Fundamentals of closed-loop control technology
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Use for intended purpose

The training package for “Fundamental principles of closed-loop control technology” 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 learning system from Festo Didactic has been developed and produced exclusively for training and continuing vocational education in the field of automation technology. The training company and/or trainers must ensure that all trainees observe the safety precautions 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 learning system for automation and technology is geared towards various educational backgrounds and vocational requirements. The learning system is therefore broken down as follows:

- Technology-oriented training packages
- Mechatronics and factory automation
- Process automation and control technology
- Robotino® – training and research with mobile robots
- Hybrid learning factories

The technology packages deal with various technologies including pneumatics, electropneumatics, hydraulics, electrohydraulics, proportional hydraulics, Programmable Logic Controllers, sensor technology, electrical engineering and electric drives.

The modular design of the learning system allows for applications which go above and beyond the limitations of the individual 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)
- Dictionaries, 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 programs (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.

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Do you have tips, feedback or suggestions for improving this workbook?

If so, please send us an e-mail at did@de.festo.com.

The authors and Festo Didactic look forward to your feedback.
Introduction

This workbook is part of the learning system for automation technology from Festo Didactic SE. The system provides a solid basis for practice oriented training and vocational education. The training package for “Fundamentals of closed-loop control technology” (TP 1013) provides a fast and easy-to-understand introduction to the subject of controllers and controlled systems.

Basic terminology for control technology, the behaviour of various controllers and the structured analysis of requirements for controlled systems are especially important in this respect.

In the projects, ways and means of analysing and solving control problems are shown and looked at in depth through experiments.

The equipment set permits the fast and flexible setup of different controllers, thus allowing simple examination of behaviour based on interaction with controlled systems of different types.

All of the equipment set’s components are equipped with safety plug connections. The Combiboard Digital and Control Technology EduTrainer® included in the equipment set provides the required supply voltages for all tests, and also includes a square-wave generator with seven different output frequencies. This Combiboard EduTrainer® is also used in the “Digital technology” training package (TP 1012).

The circuits for all 9 exercises are set up using the TP 1013 equipment set. The theoretical fundamentals for understanding these exercises are included in the textbooks:
- Skills for the Electrical Industry, order no. 567297
- Electrical engineering, order no. 567298.
Work and safety instructions

General information
• Trainees may only work with the circuits under the supervision of a trainer.
• The test area must be protected by residual current devices (RCDs).
  – Electrical devices (e.g. power supply units, compressors and hydraulic power units) may only be operated in training rooms which are equipped with residual current devices (RCDs).
  – A type B residual current circuit breakers with a residual current rating of ≤ 30 mA must be used.
• Observe the specifications included in the technical data and operating instructions for the individual components, and in particular all safety instructions!
• Malfunctions which may impair safety must not be generated.
• Wear personal protective equipment (safety glasses, hearing protection, safety shoes) when working on circuits.

Electrical safety
• Risk of death in case of interrupted protective earth conductor!
  – The protective earth conductor (yellow/green) must never be interrupted, either inside or outside of the device.
  – The insulation of the protective earth conductor must never be damaged or removed.
• German trade association regulations BGV A3, “Electrical systems and equipment”, must be observed in commercial facilities.
• In schools and training facilities, the operation of power supply units must be responsibly monitored by trained personnel
• Caution!
The capacitors in the device may still carry a charge, even after it has been disconnected from all voltage sources.
• When replacing fuses, use specified fuses with the correct current rating only.
• Never switch the power supply unit on immediately after it has been moved from a cold room to a warm room. Under unfavourable conditions, the condensate which forms as a result may damage the device. Leave the device switched off until it has reached room temperature.
• Use only extra-low voltage (max. +5 V DC) as the operating voltage for the circuits in the various exercises.
• Electrical connections may only be established in the absence of voltage.
• Electrical connections may only be interrupted in the absence of voltage.
• Use only connecting cables with safety plugs for electrical connections.
• Pull the plug only when disconnecting connecting cables; never pull the cable.
Training package for “Fundamentals of closed-loop control technology” (TP 1013)

Training package TP 1013 consists of a number of individual training materials. The subject of training package TP 1013 is the basic principles of control technology. Individual components from training package TP 1013 may also be included in other packages.

Important components of TP 1013
- Permanent workstation with EduTrainer® universal patch panel
- Control technology component set and laboratory safety cables
- EduTrainer® Combiboard for digital and closed-loop control technology
- Complete set of laboratory equipment

Media
The teachware for training package TP 1013 consists of a textbook, a book of tables and a workbook. The textbooks explain the basic principles of control technology in a clearly structured and easy-to-follow way. The workbook includes worksheets for each exercise, the solutions to each individual worksheet and a CD-ROM. A set of ready-to-use exercise sheets and worksheets is included with the workbook for all of the exercises.

Data sheets for the hardware components are made available along with the training package, and on the CD-ROM.

<table>
<thead>
<tr>
<th>Media</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical books</td>
<td>Technical expertise for the electrical professions</td>
</tr>
<tr>
<td></td>
<td>Electrical engineering</td>
</tr>
<tr>
<td>Book of tables</td>
<td>Electrical engineering/mechatronics</td>
</tr>
<tr>
<td>Workbook</td>
<td>Fundamentals of closed-loop control technology</td>
</tr>
</tbody>
</table>

Overview of media for training package TP 1013

The media are offered in several languages. Further training materials can be found in our catalogues and on the Internet.
Learning objectives

Exercise 1: Fundamentals of signal and closed-loop control technology
- Be able to identify terms such as sinusoidal, square-wave and triangle signal.
- Be able to identify terms such as step response, open-loop and closed-loop control.
- Become familiar with the behaviour and function of a hysteresis element.

Exercise 2: Analysing a proportional element and a PT1 element
- Become familiar with the behaviour of a P element.
- Become familiar with the behaviour of a PT1 element.
- Learn to record its step responses.
- Learn how to determine time delay using the tangent method and the 63% method.

Exercise 3: Analysing an integral element
- Become familiar with the behaviour of an I element.
- Learn to record its step response.

Exercise 4: Analysing a PT2 element
- Become familiar with the behaviour of a PT2 element.
- Learn to record its step response.
- Learn to determine time delay and balance time using the tangent method by entering a tangent at the turning point.

Exercise 5: Regulating temperature with a 2-step controller
- Learn to set up a 2-step controller.
- Become familiar with the functions of this component.

Exercise 6: Examining a control circuit consisting of a P or an I element as controller and a PT1 element as controlled system
- Become familiar with the terminology associated with controlled systems.
- Become familiar with the behaviour of a controlled system consisting of a P controller and a PT1 controlled system.
- Become familiar with the behaviour of a controlled system consisting of an I controller and a PT1 controlled system.
- Become familiar with the oscillatory response of a system.

Exercise 7: Examining a control circuit consisting of a P or an I element as controller and a PT2 element as controlled system
- Become familiar with the behaviour of a controlled system consisting of a P controller and a PT2 controlled system.
- Become familiar with the behaviour of a controlled system consisting of an I controller and a PT2 controlled system.
Exercise 8: Analysing a derivative element and examining a PID controller
- Become familiar with the behaviour of a D element.
- Become familiar with the step response of a D element.
- Learn how to set up a PID controller.

Exercise 9: Adjusting a controller according to Ziegler-Nichols
- Learn how to determine control parameters using the procedure according to Ziegler-Nichols.
- Become familiar with controlled system identification based on the step response.

Equipment set

The workbook for “Fundamentals of closed-loop control technology” provides an introduction to closed-loop control technology. The basic terms are first explained with the help of examples, after which the focus is on behaviour and interrelations. Special attention is given to the issues of behaviour and the analysis of controlled systems.

The equipment set for “Fundamentals of closed-loop control technology” includes all of the components required for achieving the specified learning objectives. The following are additionally required in order to set up and evaluate functional circuits:
- Oscilloscope
- Function generator
- Laboratory safety cables

Equipment set for fundamentals of closed-loop control technology, order no. 8023964

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<tr>
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</tr>
<tr>
<td>Set of components for control technology</td>
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Overview of component set for “closed-loop control technology” (order no. 8023693)

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<tr>
<td>I element</td>
<td>760541</td>
<td>1</td>
</tr>
<tr>
<td>D element</td>
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<td>1</td>
</tr>
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<td>1</td>
</tr>
<tr>
<td>Summator with adjustable offset</td>
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<tr>
<td>Limiter with level matching for the output signals</td>
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<td>PT2 element</td>
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Allocation of components to exercises

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<th>Exercise 1</th>
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<th>4</th>
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<td>x</td>
<td>x</td>
</tr>
<tr>
<td>I element</td>
<td>x</td>
<td></td>
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<tr>
<td>D element</td>
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<td>Limiter with level matching for the output signals</td>
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<tr>
<td>PT1 element</td>
<td>x</td>
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<td>x</td>
</tr>
<tr>
<td>PT2 element</td>
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<td>x</td>
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<td>x</td>
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<tr>
<td>Hysteresis element</td>
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<td></td>
<td></td>
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</tbody>
</table>

Notes for the teacher/trainer

Learning objectives
The basic learning objective of this workbook is the setup and analysis of selected basic circuits used in closed-loop control technology. The content includes, amongst other things, elementary basic circuits, controlled systems, 2-step controllers, PID controllers and calculations.
Required time
The time required for working through the exercises depends on the student's previous knowledge of the subject matter. Roughly 1 to 1½ hours should be scheduled for each exercise.

Equipment set components
The workbook and the equipment set are designed to be used together. All 9 exercises can be completed using components from one TP 1013 equipment set.

Standards
The following standards are applied in this workbook:
- EN 60617-2 to EN 60617-13 Graphic symbols for diagrams
- EN 81346-2 Industrial systems, installations and equipment and industrial products – Structuring principles and reference designations
- IEC 60364-1 Low-voltage electrical installations – Fundamental principles, assessment of general characteristics, definitions
- IEC 60346-4-41 Low-voltage electrical installations – Protective measures – Protection against electric shock
- IEC 60050-351 International Electrotechnical Vocabulary – Part 351: Control technology
- IEC 60027-6 Letter symbols to be used in electrical technology – Part 6: Control technology

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

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

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

This applies in particular to components whose parameters can be adjusted with a potentiometer.

Learning topics
The training subject "fundamentals of closed-loop control technology" is part of learning topic 1 in technical colleges for mechatronics/electronic engineering.
Structure of the exercises

All 9 exercises have the same structure and are broken down into:
• Title
• Learning objectives
• Problem descriptions
• Circuit or layout
• Work assignment
• Work aids
• Worksheets

The workbook contains the solutions to each worksheet included in the exercise book.

CD-ROM contents

The workbook is included on the 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

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 practical applications are made available. These can be used to illustrate individual tasks or to supplement project presentations.
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- **Exercise 5:** Regulating temperature with a 2-step controller 35
- **Exercise 6:** Examining a control circuit consisting of a P or an I element as controller and a PT1 element as controlled system 41
- **Exercise 7:** Examining a control circuit consisting of a P or an I element as controller and a PT2 element as controlled system 55
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Exercise 1:
Fundamentals of signal and closed-loop control technology

Learning objectives
After completing this exercise:
- You’ll be able to identify terms such as sinusoidal, square-wave and triangle signal.
- You’ll be able to identify terms such as step response, open-loop and closed-loop control.
- You’ll be familiar with the behaviour and function of a hysteresis element.

Problem description
The dynamic operating characteristics of a machine, for example a 3-phase motor, is defined in terms of basic modules in system theory. A system can thus be described in a technically explicit manner. In combination with a controller, the basic modules are depicted in a block diagram as a control circuit.

The basic modules of a control circuit are described on the basis of their response characteristics. The response characteristics result from the mathematical relationship between the input and output signals. Behaviour is evaluated on the basis of various test signals used as input signal $x_e$ and the associated reaction as output signal $x_a$, usually with delay.

![Response characteristics of a basic module](image)

If the controlled system’s response characteristics are known, a suitable controller can be selected.
Work assignments
1. Answer the questions about closed-loop control technology.
2. Record various signals from a function generator with an oscilloscope.
3. Familiarise yourself with the term step response.
4. Set up the circuit for examining the hysteresis element.
5. Record the characteristic curve of the hysteresis element.
6. Describe the function of the hysteresis element based on the measured characteristic curves.

Work aids
- Textbooks
- Books of tables
- Operating instructions
- Data sheets
- Internet
1. Questions about closed-loop control technology

Information – definition of closed-loop control in accordance with DIN IEC 60050-351 (351-26-01)
Closed-loop control is a process by means of which a variable (the controlled variable) is continuously monitored and compared with another variable (the reference variable) and is influenced so that it approaches the reference variable. Closed-loop control is characterised by its closed sequence of actions, within which the controlled variable continuously influences itself within the control circuit’s signal path.

Information – definition of open-loop control in accordance with DIN IEC 60050-351 (351-26-02)
Open-loop control is a process by means of which one or more variables influence other variables as output variables on the basis of the system’s own principles. Open-loop control is characterised by its open signal flow path, or by a closed signal flow path by means of which the output variables influenced by the input variables do not continuously or repeatedly act upon themselves via the same input variables.

a) List examples of variables to be controlled.

Variables such as
– rotational speed,
– flow rate,
– temperature
– fill-level etc.
are set to specified values at machines and systems. These selected values should not change even if malfunctions occur. Tasks of this type are performed by means of closed-loop control.

b) How is the variable to be controlled made available to the controller?

In order to make the variable to be controlled available to an automated controller as an electric signal, it first has to be detected and converted to a standardised quantity such as 0 ... 10 V, -1/+1 or 0 ... 100%.

This quantity is then compared to the specified value or values curve by the closed-loop controller. A control function determines how the system will be influenced on the basis of this comparison. In closed-loop control terminology, the machine or equipment is referred to as a system.
c) Which component must be included in the machine or system in order to make control possible?

The machine or system must include a component which can be used to influence the variable to be controlled (e.g. a regulator in a heating system or a valve in a piping system), i.e. a control device.

d) Complete the following table.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Open-loop control</th>
<th>Closed-loop control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of action sequence/signal flow path</td>
<td>Open (series connection)</td>
<td>Closed</td>
</tr>
<tr>
<td>Measurement of the output signal</td>
<td>Not necessary</td>
<td>Continuous measurement</td>
</tr>
<tr>
<td>Output signal feedback</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

2. Recording signals from a function generator

Note

This subtask allows you to become familiar with the operation of an oscilloscope. Neither the oscilloscope nor the function generator are included in equipment set TP 1013 for “Fundamentals of closed-loop control technology”.

Components list

- Function generator
- Digital storage oscilloscope

Preparing the test setup

Tick each task after you have completed it.

- Connect the function generator to channel 1 at the oscilloscope. Make sure that the earth cables are connected to each other.
- Select the signal shape: sinusoidal, square-wave or triangle.
- Select a frequency of 20 Hz and an amplitude of 10 V at the function generator.
- Set the voltage per division to 5 V and the time per division to 25 ms at the oscilloscope.
- Measure the amplitude voltage and frequency with the oscilloscope.
Measuring the signals

Recording
Input CH1: sinusoidal signal $f = 20$ Hz, $V_{ss} = 10$ V

Recording
Input CH1: square-wave signal $f = 20$ Hz, $V_{ss} = 10$ V

Recording
Input CH1: triangle signal $f = 20$ Hz, $V_{ss} = 10$ V
Information – signal technology terms

Amplitude is the maximum oscillation of a sinusoidal alternating voltage. Amplitude is measured from zero crossover to maximum signal oscillation.

The period (of oscillation) is the smallest interval after which a process regularly repeats itself.

Offset is a constant corrective (positive or negative) for a measured value.

3. Become familiar with the term step response

Information – step response

The step response depicts the system’s time characteristics at the output when its input is suddenly changed. The easiest way to test an unknown controlled system is to perform the following experiment: a stepped signal is generated as a manipulated variable, for example by closing a switch. The time characteristics of the controlled variable are then measured. This is known as the system’s “step response”.

The step response tells us something about the controlled system’s time characteristics, for example how quickly or slowly it reacts, whether or not it oscillates and whether or not a final value is reached.

A step response indicates the system’s dynamic operating behaviour for as long as the output value continues to change. If the output value remains constant and no longer changes, we then speak of static behaviour.
4. Setting up the circuit for examining the hysteresis element

![Circuit symbol, hysteresis element](image)

**Test setup**

**Components list**

- Hysteresis element
- Combiboard Digital and Control Technology EduTrainer®
- Digital storage oscilloscope
- Safety laboratory cables with 2 mm safety plugs

**Preparing the test setup**

Tick each task after you have completed it.

- Connect the hysteresis element to +15 V (red wire), -15 V (black wire) and earth/0 V (blue wire).
- Connect the sinusoidal signal from the function generator to the hysteresis element's signal input.
- Connect channel 1 at the oscilloscope to the signal input, and channel 2 to the signal output at the hysteresis element.
- Connect the earth conductor for channels 1 and 2 to earth at the Combiboard EduTrainer®.
- Set the function generator to a sinusoidal signal with a frequency of 20 Hz and an amplitude of 10 V.
- Set the voltage per division to 5 V and the time per division to 10 ms for channels 1 and 2 at the oscilloscope.
5. Recording the characteristic curve of the hysteresis element

Note – threshold value display at the oscilloscope
In order to be able to precisely determine the threshold values, the oscilloscope includes a measuring function which displays the exact switch-on and switch-off points. Amplitude, time and the difference between signals can be determined and displayed with the help of the so-called cursor.

a) Set the values specified in the table using the potentiometer.

b) Save the measured characteristic curves.

c) Read the threshold value voltages, for example with the help of an oscillator’s measuring function. Enter the measured values in the table.

<table>
<thead>
<tr>
<th>Hysteresis voltage [V]</th>
<th>Switch-on point [V]</th>
<th>Switch-off point [V]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1.20</td>
<td>-1.80</td>
</tr>
<tr>
<td>2</td>
<td>3.60</td>
<td>-4.20</td>
</tr>
<tr>
<td>4</td>
<td>5.80</td>
<td>-6.20</td>
</tr>
<tr>
<td>8</td>
<td>8.80</td>
<td>-9.00</td>
</tr>
</tbody>
</table>

6. Description of the function of the hysteresis element

There are two switching points. The hysteresis element switches the output voltage to ±15 V as soon as positive or negative input voltage exceeds or falls below a specified threshold value. The threshold value is set with the potentiometer.
Hysteresis element characteristic curve
Recording with potentiometer set to 0 V,
input CH1: sinusoidal signal $f = 20$ Hz, $V_{ss} = 10$ V,
output CH2

Hysteresis element characteristic curve
Recording with potentiometer set to 1 V,
input CH1: sinusoidal signal $f = 20$ Hz, $V_{ss} = 10$ V,
output CH2

Hysteresis element characteristic curve
Recording with potentiometer set to 2 V,
input CH1: sinusoidal signal $f = 20$ Hz, $V_{ss} = 10$ V,
output CH2
Exercise 1 – Fundamentals of signal and closed-loop control technology

Hysteresis element characteristic curve
Recording with potentiometer set to 4 V,
input CH1: sinusoidal signal $f = 20$ Hz, $V_{ss} = 10$ V,
output CH2

Hysteresis element characteristic curve
Recording with potentiometer set to 8 V,
input CH1: sinusoidal signal $f = 20$ Hz, $V_{ss} = 10$ V,
output CH2
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## Exercises and worksheets

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## Questions

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</tbody>
</table>
Exercise 1:
Fundamentals of signal and closed-loop control technology

Learning objectives
After completing this exercise:
- You’ll be able to identify terms such as sinusoidal, square-wave and triangle signal.
- You’ll be able to identify terms such as step response, open-loop and closed-loop control.
- You’ll be familiar with the behaviour and function of a hysteresis element.

Problem description
The dynamic operating characteristics of a machine, for example a 3-phase motor, is defined in terms of basic modules in system theory. A system can thus be described in a technically explicit manner. In combination with a controller, the basic modules are depicted in a block diagram as a control circuit.

The basic modules of a control circuit are described on the basis of their response characteristics. The response characteristics result from the mathematical relationship between the input and output signals. Behaviour is evaluated on the basis of various test signals used as input signal \( x_e \) and the associated reaction as output signal \( x_a \), usually with delay.

![Response characteristics of a basic module](image)

If the controlled system’s response characteristics are known, a suitable controller can be selected.
Exercise 1 – Fundamentals of signal and closed-loop control technology

Work assignments
1. Answer the questions about closed-loop control technology.
2. Record various signals from a function generator with an oscilloscope.
3. Familiarise yourself with the term step response.
4. Set up the circuit for examining the hysteresis element.
5. Record the characteristic curve of the hysteresis element.
6. Describe the function of the hysteresis element based on the measured characteristic curves.

Work aids
• Textbooks
• Books of tables
• Operating instructions
• Data sheets
• Internet
1. Questions about closed-loop control technology

Information – definition of closed-loop control in accordance with DIN IEC 60050-351 (351-26-01)
Closed-loop control is a process by means of which a variable (the controlled variable) is continuously monitored and compared with another variable (the reference variable) and is influenced so that it approaches the reference variable. Closed-loop control is characterised by its closed sequence of actions, within which the controlled variable continuously influences itself within the control circuit’s signal path.

Information – definition of open-loop control in accordance with DIN IEC 60050-351 (351-26-02)
Open-loop control is a process by means of which one or more variables influence other variables as output variables on the basis of the system’s own principles. Open-loop control is characterised by its open signal flow path, or by a closed signal flow path by means of which the output variables influenced by the input variables do not continuously or repeatedly act upon themselves via the same input variables.

a) List examples of variables to be controlled.

b) How is the variable to be controlled made available to the controller?
Exercise 1 – Fundamentals of signal and closed-loop control technology

Name: ____________________________ Date: ____________ © Festo Didactic 8023437

c) Which component must be included in the machine or system in order to make control possible?


d) Complete the following table.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Open-loop control</th>
<th>Closed-loop control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of action sequence/signal flow path</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measurement of the output signal</td>
<td></td>
<td></td>
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<tr>
<td>Output signal feedback</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Recording signals from a function generator

Note
This subtask allows you to become familiar with the operation of an oscilloscope. Neither the oscilloscope nor the function generator are included in equipment set TP 1013 for “Fundamentals of closed-loop control technology”.

Components list
Function generator
Digital storage oscilloscope

Preparing the test setup
Tick each task after you have completed it.

- Connect the function generator to channel 1 at the oscilloscope.
  Make sure that the earth cables are connected to each other!  
- Select the signal shape: sinusoidal, square-wave or triangle.
- Select a frequency of 20 Hz and an amplitude of 10 V at the function generator.
- Set the voltage per division to 5 V and the time per division to 25 ms at the oscilloscope.
- Measure the amplitude voltage and frequency with the oscilloscope.
Measuring the signals

Recording
Input CH1: sinusoidal signal $f = 20$ Hz, $V_{ss} = 10$ V

Recording
Input CH1: square-wave signal $f = 20$ Hz, $V_{ss} = 10$ V

Recording
Input CH1: triangle signal $f = 20$ Hz, $V_{ss} = 10$ V
Information – signal technology terms

**Amplitude** is the maximum oscillation of a sinusoidal alternating voltage. Amplitude is measured from zero crossover to maximum signal oscillation.

The **period (of oscillation)** is the smallest interval after which a process regularly repeats itself.

**Offset** is a constant corrective (positive or negative) for a measured value.

3. **Become familiar with the term step response**

Information – step response

The **step response** depicts the system's time characteristics at the output when its input is suddenly changed. The easiest way to test an unknown controlled system is to perform the following experiment: a stepped signal is generated as a manipulated variable, for example by closing a switch. The time characteristics of the controlled variable are then measured. This is known as the system's “step response”.

The step response tells us something about the controlled system’s time characteristics, for example how quickly or slowly it reacts, whether or not it oscillates and whether or not a final value is reached.

A step response indicates the system’s dynamic operating behaviour for as long as the output value continues to change. If the output value remains constant and no longer changes, we then speak of static behaviour.
4. Setting up the circuit for examining the hysteresis element

Circuit symbol, hysteresis element

Components list

- Hysteresis element
- Combiboard Digital and Control Technology EduTrainer®
- Digital storage oscilloscope
- Safety laboratory cables with 2 mm safety plugs

Test setup

Preparing the test setup

Tick each task after you have completed it.

- Connect the hysteresis element to +15 V (red wire), -15 V (black wire) and earth/0 V (blue wire).
- Connect the sinusoidal signal from the function generator to the hysteresis element’s signal input.
- Connect channel 1 at the oscilloscope to the signal input, and channel 2 to the signal output at the hysteresis element.
- Connect the earth conductor for channels 1 and 2 to earth at the Combiboard EduTrainer®.
- Set the function generator to a sinusoidal signal with a frequency of 20 Hz and an amplitude of 10 V.
- Set the voltage per division to 5 V and the time per division to 10 ms for channels 1 and 2 at the oscilloscope.
5. **Recording the characteristic curve of the hysteresis element**

**Note – threshold value display at the oscilloscope**
In order to be able to precisely determine the threshold values, the oscilloscope includes a measuring function which displays the exact switch-on and switch-off points. Amplitude, time and the difference between signals can be determined and displayed with the help of the so-called cursor.

a) Set the values specified in the table using the potentiometer.

b) Save the measured characteristic curves.

c) Read the threshold value voltages, for example with the help of an oscillator’s measuring function. Enter the measured values in the table.

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6. **Description of the function of the hysteresis element**
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Recording with potentiometer set to 0 V,
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output CH2

Hysteresis element characteristic curve
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input CH1: sinusoidal signal $f = 20$ Hz, $V_{ss} = 10$ V,
output CH2

Hysteresis element characteristic curve
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input CH1: sinusoidal signal $f = 20$ Hz, $V_{ss} = 10$ V,
output CH2
Hysteresis element characteristic curve
Recording with potentiometer set to 4 V,
input CH1: sinusoidal signal $f = 20$ Hz, $V_{ss} = 10$ V,
output CH2

Hysteresis element characteristic curve
Recording with potentiometer set to 8 V,
input CH1: sinusoidal signal $f = 20$ Hz, $V_{ss} = 10$ V,
output CH2