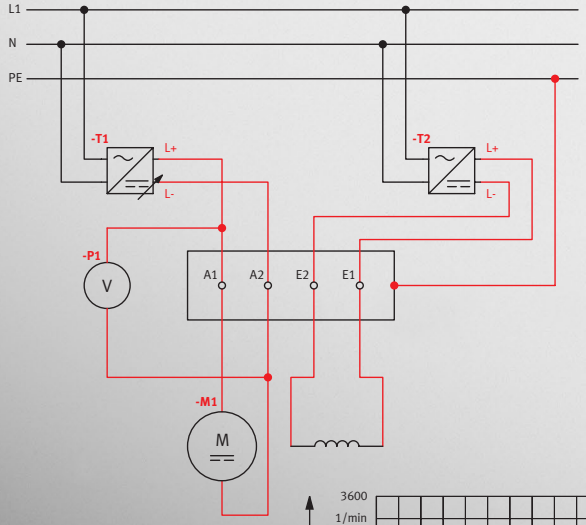
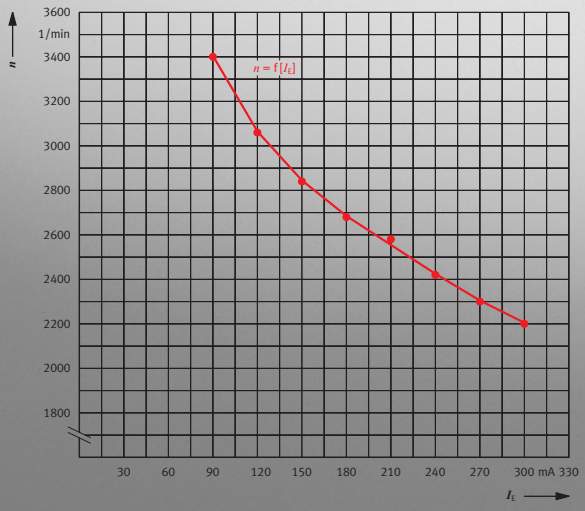
Fundamentals of DC machines

FESTO

Workbook

With CD-ROM





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Use for intended purpose

The training package for “basic principles of direct current machines” may only be used:

- For its intended purpose in teaching and training applications
- When its safety functions are in flawless condition

The components included in the training package are designed in accordance with the latest technology as well as recognised safety rules. However, life and limb of the user and third parties may be endangered, and the components may be impaired, if they are used incorrectly.

The training system from Festo Didactic has been developed and produced exclusively for training and further education in the field of automation technology. The training companies and/or trainers must ensure that all trainees observe the safety instructions described in this workbook.

Festo Didactic hereby excludes any and all liability for damages suffered by trainees, the training company and/or any third parties, which occur during use of the equipment sets in situations which serve any purpose other than training and/or vocational education, unless such damages have been caused by Festo Didactic due to malicious intent or gross negligence.

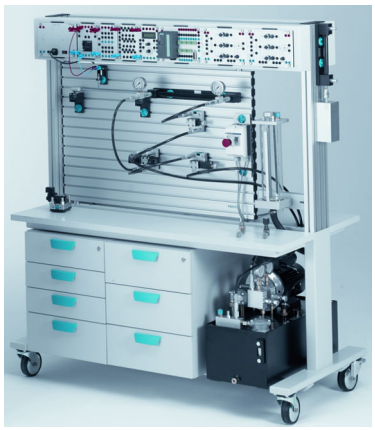
Preface

Festo Didactic's training system for automation and technology is geared towards various educational backgrounds and vocational requirements. The training system is therefore broken down as follows:

- Technology-oriented training packages
- Mechatronics and factory automation
- Process automation and control technology
- Mobile robotics
- Hybrid learning factories

The training system for automation and technology is continuously updated and expanded in accordance with developments in the field of education, as well as actual professional practice.

The technology packages deal with various technologies including pneumatics, electro-pneumatics, hydraulics, electro-hydraulics, proportional hydraulics, programmable logic controllers, sensor technology, electrical engineering, electronics and electric drives.



The modular design of the training system allows for applications which go above and beyond the limitations of the individual training packages. For example, PLC actuation of pneumatic, hydraulic and electric drives is possible.

All training packages feature the following elements:

- Hardware
- Media
- Seminars

Hardware

The hardware in the training packages is comprised of industrial components and systems that are specially designed for training purposes. The components contained in the training packages are specifically designed and selected for the projects in the accompanying media.

Media

The media provided for the individual topics consist of a mixture of teachware and software. The teachware includes:

- Technical literature and textbooks (standard works for teaching basic knowledge)
- Workbooks (practical exercises with supplementary instructions and sample solutions)
- Lexicons, manuals and technical books (which provide technical information on groups of topics for further exploration)
- Transparencies and videos (for easy-to-follow, dynamic instruction)
- Posters (for presenting information in a clear-cut way)

Within the software, the following programmes are available:

- Digital training programmes (learning content specifically designed for virtual training)
- Simulation software
- Visualisation software
- Software for acquiring measurement data
- Project engineering and design engineering software
- Programming software for programmable logic controllers

The teaching and learning media are available in several languages. They are intended for use in classroom instruction, but are also suitable for self-study.

Seminars

A wide range of seminars covering the contents of the training packages round off the system for training and vocational education.

Do you have suggestions or criticism regarding this manual?

If so, send us an e-mail at did@de.festo.com.
The authors and Festo Didactic look forward to your comments.

Introduction

This workbook is part of the training system for automation and technology from Festo Didactic GmbH & Co. KG. The system provides a solid basis for practice-oriented training and continuing vocational education. Training package TP 1410, “Servo brake and drive system” deals with the following topics:

- Basic principles of DC machines
- Basic principles of AC machines
- Basic principles of 3-phase machines

In the field of drive technology, DC drives currently play a major role in mobile drive solutions. The workbook for “Basic principles of DC machines” covers issues relating to DC drives in a targeted fashion. The content is first elaborated theoretically, and then consolidated in exercises. In addition to the design of the machines, their circuitry and areas of application are demonstrated in realistic projects.

Technical prerequisites for setting up the circuits include:

- A laboratory workbench equipped with an A4 frame
- Servo brake and drive system equipment set TP 1410
- A power pack with 0 to 250 V DC, 4 A and 60 to 250 V DC, 1.5 A
- A direct current shunt-wound machine
- A direct current series-wound machine
- Components for controlling the electric machines
- Laboratory safety cables

The circuits for all 6 exercises are set up using the TP 1410 equipment set and the DC drives.

In addition to this, data sheets are available for the individual components (direct current shunt-wound machine, direct current series-wound machine etc.).

Work and safety instructions

General information

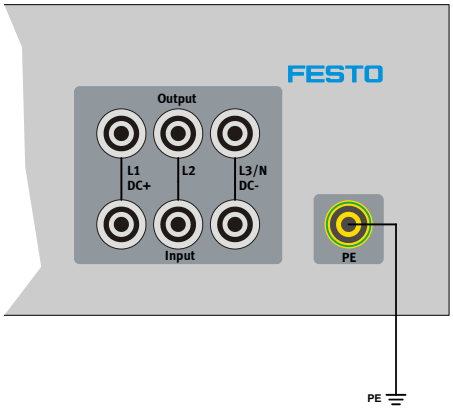
- Trainees should only work with the circuits under the supervision of a trainer.
- Observe specifications included in the technical data for the individual components, and in particular all safety instructions!
- Malfunctions which may impair safety must not be generated in the training environment and must be eliminated immediately.

Mechanical components

- Attach all components intended for mounting of this sort to the A4 frame.
- Adhere to the instructions regarding positioning of the components.

Electrical components

- The servo brake and drive system (motor test bench) may only be placed into service with an additional protective earth conductor.



- Always connect the motor's thermo-switch to the "Motor ϑ" input at the motor test bench.
- Establish or interrupt electrical connections only in the absence of voltage!
- Use only connecting cables with safety plugs for electrical connections.
- Always pull the safety plug when disconnecting connecting cables – never pull the cable.

Training package for “Basic principles of DC machines”

The subject matter of this section of the TP 1410 training package is basic principles of DC machines. Individual components from training package TP 1410 may also be included in other packages.

Important TP 1410 components

- Permanently installed workstation with A4 frame
- Equipment set or individual components (direct current shunt motor, direct current series motor)
- Laboratory safety cables
- Set of laboratory equipment

Media

The teachware for training package TP 1410 consists of three workbooks. The workbooks contain worksheets for each exercise, the solutions for each individual worksheet and a CD-ROM. A set of ready-to-use exercise sheets and worksheets is included for each exercise.

Data sheets for the hardware components are made available along with the training package.

Media	
Workbook	Basic principles of DC machines Basic principles of AC machines Basic principles of 3-phase machines
Digital training programmes	WBT, “Electric drives 1” WBT, “Electric drives 2”

Overview of media for training package TP 1410

Software available for training package TP 1410 includes digital learning programmes entitled “Electric drives 1” and “Electric drives 2”. These programmes explore the basic principles of electric drive technology in detail. Training content is elucidated on the basis of practical case studies in a systematic, applications-oriented fashion.

Further training materials can be found in our catalogue and on the Internet. The training system for automation and technology is continuously updated and expanded. Transparency sets, videos, CD-ROMs, DVDs and training programmes, as well as additional teachware, are offered in several languages.

Learning objectives

Basic principles of DC machines – direct current shunt motor

- You become familiar with the working principle of the DC motor.
- You become familiar with the ohmic resistances of the armature winding and the excitation winding in the direct current shunt motor.
- You learn to evaluate the resistance values of armature and excitation windings.
- You learn the designations of the individual windings in DC machines.
- You learn the significance of the numbers to the right of the letters in the designations of the windings.
- You learn to determine the direction of rotation of DC machines.
- You become familiar with the occurrence of high starting currents associated with DC motors.
- You become familiar with speed control for DC motors.
- You become familiar with the measuring circuit for commissioning a direct current shunt motor.
- You learn the significance of the data included on the rating plate of a DC motor.
- You learn how to commission a direct current shunt motor.
- You become familiar with the motor's no-load values as compared with the values on the rating plate.
- You become familiar with the dependence of speed on armature voltage.
- You become familiar with graphic representation of the dependence of speed on armature voltage.
- You become familiar with the dependence of speed on excitation current.
- You become familiar with graphic representation of the dependence of speed on excitation current.
- You become familiar with the measuring circuit for measuring motor performance.
- You become familiar with the performance of measurements and the required calculations.
- You become familiar with the graphic representation of characteristic load curves.
- You learn to evaluate the characteristic curves.

Basic principles of DC machines – direct current series motor

- You learn the meaning of the term "series motor".
- You become familiar with the ohmic resistances of the armature winding and the excitation winding in the direct current series motor.
- You learn to evaluate the resistance values of armature and excitation windings.
- You become familiar with the motor's starting current without starting device.
- You become familiar with the problem associated with the series motor when idling (no-load operation).
- You become familiar with the problem associated with the series motor when coupled to a machine.
- You become familiar with the effects of high starting current on the speed and the torque of the motor.
- You become familiar with a common application for the series motor and the reason for its use.
- You become familiar with the measuring circuit for commissioning a direct current series motor.
- You learn how to commission a direct current series motor.
- You become familiar with the dependence of speed on armature voltage.
- You become familiar with graphic representation of speed for armature voltage.

- You become familiar with the measuring circuit for measuring motor performance.
- You become familiar with the performance of measurements and the required calculations.
- You become familiar with the graphic representation of characteristic load curves.
- You learn to evaluate the characteristic curves.

Use of the servo brake and drive system and DriveLab software

- You learn how to work with the servo brake and drive system and DriveLab software.
- You learn how to connect and commission the motor with the servo brake and drive system and DriveLab software.
- You become familiar with the programming interface for DriveLab software.
- You learn how to select and change measured variables at the X-axis and the Y-axis.
- You learn how to customise the colour and style of measured curves.
- You learn to adjust speed and torque from the computer.
- You learn to prepare and start a measurement from the computer.
- You learn to enter a new motor to the motor library.
- You learn to record and document characteristic load curves at the computer.

Allocation of learning objectives to exercises

Exercise / Learning objective	1	2	3	4	5	6
You become familiar with the working principle of the DC motor.	•					
You become familiar with the ohmic resistances of the armature winding and the excitation winding in the direct current shunt motor.	•					
You learn to evaluate the resistance values of armature and excitation windings.	•					
You learn the designations of the individual windings in DC machines.	•					
You learn the significance of the numbers to the right of the letters in the designations of the windings.	•					
You learn to determine the direction of rotation of DC machines.	•					
You become familiar with the occurrence of high starting currents associated with DC motors.	•					
You become familiar with speed control for DC motors.	•					
You become familiar with the measuring circuit for commissioning a direct current shunt motor.		•				
You learn the significance of the data included on the rating plate of a DC motor.		•				
You learn how to commission a direct current shunt motor.		•				
You become familiar with the motor's no-load values as compared with the values on the rating plate.		•				
You become familiar with the dependence of speed on armature voltage.		•				
You become familiar with graphic representation of the dependence of speed on armature voltage.		•				
You become familiar with the dependence of speed on excitation current.		•				
You become familiar with graphic representation of the dependence of speed on excitation current.		•				
You become familiar with the measuring circuit for measuring motor performance.		•				
You become familiar with the performance of measurements and the required calculations.		•				
You become familiar with the graphic representation of characteristic load curves.		•				
You learn to evaluate the characteristic curves.		•				

Learning objective \ Exercise	1	2	3	4	5	6
You learn how to work with the motor test bench and DriveLab software.			•			•
You learn how to connect and commission the direct current shunt motor with the motor test bench and DriveLab software.			•			
You learn how to connect and commission the direct current series motor with the motor test bench and DriveLab software.						•
You become familiar with the programming interface for DriveLab software.			•			•
You learn how to select and change measured variables at the X-axis and the Y-axis.			•			•
You learn how to customise the colour and style of measured curves.			•			•
You learn to adjust speed and torque from the computer.			•			•
You learn to prepare and start a measurement from the computer.			•			•
You learn to enter a new motor to the motor library.			•			•
You become familiar with the dependence of speed on armature voltage.			•			
You learn to record and document characteristic load curves at the computer.			•			•
You learn the meaning of the term “series motor”.				•		
You become familiar with the ohmic resistances of the armature winding and the excitation winding in the direct current series motor.				•		
You learn to evaluate the resistance values of armature and excitation windings.				•		
You become familiar with the motor’s starting current without starting device.				•		
You become familiar with the problem associated with the series motor when idling.				•		
You become familiar with the problem associated with the series motor when coupled to a machine.				•		
You become familiar with the effects of high starting current on the speed and the torque of the motor.				•		
You become familiar with a common application for the series motor and the reason for its use.				•		
You become familiar with the measuring circuit for commissioning a direct current series motor.					•	
You learn how to commission a direct current series motor.					•	
You become familiar with the dependence of speed on armature voltage.					•	
You become familiar with graphic representation of speed for armature voltage.					•	
You become familiar with the measuring circuit for measuring motor performance.					•	
You become familiar with the performance of measurements and the required calculations.					•	
You become familiar with the graphic representation of characteristic load curves.					•	
You learn to evaluate the characteristic curves.					•	

Components

The components included in the training package for “Basic principles of DC machines” impart knowledge regarding setup, connection and the range of applications of DC machines. In order to set up functional circuits, you will also need a laboratory workstation (optionally equipped with an A4 frame), “servo brake and drive system” equipment set TP 1410, a 250 V DC power supply and controllers for the electric machines.

“Servo brake and drive system” equipment set TP 1410

Component	Order no.	Quantity
Servo brake and drive system	571870	1

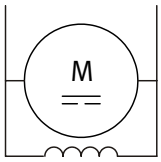
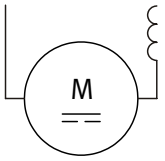
Electric machines, “Basic principles of DC machines”

Component	Order no.	Quantity
Direct current shunt machine	571868	1
Direct current series machine	571869	1

Controllers for the electric machines

Component	Order no.	Quantity
EduTrainer 3-phase power supply	571812	1
EduTrainer 24 V power supply	571813	1
EduTrainer contactor board	571814	1
Motor technology contactor set	571816	1
EduTrainer operator and signaling unit	571815	1

Graphic symbols, equipment set

Component	Graphic symbol
Direct current shunt machine	
Direct current series machine	

Notes for the teacher/trainer

Learning objectives
The overall learning objective of this workbook is familiarisation with the basic principles of DC machines. Direct interplay of theory and practice ensures fast progress and long-lasting learning. The more specific learning objectives are documented in the matrix. Concrete, individual learning objectives are assigned to each exercise.

Required time
The time required for working through the exercises depends on the learner's previous knowledge of the subject matter. For apprentices in the field of electrical engineering: approx. 3 days With training as a skilled worker: approx. 1 day

Components
The workbook and the components are designed to be used together. A direct current shunt motor is required for exercises 1 through 3. A direct current series motor is required for exercises 4 through 6.

Standards
The following standards are apply to this workbook:
EN 60617-2 through
EN 60617-8: Graphic symbols for circuit diagrams
EN 81346-2: Industrial systems, installations and equipment and industrial products; structuring principles and reference designations

Identification of solutions
Solutions and supplements in graphics or diagrams appear in red.

Identification in the worksheets
Texts which require completion are identified with a grid or grey table cells.
Graphics and diagrams which require completion include a grid.

Notes for the lesson
Additional information regarding the individual components and the circuits is provided here. These notes are not included in the worksheets.

Solutions
The solutions specified in this workbook result from test measurements. The results of your measurements may vary from these data.

Learning topics
Allocation of the fields of learning offered by vocational schools to the training subject matter of "basic principles of DC machines" is provided below for selected vocations.

Vocation	Topic
Electronics engineer for automation technology	Analysing electrical systems and testing their functions
	Analysing and customising control systems
	Analysing systems and testing their safety
Mechatronics technician	Installation of electric equipment taking technical safety aspects into account
	Examination of the flow of energy and information in electrical, pneumatic and hydraulic assemblies
	Implementation of mechatronic subsystems
	Commissioning, troubleshooting and repair

Structure of the exercises

All 6 exercises have the same structure and are broken down into:

- Title
- Learning objectives
- Problem description
- Positional sketch
- Project assignments
- Work aids
- Worksheets

The workbook includes the solutions for all of the worksheets.

Component designations

The components in the circuit diagrams are identified in accordance with DIN EN 81346-2. Letters are assigned as appropriate to each component. Multiple components of the same type within a single circuit are numbered.

Relays:	K, K1, K2, ...
Switches/pushbuttons:	S, S1, S2, ...
Contactors:	Q, Q1, Q2, ...
Fuses:	F, F1, F2, ...
Indicators:	P, P1, P2, ...

Contents of the CD-ROM

The workbook is included on the accompanying CD-ROM as a PDF file. The CD-ROM also provides you with additional media.

The CD-ROM contains the following folders:

- Operating instructions
- Illustrations
- Data sheets

Operating instructions
Operating instructions are provided for various components included in the training package. These instructions are helpful when using and commissioning the components.

Illustrations
Photos and graphics of components and industrial applications are made available. These can be used to illustrate individual tasks or to supplement project presentations.

Data sheets
Technical data for the components included in the training package are available as PDF files.

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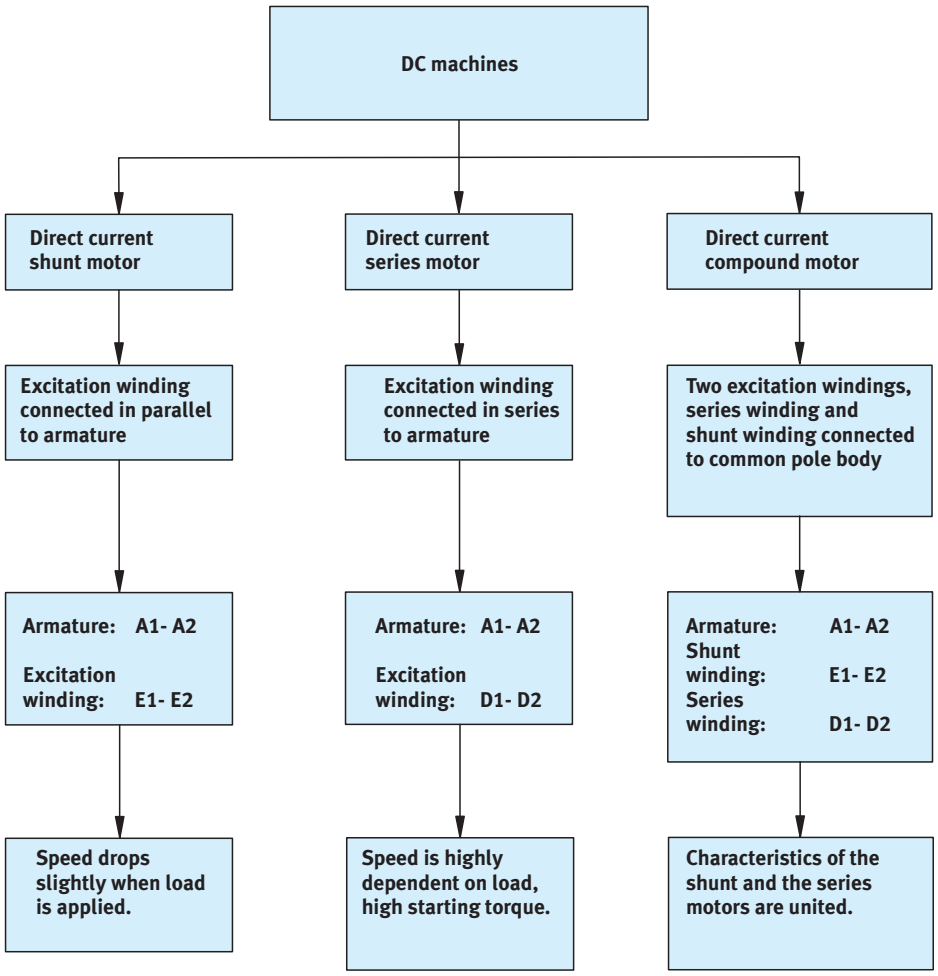
Exercises and solutions

Overview of direct current machines



Exercise 1

Basic principles of the direct current shunt motor

Learning objective

After completing this exercise:

- You will be familiar with the layout of a DC motor.
- You will be familiar with the working principle of the DC motor.
- You will be familiar with the ohmic resistances of the armature winding and the excitation winding in the direct current shunt motor.
- You will be able to evaluate the resistance values of armature and excitation windings.
- You will know the designations of the individual windings in DC machines.
- You will know the significance of the numbers to the right of the letters in the designations of the windings.
- You will be able to determine the direction of rotation of DC machines.
- You will be familiar with the occurrence of high starting currents associated with DC motors.
- You will be familiar with speed control for DC motors.

Problem description

An apprentice at the end of his second year of training is assigned the task of inspecting motors in the receiving department.

After receiving detailed instructions, the trainer gives him a motor for examination. The examination results will need to be documented in a report.

Note
The motor is not started up during this exercise!

Project assignments

1. Describe the working principle of a DC motor.
2. Measure ohmic resistance at the armature winding and the excitation winding with the help of an ohmmeter.
3. Evaluate the resistance values of the armature and excitation windings in a shunt motor.
4. Allocate the corresponding designations to the individual windings.
5. Explain the significance of the numbers to the right of the letters in the designations of the windings.
6. How can the direction of rotation of a DC motor be determined?
7. Describe why a relatively large amount of current flows at the moment the DC motor is switched on.
8. Explain how the speed of the DC motor can be changed.
9. Explain the significance of the commutating poles in a DC motor.

Work aids

- Textbooks, books of tables
- Excerpts from manufacturers' catalogues
- Data sheets
- Internet
- WBT, "Electric drives 1"

1. Working principle of the DC motor.

– Describe the working principle of a DC motor.

The working principle of the DC motor is based on the current-carrying conductor in the magnetic field. The current-carrying conductor is the armature and the magnetic field is generated by the excitation winding.

The magnetic field can be generated by means of a permanent magnet for smaller motors, and with an electromagnet (excitation winding) for larger motors.

2. Armature and excitation winding resistance

Information
The ohmic resistances of the armature and excitation windings are important in understanding the concept of the shunt motor.

– Measure the values required to complete the table below with an ohmmeter.

	R [Ω]
Armature winding	11
Excitation winding	595

3. Evaluating the resistance values of the armature and excitation windings in a shunt motor

– Evaluate the measured resistance values of the armature and excitation windings.

Armature winding
Resistance value: 11 Ω

Evaluation
Armature resistance is relatively low.

The high starting current which occurs as a result must therefore be reduced during start-up by means of suitable measures (controlled rectifier, direct current PWM regulator, deteriorates the starter). A countervoltage is created during operation, which limits current to a specific value.

Excitation winding
Resistance value: 595 Ω

Evaluation
Excitation winding resistance is relatively high.

The excitation winding has to have a high resistance value (many windings with fine winding wire), because the winding is connected to nominal voltage at the DC network during operation (220 V), and only the resistance of the copper winding (ohmic resistance) is effective in the case of direct current.

4. Winding designations for DC machines

– Complete the table with the required designations.

Winding	Designation
Armature winding: Shunt Series	 A1 – A2 A1 – A2
Excitation winding: Shunt Series	 E1 – E2 D1 – D2
Compensation winding	1C1 – 1C2
Commutating winding	1B1 – 1B2

Winding designations for DC machines

5. Significance of the numbers to the right of the windings' identifying letters

– Explain the significance of the numbers to the right of the windings' identifying letters.

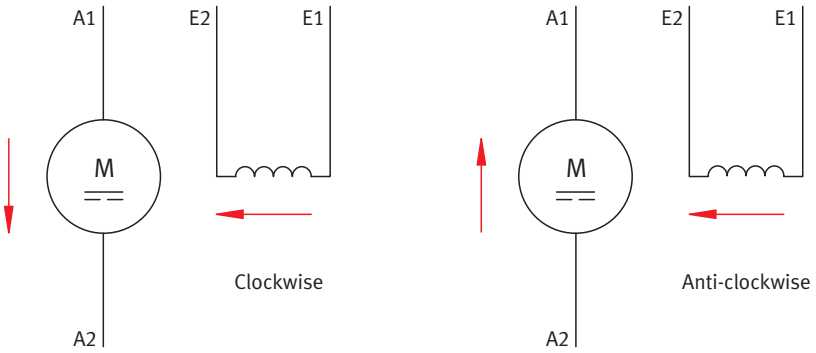
The numbers to the right of the windings' identifying letters specify the beginning of the winding (1) and the end of the winding (2).

If current flows through all windings from 1 to 2, the motor demonstrates clockwise rotation.

If the direction in which current flows in one winding is reversed (from 2 to 1), the motor demonstrates anticlockwise rotation.

6. Direction of rotation of a DC motor

a) Define the direction of rotation by drawing arrows indicating the direction of flow through the windings (clockwise rotation, anti-clockwise rotation).



b) Explain how the direction of rotation is changed in actual practice.

In actual practice, the direction in which current flows through the armature (A1 – A2) is reversed in order to change the direction of rotation of a DC motor.

In the case of motors with commutating poles, it must be assured that the commutating poles (1B1 – 1B2) are reversed as well.

7. DC motor starting current

– Explain why a DC motor cannot be directly connected to the DC network.

Torque generated by a DC motor is based on the action of force of a current-carrying conductor within the magnetic field (the magnetic field can be generated by either a permanent magnet or an electromagnet).

When the armature rotates within the magnetic field, a voltage is induced in the armature winding which counteracts supply voltage.

This countervoltage is zero when the armature is at a standstill. At the moment the motor is switched on, only the ohmic resistance of the armature winding is effective, which is quite small. Starting current would reach very high values as a result, and must therefore be limited by implementing appropriate measures.

8. Changing the speed of a DC motor

Differentiation is made between two setting ranges with regard to controlling DC motors:
1. Below nominal speed
2. Above nominal speed

a) Explain how speed can be set to below nominal speed.

A speed of less than nominal speed is achieved by reducing armature voltage to within a range of zero to nominal voltage (deteriorates the starter).

b) Explain how speed can be set to above nominal speed.

If no specifications are provided by the manufacturer for controlling speed at above nominal speed, the controlled speed may not exceed nominal speed by any more than 10%.

Rotary frequencies of greater than nominal speed are achieved by reducing excitation current. Excitation voltage is reduced to this end (deteriorates the field regulator).

9. Significance of the commutating poles in a DC motor

– What is the significance of the commutating poles in a DC motor?

The commutating poles are additional, small magnetic poles.

The commutating poles generate a magnetic field which counteracts the armature quadrative-axis field and, if the commutating poles are correctly dimensioned, eliminates armature quadrative-axis field offset.

Due to the fact that the armature quadrative-axis field depends upon load current, the magnetic field generated by the commutating poles must also be made dependent on load current. This is why the armature winding and the commutating pole winding are connected in series.

Because the commutating poles neutralise the armature quadrative-axis field in the neutral zone, arcing is avoided to a great extent during commutation.

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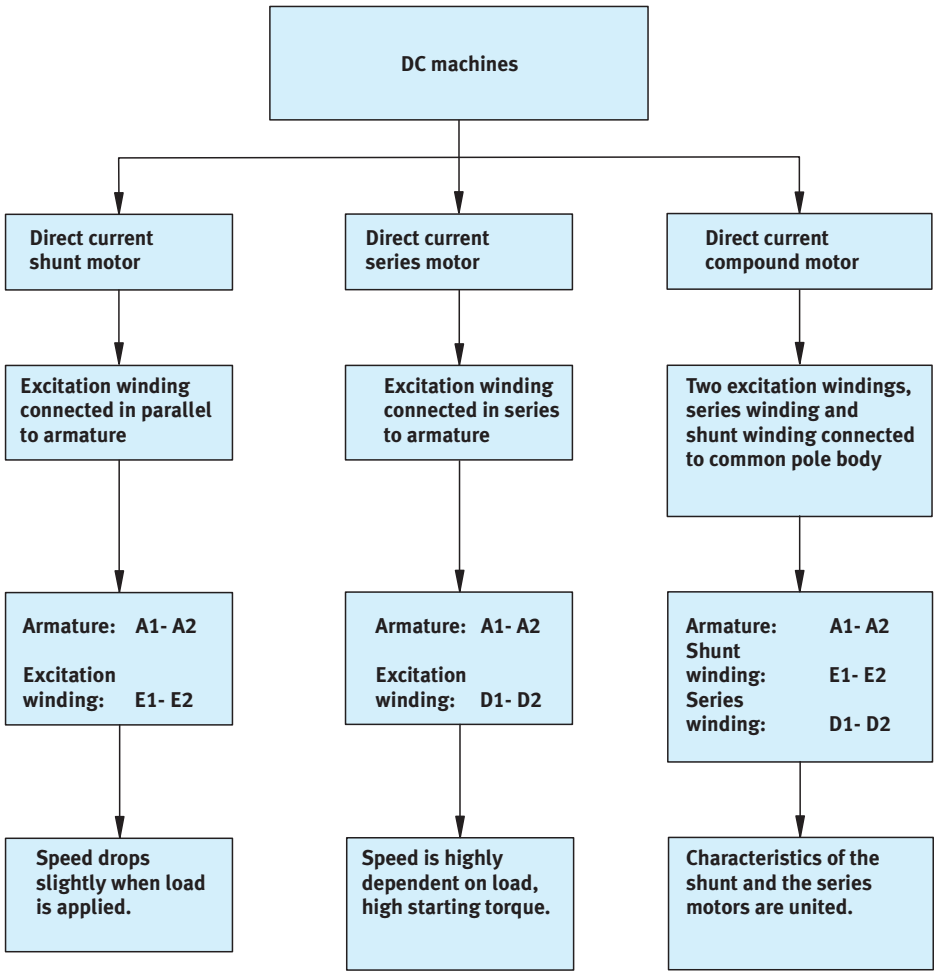

Exercise 1

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- You will be able to determine the direction of rotation of DC machines.
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Note
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3. Evaluate the resistance values of the armature and excitation windings in a shunt motor.
4. Allocate the corresponding designations to the individual windings.
5. Explain the significance of the numbers to the right of the letters in the designations of the windings.
6. How can the direction of rotation of a DC motor be determined?
7. Describe why a relatively large amount of current flows at the moment the DC motor is switched on.
8. Explain how the speed of the DC motor can be changed.
9. Explain the significance of the commutating poles in a DC motor.

Work aids

- Textbooks, books of tables
- Excerpts from manufacturers' catalogues
- Data sheets
- Internet
- WBT, "Electric drives 1"

1. Working principle of the DC motor.

– Describe the working principle of a DC motor.

2. Armature and excitation winding resistance

Information
The ohmic resistances of the armature and excitation windings are important in understanding the concept of the shunt motor.

– Measure the values required to complete the table below with an ohmmeter.

	R [Ω]
Armature winding	
Excitation winding	

3. Evaluating the resistance values of the armature and excitation windings in a shunt motor

– Evaluate the measured resistance values of the armature and excitation windings.

Armature winding

Excitation winding

4. Winding designations for DC machines

– Complete the table with the required designations.

Winding	Designation
Armature winding: Shunt Series	
Excitation winding: Shunt Series	
Compensation winding	
Commutating winding	

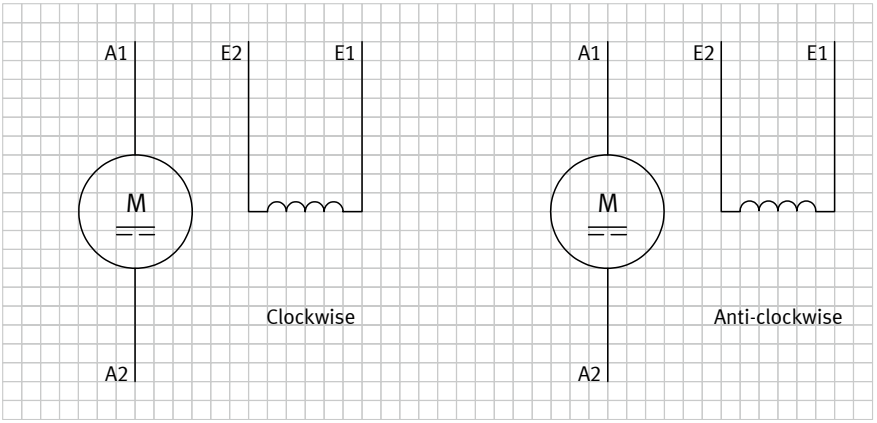
Winding designations for DC machines

5. Significance of the numbers to the right of the windings' identifying letters

– Explain the significance of the numbers to the right of the windings' identifying letters.

6. Direction of rotation of a DC motor

a) Define the direction of rotation by drawing arrows indicating the direction of flow through the windings (clockwise rotation, anticlockwise rotation).



b) Explain how the direction of rotation is changed in actual practice.

7. DC motor starting current

– Explain why a DC motor cannot be directly connected to the DC network.

8. Changing the speed of a DC motor

Differentiation is made between two setting ranges with regard to controlling DC motors:

1. Below nominal speed
2. Above nominal speed

a) Explain how speed can be set to below nominal speed.

b) Explain how speed can be set to above nominal speed.

9. Significance of the commutating poles in a DC motor

– What is the significance of the commutating poles in a DC motor?