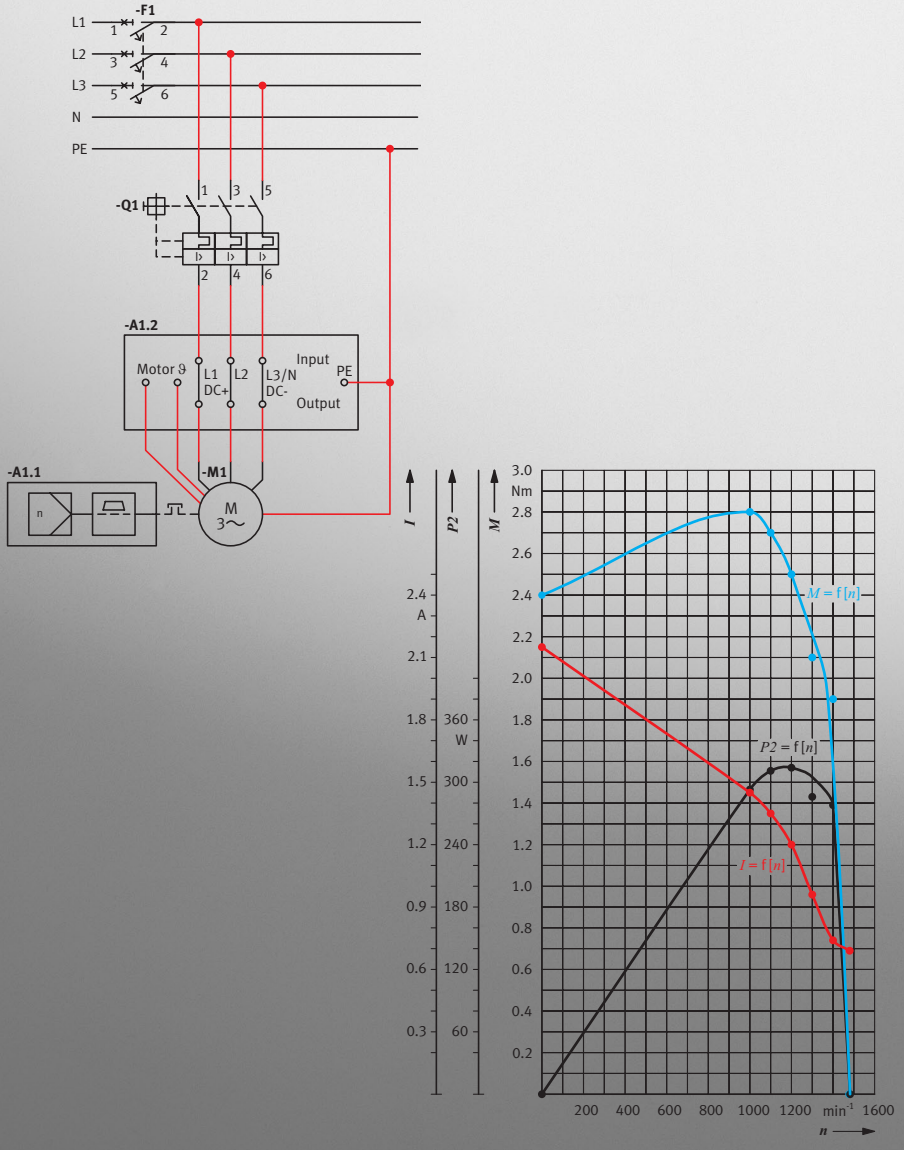
Fundamentals of three-phase current machines

FESTO

Workbook

With CD-ROM



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Contents

Exercises and solutions

Exercises and worksheets

Use for intended purpose

The training package for “basic principles of 3-phase 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.

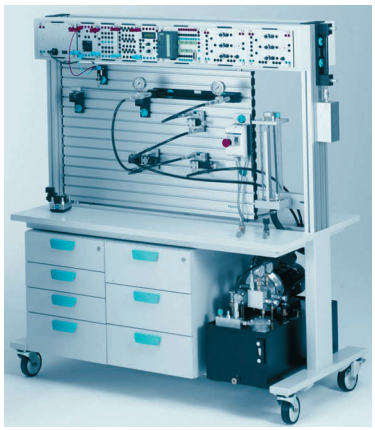
Preface

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 programs 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 learning system for automation and technology by Festo Didactic GmbH & Co. KG. The system provides a solid basis for practice-oriented basic 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

The workbook entitled “Basic principles of 3-phase machines” provides an introduction to the topic of electric machines with 3-phase connection. Knowledge regarding layout, connection and applications ranges is imparted. In doing so, the machines are exposed to a wide range of simulated load situations in order to ascertain their capabilities.

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
- 400 V AC mains outlet
- A 3-phase asynchronous motor
- A 3-phase synchronous machine
- Components for controlling the electric machines
- Laboratory safety cables

The circuits for all of the exercises are set up using the TP 1410 equipment set and the 3-phase drives.

Data sheets for the individual components are also available (3-phase asynchronous motors, 3-phase synchronous machines etc.).

Work and safety instructions

General information

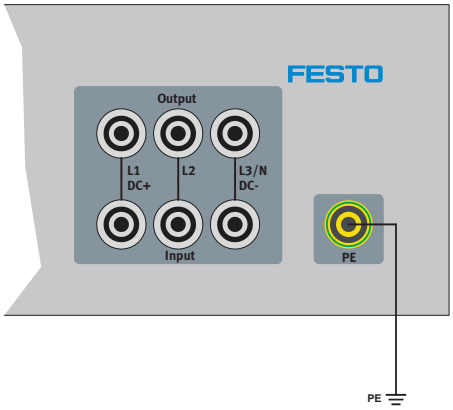
- Trainees should only work with the circuits under the supervision of a trainer.
- Observe specifications included in the technical data for the individual components, and in particular all safety instructions!
- Malfunctions which may impair safety must not be generated in the training environment 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, “basic principles of 3-phase machines”

The subject matter of this section of the TP 1410 training package is basic principles of 3-phase 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 (3-phase asynchronous motor, 3-phase synchronous 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 exercises 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 learning 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 the 3-phase asynchronous motor

- You become familiar with the layout of an asynchronous motor with squirrel-cage rotor.
- You become familiar with the motor terminal board and its designations.
- You become familiar with the location of the jumpers on the motor terminal board for star and delta connection
- You become familiar with the difference between star and delta connection in actual practice.
- You become familiar with the working principle of the 3-phase motor.
- You become familiar with the meaning of the term “asynchronous motor”.
- You become familiar with start-up performance of the 3-phase motor.
- You learn how to change the direction of rotation of a 3-phase motor.
- You become familiar with options for changing the speed of a 3-phase motor.
- You become familiar with the measuring circuit for recording the individual points in the characteristic load curves with a single-phase power meter and a 3-phase power meter.
- You learn the prerequisites for starting up the motor in no-load operation.
- You become familiar with starting the motor up with various loads.
- You learn how to calculate apparent power and effective power output.
- You learn how to create a chart with the motor’s characteristic load curves.
- You learn how to calculate reactive power, efficiency and power factor.
- You learn how to evaluate characteristic load curves with the calculated values.
- You become familiar with specifications for motor torque and start-up characteristics.

Basic principles of the 3-phase synchronous motor

- You become familiar with the setup and function of a 3-phase synchronous motor.
- You become familiar with the start-up utility in the synchronous motor.
- You become familiar with the meaning of the term “synchronous motor”.
- You become familiar with the location of the jumpers on the motor for star or delta connection
- You become familiar with the location of the jumpers on the motor for a 230/400 V, 3-phase electrical system.
- You learn how to change the direction of rotation of a synchronous motor.
- You become familiar with options for changing the speed of a synchronous motor.
- You become familiar with the problem of adjusting excitation voltage.
- You become familiar with the problem associated with starting up synchronous motors.
- You become familiar with the measuring circuit for the synchronous motor in no-load operation.
- You learn how to start up a synchronous motor in no-load operation.
- You learn how to perform a measurement for the representation of underexcitation and overexcitation.
- You become familiar with the representation of characteristic curves for underexcitation and overexcitation.
- You learn the meanings of underexcitation and overexcitation.
- You learn to control reactive power by means of excitation current with various loads.
- You become familiar with the representation of characteristic curves for controlling reactive power with excitation current.
- You learn how to evaluate characteristic curves with capacitive and inductive reactive power.

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 motors 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 layout of an asynchronous motor with squirrel-cage rotor.	•					
You become familiar with the motor terminal board and its designations.	•					
You become familiar with the location of the jumpers on the motor terminal board for star and delta connection	•					
You become familiar with the difference between star and delta connection in actual practice.	•					
You become familiar with the working principle of the 3-phase motor.	•					
You become familiar with the meaning of the term “asynchronous motor”.	•					
You become familiar with start-up performance of the 3-phase motor.	•					
You learn how to change the direction of rotation of a 3-phase motor.	•					
You become familiar with options for changing the speed of a 3-phase motor.	•					
You learn how to work with the servo brake and drive system, and DriveLab software.		•				
You become familiar with the measuring circuit for recording the individual points in the characteristic load curves with a single-phase power meter and a 3-phase power meter.		•				
You learn the prerequisites for starting up the motor in no-load operation.		•				
You become familiar with starting the motor up with various loads.		•				
You learn how to calculate apparent power and effective power output.		•				
You learn how to create a chart with the motor’s characteristic load curves.		•				
You learn how to calculate reactive power, efficiency and power factor.		•				
You learn how to evaluate characteristic load curves with the calculated values.		•				
You become familiar with specifications for motor torque and start-up characteristics.		•				

Learning objective / Exercise	1	2	3	4	5	6
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 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 learn to record and document characteristic load curves at the computer.			•			•
You become familiar with the setup and function of a 3-phase synchronous motor.				•		
You become familiar with the start-up utility in the synchronous motor.				•		
You become familiar with the meaning of the term “asynchronous motor”.				•		
You become familiar with the location of the jumpers on the motor terminal board for star or delta connection				•		
You become familiar with the location of the jumpers on the motor terminal board for a 230/400 V, 3-phase electrical system.				•		
You learn how to change the direction of rotation of a synchronous motor.				•		
You become familiar with options for changing the speed of a synchronous motor.				•		
You become familiar with the problem of adjusting excitation voltage.				•		
You become familiar with the problem associated with starting up synchronous motors.				•		
You become familiar with the measuring circuit for the synchronous motor in no-load operation.					•	
You learn how to start up a synchronous motor in no-load operation.					•	
You learn how to perform a measurement for the representation of underexcitation and overexcitation.					•	
You become familiar with the representation of characteristic curves for underexcitation and overexcitation.					•	
You learn the meanings of underexcitation and overexcitation.					•	
You learn to control reactive power by means of excitation current with various loads.					•	
You become familiar with the representation of characteristic curves for controlling reactive power with excitation current.					•	
You learn how to evaluate characteristic curves with capacitive and inductive reactive power.					•	

Components

The components included in the training package for “Basic principles of 3-phase machines” impart knowledge regarding setup, connection and the range of applications of 3-phase 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 400 V AC 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

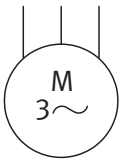
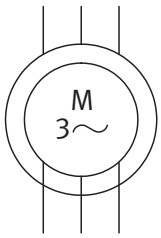
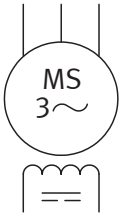
Electric machines, “Basic principles of 3-phase machines”

Component	Order no.	Quantity
3-phase asynchronous motor, 400/690 V	571875	1
Synchronous machine	572095	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
3-phase asynchronous motor with squirrel-cage rotor (short-circuited rotor)	
3-phase asynchronous motor with slip-ring rotor	
3-phase synchronous machine	

Notes for the teacher/trainer

Learning objectives
The overall learning objective of this workbook is familiarisation with the basic principles of 3-phase 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 3-phase asynchronous motor is required for three of the tasks, and a 3-phase synchronous machine is required for the other three.

Standards
The following standards 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.

Learning topics
Allocation of the fields of learning offered by vocational schools to the training subject matter of "basic principles of 3-phase machines" is provided below for selected vocations.

Vocation	Topic
Electronics engineer for automation technology	Analysing electrical systems and testing their functions
	Analysing and adapting control systems
	Analysing systems and testing their safety
Mechatronics technician	Installation of electrical 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 of the 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.

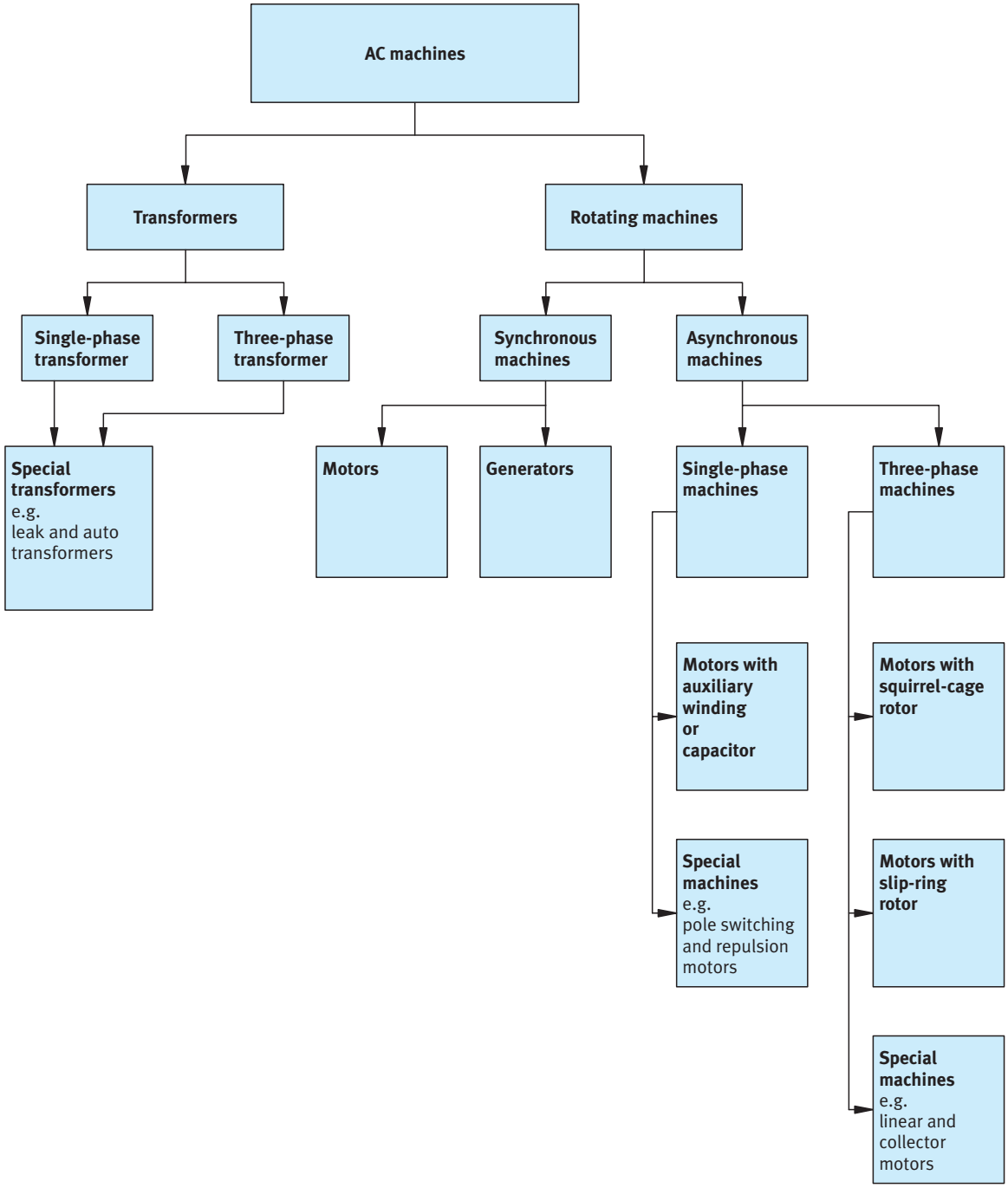
Illustrations
Photos and graphics of components and industrial applications are made available. These can be used to illustrate individual tasks or to supplement project presentations.

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

Contents

Exercises and solutions

Overview of alternating current machines



Exercise 1

Basic principles of the 3-phase asynchronous motor with squirrel-cage rotor

Learning objectives

After completing this exercise:

- You will be familiar with the layout of an asynchronous motor with squirrel-cage rotor.
- You will be familiar with the motor terminal board and its designations.
- You will be familiar with the location of the jumpers on the motor terminal board for star and delta connection
- You will be familiar with the difference between star and delta connection in actual practice.
- You will be familiar with the working principle of the 3-phase motor.
- You will be familiar with the meaning of the term “asynchronous motor”.
- You will be familiar with start-up performance of the 3-phase motor.
- You will know how to change the direction of rotation of a 3-phase motor.
- You will be familiar with options for changing the speed of a 3-phase motor.

Problem description

An apprentice in the training workshop is assigned the task of examining a 3-phase motor which has just been received, and preparing a complete inspection report.

Note

The motor is not started up during this exercise!

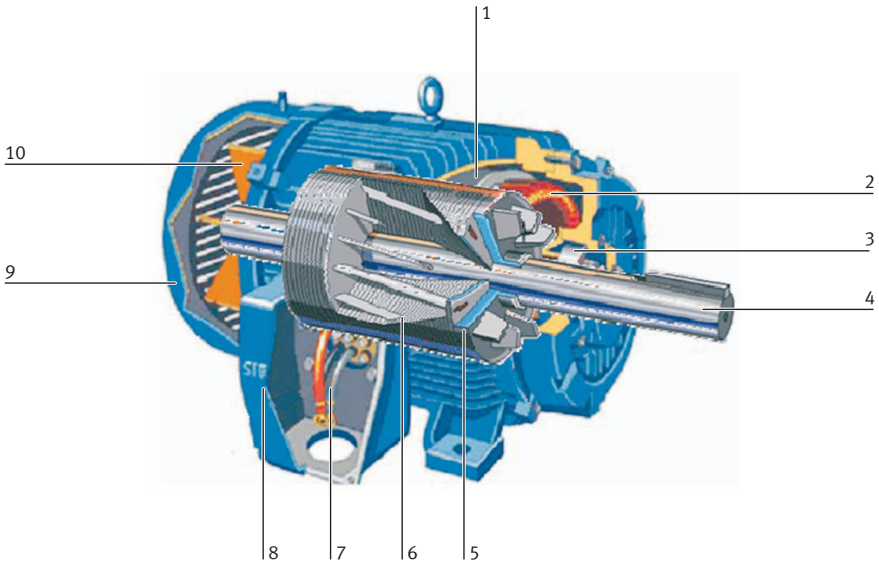
Project assignments

1. Describe the layout of a 3-phase asynchronous motor with squirrel-cage rotor.
2. Allocate the individual specifications to the corresponding items in the rating plate.
3. Complete the specifications for the motor terminal board for star and delta connection.
4. Explain the difference between star and delta connection in actual practice.
5. Describe the working principle of the 3-phase motor.
6. Explain the meaning of the term “asynchronous motor”.
7. Describe start-up performance of the 3-phase motor.
8. Explain how the direction of rotation of a 3-phase motor can be changed.
9. What does the speed of a 3-phase motor depend on and how can it be changed?

Work aids

- Textbooks, books of tables
- Excerpts from manufacturers’ catalogues
- Data sheets
- Internet
- WBT, “Electric drives 1”

1. Layout of a 3-phase asynchronous motor with squirrel-cage rotor



3-phase asynchronous motor with squirrel-cage rotor – cutaway view

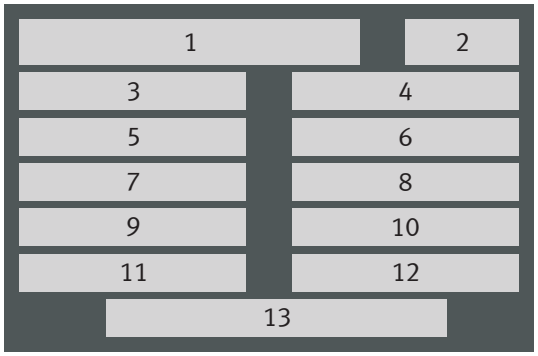
Designations

Drive shaft; stator core for accommodating the stator winding; short-circuit ring of the squirrel-cage rotor; stator winding; terminal box; roller bearing for the drive shaft; rotor core of the squirrel-cage rotor; motor terminal board for star or delta connection of the motor; fan for cooling the motor; rotor cover for enclosing the fan

– Match up the numbers in the cutaway view to the designations of the individual components.

No.	Designation
1	Stator core for accommodating the stator winding
2	Stator winding
3	Roller bearing for the drive shaft
4	Drive shaft
5	Short-circuit ring of the squirrel-cage rotor
6	Rotor core of the squirrel-cage rotor
7	Motor terminal board for star or delta connection of the motor
8	Terminal box
9	Rotor cover for enclosing the fan
10	Fan for cooling the motor

2. Rating plate of a 3-phase asynchronous motor with squirrel-cage rotor



– Allocate the numbers in the rating plate to the motor's corresponding characteristic values.

Characteristic motor values: Number of phases for AC machines; Rated supply frequency for AC machines; Manufacturer's name and designation; Manufacturer's serial number or identifying marks; VDE directive for rotating electric machines; Rated current; Rated power; Rated speed; Manufacturer's type designation; Degree of protection provided by enclosure (IP code) per EN 60529; Insulation and thermal class of the windings; Power factor; Phase voltage

No.	Characteristic motor values
1	Manufacturer's name and designation
2	Manufacturer's serial number or identifying marks
3	Manufacturer's type designation
4	Number of phases for AC machines
5	Phase voltage
6	Rated current
7	Rated power
8	Power factor
9	Rated speed
10	Rated supply frequency for AC machines
11	Insulation and thermal class of the windings
12	Degree of protection provided by enclosure (IP code) per EN 60529
13	VDE directive for rotating electric machines

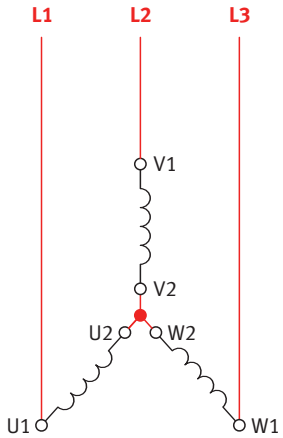
3. Motor terminal board for star and delta connection

Information

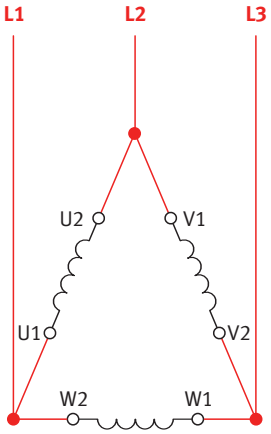
The motor's stator winding is a 3-phase winding which generates the rotary field.

The beginnings and ends of the phases are connected to the terminals at the motor terminal board, by means of which the phases can be wired for star or delta connection.

a) Complete the circuits for the windings for star and delta connection.

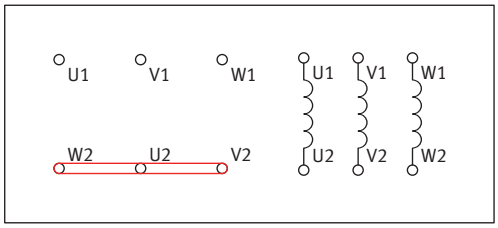


Star connection

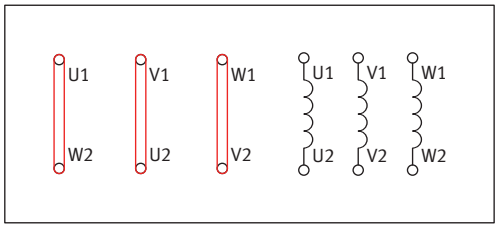


Delta connection

b) Sketch in the positions of the jumpers on the motor terminal board for star and delta connection.



Star connection



Delta connection

c) Which value on the rating plate indicates whether the motor will be operated with star or delta connection?

The motor's phase voltage is important with regard to whether star or delta connection is used.

If a phase voltage of 400 V is specified, each individual winding must be supplied with 400 V. This is only the case when the motor is set up with delta connection. In the case of delta connection, phase voltage is equal to supply voltage.

If a phase voltage of 230 V is specified, each individual winding must be supplied with 230 V. This is only the case when the motor is set up with star connection. In the case of star connection, phase voltage is $\sqrt{3}$ less than supply voltage.

4. Difference between star and delta connection in actual practice

Information
The stator winding of a 3-phase motor may consist of either a 2-pole or a multi-pole winding. The winding's three separate phases are offset from each other by 120° (electrically).

Connecting the ends of the three phase windings results in star connection. Connecting the end of each phase with the beginning of the next results in delta connection.

a) Enter the appropriate type of connection (star or delta) to the empty columns.

Supply power		Permissible phase voltage
400 V	230 V	
Delta	—	400 V
Star	Delta	230 V

b) The motor is laid out for star connection and is mistakenly set up with delta connection. Describe the consequences.

If the motor is laid out for star connection (jumpers set horizontal on the motor terminal board), each individual winding may only receive 230 V from our power supply system (230/400 V).

However, if the motor is mistakenly operated with delta connection, each individual winding is supplied with 400 V (phase voltage for delta connection). The motor winding is supplied with too much voltage, current exceeds nominal current and the windings burn – the motor is destroyed.

c) The motor is laid out for delta connection and is mistakenly set up with star connection. Describe the consequences.

If the motor is laid out for delta connection (jumpers set vertical on the motor terminal board), each individual winding must receive 400 V.

If the motor is mistakenly operated at nominal load with star connection, the stator winding is supplied with too little voltage. Due to the fact that speed does not depend on voltage, it remains unaffected.

However, torque is proportional to the square of voltage, so that reduced voltage results in less torque. The motor remains at a standstill and consumes starting current. This current is greater than nominal current and the motor consumes too much current despite the decreased voltage value. The motor heats up and the windings would be destroyed after a long enough period of time.

Information

	Star connection	Delta connection
Symbol	Y	Δ
Phase voltage	$U_{Str} = \frac{U}{\sqrt{3}}$	$U_{Str} = U$
Phase current	$I_{Str} = I$	$I_{Str} = \frac{I}{\sqrt{3}}$
Apparent power for one phase	$S_{Str} = \frac{U}{\sqrt{3}} \cdot I$	$S_{Str} = \frac{U}{\sqrt{3}} \cdot I$
Total apparent power	$S = 3 \cdot \frac{U}{\sqrt{3}} \cdot I$	$S = 3 \cdot \frac{U}{\sqrt{3}} \cdot I$
Input power	$P1 = \sqrt{3} \cdot U \cdot I \cdot \cos\varphi$	

5. The working principle of the 3-phase motor

– Explain how rotary motion of the armature occurs with the 3-phase motor.

When current flows through the winding located in the 3-phase motor's stator, it generates a rotary field.

The rotational speed of the rotary field can be determined with the following formula: $n = \frac{f \cdot 60}{P}$,

where
n = speed in rpm, f = frequency in Hz and P = number of pole pairs.
In accordance with this formula, the highest possible speed of the field with a 50 Hz system is 3000 rpm.

The rotor conductor bars of the squirrel-cage rotor, which is initially at a standstill, are subjected to changing magnetic flux due to the stator's rotary field, which induces a voltage in the rotor conductor bars. This voltage causes current to flow within the short-circuited rotor winding.

The short-circuited winding through which current now flows is deflected out of its neutral position, and the rotor begins to turn. The rotor "follows" the rotary field which turns at a constant speed. The direction of rotation of the rotor coincides with that of the field.

The closer rotor speed approaches the speed of the rotary field, the smaller the field change becomes. Voltage induced in the rotor, and thus current as well, becomes smaller.

6. The meaning of the term "asynchronous motor"

– Explain the meaning of the term "asynchronous motor".

Rotor speed never catches up with the speed of the synchronous rotary field. The difference between rotor speed and the speed of the rotary field is called slippage. The motor runs as an asynchronous motor.

Slippage is usually expressed as a percentage of the speed of the rotary field. Slippage is between 1% and 8% when motors are operated at nominal load. Motors with higher power ratings have smaller slippage values.

7. Start-up performance

– Describe start-up performance of the 3-phase asynchronous motor.

The greatest amount of current flows at the moment the motor is switched on, i.e. when the rotor is still at a standstill. Depending upon rotor design, this starting current amounts to between 4 and 8 times nominal current when the motor is operated at full line voltage.

This extreme loading of the power supply network may result in an interfering voltage depression. For this reason, start-up current limiters are specified for large motors which are connected to public power supply networks.

The star-delta circuit (switch or contactor) and the frequency converter are used most commonly for start-up current limiting at public power networks.

8. Changing direction of rotation at a 3-phase asynchronous motor with squirrel-cage rotor

a) Explain how the direction of rotation of a 3-phase motor can be changed.

The direction of rotation of a 3-phase motor can be changed by reversing two of the phase conductors. It does not make any difference which phase conductors are reversed.

b) Explain two ways of changing the direction of rotation of a 3-phase motor in actual practice.

In actual practice, the direction of rotation is changed with the help of either a reversing switch or a reversing contactor circuit.

9. Dependence of 3-phase motor speed

Information
When the winding of a 3-phase motor is connected to the 3-phase power network, a rotary field is generated. The speed at which the field rotates depends on frequency and the number of pole pairs in the windings.

a) Fill in the missing data regarding the number of pole pars and the associated rotary speeds.

Synchronous rotary speeds for common numbers of poles at a frequency of 50 Hz						
Number of poles	2	4	6	8	10	12
Number of pole pairs	1	2	3	4	5	6
Speed [rpm]	3000	1500	1000	750	600	500

b) Describe options for changing the speed of 3-phase motors in actual practice.

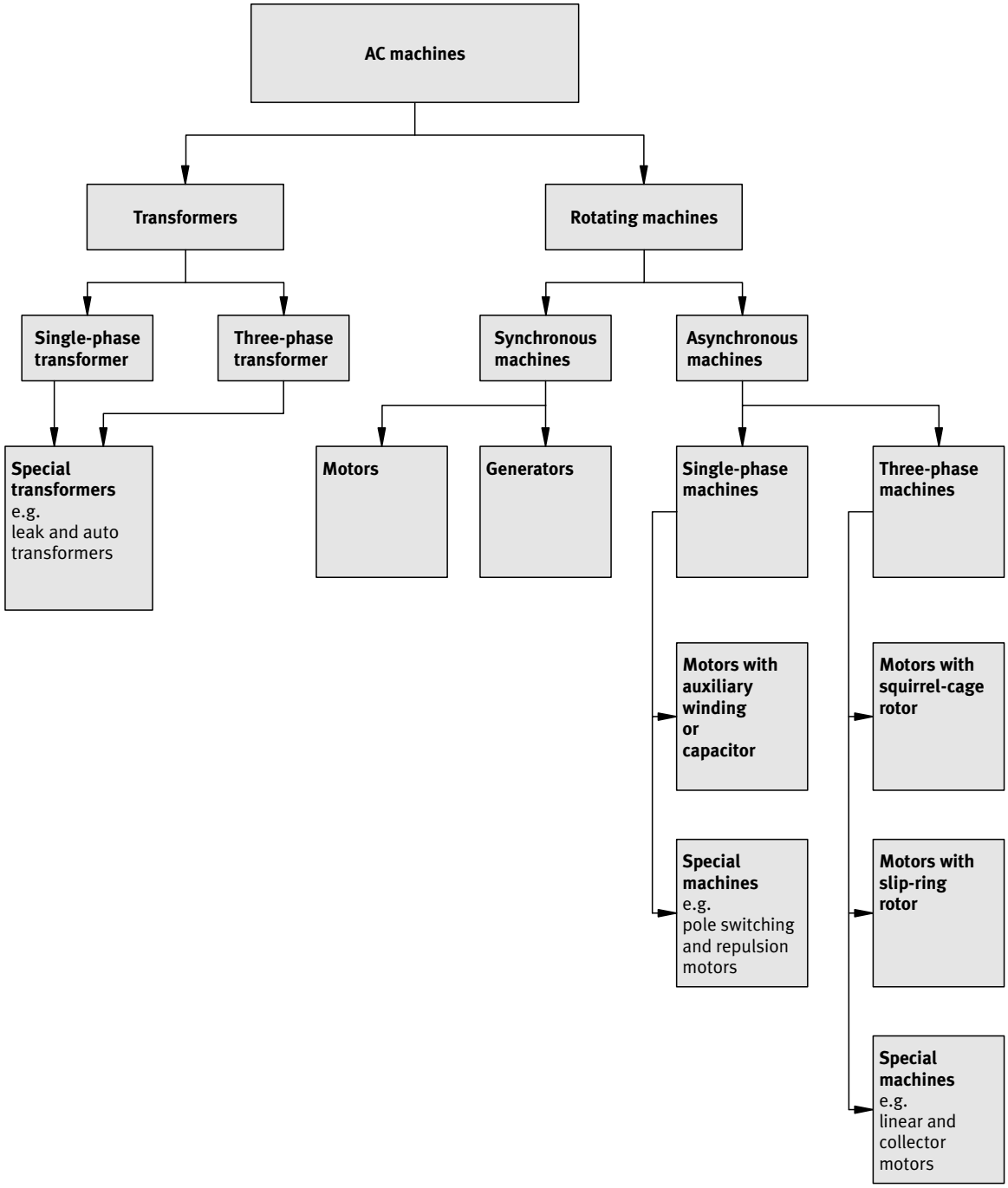
In actual practice, the speed of a 3-phase motor can be changed by changing the number of pole pairs. However, speed can only be changed in steps in this way (pole changing with a Dahlander circuit).

A more elegant way of changing speed is to change frequency. Frequency can be infinitely adjusted with the help of a frequency converter.

Contents

Exercises and worksheets

Overview of alternating current machines



Exercise 1

Basic principles of the 3-phase asynchronous motor with squirrel-cage rotor

Learning objectives

After completing this exercise:

- You will be familiar with the layout of an asynchronous motor with squirrel-cage rotor.
- You will be familiar with the motor terminal board and its designations.
- You will be familiar with the location of the jumpers on the motor terminal board for star and delta connection
- You will be familiar with the difference between star and delta connection in actual practice.
- You will be familiar with the working principle of the 3-phase motor.
- You will be familiar with the meaning of the term “asynchronous motor”.
- You will be familiar with start-up performance of the 3-phase motor.
- You will know how to change the direction of rotation of a 3-phase motor.
- You will be familiar with options for changing the speed of a 3-phase motor.

Problem description

An apprentice in the training workshop is assigned the task of examining a 3-phase motor which has just been received, and preparing a complete inspection report.

Note

The motor is not started up during this exercise!

Project assignments

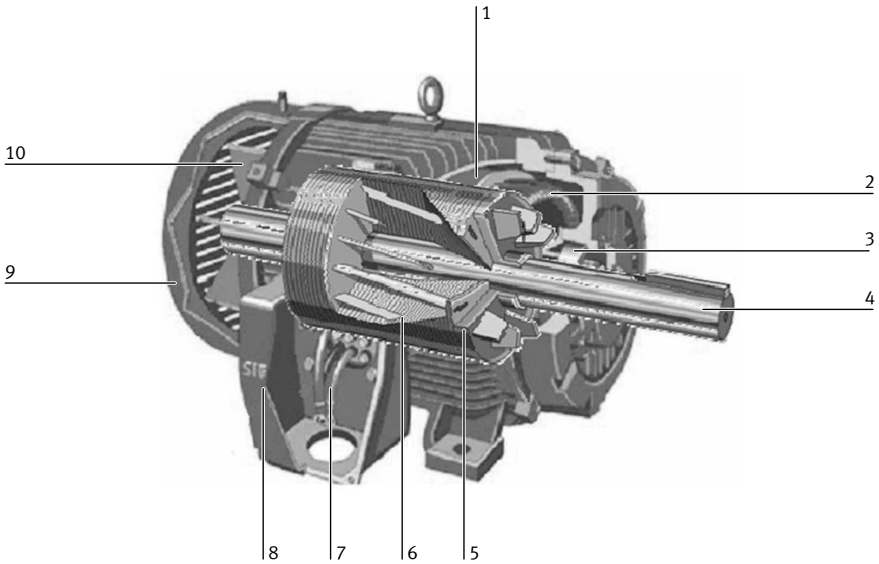
1. Describe the layout of a 3-phase asynchronous motor with squirrel-cage rotor.
2. Allocate the individual specifications to the corresponding items in the rating plate.
3. Complete the specifications for the motor terminal board for star and delta connection.
4. Explain the difference between star and delta connection in actual practice.
5. Describe the working principle of the 3-phase motor.
6. Explain the meaning of the term “asynchronous motor”.
7. Describe start-up performance of the 3-phase motor.
8. Explain how the direction of rotation of a 3-phase motor can be changed.
9. What does the speed of a 3-phase motor depend on and how can it be changed?

Work aids

- Textbooks, books of tables
- Excerpts from manufacturers’ catalogues
- Data sheets
- Internet
- WBT, “Electric drives 1”

 Name: _____ Date: _____

1. Layout of a 3-phase asynchronous motor with squirrel-cage rotor



3-phase asynchronous motor with squirrel-cage rotor – cutaway view

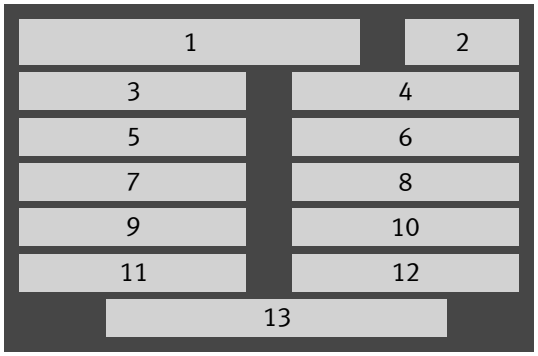
Designations

Drive shaft; stator core for accommodating the stator winding; short-circuit ring of the squirrel-cage rotor; stator winding; terminal box; roller bearing for the drive shaft; rotor core of the squirrel-cage rotor; motor terminal board for star or delta connection of the motor; fan for cooling the motor; rotor cover for enclosing the fan

– Match up the numbers in the cutaway view to the designations of the individual components.

No.	Designation
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

2. Rating plate of a 3-phase asynchronous motor with squirrel-cage rotor



– Allocate the numbers in the rating plate to the motor's corresponding characteristic values.

Characteristic motor values: Number of phases for AC machines; Rated supply frequency for AC machines; Manufacturer's name and designation; Manufacturer's serial number or identifying marks; VDE directive for rotating electric machines; Rated current; Rated power; Rated speed; Manufacturer's type designation; Degree of protection provided by enclosure (IP code) per EN 60529; Insulation and thermal class of the windings; Power factor; Phase voltage

No.	Characteristic motor values
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	

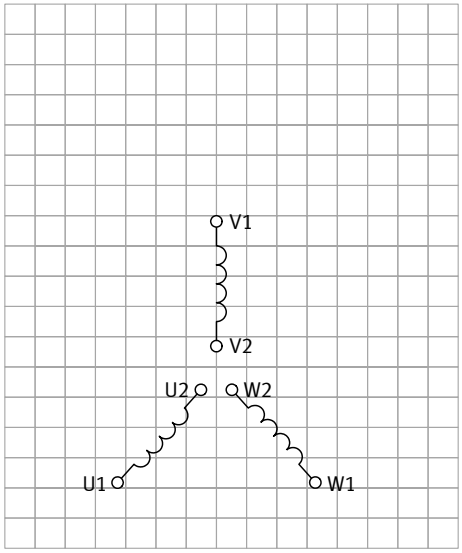
3. Motor terminal board for star and delta connection

Information

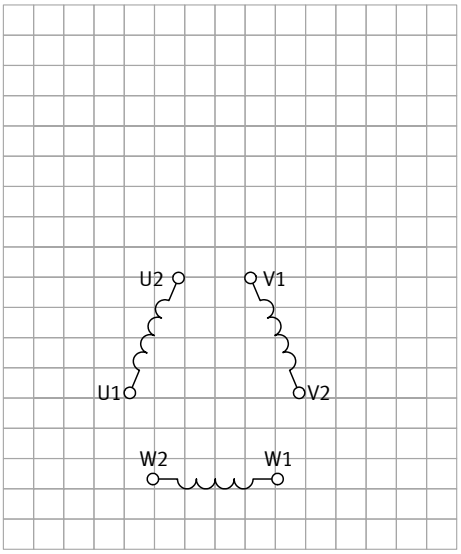
The motor's stator winding is a 3-phase winding which generates the rotary field.

The beginnings and ends of the phases are connected to the terminals at the motor terminal board, by means of which the phases can be wired for star or delta connection.

a) Complete the circuits for the windings for star and delta connection.

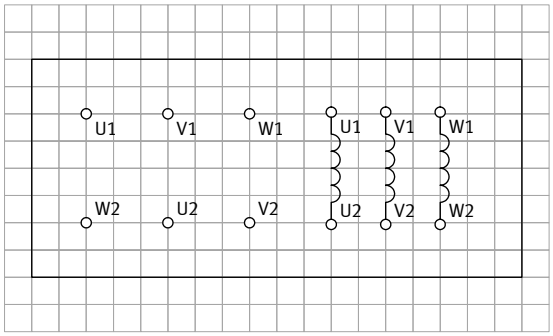


Star connection

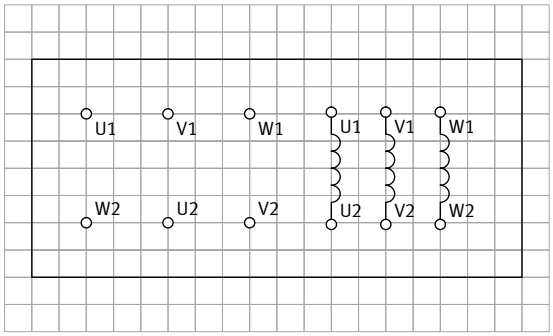


Delta connection

b) Sketch in the positions of the jumpers on the motor terminal board for star and delta connection.



Star connection



Delta connection

c) Which value on the rating plate indicates whether the motor will be operated with star or delta connection?

4. Difference between star and delta connection in actual practice

Information

The stator winding of a 3-phase motor may consist of either a 2-pole or a multi-pole winding. The winding's three separate phases are offset from each other by 120° (electrically).

Connecting the ends of the three phase windings results in star connection. Connecting the end of each phase with the beginning of the next results in delta connection.

a) Enter the appropriate type of connection (star or delta) to the empty columns.

Supply power		Permissible phase voltage
400 V	230 V	
		400 V
		230 V

 Name: _____ Date: _____

b) The motor is laid out for star connection and is mistakenly set up with delta connection. Describe the consequences.

c) The motor is laid out for delta connection and is mistakenly set up with star connection. Describe the consequences.

Information

	Star connection	Delta connection
Symbol	Y	Δ
Phase voltage	$U_{Str} = \frac{U}{\sqrt{3}}$	$U_{Str} = U$
Phase current	$I_{Str} = I$	$I_{Str} = \frac{I}{\sqrt{3}}$
Apparent power for one phase	$S_{Str} = \frac{U}{\sqrt{3}} \cdot I$	$S_{Str} = \frac{U}{\sqrt{3}} \cdot I$
Total apparent power	$S = 3 \cdot \frac{U}{\sqrt{3}} \cdot I$	$S = 3 \cdot \frac{U}{\sqrt{3}} \cdot I$
Input power	$P1 = \sqrt{3} \cdot U \cdot I \cdot cos\,\varphi$	

5. The working principle of the 3-phase motor

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– Explain the meaning of the term “asynchronous motor”.

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– Describe start-up performance of the 3-phase asynchronous motor.

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Synchronous rotary speeds for common numbers of poles at a frequency of 50 Hz						
Number of poles	2	4	6	8	10	12
Number of pole pairs						
Speed [rpm]						

b) Describe options for changing the speed of 3-phase motors in actual practice.

