The purchaser shall receive a single right of use which is non-exclusive, non-time-limited and limited geographically to use at the purchaser's site/location as follows.

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Exercise 2: Developing an energy-saving circuit (bypass circuit) ...................................... 13
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Use for intended purpose

The training package for advanced hydraulics 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 companies and/or trainers must ensure that all trainees observe the safety instructions described in this workbook.

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

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

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

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

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

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

- Hardware
- Media
- Seminars

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

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

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

Within the software, the following programmes are available:

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

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

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

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Do you have suggestions or criticism regarding this manual?

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

This workbook is part of the learning system for automation and technology by Festo Didactic SE. The system provides a solid basis for practice-oriented training and continuing vocational education. Training packages TP 501 and TP 502 include hydraulic controllers only.

TP 501, “Hydraulics, basic level”, is the ideal introduction to hydraulic control technology. Knowledge regarding the basic physical principles of hydraulics, as well as the function and use of hydraulic components, is imparted. Simple hydraulic controllers can be set up with the equipment set. TP 502, “Hydraulics, advanced level”, is targeted at students who require further training in hydraulic control technology. More advanced hydraulic circuits can be set up with this equipment set.

This workbook conveys knowledge of the physical relationships and the most important, basic hydraulic circuits. The subject matter of the exercises covers:

- Recording the characteristics of individual components
- Comparing the use of different components
- Setting up various basic circuits
- Use of basic hydraulic equations

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 hydraulic power unit (operating voltage: 230 V, 50 Hz, operating pressure: 6 MPa (60 bar), volumetric flow rate: 2 l/min.).
- A power pack with short-circuit protection (input: 230 V, 50 Hz, output: 24 V, max. 5 A) for supplying power to the flow sensor.
- Laboratory safety cables

You will need components included in equipment sets TP 501 and TP 502 in order to complete the 15 exercises. The theoretical fundamentals for understanding these exercises are included in the textbook:

- Hydraulics, basic level

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

General information
- Trainees should only work with the circuits under the supervision of a trainer.
- Electrical devices (e.g. power supply units, compressors and hydraulic power units) may only be operated in laboratory rooms which are equipped with residual current devices (RCDs).
- Observe specifications included in the technical data for the individual components, and in particular all safety instructions!
- Malfunctions which may impair safety must not be generated in the training environment, and must be eliminated immediately.
- Wear personal safety gear (safety glasses, safety shoes) when working on circuits.

Mechanical components
- Only reach into the setup when it is at a complete standstill.
- Mount all of the components securely onto the slotted profile plate.
- Limit switches may not be actuated frontally.
- Danger of injury during troubleshooting!
  Use a tool to actuate the limit switches, for example a screwdriver.
- Set all components up so that activation of switches and disconnectors is not made difficult.
- Adhere to the instructions regarding positioning of the components.
- Always set up cylinders together with the appropriate cover.

Electrical components
- Use extra-low voltage only (max. 24 V DC).
- Establish or interrupt electrical connections only in the absence of voltage!
- Use only connecting cables with safety plugs for electrical connections.
- Always pull the safety plug when disconnecting connecting cables – never pull the cable.

Hydraulics
- Limit system pressure to 6 MPa (60 bar).
  Maximum permissible pressure for all devices included in the training package is 12 MPa (120 bar).
- Danger of injury due to oil temperatures of greater than 50° C!
  Hydraulic fluid with a temperature of greater than 50° C may result in burns or scalding.
- Danger of injury when switching on the hydraulic power unit!
  Cylinders may advance and retract automatically.
- All valves, devices and hose lines are equipped with self-sealing quick-release couplings.
• Connecting hose lines
  – Never connect or disconnect hose lines when the hydraulic power unit is running, or while under pressure!
    Couplings must be connected in the unpressurised state.
  – Set the coupling socket vertically onto the coupling nipple!
    The coupling socket and the coupling nipple must not be fitted askew.
  – After each disconnection, make sure that the couplings have closed themselves!
• Hydraulic circuit assembly
  – The hydraulic power unit and the electrical power pack must be switched off when assembling the circuit.
  – Before commissioning, make sure that all tank lines have been connected and that all couplings have been securely fitted.
• Commissioning
  – Cylinders may only be commissioned with their covers in place.
  – Switch on the electrical power pack first, and then the hydraulic power unit.
• Hydraulic circuit dismantling
  – Make sure that pressure has been relieved before dismantling the circuit.
  – Switch on the electrical power pack first, and then the hydraulic power unit.
• If connections are decoupled while under pressure, pressure is trapped in the device by the non-return valve in the coupling. This pressure can be vented with the pressure-relief unit.

Mounting technology
The mounting boards for the components are equipped with mounting variant A, B or C:
• Variant A, snap-in system
  Lightweight components that are not subject to loads (e.g. directional control valves, sensors). Simply clip the components into the slots on the slotted profile plate. Release the components by turning the blue lever.
• Variant B, bolt
  Components subject to medium loads (e.g. hydraulic or pneumatic cylinders). These components are clamped to the slotted profile plate with T-head bolts. The blue, knurled nut is used for clamping and loosening. Make sure that the T-head bolts have been turned 90° after tightening.
• Version 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. on-off valve with filter regulator). These devices are fastened with socket head screws and T-head nuts.

Required accessories
A digital multimeter is required in order to evaluate exercises which make use of the flow sensor.
The output voltage of the flow sensor is measured with the multimeter.

You will need a stopwatch in order to measure hydraulic cylinder retracting and advancing times.
Hydraulics training package (TP 500)

The TP 500 training package consists of a multitude of individual training materials and seminars. The subject matter of this package is strictly hydraulic controllers. Individual components included in training package TP 500 may also be included in other packages.

Important TP 500 components
- Permanent workstation with Festo Didactic slotted profile plate
- Equipment sets or individual components (e.g. cylinders, valves and pressure gauges)
- Complete set of laboratory equipment

Media
The teachware for the TP 500 training package consists of a textbook and two workbooks. The textbook imparts basic physical and technical knowledge regarding hydraulics. The workbooks contain worksheets for each exercise, the solutions for each individual worksheet and a CD-ROM. A set of ready-to-use exercise sheets and worksheets is included 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>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Textbook</td>
<td>Hydraulics, basic level</td>
</tr>
<tr>
<td>Workbook</td>
<td>Hydraulics, basic level (TP 501)</td>
</tr>
<tr>
<td></td>
<td>Hydraulics, advanced level (TP 502)</td>
</tr>
<tr>
<td>Set of transparencies</td>
<td>Fundamentals of hydraulics</td>
</tr>
<tr>
<td>Simulation programme</td>
<td>FluidSIM® Hydraulic</td>
</tr>
<tr>
<td>Digital learning program</td>
<td>WBT hydraulics</td>
</tr>
</tbody>
</table>

Overview of media for training package TP 500

Available software for use in combination with training package TP 500 includes FluidSIM® H and the Hydraulics digital training programme. FluidSIM® H supports preparation of the lessons. Hydraulic controllers can be set up and simulated. The Hydraulics digital training programme imparts knowledge regarding the fundamentals of hydraulic controllers. With the help of examples based on actual industrial practice, the learner works through the basic principles of hydraulics and becomes familiar with components used in hydraulic systems.

The media are offered in several languages. You can find further training materials in our catalogue and on the Internet.
Learning objectives, advanced hydraulics (TP 502)

**Components**
- You will become familiar with the setup and function of a hydraulic motor.
- You will become familiar with the setup and function of a flow divider.
- You will become familiar with the setup and function of a pressure regulator.

**Circuits**
- You will learn how to set the direction and speed of rotation of a hydraulic motor.
- You will learn how to implement circuits with a bypass function.
- You will learn how to use a flow divider in order to synchronise two cylinders.
- You will learn to assure synchronisation for both the forward and return strokes.
- You will become familiar with the bypass circuit.
- You will become familiar with the rapid traversing circuit.
- You will learn how to create a displacement-step diagram based on a sequence description.
- You will learn how to use a diaphragm accumulator as a volumetric reservoir.
- You will learn how to advance and retract a cylinder using the reservoir after the pump is switched off.
- You will learn how to use a diaphragm accumulator for a rapid traversing circuit.
- You will become familiar with the rectifier circuit.
- You will learn how to use a pressure regulator in a circuit.
- You will learn how to specify pressure for a double-acting cylinder.
- You will be able to decide to use either a pressure-relief valve or a pressure regulator.
- You will learn how to describe and set up sequence control with two cylinders.
- You will become familiar with a pressure sequence circuit.
- You will become familiar with a pressure step circuit.
- You will become familiar with a protective function for pulling loads.

**Measurements and calculations**
- You will learn how to calculate the power balance for hydraulic circuits from measured values.
- You will learn how to calculate forces at the cylinder.
### Allocation of learning objectives to exercises

<table>
<thead>
<tr>
<th>Learning objective</th>
<th>Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>You will become familiar with the setup and function of a hydraulic motor.</td>
<td>x</td>
</tr>
<tr>
<td>You will learn how to set the direction and speed of rotation of a hydraulic motor.</td>
<td>x</td>
</tr>
<tr>
<td>You will learn how to implement circuits with a bypass function.</td>
<td>x</td>
</tr>
<tr>
<td>You will learn how to calculate the power balance for hydraulic circuits from measured values.</td>
<td>x</td>
</tr>
<tr>
<td>You will become familiar with the setup and function of a flow divider.</td>
<td>x x</td>
</tr>
<tr>
<td>You will learn how to use a flow divider in order to synchronise two cylinders.</td>
<td>x x</td>
</tr>
<tr>
<td>You will learn to assure synchronisation for both the forward and return strokes.</td>
<td>x</td>
</tr>
<tr>
<td>You will become familiar with the bypass circuit.</td>
<td>x</td>
</tr>
<tr>
<td>You will learn how to calculate forces at the cylinder.</td>
<td>x</td>
</tr>
<tr>
<td>You will become familiar with the rapid traversing circuit.</td>
<td>x</td>
</tr>
<tr>
<td>You will learn how to create a displacement-step diagram based on a sequence description.</td>
<td>x</td>
</tr>
<tr>
<td>You will learn how to use a diaphragm accumulator as a volumetric reservoir.</td>
<td>x</td>
</tr>
<tr>
<td>You will learn how to advance and retract a cylinder using the reservoir after the pump is switched off.</td>
<td>x</td>
</tr>
<tr>
<td>You will learn how to use a diaphragm accumulator as a pressure reservoir.</td>
<td>x</td>
</tr>
<tr>
<td>You will learn how to use a diaphragm accumulator for a rapid traversing circuit.</td>
<td>x</td>
</tr>
<tr>
<td>You will become familiar with the rectifier circuit.</td>
<td>x</td>
</tr>
<tr>
<td>You will become familiar with the setup and function of a pressure regulator.</td>
<td>x</td>
</tr>
<tr>
<td>You will learn how to use a pressure regulator in a circuit.</td>
<td>x</td>
</tr>
</tbody>
</table>
Learning objective

<table>
<thead>
<tr>
<th>Exercise</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>You will learn how to specify pressure for a double-acting cylinder.</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>You will be able to decide to use either a pressure-relief valve or a pressure regulator.</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>You will learn how to describe and set up sequence control with two cylinders.</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>You will become familiar with a pressure sequence circuit.</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>You will become familiar with a pressure step circuit.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>You will become familiar with a protective function for pulling loads.</td>
<td></td>
<td></td>
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<td>x</td>
</tr>
</tbody>
</table>

**Equipment set**

The equipment set for the advanced level has been put together for vocational training in the field of hydraulic control technology. The two equipment sets (TP 501 and TP 502) include components which are necessary for mastering the predefined learning objectives and can be supplemented with other equipment sets for the training system for automation technology as desired.

**Equipment set: Hydraulics, advanced level (TP 502)**

<table>
<thead>
<tr>
<th>Component</th>
<th>Order number</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/2-way stem actuated valve, convertible</td>
<td>544353</td>
<td>1</td>
</tr>
<tr>
<td>3-way pressure regulator</td>
<td>544337</td>
<td>1</td>
</tr>
<tr>
<td>Pressure-relief valve, compensated</td>
<td>567237</td>
<td>1</td>
</tr>
<tr>
<td>Diaphragm accumulator with shutoff block</td>
<td>152859</td>
<td>1</td>
</tr>
<tr>
<td>Non-return valve, opening pressure: 0.6 MPa</td>
<td>548618</td>
<td>3</td>
</tr>
<tr>
<td>Flow divider</td>
<td>544340</td>
<td>1</td>
</tr>
<tr>
<td>Differential cylinder, 16/10/200, with cover</td>
<td>572746</td>
<td>1</td>
</tr>
<tr>
<td>Mounting kit for cylinders</td>
<td>544371</td>
<td>1</td>
</tr>
<tr>
<td>T-distributor</td>
<td>152847</td>
<td>5</td>
</tr>
</tbody>
</table>
### Hose lines with quick connection couplings

<table>
<thead>
<tr>
<th>Designation</th>
<th>Order number</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hose, 600 mm</td>
<td>152960</td>
<td>7</td>
</tr>
<tr>
<td>Hose, 1000 mm</td>
<td>152970</td>
<td>4</td>
</tr>
<tr>
<td>Hose, 1500 mm</td>
<td>159386</td>
<td>2</td>
</tr>
</tbody>
</table>

### Graphic symbols, equipment set

<table>
<thead>
<tr>
<th>Component</th>
<th>Graphic symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/2-way stem actuated valve, convertible</td>
<td><img src="image1" alt="Diagram" /></td>
</tr>
<tr>
<td>3-way pressure regulator</td>
<td><img src="image2" alt="Diagram" /></td>
</tr>
<tr>
<td>Pressure-relief valve, compensated</td>
<td><img src="image3" alt="Diagram" /></td>
</tr>
<tr>
<td>Flow divider</td>
<td><img src="image4" alt="Diagram" /></td>
</tr>
<tr>
<td>Differential cylinder, 16/10/200, with cover</td>
<td><img src="image5" alt="Diagram" /></td>
</tr>
<tr>
<td>T-distributor</td>
<td><img src="image6" alt="Diagram" /></td>
</tr>
<tr>
<td>Non-return valve, opening pressure: 0.6 MPa</td>
<td><img src="image7" alt="Diagram" /></td>
</tr>
<tr>
<td>Component</td>
<td>Graphic symbol</td>
</tr>
<tr>
<td>----------------------------------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>Diaphragm accumulator with shutoff block</td>
<td><img src="image" alt="Diagram" /></td>
</tr>
</tbody>
</table>

### Allocation of components to exercises

#### TP 502 equipment set

<table>
<thead>
<tr>
<th>Component</th>
<th>Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/2-way stem actuated valve, convertible</td>
<td>1 1 1 1 1</td>
</tr>
<tr>
<td>3-way pressure regulator</td>
<td>1 1 1</td>
</tr>
<tr>
<td>Pressure-relief valve, compensated</td>
<td>1 1 1 1 1</td>
</tr>
<tr>
<td>Diaphragm accumulator with shutoff block</td>
<td>1 1 1</td>
</tr>
<tr>
<td>Non-return valve, opening pressure: 0.6 MPa</td>
<td>2 1 3 1 1 1 1</td>
</tr>
<tr>
<td>Flow divider</td>
<td>1 1</td>
</tr>
<tr>
<td>Differential cylinder, 16/10/200, with cover</td>
<td>1 1 1 1 1 1 1 1 1</td>
</tr>
<tr>
<td>T-distributor</td>
<td>1 5 1 2 1 1 6 2 2 2 3</td>
</tr>
</tbody>
</table>
### TP 501 equipment set

<table>
<thead>
<tr>
<th>Component</th>
<th>Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydraulic motor</td>
<td>1</td>
</tr>
<tr>
<td>4/3-way hand lever valve, relieving mid-position (AB &gt; T), detenting</td>
<td>1</td>
</tr>
<tr>
<td>One-way flow control valve</td>
<td>1</td>
</tr>
<tr>
<td>On-off valve</td>
<td>1</td>
</tr>
<tr>
<td>4-way manifold plate with pressure gauge</td>
<td>1</td>
</tr>
<tr>
<td>Pressure gauge</td>
<td>1</td>
</tr>
<tr>
<td>2-way flow control valve</td>
<td>1</td>
</tr>
<tr>
<td>Differential cylinder, 16/10/200, with cover</td>
<td>1</td>
</tr>
<tr>
<td>4/2-way hand lever valve, spring return</td>
<td>1</td>
</tr>
<tr>
<td>Pressure-relief valve</td>
<td>1</td>
</tr>
<tr>
<td>Non-return valve, opening pressure: 0.6 MPa</td>
<td>1</td>
</tr>
<tr>
<td>4/3-way hand lever valve, closed mid-position, detenting</td>
<td>1</td>
</tr>
<tr>
<td>T-distributor</td>
<td>1</td>
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### Hose

<table>
<thead>
<tr>
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<tr>
<td>Hose, 600 mm</td>
<td>5 7 4 7 5 7 5 7 5 6 6 7 7 7</td>
</tr>
<tr>
<td>Hose, 1000 mm</td>
<td>1 1 4 5 1 2 3 2 2 2 2 5 4 3</td>
</tr>
<tr>
<td>Hose, 1500 mm</td>
<td>1 1 2 1 1 1 1 1 1 1 1 1 1 1</td>
</tr>
</tbody>
</table>
Notes for the teacher/trainer

Learning objectives
The basic learning goal of this workbook is to become familiar with the fundamentals of hydraulics, as well as the practical setup of circuits on the slotted profile plate. Direct interplay of theory and practice ensures fast progress and long-lasting learning. The more specific learning objectives are documented in the matrix. Concrete, individual learning objectives are assigned to each exercise.

Required time
The time required for working through the exercises depends on the learner’s previous knowledge of the subject matter. For apprentices in the field of metal working or electrical engineering: approx. 2 weeks. With training as a skilled worker: approx. 1 week

Equipment set components
The textbook, the workbook and the equipment set are matched to each other. All 15 exercises can be completed using components from one TP 502 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 are applied in this workbook:
- DIN ISO 1219-1: Fluid power systems and components – Graphic symbols and circuit diagrams – Symbols
- DIN ISO 1219-2: Fluid power systems and components – Graphic symbols and circuit diagrams – Circuit diagrams
- DIN EN 60617-7: Graphical symbols for diagrams
- DIN EN 81346-2: Industrial systems, installations and equipment and industrial products – Structuring principles and reference designations
Identification of solutions
Solutions and supplements in graphics or diagrams appear in red.

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

Notes for the lesson
Additional information is provided here regarding the individual components and the completed controllers. These notes are not included in the set of exercises.

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

Learning topics
Allocation of the fields of learning offered by vocational schools to the training subject matter of “hydraulics” is provided below for selected vocations.

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<thead>
<tr>
<th>Vocation</th>
<th>Field of learning</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronics engineer for automation technology</td>
<td>3</td>
<td>Analysing and adapting control systems</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Systems implementation and safety testing</td>
</tr>
<tr>
<td>Industrial mechanic</td>
<td>6</td>
<td>Installation and commissioning of technical control systems</td>
</tr>
<tr>
<td>Mechatronics technician</td>
<td>4</td>
<td>Examination of the flow of energy and information in electrical, pneumatic and hydraulic assemblies</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Implementation of mechatronic subsystems</td>
</tr>
</tbody>
</table>

Structure of the exercises
All 15 exercises have the same structure and are broken down into:
• Title
• Learning objectives
• Problem description
• Layout
• Project assignments
• Work aids
• Worksheets

The workbook includes the solutions for all of the worksheets for all 15 exercises.
Component designations

Elements in the circuit diagrams are labelled according to the DIN EN 1219-2 standard. All of the components in a given circuit have the same main code number. Letters are assigned depending on each respective type of component. Consecutive numbers are assigned if several components of the same type are included within a single circuit.

Cylinders: 1A1, 2A1, 2A2 ...
Valves: 1V1, 1V2, 1V3, 2V1, 2V2, 3V1 ...
Signal inputs: 1S1, 1S2 ...
Accessories: 0Z1, 0Z2, 1Z1 ...

Contents of the CD-ROM

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:

- FluidSIM® circuit diagrams

FluidSIM® circuit diagrams

The FluidSIM® circuit diagrams for all of the exercises included in the technology package are contained in this directory.
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## Exercises and solutions

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<td>Exercise 2</td>
<td>Developing an energy-saving circuit (bypass circuit)</td>
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<tr>
<td>Exercise 3</td>
<td>Lifting heavy loads (flow divider)</td>
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</tr>
<tr>
<td>Exercise 4</td>
<td>Optimising the lift (flow divider and pressure-relief valves)</td>
<td>29</td>
</tr>
<tr>
<td>Exercise 5</td>
<td>Increasing advancing speed (bypass circuit)</td>
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</tr>
<tr>
<td>Exercise 6</td>
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<tr>
<td>Exercise 7</td>
<td>Moving a cylinder in the event of a pump failure (hydraulic reservoir)</td>
<td>53</td>
</tr>
<tr>
<td>Exercise 8</td>
<td>Clamping a gear-unit housing (clamping with reservoir)</td>
<td>61</td>
</tr>
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<td>Exercise 9</td>
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</tr>
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</tr>
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<td>Exercise 11</td>
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<td>83</td>
</tr>
</tbody>
</table>
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Exercise 1
Actuating a hose reel (hydraulic motor)

Learning objectives
After completing this exercise:
• You will be familiar with the setup and function of a hydraulic motor.
• You will know how to set the direction and speed of rotation of a hydraulic motor.

Problem description
The hose reel on a heating oil tank truck is driven with a hydraulic motor. The hose needs to be rolled out, held in position for a lengthy period of time and then rolled back up again. A 4/3-way valve will be used for these switching positions. Speed should be adjustable with the help of a flow control valve.

Layout

Tank truck with hose reel
Exercise 1: Actuating a hose reel (hydraulic motor)

- **Description of the process**
  After the hydraulic circuit has been set up, 4/3-way hand lever valve 1V2 is set to its mid-position. The hydraulic power unit is switched on and system pressure is set to 5 MPa (50 bar).

  The hydraulic motor is started up by setting the 4/3-way valve to its right or left-hand switching position. The flow rate is adjusted with the help of one-way flow control valve 1V1.

- **Project assignments**
  1. Familiarise yourself with the setup and function of a hydraulic motor.
  2. Complete the equipment list.
  3. Set up the exercise.
  4. Double check the controller setup.
  5. Measure motor speed in rpm over a period of 10 seconds with different flow rates, and compare your measured values with the values from the data sheet for the flow sensor.
  6. Evaluate your measurement results.

- **Work aids**
  - Data sheets
  - Operating instructions
  - Hydraulics textbook
  - FluidSIM® H simulation programme

- **Visual inspection**
  Continuous visual inspection for defects in hose lines and hydraulic components is an essential part of hydraulic safety standards.
1. **Setup and function of a hydraulic motor.**

**Information**

As a rule, hydraulic motors have the same engineering design as hydro pumps. They are subdivided into:

- **Fixed displacement motors**
  - Constant displacement volume
- **Adjustable motors**
  - Adjustable displacement volume

These basic types include several different variants.

![Diagram of hydraulic motor types]

**Types of hydraulic motor**

Hydraulic motors are components of the drive section. They are power components (actuators). They convert hydraulic energy into mechanical energy and cause rotary motion (rotary drive). If rotary motion is confined to a certain angle range, we speak of oscillating motors.

Hydraulic motors have the same characteristic values as pumps. Displacement volume is specified in cubic centimetres per revolution by hydraulic motor manufacturers, and the speed range within which the motor works efficiently is indicated as well.
Exercise 1: Actuating a hose reel (hydraulic motor)

The following applies to hydraulic motor displacement volume:

\[
p = \frac{M}{V} \quad q = n \cdot V
\]

- \( p \) pressure \([\text{Pa}]\)
- \( M \) torque \([\text{Nm}]\)
- \( V \) geometric displacement, displacement volume \([\text{cubic cm}]\)
- \( q \) volumetric flow rate \([\text{cubic dm / min.}]\)
- \( n \) speed \([\text{rpm}]\)

The volumetric flow rate required by the motor is calculated on the basis of the displacement volume and the desired speed in rpm.

a) A motor with a displacement volume of \( V = 10 \) cubic cm should run at a speed of \( n = 600 \) rpm. Calculate volumetric flow rate \( q \) required by the motor.

\[
q = \frac{10 \text{ cm}^3 \cdot 600 \text{ min}}{\min} = 6000 \text{ cubic cm/min.} = 6 \text{ cubic dm/min.} = 6 \text{ l/min.}
\]

The pump has to deliver 6 cubic dm per minute for the motor to run at a speed of 600 rpm.

b) A hydraulic motor with a displacement volume of \( V = 12.9 \) cubic cm is operated with a pump delivery rate of \( q = 15 \) cubic dm per minute. Torque \( M \) amounts to 1 at the resulting speed in rpm. What is speed in rpm \( n \) and delivered power \( P \)?

Calculate speed in rpm \( n \):

\[
n = \frac{q \cdot V}{15 \text{ dm}^3 \cdot 12.9 \text{ cm}^3 \cdot \text{min}} = \frac{15 \cdot 10^{-3} \text{ m}^3}{12.9 \cdot 10^{-6} \text{ m}^3 \cdot \text{min}} = 1163 \text{ rpm}
\]

Calculate power \( P \) in watts:

\[
P = 2 \cdot \pi \cdot n \cdot M = 2 \cdot \pi \cdot 1163 \text{ rpm} \cdot 1 \text{ Nm} = \frac{2 \cdot \pi \cdot 1163 \cdot 1 \text{ Nm}}{60 \text{ s}} = 122 \text{ W}
\]
c) Calculate output torque when the motor is greatly decelerated, resulting in a pressure level of 14 MPa (140 bar). In doing so, do not take mechanical-hydraulic and volumetric efficiency into consideration.

Calculate torque \( M \) at maximum supply pressure:

\[
M = p \cdot V = 140 \cdot 10^5 \text{ Pa} \cdot 12.9 \cdot 10^{-6} \text{ m}^3 = 140 \cdot 10^5 \cdot 12.9 \cdot 10^{-6} \frac{N \cdot m^3}{m^2} = 1806 \cdot 10^{-1} \text{ Nm} = 180.6 \text{ Nm}
\]

2. Completing the equipment list

- Complete the equipment list by entering the required number of components, the abbreviations used to identify them in the circuit diagram and the component designations to the table below.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Identification</th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1M1</td>
<td>Hydraulic motor</td>
</tr>
<tr>
<td>1</td>
<td>1V2</td>
<td>4/3-way hand lever valve, relieving mid-position (AB &gt; T), detenting</td>
</tr>
<tr>
<td>1</td>
<td>1V1</td>
<td>One-way flow control valve (alternative: flow control valve)</td>
</tr>
<tr>
<td>1</td>
<td>0V1</td>
<td>On-off valve</td>
</tr>
<tr>
<td>2</td>
<td>—</td>
<td>4-way manifold plate, with pressure gauge</td>
</tr>
<tr>
<td>1</td>
<td>0Z1</td>
<td>Hydraulic power unit</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Hose, 600 mm</td>
</tr>
<tr>
<td>1</td>
<td>Hose, 1000 mm</td>
</tr>
<tr>
<td>1</td>
<td>Hose, 1500 mm</td>
</tr>
</tbody>
</table>

Note
You will need the following in order to perform the measurements.

- 1 power supply unit: 24 V DC, max. 4.5 A
- 1 digital multimeter
3. **Setting up the controller**
Observe the following points when setting up the controller:

- Set the pressure-relief valve at the hydraulic power unit to a pressure of 6 MPa (60 bar) before setting up the circuit.
- Use the circuit diagram.

- Designate the components.
- Observe when connecting hose lines:
  - Never connect or disconnect hose lines when the hydraulic power unit is running, or while under pressure!
    
    **Couplings must be connected in the unpressurised state.**
  - Set the coupling socket vertically onto the coupling nipple.
    
    **The coupling socket and the coupling nipple must not be fitted askew.**
• Selecting and laying hose lines:
  – Select a hose line length which provides for adequate leeway, in order to compensate for length changes caused by pressure.
  – Avoid mechanical stressing of the hosing line.
    Do not bend the hose to a radius of less than its specified minimum bending radius of 51 mm.
  – Do not twist the hose line during installation.
• Mark the completed hose connections in the hydraulic circuit diagram.

4. Double checking the controller setup
Observe the following points when commissioning the controller:
• Before commissioning, make sure that all tank lines have been connected and that all couplings have been securely fitted.
• Fully close the restrictor in one-way flow control valve 1V1, and then open the restrictor by one half of one revolution.
• Switch to pump recirculation by opening the on-off valve.
• Switch 24 V DC electrical supply power to the flow sensor on.

  Note
  Information regarding the flow sensor can be found in its operating instructions.

• Switch the hydraulic pump on.
• Slowly close the on-off valve to this end, until a circulating pressure of approximately 1.5 MPa (15 bar) prevails.
  Immediately set the pump back to recirculation in the event of leaks.
• Switch the hydraulic motor on and watch for leaks. Then switch the motor back off again.
• Fully close the on-off valve and set the hydraulic power unit to the specified system pressure of 5 MPa (50 bar).
  Switch the hydraulic motor on and set flow rate $q$ to the desired value at the hydraulic motor by closing or opening the restrictor at one-way flow control valve 1V1.

5. Recording the measured values
a) Enter the measured values to the table.

  Note
  In order to minimise measuring error, perform each measurement three times and generate a mean value from your results.
Exercise 1: Actuating a hose reel (hydraulic motor)

<table>
<thead>
<tr>
<th>Flow rate $q$ [l/min.]</th>
<th>Clockwise rotation</th>
<th>Anti-clockwise rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time for 20 revolutions [s] $t_1$, $t_2$, $t_3$</td>
<td>Speed $n$ [rpm] $t_{mean}$</td>
</tr>
<tr>
<td>0.5</td>
<td>17.8</td>
<td>68.6</td>
</tr>
<tr>
<td></td>
<td>17.1</td>
<td>17.5</td>
</tr>
<tr>
<td></td>
<td>17.6</td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>9.7</td>
<td>126.3</td>
</tr>
<tr>
<td></td>
<td>9.3</td>
<td>9.5</td>
</tr>
<tr>
<td></td>
<td>9.5</td>
<td></td>
</tr>
</tbody>
</table>

b) Create a characteristic curve for speed relative to flow rate with the values from the table.

![Characteristic curve, speed / flow rate]

Note for the lesson
The line drawn into the graph is only intended to guide the eye.
6. Evaluating the measurement results

- Evaluate your measurement results.

Reversing the 4/3-way hand lever valve changes the direction of rotation of the hydraulic motor.

The hydraulic motor's rotational speed is changed when various restrictor settings are selected.

The rotational speed of the hydraulic motor is proportional to the flow rate. Doubling the flow rate increases speed by a factor of two.
Exercise 1: Actuating a hose reel (hydraulic motor)
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## Exercises

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</tr>
<tr>
<td>12</td>
<td>Comparing various pressure limiting valves (comparison: pressure-relief valve versus pressure regulator)</td>
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</tr>
<tr>
<td>13</td>
<td>Milling material from cylinder heads (pressure sequence control)</td>
<td>99</td>
</tr>
<tr>
<td>14</td>
<td>Switching a cylinder’s working pressure (pressure step circuit)</td>
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<tr>
<td>15</td>
<td>Securing a boom arm against inadvertent sinking (pulling load)</td>
<td>113</td>
</tr>
</tbody>
</table>
Exercise 1
Actuating a hose reel (hydraulic motor)

Learning objectives
After completing this exercise:
• You will be familiar with the setup and function of a hydraulic motor.
• You will know how to set the direction and speed of rotation of a hydraulic motor.

Problem description
The hose reel on a heating oil tank truck is driven with a hydraulic motor. The hose needs to be rolled out, held in position for a lengthy period of time and then rolled back up again. A 4/3-way value will be used for these switching positions. Speed should be adjustable with the help of a flow control valve.

Layout

Tank truck with hose reel
Exercise 1: Actuating a hose reel (hydraulic motor)

Description of the process
After the hydraulic circuit has been set up, 4/3-way hand lever valve 1V2 is set to its mid-position. The hydraulic power unit is switched on and system pressure is set to 5 MPa (50 bar).

The hydraulic motor is started up by setting the 4/3-way valve to its right or left-hand switching position. The flow rate is adjusted with the help of one-way flow control valve 1V1.

Project assignments
1. Familiarise yourself with the setup and function of a hydraulic motor.
2. Complete the equipment list.
3. Set up the exercise.
4. Double check the controller setup.
5. Measure motor speed in rpm over a period of 10 seconds with different flow rates, and compare your measured values with the values from the data sheet for the flow sensor.
6. Evaluate your measurement results.

Work aids
• Data sheets
• Operating instructions
• Hydraulics textbook
• FluidSIM® H simulation programme

Visual inspection
Continuous visual inspection for defects in hose lines and hydraulic components is an essential part of hydraulic safety standards.
1. **Setup and function of a hydraulic motor.**

**Information**

As a rule, hydraulic motors have the same engineering design as hydro pumps. They are subdivided into:

- **Fixed displacement motors**
  - Constant displacement volume
- **Adjustable motors**
  - Adjustable displacement volume

These basic types include several different variants.

---

**Diagram:**

```
Hydraulic motor

<table>
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<th>Geared motor</th>
<th>Vane cell motor</th>
<th>Piston motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>External gear motor</td>
<td>Internally pressurized</td>
<td>Radial piston motor</td>
</tr>
<tr>
<td>Internal gear motor</td>
<td>Externally pressurized</td>
<td>Axial piston motor</td>
</tr>
<tr>
<td>Toothed ring motor</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```

---

**Types of hydraulic motor**

Hydraulic motors are components of the drive section. They are power components (actuators). They convert hydraulic energy into mechanical energy and cause rotary motion (rotary drive). If rotary motion is confined to a certain angle range, we speak of oscillating motors.

Hydraulic motors have the same characteristic values as pumps. Displacement volume is specified in cubic centimetres per revolution by hydraulic motor manufacturers, and the speed range within which the motor works efficiently is indicated as well.
Exercise 1: Actuating a hose reel (hydraulic motor)

The following applies to hydraulic motor displacement volume:

\[ p = \frac{M}{V} \]

\[ q = n \cdot V \]

- \( p \): pressure [Pa]
- \( M \): torque [Nm]
- \( V \): geometric displacement, displacement volume [cubic cm]
- \( q \): volumetric flow rate [cubic dm / min.]
- \( n \): speed [rpm]

The volumetric flow rate required by the motor is calculated on the basis of the displacement volume and the desired speed in rpm.

a) A motor with a displacement volume of \( V = 10 \) cubic cm should run at a speed of \( n = 600 \) rpm. Calculate volumetric flow rate \( q \) required by the motor.

b) A hydraulic motor with a displacement volume of \( V = 12.9 \) cubic cm is operated with a pump delivery rate of \( q = 15 \) cubic dm per minute. Torque \( M \) amounts to 1 at the resulting speed in rpm. What is speed in rpm \( n \) and delivered power \( P \)?
c) Calculate output torque when the motor is greatly decelerated, resulting in a pressure level of 14 MPa (140 bar). In doing so, do not take mechanical-hydraulic and volumetric efficiency into consideration.

2. Completing the equipment list

- Complete the equipment list by entering the required number of components, the abbreviations used to identify them in the circuit diagram and the component designations to the table below.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Identification</th>
<th>Component</th>
</tr>
</thead>
</table>

| 2        | 4-way manifold plate, with pressure gauge                  |
| 1        | Hydraulic power unit                                      |

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hose, 600 mm</td>
</tr>
<tr>
<td></td>
<td>Hose, 1000 mm</td>
</tr>
<tr>
<td></td>
<td>Hose, 1500 mm</td>
</tr>
</tbody>
</table>

Note

You will need the following in order to perform the measurements.
- 1 power supply unit: 24 V DC, max. 4.5 A
- 1 digital multimeter
3. **Setting up the controller**

Observe the following points when setting up the controller:

- Set the pressure-relief valve at the hydraulic power unit to a pressure of 6 MPa (60 bar) before setting up the circuit.
- Use the circuit diagram.

- Designate the components.
- Observe when connecting hose lines:
  - Never connect or disconnect hose lines when the hydraulic power unit is running, or while under pressure!
    Couplings must be connected in the unpressurised state.
  - Set the coupling socket vertically onto the coupling nipple.
    The coupling socket and the coupling nipple must not be fitted askew.
Exercise 1: Actuating a hose reel (hydraulic motor)

1. Selecting and laying hose lines:
   - Select a hose line length which provides for adequate leeway, in order to compensate for length changes caused by pressure.
   - Avoid mechanical stressing of the hosing line.
   - Do not bend the hose to a radius of less than its specified minimum bending radius of 51 mm.
   - Do not twist the hose line during installation.

2. Mark the completed hose connections in the hydraulic circuit diagram.

4. Double checking the controller setup
   Observe the following points when commissioning the controller:
   - Before commissioning, make sure that all tank lines have been connected and that all couplings have been securely fitted.
   - Fully close the restrictor in one-way flow control valve 1V1, and then open the restrictor by one half of one revolution.
   - Switch to pump recirculation by opening the on-off valve.
   - Switch 24 V DC electrical supply power to the flow sensor on.

   **Note**
   Information regarding the flow sensor can be found in its operating instructions.

   - Switch the hydraulic pump on.
   - Slowly close the on-off valve to this end, until a circulating pressure of approximately 1.5 MPa (15 bar) prevails.
   - Immediately set the pump back to recirculation in the event of leaks.
   - Switch the hydraulic motor on and watch for leaks. Then switch the motor back off again.
   - Fully close the on-off valve and set the hydraulic power unit to the specified system pressure of 5 MPa (50 bar).
   - Switch the hydraulic motor on and set flow rate $q$ to the desired value at the hydraulic motor by closing or opening the restrictor at one-way flow control valve 1V1.

5. Recording the measured values
   a) Enter the measured values to the table.

   **Note**
   In order to minimise measuring error, perform each measurement three times and generate a mean value from your results.
Exercise 1: Actuating a hose reel (hydraulic motor)

Flow rate $q$ [l/min.]

<table>
<thead>
<tr>
<th></th>
<th>Clockwise rotation</th>
<th>Anti-clockwise rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time for 20 revolutions [s]</td>
<td>Speed $n$ [rpm]</td>
<td>Time for 20 revolutions [s]</td>
</tr>
<tr>
<td>$t_1$, $t_2$, $t_3$</td>
<td>$ar{t}$</td>
<td>$t_1$, $t_2$, $t_3$</td>
</tr>
</tbody>
</table>

b) Create a characteristic curve for speed relative to flow rate with the values from the table.
6. Evaluating the measurement results

- Evaluate your measurement results.
Exercise 1: Actuating a hose reel (hydraulic motor)