Electropneumatics
Basic level
The purchaser shall receive a single right of use that is non-exclusive, non-time-limited and limited geographically to the purchaser’s site/location as follows.

- The purchaser shall be entitled to use the contents of the documentation to train his staff at the purchaser’s location and shall also be entitled to use parts of the contents of the documentation to create his own training documentation for the training of his staff at the purchaser’s location with acknowledgement of source, and to make copies for this purpose. In the case of schools/technical colleges and training centers, the right of use shall also include use by school pupils, college students and trainees at the purchaser’s location for teaching purposes.

- The right of use shall in all cases exclude the right to publish any content or make it available for use on intranet, Internet and LMS platforms and databases such as Moodle, which allow access by a wide variety of users, including those outside of the purchaser’s location.

- Entitlement to other rights relating to duplication, copies, adaptations, translations, microfilming and transfer to, as well as storage and processing in electronic systems, either in whole or in part, shall require the prior consent of Festo Didactic.

**Notice**

Wherever teachers, trainees etc. are referred to in the masculine form in this manual, the feminine form is, of course, also implied. The use of a single gender form is not intended as gender-specific discrimination, but simply to aid readability and comprehension of the document and the formulations used.
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Use for intended purpose

The training package for basic level electropneumatics may only be used:

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

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

The learning system from Festo Didactic has been developed and produced exclusively for basic and further training in the field of automation technology. The training company and/or instructors 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 that 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 training system is therefore broken down as follows:

- Technology-oriented training packages
- Mechatronics and factory automation
- Process automation and closed-loop control technology
- Mobile robotics
- Hybrid training 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 training packages deal with various technologies including pneumatics, electropneumatics, servopneumatics, hydraulics, electrohydraulics, proportional hydraulics, servohydraulics, mobile 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 control 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)

The following software programs are available:

- Digital training programs (learning content specifically designed for virtual training)
- Simulation software
- Visualization 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’re intended for use in classroom instruction, but are also suitable for self-study.

**Workbook license types**
We offer the following three license types for workbooks:

- **Home use license**
  For personal use. You order the workbook online as a PDF file. All of the workbook’s pages are watermarked. You can store the PDF file to your PC, print it out and edit it. The multimedia CD-ROM is not included.

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  This is the standard option for commercial use. You order a printed version of the workbook with multimedia CD-ROM in the language of your choice. The files included on the multimedia CD-ROM can be stored to your PC, printed out and edited.
• Enterprise license
  For large companies and educational institutions with multiple locations. You order either:
  – A printed version of the workbook in the language of your choice including a multimedia CD-ROM
    with multilingual content
  or
  – A multimedia CD-ROM with multilingual content.
  The files included on the multimedia CD-ROM can be stored to your PC, printed out and edited.

  **Note**
  The full rights of use are in compliance with the stipulations included in the legal notice of the
  purchased workbook.

  **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 tips or suggestions for improving this workbook?**
  If so, please inform us by e-mail at did@festo.com.
  The authors and Festo Didactic look forward to your comments.
Introduction

This workbook is part of the learning system for automation technology from Festo Didactic. The system provides a solid basis for practice-oriented basic and further training. Technology package TP 200 contains electropneumatic control systems only.

TP 201, “Electropneumatics, basic level”, is the ideal introduction to electropneumatic control technology. Knowledge regarding the basic physical principles of electropneumatics, as well as the function and use of electropneumatic components, is imparted. Simple electropneumatic controllers can be set up with the equipment set.

TP 202, “Electropneumatics, advanced level”, is targeted at students who require further training in electropneumatic control technology. The two device sets can be used to set up extensive combinatory circuits with linking of the input and output signals, as well as program controllers.

Technical prerequisites for setting up the controllers include:

- A Learnline or Learntop-S workstation equipped with a Festo Didactic slotted profile plate. The slotted profile plate has 14 parallel T-slots at 50 mm intervals.
- A power pack with short-circuit protection (input: 230 V, 50 Hz, output: 24 V, max. 5 A).
- A portable, sound-insulated compressor (230 V, max. 800 kPa = 8 bar) is used to supply compressed air.

The working pressure should not exceed $p = 600 \text{ kPa (6 bar)}$.

Ideal operating safety can be achieved by operating the control system at a working pressure of $p = 500 \text{ kPa (5 bar)}$ without oil.

Complete controllers for all 12 exercises are set up using the TP 201 basic level equipment set. The theoretical fundamentals for understanding the exercises listed in this workbook are included in the textbook entitled:

- Fundamentals of pneumatics and electropneumatics

Data sheets for the individual components are also available (cylinders, valves, measuring devices, etc.).
Work and safety instructions

General
- Trainees should only work with the circuits under the supervision of an instructor.
- Electrical devices (e.g. power packs, compressors and hydraulic units) may only be operated in training rooms that are equipped with residual current devices (RCDs).
- Observe the 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.
- Wear personal safety equipment (safety glasses, safety shoes) when working on circuits.

Mechanical safety
- Switch off the power supply!
  - Switch off working and control power before working on the circuit.
  - Only reach into the setup when it's at a complete standstill.
  - Be aware of potential overtravel times for the drives.
- Mount all of the components on the profile plate securely.
- Make sure that limit switches are not actuated from the front.
- Risk of injury during troubleshooting!
  Use a tool such as a screwdriver to actuate the limit switches.
- Set all components up in a way that makes it easy to activate the switches and disconnectors.
- Follow the instructions regarding positioning of the components.

Electrical safety
- Disconnect from all sources of electrical power!
  - Switch off the power supply before working on the circuit.
  - Please note that electrical energy may be stored in individual components.
    Further information on this issue is available in the data sheets and operating instructions included with the components.
- Use protective extra-low voltage only: max. 24 V DC.
- Establishing and disconnecting electrical connections
  - Electrical connections may only be established in the absence of voltage.
  - Electrical connections may only be disconnected in the absence of voltage.
- Use only connecting cables with safety plugs for electrical connections.
- When laying connecting cables, make sure they’re not kinked or pinched.
- Do not lay cables over hot surfaces.
  - Hot surfaces are identified with a corresponding warning symbol.
- Make sure that connecting cables are not subjected to continuous tensile loads.
- Always pull on the safety plug when disconnecting connecting cables; never pull the cable.

**Pneumatic safety**

- Depressurize the system!
  - Switch off the compressed air supply before working on the circuit.
  - Check the system with pressure gauges to make sure that the entire circuit is fully depressurized.
  - Please note that energy may be stored in air reservoirs.
    Further information on this issue is available in the data sheets and operating instructions included with the components.
- Do not exceed the maximum permissible pressure of 600 kPa (6 bar).
- Do not switch on the compressed air until all tubing connections have been established and secured.
- Do not disconnect tubing while under pressure.
- Risk of injury when switching on the compressed air!
  Cylinders may advance and retract automatically.
- Risk of accident due to advancing cylinders!
  - Always position pneumatic cylinders so that the piston rod’s working space is unobstructed over the entire stroke range.
  - Make sure that the piston rod cannot collide with any rigid components of the setup.
- Risk of accident due to tubing slipping off!
  - Use the shortest possible tubing connections.
  - If tubing slips off:
    Switch off the compressed air supply immediately.
- Pneumatic circuit setup:
  Connect the devices using plastic tubing with an outside diameter of 4 or 6 mm. Push the tubing into the push-in connector as far as it will go.
- Switch the compressed air supply off before dismantling the circuit.
- Dismantling the pneumatic circuit
  Press the blue release ring down so that the tube can be pulled out.
• Noise due to escaping compressed air
  – Noise caused by escaping compressed air may damage your hearing. Reduce noise by using silencers, or wear hearing protection if noise cannot be avoided.
  – All of the exhaust ports for the components included in the equipment set are equipped with silencers. Do not remove these silencers.

**Mounting technology**
The mounting boards for the devices are equipped with mounting variant A, B, C or D:

- **Variant A, snap-in system**
  Lightweight devices that cannot be subjected to loads (e.g. directional control valves). Simply clip the components into the slots on the slotted profile plate. Release the components by turning the blue lever.

- **Variant B, rotary system**
  Devices with medium load capacity (e.g. drives). These components are clamped to the slotted profile plate with T-head bolts. The blue knurled nut is used for clamping and loosening.

- **Variant C, screw system**
  For devices that will be subject to heavy loads and that will rarely need to be taken off the slotted profile plate (e.g. shutoff valve with filter regulator). The devices are secured with socket head screws and T-head nuts.

- **Variant D, plug-in system**
  Lightweight devices with lock pins that cannot be subjected to loads (e.g. indicator units). These are secured with plug adapters.
Training package, electropneumatics (TP 200)

The TP 200 training package consists of a multitude of individual training materials and seminars. The subject matter of this package is strictly electropneumatic control systems. Individual elements included in training package TP 200 may also be included in other packages.

Important TP 200 components
- Permanent workstation with Festo Didactic slotted profile plate
- Compressor (230 V, 0.55 kW, max. 800 kPa = 8 bar)
- Equipment sets or individual components
- Optional training aids
- Complete set of laboratory equipment

Media
The teachware for the TP 200 training package consists of a textbook and workbooks. The textbook provides basic physical and technical knowledge regarding pneumatics and electropneumatics. The workbooks include exercise sheets 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 in each workbook for all of the exercises.

Data sheets for the hardware components are made available along with the equipment set.

<table>
<thead>
<tr>
<th>Media</th>
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<tbody>
<tr>
<td>Textbook</td>
<td>Fundamentals of pneumatics and electropneumatics</td>
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<tr>
<td>Workbooks</td>
<td>Electropneumatics, basic level (TP 201)</td>
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<td>Electropneumatics, advanced level (TP 202)</td>
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<tr>
<td>Optional teachware</td>
<td>DVD, electropneumatics and electrohydraulics, basic level</td>
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<td>FluidSIM® Pneumatics simulation software</td>
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<td>WBT electropneumatics, WBT pneumatics</td>
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<td></td>
<td>WBTs electrical technology 1 + 2, and electronics 1 + 2</td>
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<tr>
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<td>Set of cutaway models with storage case</td>
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</table>

Further training materials can be found in our catalogs and on the Internet. The learning system for automation and technology is continuously updated and expanded. Transparency sets, videos, CD-ROMs and DVDs, as well as textbooks, are available in several languages.
Learning objectives for the basic level (TP 201)

■ Components
- Become familiar with the setup and function of a single-acting cylinder.
- Become familiar with the setup and function of a double-acting cylinder.
- Become familiar with the setup and function of a 3/2-way solenoid valve.
- Become familiar with the setup and function of a double solenoid valve.
- Become familiar with the setup and function of magnetic proximity switches.

■ Circuits
- Be able to select solenoid valves based on control technology requirements.
- Be able to recognize and sketch the various types of actuation used for directional control valves.
- Be able to convert solenoid valves.
- Be able to explain and set up direct actuation.
- Be able to explain and set up indirect actuation.
- Become familiar with logic functions and be able to set them up.
- Become familiar with various types of end position control and be able to select the appropriate type.
- Become familiar with latching circuits with varying performance features.
- Learn to explain and set up an electrical latching circuit with dominant breaking signal.
- Be able to set up pressure-dependent control systems.
- Become familiar with displacement-step diagrams and be able to prepare them for specified problems.
- Learn to implement sequence control with two cylinders.
- Be able to detect and eliminate errors in simple electropneumatic controllers.

■ Measurements, settings and calculations
- Be able to calculate piston forces on the basis of specified values.
- Be able to calculate characteristic electrical values.
## Allocation of learning objectives to exercises

<table>
<thead>
<tr>
<th>Learning objectives</th>
<th>Exercise 1</th>
<th>Exercise 2</th>
<th>Exercise 3</th>
<th>Exercise 4</th>
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<th>Exercise 6</th>
<th>Exercise 7</th>
<th>Exercise 8</th>
<th>Exercise 9</th>
<th>Exercise 10</th>
<th>Exercise 11</th>
<th>Exercise 12</th>
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</thead>
<tbody>
<tr>
<td>Become familiar with the setup and function of a single-acting cylinder.</td>
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<td>Become familiar with the setup and function of a double-acting cylinder.</td>
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<tr>
<td>Be able to calculate piston forces on the basis of specified values.</td>
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<tr>
<td>Become familiar with the setup and function of a 3/2-way solenoid valve.</td>
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<tr>
<td>Become familiar with the setup and function of a double solenoid valve.</td>
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<td>Be able to select solenoid valves based on control technology requirements.</td>
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<tr>
<td>Be able to recognize and sketch the various types of actuation used for directional control valves.</td>
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<tr>
<td>Be able to convert solenoid valves.</td>
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<td>Be able to explain and set up direct actuation.</td>
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<td>Be able to explain and set up indirect actuation.</td>
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<td>Become familiar with various types of end position control and be able to select the appropriate type.</td>
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<td>Become familiar with logic functions and be able to set them up.</td>
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<td>Be able to calculate characteristic electrical values.</td>
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<td>Become familiar with latching circuits with varying performance features.</td>
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<tr>
<td>Learn to explain and set up an electrical latching circuit with dominant breaking signal.</td>
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<td>Be able to set up pressure-dependent control systems.</td>
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<td>Become familiar with the setup and function of magnetic proximity switches.</td>
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<tr>
<td>Become familiar with displacement-step diagrams and be able to prepare them for specified problems.</td>
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<tr>
<td>Learn to implement sequence control with two cylinders.</td>
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<tr>
<td>Be able to detect and eliminate errors in simple electropneumatic controllers.</td>
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### Equipment set for the basic level (TP 201)

This equipment set has been put together for basic training in the field of electropneumatic control technology. It includes all of the elements which are necessary for achieving the specified learning objectives, and can be supplemented with any other equipment sets.

A profile plate, an electrical power pack and a source of compressed air are also required in order to set up functional control systems.

#### Equipment set for the basic level (TP 201), order no. 540712

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Designation</th>
<th>Order no.</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>2 ea. 3/2-way solenoid valve, normally closed</td>
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<tr>
<td>2</td>
<td>5/2-way double solenoid valve</td>
<td>567200</td>
</tr>
<tr>
<td>1</td>
<td>5/2-way solenoid valve</td>
<td>567199</td>
</tr>
<tr>
<td>10</td>
<td>Blanking plug</td>
<td>153267</td>
</tr>
<tr>
<td>2</td>
<td>Double-acting cylinder</td>
<td>152888</td>
</tr>
<tr>
<td>4</td>
<td>One-way flow control valve</td>
<td>193967</td>
</tr>
<tr>
<td>1</td>
<td>Pressure sensor</td>
<td>572745</td>
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<tr>
<td>1</td>
<td>Single-acting cylinder</td>
<td>152887</td>
</tr>
<tr>
<td>1</td>
<td>On-off valve with filter regulating valve</td>
<td>540691</td>
</tr>
<tr>
<td>1</td>
<td>Limit switch, electrical, actuated from the left</td>
<td>183322</td>
</tr>
<tr>
<td>1</td>
<td>Limit switch, electrical, actuated from the right</td>
<td>183345</td>
</tr>
<tr>
<td>2</td>
<td>Electronic proximity sensor</td>
<td>2344752</td>
</tr>
<tr>
<td>1</td>
<td>Optical proximity sensor</td>
<td>572744</td>
</tr>
<tr>
<td>2</td>
<td>Relay, 3-way</td>
<td>162241</td>
</tr>
<tr>
<td>1</td>
<td>Signal input, electrical</td>
<td>162242</td>
</tr>
<tr>
<td>10</td>
<td>Push-in sleeve</td>
<td>153251</td>
</tr>
<tr>
<td>20</td>
<td>T-plug connector</td>
<td>153128</td>
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<tr>
<td>1</td>
<td>Distributor block</td>
<td>152896</td>
</tr>
<tr>
<td>1</td>
<td>Plastic tubing, 4 x 0.75, 10 m</td>
<td>151496</td>
</tr>
</tbody>
</table>
## Equipment set symbols

<table>
<thead>
<tr>
<th>Component</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relay, 3-way</td>
<td>![Relay Symbol]</td>
</tr>
<tr>
<td>Signal input, electrical</td>
<td>![Signal Input Symbol]</td>
</tr>
<tr>
<td>5/2-way solenoid valve</td>
<td>![Solenoid Valve Symbol]</td>
</tr>
<tr>
<td>Component</td>
<td>Symbol</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>--------</td>
</tr>
<tr>
<td>3/2-way solenoid valve, normally closed</td>
<td>Internal layout</td>
</tr>
<tr>
<td><img src="image" alt="Diagram of 3/2-way solenoid valve" /></td>
<td></td>
</tr>
<tr>
<td>5/2-way double solenoid valve</td>
<td><img src="image" alt="Diagram of 5/2-way double solenoid valve" /></td>
</tr>
<tr>
<td>Electronic proximity sensor</td>
<td><img src="image" alt="Diagram of Electronic proximity sensor" /></td>
</tr>
<tr>
<td>Pressure sensor</td>
<td><img src="image" alt="Diagram of Pressure sensor" /></td>
</tr>
<tr>
<td>Optical proximity sensor</td>
<td><img src="image" alt="Diagram of Optical proximity sensor" /></td>
</tr>
<tr>
<td>Electrical limit switch</td>
<td><img src="image" alt="Diagram of Electrical limit switch" /></td>
</tr>
<tr>
<td>Component</td>
<td>Symbol</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td>--------</td>
</tr>
<tr>
<td>One-way flow control valve</td>
<td><img src="image" alt="One-way flow control valve" /></td>
</tr>
<tr>
<td>Single-acting cylinder</td>
<td><img src="image" alt="Single-acting cylinder" /></td>
</tr>
<tr>
<td>Double-acting cylinder</td>
<td><img src="image" alt="Double-acting cylinder" /></td>
</tr>
<tr>
<td>On-off valve with filter regulating valve</td>
<td><img src="image" alt="On-off valve with filter regulating valve" /></td>
</tr>
<tr>
<td>Distributor block</td>
<td><img src="image" alt="Distributor block" /></td>
</tr>
</tbody>
</table>
# Allocation of components to exercises

<table>
<thead>
<tr>
<th>Component</th>
<th>Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-acting cylinder</td>
<td>1 1 1 1</td>
</tr>
<tr>
<td>Double-acting cylinder</td>
<td>1 1 1 1 1 1 1 1 1 1 1</td>
</tr>
<tr>
<td>One-way flow control valve</td>
<td>1 2 2 1 2 2 2 2 2 2 3 3</td>
</tr>
<tr>
<td>3/2-way solenoid valve, normally closed</td>
<td>1 (1) 1 1</td>
</tr>
<tr>
<td>5/2-way solenoid valve</td>
<td>1 1 1</td>
</tr>
<tr>
<td>5/2-way double solenoid valve</td>
<td>1 1 1 1 1 1 1</td>
</tr>
<tr>
<td>Pressure sensor</td>
<td>1</td>
</tr>
<tr>
<td>Electrical limit switch</td>
<td>1 2</td>
</tr>
<tr>
<td>Electronic proximity sensor</td>
<td>2 2 2 2</td>
</tr>
<tr>
<td>Optical proximity sensor</td>
<td>1</td>
</tr>
<tr>
<td>Electrical pushbutton, normally open</td>
<td>1 1 1 1 1 2 1 1 1 1</td>
</tr>
<tr>
<td>Electrical pushbutton, normally closed</td>
<td>1</td>
</tr>
<tr>
<td>Relay</td>
<td>1 1 2 2 3 1 3 3 3 3</td>
</tr>
<tr>
<td>Distributor block</td>
<td>1 1 1 1 1 1 1 1 1</td>
</tr>
<tr>
<td>On-off valve with filter regulating valve</td>
<td>1 1 1 1 1 1 1 1 1 1 1 1</td>
</tr>
<tr>
<td>24 V DC power pack</td>
<td>1 1 1 1 1 1 1 1 1 1 1 1</td>
</tr>
</tbody>
</table>
Notes for the teacher/instructor

Learning objectives
The basic learning objectives for the book of exercises are the systematic drafting of circuit diagrams, as well as the practical setup of the control system on the profile plate. This direct interaction involving both theory and practice ensures faster learning progress. Concrete, individual learning objectives are assigned to each exercise. Important learning objectives for post-processing appear in parentheses.

Required time
The time required for working through the exercises depends on the student’s previous knowledge of the subject matter. For a skilled laborer in the field of metalworking or electrical installation, the time required is approx. 2 weeks. For a technician or engineer, it’s approx. 1 week.

Equipment set components
The textbook, the workbook and the equipment set are designed to be used together. All 12 exercises can be completed using the components from one TP 201 equipment set.

Each exercise can be set up on a slotted profile plate with a width of at least 700 mm.

Standards
The following standards apply to this workbook:
ISO 1219-1: Fluid power systems and components – Graphic symbols and circuit diagrams – Symbols
DIN EN 81346-2: Industrial systems, installations and equipment and industrial products – Structuring principles and reference designations

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

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

Training notes
Additional information is provided here regarding the individual components and the completed controllers. These notes are not included in the book of exercises.
Solutions
The solutions provided in this workbook result from test measurements. The results of your measurements may deviate from these.

Fields of learning
The allocation of the fields of learning offered by vocational schools to the subject matter of “fluid power” is provided below for selected vocational apprenticeships.

<table>
<thead>
<tr>
<th>Vocational apprenticeship</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronics engineer for automation technology</td>
<td>Analyzing and adapting control systems</td>
</tr>
<tr>
<td></td>
<td>Systems implementation and safety testing</td>
</tr>
<tr>
<td>Industrial mechanic</td>
<td>Installing and commissioning control systems</td>
</tr>
<tr>
<td>Mechatronics technician</td>
<td>Examination of the flow of energy and information in electrical, pneumatic and hydraulic assemblies</td>
</tr>
<tr>
<td></td>
<td>Implementation of mechatronic subsystems</td>
</tr>
</tbody>
</table>

Structure of the exercises
All 12 exercises have the same structure and are broken down into:
- Title
- Learning objectives
- Description of the problem
- Layout
- General conditions
- Work assignments
- Work aids
- Worksheets

The workbook includes the solutions for each of the worksheets for all 12 exercises.
Reference designations of the components

The reference designations in the circuit diagrams are in compliance with EN 81346-2:2010-05, Industrial systems, installations and equipment and industrial products – Structuring principles and reference designations – Part 2, Classification of objects and codes for classes. The product-related aspect of the components is taken into consideration, for which reason all reference designations begin with a dash. Identification letters are assigned depending on the component. If several components within a circuit have the same identification letter, consecutive numbers are assigned to them as well.

Cylinders: -MM1, -MM2 ...
Valves: -QM1, -QM2, -KH1, -KH2, -RM1 -RZ1 ...
Sensors: -BG1, -BG2, -BF1, -BP1 ...
Signal inputs: -SF1, -SF2, -SJ1, -SJ2 ...
Accessories: -AZ1, -AZ2, -XM1, -XM2, -PG1 ...

Contents of the CD-ROM

In the case of the Campus and Enterprise license types, a multimedia CD-ROM is supplied with the workbook. The entire workbook is included on the CD-ROM as a PDF file. The CD-ROM also provides you with additional media.

The CD-ROM has the following structure:
- Operating instructions
- Images
- FluidSIM® circuit diagrams
- Presentations
- Videos

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

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

FluidSIM® circuit diagrams
The FluidSIM® circuit diagrams for all of the exercises included in the training package are contained in this directory.
Presentations
This directory contains short presentations for the devices included in the training package. These can be used to create project presentations, for example.

Videos
Finally, there are several short videos of industrial applications in their actual environments.
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Exercises and solutions

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Exercise 6: Pushing boards out of a stacking magazine ....................... 55
Exercise 7: Optimizing the inspection of beverage crates .................... 67
Exercise 8: Shifting roller conveyors .................................................... 79
Exercise 9: Transferring bottles ............................................................ 89
Exercise 10: Stamping mounting wedges .............................................. 101
Exercise 11: Palletizing roof tiles ......................................................... 111
Exercise 12: Eliminating a malfunction at a pallet loading station ....... 121
Exercise 1: Inspecting beverage crates

- **Learning objectives**
  After completing this exercise:
  - You'll be familiar with the setup and function of a single-acting cylinder.
  - You'll be familiar with the setup and function of a 3/2-way solenoid valve.
  - You'll be able to recognize and sketch the various types of actuation used for directional control valves.
  - You'll be able to explain and set up direct actuation.

- **Description of the problem**
  Beverage crates are checked for completeness with the help of an inspection unit. Incomplete crates are pushed off of the roller conveyor by pressing a pushbutton.

  Develop a controller with which this process can be executed.

- **Layout**

  Inspection unit for beverage crates
Exercise 1: Inspecting beverage crates

- **Description of the process**
  1. Beverage crates are inspected at a manual workstation.
  2. After pressing a pushbutton, incompletely filled beverage crates are pushed off of the conveyor by the piston rod of a single-acting cylinder.
  3. When the pushbutton is released, the piston rod is retracted to the rear end position.

- **General conditions**
  - A single-acting cylinder will be used.
  - The cylinder will be controlled by means of a pushbutton.
  - In the event of a power failure, the cylinder’s piston rod should be retracted to the rear end position.

- **Work assignments**
  1. Describe the function of pneumatic power components.
  2. Complete the circuit symbols for solenoid valves.
  3. Describe the meaning and the function of the port designations for valves.
  4. Describe how the neutral positions of directional control valves influence the motion sequence of a cylinder.
  5. Describe the functions of various valve types.
  6. Explain the difference between direct and indirect actuation.
  7. Describe the design and function of electrical switches.
  8. Complete the pneumatic and electrical circuit diagrams.
  9. Complete the equipment list.
  10. Set up the controller’s pneumatic and electrical sections.
  11. Double check the controller configuration.
  12. Describe the controller’s work sequence.

- **Work aids**
  - Books of tables
  - Textbook: Fundamentals of pneumatics and electropneumatics
  - Component data sheets
  - FluidSIM® P design and simulation software
  - WBT: Electropneumatics
1. Function of pneumatic power components

Information
Pneumatic power components can be subdivided into two groups:
- Power components with motion in a straight line
- Power components with rotary motion

- Describe the power components shown below and their functions.

Single-acting cylinder, return spring in piston chamber, return stroke by means of compressed air, forward stroke by means of return spring

Function
The piston rod of this single-acting cylinder is moved to the rear end position by activating compressed air. After deactivating compressed air and exhausting the piston rod chamber, the piston is moved to the front end position by a return spring in the piston chamber.

Single-acting cylinder, return spring in piston rod chamber, forward stroke by means of compressed air, return stroke by means of return spring

Function
The piston rod of this single-acting cylinder is moved to the front end position by activating compressed air. After deactivating compressed air and exhausting the piston rod chamber, the piston is moved to the rear end position by a return spring.
Exercise 1: Inspecting beverage crates

Pneumatic quarter turn actuator (rotary drive) with limited swivel angle

**Function**

This swivel cylinder is double-acting and is reversed by alternately activating compressed air at either end.

2. **Circuit symbols for solenoid valves**

   - Complete the circuit symbols with the help of the descriptions of the respective components.

   ![Circuit Symbol 1](image)

   Directly actuated 3/2-way solenoid valve, normally open, with manual override, pneumatic spring return

   ![Circuit Symbol 2](image)

   Pilot-actuated 3/2-way solenoid valve, normally closed, with manual override, mechanical spring return
3. Identification of valve ports

**Information**

In order to prevent incorrect tubing connections at directional control valves, the valve ports (working and pilot lines) are identified in accordance with ISO 5599-3 on the valves themselves, as well as in the circuit diagram.

- Explain the meanings and functions of the port designations listed below.

<table>
<thead>
<tr>
<th>Port designation</th>
<th>Meaning and function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Compressed air supply port</td>
</tr>
<tr>
<td>2, 4</td>
<td>Working port</td>
</tr>
<tr>
<td>3, 5</td>
<td>Exhaust port</td>
</tr>
</tbody>
</table>
| 12               | Pilot port  
Function when actuated: connects supply port 1 and working port 2. |
| 14               | Pilot port  
Function when actuated: connects supply port 1 and working port 4. |
| 10               | Pilot port  
Function when actuated: blocks supply port 1. |
| 82/84            | Pilot line, function for pilot-actuated or pneumatically actuated directional control valves when actuated: auxiliary pilot air exhaust |
4. **Directional control valve neutral position**

**Information**
An electrically actuated 3/2-way solenoid valve has two switching positions. It can be in the neutral position (unactuated) or the switched position (actuated). The valve can be either closed or open in its neutral position.

- A single-acting cylinder is controlled by an electrically actuated 3/2-way solenoid valve. Describe how the two different neutral positions effect the motion sequence of the cylinder:

**3/2-way solenoid valve, normally closed**
The utilized solenoid valve is reversed when voltage is applied to the solenoid coil. Flow from supply port 1 to working port 2 is enabled. After stopping the signal, the valve is returned to its normal position by a return spring and supply port 1 is closed, thus stopping flow. If the directional control valve’s solenoid coil is deenergized, the cylinder’s piston chamber is vented via exhaust port 3 at the directional control valve. The piston rod is retracted. When current is applied to the solenoid coil, the directional control valve switches and the piston chamber is pressurized. The piston rod advances. When the solenoid coil is deenergized, the valve is switched back again. The piston chamber is exhausted and the piston rod is retracted.

The motion sequence is thus as follows: MM1+ - MM1-.

**3/2-way solenoid valve, normally open**
The utilized solenoid valve is reversed when voltage is applied to the solenoid coil. Supply port 1 (and thus flow) is blocked. After stopping the signal, the valve is returned to its initial position by a return spring. Flow from supply port 1 to working port 2 is enabled. If the directional control valve’s solenoid coil is deenergized, the cylinder’s piston chamber is pressurized via the directional control valve. The piston rod is advanced. When the solenoid coil is energized the directional control valve is switched, and the piston chamber is exhausted via exhaust port 3 at the directional control valve. The piston rod is retracted. When the solenoid coil is deenergized, the valve is switched back again. The piston chamber is pressurized and the piston rod is advanced.

The motion sequence is thus as follows: MM1- - MM1+.
5. **Functions of various valve types**

**Information**

Electrically actuated directional control valves are switched with the help of solenoid coils (electromagnets). In principle, they can be subdivided into two groups:

- Solenoid valves with spring return
- Double solenoid valves

- Explain the difference between the two groups with regard to function and performance in the event of electrical power failure.

**Solenoid valve with spring return**

The actuated switching position is only retained as long as electrical current flows through the solenoid coil. The normal position is unequivocally defined by the return spring. If electrical power fails, the valve is returned to its neutral position by the return spring. This may cause dangerous machine motion.

For example, the piston rod of a pneumatic cylinder could be returned to its initial position thus releasing a previously clamped workpiece.

**Double solenoid valve**

Only a brief signal is required in order to reverse the valve. The last switching position is retained even in the deenergized state as the result of static friction. The solenoid coils are deenergized in the neutral position, and the neutral position cannot be unequivocally defined. The valve stays in its last switching position in the event of electrical power failure. No dangerous machine motion can be triggered as a result.

For example, the piston rod of a pneumatic cylinder is kept in its operating position and workpiece clamping is thus retained.
6. **Direct and indirect actuation**

   Explain the difference between direct and indirect actuation based on the following application:

   Electrical actuation of a 3/2-way solenoid valve with return spring by means of a pushbutton.

   **Direct actuation**
   When the pushbutton is actuated, current flows through the directional control valve’s solenoid coil. The solenoid picks up and the directional control valve is switched to the actuated position.

   The flow of electrical current is interrupted when the pushbutton is released. The solenoid drops out and the valve is switched to the normal position.

   **Indirect actuation**
   In the case of indirect actuation, current flows through a relay coil when a pushbutton is activated. The relay contact closes and the directional control valve is switched. The switching position is retained for as long as current flows through the solenoid coil or relay coil. The relay drops out when the flow of electrical current through the relay coil is interrupted, and the directional control valve is switched to its initial position.

   The more complex indirect control is used if:
   - the control circuit and main circuit are working with different voltages,
   - current flowing through the directional control valve’s solenoid coil exceeds the pushbutton’s maximum permissible current value,
   - one pushbutton or control switch is used to switch a number of valves or
   - links are required between the signals of the various pushbuttons.
7. **Design and function of electrical switches**

- Describe the design and function of the switches depicted below.

![Diagram of a pushbutton with NO contact](image)

**Design**
Pushbutton with NO contact

**Function**
With a pushbutton, the chosen switching position is only maintained for as long as the pushbutton is actuated. The pushbutton shown here has a normally open function. With normally open contacts, the electrical circuit is interrupted when the pushbutton is in its neutral position, i.e. in the unactivated state. When the control stem is actuated, the electrical circuit is closed and current flows to the consuming device. When the control stem is released, spring force returns the pushbutton to its neutral position and the electrical circuit is interrupted.

![Diagram of a control switch with NC contacts](image)

**Design**
Control switch with NC contacts

**Function**
Control switches are mechanically locked into the two switching positions. Either switching position is retained until the switch is actuated once again. The control switch shown here has a normally closed function. In the case of normally closed contacts, the electrical circuit is closed when the control switch is in its neutral position. When the control switch is activated, the electrical circuit is interrupted and reactivation closes the circuit again.
Exercise 1: Inspecting beverage crates

Design
Pushbutton with changeover contacts.

Function
With a pushbutton, the chosen switching position is only maintained for as long as the pushbutton is actuated. The pushbutton shown here has a changeover function. In the case of changeover contacts, NC and NO functions are combined into a single device. One electrical circuit is closed and another is interrupted with a single switching operation. Both circuits are briefly interrupted during changeover.

8. Completing the pneumatic and electrical circuit diagrams

- Complete the pneumatic and electrical circuit diagrams for the inspection unit. Supplement any incomplete circuit symbols. Label the individual components and enter the missing port designations.

Pneumatic circuit diagram

Electrical circuit diagram
9. Completing the equipment list

- Complete the equipment list. Enter the quantity, identification and designation of the required components to the table below.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Identification</th>
<th>Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-MM1</td>
<td>Single-acting cylinder</td>
</tr>
<tr>
<td>1</td>
<td>-RZ1</td>
<td>One-way flow control valve</td>
</tr>
<tr>
<td>1</td>
<td>-QM1</td>
<td>3/2-way solenoid valve</td>
</tr>
<tr>
<td>1</td>
<td>-XM1</td>
<td>Distributor block</td>
</tr>
<tr>
<td>1</td>
<td>-AZ1</td>
<td>On-off valve with filter regulating valve</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>Compressed air source</td>
</tr>
</tbody>
</table>

Pneumatic components

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Identification</th>
<th>Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-SF1</td>
<td>Pushbutton (normally open)</td>
</tr>
<tr>
<td>1</td>
<td>-MB1</td>
<td>Solenoid coil for 3/2-way solenoid valve -QM1</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>24 V DC power pack</td>
</tr>
</tbody>
</table>

Electrical components

10. Setting up the pneumatic and electrical sections of the control system

Observe the following points when setting up the control system:

- Use the circuit diagrams.
- Designate the components.
- Lay compressed air tubing using the shortest possible routes.
- Push the compressed air tubing into the push-in connector as far as it will go.
- Mark the connected compressed air tubing on the pneumatic circuit diagram.
- Establish the electrical connections with laboratory safety cables.
- Mark the connected laboratory safety cables on the electrical circuit diagram.
11. **Double checking the control system setup**

Observe the following points when commissioning the controller:

- Check all tubing connectors.
- Switch on 24 V supply power.
- Switch on compressed air supply at the service unit.
- Set the one-way flow control valve to maintain an advancing time of approx. 1 second. Use a stopwatch to this end.
- Allow the control system to run through several complete cycles.

**Risk of injury when switching on compressed air!**

Cylinders may advance and retract automatically.

**Risk of injury if compressed air tubing slips off!**

If compressed air tubing slips off, shut off compressed air supply immediately.

12. **Describing the controller sequence**

- Describe the individual steps of the controller sequence.

**Initial position**

Cylinder -MM1 is in the rear end position and the piston rod is retracted.

**Step 1-2**

After activating pushbutton -SF1 (NO contact), the electrical circuit of solenoid coil -MB1 at 3/2-way solenoid valve -QM1 is closed. 3/2-way solenoid valve -QM1 is reversed. Compressed air flows into the piston chamber of cylinder -MM1. The piston rod in cylinder -MM1 advances.

**Step 2-3**

As soon as pushbutton -SF1 (NO contact) is no longer activated, the electrical circuit at solenoid coil -MB1 is interrupted. 3/2-way solenoid valve -QM1 is switched back to its initial position by the valve’s return spring. The piston chamber of cylinder -MM1 is exhausted. The return spring in cylinder -MM1 returns the piston rod to its rear end position.
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Exercise 7: Optimizing the inspection of beverage crates ...................... 67
Exercise 8: Shifting roller conveyors .................................................... 79
Exercise 9: Transferring bottles ........................................................... 89
Exercise 10: Stamping mounting wedges ............................................... 101
Exercise 11: Palletizing roof tiles ......................................................... 111
Exercise 12: Eliminating a malfunction at a pallet loading station .......... 121
Exercise 1:
Inspecting beverage crates

■ Learning objectives
After completing this exercise:
- You'll be familiar with the setup and function of a single-acting cylinder.
- You'll be familiar with the setup and function of a 3/2-way solenoid valve.
- You'll be able to recognize and sketch the various types of actuation used for directional control valves.
- You'll be able to explain and set up direct actuation.

■ Description of the problem
Beverage crates are checked for completeness with the help of an inspection unit. Incomplete crates are pushed off of the roller conveyor by pressing a pushbutton.

Develop a controller with which this process can be executed.

■ Layout

Inspection unit for beverage crates
Exercise 1: Inspecting beverage crates

- **Description of the process**
  1. Beverage crates are inspected at a manual workstation.
  2. After pressing a pushbutton, incompletely filled beverage crates are pushed off of the conveyor by the piston rod of a single-acting cylinder.
  3. When the pushbutton is released, the piston rod is retracted to the rear end position.

- **General conditions**
  - A single-acting cylinder will be used.
  - The cylinder will be controlled by means of a pushbutton.
  - In the event of a power failure, the cylinder’s piston rod should be retracted to the rear end position.

- **Work assignments**
  1. Describe the function of pneumatic power components.
  2. Complete the circuit symbols for solenoid valves.
  3. Describe the meaning and the function of the port designations for valves.
  4. Describe how the neutral positions of directional control valves influence the motion sequence of a cylinder.
  5. Describe the functions of various valve types.
  6. Explain the difference between direct and indirect actuation.
  7. Describe the design and function of electrical switches.
  8. Complete the pneumatic and electrical circuit diagrams.
  9. Complete the equipment list.
 10. Set up the controller’s pneumatic and electrical sections.
 11. Double check the controller configuration.
 12. Describe the controller’s work sequence.

- **Work aids**
  - Books of tables
  - Textbook: Fundamentals of pneumatics and electropneumatics
  - Component data sheets
  - FluidSIM® P design and simulation software
  - WBT: Electropneumatics
1. Function of pneumatic power components

**Information**

Pneumatic power components can be subdivided into two groups:

- Power components with motion in a straight line
- Power components with rotary motion

- Describe the power components shown below and their functions.

![Diagram of power component]

Function

_______________________________________________________________________________________

_______________________________________________________________________________________

_______________________________________________________________________________________

_______________________________________________________________________________________

![Diagram of power component]

Function

_______________________________________________________________________________________

_______________________________________________________________________________________

_______________________________________________________________________________________

_______________________________________________________________________________________
Exercise 1: Inspecting beverage crates

2. Circuit symbols for solenoid valves

- Complete the circuit symbols with the help of the descriptions of the respective components.

Directly actuated 3/2-way solenoid valve, normally open, with manual override, pneumatic spring return

Pilot-actuated 3/2-way solenoid valve, normally closed, with manual override, mechanical spring return
3. **Identification of valve ports**

**Information**
In order to prevent incorrect tubing connections at directional control valves, the valve ports (working and pilot lines) are identified in accordance with ISO 5599-3 on the valves themselves, as well as in the circuit diagram.

- Explain the meanings and functions of the port designations listed below.

<table>
<thead>
<tr>
<th>Port designation</th>
<th>Meaning and function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2, 4</td>
<td></td>
</tr>
<tr>
<td>3, 5</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
</tr>
<tr>
<td>82/84</td>
<td></td>
</tr>
</tbody>
</table>
4. Directional control valve neutral position

Information
An electrically actuated 3/2-way solenoid valve has two switching positions. It can be in the neutral position (unactuated) or the switched position (actuated). The valve can be either closed or open in its neutral position.

- A single-acting cylinder is controlled by an electrically actuated 3/2-way solenoid valve. Describe how the two different neutral positions effect the motion sequence of the cylinder:

3/2-way solenoid valve, normally closed

_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________

3/2-way solenoid valve, normally open

_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________

_______________________________________________________________________________________
5. Functions of various valve types

Information
Electrically actuated directional control valves are switched with the help of solenoid coils (electromagnets). In principle, they can be subdivided into two groups:
- Solenoid valves with spring return
- Double solenoid valves

- Explain the difference between the two groups with regard to function and performance in the event of electrical power failure.

Solenoid valve with spring return

_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________

Double solenoid valve

_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________
6. **Direct and indirect actuation**

   - Explain the difference between direct and indirect actuation based on the following application:

     Electrical actuation of a 3/2-way solenoid valve with return spring by means of a pushbutton.

   **Direct actuation**

   __________________________________________________________

   __________________________________________________________

   __________________________________________________________

   __________________________________________________________

   **Indirect actuation**

   __________________________________________________________

   __________________________________________________________

   __________________________________________________________

   __________________________________________________________

   __________________________________________________________
7. Design and function of electrical switches

- Describe the design and function of the switches depicted below.

![Switch Diagram](Image)

**Design**

_______________________________________________________________________________________

**Function**

_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________

![Switch Diagram](Image)

**Design**

_______________________________________________________________________________________

**Function**

_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________
Exercise 1: Inspecting beverage crates

Design
_______________________________________________________________________________________

Function
_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________

8. Completing the pneumatic and electrical circuit diagrams

- Complete the pneumatic and electrical circuit diagrams for the inspection unit. Supplement any incomplete circuit symbols. Label the individual components and enter the missing port designations.

[Diagram of Pneumatic circuit diagram]

[Diagram of Electrical circuit diagram]
9. Completing the equipment list

- Complete the equipment list. Enter the quantity, identification and designation of the required components to the table below.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Identification</th>
<th>Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-XM1</td>
<td>Distributor block</td>
</tr>
<tr>
<td>1</td>
<td>-AZ1</td>
<td>On-off valve with filter regulating valve</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>Compressed air source</td>
</tr>
</tbody>
</table>

Pneumatic components

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Identification</th>
<th>Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>24 V DC power pack</td>
</tr>
</tbody>
</table>

Electrical components

10. Setting up the pneumatic and electrical sections of the control system

Observe the following points when setting up the control system:

- Use the circuit diagrams.
- Designate the components.
- Lay compressed air tubing using the shortest possible routes.
- Push the compressed air tubing into the push-in connector as far as it will go.
- Mark the connected compressed air tubing on the pneumatic circuit diagram.
- Establish the electrical connections with laboratory safety cables.
- Mark the connected laboratory safety cables on the electrical circuit diagram.
11. **Double checking the control system setup**

Observe the following points when commissioning the controller:

- Check all tubing connectors.
- Switch on 24 V supply power.
- Switch on compressed air supply at the service unit.
- Set the one-way flow control valve to maintain an advancing time of approx. 1 second. Use a stopwatch to this end.
- Allow the control system to run through several complete cycles.

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**Risk of injury when switching on compressed air!**

Cylinders may advance and retract automatically.

**Risk of injury if compressed air tubing slips off!**

If compressed air tubing slips off, shut off compressed air supply immediately.

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12. **Describing the controller sequence**

- Describe the individual steps of the controller sequence.

**Initial position**

_______________________________________________________________________________________

**Step 1-2**

_______________________________________________________________________________________

_______________________________________________________________________________________

_______________________________________________________________________________________

**Step 2-3**

_______________________________________________________________________________________

_______________________________________________________________________________________

_______________________________________________________________________________________

_______________________________________________________________________________________