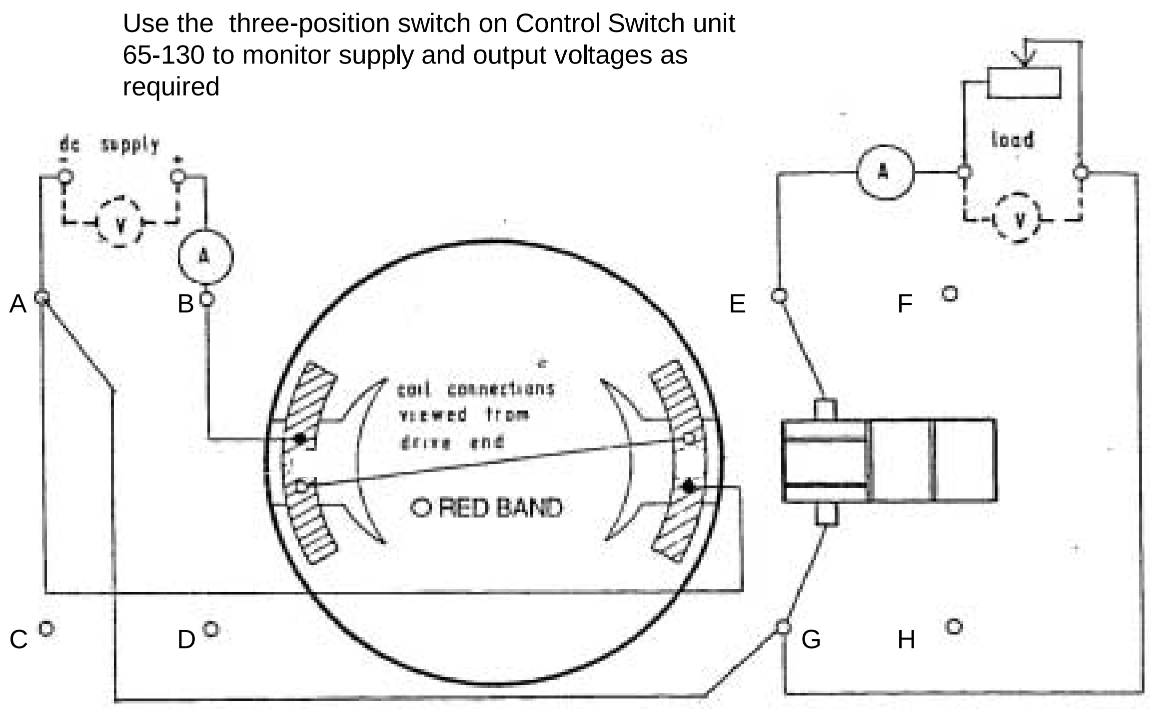


Figure A50-2: Separately Excited Wiring Diagram

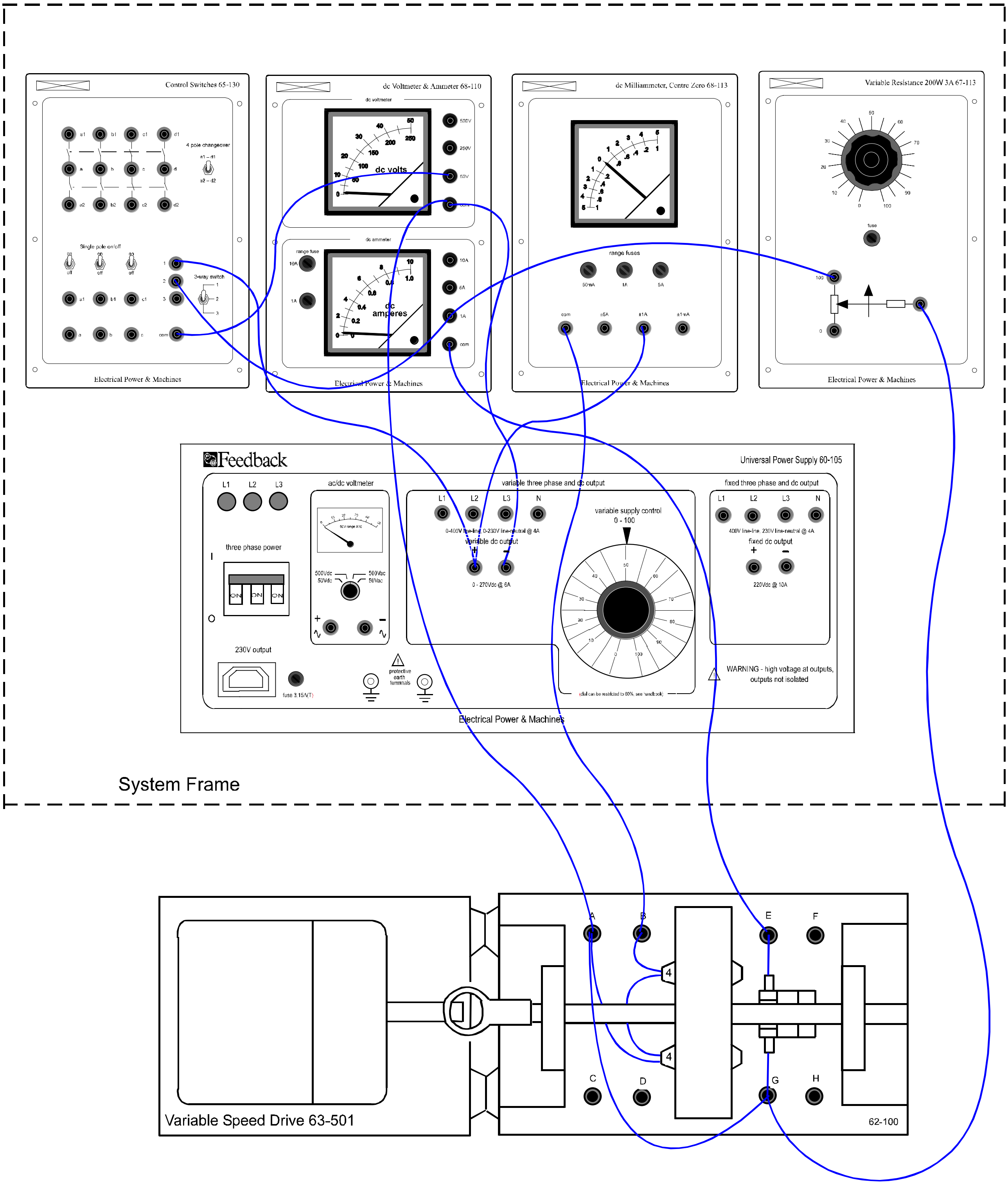


Figure A50-4: Connections for dc Separately Excited Generator

PRACTICAL 50.1

Separately Excited Generator

Switch on the drive motor, raise the shaft speed to 1500 rev/min and maintain at this level throughout the test. Set the load resistor initially to maximum and set the field current to 2.5 A dc. Measure the field voltage (switch to position 1). Adjust the load resistor in steps to give a range of load currents from minimum to 3 A, and take readings of drive motor input current, load current (switch to position 2) and voltage at each step for constant speed and field current. Plot the results in Figure A50.6 (see Results Tables for graph axis and Typical Results and Answers for a complete graph).

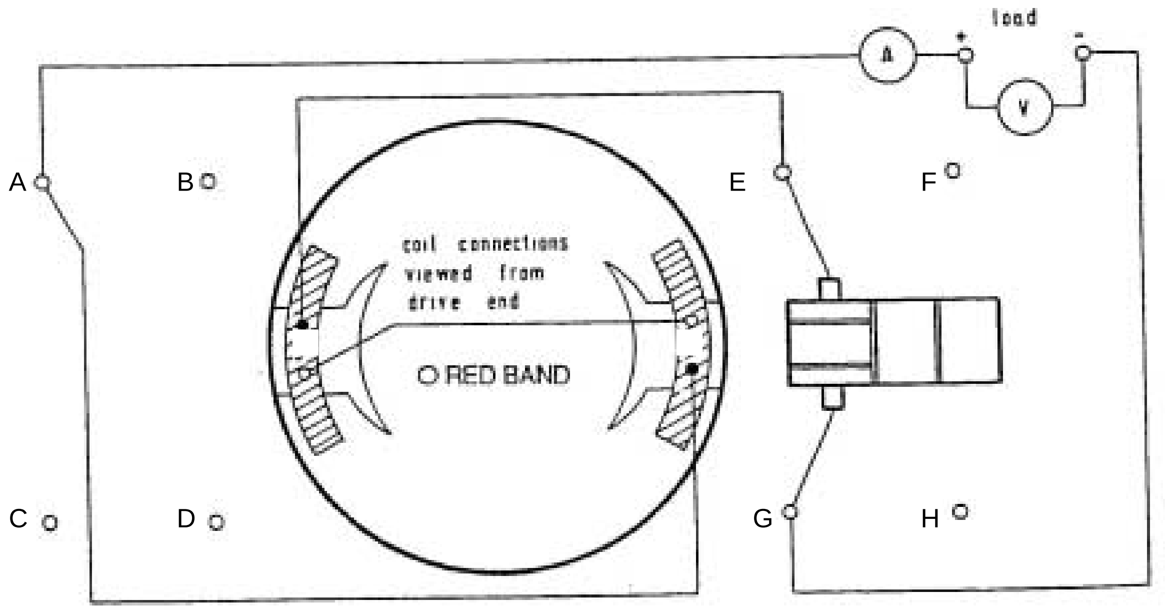


Figure A50-3: dc Series Generator

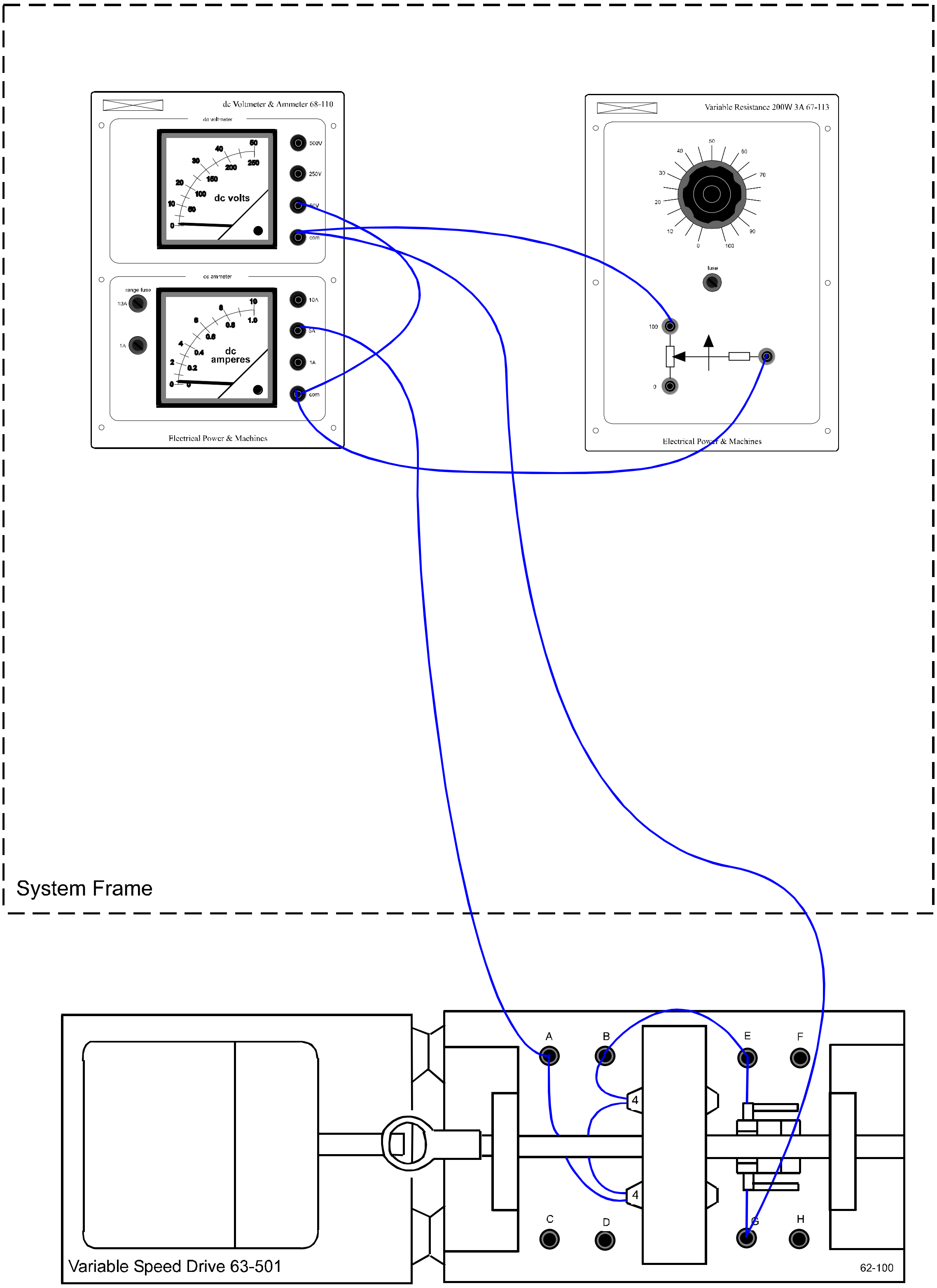


Figure A50-5: Connections for dc Series Generator

PRACTICAL 50.2

Series Generator

In any self-excited generator, the initial build-up of voltage is dependent on the residual magnetism present in the magnetic circuit. If this is insufficient, it may be necessary to momentarily excite the field coils from a low voltage dc source. Usually, however, there is sufficient residual voltage to give a small indication on the dc voltmeter when set to 50,V. The direction of rotation and field polarity must be such that loading the generator produces an increase in this residual voltage.

Set the variable load resistor to 20 ohms, switch on the drive unit and raise the shaft speed in steps from 300 to 1800rev/min, taking readings of shaft speed, motor/controller input current, generator terminal voltage, and load current at each step.

Plot terminal voltage against shaft speed as in Figure A50-7 (see Results Tables for graph axis and Typical Results and Answers for a complete graph).

DISCUSSION

To obtain the efficiency of either of these generators, the input power, supplied as torque, must be know. Torque/current curves for the drive motor enable the torque applied to the generator to be derived from measurements of the ac input current to the controller.

Typical efficiency calculations are as follows:

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

$$\text{Input power} = \frac{2\pi NT}{60} \text{ watts}$$

where N = rev/min

T = torque input to generator, Newton-Metres

or $$\text{Input power} = \frac{2\pi NT}{44.2} \text{ watts}$$

where N = rev/min

T = torque input to generator, pounds-feet

	Shaft Speed	Generated Output			Drive Power			Efficiency
	rev/min	Volts	Amps	Watts	Amps	Nm	Watts	%
Series Generator	1530	21	1.0	21	1.6	0.32	51	41
Separately Excited Generator	1500	58	3.2	185	3.9	1.38	289	54.5
					+ Power into field		$^{51}/_{340}$	

Notes

Practical 50.1

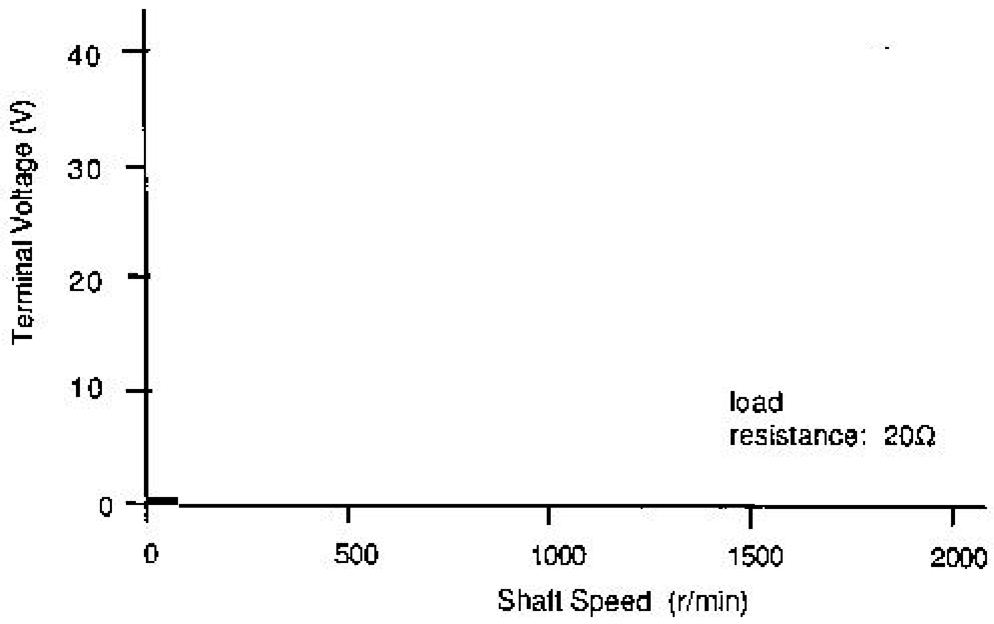


Figure A50-6: Graph axis

Practical 50.2

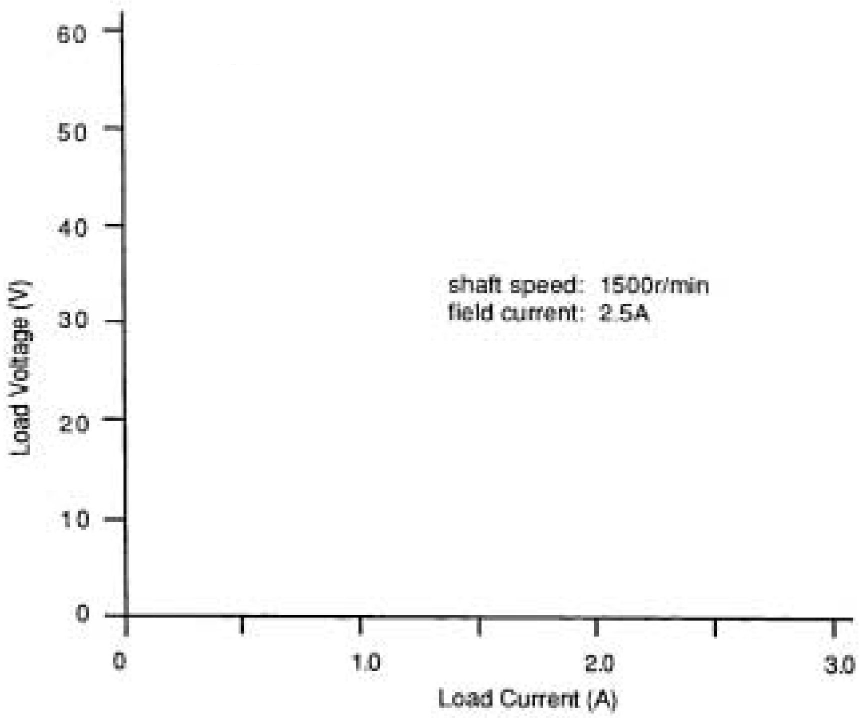


Figure A50-7: Graph axis

Notes

Practical 50.1

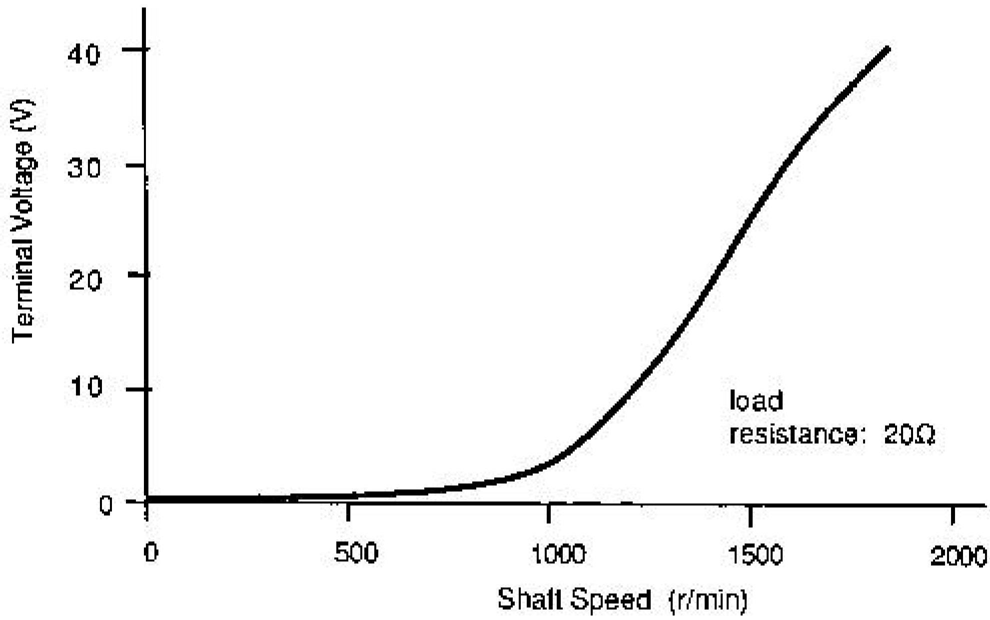


Figure A50-6: Series Generator Characteristics

Practical 50.2

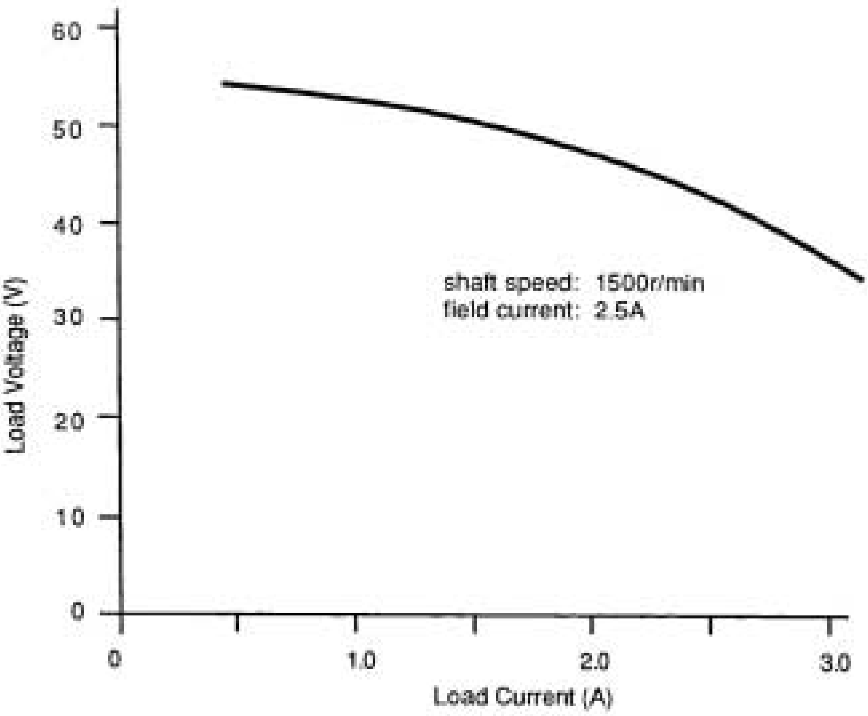


Figure A50-7: Separately Excited Generated Characteristics

Notes

DISSECTIBLE MACHINES SYSTEM

Assignment 51
ac Generator
Synchronised with Mains Supply

PRACTICAL

51.1 Separately Excited Generator

51.2 Series Generator

EQUIPMENT REQUIRED

	Qty	Item
62-100 Kit	1	Base Unit
	1	12-Slot Wound Stator
	1	Rotor Hub
	4	Rotor Poles
	2	L1 Coils
	1	Slipring/Commutator
	2	Brushholders with Brushes
	1	Flexible Coupling
General	1	Variable Speed Motor: 1/3 hp, 1200 rev/min (eg, Feedback 63-501)
	1	0-135 V, 5 A, ac Power Supply (eg, Feedback 60-121)
	1	0-20 V, 5 A dc Power Supply (eg, Feedback 60-105)
	1 1	1 A/10 A ac Ammeter 250 V/500 V, ac Voltmeter (eg, Feedback 68-117)
	1 1	1 A/5 A dc Ammeter 50 V/250 V dc Voltmeter (eg, Feedback 68-110)
	1	Synchronising Lamps Unit (eg, Feedback 68-120)
	1	Control Switches (eg, Feedback 65-130)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

A variable-speed motor may be coupled directly to the 62-100 to provide the mechanical drive required to operate any of the ac generator assemblies over a wide speed range. In this assignment, a single-phase ac generator is brought into synchronism with 135 V ac mains supply available from the variable ac/dc supply unit 60-121, and is then coupled directly to this supply.

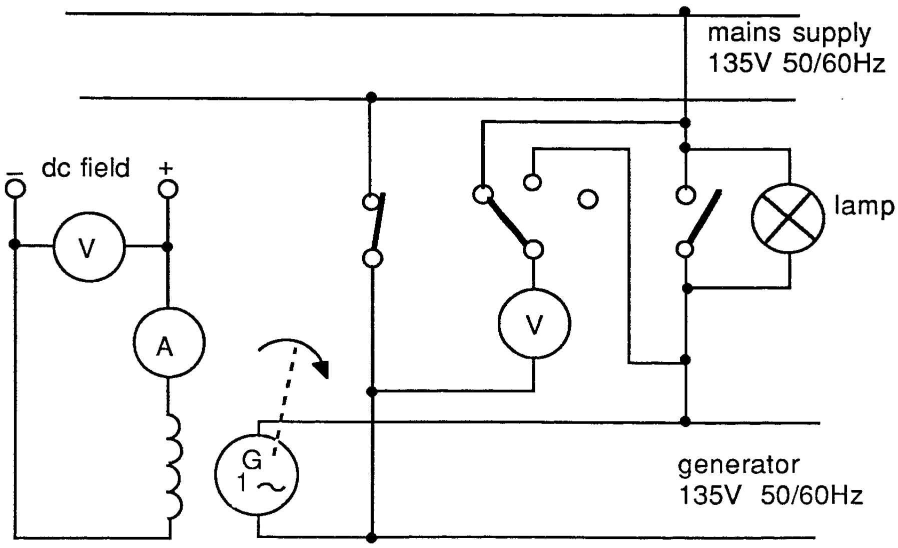


Figure A51-1: Circuit Diagrams

ASSEMBLY

Construct the rotating field ac generator as described in Assignment 38.

Couple the drive motor 63-501 to the 62-100 base unit in accordance with the instructions give in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 7.

Make the circuit shown in Figure A51-2 in accordance with the connections shown in Figure A51-3.

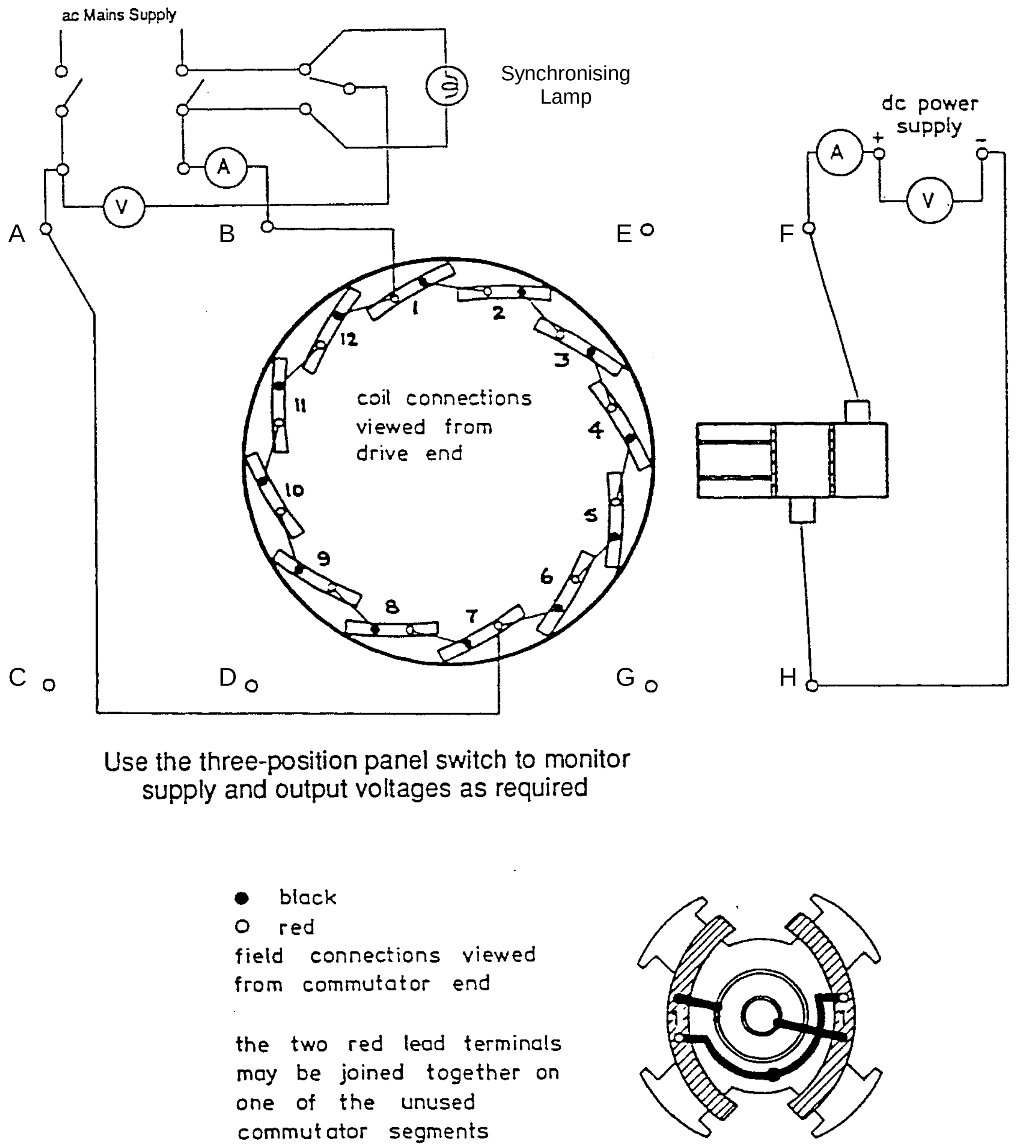


Figure A51-2: ac Single-Phase Generator, Rotating Field, Distributed Stator Winding

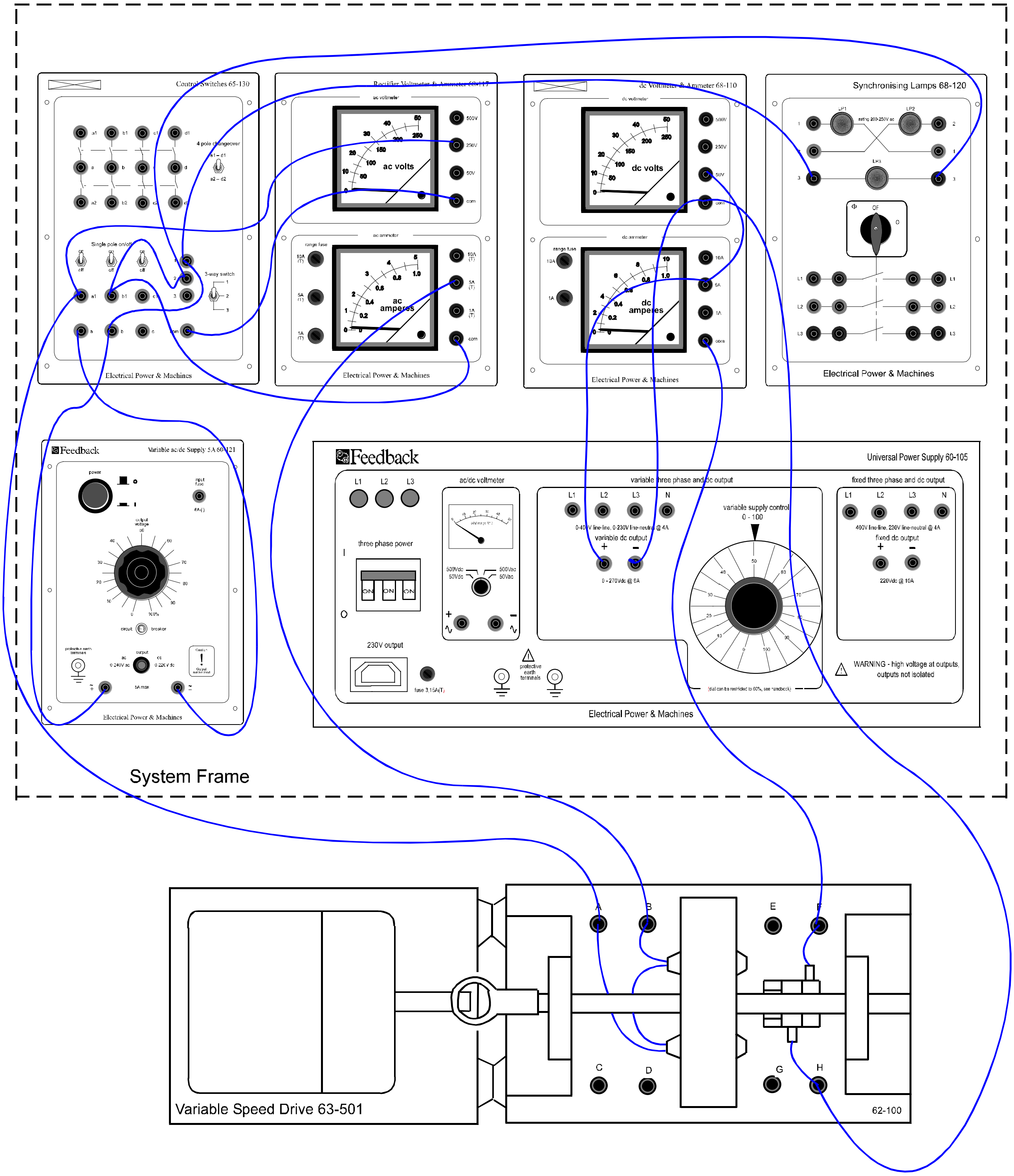


Figure A51-3: Connections for ac Generator Synchronised to Mains Supply

PRACTICAL 51.1

To synchronise the ac generator with the supply, three requirements must be met:

1. The voltage of the generator must be the same as the supply voltage.
2. The generator must be in phase with the supply.
3. The generator frequency must be the same as that of the supply.

Power up the drive motor 63-501 and bring the ac generator shaft speed up to the value calculated from the equation:

$$N = \frac{60f}{p}$$

Where N = shaft speed, rev/min
F = mains frequency, Hz
P = generator pole pairs
(for 2-pole machine p = 1)

For 50 Hz supplies:

$$N = \frac{60 \times 50}{1} = 3000 \text{ rev/min}$$

For 60 Hz supplies:

$$N = \frac{60 \times 60}{1} = 3600 \text{ rev/min}$$

Switch on the dc power supply on unit 60-105 and raise the dc rotor current to 2.5 A. Measure the generator output voltage (switch to position 2) and bring this to 135 V by adjustment of rotor current.

Switch on the ac power supply on unit 60-121 and turn the voltage control to maximum. On unit 65-130, close switch ‘a’ to link one supply line. By switching the ac voltmeter from position 2 to 1 alternately on 65-13, check that the power supply and ac generator agree to within ±5 V.

At this stage, the synchronising lamp intensity should slowly increase and decrease, indicating that the generator is near synchronism. Adjust the drive motor speed until the lamp is extinguished, and close switch ‘b’ to connect the generator in parallel with the mains supply.

When the ac generator is in parallel with the supply, it may be used to demonstrate many of the characteristics of a large generator connected to the bus-bars of a power system. By altering the torque applied to the generator shaft while maintaining constant excitation, the ac output can be increased or decreased. If the drive torque is reduced to zero, the machine operates as a synchronous motor drawing power from the supply mains. In this assignment, the drive torque is altered by adjustment of the drive motor speed control setting. The diagram in Figure A51-4 shows how mechanical load or drive causes the machine to behave as a motor or generator and how excitation alters the power factor; ie, an over-excited synchronous motor produces leading power factor, and an over-excited generator produces a lagging power factor (cos ϕ).

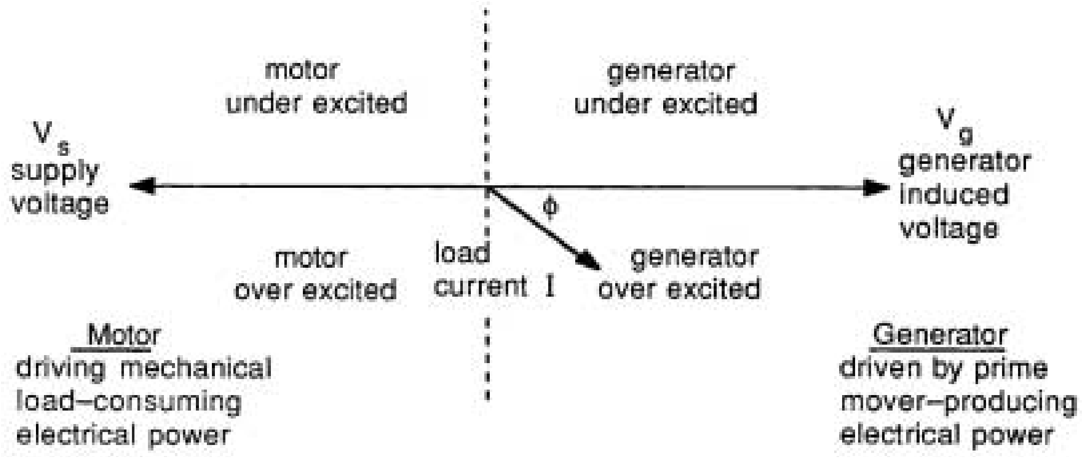


Figure A51-4: Synchronous Machine Operation

PRACTICAL 51.2

Generator Current/ Input Curve

With the drive motor connected to dc power, measure external line current.

Use the synchronising procedure previously described in Practical 51.1 to connect the ac generator in parallel with the 135 V ac supply. Set the rotor current to 2.5 A and maintain it at this value throughout the test. The 'set speed' control on the drive motor will now provide a means of adjusting the torque applied to the ac generator – its level being determined from the input current as read on the ac ammeter and the current/torque curves for the motor derived in Assignment 49.

Adjust the applied torque in steps to obtain a range of load currents from a minimum of approximately 0.3 A to a maximum of 2.5 A. Read input current to the drive motor and generated output current at each step. Plot the results using the graph axis in Figure A51-5 (a) given in the Results Table section and, from the drive motor calibration curves, convert input currents to torque.

Plot load current against motor torque using the graph axis in Figure A51-5 (b) given in the Results Table section.

Typical plots are shown for Figures A51-5(a) and (b) in the Typical Results and Answers section.

Practical 51.2

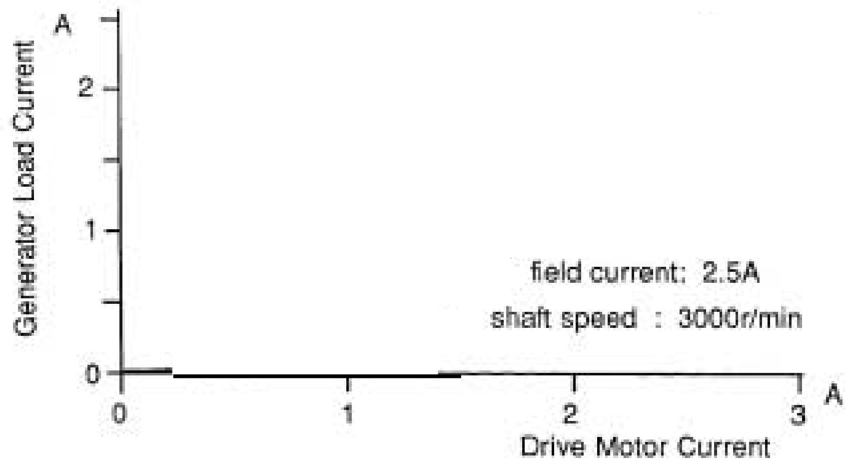


Figure A51-5(a): Graph axis

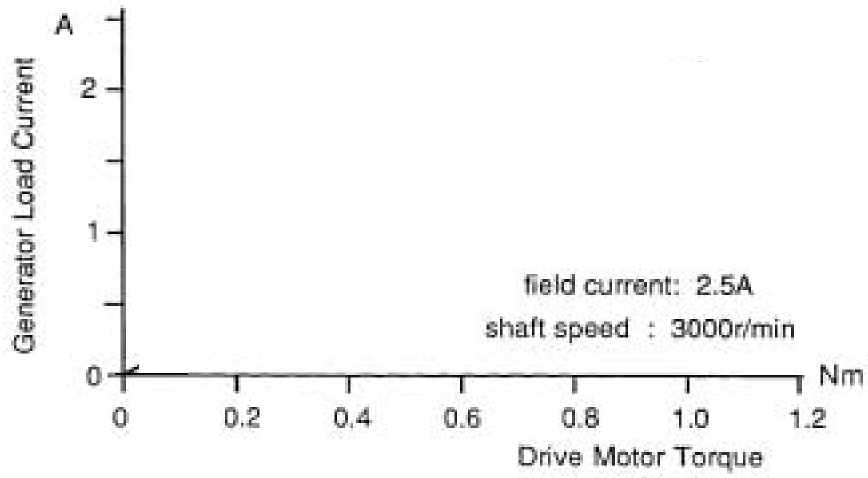


Figure A51-5(b): Graph axis

Notes

Practical 51.2

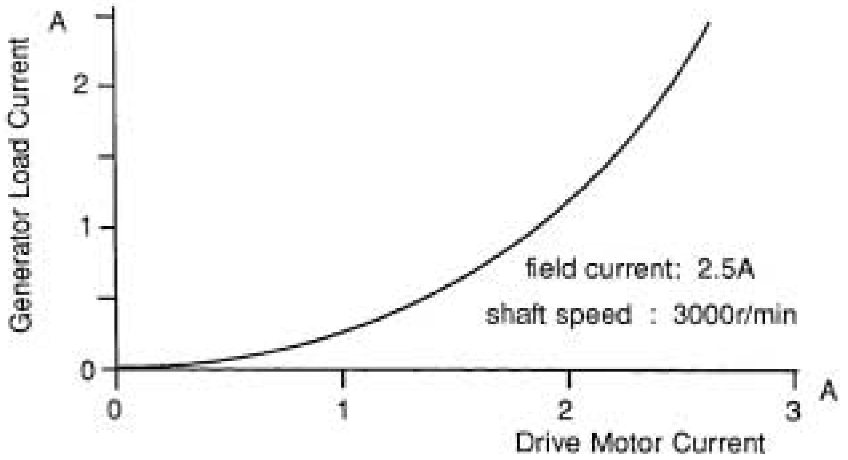


Figure A51-5(a): ac Generator Characteristics – Generator Load Current Against drive motor current

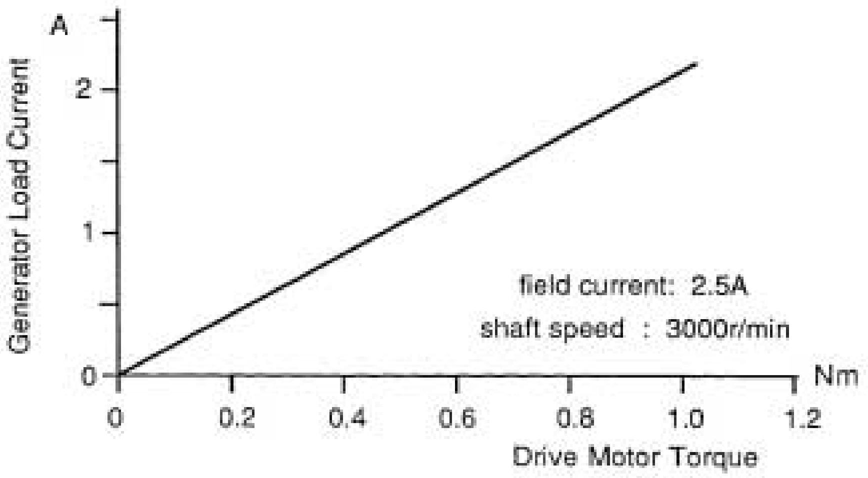


Figure A51-5(b): ac Generator Characteristics – Generator Load Current Against drive motor torque

Notes

DISSECTIBLE MACHINES SYSTEM

Assignment 52

Synchronous Motor Characteristics

PRACTICAL	52.1	
	52.2	Temperature of Field Windings

EQUIPMENT REQUIRED	**Qty**	**Item**
62-100 Kit	1	Base Unit
	1	12-Slot Wound Stator
	1	Rotor Hub
	4	Rotor Poles
	2	L1 Coils
	1	Slipring/Commutator
	2	Brushholders with Brushes
	1	Flexible Coupling
General	1	Variable Speed Motor: 1/3 hp, 1200 rev/min (eg, Feedback 63-501)
	1	0-135 V, 5 A, ac Power Supply (eg, Feedback 60-121)
	1	0-20 V, 5 A, dc Power Supply (eg, Feedback 60-105)
	1 1	1 A/10 A ac Ammeter 250 V/500 V, ac Voltmeter (eg, Feedback 68-117)
	1 1	1 A/5 A dc Ammeter 50 V/250 V dc Voltmeter (eg, Feedback 68-110)
	1	Control Switches (eg, Feedback 65-130)
	1	Electrodynamic Wattmeter (eg, Feedback 68-201(not supplied))

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

After the 62-100 has been assembled as a single-phase synchronous motor, it is driven up to its operating speed and connected to the ac supply. The relationship between excitation, load current and power factor is investigated and from the test results obtained 'V' curves of load current against excitation are plotted.

The application of lightly loaded synchronous motors to power factor correction is illustrated by the power factor correction is illustrated by the power factor-field current characteristics, in which over-excitation of the motor produces a leading supply current.

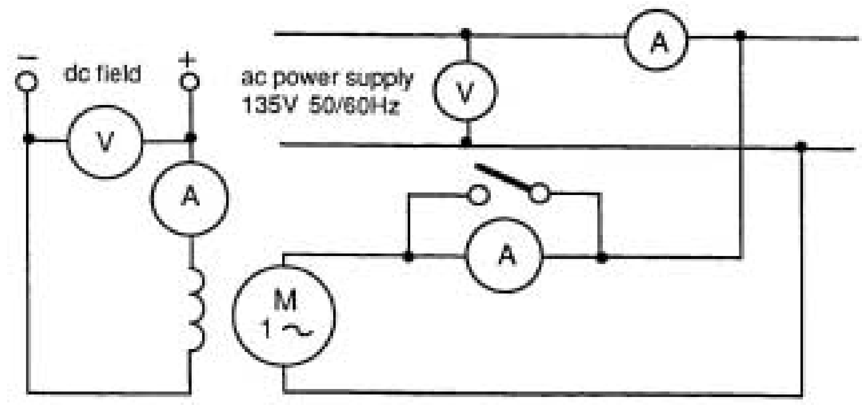


Figure A52-1: Circuit Diagrams

ASSEMBLY

Construct the single-phase two-pole synchronous motor as described in Assignment 35

Couple the drive motor 63-501 to base unit 62-100 in accordance with the instructions given in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 7. Make the circuit shown in Figure A52-2 in accordance with the connections shown in Figure A52-3.

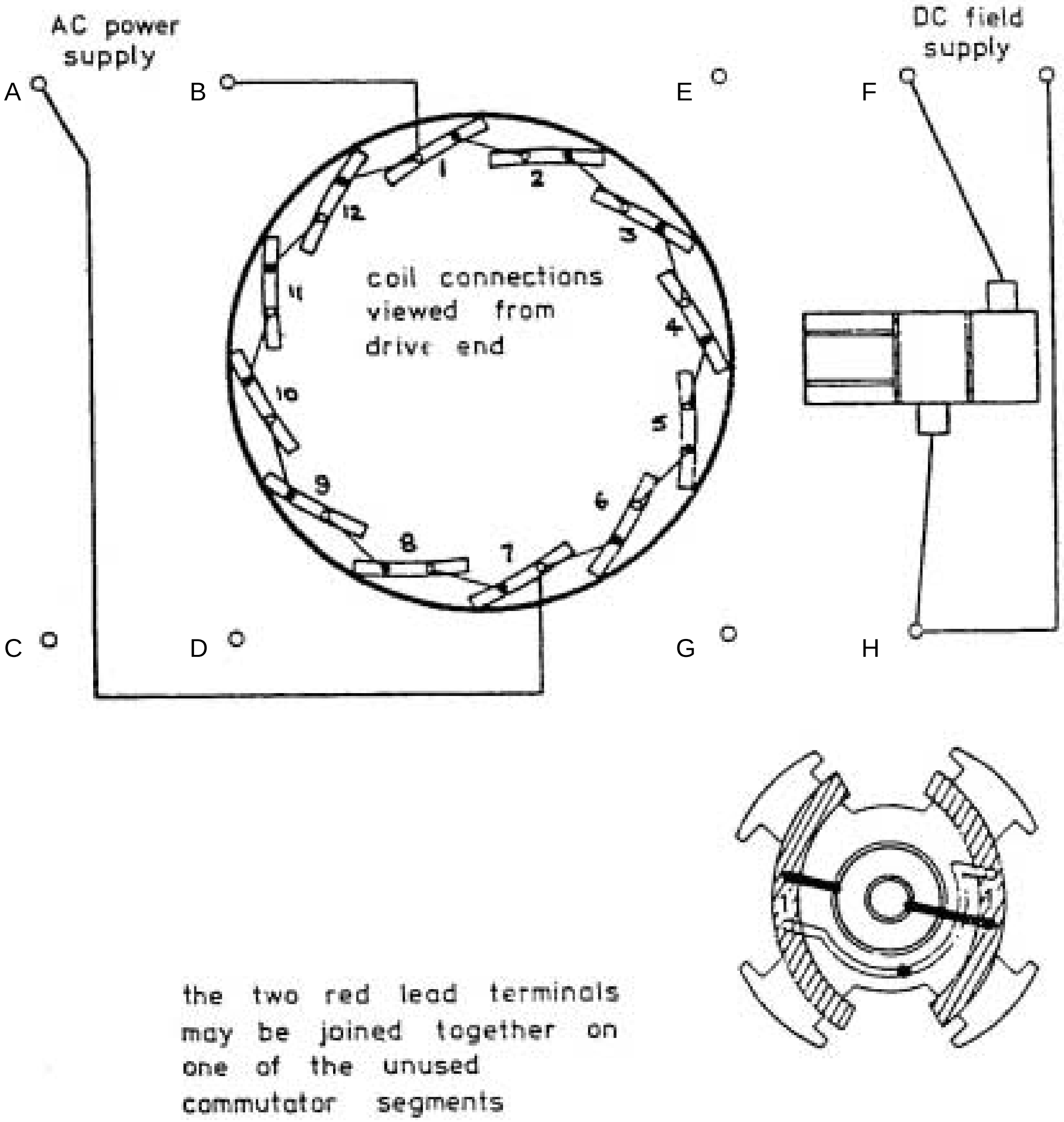


Figure A52-2: Synchronous Motor Wiring Diagram

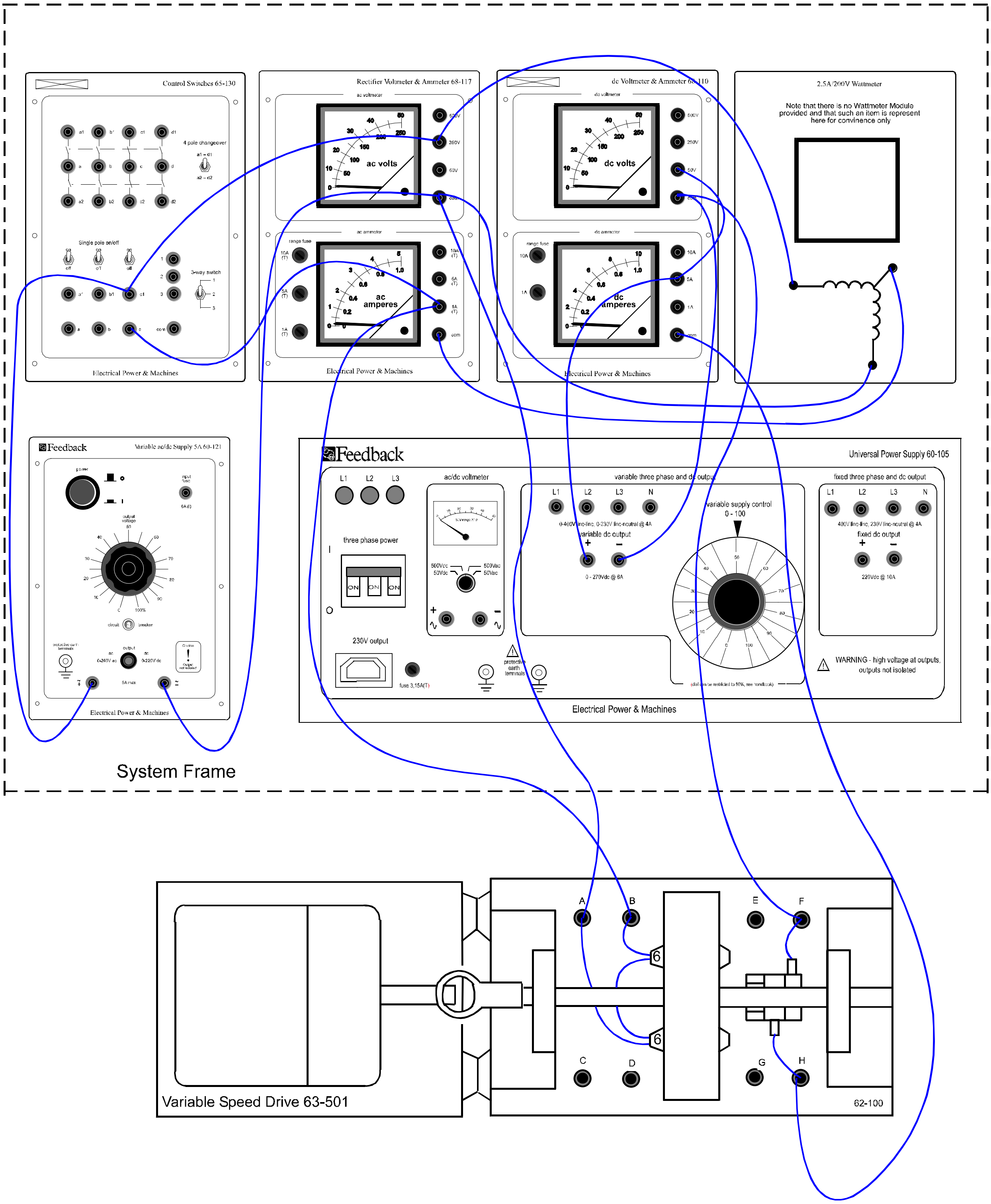


Figure A52-3: Connections for Synchronous Motor

PRACTICAL 52.1

The operating speed of a synchronous motor is dependent on supply frequency f, and number of pole pairs p:

$$N = \frac{60f}{p} \text{ rev/min}$$

In this case, p = 1

$\therefore$ N = 3000 rev/min at 50 Hz and 3600 rev/min at 60 Hz

To start the synchronous motor, switch on the drive motor and raise the shaft speed to 3000 rev/min. Close switch 'c' to prevent the starting current surge causing damage to the ac ammeter or wattmeter. Switch on the dc power supply and adjust the output to give 2.5 A through the rotor. Switch on the ac power supply and raise the output to 135 V. The motor should pull in and run steadily at synchronous speed. The drive motor can now be switched off but, as the shafts remain coupled, it still represents a load on the synchronous motor. The tests described below are carried out with this mode of operation but for reference, the accompanying graphs also show typical results obtained when the synchronous motor is uncoupled from the drive.

After starting the motor, open switch 'c' and reduce the rotor current to 1.5 A. Take readings of applied voltage, input current and input power at this excitation and repeat at increasing values of rotor current up to 4.5 A. The rotor can be operated continuously at currents of up to 2.5 A but prolonged periods of running at currents greater than this may cause overheating of the rotor coils. However, for the periods required to carry out these tests, excessive temperature rise should not occur.

From the measured values of supply voltage and current, calculate the input volt-amp to the motor at each step of field current, then take the ratio of input power to VA and obtain the power factor at each step. From these results, plot graphs of load current against excitation on Figure A52-4 (see Results Table section – typical results are given in the Typical Results and Answers section). As excitation is increased, it is seen that motor power factor changes from lagging through unity to leading.

PRACTICAL 52.2

Temperature of Field Winding

The temperature rise of the rotor windings may be found by measuring the increase of resistance after a period of running at fixed speed and current. Before commencing the test, check by thermometer that the temperature of the field windings is the same as the ambient temperature.

With the rotor and stator windings unexcited, drive the motor shaft up to synchronous speed, switch on the rotor power supply and take readings of the applied voltage and current. These initial readings should be taken rapidly to avoid error due to heating of the rotor windings.

Follow the starting procedure previously described and operate the motor with a set value of rotor current, take readings of rotor voltage initially every 5 minutes and subsequently every 15 minutes until the readings become constant.

From these values, the rise above the initial ambient temperature can be calculated as in the following example:

Ambient temperature = 22°

V_f	I_f	R_f	
15.1	3.5	0.431	machine at ambient temperature
17.2	3.5	0.491	machine after one hour's running

let R_1 = winding resistance, cold
R_2 = winding resistance, hot
t_1 = winding temperature, cold
t_2 = winding temperature, hot

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

$$= \frac{0.491}{0.431}(22 + 234.5) - 234.5$$

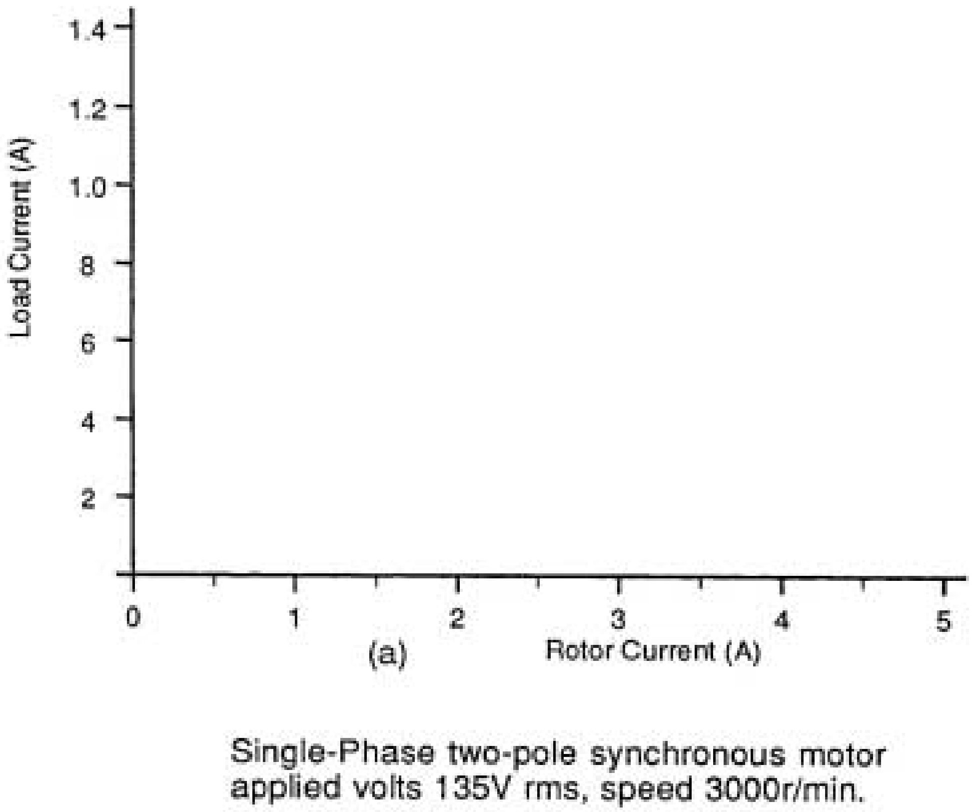
$$= 292 - 234.5$$

$$\therefore t_2 = 57.5°\text{C}$$

This represents a temperature rise of 35.5°C and is well within the safe working range of the windings. The 62-100 uses Class A (105°C) insulation and, for the rotor windings, a temperature of 60°C is permissible.

If this calculation is carried out for each set of rotor voltage and current readings, a plot of temperature against time can be made.

Practical 52.1



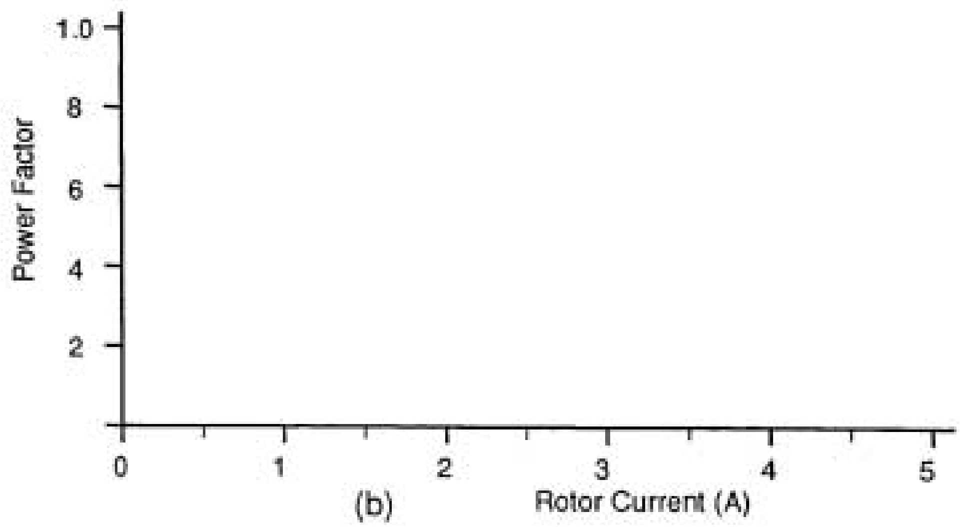


Figure A52-4: Graph axis

Notes

Practical 52.1

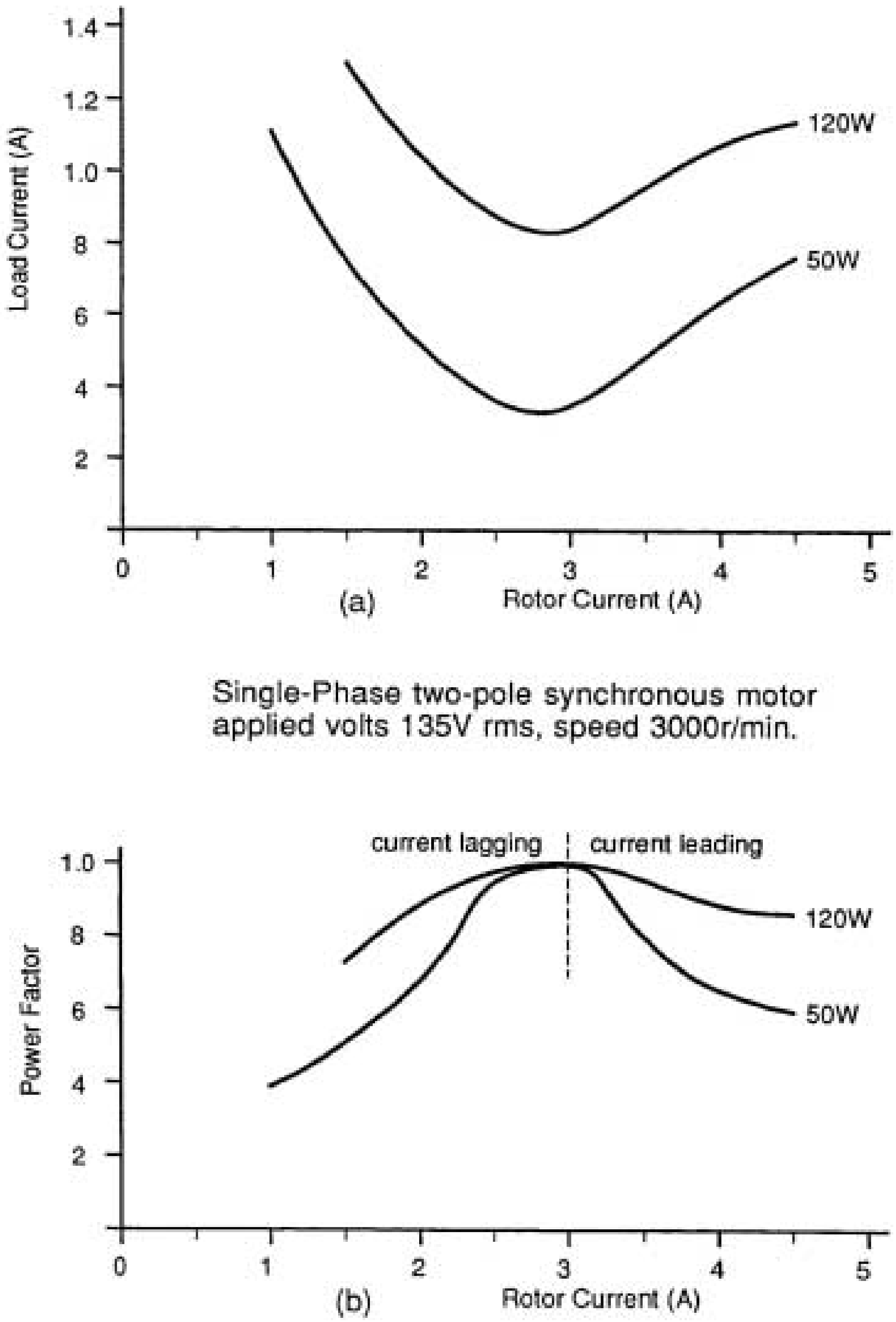


Figure A52-4: Synchronous Motor Characteristics

Notes

DISSECTIBLE MACHINES SYSTEM

Assignment 53

Induction Motor with Wound Rotor

PRACTICAL

53.1	Speed Variation with Rotor Resistance	
53.2	Load Tests	
53.3	Starting Torque Tests	

EQUIPMENT REQUIRED

	Qty	Item
62-100 Kit	1	Base Unit
	1	12-Slot Wound Stator
	1	Rotor Hub
	4	Rotor Poles
	2	L3 Coils
	1	Slipring/Commutator
	2	Brushholders with Brushes
General	1	0-135 V, 5 A, ac Power Supply (eg, Feedback 60-121)
	1 1	150 V, ac Voltmeter 0-5 A, ac Ammeter (eg, Feedback 68-117)
	1	1-0-1 mA Centre-Zero dc Ammeter (eg, Feedback 68-113)
	1	Resistor/Capacitor Unit (eg, Feedback 67-190)
	1	Variable Resistance (eg, Feedback 67-113)
	1	Friction (Prony) Brake or other Dynamometer 0.5 Nm (eg, Feedback 67-470)
	1	Optical/Contact Tachometer 68-470

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

INTRODUCTION

The 62-100 is assembled as a single-phase capacitor-run two-pole induction motor in which a wound rotor is connected by sliprings to an external resistor. The effects of various values of rotor circuit resistance on starting torque and running speed are investigated.

ASSEMBLY

Mount the stator in the frame ring with coil No. 1 at the top, fixing it in position by two ¼" long cap head socket screws at the 10 and 2 o'clock positions. Connect the stator windings together in accordance with the wiring diagram Figure A29-3.

The rotor should be assembled mechanically as indicated for a 4-pole rotor in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 2.. Basic Assembly Instruction 3 should also be consulted regarding use of the insulating pillars which are used to interconnect the rotor coils and commutator as shown in Figure A53-1.

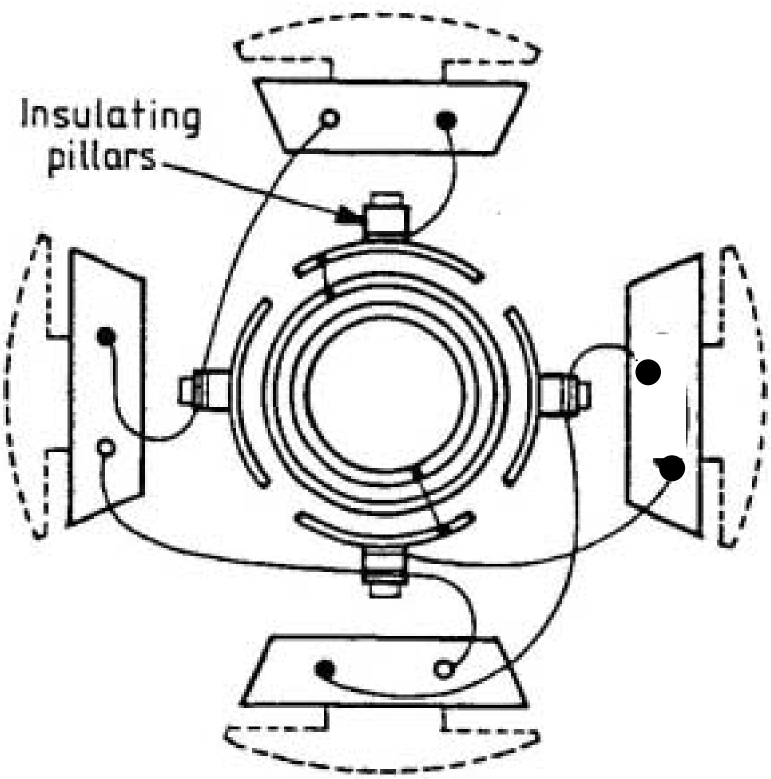


Figure A53-1: Rotor Connections

The rotor is connected as a two-pole rotor, since pairs of adjacent coils are connected with similar polarity. Fit the assembled rotor on to the shaft and secure it. Then fit the commutator/slipring on to the shaft, secure it and complete the rotor connections as in Figure A53-1. Assemble the shaft into the base unit and fit the removable bearing housing, but before finally tightening down, check that the shaft rotates freely and moves axially against the pre-loading washer. Connect the friction (Prony) brake or other dynamometer to the shaft and adjust it for zero load initially. Instructions for mounting the Prony Brake are given in Basic Assembly Instruction 6. Fit the brushholders so that the brushes bear on the sliprings.

Set the variable resistor initially to 10 ohms. Complete the stator and supply connections for a 2-pole, capacitor-run motor, as indicated in Figure A29-3 and A29-4(b) for Assignment 29.

PRACTICAL 53.1
Speed Variation with Rotor Resistance

Switch on the ac power supply and apply 135 V to the motor. When it has run up to speed, reduce the external rotor circuit resistance to zero ohms and check the motor speed; it should be about 2950 rev/min on a 50 Hz supply or 3530 rev/min on a 60 Hz supply. Record this speed then set the resistor to 5, 10, 15, 20, 30 and 50 ohms in turn and tabulate the speed against the resistance using the graph axis shown in the Results Tables (Figure A53-2(a)). Typical Results are shown in the Typical Results and Answers section.

PRACTICAL 53.2
Load Tests

Set the resistor to 10 ohms. Then increase the load torque in steps of 0.1 Nm until the motor stalls, tabulating values of speed against torque in Figure A53-2(b) (see Results Tables section for axis). If the motor is inadvertently stalled, it may be restarted by momentarily increasing the rotor circuit resistance. Repeat the load test using a resistance of 15 ohms and with zero ohms. Typical results are shown in the Typical Results and Answers section.

PRACTICAL 53.3
Starting Torque Tests

For each of the resistance values 10, 15, 20, 30 and 50 ohms, stall the motor, then reduce the load torque carefully observing its value when the motor just starts to move. Tabulate values of this starting torque against resistance values. Finally repeat the test for zero external resistance. The starting torques for 10 and 15 ohms may conveniently be plotted as additional points on the speed-torque curves.

Note:
If the dynamometer used is Feedback Motor Load Unit MLU188 or similar and not limited to operation at (approximately) constant torque, it will be found possible to explore the load speed curves for various rotor resistances more thoroughly, since stable running is possible at speeds below the normal stall point, although because it is not possible using the available components to make a wound-rotor motor of orthodox design the characteristics in that region are not to be taken as typical. They may however be useful as an indication of the kinks in the load curve which are possible due to harmonics in the magnetic flux waveform and in the geometry. Sample results obtained in this way are indicated in the dotted portions of Figure A53-2.

Practical 53.1/2/3

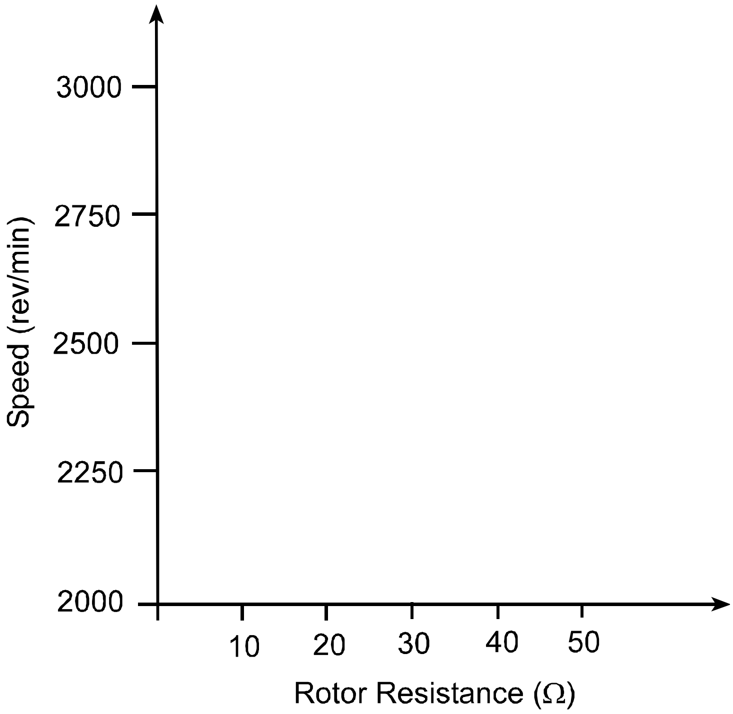
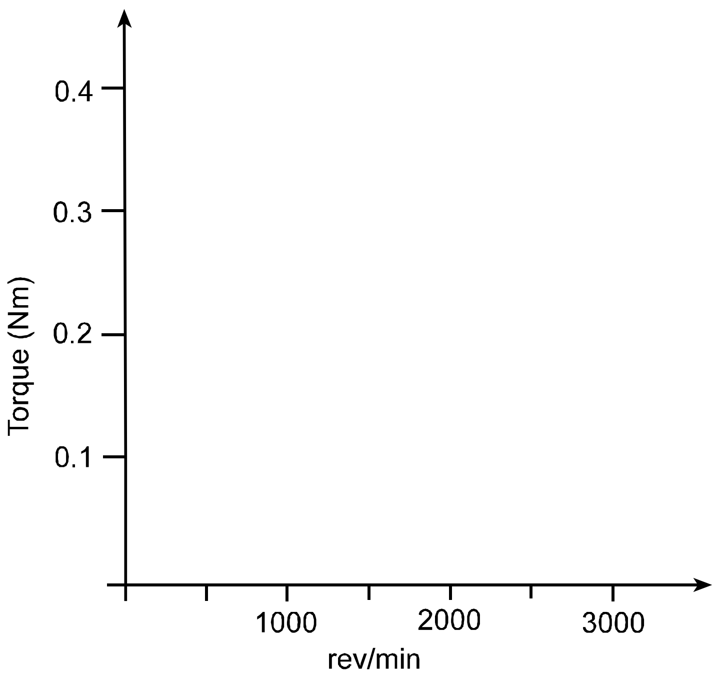


Figure A53-2(a): Graph axis

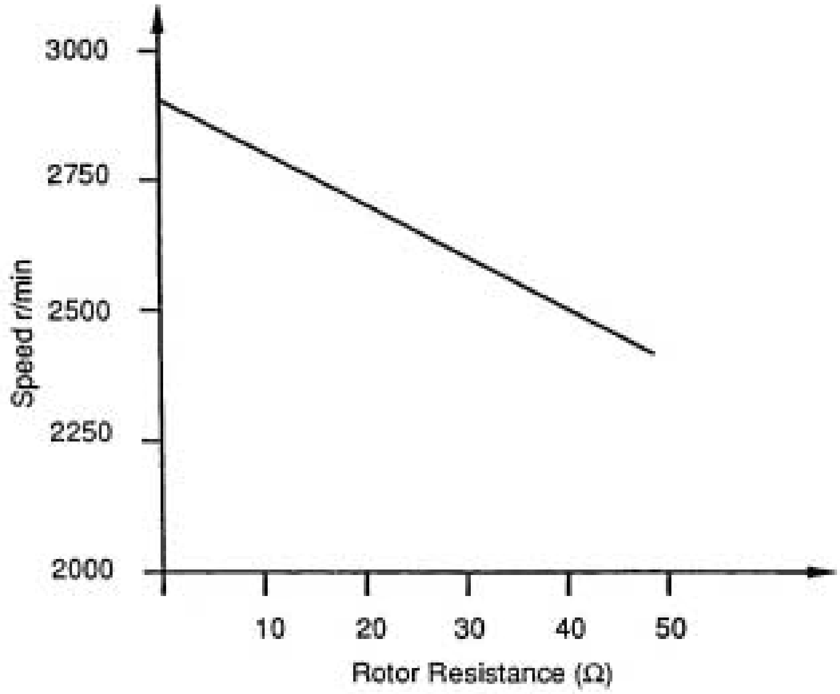


rev/min

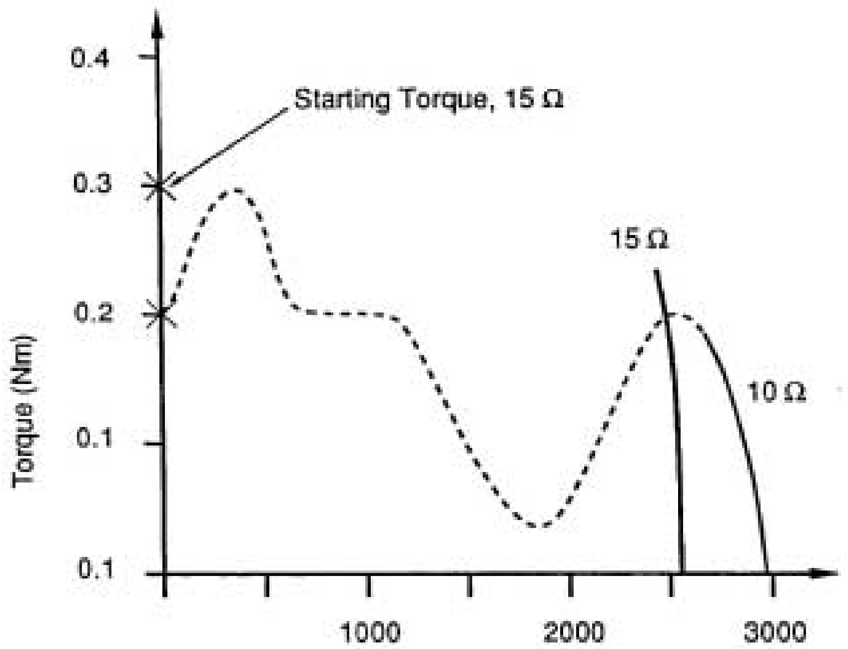
Figure A53-2b): Graph axis

Notes

Practical 53.1/2/3



(a)



(b)

Figure A53-2: Motor Characteristics (at 50 Hz)

Notes

Assignment 54

Rotor Assemblies for 62-100

INTRODUCTION

Construction of 2 and 4-pole rotor assemblies for the 62-100 as an alternative to those supplied in a standard kit is described below.

ASSEMBLY

Figure A54-1 shows a rotor assembly with two pole pieces only fitted. The former is locally produced and the coils wound by hand from 100-200 turns of 14/0.0076 or similar plastic covered connecting wire.

A current of 2 A dc can be applied to such a winding for periods of about 30 minutes without undue temperature rise.

Figure A54-2 shows a rotor assembly with four pole pieces fitted and with the winding polarities arranged to give two consequent poles and so produce 4-pole rotor.

These rotor assemblies can be used for generation of 1, 2 and 3-phase supplies and also as 1, 2 and 3-phase synchronous rotating field motors.

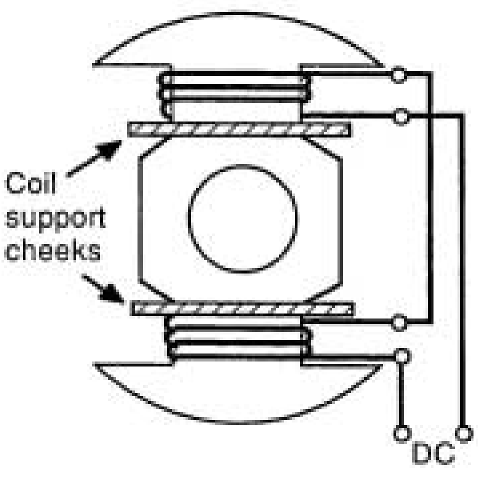


Figure A54-1

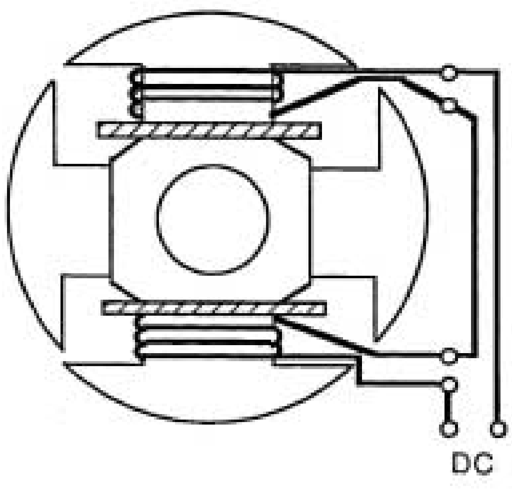


Figure A54-2

Notes

DISSECTIBLE

MACHINES SYSTEM

Assignment 55

Stepping Motors

PRACTICAL	55.1	Single Phase Energised Operation
	55.2	Two Phase Energised Operation
	55.3	Effect of Oscillations

EQUIPMENT REQUIRED	**Qty**	**Item**
Ancillary Kit	1	Shaft
	4	Stepper Rotor Poles
	1	Rotor Hub
	1	Scale Plate graduated in 15° steps
	1	Knob with Pointer Disc
	6	Interpoles (2 from 62-100 Basic Kit)
	6	L7 Coils
62-100 Kit	1	Base Unit
General	1	0-135 V, 5 A, dc Power Supply (eg, Feedback 60-105)
	1	50 V/250 V, dc Voltmeter
	1	1 A/5 A, dc Ammeter (eg, Feedback 68-110)
	1	Control Switches (eg, Feedback 65-130)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

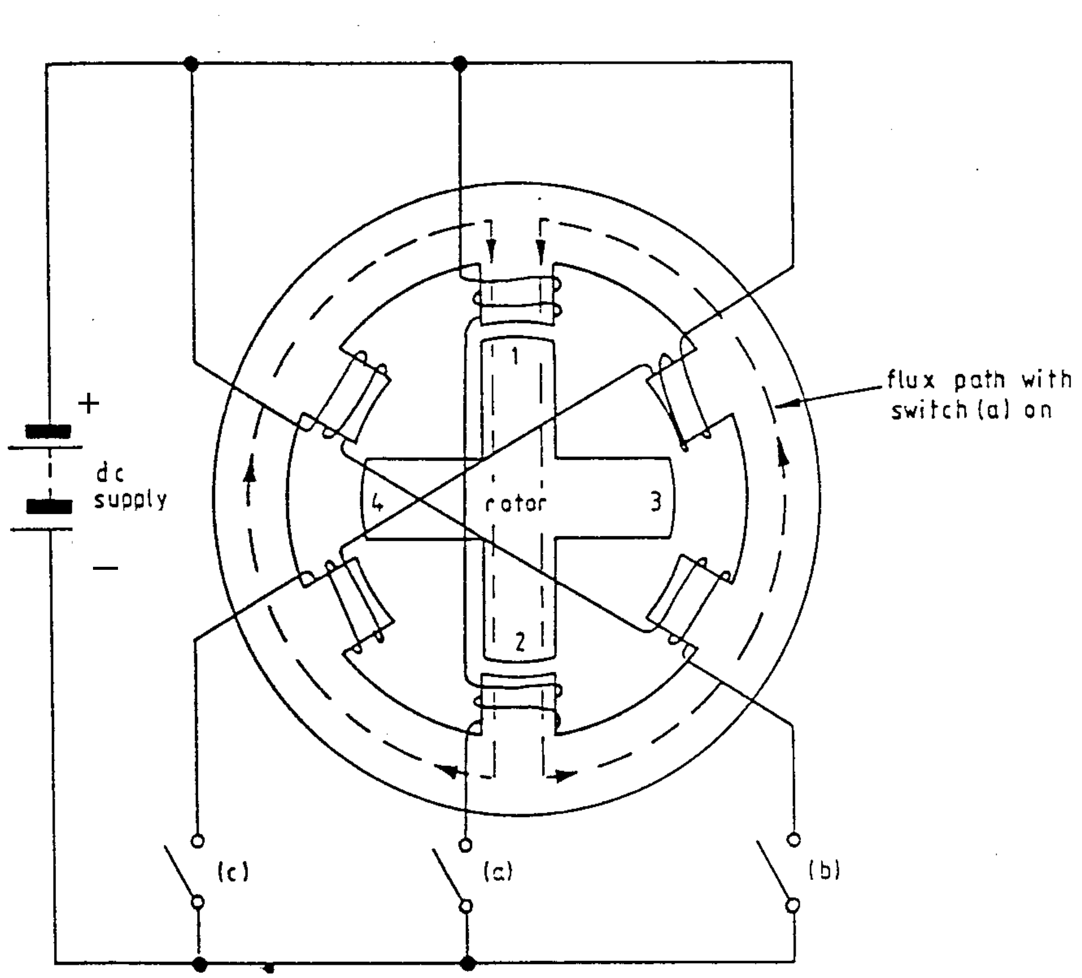


Figure A55-1: Basic Operation – 3-phase Reluctance Stepping Motor

INTRODUCTION

A stepping motor has a number of windings, or groups of windings, which can be separately energised. Each is called a 'phase' of the motor. The number of phases is typically two, three or four.

If one phase is energised, the motor's shaft will be held still. In order to move the shaft, a supply is switched sequentially to each phase in turn. Each phase, when it is energised, pulls the shaft into a new position, so that the motor moves in a series of 'steps'. The construction is such that when the switching cycle is complete and another similar cycle is begun, the first step in the new cycle will continue the stepping motion.

In the case of a reluctance-type stepping motor, the rotor aligns itself to a position giving the minimum reluctance of the magnetic path which is energised at the time. Figure A55-1 is a diagram of the three-phase reluctance-type stepping motor about to be constructed. If switch (a) is on, the rotor will align itself as shown, giving the easiest possible path for the magnetic flux. If now (a) is switched off and (b) is switched on, the rotor will move through 30° clockwise, to align rotor teeth 3 and 4 with the stator teeth carrying the (b) phase windings.

The step angle can be calculated from the number of stator slots, S, and number of rotor slots, R. The number of steps per revolution is

$$N = \frac{SR}{S - R}$$

The step angle is $\frac{360^{\circ}}{N}$

ASSEMBLY

Fit the stepper rotor poles on to the shaft. Be sure to align the pole pieces in their correct positions 1, 2, 3 and 4 on the rotor hub. Slide the shaft into the fixed bearing housing, then fit and secure the other bearing housing. Check that the shaft rotates freely and moves axially against the pre-loading washer.

Fit the L7 coils on to the interpole pieces and attach them to the frame ring at the 12, 2, 4, 6, 8 and 10 o'clock positions. (Note: Two of the interpole pieces must be taken from the 62-100 kit).

Connect the coils as shown in Figure A55-2. Make the connections shown in Figure A55-3, between the motor and the supply.

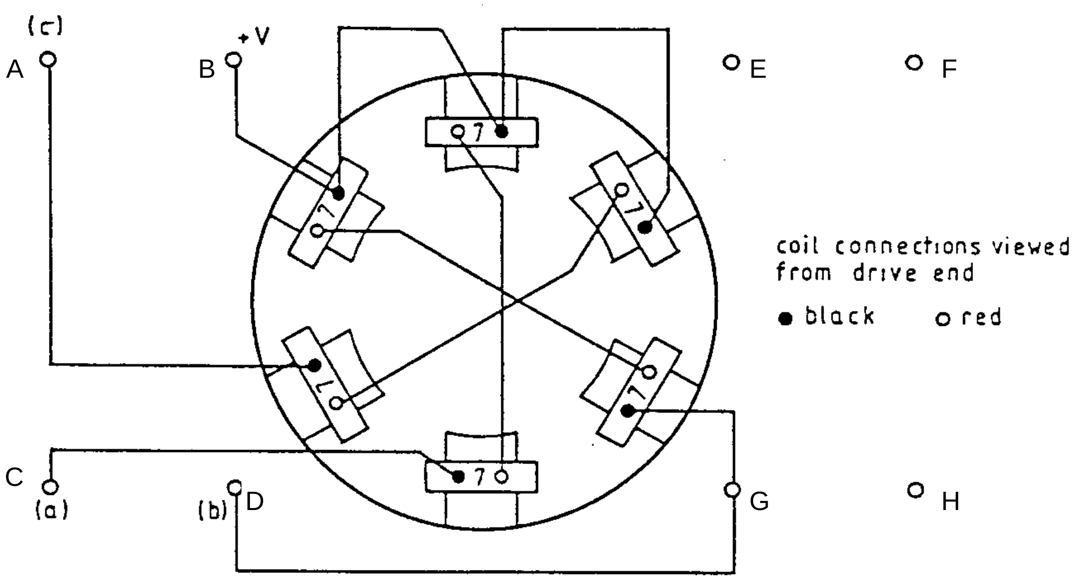


Figure A55-2: 3-Phase Reluctance Stepping Motor Wiring Diagram

Fit the scale plate to the drive-end bearing housing and rotate the motor so that the red dot on the pole piece is in the 12 o'clock position. Fit the pointer to the shaft at the position marked 1 on the scale.

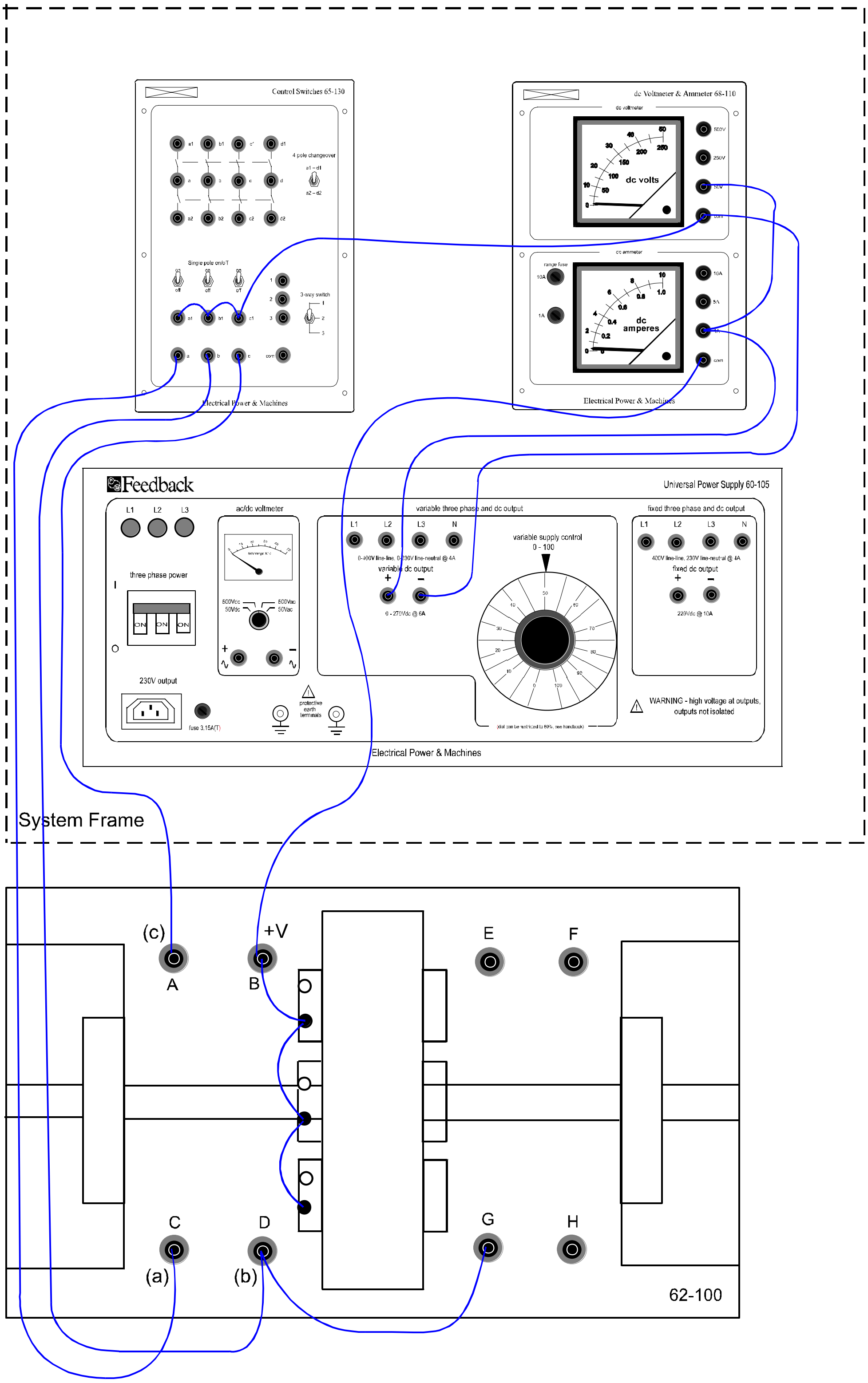


Figure A55-3: Connections for 3-Phase, Reluctance Stepping Motor

PRACTICAL 55.1

Single Phase Energised Operation

On power supply 60-105, ensure that the dial is set for zero voltage output.

On the control switches unit 65-130, set the 'Single pole on/off' switch 'a' to 'on'.

On the power supply 60-105, rotate the dial to slowly increase the output voltage to obtain 1.5 A as shown on the ammeter on 68-110. The supply voltage should then be about 10 V dc.

The rotor pole with the red dot should remain in the 12 o'clock position with the pointer at 1 on the scale. If it does not, check the wiring and reset the rotor and pointer positions as required.

The motor can be made to rotate by energising the phases in sequence, one phase at a time. Do this, always remembering to switch off one switch, (a), (b) or (c), before switching on the next (simultaneous switching is ideal).

Question 55.1

Does the rotor move in the same direction as the sequence of coils energised?

Switch all phases off and reset the pointer to dial position '1'. Record, on a copy of Table A55-1 in the Results section at the end of this assignment, the switch settings required to reach the other dial positions, in sequence, in a clockwise direction.

If you make a mistake in the switching sequence, the motor may move into an incorrect position. You should then restart with the rotor moved back to the position 1 and switch (a) on.

Repeat the procedure to record on a copy of Table A55-2 the sequence of switching for anticlockwise rotation, starting from position 1 as before.

PRACTICAL 55.2

Two Phase Energised Operation

As in the single-phase practical (Practical 55.2), set the pointer and switches for position 1 on the dial, switch (a) on, (b) and (c) off.

Question 55.2

By looking at Figure A55-1, can you tell where the rotor will position itself if, without turning off switch (a), switch (b) is also turned on?

Switch on (b) and you will notice that the rotor moves clockwise, positioning itself centrally about the four stator poles. The pointer will move to a new position '1', half-way between two of the step positions for one phase energised.

Think carefully about how to switch the coils, two phases on at a time, so that the rotor moves clockwise. When you have worked it out, try it, starting at position '1' with switches (a) and (b) on. Record the switching sequence on a copy of Table A55-3. Remember that if you make a mistake you should start again.

Repeat this for the reverse sequence of numbers '12' to '1' and record the switching sequence on a copy of Table A55-4.

PRACTICAL 55.3

Effect of Oscillations

Again set the rotor to position 1 with the one phase (a) energised. Switch off (a), then watch the motor as you switch on (c). You will see it oscillate considerably before it finally settles at position 2.

Step the motor round as quickly as you can, energising one phase at a time, and switching in a new phase just twelve times. This should rotate the rotor through one revolution, but you will probably find that the shaft has not reached the correct position. If you have not made a mistake in operating the switches, the error in position will be due to switching having taken place when the oscillation was swinging the rotor away from its nominal position.

Now set the shaft to position '1' with switches (a) and (b) on. Observe the oscillation which takes place when switch (c) is switched on and switch (a) off simultaneously. The overshoot beyond the next position should be less than in the one-phase case, and the rotor settles very quickly.

SUMMARY

A stepping motor is intended normally for positioning its shaft, using no external position reference apart from a datum. It has a number of 'phases' or windings which can be energised separately, normally by switching a dc supply. Energising one, or more but not all, causes the motor to be held in the nearest stable position. Motion is achieved by switching the energisation of the phases in sequence.

Important characteristics are the step size, holding torque, and the starting and drop-out torques; the last two being functions of speed and load inertia.

DISCUSSION

The step angle is clearly an important parameter of the specification.

Stepping motors provide a simple and inexpensive way of positioning mechanisms to an accuracy related to the step size. Some reference datum is needed to establish one position, but this is usually much simpler than providing a position measuring device operative at all required positions. Another requirement is some way of counting the number of steps taken; modern integrated electronics provide inexpensive counters. The final important requirement is that the motor shall have adequate torque to control the load, otherwise steps will be lost.

As a stepping motor is displaced from one of its equilibrium positions, it produces a torque which increases up a maximum value, after which further displacement reduces the torque (see Figure A55-4).

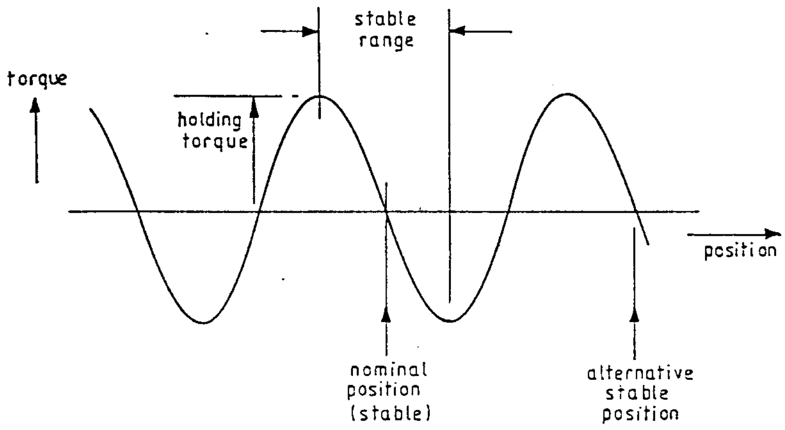


Figure A55-4: Variation of Torque with Shaft Position

This maximum value is called is the 'holding torque', since it represents the greatest torque available to hold the rotor stationary.

Suppose that a stepping motor is at rest, and the windings then suddenly switched in proper sequence to give some particular speed. If the motor remained still, the first switching would attempt to pull it one way, and the next would pull it the other way. For the motor to start, it must therefore accelerate and travel sufficiently during the first step to ensure that when the next switching occurs it is pulled on, not back. Consequently, there is a maximum speed for which the motor can be started in this way, for which all the motor's torque is required to accelerate the motor, leaving none to spare for any load. Starting to a lesser speed requires less acceleration and therefore less torque. Consequently, the starting performance is often represented by a characteristic such as the 'starting' graph in Figure A55-5

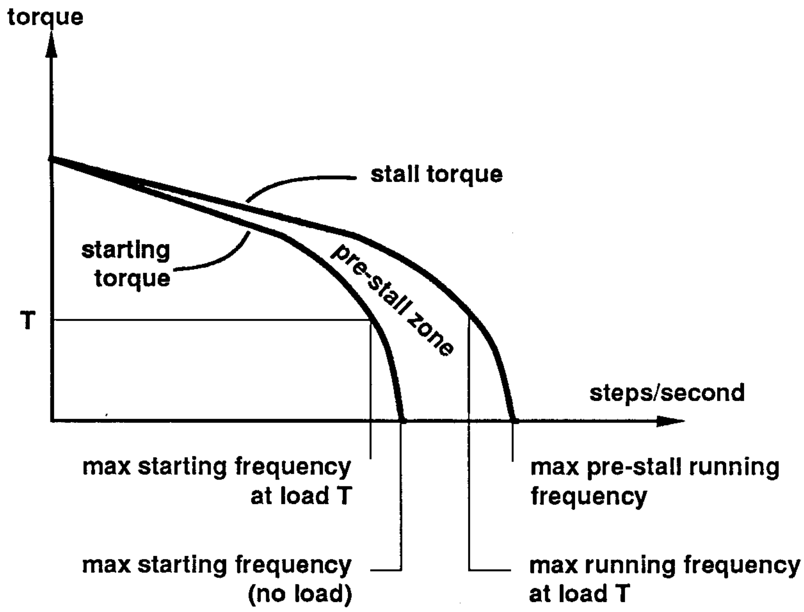


Figure A55-5: 'Starting' Graph of Stepping Motor

Once the motor is running at the proper speed it can maintain that speed against a torque which at low speeds approximates to the holding torque. At higher speeds the available torque may be reduced because of the effect of winding inductance on the current, and other factors. The motor will suddenly stall if too much opposing torque is applied, so the maximum available torque is called the 'stall torque', also shown in Figure A55-5.

An inertia load complicates matters in two ways. Accelerating a stepping motor requires a torque which uses up some of the available starting torque and also the oscillation which occurs at each step takes a lower natural frequency and lower damping factor. When the natural frequency and the switching rate are too close, the motor (and load) can swing wildly, putting the motor well away from its maximum torque position, so that synchronism can be lost well below the speed indicated by Figure A55-5; see Figure A55-6.

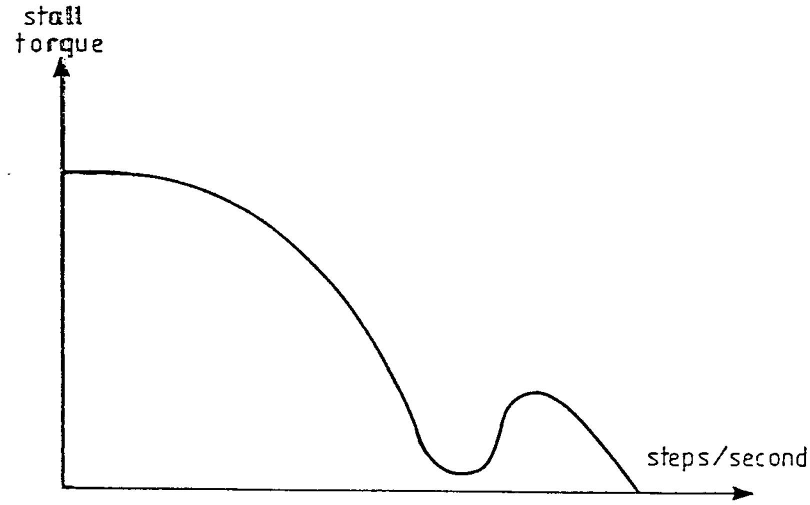


Figure A55-6: Effect of Inertia Load

Stepping motors are most successful therefore in applications where the load is fairly light, and of moderate inertia relative to the motor. In marginal cases, a great difference may be made by using the windings to control the damping, as indicated in the experiment by using phases in pairs rather than singly.

Stepping motors can be of many constructions. A permanent magnet is often included. This can increase the available torque, reduce the number of phases required, and increase the damping factor of the inherent oscillations. It can also provide a small holding torque even when the windings are not energised.

Practical 55.1

Energised One Phase (clockwise rotation)			
Pointer Position	Switch Setting		
	a	b	c
1	on	off	off
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			

Table A55-1

Energised One Phase (anti-clockwise rotation)			
Pointer Position	Switch Setting		
	a	b	c
1	on	off	off
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			

Table A55-2

Notes

Practical 55.2

Energised Two Phase (clockwise rotation)			
Pointer Position	**Switch Setting**		
	a	**b**	**c**
1	on	off	off
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			

Table A55-3

Energised Two Phase (anti-clockwise rotation)			
Pointer Position	**Switch Setting**		
	a	**b**	**c**
1	on	off	off
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			

Table A55-4

Notes

Practical 55.1

Energised One Phase (clockwise rotation)			
Pointer Position	Switch Setting		
	a	b	c
1	on	off	off
2	off	on	off
3	off	off	on
4	on	off	off
5	off	on	off
6	off	off	on
7	on	off	off
8	off	on	off
9	off	off	on
10	on	off	off
11	off	on	off
12	off	off	on

Table A55-1

Energised One Phase (anti-clockwise rotation)			
Pointer Position	Switch Setting		
	a	b	c
12	off	off	on
11	off	on	off
10	on	off	off
9	off	off	on
8	off	on	off
7	on	off	off
6	off	off	on
5	off	on	off
4	on	off	off
3	off	off	on
2	off	on	off
1	on	off	off

Table A55-2

Practical 55.2

Energised Two Phase (clockwise rotation)			
Pointer Position	Switch Setting		
	a	b	c
1	on	on	off
2	off	on	on
3	on	off	on
4	on	on	off
5	off	on	on
6	on	off	on
7	on	on	off
8	off	on	on
9	on	off	on
10	on	on	off
11	off	on	on
12	on	off	on

Table A55-3

Energised Two Phase (anti-clockwise rotation)			
Pointer Position	Switch Setting		
	a	b	c
12	on	off	on
11	off	on	on
10	on	on	off
9	on	off	on
8	off	on	on
7	on	on	off
6	on	off	on
5	off	on	on
4	on	on	off
3	on	off	on
2	off	on	on
1	on	on	off

Table A55-4

DISSECTIBLE

MACHINES SYSTEM

Assignment 56

Shaded-Pole Induction Motor

PRACTICAL	56.1	Operation
EQUIPMENT REQUIRED	**Qty**	**Item**
Ancillary Kit	1	Shaft
	2	L11 Coils
	2	Field Coils, Shaded
62-100 Kit	1	Base Unit
General	1	0-70 V, 5 A, Single-Phase, ac Power Supply (eg, Feedback 60-121)
	1	250 V, ac Voltmeter
	1	5 A, ac Ammeter (eg, Feedback 68-117)
	1	Friction (Prony) Brake or other Dynamometer 0-1 Nm at 1500 rev/min (eg, Feedback 67-470)
	1	Optical/Contact Tachometer (eg, Feedback 68-470)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

The shaded-pole induction motor can take several forms, but is most commonly a salient-pole induction motor as in Figure A56-1. A simple single-phase induction motor produces no starting torque. In order to produce a starting torque, what is required is some element of rotation in the ac field produced by the stator. This implies an additional field which is displaced both in space and in phase with respect to the main field. In some forms of single-phase motor this is the function of the starting winding, or a capacitor-fed winding.

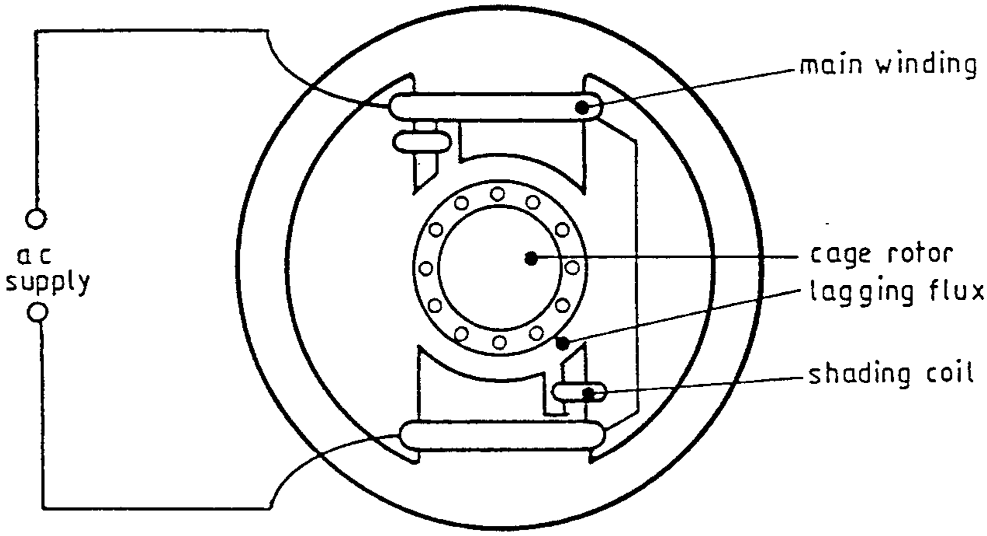


Figure A56-1: Shaded-Pole Motor – Salient-Pole Type

In the shaded-pole motor the function is performed by the split in the pole and the shading coil. Induced currents in the shading coil cause the flux in the shaded part of the pole to lag the flux in the other part. This provides the effect of rotation of flux from the unshaded to the shaded part of the pole, generating a small starting torque.

ASSEMBLY

Attach the L11 coils to the field poles with shading coils, then attach these poles to the frame ring in the 3 o'clock and 9 o'clock positions.

Fit the cage rotor to the shaft and slide the shaft into the bearing housings. Secure the free bearing housing.

Fit the Prony brake to the drive end of the shaft.

Connect the coils as shown in Figure A56-2. Make the connections shown in Figure A56-3, between the motor and the supply.

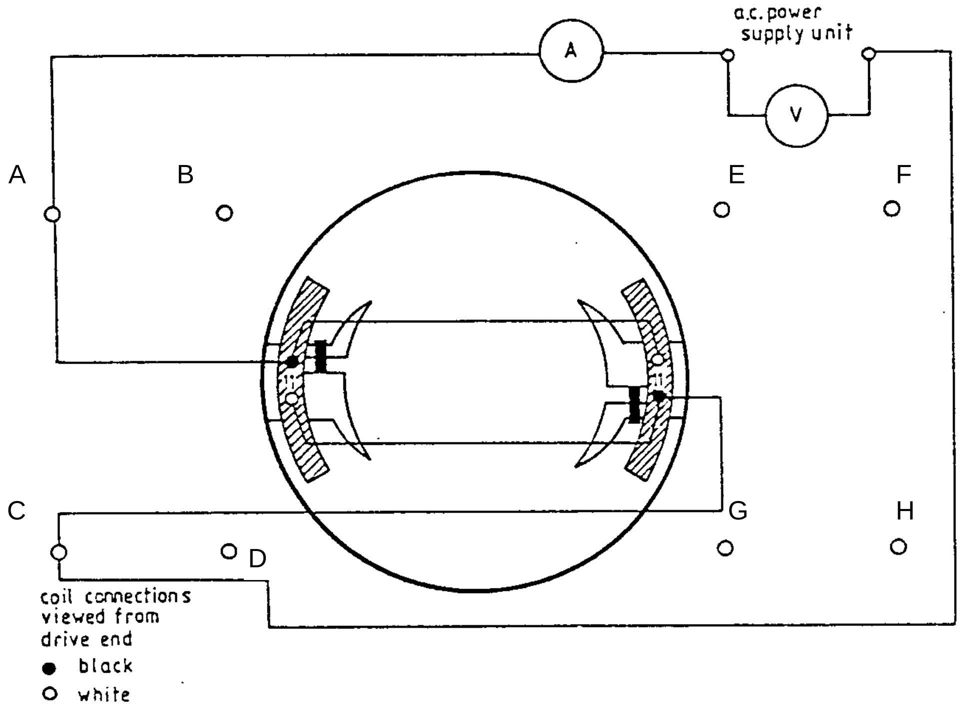


Figure A56-2: 3-Shaded-Pole Motor - Wiring Diagram

Remove the brake calliper from the drum and attach it the brake scale arm.

Remove the brake drum.

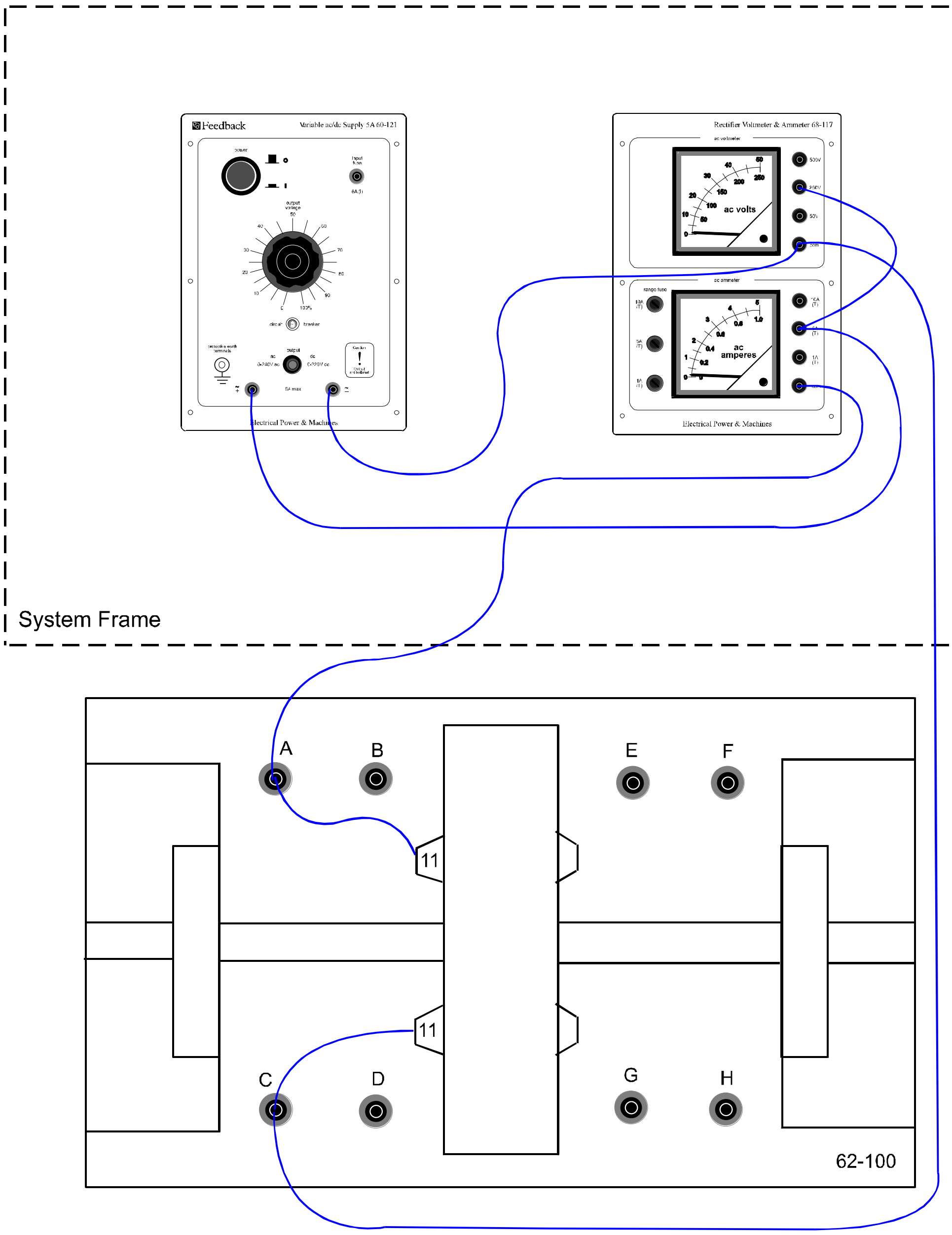


Figure A56-3: Connections for Shaded-Pole Motor

PRACTICAL 56.1

Operation

On power supply 60-121, ensure that the dial is set to zero voltage output and the ac/dc switch is set to 0-240 V ac.

On power supply 60-121, press the green ‘power’ pushbutton to switch on the ac supply and rotate the dial to give an output of 70 V as indicated on the voltmeter on 68-117 unit

Observe the behaviour of the motor as it runs up to a speed which should be about 2850 rev/min as measured with the tachometer. Correct the supply voltage, if necessary, to 70V. The current will then be about 3 A as indicated on the ammeter on 68-117 unit.

Starting Torque

Switch off the supply by pressing the green ‘power’ pushbutton on power supply 60-121 again; wait for the motor to stop. Firmly grasp the open end of the shaft above the brush holder block and feel the torque when the supply is switched on again. The torque at standstill will be very small. If the motor is now gradually allowed to rotate by restoring the supply again slowly, its torque will increase quickly.

Behaviour on Load

Switch off the supply by pressing the green ‘power’ pushbutton on power supply 60-121 again to stop the motor. Fit the brake drum to the motor shaft, place the brake calliper on the drum and adjust it for minimum load.

On power supply 60-121, press the green ‘power’ pushbutton to switch on the ac supply and rotate the dial to give an output of 70 V as indicated on the voltmeter on 68-117 unit. It is quite likely that the motor will not start because of the small braking effect of the calliper. Ensure that the calliper is very slack and move the brake arm to reduce the load as much as possible. If the motor will still not run up to speed, spin the shaft by hand in the normal running direction. Once the motor has started accelerating the torque will rapidly become sufficient to overcome the drag of the brake calliper.

Slowly apply load. It will be found that the speed decreases quite rapidly with load, and that only 0.1 to 0.2 Nm of torque can be sustained before the motor stalls. This is much less than that available from a normal induction motor of comparable size and distributed windings.

Direction of Rotation

Remove the brake drum from the motor shaft and attach the brake calliper to the brake scale arm.

On power supply 60-121, press the green 'power' pushbutton to switch on the ac supply and rotate the dial to give an output of 70 V; note the direction of motor rotation.

Question 1

If the connections to the coils are changed, can the direction of rotation be reversed?

Stop the motor. Reverse the connections and verify your answer.

Question 2

What other change could be made to make the motor run in the reverse direction?

Reassemble the motor with the shaded-poles rotated so that the shading coils are the other side of the pole axis. Observe and note how the motor runs now.

If you have time, try the effect of turning only one of the shaded-pole pieces and applying 70 V to each one singly. (Do not expect high performance, since, of the flux excited by one pole, any which passes through the opposite shaded-pole will reduce the starting torque).

SUMMARY

A shaded-pole induction motor is a single-phase motor in which starting torque is generated by the use of a 'shading coil'. Currents induced in this coil produce a lagging flux in the part of the split pole with which the coil is linked.

The starting torque is very small, and the maximum torque less than one would expect from other types of induction motor of similar size.

It is not possible to reverse the simple shaded-pole motor, although reversal is just possible by using excitation of one pole at a time.

DISCUSSION

It may seem from the foregoing summary that the shaded-pole motor is not very useful; yet it is widely used, where possible. The main reason is that, in small sizes, it is cheap and simple, requiring no external components such as capacitors or switches. It is also robust, many designs being capable of being stalled indefinitely because the stall current is limited by large leakage inductance.

Its torque characteristics make the shaded-pole motor suitable only for loads which exert very small torque when starting to move. Typical examples are:

- loads which are almost pure inertia and not critical on starting time, such as gramophone turntables with mechanical governing.
- loads whose torque is proportional to some positive power of the speed. Examples are fans and centrifugal pumps, for which torque is proportional to the square of the speed.

Figure A56-4 shows superimposed characteristics of a shaded-pole motor and a typical fan load.

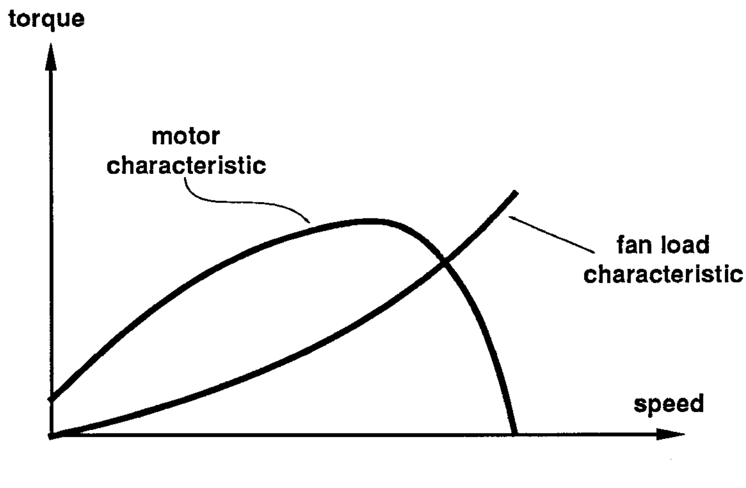


Figure A56-4: Shaded-Pole Motor and Typical Fan Load – Characteristics Graph

DISSECTIBLE

MACHINES SYSTEM

Assignment 57

Split-Field Series dc Motor

PRACTICAL	57.1	Operation
EQUIPMENT REQUIRED	**Qty**	**Item**
62-100 Kit	1	Base Unit
	1	Commutator/Slipring
	2	Brushholders with Brushes
	2	L9 Coils
	2	L1 Coils
	2	L2 Coils
	2	Field Poles
	1	Rotor Hub
	4	Rotor Poles
	2	L8 Coils
	2	Interpoles
General	1	0-135 V, 5 A, dc Power Supply (eg, Feedback 60-105)
	1 1	50 V/250 V, dc Voltmeter 1 A/5 A, dc Ammeter (eg, Feedback 68-110)
	1	200Ω, 3 A Variable Resistance (eg, Feedback 67-113)
	1	Control Switches (eg, Feedback 65-130)
	1	Friction (Pony) Brake or other Dynamometer 0-1 Nm at 1500 rev/min (eg, Feedback 67-470)
	1	Optical/Contact Tachometer (eg, Feedback 68-470)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

The split-field series motor is in effect an ordinary series motor, except that it is provided with two field windings (or equivalently a field winding with a centre-tap) arranged as shown in Figure A57-1, so that the motor will drive in one direction or the other, according to which field winding is used. It is therefore suitable for use in position servomechanisms.

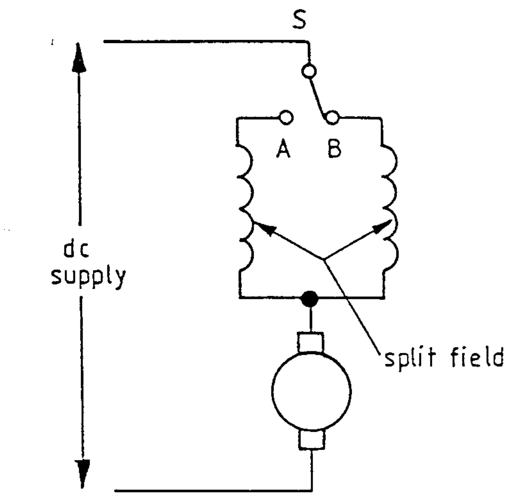


Figure A57-1: Example of a dc Split-Field Series Motor

ASSEMBLY

Fix the armature and commutator to the shaft as shown in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 1 and fit the shaft into its bearings. Before finally tightening the screws holding the bearing housing to the base plate, check that the shaft rotates freely and moves axially against the pre-loading washer.

Fit the L9 coils to the field poles then attach the poles to the frame ring in the 3 o'clock and 9 o'clock positions. Attach the L8 interpoles with their coils to the frame ring in the 6 o'clock and 12 o'clock positions.

Fit the brushes into their holders and attach them to the mounting block positions on each side of the commutator. The brushes should move freely in the holders under the action of the brush springs.

Fit the Prony brake to the drive end of the shaft and adjust to give zero load (see Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 6).

Connect the coils as shown in Figure A57-2. Make the connections shown in Figure A57-3, between the motor and the supply.

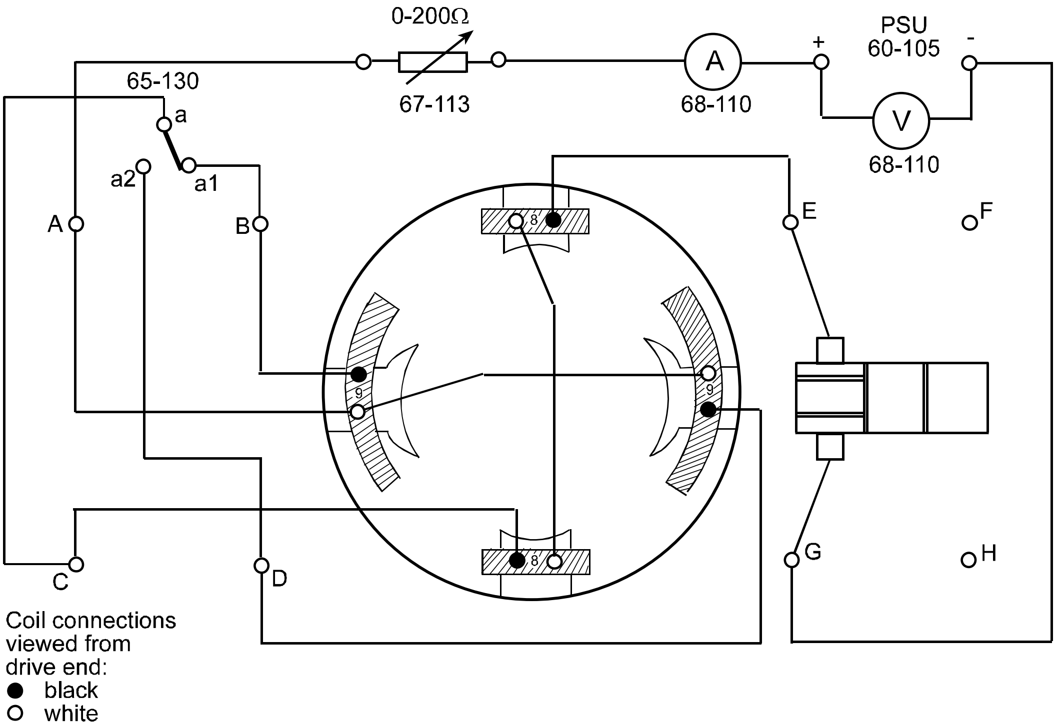


Figure A57-2: DC Split Field Series Motor Wiring Diagram

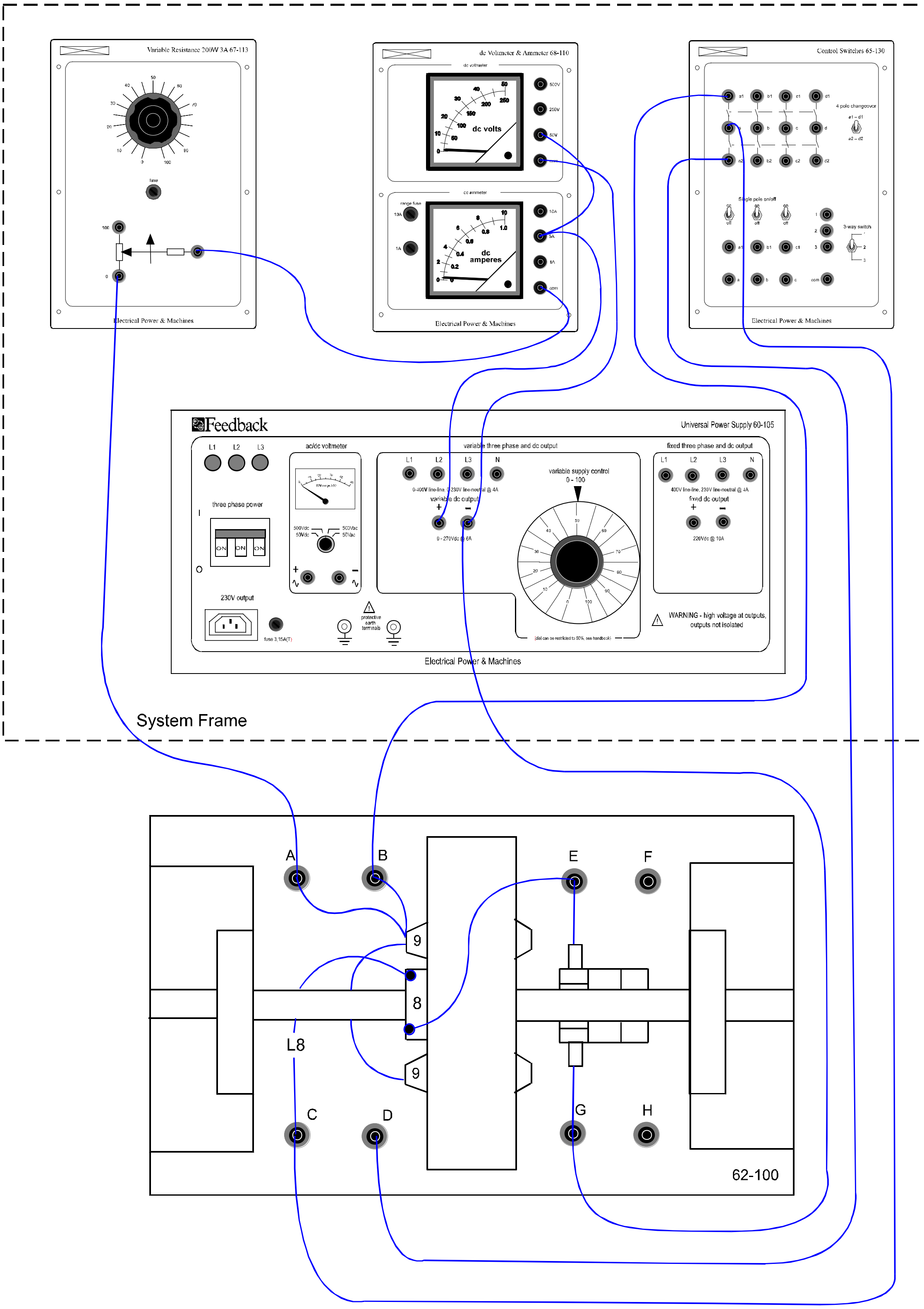


Figure A57-3: Connections for DC Split Field Series Motor

PRACTICAL 57.1

Operation

On variable resistor unit 67-113, ensure that the dial is set to zero.

On power supply 60-105, ensure that the dial is set for zero voltage output.

On the control switches unit 65-130, set the ‘4 pole changeover’ switch to ‘a1-d1’.

On the power supply 60-105, rotate the dial slowly to increase the output voltage to obtain 30 V as shown on the voltmeter on 68-110. The motor should run at about 750 rev/min, as indicated on tachometer 68-470, in an anticlockwise direction looking from the shaft end. The supply current should be about 1.3 A as indicated on the ammeter on 68-110.

Control of Direction and Speed

On the control switches unit 65-130, set the ‘4 pole changeover’ switch to ‘a2-d2’. Note that the motor reverses and runs up to a similar speed in the opposite direction.

On power supply 60-105, increase the motor supply voltage to 35 V by slowly rotating the dial. The speed will increase to about 1500 rev/min. Now increase the resistance of the variable resistor 67-113 by rotating its dial and verify that the speed can now be controlled down to zero.

Rotate the variable resistor dial again so that the motor speed increases to 1000 rev/min. Using the ‘4 pole changeover’ switch on 65-130, reverse the direction again and confirm that the speed is controllable in either direction.

Torque/Speed Characteristic

On variable resistor unit 67-113, set the dial zero and let the motor run up to speed.

Using the Prony brake 67-470, load the motor with torque increments of 0.1Nm up to 0.6 Nm and record the speed obtained for each value of torque on a copy of Table A57-1 in the Results section at the end of this assignment.

Using the ‘4 pole changeover’ switch on 65-130, reverse the motor direction of rotation and repeat the torque/speed characteristic test. Record the results on a copy of Table A57-2.

From your results recorded in Tables A57-1 and A57-2, plot a graph of torque against speed in both directions, as indicated in Figure A57-4.

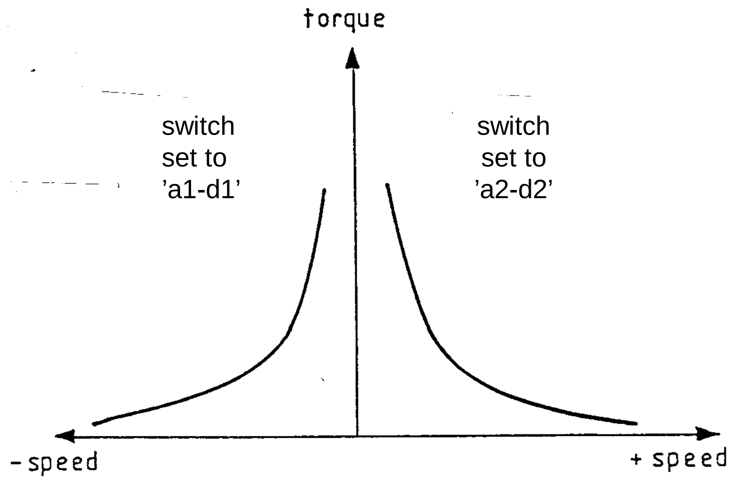


Figure A57-4: Torque/Speed Graph – dc Split-Field Series Motor

SUMMARY

The split-field series motor is one provided with two field windings so that its direction can be reversed without complicated switching.

Characteristics of a split-field series motor resemble those of a conventional series motor, providing large starting torque and high speed on light load.

Control of speed in either direction can be conveniently arranged using a variable series resistor.

DISCUSSION

The split-field series motor is primarily used in low-power applications requiring rapid reversal of torque or speed. The function of reversing switch and speed-controlling resistor may then be combined in a pair of transistors, one for each field winding. The resulting circuit is much simpler than that required to reverse the connections of single field winding's.

In a position control system, there are several usual reasons for wanting a motor with conveniently reversible torque:

- It is commonly a requirement to move back and forth along some range of possible positions, so that reversing is at least necessary between one motion and another.

- In a rapid approach to a position, inertia may carry the load too far, necessitating a rapid reverse movement to correct the overshoot. Overshoot may be prevented by applying reverse torque before the target position is reached. (If this is done using transistor control, the transistors must have ratings exceeding the supply voltage and motor power).

Practical 57.1

Effect of Increased Loads (clockwise rotation)	
Torque (Nm)	**Speed (rpm)**
0.1	
0.2	
0.3	
0.4	
0.5	
0.6	

Table A57-1

Effect of Increased Loads (anti-clockwise rotation)	
Torque (Nm)	**Speed (rpm)**
0.1	
0.2	
0.3	
0.4	
0.5	
0.6	

Table A57-2

Notes

Practical 57.1

Effect of Increased Loads (clockwise rotation)	
Torque (Nm)	**Speed (rpm)**
0.1	1400
0.2	1035
0.3	750
0.4	595
0.5	500
0.6	410

Table A57-1

Effect of Increased Loads (anti-clockwise rotation)	
Torque (Nm)	**Speed (rpm)**
0.1	1250
0.2	920
0.3	710
0.4	590
0.5	470
0.6	400

Table A57-2

Notes

DISSECTIBLE MACHINES SYSTEM

Assignment 58

Dynamic Braking of a dc Motor

PRACTICAL 58.1 Operation

EQUIPMENT REQUIRED

	Qty	Item
62-100 Kit	1	Base Unit
	1	Commutator/Slipring
	2	Brushholders with Brushes
	2	L9 Coils
	2	L1 Coils
	2	L2 Coils
	2	Field Poles
	1	Rotor Hub
	4	Rotor Poles
	2	L8 Coils
	2	Interpoles
General	1	0-135 V, 5 A, dc Power Supply (eg, Feedback 60-105)
	1 2	50 V/250 V, dc Voltmeter 1 A/5 A, dc Ammeter (eg, Feedback 68-110)
	1	200Ω, 3 A Variable Resistance (eg, Feedback 67-113)
	1	34Ω, Resistance (eg, Feedback 67-190)
	1	Control Switches (eg, Feedback 65-130)
	1	Friction (Prony) Brake or other Dynamometer 0-1 Nm at 1500 rev/min (eg, Feedback 67-470)
	1	Optical/Contact Tachometer (eg, Feedback 68-470)
	1	Stop Watch (not supplied)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

Normally, when the driving power is removed from a motor, inertia will tend to keep it revolving. In practice, however, it is often desirable that the motor be stopped quickly. This can be done using a mechanical brake, but electrical braking is usually cheaper and requires less maintenance.

In machines such as cranes or hoists, the load may be capable of accelerating the motor or of driving it in the reverse direction. A mechanical brake is then needed to stop the motor but, for additional safety and reduced wear on the mechanical brake, electrical braking is often used as well, and can at least slow the motor to a safe speed.

To brake a rotating dc machine, its field is excited and a load is connected to its armature, which acts as a generator. The generated current exerts a reverse torque on the motor, removing mechanical energy from it as it supplies electrical energy to the load.

Suitable connections for a shunt and for a series machine are shown in Figure A58-1. In both cases, the degree of braking will depend on the value of the braking resistance R.

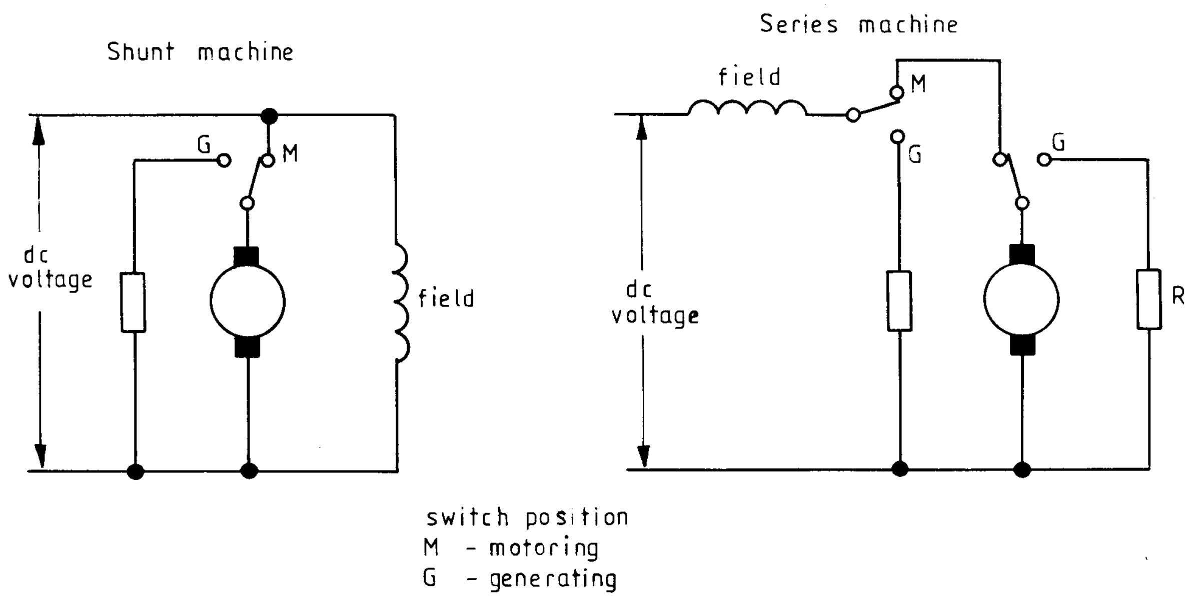


Figure A58-1: Resistance Braking Circuits

ASSEMBLY

Fix the armature and commutator to the shaft as shown in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 1 and fit the shaft into its bearings. Before finally tightening the screws holding the bearing housing to the base plate, check that the shaft rotates freely and moves axially against the pre-loading washer.

Fit the L9 coils to the field poles then attach the poles to the frame ring in the 3 o'clock and 9 o'clock positions. Attach the L8 interpoles with their coils to the frame ring in the 6 o'clock and 12 o'clock positions.

Fit the brushes into their holders and attach them to the mounting block positions on each side of the commutator. The brushes should move freely in the holders under the action of the brush springs.

Connect the coils as shown in Figure A58-2. Make the connections shown in Figure A58-3, corresponding to the shunt motor connections of Figure A58-1.

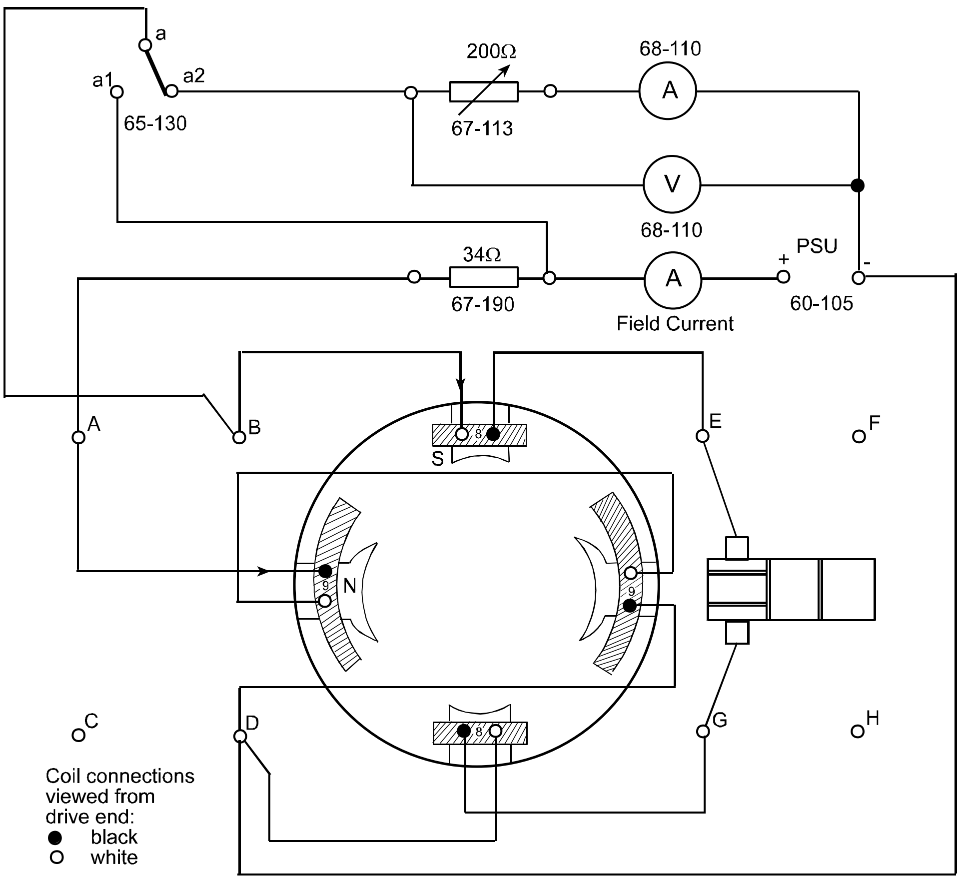


Figure A58-2: DC Shunt Motor with Interpoles Wiring Diagram

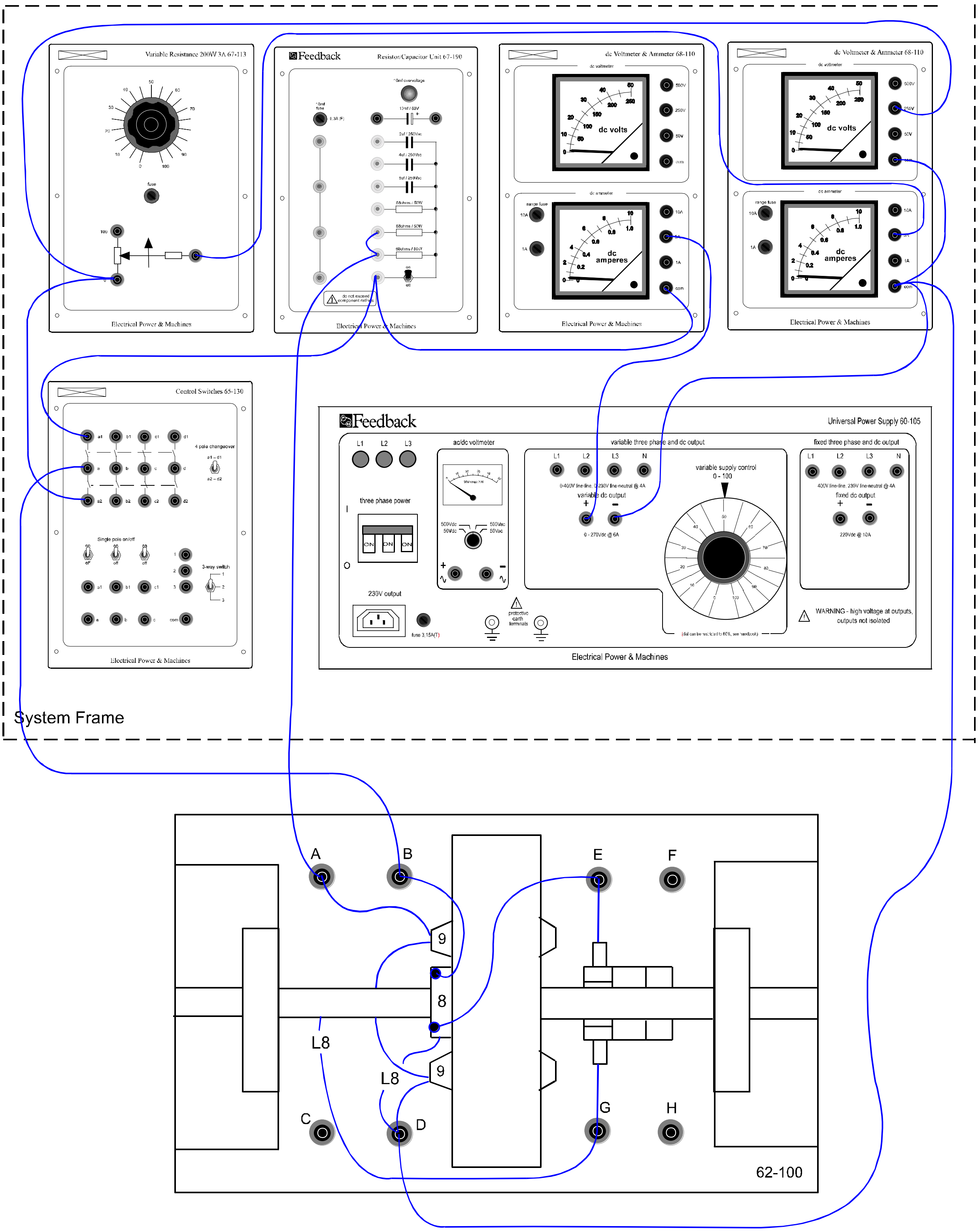


Figure A58-3: Connections for DC Shunt Motor with Interpoles

PRACTICAL 58.1

Operation

On power supply 60-105, ensure that the dial is set for zero voltage output.

On the resistor/capacitor unit 67-190, ensure the on/off switch is set to ‘on’.

On variable resistor unit 67-113, ensure that the dial is set to zero and disconnect one side of the resistor.

On the control switches unit 65-130, set the ‘4 pole changeover’ switch to ‘a2-d2’.

On the power supply 60-105, rotate the dial slowly to increase the output voltage to obtain 50 V dc as shown on the voltmeter on 68-110. The field current should be about 1 A as indicated on the ammeter on 68-110.

On the control switches unit 65-130, set the ‘4 pole changeover’ switch to ‘a1-d1’. The motor should run at about 1700 rev/min, as indicated on tachometer 68-470, with a field current reading of about 1.6 A.

Dynamic Braking Procedure

On the control switches unit 65-130, set the ‘4 pole changeover’ switch to ‘a2-d2’, which will disconnect the armature from the supply and connect it to the voltmeter. A voltage will be indicated that will decay with the speed of the machine.

With the switch in position ‘a1-d1, the machine runs as a shunt motor; selecting switch position ‘a2-d2’ converts the machine into a separately-excited generator.

Use a stop watch to measure the time taken for the motor to stop after switching it from 'motoring’ (switch position a1-d1) to 'generating' (switch position a2-d2).

On power supply 60-105, set the dial to zero voltage output.

On variable resistor unit 67-113, reconnect the variable resistor and rotate its dial to select 200 ohms. Again measure the time taken to stop after switching from 'motoring' to 'generating' and record the result in the ‘Without added Inertia’ column of Table A58-1 in the Results section at the end of this assignment.

Repeat the dynamic braking procedure for values of braking resistances of 150, 100, 50, 25 and 10 ohms, and record the results in the ‘Without added Inertia’ column of Table A58-1

Effect of Inertia Load Procedure

On power supply 60-105, ensure that the dial is set for zero voltage output.

Fit the Prony brake to the drive end of the shaft (see Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 6).

For each of the previously used values of braking resistance, select 'motoring', wait until a steady speed is reached, and measure the time taken after 'generating' is selected for the motor to stop. Record the results in the 'With added Inertia' column of Table A58-1.

Exercise 58.1

On a sheet of graph paper, plot two graphs of time to stop against braking resistance. Label the graphs 'without added inertia' and 'with added inertia'.

SUMMARY

A motor can be braked by switching it to act as a generator. The amount of braking depends on the applied electrical load. The time taken to stop depends on the inertia of the motor and its mechanical load.

Notes

Practical 58.1

Braking Resistance (ohms)	Braking Time (seconds)	
	Without Added Inertia	With Added Inertia
α		
200		
150		
100		
50		
25		
10		

Table A58-1: Resistance Braking Results

Notes

Practical 58.1

Braking Resistance (ohms)	Braking Time (seconds)	
	Without Added Inertia	With Added Inertia
α	4.7	7.4
200	3.8	5.9
150	3.6	5.7
100	3.2	5.3
50	2.5	4.2
25	1.9	3.2
10	1.3	2.6

Table A58-1: Resistance Braking Results

Notes

DISSECTIBLE

MACHINES SYSTEM

Assignment 59
Power Factor Correction of Induction Motors

PRACTICAL	59.1	Operation
EQUIPMENT REQUIRED	**Qty**	**Item**
62-100 Kit	1	Base Unit
	1	Centrifugal Switch
	1	12-slot Wound Stator
	1	Squirrel-Cage Rotor
General	1	0-135 V, Single-Phase ac Supply (eg, Feedback 60-121)
	1	Electronic Single & Three Phase Measurements (Voltmeter, Ammeter & Wattmeter) (eg, Feedback 68-100)
	1	Control Switches (eg, Feedback 65-130)
	1	Resistor/Capacitor Unit (eg, Feedback 67-190)
	1	Friction (Prony) Brake or other Dynamometer: 0-1 Nm, 1500 rev/min (eg, Feedback 67-470)
	1	Optical/Contact Tachometer (eg, Feedback 68-470)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

Every induction motor draws a lagging current from the supply, resulting in a bad power factor. This experiment is about improving the power factor by using capacitors.

Reason for Bad Power Factor

An induction motor connected to an ac supply requires alternating flux in its stator to generate an emf approximating to the supply voltage. This flux is nearly in quadrature with (at 90° phase difference from) the supply voltage. To drive the flux through the stator, the rotor and the air-gaps between them requires a magnetising current in the stator coils which must also have a component in quadrature with the supply voltage. (There may also be an in-phase component, due to iron losses). The magnetising current lags the supply voltage, in the same way as for a simple inductor.

The magnetising current contributes to the total current required to be supplied, without doing useful work. This adds to the costs incurred by the electricity supplier. He in turn charges the consumer, on a tariff which may be related either to the power factor, or to the 'VAR' (Volt-Amperes Reactive).

The 'power factor' (PF) is defined as the ratio:

$$PF = \frac{\text{(power supplied)}}{\text{(power which could be supplied by the same current if it were in phase with the supply voltage)}}$$

For sinusoidal waveforms it can be shown to be equal to cos ϕ, where ϕ is the phase angle between voltage and current.

'VAR' is the product of the supply voltage multiplied by the quadrature component of current.

Decreasing the reactive, or quadrature, current improves both PF (increased) and VAR (decreased).

Improving the Power Factor

In the induction motor, the in-phase component of the magnetising current is controlled by design to keep the iron losses as small as economically possible. The quadrature magnetising current however is often much larger, and dependent on the air-gap, which cannot be reduced too far for mechanical reasons. The proportion of quadrature current flowing in the supply can be reduced by the use of capacitors or synchronous motors.

If a capacitor is connected across the motor terminals, as shown in Figure A59-1, it contributes to the supply current a leading component denoted by I_C in the phasor diagram, Figure A59-2. The total supply current is reduced.

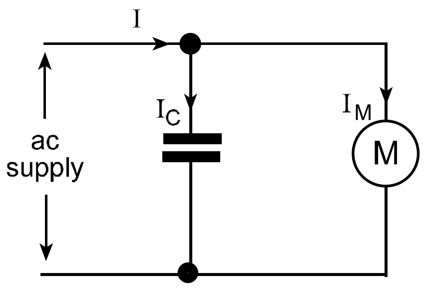


Figure A59-1: Connections for Capacitor

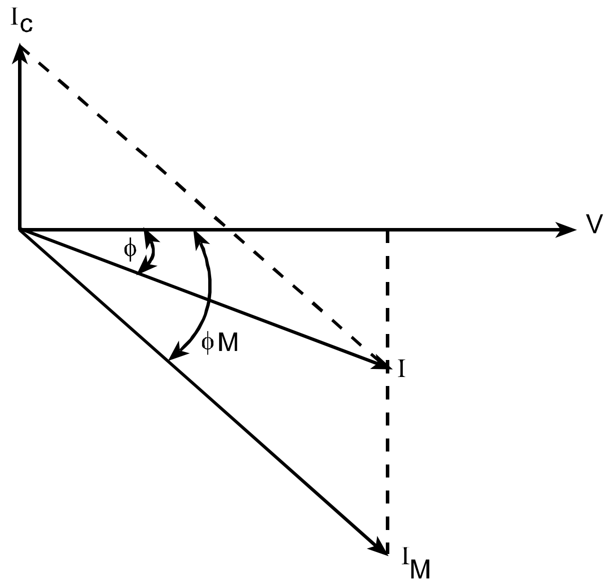


Figure A59-2: Phasor Diagram

Behaviour of Power Factor with Varying Load

This assignment is mainly intended to show that the reactive current drawn by the motor does not vary much with load, from which we shall later draw some conclusions about how to use induction motors.

ASSEMBLY

Mount the stator in the frame ring, with coil No 1 at the top, fixing it in position by three 1 3/8" long cap-head socket screws at the 12, 4 and 8 o'clock positions. Attach the fixed element of the centrifugal switch to the drive-end bearing housing using the screws as described in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 4.

Fit the squirrel-cage rotor to the shaft, locating the hub set screw in the conical recess on the non-drive side of the shaft. Attach the rotating element of the centrifugal switch to the drive-end of the shaft adjacent to the rotor. Fit the shaft into its bearing and lightly screw the removable bearing housing to the baseplate; before finally tightening down, check that the shaft rotates freely and moves axially against the pre-loading washer.

Fasten the friction brake to the baseplate as described in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 6. Adjust the brake for zero load initially.

Connect the coils as shown in Figure A59-3. Make the connections shown in Figure A59-4, between the motor and the supply.

Notes

Ensure that the Electronic Single & Three Phase Measurements unit 68-100 is set to measure single-phase power as described in the VIPD User's Manual.

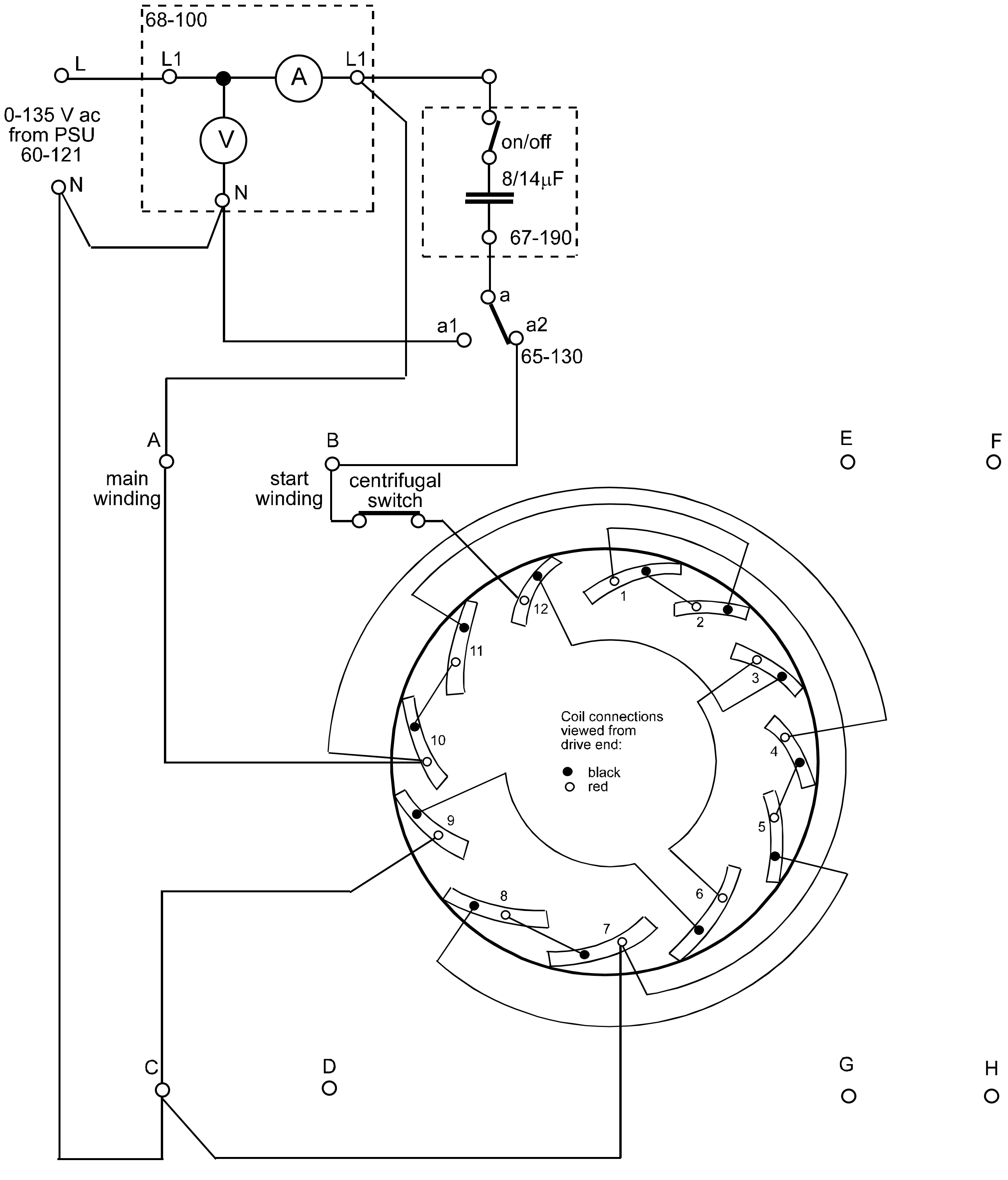


Figure A59-3: 4-Pole Single-Phase Induction Motor (Capacitor Start) Wiring Diagram

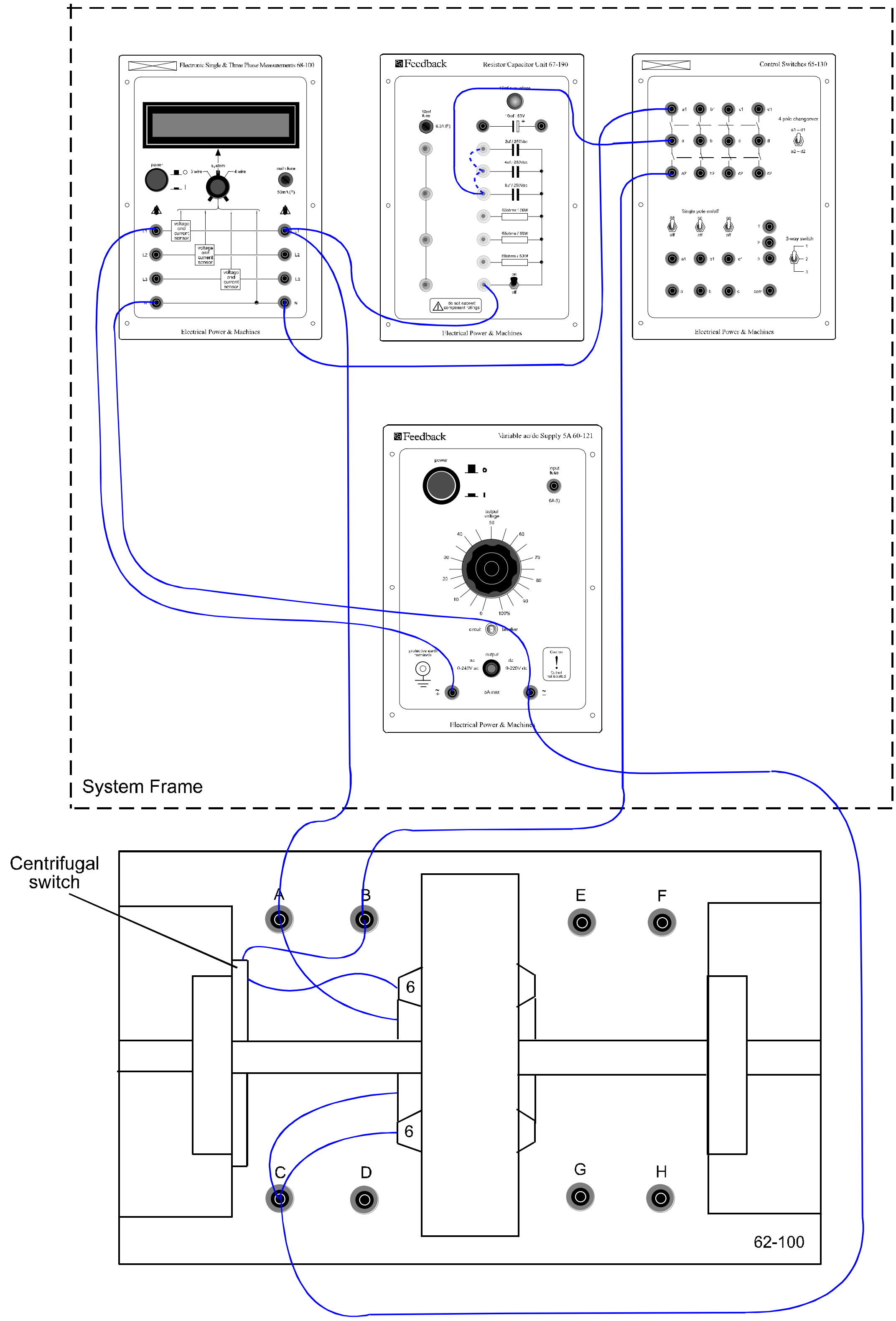


Figure A59-4: Connections for 4-Pole Single-Phase Induction Motor (Capacitor Start)

PRACTICAL 59.1

Operation

On power supply 60-121, ensure the ‘power’ pushbutton is set to off, the ‘output’ switch is set to ‘0-240V ac’, and that the ‘output voltage’ dial is set to zero.

On the resistor/capacitor unit 67-190, ensure the 8 µF capacitor is connected and that the on/off switch is set to ‘on’.

Capacitor not across Supply

On the control switches unit 65-130, set the ‘4 pole changeover’ switch to ‘a2-d2’.

On power supply 60-121, press the ‘power’ pushbutton to switch on the supply and rotate the ‘output voltage’ dial to give an output of 135 V ac as indicated on 68-100 (set to voltage measurement).

When the shaft speed reaches approximately 1150 rev/min as indicated on tachometer 68-470, the centrifugal starting switch will operate and disconnect the starting circuit. The motor should continue to run up to a steady speed of very nearly 1500 rev/min for a 50 Hz supply, or 1800 rev/min for 60 Hz supply.

Using the Prony brake 67-470, set the torque to 0.1 Nm. On 68-100, observe supply voltage, current and power, and record the observations in the first row of Table A59-1 in the Results section at the end of this assignment. The VA, VAR and PF columns should be left blank, to be filled in later.

Complete the first three columns of Table A59-1 by repeating these observations for values of torque increased by 0.1 Nm steps up to 0.5 Nm. Note that the results have been obtained without a corrective capacitor across the supply.

8 µF Capacitor across Supply

Without switching off the power supply, move the ‘4 pole changeover’ switch on 65-130 to ‘a1-d1’, which connects the 8 µF capacitor across the supply. On t68-100, observe the supply current, which should fall when the switch changes over. Record the voltage, current and power parameters observed on 68-100 in Table A59-2 with the 8 µF corrective capacitor across the supply.

14 μF Capacitor across Supply

Without switching off the power supply, move the '4 pole changeover' switch on 65-130 to 'a2-d2' to disconnect the capacitor from across the supply.

On the resistor/capacitor unit 67-190, connect the 2 μF and 4 μF capacitors in parallel with the 8 μF capacitor to create an effective corrective capacitor of 14 μF (see broken line connections on Figure A59-5).

On the control switches unit 65-130, set the '4 pole changeover' switch to 'a1-d1 which connects the 14 μF capacitor across the supply. On 68-100, observe the supply voltage, current and power readings as before and record the results in Table A59-3.

Finally, reduce the brake load to minimum and switch off the equipment.

Exercise 59.1

Complete the VA and power factor columns in Tables A59-1, 2 and 3 of as follows:

- calculate VA by multiplying the voltage and current together.
- calculate power factor as $\frac{\text{power}}{\text{VA}}$.

Plot, on one sheet of graph paper, graphs of power factor against load for each value of correction capacitor, including zero capacitance.

Exercise 59.2

Complete the VAR column in Tables A59-1, 2 and 3, using the values calculated in Exercise 59.1 as follows:

- VAR can be calculated as: .

$$\sqrt{(\text{VA})^2 - (\text{power})^2}$$

However, on some calculators it may be quicker and easier to calculate VA sin(arc cos PF), which is the same value.

It should be found that the values of VAR are closely similar, within each one of the three tables. Calculate the average value for no capacitance, and for 14 μF.

The negative VAR provided by a 14 μF capacitor is calculated as follows:

Current taken by the capacitor is $V(2\pi fC)$ where:

V is the supply voltage

f is the frequency

C is the capacitance

As a reminder that the VAR is usually reckoned as lagging, a negative sign may be added, while the capacitor draws leading VAR (or equivalently supplies lagging VAR). Thus:

$$VAR_C = -V^2(2\pi fC)$$

For nominal values, VAR_C is:

for 50 Hz supplies

$$-135^2 \times 2 \times \pi \times 50 \times 14 \times 10^6 = 80.2 \text{ VAR}$$

for 60 Hz supplies:

$$-135^2 \times 2 \times \pi \times 60 \times 14 \times 10^6 = 96.2 \text{ VAR}$$

Add the appropriate negative value to the uncorrected average VAR reading calculated earlier. The result should agree fairly closely with the average VAR found experimentally with 14 μF.

SUMMARY

The experiment and exercises should have shown that:

- An induction motor always draws a magnetising current with a quadrature component which is largely independent of its mechanical output.
- Consequently, its power factor tends to be low, and worse when lightly loaded.
- The quadrature current drawn from the supply can be reduced by means of capacitors.

DISCUSSION

In a typical factory it is not unusual for induction motors to be running most of the time during working hours, and the load may vary enormously, depending on the item being machined, or the flow of process material. Motors must be large enough to stand up to the greatest loads, and a large motor will tend to have a large magnetising current and VAR consumption. However, if the motor spends much of the time with little or no load, the power factor is reduced (as shown by Exercise 59.1), and the VAR consumption remains as high as before, (as shown by Exercise 59.2). The provision of PF correction in a factory is therefore always to be considered as a possible way of saving money.

The fact that the amount of VAR does not vary much with load is convenient, because it means that a fixed amount of VAR compensation can work well.

The necessity for PF correction is often increased by the use of over-large motors. A breakdown on a production line usually costs very much more than the cost of new motor. So after a breakdown of a motor, perhaps caused by temporary mechanical problems, people will sometimes install a huge replacement motor, in the hope of avoiding further losses of production.

The trouble with this is that the increased VAR of the bigger motor (which will always be lightly loaded) causes a new and far less obvious cost, either in the form of continual increased charges for bad power factor, or in the increased cost of PF correction.

Notes

Practical 59.1

Torque (Nm)	Supply			VA	Power factor	VAR
	(V)	(A)	(W)			
0.1						
0.2						
0.3						
0.4						
0.5						

Table A59-1: Results Without Capacitor Across Supply

Torque (Nm)	Supply			VA	Power factor	VAR
	(V)	(A)	(W)			
0.1						
0.2						
0.3						
0.4						
0.5						

Table A59-2: Results With 8 μF Capacitor Across Supply

Torque (Nm)	Supply			VA	Power factor	VAR
	(V)	(A)	(W)			
0.1						
0.2						
0.3						
0.4						
0.5						

Table A59-3: Results With 14 μF Capacitor Across Supply

Notes

Practical 59.1

Torque (Nm)	Supply			VA	Power factor	VAR
	(V)	(A)	(W)			
0.1	135	2.68	140	361	0.39	332
0.2	135	2.7	156	364	0.43	329
0.3	135	2.8	188	378	0.5	327
0.4	135	2.92	220	394	0.56	326
0.5	135	3.12	252	421	0.6	337

Average: 330.2 VAR

Table A59-1: Results Without Capacitor Across Supply

Torque (Nm)	Supply			VA	Power factor	VAR
	(V)	(A)	(W)			
0.1	135	2.39	140	322	0.43	291
0.2	135	2.4	156	324	0.48	284
0.3	135	2.5	188	337	0.56	279
0.4	135	2.6	220	351	0.63	273
0.5	135	2.8	252	378	0.67	281

Average: 281.6 VAR

Table A59-2: Results With 8 μF Capacitor Across Supply

Torque (Nm)	Supply			VA	Power factor	VAR
	(V)	(A)	(W)			
0.1	135	2.1	140	283	0.49	247
0.2	135	2.18	156	294	0.53	249
0.3	135	2.23	188	301	0.63	233
0.4	135	2.4	220	324	0.68	238
0.5	135	2.6	252	351	0.72	243

Average: 242 VAR

Table A59-3: Results With 14 μF Capacitor Across Supply

Average uncorrected VAR = 330.2 VAR

Capacitor VAR (50 Hz) = -80.2 VAR

Sum = 250.0 VAR (= 242 VAR + 3.3%)

DISSECTIBLE

MACHINES SYSTEM

Assignment 60

Pole-Changing Induction Motor

PRACTICAL	59.1	Operation
EQUIPMENT REQUIRED	**Qty**	**Item**
62-100 Kit	1	Base Unit
	1	12-slot Wound Stator
	1	Squirrel-Cage Rotor
General	1	0-135 V, Single-Phase ac Supply (eg, Feedback 60-121)
	1	0-250 V ac Voltmeter
	1	0-5 A ac Ammeter (eg, Feedback 68-117)
	1	Control Switches (eg, Feedback 65-130)
	1	Resistor/Capacitor Unit (eg, Feedback 67-190)
	1	Friction (Prony) Brake or other Dynamometer: 0-1 Nm, 1500 rev/min (eg, Feedback 67-470)
	1	Optical/Contact Tachometer (eg, Feedback 68-470)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

In many applications it is desirable to change the speed of a motor-driven load. The ideal is continuous variation of speed over a wide range, but this is expensive and difficult to achieve.

In an induction motor, speed can be controlled by varying the supply voltage, or varying the rotor circuit resistance of a wound-rotor machine. But in both cases the efficiency and the speed regulation are poor at reduced speeds. The supply frequency can be varied, but this is usually expensive, especially since it probably requires changing the voltage as well.

The speed (rev/min) at which an induction motor runs is given by:

$$\frac{60(1-s)}{(p.f)}$$

where:

p is the number of pole pairs

f is the supply frequency (Hz)

s is the fractional slip

For efficiency and good speed regulation, s is to be kept a small fraction and then it makes little difference to the speed. If the number of pole pairs p is changed, the speed will be altered. This can be done by having two stator windings and switching between them. An alternative method (pioneered by Lindstrom and Dahlander) is to have a group of coils for each phase arranged with external switching so that some of the coils can have the current in them reversed to alter the number of poles. This has the advantage of using the coil winding space efficiently, but is restricted to a 2:1 change in speed if the switching is not to become over-complicated.

Figure A60-1 shows how an arrangement of 62-100 coils and switching will be used to make a 2/4-pole induction motor.

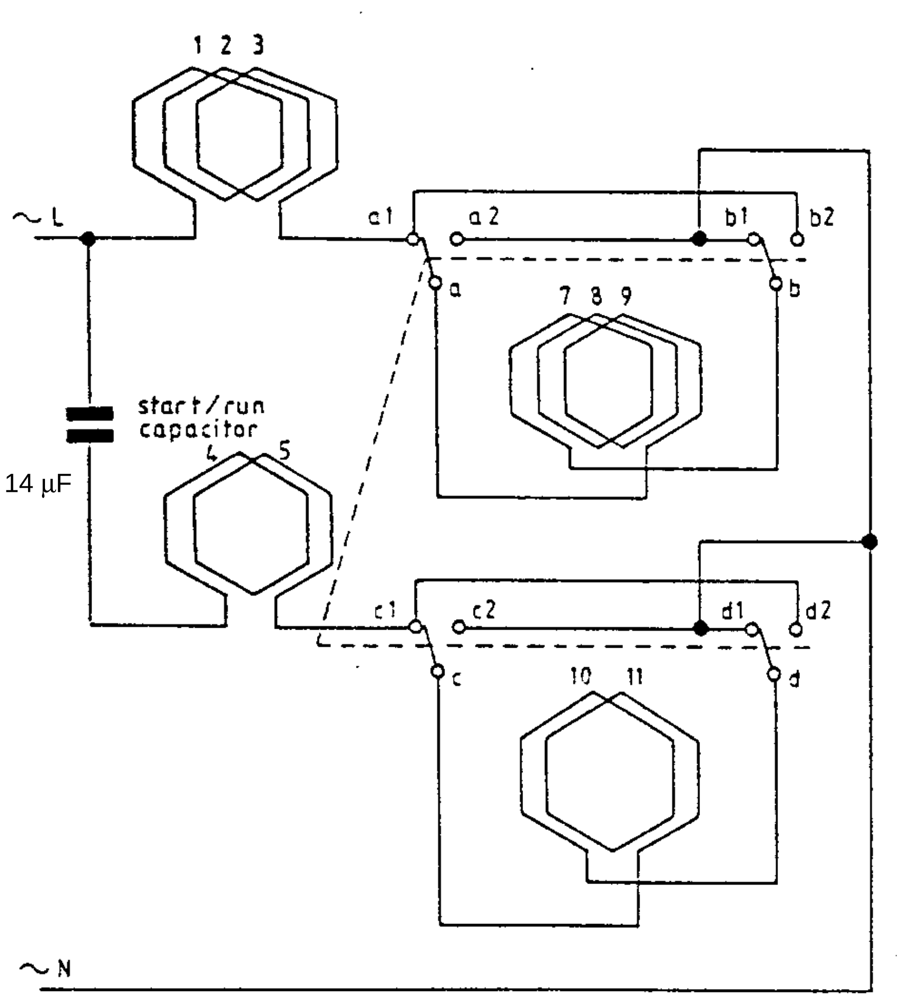


Figure A60-1: Coil Arrangement for 2/4-Pole Induction Motor

ASSEMBLY

Mount the stator in the frame ring, with coil No 1 at the top, fixing it in position by three 1 3/8" long cap-head socket screws at the 12, 4 and 8 o'clock positions.

Fit the squirrel-cage rotor to the shaft, locating the hub set screw in the conical recess on the non-drive side of the shaft.

Fit the shaft into its bearing and lightly screw the removable bearing housing to the baseplate; before finally tightening down, check that the shaft rotates freely and moves axially against the pre-loading washer.

Fasten the friction brake to the baseplate as described in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 6. Adjust the brake for zero load initially.

Connect the coils as shown in Figure A60-2. Make the connections shown in Figure A60-3, between the motor and the supply.

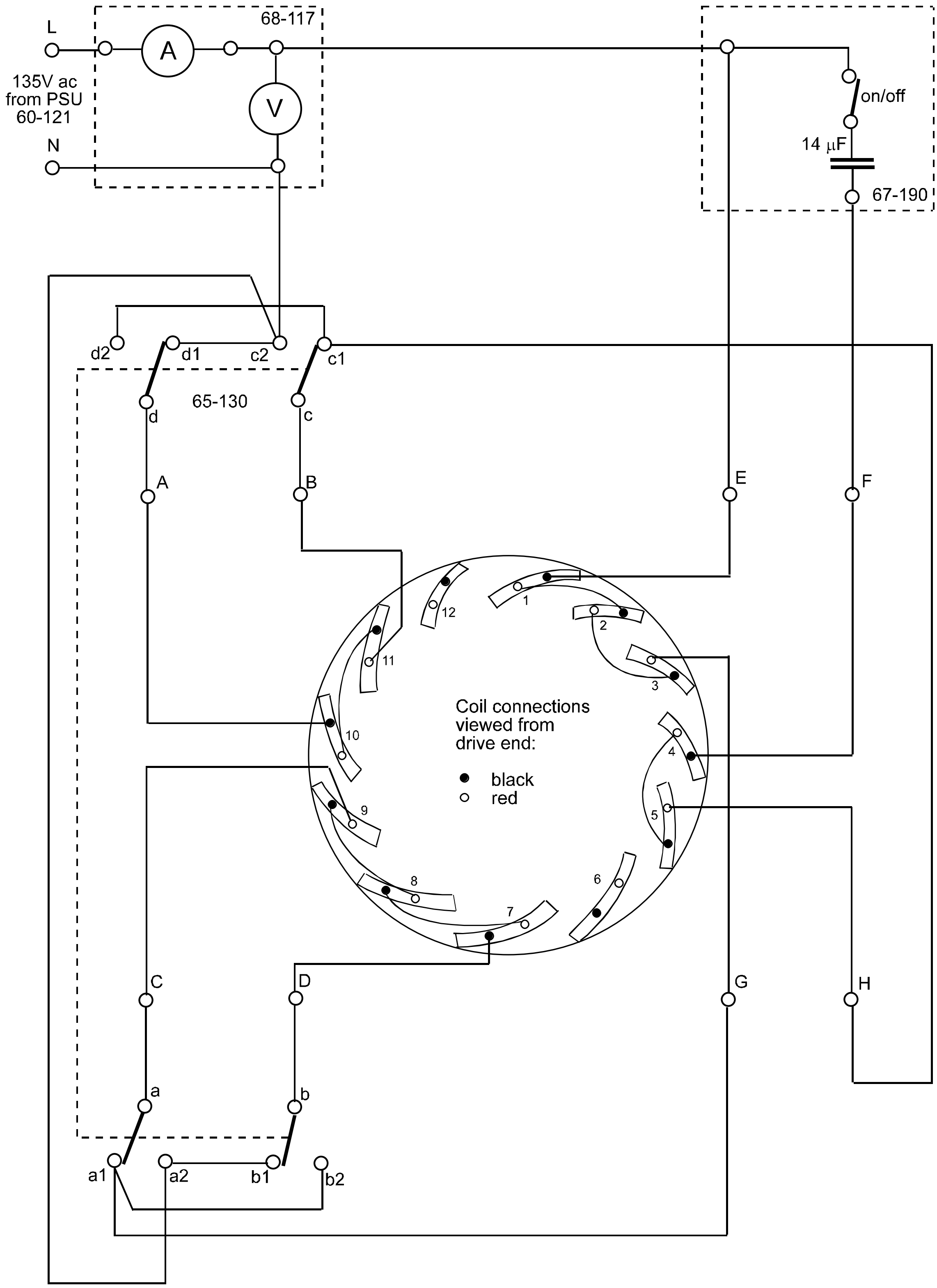


Figure A60-2: Pole-Changing Induction Motor Wiring Diagram

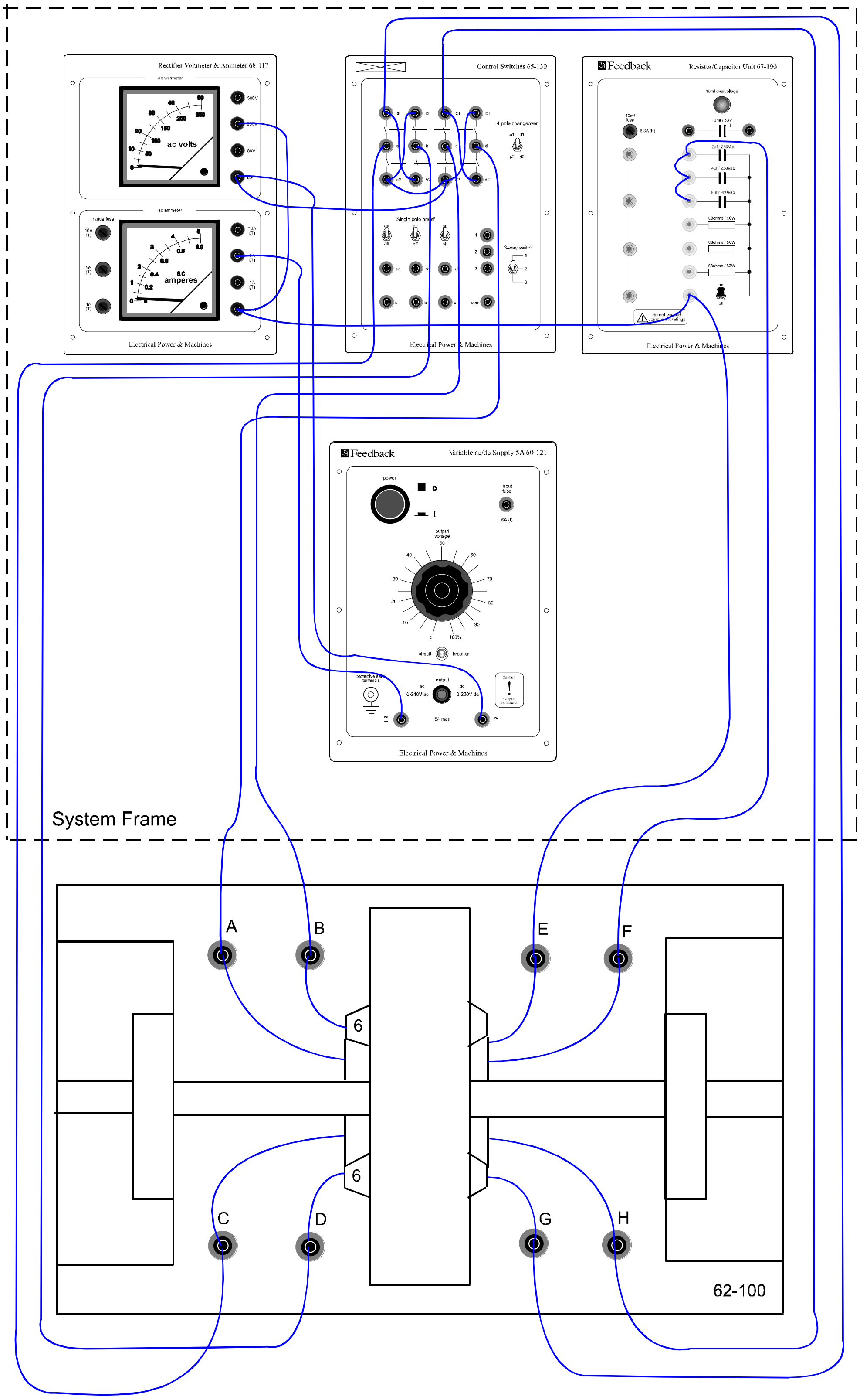


Figure A60-3: Connections for Pole-Changing Induction Motor

PRACTICAL 60.1

Operation

On power supply 60-121, ensure the ‘power’ pushbutton is set to off, the ‘output’ switch is set to ‘0-240V ac’, and that the ‘output voltage’ dial is set to zero.

On the resistor/capacitor unit 67-190, ensure the 2 μF, 4 μF and 8 μF capacitors are connected in parallel to create an effective capacitor of 14 μF, and that the on/off switch is set to ‘on’.

On the control switches unit 65-130, set the ‘4 pole changeover’ switch to ‘a2-d2’.

On power supply 60-121, press the ‘power’ pushbutton to switch on the supply and rotate the ‘output voltage’ dial to give an output of 135 V ac as indicated on 68-117 voltmeter.

The motor should run up to a steady speed (speed 1) of very nearly 1500 rev/min for a 50 Hz supply, or 1800 rev/min for 60 Hz supply, as indicated on tachometer 68-470.

Now select speed 2 by setting the ‘4 pole changeover’ switch to ‘a1-d1’ on 65-130. The shaft speed should rise to about twice the former speed.

At the higher speed, both the in-phase and the quadrature windings are connected to give a conventional arrangement of successive north and south poles. At the lower speed, the windings are connected to give similar, say north, poles between which 'consequent' south poles occur. ('North' and 'South' of course apply only to a particular phase of the supply, since the flux alternates).

Braking

On the control switches unit 65-130, set the ‘4 pole changeover’ switch to ‘a2-d2’ (speed 1) and note how the motor decelerates.

Repeat the change from speed 2 to speed 1 a few times, observing the speed with tachometer 68-470 . Compare the behaviour when the motor is running at speed 2 and the supply is then switched off.

Question 60.1

Why is there a braking effect when switching from speed 2 to speed 1?

Torque-Speed Characteristic

With the motor running at speed 2, apply the brake load in steps of 0.1 Nm up to 0.3 Nm, and record speed values measured with the tachometer on a copy of Table A60-1 in the Results section at the end of this assignment.

Repeat the above test for speed 1 and record on a copy of Table A60-2.

Switch off the motor supply on test completion.

SUMMARY

The induction motor can be wound so that external switching alters the effective number of poles, and consequently the synchronous speed. This may be used to drive a load at alternative speeds. Switching from the higher to the lower speed produces a braking effect.

DISCUSSION

The induction motor can be wound to provide pole switching of 2, 4, 6 and 8 poles, but a sacrifice has to be made in the output torque available at each setting. The flux paths change with the numbers of poles, and many of the leakage reactances vary also, so that performance at some speeds tends to be inferior. However there can be many advantages of being able to start or to brake a high-inertia load with the low-speed winding, and in such an application the motor might well be optimised for high-speed running.

In the late 1950's, a special method of winding and pole switching was introduced, applicable to three-phase machines. The technique is called Pole-Amplitude Modulation (PAM), from its similarity to amplitude modulation as used in radio communication, the difference being that the latter modulates the amplitude of a carrier signal as a function of time, whereas PAM involves modulation of the spatial distribution of the stator windings. The advantage of PAM is that it offers a wide choice of speed ratios, and in particular allows close ratios like 4/6, 6/8, 8/10 and 10/12 poles to be achieved.

Practical 60.1

Torque (Nm)	Speed (rev/min)
0	
0.1	
0.2	
0.3	

Table A60-1: Results for Speed 2

Torque (Nm)	Speed (rev/min)
0	
0.1	
0.2	
0.3	

Table A60-2: Results for Speed 1

Notes

Practical 60.1

Torque (Nm)	Speed (rev/min)
0	2960
0.1	2800
0.2	2600
0.3	2400

Table A60-1: Results for Speed 2

Torque (Nm)	Speed (rev/min)
0	1470
0.1	1440
0.2	1380
0.3	1300

Table A60-2: Results for Speed 1

Question 60.1

The braking effect occurs when switching speed because the flux is reversed and any change is opposed (Lens' Law)

Notes

DISSECTIBLE

MACHINES SYSTEM

Assignment 61
Faults Occurring on a dc Shunt Motor

PRACTICAL 61.1 Operation

EQUIPMENT REQUIRED

	Qty	**Item**
Ancillary Kit	1	Contact Strip, Brass
	1	Link (for short-circuiting field coil)
62-100 Kit	1	Base Unit
	1	Commutator/Slipring
	2	Brushholders with Brushes
	2	L9 Coils
	2	L1 Coils
	2	L2 Coils
	2	Field Poles
	1	Rotor Hub
	4	Rotor Poles
	2	L8 Coils
	2	Interpoles
General	1	0-135 V, 5 A, dc Power Supply (eg, Feedback 60-105)
	1 2	50 V/250 V, dc Voltmeter 1 A/5 A, dc Ammeter (eg, Feedback 68-110)
	3	68Ω Resistors (eg, Feedback 67-190)
	1	Friction (Prony) Brake or other Dynamometer 0-1 Nm at 1500 rev/min (eg, Feedback 67-470)
	1	Optical/Contact Tachometer (eg, Feedback 68-470)
	1	500 V dc Insulation Tester (not supplied)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

Notes

INTRODUCTION

If maintenance is carried out on a properly organised schedule, the occurrence of a fault will be the exception rather than the rule. However, faults do sometimes occur and it is important to be able to deduce quickly what has failed and decide the quickest way to repair it, since 'down time' is very costly, especially in high-volume manufacturing industry. There are many types of machine, each with their own behaviour when a fault develops, so that only with considerable experience can the cause of a failure be correctly identified from the symptoms alone. A logical and systematic approach to the problem is therefore generally quickest.

Insulation Tests

Any breakdown of insulation can give rise to other serious faults, or an increased risk of them. It therefore requires the motor to be taken out of service and stripped down for examination. The cause of failure should be investigated since different action is required if one coil has failed for some specific reason from that required if all the insulation is in poor condition and likely to fail at any time. Insulation failures are not restricted to windings; for instance, commutator insulation can break down due to tracking or excessive commutator sparking.

Insulation is checked by an instrument which applies a high voltage across suspected parts. Any small current which flows is detected, and usually indicated in terms of the insulation resistance.

Continuity Faults

Breaks or high resistance in the current path are usually caused either by poor connections or by conductors burning out, conductors fractured by vibration or other mechanical damage.

Continuity is tested by applying a low voltage between the ends of a conductor and checking for an expected value of current, again usually indicated on a scale calibrated in resistance. The 'ohms' range of a multimeter may be used, or the low-voltage range often provided on an insulation tester.

Other Faults

In addition to the basic electrical faults mentioned, there are others peculiar to motors. This assignment will look at commutation faults. Other faults include problems due to mechanical out-of-balance and bearing failures.

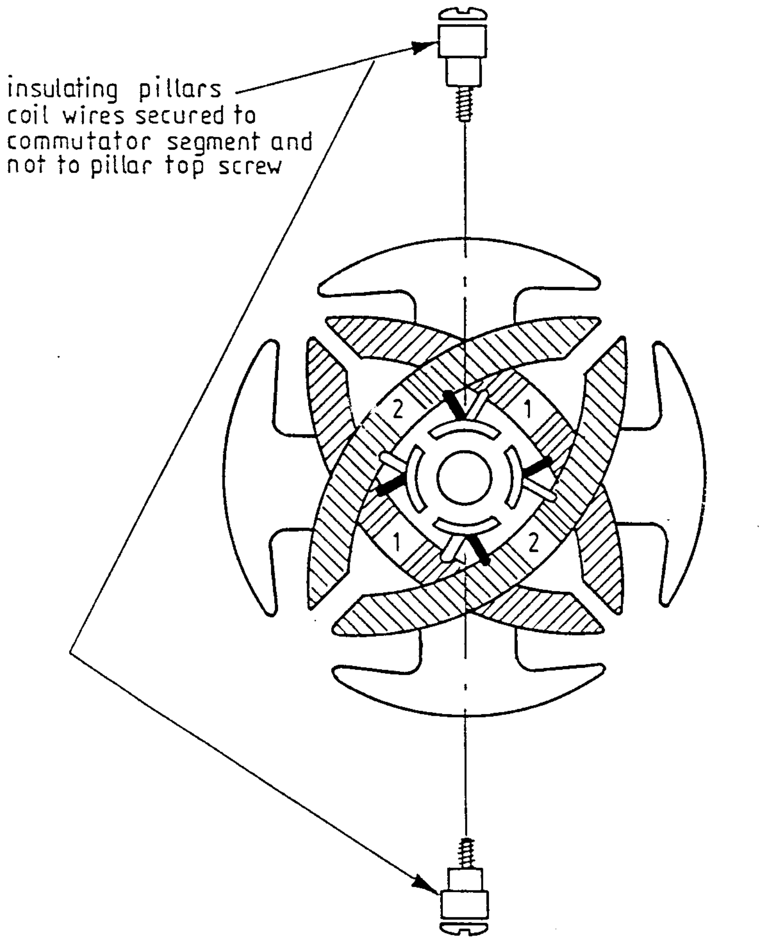


Figure A61-1: Assembly of Armature and Commutator

ASSEMBLY

Fix the armature and commutator to the shaft as shown in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 1. However, use two insulating pillars on opposite commutator segments, instead of normal screws, to terminate coil leads as shown in Figure A61-1. Fit the shaft into its bearings. Before finally tightening the screws holding the bearing housing to the base plate, check that the shaft rotates freely and moves axially against the pre-loading washer.

Fit the L9 coils to the field poles then attach the poles to the frame ring in the 3 o'clock and 9 o'clock positions. Attach the L8 interpoles with their coils to the frame ring in the 6 o'clock and 12 o'clock positions.

Fit the brushes into their holders and attach them to the mounting block positions on each side of the commutator. The brushes should move freely in the holders under the action of the brush springs.

Fit the Prony brake to the drive end of the shaft and adjust to give zero load (see Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 6).

Connect the coils as shown in Figure A61-2. Make the connections shown in Figure A61-3, between the motor and the supply.

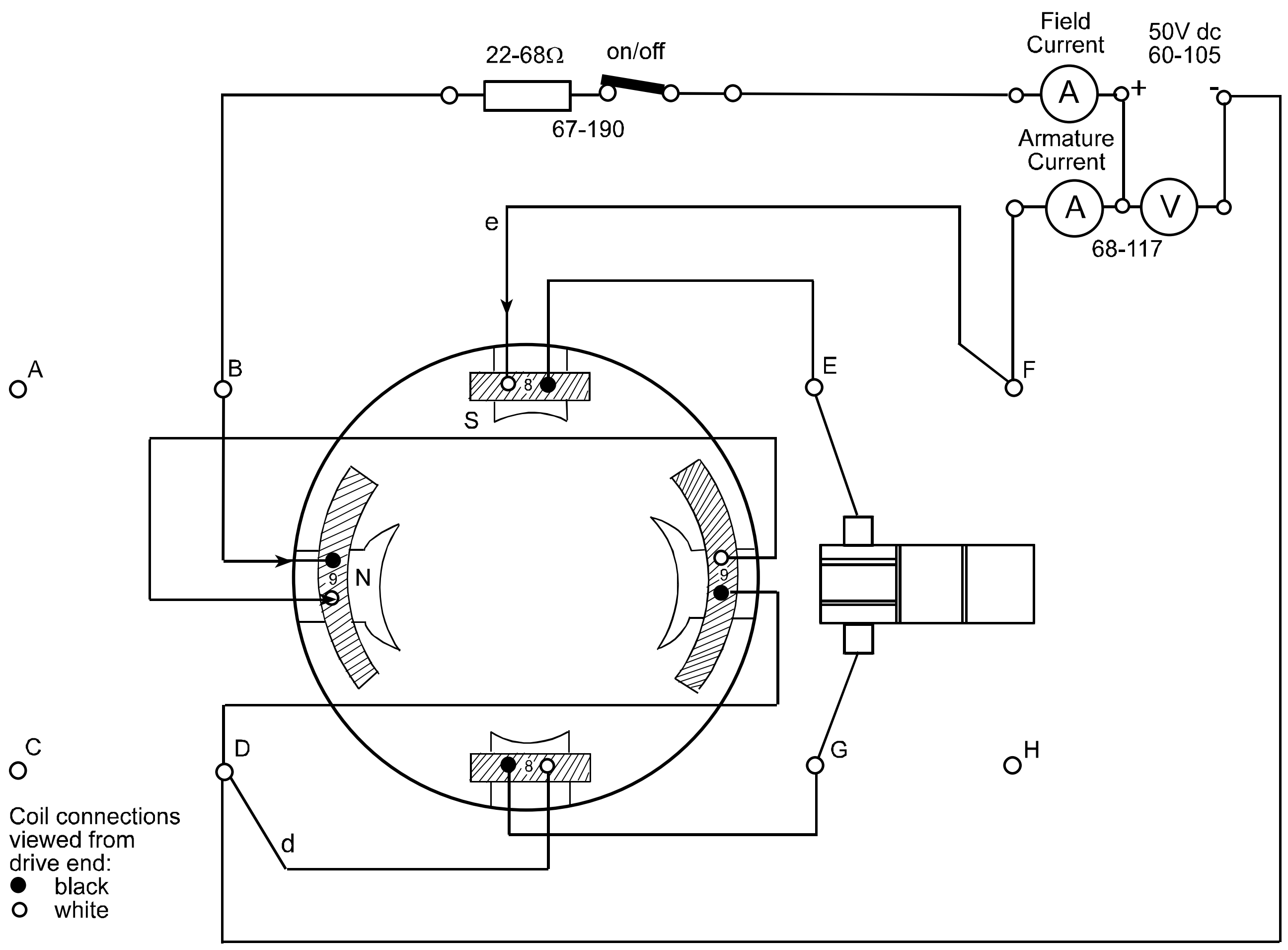


Figure A61-2: dc Shunt Motor with Interpoles Wiring Diagram

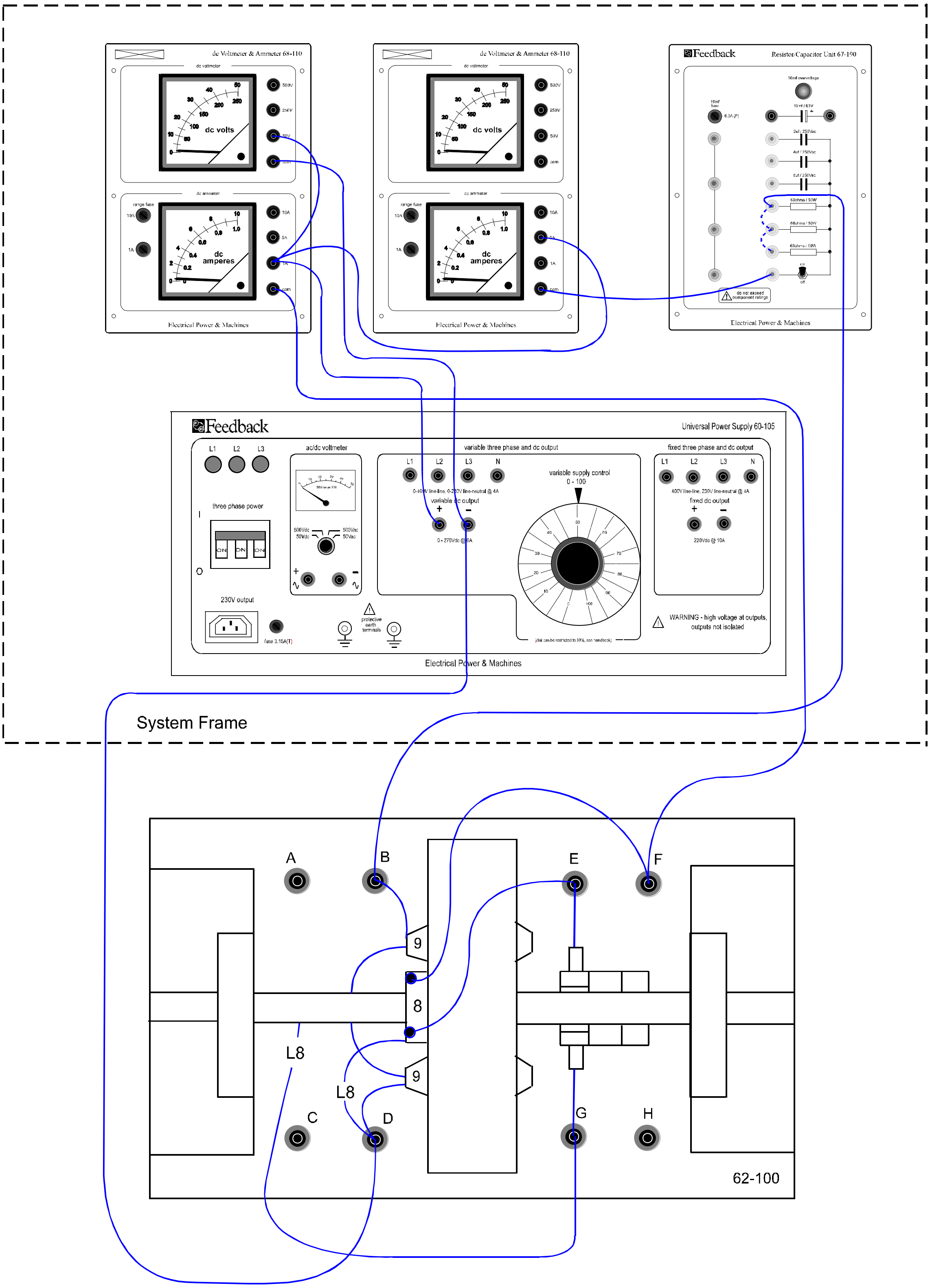


Figure A61-3: Connections for dc Shunt Motor with Interpoles

PRACTICAL 61.1

Operation

On power supply 60-105, ensure that the dial is set for zero voltage output.

On the resistor/capacitor unit 67-190, ensure that the on/off switch is set to 'on' and the three 68 ohm resistors are connected in parallel to give a combined resistance of 22.6 ohms.

On the power supply 60-105, rotate the dial slowly to increase the output voltage to obtain 50 V dc as indicated on 68-110 voltmeter. The motor should run at about 1350 rev/min, as indicated on tachometer 68-470, in an anticlockwise direction looking from the brake end. The field current should be about 1.5 A and the armature current 0.5 A as indicated on the appropriate 68-110 ammeters.

Commutation Tests

Listen to the motor running and look at the commutator for signs of sparking, especially on the portions of the commutator just leaving each brush. Excessive sparking could be due to several causes. Assuming that no deliberate fault has been applied:

- The commutator may be wrongly positioned relative to the armature.
- The brushes may not be seating properly on the commutator, or the commutator segments may have a build-up of carbon.

Clean the commutator first, if necessary, then, if the sparking persists, try adjusting the commutator slot position relative to the armature poles to reduce it. If after this the sparks are still there, the brushes should be shaped to the commutator. To do this, place a strip of fine abrasive paper round the commutator underneath the brushes and rotate the shaft about ten times, which should be enough. After shaping the brushes, the position of the commutator should be re-adjusted again if necessary.

Winding Tests

The sound a motor makes can indicate to the trained ear the state of the motor's health. As you will hear and see, different faults produce different symptoms.

On a copy of Table A61-1 in the Results section at the end of this assignment, complete lines 1 and 2 by entering a reference set of measurements, taken with no faults. This will be used for comparison with later results.

Complete the copy of Table A61-1 from measurement and observation of the effects when each of the following faults is applied.

Line 3 Reduce the load to minimum and set-up a short circuit by connecting a lead across the terminals of one of the L9 field coils. Complete line 3 by entering the values of armature current, field current, speed and torque, and in the appropriate columns describe briefly what you can see and hear compared with the normal conditions of line 1.

Line 4 Apply increasing load for a brief period, without taking detailed measurements. Comment briefly in line 4 on the motor's behaviour and the armature current, compared with line 2.

Remove the short-circuit when this is done.

Line 5 Reduce the field current by disconnecting first one of the 68-ohm resistors. Then once more, record the effects, and reconnect the resistors.

Line 6 With the power off, connect the shorting link provided across two commutator segments, so that it short-circuits one L2 coil. Ensure that the lead is clear of the brush boxes. Apply power to the motor and record the effects observed as quickly as possible, to avoid damaging the commutator or windings. Then switch off the power and remove the shorting link.

Line 7 Open-circuit an armature coil. To do this, slacken one of the insulating pillars, remove one of the L2 coil leads from under it, re-tighten the pillar to re-secure the other lead to the commutator segment, then fasten the freed lead to the top of the pillar. Switch on the power and set a load of 0.4 Nm. Complete line 7. Finally reconnect the coil lead in its normal position.

Line 8 — Run the motor with a load of 0.4 Nm. Short-circuit the top L8 coil and note the effects on the running of the motor. Then remove the short-circuit.

Line 9 — Disconnect one lead from the L8 coil. Apply power to the motor and complete line 9.

Insulation Tests

Field to Armature

Disconnect the field leads, marked B and D in Figure A61-2, and connect them together. Disconnect the armature circuit, brush leads d and e, and connect these leads together. Connect the insulation tester; one of its leads to B, D and the other to d, e. Measure the insulation resistance and record its value in the 'without contact strip' column of Table A61-2.

Field to Motor Casing

Remove the lead of the tester from the armature leads d and e and connect it, instead, to the terminal post directly in contact with the casting. Measure the insulation resistance and record its value in the 'without contact strip' column of Table A61-2.

Armature to Motor Casing

Move the tester lead from the field to the armature connections and again measure and record the insulation resistance in the 'without contact strip' column of Table A61-2.

Effect of an Armature Insulation Fault

Fit the metal contact strip provided to one of the commutator segments that does not have an insulating pillar fitted, see Figure A61-4. Check that the commutator segment is electrically connected to the motor casting. Now run the motor. You should find that the added connection makes no difference to the running. Note this.

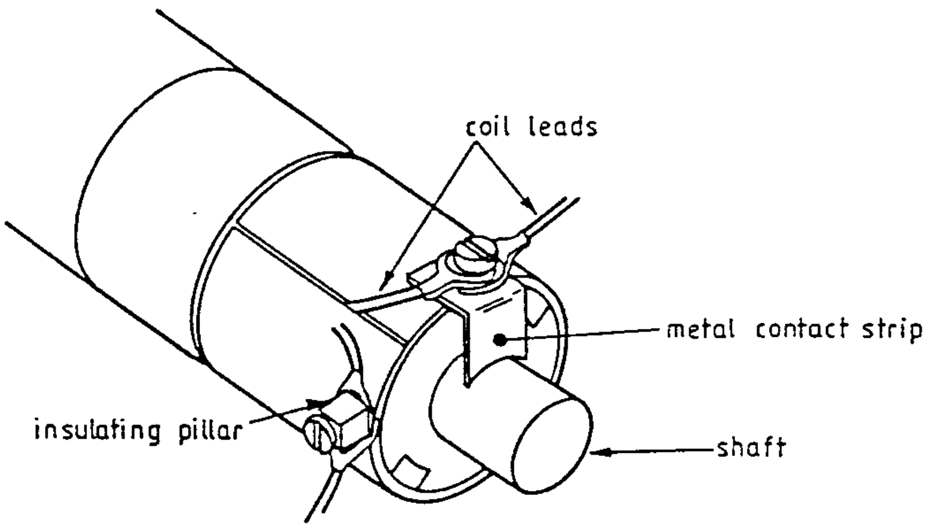


Figure A61-4: Fitment of Contact Strip to Commutator

Question 61.1 ***What effect would you expect if either the positive or the negative terminal of the supply were now connected to the motor casting?***

To check your answer, switch off the power supply and connect its negative terminal to the motor casting. Then switch on the supply for only a few seconds and switch it off again.

Question 61.2 ***By what path can such a large current flow?***

Repeat the insulation tests and record the results in the 'with contact strip' column of Table A61-2. This should help you to find the path of the current. Verify that, if the contact strip is removed, the motor will run satisfactorily even with the negative terminal of the supply connected to the motor casting.

DISCUSSION

The last test indicates how insulation faults can have effects difficult to foresee. A motor with an armature insulation fault might work well on a local generator or battery. However, if it were transferred to a public supply, the latter would almost certainly be earthed and thereby connected to the motor structure, with the results you have seen.

The winding faults applied in this experiment were 'all or nothing' - disconnections or short-circuits. In practice, disconnections may affect only one of several parallel paths in a motor causing the undamaged windings to carry excess current and overheat. Similarly, short-circuits often affect only a few turns of a coil causing a less decisive effect on motor performance. However, local overheating could occur (possibly leading to complete breakdown). This makes it especially valuable to have a set of reference measurements, against which subsequent performance can be compared.

SUMMARY

The effects of various faults have been investigated, with results summed up in your table. Compare these with the typical results given at the end of this assignment.

Review of Table Results

The following comments should bear some relationship to your table of results.

Line 4 — Reduced field current. This reduced the flux almost proportionally. The motor speed increased in almost the same ratio, to enable the motor to generate a back-emf close to the supply voltage. The armature current increased to maintain the required torque.

Line 5 — A short-circuited armature coil. A drumming noise resulted due to the asymmetry of the forces acting on the rotor. An increased armature current was due partly to the fewer armature turns available to generate torque, and partly because eddy currents induced in the shorted coil generated an opposing torque; both factors contributing to the brush sparking. If this fault were allowed to persist with the motor loaded, insulation failure and burning of the commutator could be expected.

Line 6	Open-circuit armature coil. Similar to previous case except less severe because the losses in the shorted coil are not present.
Line 7	Short-circuited interpole. Most noticeable on load due to the increase in noise and sparking at the commutator.
Line 8	Open-circuited interpole. The armature circuit is broken. The field supply is unaffected.

Notes

Practical 61.1

Fault		Armature Current (A)	Field Current (A)	Brush Sparking	Speed (rpm)	Torque (Nm)	Motor Noise
1	None (min load)	0.5	1.5	very little	1300	minimum	Low. Running Smoothly
2	None (0.4 Nm load)	1.9	1.5	increased	970	0.4	Low. Running Smoothly
3	Short Circuit Field Coil (min load)						
4	Short Circuit Field Coil (increased load)						
5	Reduced Field Current						
6	Short Circuit Armature Coil						
7	Open Circuit Armature Coil						
8	Short Circuit Interpole Coil						
9	Open Circuit Interpole Coil						

Table A61-1: Windings Tests Results

Test	Result	
	Without Contact Strip	With Contact Strip
Field to Armature		
Field to Motor Casing		
Armature to Motor Casing		
Effect of an Armature Insulation Fault		

Table A61-2: Insulation Tests Results

Notes

Practical 61.1

Fault		Armature Current (A)	Field Current (A)	Brush Sparking	Speed (rpm)	Torque (Nm)	Motor Noise
1	None (min load)	0.5	1.5	very little	1300	minimum	Low. Running Smoothly
2	None (0.4 Nm load)	1.9	1.5	increased	970	0.4	Low. Running Smoothly
3	Short Circuit Field Coil (min load)	0.6	1.7	small increase	1800	minimum	More noisy with vibration
4	Short Circuit Field Coil (increased load)	large	1.8	severe	falls	increased	Noisy
5	Reduced Field Current	0.8	0.6	small increase	2070	minimum	Low. Running Smoothly
6	Short Circuit Armature Coil	2.5	1.5	very much increased	880	0.4	More noisy with vibration
7	Open Circuit Armature Coil	1.8	1.5	increased	970	0.4	More noisy with vibration
8	Short Circuit Interpole Coil	2.0	1.5	much increased	970	0.4	Much more noisy
9	Open Circuit Interpole Coil	0	1.5	-	-	-	-

Table A61-1: Windings Test Results

Test	Result	
	Without Contact Strip	**With Contact Strip**
Field to Armature	>50 MΩ	>50 MΩ
Field to Motor Casing	>50 MΩ	>50 MΩ
Armature to Motor Casing	>10 MΩ	0 Ω
Effect of an Armature Insulation Fault		

Table A61-2: Insulation Tests Results

Notes

DISSECTIBLE

MACHINES SYSTEM

Assignment 62
Faults Occurring on a Four-Pole Induction Motor

PRACTICAL 62.1 Operation

EQUIPMENT REQUIRED

	Qty	Item
62-100 Kit	1	Base Unit
	1	Centrifugal Switch
	1	12-slot Wound Stator
	1	Squirrel-Cage Rotor
General	1	0-135 V, Single-Phase ac Supply (eg, Feedback 60-121)
	1	0-250 V ac Voltmeter 0-5 A ac Ammeter (eg, Feedback 68-117)
	1	Resistor/Capacitor Unit (eg, Feedback 67-190)
	1	Friction (Prony) Brake or other Dynamometer: 0-1 Nm, 1500 rev/min (eg, Feedback 67-470)
	1	Optical/Contact Tachometer (eg, Feedback 68-470)

KNOWLEDGE LEVEL

Before you start this assignment, you should have read Appendix A Basic Electrical Machine Theory.

INTRODUCTION

Induction motors are generally more reliable than commutator motors, since they have fewer wearing parts which, unlike brush gear on a dc motor, need little or no maintenance. However, faults can arise from entry of moisture causing breakdown of winding insulation and from excessive temperatures. The latter can be caused by overloading (leading to high currents) or by unduly high ambient temperature. The consequences can be insulation breakdown or burning out of coils. Rotor coils, even of squirrel-cage type, can be over-heated just as easily as stators, often leading to the melting of solder around rivets holding the rotor core together.

Single-phase induction motors have additional possible causes of failure. They are normally started by a separate winding associated with a capacitor or resistors and, depending on the type of motor, possibly a centrifugal starting switch. Resistors can burn out. Capacitors can fail by short-circuit, open-circuit, or, in the case of electrolytic types, by reduction of effective capacitance with age. Starting switches suffer both mechanical and electrical wear; failure modes include possible welding of the contacts if other faults cause excessive currents. Windings designed for use in starting only can easily be burnt out if continually energised, whether through the motor stalling or through a faulty starting switch.

ASSEMBLY

Mount the stator in the frame ring, with coil No 1 at the top, fixing it in position by three 1 3/8" long cap-head socket screws at the 12, 4 and 8 o'clock positions. Attach the fixed element of the centrifugal switch to the drive-end bearing housing using the screws as described in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 4.

Fit the squirrel-cage rotor to the shaft, locating the hub set screw in the conical recess on the non-drive side of the shaft. Attach the rotating element of the centrifugal switch to the drive-end of the shaft adjacent to the rotor. Fit the shaft into its bearing and lightly screw the removable bearing housing to the baseplate; before finally tightening down, check that the shaft rotates freely and moves axially against the pre-loading washer.

Fasten the friction brake to the baseplate as described in the Utility Manual, Sheet 62-100, Chapter 3, Basic Assembly Instruction 6. Adjust the brake for zero load initially.

Connect the coils as shown in Figure A62-1. Make the connections shown in Figure A62-2, between the motor and the supply.

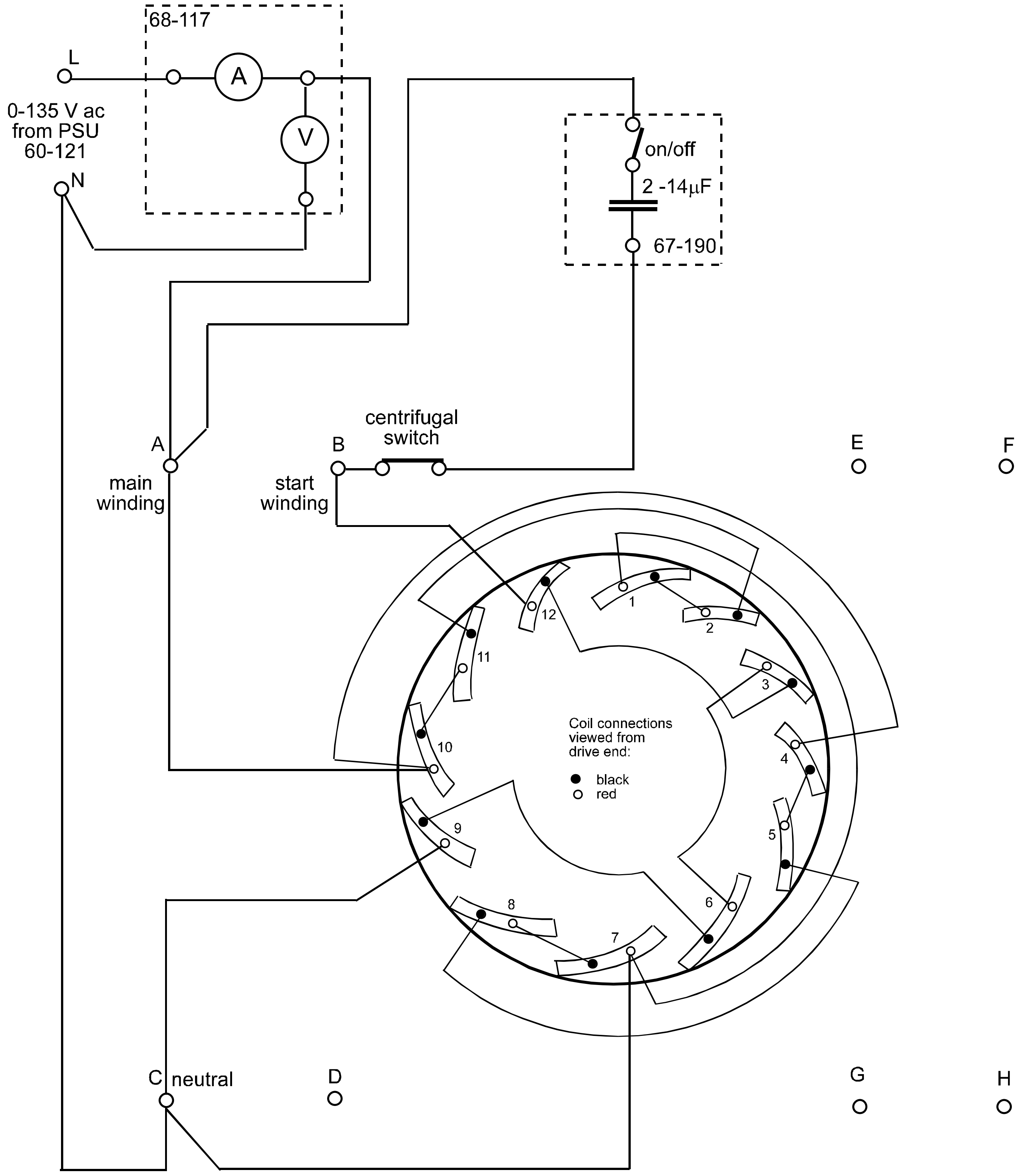


Figure A62-1: 4-Pole Single-Phase Induction Motor (Capacitor Start) Wiring Diagram

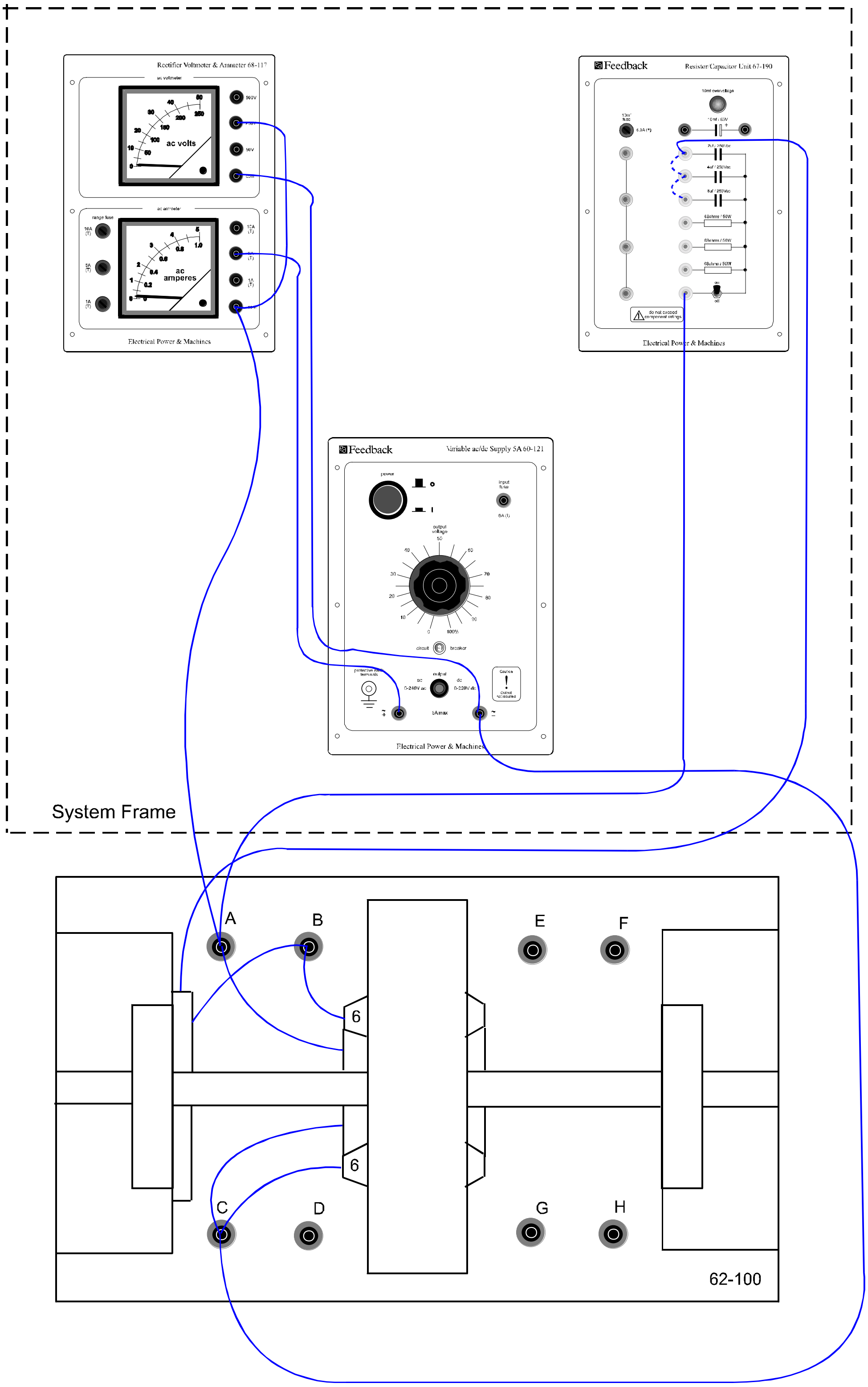


Figure A62-2: Connections for 4-Pole Single-Phase Induction Motor (Capacitor Start)

PRACTICAL 62.1

Operation

On power supply 60-121, ensure the 'power' pushbutton is set to off, the 'output' switch is set to '0-240V ac', and that the 'output voltage' dial is set to zero.

On the resistor/capacitor unit 67-190, ensure the 2 μF and 4 μF capacitors are connected in parallel with the 8 μF capacitor to create an effective capacitance of 14 μF (see broken line connections on Figure A62-2), and that the on/off switch is set to 'on'.

On power supply 60-121, press the 'power' pushbutton to switch on the supply and rotate the 'output voltage' dial to give an output of 135 V ac as indicated on 68-117 voltmeter.

When the shaft speed reaches approximately 1150 rev/min as indicated on tachometer 68-470, the centrifugal switch operates and disconnects the starting circuit. The motor will then run up to a steady speed of nearly 1500 rev/min for a 50 Hz supply, or 1800 rev/min for 60 Hz supply.

Pre-Test Measurements

Before applying faults to the motor, a set of measurements must be taken for comparison with results under fault conditions. Record values of supply voltage, supply current, motor speed, and load torque in a copy of Table A62-1 located in the Results section at the end of this assignment. An additional column for a brief comment on the sound of the motor has been provided.

For line 1 of Table A62-1, record the measurements with no load applied. For line 2, use the Prony brake to apply 0.4 Nm of load and record the measurements again.

Fault Condition Measurements

Complete Table A62-2 with values applicable for each line fault condition as follows;

Line 3 — Low value start capacitor. Switch off the motor supply. Wait for the shaft to stop rotating, then disconnect the 2 μF capacitor on 67-190. Switch on the motor supply and observe the behaviour of the motor. Repeat this test for values of starting capacitance 10, 8, 6, 4 and 2 μF. Note briefly the effect of reducing the capacitance:

- on the acceleration, in the speed column.
- on the starting torque, in the torque column.

Note the sound of the motor when stalled. Restore the full capacitance value when finished.

Line 4 Open-circuit start winding. With the supply off, disconnect one of leads of coil 3 on the stator. Switch on the supply and note the results. Switch off and reconnect the lead.

Line 5 Short-circuited start coil. Short-circuit coil 3 with a 4 mm plug lead connected between its sockets. Apply power to the motor and complete line 5 of the table.

Line 6 Short-circuited start coil, with load. Apply a gradually increasing load, up to 0.4 Nm, and note the general behaviour of the speed. (Exact speed measurements may be difficult at the higher values of torque, and are not required). Remove the short-circuit when this test is complete.

Line 7 Excessive load torque at start. Set the brake load to minimum. Run the motor up to speed. Increase the torque until the speed starts to fall fairly quickly with increasing load. Switch off the motor supply and wait for the motor to stop. Switch the supply on and complete line 7 of the table. Then switch off and reset the brake load to minimum.

Line 8 Open-circuit in main winding. Make sure the supply is switched off. Disconnect one lead from coil 2 and ensure that the free end is in a safe position, away from the shaft. Run the motor up to full speed, then gradually apply load up to 0.4 Nm. It may at this stage be difficult to measure speed and current, so complete the table entry using approximate figures. Switch off the supply, wait for the motor to stop and reconnect coil 2.

Line 9 Short-circuit in main winding. Connect a 4 mm plug lead between the sockets on coil 2. Switch on the supply. Complete line 9 of the table. Switch off and remove the short-circuit.

Line 10 Open-circuit main winding. Disconnect the lead from coil 10 to the 4 mm terminal on the 62-100 base casting. Switch on the motor supply and enter your observations in line 10 of the table. Switch off the supply.

DISCUSSION

Industrial induction motors are constructed in such a way that usually the only electrical connections easily accessible are the supply terminals. To determine whether a change in the running conditions has taken place, the easiest check is usually the speed (using stroboscopic methods, which require no access to the terminals at all). The maintenance engineer can usually then measure the voltage(s) and currents at the motor terminals, and the power supplied. These may be compared with previously recorded results. Where changes have taken place, they may be due to changes in the mechanical load, so that some judgement is needed in interpreting the test results.

The symptoms induced in the 62-100 during the experiment will not necessarily appear, or lead to a correct diagnosis of a fault, on every occasion. Rather, the assignment has shown the kind of systematic approach to measurement and observation of behaviour which can direct the maintenance engineer's attention to particular problem areas. It is possible that complete coils may become short-circuited, but in most cases there will be only some shorted turns. The effects on performance may not be easy to notice; often the fault will lead to local hot-spots, which, if neglected, will lead to insulation failure and/or a burn-out.

SUMMARY

Various faults have been investigated, with results summed up in your table. Compare these with the typical results given at the end of the assignment.

Review of Table Results

Lines 1 and 2 are a basis for comparison, off-load and on-load respectively.

Line 3 showed the deterioration of starting torque as capacitor performance is degraded. The high current in both stator and rotor under stalled conditions can easily burn a motor out if it is not switched off. In capacitor-run motors, reduced capacitance also affects the running torque and current.

Line 4 is like an extreme case of line 3, with zero-starting torque. It can be caused by any break in the starting circuit, such as a broken wire, faulty starting switch, open-circuit capacitor or open-circuit coil.

Line 5 showed that a partial short-circuit of the start winding (in this case shorting out one of the four coils) did not prevent starting, although it did substantially increase the running current.

Line 6 (similar conditions, but on load) showed that the available running torque was also reduced. In a practical case with some turns short-circuited, over-heating is likely to occur, resulting in progressive breakdown of the insulation.

Line 7 resembles lines 3 and 4, showing that excessive mechanical load when attempting to start the motor produces very similar results to electrical faults of kinds which reduce the available starting torque. This is perhaps not surprising, but indicates that whenever a failure to start is reported, the mechanical load should be examined as a possible cause, in additional to possible causes within the motor and its circuit.

Lines 8, 9 and 10 dealt with faults related to the main winding of the motor.

Line 8 was a case where one of two parallel paths in the main winding was open-circuit. The resultant reduction in current, although slight, produced a reduction in power output. Note however that the current in the remaining part-winding was increased some 50 or 60%, so that the heat generated by it would be increased well over twofold.

Line 9 showed that one short-circuited coil can cause even the no-load current to exceed full-load rating. With a mechanical load applied as well, the current overload will be worse, and the motor would tend to stall, or might oscillate about the range of speed which operates the starting switch.

Line 10 shows that in the case of completely open-circuit main winding, the motor does not start. The presence of start-winding current however confirms the presence of the supply. In many cases prolonged energisation of the start winding at stall will burn it out.

Practical 62.1

Fault		Supply Current (A)	Speed (rpm)	Torque (Nm)	Motor Noise
1	None (minimum load)			minimum	
2	None (0.4 Nm load)			0.4	
3	Start Capacitor 12 μF				
3a	Start Capacitor 10 μF				
3b	Start Capacitor 8 μF				
3c	Start Capacitor 6 μF				
3d	Start Capacitor 4 μF				
3e	Start Capacitor 2 μF				
4	Open Circuit Start Windings			minimum	
5	Short Circuit Start Coil (minimum load)			minimum	
6	Short Circuit Start Coil (0.4 Nm load)			0.4	
7	Excessive Load Torque on Start-up				
8	Open Circuited Path in Main Wiring			0.4	
9	Short Circuit in Main Wiring			minimum	
10	Open Circuit in Main Wiring			minimum	

Table A62-1: Fault Conditions Results

Notes

Practical 62.1

Fault		Supply Current (A)	Speed (rpm)	Torque (Nm)	Motor Noise
1	None (minimum load)	2.6	1470	minimum	Low level whine
2	None (0.4 Nm load)	2.9	1360	0.4	Reduced frequency whine
3	Start Capacitor 12 µF	4.5 (at stall)	Starting acceleration reduced	Starting torque reduced	Hum at stall
3a	Start Capacitor 10 µF				
3b	Start Capacitor 8 µF				
3c	Start Capacitor 6 µF				
3d	Start Capacitor 4 µF				
3e	Start Capacitor 2 µF				
4	Open Circuit Start Windings	4.6	0	minimum	Hum at stall
5	Short Circuit Start Coil (minimum load)	2.8	1420	minimum	Whining and drumming
6	Short Circuit Start Coil (0.4 Nm load)	3.5 (varying)	Falling, hard to measure	0.4	Whining and drumming
7	Excessive Load Torque on Start-up	4.0	0	About 0.15	Buzzing sound
8	Open Circuited Path in Main Wiring	2.3 (varying)	Falling, hard to measure	0.4	Varying whine switch operating
9	Short Circuit in Main Wiring	4.0	1400	minimum	Loud, low frequency hum
10	Open Circuit in Main Wiring	0.7	0	minimum	none

Table A62-1: Fault Conditions Results

Notes

THE MAGNETIC CIRCUIT

The magnetic circuit of one form of electrical machine is shown in Figure A-1. It shows a flux path applicable to many ac and dc motors and generators, where flux travels in a closed path from a magnetically north pole face through the air gaps and rotor to a magnetically south pole face, returning through the surrounding frame. The excitation or magneto-motive force F required to drive flux through the circuit is developed by the field coils and is proportional to the total number of turns T and the current 1 in each turn.

In SI units F = IT ampere turns.

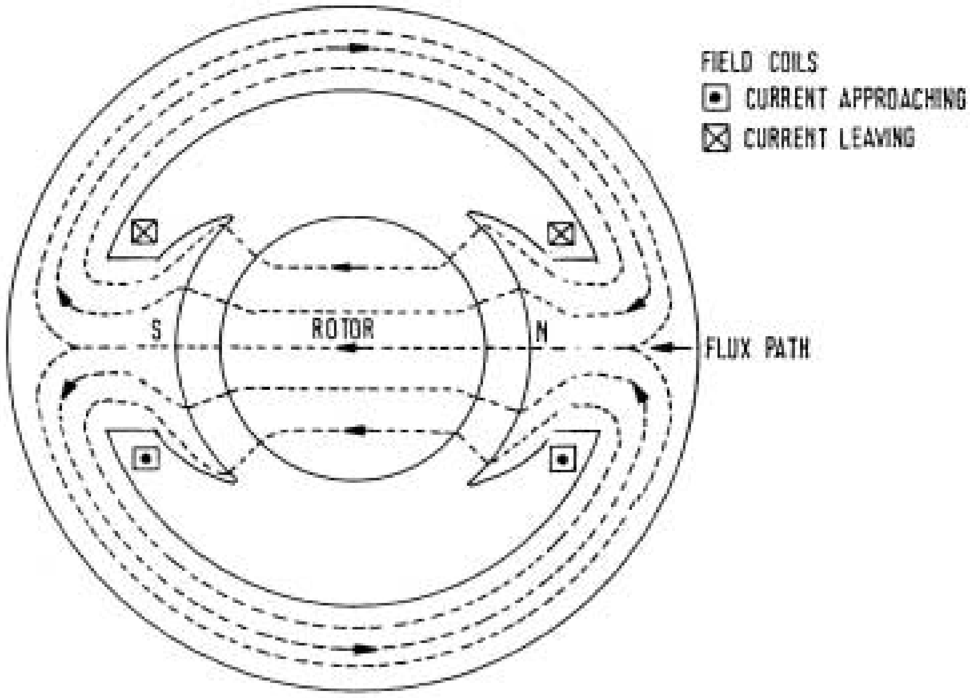


Figure A-1: Magnetic Circuit of Electrical Machines

The value of flux flowing in the magnetic circuit is proportional to the excitation ampere turns and inversely proportional to the total reluctance of the circuit, Rm. Reluctance is a measure of the opposition offered to the passage of flux by the materials which form the magnetic circuit.

$$\text{Flux} = \frac{\text{Excitation}}{\text{Reluctance}} \text{ or } \Phi = \frac{F}{R_m}$$

where: ϕ = flux in Webers (Wb)

F = excitation, ampere turns (A)

R_m = reluctance, (A/Wb)

This is analogous to an electrical circuit where:

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}}$$

The reluctance of any part of the magnetic circuit can be calculated from the equation:

$$\text{Reluctance}, R_m = \frac{1}{\mu} \cdot \frac{l}{a}$$

Where: μ = absolute permeability of the material

l = length of flux path

a = cross-sectional area

This resembles the electrical equation for resistance:

$$R = \rho . \frac{l}{a}$$

where the inverse of permeability $\frac{1}{\mu}$ is analogous to:

resistivity ρ.

The total reluctance of the magnetic circuit is the sum of the reluctances of each section; poles, air gaps, rotor, frame, etc, and the flux in the circuit is dependent upon the excitation ampere turns and the total reluctance.

$R_{m\ total} = R_{m1} + R_{m2} + R_{m3}$.................

Excitation Requirements

In general, the flux levels in different parts of the circuit bear a simple relationship to one another, ie, the flux in the pole body is twice that in a section of the frame. However, in some sections the effect of magnetic leakage has to be taken into consideration. One of these is the region around the pole tips, where some flux will flow to the frame or to an adjacent pole.

As it is the air gap flux which determines the output of the machine, this is termed useful and the leakage factor is expressed as:

$$\frac{\text{total flux}}{\text{useful flux}} = \frac{\text{useful flux} + \text{leakage flux}}{\text{useful flux}}$$

a typical value being 1.2.

The ampere turns required to produce a given value of flux in any section of the magnetic circuit is given by the equation.

$F = \Phi R_m$ ampere turns

and since $R_m = \frac{1}{\mu}.\frac{l}{a}$ and $\frac{\Phi}{a}$ = flux density, B

$$F = \frac{B}{\mu} l \text{ ampere turns}$$

The total ampere turns required for the magnetic circuit is the sum of the pole, air gap, frame, teeth, etc ampere turns.

$$T_{total} = F_1 + F_2 + F_3 \quad \text{AT}$$

$$= \frac{B_1}{\mu_1} l_1 + \frac{B_2}{\mu_2} l_2 + \frac{B_3}{\mu_3} l_3 \quad \text{AT}$$

For the air gap, $AT = \frac{B}{\mu_0} l$

Where $\mu_o = 4\pi \times 10^{-7}$

$$\therefore AT_{gap} = \frac{B}{4\pi} \times 10^{7} l$$

$$= 796 \times 10^3 \times Bl$$

With an air gap 0.001 meters long and with a flux density of 0.7 Tesla (weber per m^2) in the gap

$AT_{gap} = 796 \times 10^3 \times 0.7 \times 0.001$

= 557 ampere turns

required for a range of flux densities in the material.

The graph in Figure A-2 is for the silicon steel used in the 62-100, and shows flux density in Tesla against excitation in AT per meter of flux path.

For the field poles, assuming a flux density of say,1.3 Tesla, from the graph:

AT per meter	= 398
Length of pole Body	= 0.21 m
AT pole	= 398 x 021 = 8.4 ampere turns

Other parts of the magnetic circuit are calculated in a similar way and the individual values of the ampere turns added to obtain the total ampere turns, usually as AT per pole. The air gap ampere turns comprise by far the greatest proportion of the total.

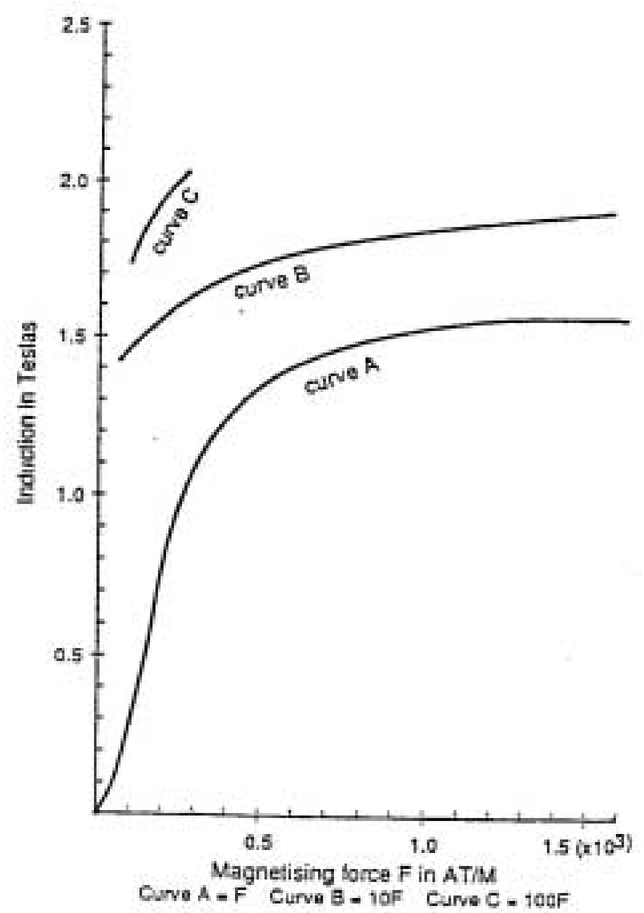


Figure A-2: Typical dc Magnetisation Curve (Ferrosil 216) (Reproduced by courtesy of the British Steel Corporation)

CONDUCTOR IN A MAGNETIC FIELD

Motor Effect

A conductor carrying a current I produces concentric lines of magnetic flux, as shown in Figure A-3. The right-hand grip rule can be used to show the direction of flux around a current carrying conductor. In this case, the thumb represents the direction of current and the fingers the flux surrounding the conductor.

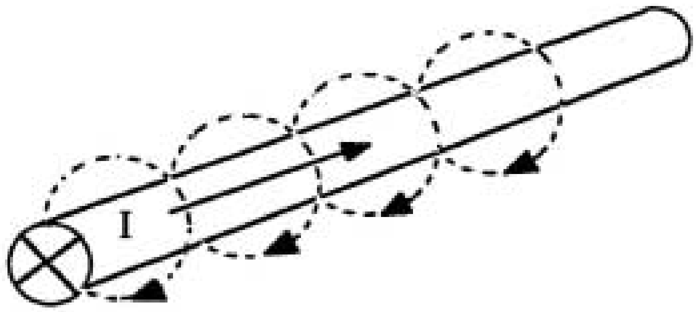


Figure A-3

If a conductor of length l lies perpendicular to a magnetic field of flux density B, the interaction between the flux due to current I in conductor and the field flux causes a force F to be exerted on the conductor as given by the equation:

$F = BIl$ newtons see Figure A-4

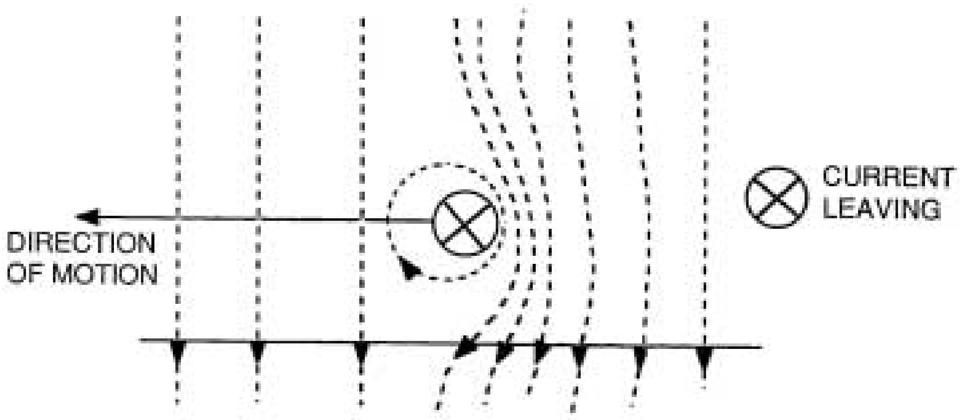


Figure A-4: The direction of motion of the conductor relative to the field and the current flow

Generator Effect

If a conductor, not connected to any external power source, is moved through a magnetic field by the application of an external force, as in Figure A-5, an emf will be generated between the ends of the conductor, proportional to the rate at which it cuts lines of flux.

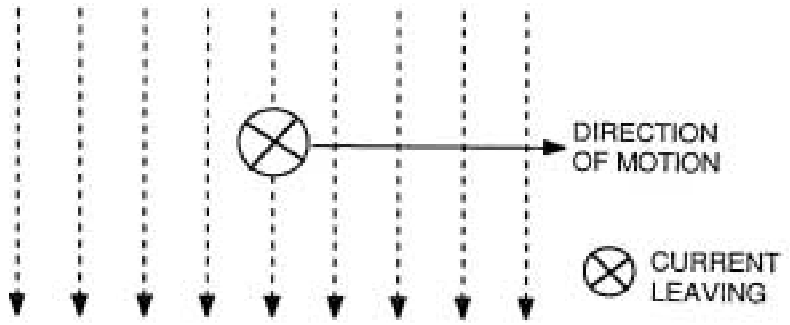


Figure A-5: Generator Effect

The magnitude of the voltage generated is:

$$E = \frac{\Phi}{t} \text{ volts}$$

where Φ = flux cut by conductor, webers

t = time in seconds

but since Φ = flux density x area of field cut by conductor

$$E = \frac{Ba}{t} = \text{Biv volts}$$

where B = flux density, Tesla

l = active length of conductor, meters

V = velocity of conductor, m/s

With the conductor connected to an external load, the direction of current flow is given by Fleming's Right-hand Rule, in which the thumb, first finger and second finger are set perpendicular to one another. Then the thumb showing the direction of motion and the first finger the direction of flux the second finger gives the direction of current flow. See Figure A-6.

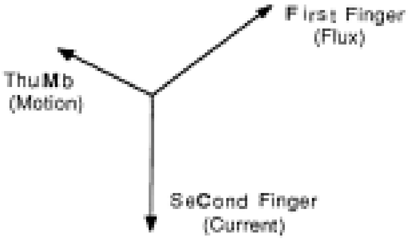


Figure A-6: Right-hand Rule for Generator

If the rotor of the Elementary Generator of Machine in Assignment 12 is driven at 300 rev/min and its diameter is 0.1 meter, the velocity of each conductor is:

$$\pi \text{ x } \frac{0.1 \text{ x } 300}{60} \text{ m/s}$$

Also, taking the active length under the poles to be 1/30 meter, and the flux density in the air gap as 0.7 Tesla, the voltage generated per conductor is:

$$0.7 x \frac{\pi}{10} x \frac{300}{60} x \frac{1}{30} = 0.037 \text{ volts}$$

The four conductors which form the two-turn coil would generate 0.148 volt under these conditions.

Induced EMF

When the flux through a coil increases or decreases, an emf is induced in the coil which is proportional to the rate of change of flux. The magnitude of this emf is:

$$E = \frac{\Phi}{t} \text{ x T volts}$$

where Φ = change of flux, webers
t = time in seconds
T = no. of turns in coil
E = average emf

There are many different ways in which the level of flux in a coil may be changed, but they may be summarised as:

1. Relative movement between a coil and a magnetic system – rotating electrical machines are examples of this. In a conventional ac generator, the flux in each stator coil is continually reversed as the poles move past it. The effect of varying the flux through the coil may be demonstrated by connecting an L4 coil to a sensitive centre-zero millivoltmeter and rapidly moving a strong bar magnet into the centre of the coil. As the flux linking the coil increases, an emf is induced in it causing the

meter to deflect in one direction. When the magnet is withdrawn, the induced emf and meter deflection are reversed.

2. A change of current in a primary coil causes an emf to be induced in a secondary coil which is magnetically coupled to it. In a transformer, the primary winding is connected to an alternating current source and sets up an alternating magnetic flux. This produces an induced emf in the secondary winding which alternates at the same frequency as the supply. In an ideal transformer, with no flux leakage between windings, coils of zero resistance, etc, the relationship between primary and secondary voltage is:

$$\frac{V_s}{V_p} = \frac{\text{number of secondary turns}}{\text{number of primary turns}} = \frac{T_s}{T_p}$$

and between primary and secondary load current is:

$$\frac{I_s}{I_p} = \frac{T_p}{T_s}$$

Power system transformers have coils wound on a core made from a ferromagnetic material, such as silicon steel. This gives a low reluctance magnetic circuit with negligible flux leakage. The effect of resistance, reactance, etc are not negligible but are sufficiently small within the load range of the transformer for the above relationships to be approximately true.

ROTATING FIELDS

When the field coils of an electrical machine are energised from a single-phase source, the polarity of the resulting magnetic field will alternate but the path taken by the flux will not change. If the field windings are so arranged that they can be connected to a polyphase supply, the magnetic field will now be of fixed magnitude but will rotate at a speed determined by the frequency of the supply and the number of poles per phase.

In Figure A-7 is shown a three-phase stator winding A-A' , B-B', C-C' which is connected to a three-phase supply. There are two poles per phase and the two coils of each phase are connected in series. The graph in the lower part of the diagram shows one complete cycle of the three-phase supply, and values of current in each phase may be read off this graph at any point in the cycle.

The stator sections in the upper part of the diagram show the flux patterns at six points in the cycle, points 1 and 7, the start and finish, being identical. Positive-going currents are taken to flow from A to A', B to B', C to C', negative-going currents from A' to A, etc. By drawing in the direction of current in each winding at any point in the cycle, the direction of flux in each pole can be determined using the right-hand grip rule and assuming each coil is wound in the same direction. In this diagram, a compass needle shows the mean direction of flux in each case and it is seen that it turns through a full revolution for one cycle of the electrical supply.

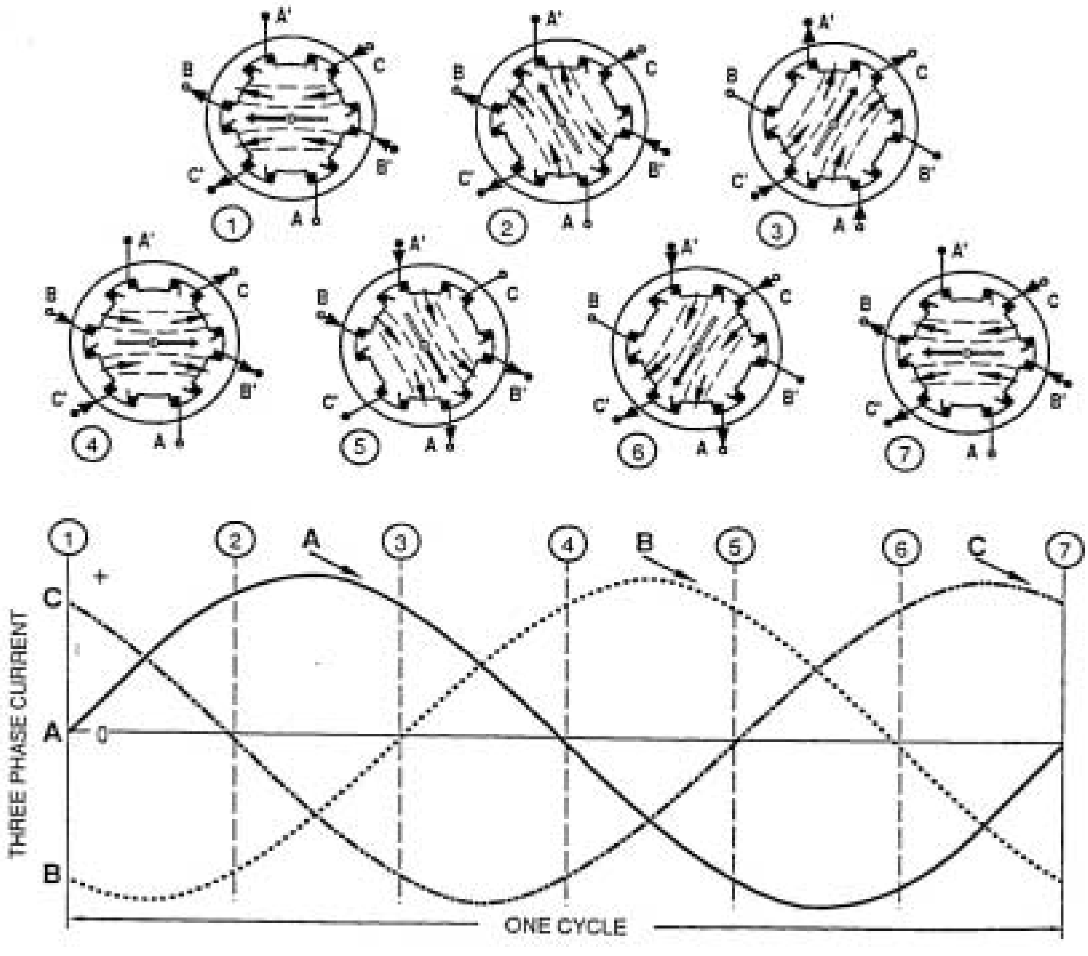


Figure A-7

The magnetic field developed by the stator windings of a polyphase machine rotates at a speed given by the equation:

$$n = \frac{f}{p} \text{ x } 60$$

where n = revolutions/minute
f = supply frequency, Hz
p = pole pairs per phase

Most polyphase electrical machines are either two-phase or three-phase, although systems with six or more phases are used. The single-phase induction motor is often started up as a two-phase machine and may run as one. In this case, one of the two stator windings is connected to the supply via a capacitor which produces a phase difference in the currents through the two windings. Alternatively, the start winding may have wire of small diameter than is used in the main winding so increasing its resistive component and producing the required phase shift.

In the single-phase induction motor assemblies described later in this manual, the resistor/capacitor board is connected in series with the start winding.

COMMUTATION AND ARMATURE REACTION

In the elementary dc generator shown in Figure A-8, each armature coil-side passes alternately under North and South field poles so generating an emf which alternates in polarity. To produce a uni-directional output at the terminals of the generator, a commutator is used to reverse the connections to the coil when the emf induced in it passes through zero. This occurs when the coil sides are in the magnetic neutral plane (MNP).

In a multicoil armature, the main field is distorted by a flux due to load current flowing in the armature coils, and the magnetic neutral plane is shifted away from the geometric neutral plane (GNP) by an amount which is dependent on the strength of the armature current.

To obtain good commutation it is necessary either to move the brushes so that commutation again occurs in the magnetic neutral plane, or to produce an additional magnetic flux to compensate for that due to armature reaction.

Shifting the brushes has the disadvantage that each value of load current requires a particular brush setting, although in practice a compromise setting may be used.

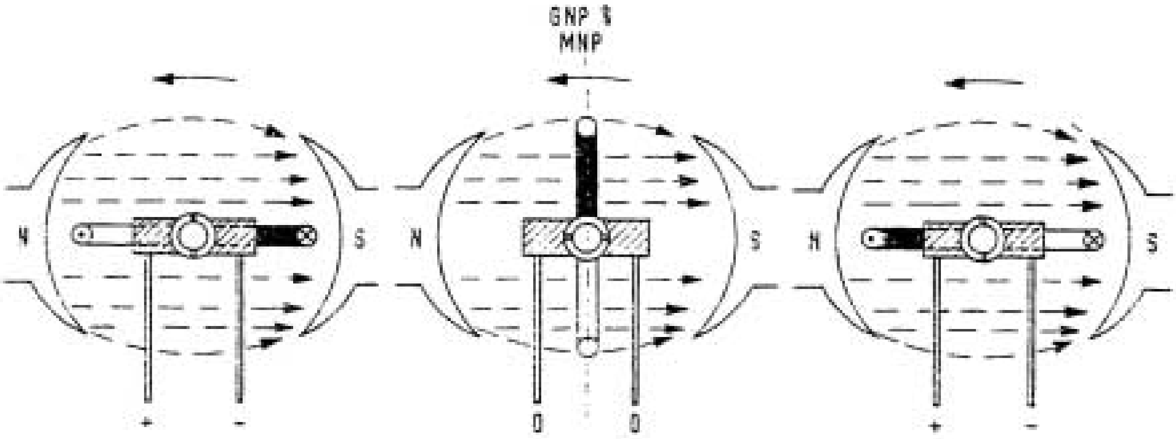


Figure A-8: Commutation in Generator Armature Coil

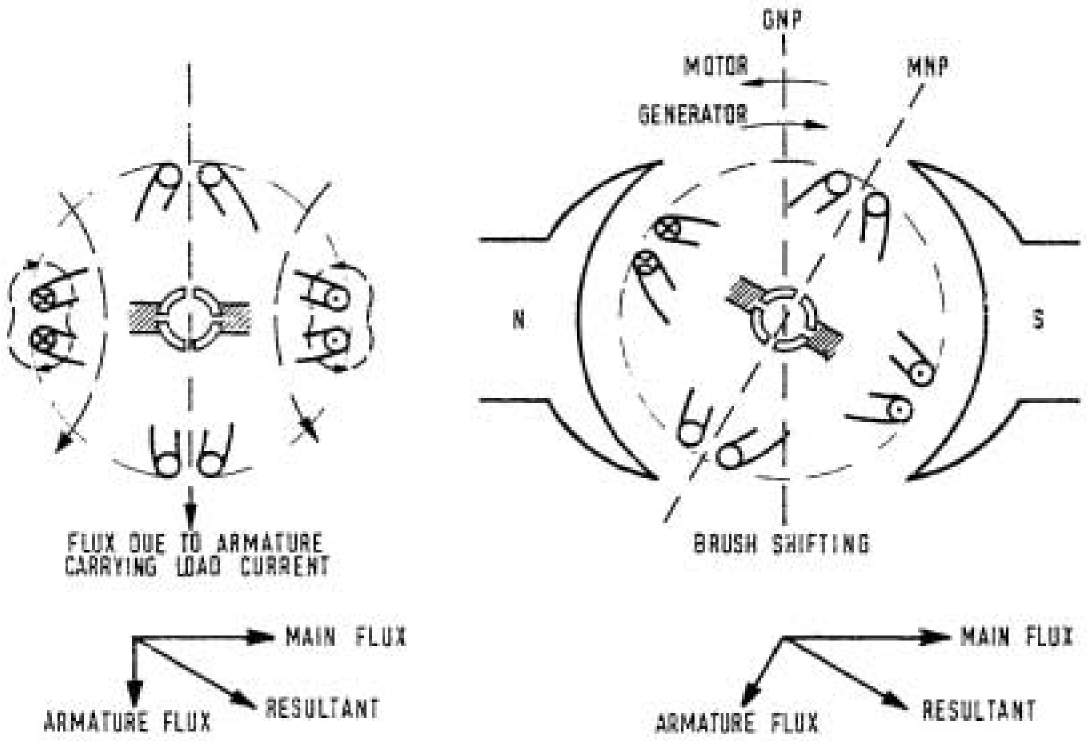


Figure A-9: Field Distortion due to Armature Reaction

One method of producing a flux to counteract that due to armature reaction is to place interpoles between the main field poles and connect the interpole coils in series with the armature. The interpole flux thus varies with armature current and will improve commutation, without brush shifting, over the load range of the machine.

Application to 62-100

Interpoles — Interpoles are provided and should be connected as follows.

Motors — Interpole to have opposite polarity to that of next main pole with respect to direction of rotation.

Generators — Interpole to have some polarity as that of next main pole with respect to direction of rotation.

Commutator Adjustment — Rotatable brushgear is not provided in the basic 62-100 kit but is available either as RB185 Rotatable Brushgear, or as part of MTK181 Motor Test Kit. However, shifting the angular position of the commutator relative to the armature coils produces the same effect as a shift in brush position. The following procedure applies to all the dc machine assemblies:

1. Assemble the armature as in Utility Sheet 62-100, Chapter 3, Basic Assembly Instruction 1, but do not tighten the set screw on to the shaft.
2. Rotate the commutator by approximately 20° in the direction given below (the best angular setting is found by trial, with the machine on load).

Motors — Shift the commutator in the direction of rotation.

Generators — Shift the commutator opposite to the direction of rotation.

Brush Shifting — If rotatable brushgear is used it should be adjusted as follows:

Motors — Shift the brushes opposite to the direction of rotation.

Generators — Shift the brushes in the direction of rotation.

SIMPLIFIED MOTOR, GENERATOR AND TORQUE EQUATIONS

A great deal can be predicted about the behaviour of motors and generators, especially dc types, by the application of simplified equations relating the speed, back-emf, field current, armature current, armature resistance and torque. These equations are easily understood and use constant factors to take into account the complex effects of magnetic flux leakage, copper and iron losses, etc.

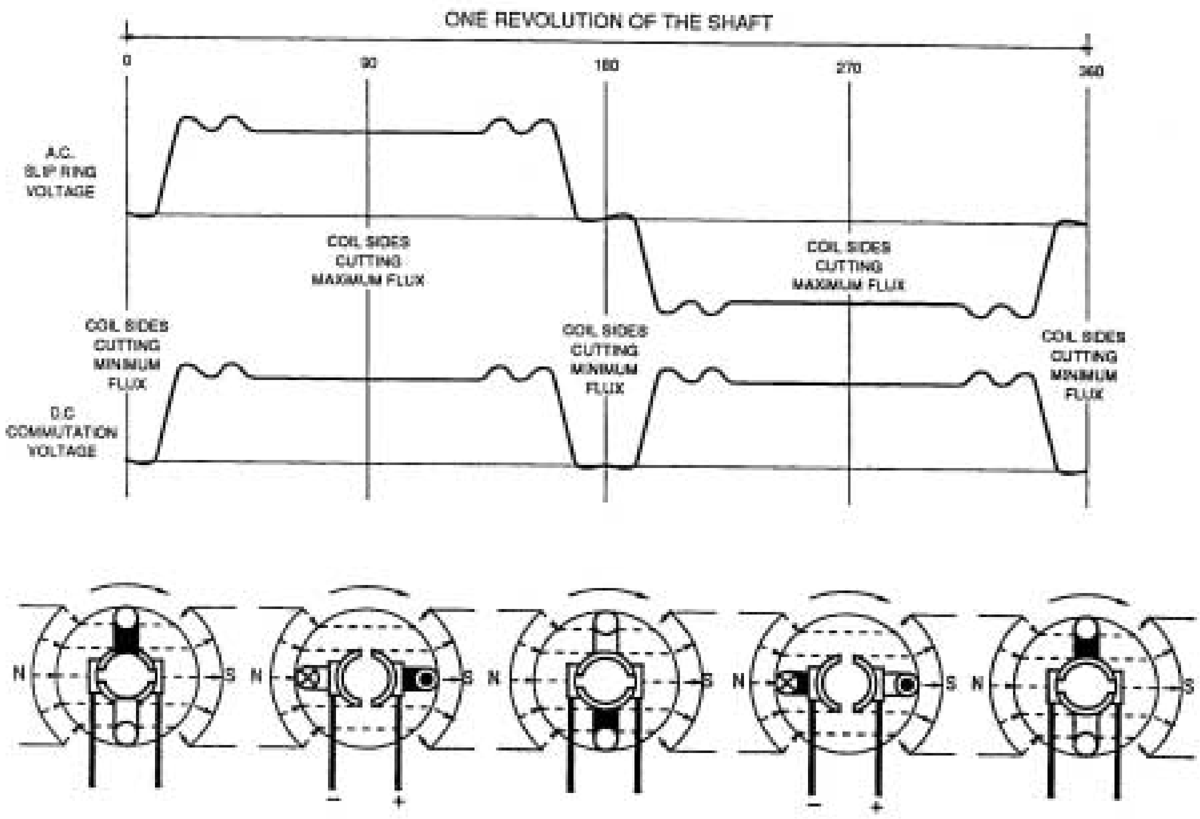


Figure A-10: The Action of the Elementary Generator

Generated emf

We saw earlier that the commutator of a dc machine serves to ensure that the emf appearing between the brushes is unidirectional, but nevertheless it varies between zero, when the side of the armature coil is in the geometric neutral plane, and a maximum when it is opposite a pole. The action of an elementary generator whose rotor winding is on an iron core is shown in Figure A-10. The magnetic field is substantially radial and of more or less constant flux density over the pole face. The generated emf is thus fairly constant over the pole face angle but drops sharply as the neutral plane is approached. These waveforms will be altered by armature reaction, as already mentioned earlier, but this will be disregarded in what follows.

Although subject to variation as shown, the emf has an average value which is governed by:

The total magnetic flux caused by the field current and cut by the coil in rotating,

The speed of rotation of the coil,

The number of turns in the coil.

If the total flux is denoted by 0, E is the generated emf in volts and N the rotational speed in revolutions per minute, then:

$$E = K_1 N\Phi$$

where the constant K1 includes all the unspecified factors such as flux leakage, number of turns in the coil, length of the coil sides and unit conversion constants.

Generator Equation

If a generator producing an emf E and having armature resistance Ra is loaded by an external circuit such that an armature current la flows, then the terminal voltage will be reduced below E by the resistive voltage drop in the armature.

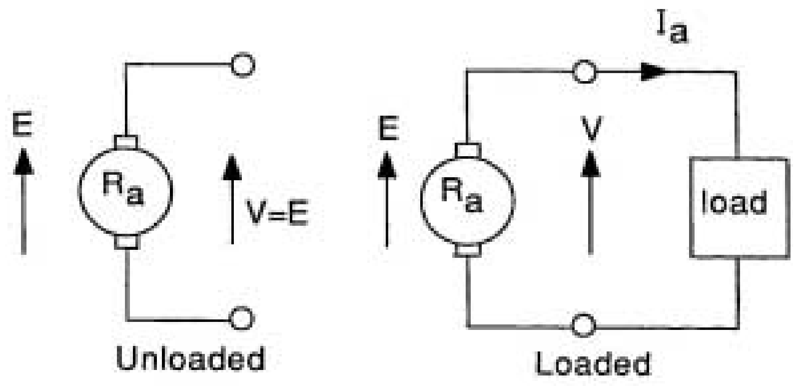


Figure A-11: Generator

In the unloaded case V = E

In the loaded case $V = E - I_a R_a$

This is the Generation Equation and by substitution for E can also be written as:

$$V = K_1 N\Phi - I_a R_a$$

Motor Equation

When voltage is applied to the armature of a dc motor and the armature rotates, an emf is generated in the armature coil due to its motion in the magnetic field, just as in the case of the generator. Its magnitude is determined by the same expression but it is referred to as the 'back-emf' because it is always in a direction such as to oppose the applied voltage. The armature current which flows is that caused by the difference between the applied voltage and the back-emf, acting across the armature resistance.

That is, by Ohm's Law: $I_a = \dfrac{V - E}{R_a}$

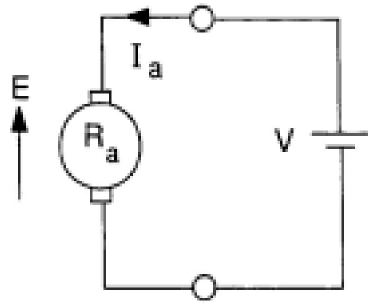


Figure A-12:: Motor

When voltage is first applied and the rotor is still stationary, E = 0 because N = 0

so that $I_a = \dfrac{V}{R_a}$

As the rotor accelerates, N and E increase and thus I_a decreases.

Rearranging the equation gives us:

$$V = E + I_a R_a$$

or:

$$V = K_1 N \Phi + I_a R_a$$

This is the Motor Equation

Torque Equation

In any machine, whether motor or generator, the torque acting between the rotor and stator is governed by:

The flux density of the magnetic field,

The current in the armature coils,

The number of turns in the armature coils,

The distance of the armature coil sides from the centre of rotation,

The length of the coil sides.

As with generated emf, the torque is not steady but fluctuates with the position of the armature coils relative to the magnetic poles. However, it has an average value which can be expressed as:

$$T = K_2 I_a \Phi$$

In this torque equation K_2 is a constant accounting for flux leakage, number of turns in the armature coil, armature geometry, and unit conversion constants.

For a given direction of armature current and a given direction of the magnetic field the torque direction is fixed. Thus we have the two cases of motor and generator as in Figures A-13 and A-14.

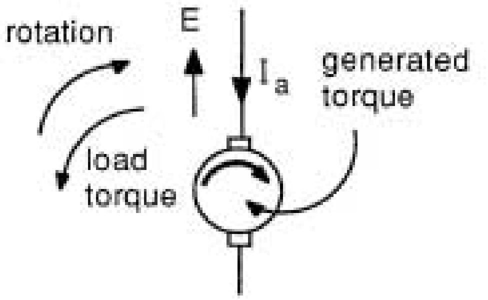


Figure 4-13: Motor

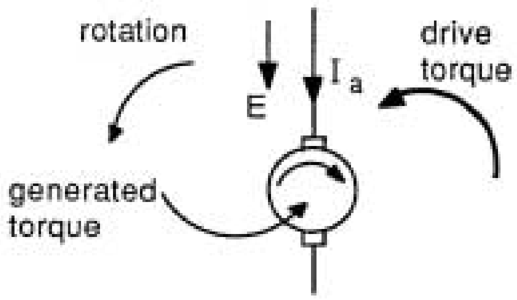


Figure 4-14: Generator

From this can be seen that the difference between a motor and a generator is simply that in the motor, the generated torque is greater than the load torque, causing acceleration of the motor in the direction of the generated torque. Whereas in the generator, the drive torque exceeds the generated torque and the rotor accelerates in the direction of the drive torque.

SUMMARY

Three important equations to remember are:

Generator Equation	$V = K_1 N \Phi - I_a R_a$
Motor Equation	$V = K_1 N \Phi + I_a R_a$
Torque Equation	$T = K_2 I_a \Phi$

If a further assumption is made that the total flux Φ is proportional to the field current I_f so that:

$$\Phi = K_3 I_f$$

The above equations may be expressed as:

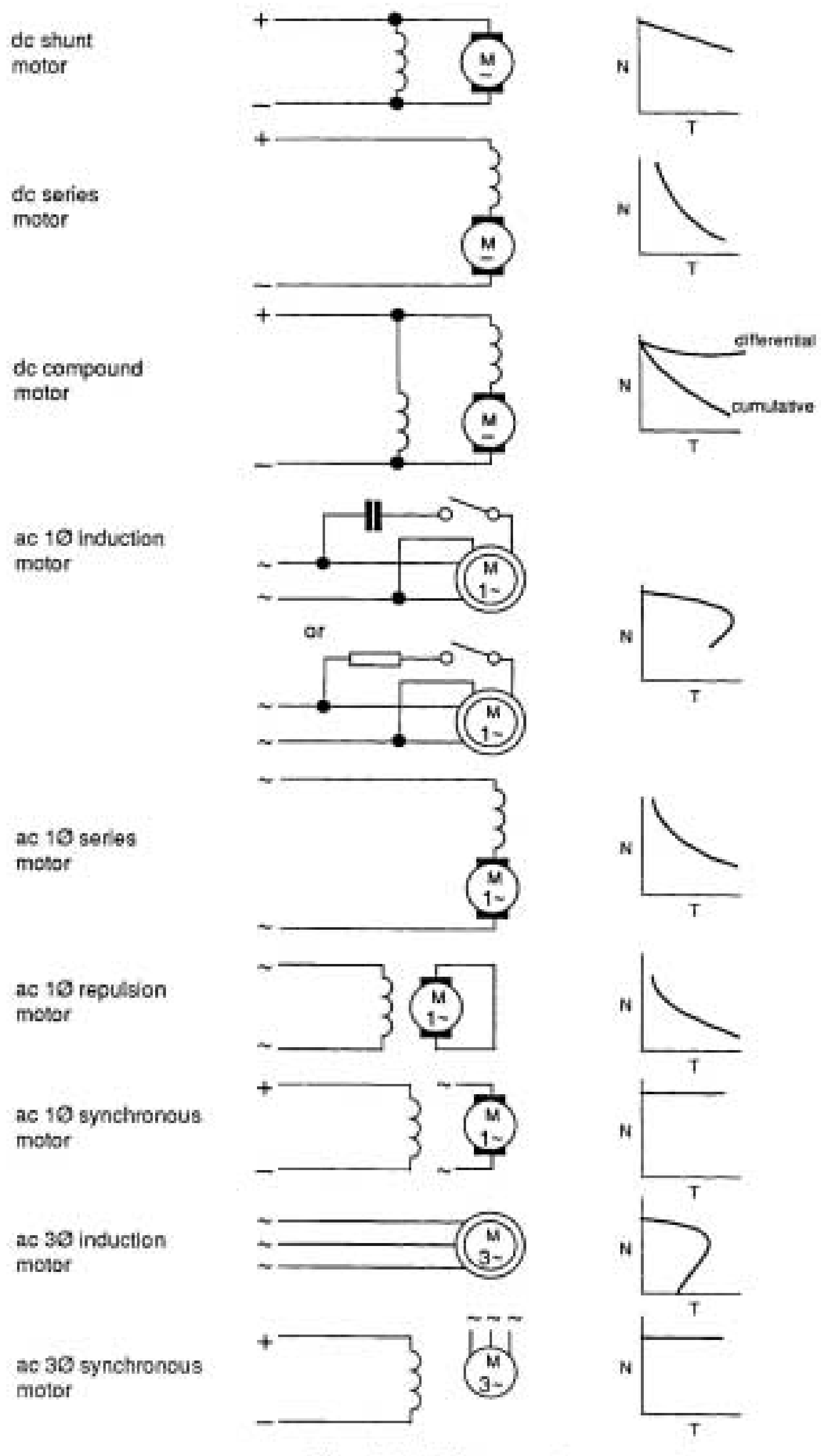
Generator	$V = K_1 K_3 N I_f - I_a R_a$
Motor	$V = K_1 K_3 N I_f + I_a R_a$
Torque	$T = K_2 K_3 I_f I_a$

This set of equations is less accurate than the first since at high field currents, saturation of the core may occur so that a constant relation between I_f and Φ is not justified.

However, if sensibly applied in the knowledge of their limitations they are adequate to explain the basic characteristics of many types of machine.

MACHINE APPLICATIONS

Summary of Characteristics with relevant 62-100 Assemblies



62-100 Assignments

Ass 13, 14

Ass 19, 20

Ass 23, 24

Ass 27, 28, 29, 30

Ass 31, 32

Ass 33, 34

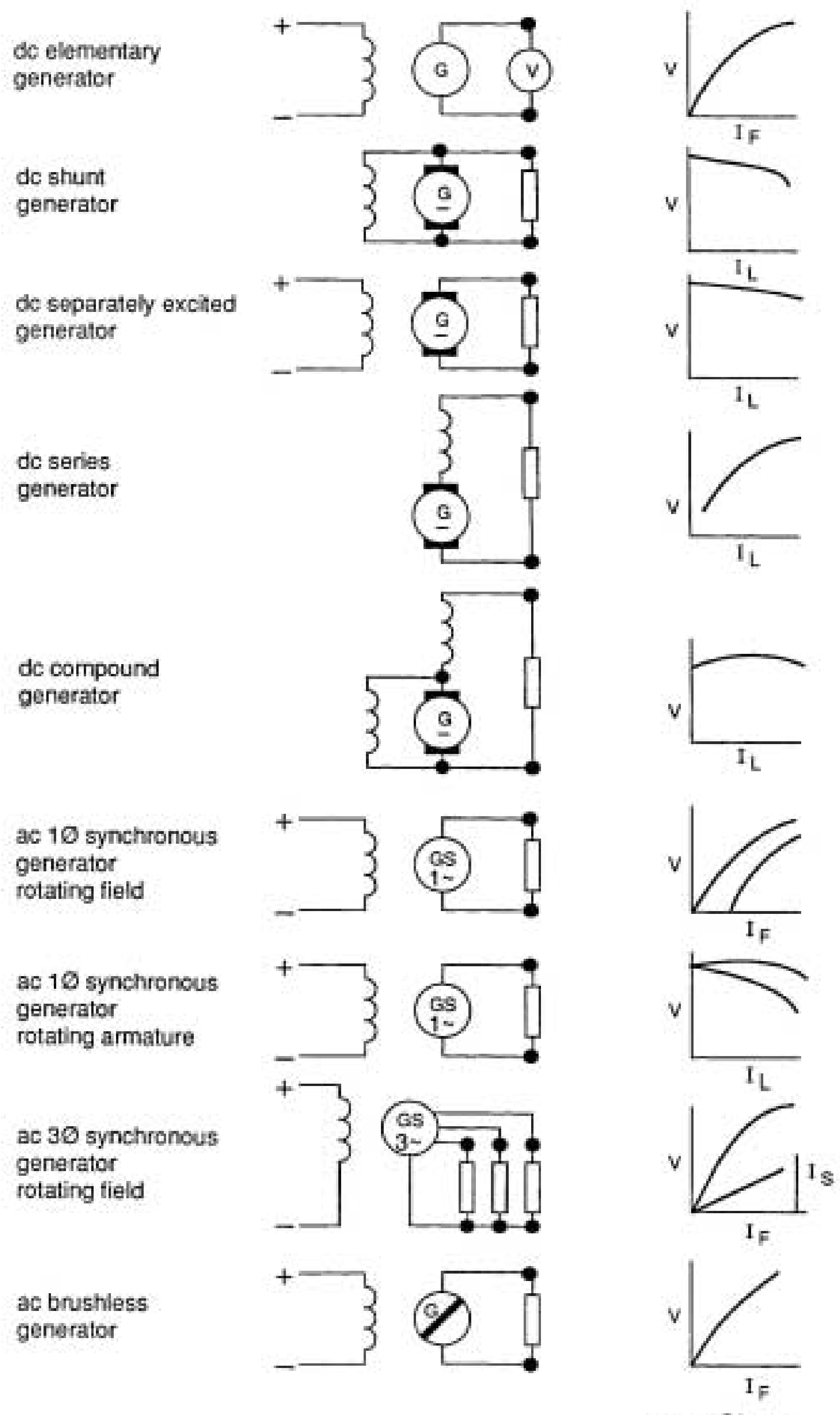
Ass 35, 36

Ass 40, 41

Ass 42

Figure A-15: Motor Reference Sheet

62-100
Assignments



Ass 12

Ass 15, 16

Ass 17, 18

Ass 21, 22

Ass 25, 26

Ass 37, 38

Ass 39

Ass 43

Ass 44

Figure A-16: Generator Reference Sheet

62-100
Assignments

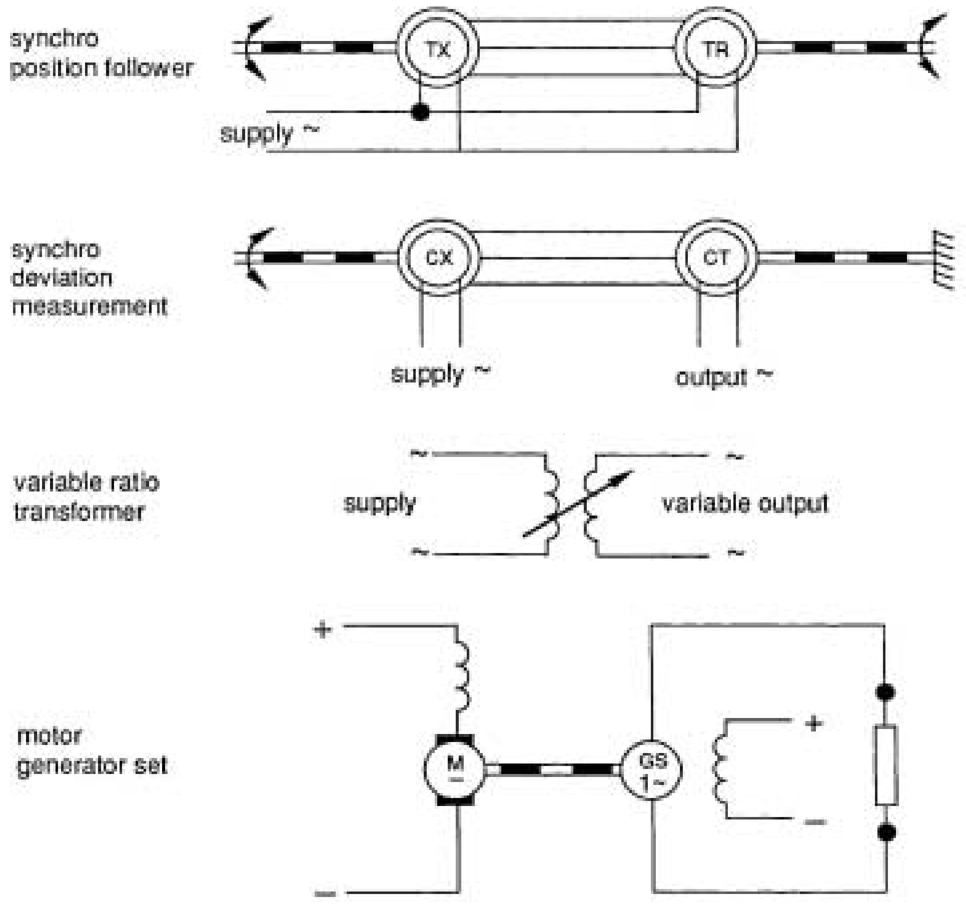


Figure A-17: Other Assemblies

MATCHING THE MOTOR TO ITS LOAD

In selecting a motor for a particular application, consideration should be given to the factors briefly surveyed below to ensure that the motor performs reliably and is economical to purchase and operate.

Survey of Factors to be Considered in Selecting the Motor

Torque/Speed Characteristic

The starting torque and the maximum torque presented by the load at its normal running speed needs to be specified as a first step in the selection of a compatible motor. The relationship between the motor torque/speed curve and that of the load will be dealt with in greater detail later.

Operating Speeds/ Speed Control

The speed may need to be continuously variable or variable in steps with reversing duty in either case. Single-speed operation only may be required. Accurate control of speed may be required with some form of closed-loop system minimize error, or a simple speed regulator may be sufficient.

The use of a geared drive in slow-speed applications may allow a high-speed motor to be used, with a consequent reduction in size and cost.

Special Duties

In some motors, the load may have particular features; eg, torque variation throughout each revolution or rapid acceleration from rest to operating speed These need to be considered at an early stage in the selection of a suitable motor.

Power Supplies

Generally, supplies for ac motors are obtained more readily than for dc motors and can normally be taken directly from the incoming mains. In some cases, a frequency-changer or special transformer connection may need to be used.

DC motor power supply systems vary considerably from a simple, encapsulated bridge rectifier arrangement to the provision of a dc generator driven by a motor powered from the ac supply for the larger machines.

Protective Gear

The provision of adequate motor protection is justified as a means of avoiding damage to the motor itself, damage to the driven equipment, interruption of production or process. The protective equipment must be so designed to present no hazard to the operators when they investigating the fault.

The two principle forms of protection are current sensing devices to disconnect the supply on overload, and thermal devices which operate when the frame or winding temperature reaches a specified limit.

Motor Enclosure

The motor case can take various forms, including screen protected, totally enclosed, weatherproof, drip-proof, flame proof, etc. However, most motors are available as standard in two forms, either drip-proof or totally enclosed fan-cooled. Fixing centres, shaft diameter and height, together with other critical dimensions have now been standardised for both imperial and metric systems.

Reliability

The servicing which the motor will require during its operating life is affected by basic aspects, such as the use of ball races or plain bearing, brush gear in dc machines and the absence of sliding contacts in squirrel-cage motors.

Torque/Speed Characteristics

The torque/speed curve of the load is a composite of several factors - 'stiction' torque when moving from standstill, particularly where plain bearings are used; running friction, often virtually constant with speed; the specific load characteristic; eg, torque proportional to the square or cube of speed as with fans and certain types of pump.

The motor rating is usually fixed on the basis of mean load torque, but where significant periods of running at high torque level can occur or where rapid acceleration is required, the rating of the motor and its supply will be affected.

The following list of motors and their characteristics is by no means complete, but provides examples which can be used to illustrate how specific loads can be accommodated.

Common Types of DC Motors

Shunt Field

Has continuously variable speed range, and is reversible. Simple speed control methods applicable. Speed fails slightly with increasing torque.

Applications
Machine tools, reciprocating pumps, compressors, winding machines, mixing machines, fans.

Separately Excited

Characteristics similar to those of shunt machine. Separate field supply with associated controls required. Rarely used except in larger dc machines.

Applications
Ward Leonard sets, special servo drives.

Series Field

Continuously variable speed range in either direction or rotation. Simple controls where only coarse speed adjustment is required. High speed at low torque failing rapidly as torque is increased. Provides good acceleration but shaft must always be loaded to avoid 'run-away' - flat belt drive to be avoided.

Applications
Cranes, traction machines. A mechanical brake is required during over-run conditions.

Compound Field

Series winding can assist (cumulative) or oppose (differential) the shunt winding. With differential connection, speed can be virtually constant from zero to full load, but on overload the series field may pre-dominate causing motor to reverse. The cumulative connection provides similar characteristics to series motor, but allows the no-load speed to be limited a safe value.

Applications

Cranes, traction machines, machine tools where heavy roughing cuts are carried out at low speeds.

Permanent Magnet Field

Confined to fractional horse power (fhp) and miniature motors. Similar characteristics to shunt field but speed fails more rapidly with increasing torque.

Applications

Servo drives, disc drives and loads where high acceleration required, since a permanent magnet field is often associated with iron-free armatures; eg, printed motor, etc.

Common Types of AC Motor

Single-phase Universal

Similar to a dc series motor with a failing speed/torque characteristic. Suitable only for low powers due to commutation difficulties at high current levels.

Applications

Domestic appliances - vacuum cleaners, small drilling machines.

Single-phase Squirrel-cage Induction

Effectively a single-speed machine though in special cases change-pole methods give two or more running speeds. Speed falls from synchronous value as load is increased (normally up to 5% slip) until the pull-out torque is reached. Capacitor start or run motors have good starting torque and are reversible. Shaded-pole versions have low starting torque and are not reversible.

Applications

Refrigerator compressors, washing machine drives, power tools, water pumps, fans.

Single-phase Synchronous

Available in fhp and miniature sizes. Constant speed independent of load till pull-out torque is reached. Not inherently self-starting but may be made so by impulse, induction or hysteresis starting system. Usually have multi-pole motors designed for low-speed running with or without gearing.

Applications

Low torque paper drives, clocks, gramophone turntables.

Three-phase Squirrel-

Cage Induction

Effectively single-speed but can be designed to give several set speeds by pole-changing. Speed within approximately 5% of synchronous value over load range until pull-out torque is reached. Starting torque usually low but can be increased by use of high resistance squirrel-cage material. Motor is reversible.

Applications
Machine tools, woodworking machines, mixing machines, conveyors, compressors.

Three-phase
Wound-rotor Induction

Differs from squirrel-cage motor in that rotor current can be varied, enabling the starting torque to be increased to twice the full load torque. Also provides means of speed control when motor is running under load.

Applications
Similar to those of squirrel-cage motor but includes cranes and machines with considerable inertia.

Three-phase
Synchronous

Not inherently self-starting but may be made so by use of induction starting winding inserted into pole faces. Constant speed up to pull-out torque level at which motor stall. Capable of high efficiency but requires dc field supply.

Applications
Large compressors, centrifugal pumps, mixing and heavy grinding machines, fans and blowers. Can be used for power factor correction when lightly loaded.

Load Characteristics

A motor will accelerate from rest or from one speed to another provided its torque exceeds that demanded by the load over the desired speed range. This torque difference is known as 'available torque'.

The final running speed is given by the point of intersection of the motor and the load torque speed curves as shown in the examples which follow.

Load Varies
with Speed

Fans, centrifugal pumps, blowers - the load increases as the square or cube of speed. See Figure A-18a.

Generator supplying resistive load - load increases linearly with speed. See Figure A-18b

Suitable Drives
Single-phase or three-phase induction motors.

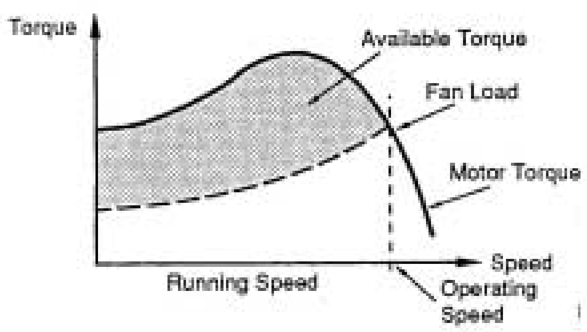


Figure 4-18a

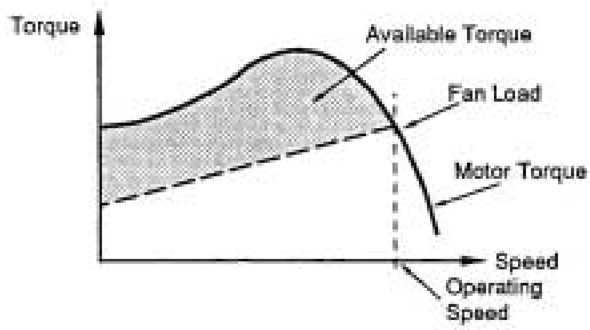


Figure 4-18b

Load Constant with Speed, Figure A-19

Mixing machines, conveyors, compressors.

Suitable drives
DC shunt or compound motor, AC synchronous motor, some forms of squirrel cage induction motor.

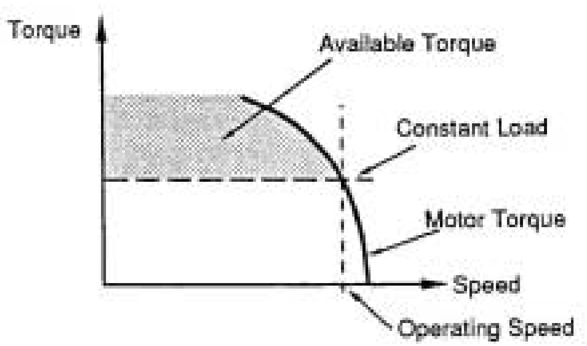


Figure 4-19

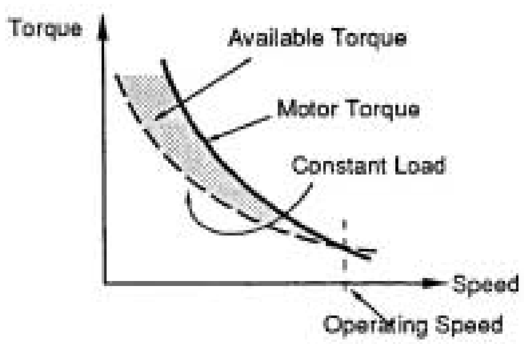


Figure 4-20

Constant Horsepower Load, Figure A-20

Machine tools requiring heavy cuts at low speed and fight industry cuts at high speed. Traction machines.

High Inertia Load

Machines with flywheel or massive rotating parts. Cranes, hoists, lifts.

Suitable Drives
DC series or cumulative compound motor, AC wound rotor induction motor, squirrel-cage motor designed for high starting torque.

Notes

INTRODUCTION

In manufacturing industries such as the manufacture of motor cars, steel, chemicals etc, electric motors are frequently used as the source of mechanical power. If a motor breaks down it can often stop an entire production line. The cost of a stoppage can be many times the value of the machine itself. It is necessary in such cases to reduce as far as possible the cost of breakdowns, and usually this calls for some scheme of regular maintenance aimed at making them less frequent. This is often called 'preventive maintenance', since it is aimed at preventing breakdowns, as distinct from repairing broken-down equipment.

The kind of preventive maintenance scheme required varies according to circumstances, requiring a balance to be struck between the reduction of breakdown costs on one hand, and the cost of the maintenance scheme itself on the other.

MAINTENANCE SCHEMES

No Scheme

Most households operate without any scheme for preventive maintenance of equipment, although the washing machine is one item which may be regularly serviced. What generally happens is that a breakdown occurs, then action is taken to get the equipment repaired. It may take a few hours, or several days, before the item is operational again. This is acceptable in a domestic environment, but not for industrial manufacture, where machine failure is costly.

Fixed Period

This is performed on a calendar basis, each machine or item being maintained at scheduled times. The advantage of this scheme is that those concerned know in advance that a machine will be taken out of service and alternative provisions can be introduced. The disadvantage is that machines may be taken out of service that do not require attention so causing an interruption which is not necessary. In disturbing a machine for maintenance, it is possible to shorten the life of a component that is not faulty.

Fixed Running Time

To operate this scheme it is necessary to keep records of the running times of the various machines. This is not easy, especially when the manufacturing process is changed fairly frequently and the duty cycles of the machines vary throughout the process cycle. Having recorded this information it is possible, with the aid of the manufacturer's information on component life expectancy, to work out when parts need to be replaced and so plan accordingly. This gives a more accurate method of controlling maintenance according to need. However, it can create peak and idle periods for the maintenance staff and draw on other resources over which there is little control.

Planned Preventive Maintenance

This category includes the previous two, but can be taken considerably further. In an ideal preventive maintenance scheme, an enormous amount of information must be acquired and analysed. In addition to manufacturers' recommendations about component replacement and records of running times, a comprehensive history of each unit can help track down the odd item which gives regular trouble; eg, because of faulty manufacture. To achieve this involves noting the serial number of every item handled during the maintenance process, and collation of records in various classifications.

The more elaborate the maintenance scheme is, the more it is likely to cost. The objective should always be to tailor the scheme to minimise the total cost of it and the breakdowns and malfunctions which it prevents.

GENERAL MAINTENANCE PRACTICE

Cleaning

The entry of foreign matter, such as grit, dust, moisture and oil, is the cause of many motor failures. Cleanliness is therefore the first essential in maintenance. The frequency of cleaning necessary will depend mainly on the role the machine has to play in the manufacturing process and the type of motor involved. In some large industrial plants, motors are blown out once a week by means of a supply of dry compressed air or electric blowers. Care should be taken to blow the foreign matter out and not further into the casing where it can affect bearings and insulation. The cleaning of external surfaces is very important because it is through these that heat generated inside the motor by its internal losses is dissipated. A thick layer of dust may result in excessively high running temperatures damaging the insulation, reducing the life of the winding considerably.

Machine Removal

Where many machines are involved it is important to identify the one requiring attention and having done so ensure that it is safe to start work by ensuring the electrical power is isolated and the load is inactive. When disconnecting power cables, identify the leads if necessary and insulate the bare wires to avoid damage and possible hazards whilst the motor is away.

Disconnect couplings, driving belts or whatever is used to transmit the drive. Remove the holding-down nuts or bolts and ensure that any packing shims are marked so that they can be correctly positioned when the motor is refitted.

Inspection

Taking a machine apart requires the removal of many nuts, washers, bolts, clips etc, as well as larger items. It is very desirable that parts (and especially moving parts) be refitted in the same position when the machine is re-assembled. To make this possible, each part, as it is removed, should be marked, labelled or placed in a labelled container (depending on its size and on the circumstances).

Parts may need to be washed or soaked in an appropriate fluid before inspection can begin, in order to clean them, loosen corrosion or lubricate.

Stator

This should be inspected for damage to the insulation, signs of overheating and movement. Discolouration of the insulation may be an indication that the windings have been overheating, and in such cases the cause must be found. The slot wedges must be checked for tightness, as must the windings and turn bracings, to ensure that there is no movement of the windings. If movement is found it must be eliminated because over a period of time it will fray the insulation. The terminal connections and terminal insulators should be examined for signs of overheating due to loose nuts or bolts increasing the terminating resistance and hence power dissipation. An insulation test should be carried out and the result compared with previous tests to see if any deterioration in insulation resistance has occurred.

A slow progressive fall in insulation resistance is the normal result of ageing. A sudden fall indicates either damage or ingress of moisture. The cause should be found. If it appears to be moisture, the windings should be carefully dried (which may be helped by passing dc through the windings to heat them), before taking any action to seal the insulation. After this, if the insulation includes varnish, a fresh coat of insulating varnish may help to prevent further trouble.

The stator core should be examined carefully for signs of damage due to an out-of-true rotor caused by unbalance or a damaged bearing. If the core is damaged, it may be necessary to replace some plates and the insulation between them. If this is not done then excessive heat will be generated in the iron circuit at the point of damage.

Rotor and Armatures

The rotor must be examined for signs of damage. The end rings of a cage-type motor should be checked for cracks, and each rotor bar inspected where it is brazed to the end rings and where it enters and leaves the slot in the iron core. Each bar should be checked for movement in the slot, and the slot wedges checked to ensure that they are tight. If the motor has a wound rotor, the winding insulation must be examined, measured and recorded. Attention to the insulation, if required, will follow similar lines to that described for stators. If a fan is fitted to the shaft, it should be checked for tightness on the shaft and for damage to the blocks.

Slip Rings and Commutators

These should be inspected for signs of overheating and undue wear. The insulation between rings or commutator segments should be inspected for damage and signs of tracking. Winding connections to these should be checked for tightness, and in the case of a commutator, loss of solder at the connection indicates that the winding has been getting too hot. In cases where burning and pitting has occurred, a check should be made for flat spots and ridging. It may be necessary to have the surfaces restored by turning on a lathe to get the correct concentric shape.

Additionally, also check and rectify as necessary the undercutting of inter-segment insulation and the balance of the rotor.

Brushgear

Brushes and brushgear require regular inspection and cleaning especially in continuously running motors where they may need inspection once a week. The brush boxes should be inspected for signs of tracking, cracks and build-up of carbon dust that can cause a conductive path across the surface of insulation. The brush springs and any pivot joint on the spring arms should be cleaned and be able to move freely. If new brushes are fitted, they should be shaped to the contours of the sliprings or commutator so that the whole face of the brush is in contact. The brush spring pressures should be checked by means of a spring balance and adjusted if necessary to the manufacturer's recommended values.

Bearings

Before inspection, it is essential that the surrounding surfaces be cleaned to prevent dirt, grit etc., from entering the bearing housing. Some large low-speed machines may be fitted with a two-piece white metal bearing which requires regular inspection and must always be kept well lubricated. Oil pick-up rings may be fitted to some machines and these should be free to rotate on the shaft. Most machines these days are fitted with ball or roller bearings which are more reliable and require less or no maintenance if they are a sealed type.

The removal of a bearing from its shaft requires the use of wedges and pullers which make light work of removing even the largest bearing. Once the bearing is removed, it can be examined for wear. Excessive movement between the inner and outer case and metal particles round the casing is an indication of a well-worn bearing that must be replaced. Should a bearing be found that is aged it should be cleaned in a suitable fluid and refitted. If at any point during the refitting process it has a tendency to bind, it should be rejected and a new one fitted.

When bearings have been replaced, the locking rings or clips must be refitted (if applicable) and the bearings lubricated (if they are of that type) with grease or oil as recommended by the manufacturer. If a recommended grease is not available, every effort should be made to find a compatible grease, since different additives used in greases can neutralise each other, causing a failure to lubricate. If the grease type is unknown, it may be advisable to wash out the old grease with solvent, before drying and applying new.

Notes