Hydraulics
Basic level
The purchaser shall receive a single right of use which 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.

Note

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 hydraulics 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 trainers must ensure that all trainees observe the safety precautions described in this workbook.

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

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

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

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

The 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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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.

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

Complete controllers for all 17 exercises are set up using the TP 501 basic level equipment set. The theoretical fundamentals for understanding the exercises listed in this workbook are included in the textbook entitled:

• Basic principles of hydraulics and electrohydraulics

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

General
- Trainees should only work with the circuits under the supervision of an instructor.
- Electrical devices (e.g. power supply units, compressors and hydraulic power units) may only be operated in training rooms which are equipped with residual current devices (RCDs).
- 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 as well as control power before working on the circuit.
  - Only reach into the setup when it’s at a complete standstill.
  - Observe possible overtravel of the drives.
- Mount all of the components securely onto the slotted profile plate.
- Make sure that limit switches are not actuated from the front.
- Risk 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.
- 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 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 are 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 plug when disconnecting connecting cables; never pull the cable.

Hydraulic safety
• Depressurize the system!
  – Switch off the hydraulic power unit before working on the circuit.
  – Check the system with pressure measuring instruments to make sure that the entire circuit is pressure-free.
  – Please note that energy may be stored in pressure reservoirs.
    Further information on this issue is available in the data sheets and operating instructions included with the components.
• Limit system pressure to 6 MPa (60 bar).
• Maximum permissible pressure for all devices included in the training package is 12 MPa (120 bar).
  In the case of double-acting cylinders, pressure could be increased relative to the surface area ratio due to pressure boosting. With a surface area ratio of 1:1.7 and a system pressure of 6 MPa (60 bar), it may amount to more than 10 MPa (100 bar).
• Risk of injury due to oil temperatures of greater than 50° C!
  Escaping hydraulic fluid with a temperature of greater than 50° C may result in burns or scalding.
• As a rule, the components (devices, valves, hoses) are equipped with self-sealing quick-release couplings.
  – Exceptions include connections on components which are not designed for full operating pressure.
    For safety reasons, these components have open couplings.
• Risk of injury when switching the hydraulic power unit on!
  Cylinders may advance and retract automatically.
• Connecting the hoses
  – Never connect or disconnect the hoses when the hydraulic power unit is running, or while under pressure! Couplings must be connected in the pressure-free state.
  – Place 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!
• Observe a maximum tightening torque of 20 Nm when fitting coupling nipples or coupling sockets.
• Setting up the hydraulic circuit
  – The hydraulic power unit and the electrical power supply unit must be switched off while setting up the circuit.
  – Before commissioning, make sure that all tank pipes and leakage oil lines have been connected and that all couplings have been fitted securely.
  – Make sure that hosing lines connected to the cylinder are rinsed with hydraulic fluid, if the volume of oil accommodated by the cylinder is less than the volume which can be contained by the hose line.

• Commissioning
  – Cylinders may only be commissioned with their covers in place.
  – Switch on the electrical power supply first, and then the hydraulic power unit.

• Dismantling hydraulic circuits
  – Make sure that pressure has been relieved before dismantling the circuit.
  – Switch off the hydraulic power unit first, and then the electrical power supply unit.
  – If connections are decoupled while under pressure, pressure is trapped in the device by the check 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, C or D:

• 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. After tightening, make sure that the T-head bolts have been turned 90°.

• 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). These devices are fastened with socket head screws and T-head nuts.

• Variant D, plug-in system
  Lightweight devices with lock pins which cannot be subjected to loads (e.g. indicator units). These are secured with plug adapters.

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’ll 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 workbooks. The textbook imparts basic physical and technical knowledge regarding electrohydraulics. 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.

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| Workbooks              | Hydraulics, basic level (TP 501)  
|                        | Hydraulics, advanced level (TP 502) |
| Optional teachware     | Simulation software: FluidSIM® Hydraulik  
|                        | Web-based training: Hydraulics |

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

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.
Leaning goals for basic level hydraulics (TP 501)

**Components**
- Become familiar with the setup and function of a hydraulic pump.
- Become familiar with the most important characteristics of a hydraulic pump.
- Be able to explain how pressure occurs in hydraulic controllers.
- Become familiar with the relationship between pump delivery rate and operating pressure.
- Become familiar with the various types and possible uses of pressure relief valves.
- Become familiar with the setup and function of a pressure relief valve.
- 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 2/2-way valve.
- Become familiar with the setup and function of a 3/2-way valve.
- Become familiar with the setup and function of a 4/2-way valve.
- Become familiar with the setup and function of 4/3-way valves.
- Be able to evaluate the influences of various mid-position variants of 4/3-way valves
- Become familiar with the setup and function of a check valve.
- Become familiar with the setup and function of a one-way flow control valve.
- Become familiar with the setup and function of a delockable check valve.
- Become familiar with the setup and function of a flow control valve.

**Circuits**
- Be able to safely commission hydraulic controllers.
- Be able to control a single-acting cylinder.
- Be able to explain the differences between supply and exhaust flow control.
- Be able to compare circuits with flow control valves in the inlet and the outlet.
- Be able to use a flow control valve to adjust the speed of a drive.
- Be able to name various applications for flow control valves.
- Be able to explain the difference between flow control valves and one-way flow control valves used in the application.
- Become familiar with the setup and mode of operation of a bypass circuit.
- Be able to explain the influence of the piston’s surface area on pressure, force and travel time.
- Be able to make proper use of delockable check valves.
- Become familiar with hydraulic restraint of a double-acting cylinder.
- Be able to compare circuits with and without counter pressure.
- Be able to explain the differences between counter-pressure circuits located between the one-way flow control valve and the pressure relief valve.
- Be able to operate double-acting cylinders with changing loads.
Measurements, settings and calculations

- Learn to record and interpret the characteristic curve of a hydraulic pump.
- Learn to measure the volumetric flow rate of a hydraulic controller.
- Learn to record the characteristic curve of a pressure relief valve.
- Learn to record the characteristic curve of a flow control valve.
- Learn to ascertain times, pressures and forces during the advancing and retracting strokes of a single-acting cylinder.
- Learn to ascertain times, pressures and forces during the advancing and retracting strokes of a double-acting cylinder.
- Learn to calculate piston advancing times.
- Learn to calculate the power balance when using 4/3-way valves with different mid-positions.
## Allocation of learning objectives to exercises

| Learning objectives                                                                 | Exercise 1 | Exercise 2 | Exercise 3 | Exercise 4 | Exercise 5 | Exercise 6 | Exercise 7 | Exercise 8 | Exercise 9 | Exercise 10 | Exercise 11 | Exercise 12 | Exercise 13 | Exercise 14 | Exercise 15 | Exercise 16 | Exercise 17 |
|------------------------------------------------------------------------------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| Become familiar with the setup and function of a hydraulic pump.                   |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |
| Become familiar with the most important characteristics of a hydraulic pump.      |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |
| Be able to explain how pressure occurs in hydraulic controllers.                   |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |
| Become familiar with the various types and possible uses of pressure relief valves.|            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |
| Be able to safely commission hydraulic controllers.                                |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |
| Learn to record and interpret the characteristic curve of a hydraulic pump.        |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |
| Learn to measure the volumetric flow rate of a hydraulic controller.              |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |
| Become familiar with the relationship between pump delivery rate and operating pressure. |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |
| Become familiar with the function and setup of a pressure relief valve.            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |
| Learn to record the characteristic curve of a pressure relief valve.              |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |
| Become familiar with the setup and function of a single-acting cylinder.           |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |
| Become familiar with the setup and function of a 2/2-way valve.                    |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |
| Become familiar with the setup and function of a check valve.                     |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |
| Be able to control a single-acting cylinder.                                      |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |
| Become familiar with the setup and function of a 3/2-way valve.                    |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |
| Learn to ascertain times, pressures and forces during the advancing and retracting strokes 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 4/2-way valve.                    |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |            |
## Learning objectives

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<td>Be able to control a double-acting cylinder.</td>
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<td>Be able to calculate the forces of a double-acting cylinder.</td>
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<td>Learn to calculate piston advancing times.</td>
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<td>Be able to explain various applications for flow control valves.</td>
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<td>Become familiar with the setup and function of a one-way flow control valve.</td>
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<td>Be able to explain the differences between supply and exhaust flow control.</td>
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<td>Learn to record the characteristic curve of a flow control valve.</td>
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<td>Become familiar with the setup and function of 4/3-way valves.</td>
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<td>Be able to evaluate the influences of various mid-position variants.</td>
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<td>Be able to use a flow control valve to adjust the speed of a drive.</td>
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<td>Be able to compare circuits with flow control valves in the inlet and the outlet.</td>
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<td>Be able to explain the difference between flow control valves and one-way flow control valves used in the application.</td>
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<td>Become familiar with the setup and mode of operation of a bypass circuit.</td>
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<td>Be able to explain the influence of the piston's surface area on pressure, force and travel time.</td>
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<tr>
<td>Become familiar with the setup and function of a delockable check valve.</td>
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<tr>
<td>Be able to use a delockable check valve in a controller.</td>
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<td>Learn to calculate the power balance when using 4/3-way valves with different mid-positions.</td>
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<td>Become familiar with hydraulic restraint of a double-acting cylinder.</td>
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<td>Be able to compare circuits with and without counter pressure.</td>
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<tr>
<td>Be able to explain the differences between counter-pressure circuits located between the one-way flow control valve and the pressure relief valve.</td>
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<td>Be able to operate double-acting cylinders with changing loads.</td>
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</table>
Equipment set for the basic level (TP 501)

The equipment set has been put together for basic training in the field of hydraulic 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, hose lines with quick connection couplings and a hydraulic power unit are also required in order to set up functional controllers.

<p>| Equipment set for basic level hydraulics (TP 501), order no. 573035 |
|---------------------------------|-----------------|-----------------|
| Quantity | Designation | Order number |
| 1 | 2-way flow control valve | 544338 |
| 1 | 4/2-way hand lever valve, spring return | 544342 |
| 1 | 4/3-way hand lever valve, relieving mid-position (AB &gt; T), detenting | 544344 |
| 1 | 4/3-way hand lever valve, closed mid-position, detenting | 544343 |
| 1 | Shutoff valve | 152844 |
| 1 | Differential cylinder, 16/10/200, with cover | 572746 |
| 1 | One-way flow control valve | 152843 |
| 1 | Pressure relief valve | 544335 |
| 3 | Pressure gauge | 152841 |
| 1 | Flow sensor | 567191 |
| 1 | 9 kg weight for differential cylinder | 152972 |
| 1 | Hydraulic motor | 152858 |
| 1 | Check valve, opening pressure: 0.6 MPa | 548618 |
| 1 | Delockable check valve | 544339 |
| 1 | T-distributor | 152847 |
| 2 | 4-way distributor plate with pressure gauge | 159395 |</p>
<table>
<thead>
<tr>
<th>Component</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-way flow control valve</td>
<td><img src="image1.png" alt="Symbol" /></td>
</tr>
<tr>
<td>4/2-way hand lever valve, spring return</td>
<td><img src="image2.png" alt="Symbol" /></td>
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<tr>
<td>4/3-way hand lever valve, relieving mid-position (AB &gt; T), detenting</td>
<td><img src="image3.png" alt="Symbol" /></td>
</tr>
<tr>
<td>4/3-way hand lever valve, closed mid-position, detenting</td>
<td><img src="image4.png" alt="Symbol" /></td>
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<tr>
<td>Shutoff valve</td>
<td><img src="image5.png" alt="Symbol" /></td>
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<tr>
<td>Differential cylinder 16/10/200</td>
<td><img src="image6.png" alt="Symbol" /></td>
</tr>
<tr>
<td>One-way flow control valve</td>
<td><img src="image7.png" alt="Symbol" /></td>
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<tr>
<td>Pressure relief valve</td>
<td><img src="image8.png" alt="Symbol" /></td>
</tr>
<tr>
<td>Pressure gauge</td>
<td><img src="image9.png" alt="Symbol" /></td>
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<tr>
<td>Flow sensor</td>
<td>ISO 1219-1 EN 60617-7</td>
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<tr>
<td>Hydraulic motor</td>
<td><img src="image10.png" alt="Symbol" /></td>
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<tr>
<td>Check valve, opening pressure: 0.6 MPa</td>
<td><img src="image11.png" alt="Symbol" /></td>
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<tr>
<td>Delockable check valve</td>
<td><img src="image12.png" alt="Symbol" /></td>
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<tr>
<td>T-distributor</td>
<td><img src="image13.png" alt="Symbol" /></td>
</tr>
<tr>
<td>4-way distributor plate with pressure gauge</td>
<td><img src="image14.png" alt="Symbol" /></td>
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<tr>
<td>9 kg weight for differential cylinder</td>
<td><img src="image15.png" alt="Symbol" /></td>
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</tbody>
</table>
## Allocation of components to exercises

### TP 501 equipment set

### Notes

Exercises 1 and 8 are theoretical exercises requiring work with data sheets or calculations.

Extended setup time

For exercises 5, 6, 11, 14 and 16, the differential cylinder is screwed onto the profile column in the vertically suspended position and loaded with the weight. The cover for the weight must be installed.

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<thead>
<tr>
<th>Component</th>
<th>Exercise</th>
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<td>2-way flow control valve</td>
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<td>4/2-way hand lever valve</td>
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<td>4/3-way hand lever valve, relieving mid-position</td>
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<td>4/3-way hand lever valve, mid-position closed</td>
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<td>Differential cylinder 16/10/200</td>
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<td>One-way flow control valve</td>
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<td>9 kg weight for differential cylinder</td>
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<td>Check valve, opening pressure: 0.6 MPa</td>
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<td>Delockable check valve</td>
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<td>4-way distributor plate with pressure gauge</td>
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Required accessories

<table>
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<td>600 mm hose line</td>
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<td>1500 mm hose line</td>
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<td>Cover for 9 kg weight</td>
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<td>Digital multimeter</td>
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<td>24 V DC power supply unit</td>
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<tr>
<td>Hydraulic power unit</td>
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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. This direct interaction involving both theory and practice ensures faster progress and longer-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 designed to be used together. All 17 exercises can be completed using components from one TP 501 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
EN 60617-7: Graphical symbols for diagrams
EN 81346-2: Industrial systems, installations and equipment and industrial products –
Structuring principles and reference designations
Identification of solutions
Solutions and supplements in graphics or diagrams appear in red.

Identification in the worksheets
Texts which require completion are identified with 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 worksheets.

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

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

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

Structure of the exercises

All 17 exercises have the same structure and are broken down into:
- Title
- Learning objectives
- Description of the problem
- Layout
- Work assignments
- Work aids
- Worksheets

The workbook includes the solutions for all of the worksheets for all 17 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 includes the following folders:
- Operating instructions
- Images
- FluidSIM® circuit diagrams
- Presentations

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

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 components included in the training package. These can be used, for example, to create project presentations.
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Exercise 1:  
Setting up a hydraulic workstation

Learning objectives
After completing this exercise:
• You'll be familiar with the setup and function of a hydro pump.
• You'll be familiar with the most important characteristics of a hydro pump.
• You'll be able to select a hydraulic power unit on the basis of specified requirements.

Description of the problem
A new hydraulic workstation needs to be set up in the training department. Size NG 4 components are used. Maximum operating pressure is limited to 6 MPa (60 bar). A 230 V AC electrical outlet is available. A suitable hydraulic power unit must be selected.

Layout

Hydraulic workstation
Work assignments
1. Describe the setup and function of a hydro pump.
2. Calculate the volumetric flow rate of a hydro pump.
3. Calculate the efficiency of a hydro pump.
4. Select a hydraulic power unit on the basis of specified requirements.

Work aids
- Books of tables
- Textbook: Basic principles of hydraulics and electrohydraulics
- Component data sheets
- FluidSIM® H design and simulation software
- Web-based training: Hydraulics

1. Setup and function of a hydro pump

Information
Hydro pumps are displacement pumps which function on the basis of “suction and displacement”. We differentiate amongst three basic types of hydro pumps on the basis of displacement volume:
- Constant displacement pump: Constant displacement volume
- Variable displacement pump: Adjustable displacement volume
- Control pump: Displacement volume is controlled on the basis of pressure, volumetric flow rate and power

The hydro pump generates volumetric flow (but no pressure). The delivery rate per revolution and the drive speed dictate the pump’s delivery rate which is specified in liters per minute.

Pressure only occurs as the result of resistance to pump delivery, for example flow resistance, load resistance and pressure relief valve settings. Pressure is specified in MPa or bar.
a) Describe the function of the gear pump shown in the figure.

![Gear Pump Diagram]

Gear pumps are constant-displacement pumps, because the displaced volume which is determined by the gear tooth gap is unchangeable.

The gear pump functions on the basis of the following principle:

- One gear wheel is connected to the drive unit, and the other rotates along with it via the toothing.
- As a result of the volume enlargement which occurs when a tooth leaves a gear tooth gap, a partial vacuum is generated in the suction chamber.
- The hydraulic fluid fills the tooth chambers, and is conveyed along the housing wall and into the pressure chamber.
- Here, the hydraulic fluid is displaced from the tooth chambers and into the hydraulic lines by the teeth which then enter the tooth gaps.

**Training notes**

Trapped fluid is located in the tooth gaps between the suction chamber and the pressure chamber. This is fed to the pressure chamber via a slot, because pressure peaks would otherwise occur due to compression of the trapped oil which would result in noise and destruction of the pump.

Pump leakage oil quantities are determined by the size of the gap (between housing, tooth crests and the sides of the teeth), overlapping of the gears, viscosity and speed.
b) Name the circuit symbol shown below and briefly describe the function of the components.

1. **Electric motor with single direction of rotation**  
   Drive for hydro pumps.

2. **Hydraulic pump**  
   Pump with constant delivery rate. The volumetric flow rate is dictated by motor speed and displacement volume per revolution.

3. **Pressure gauge**  
   Indicates prevailing pressure with a specified tolerance.

4. **Pressure relief valve**  
   Adjustable pressure relief valve without oil return port. The valve begins to open when an adjustable pressure level is reached.
c) Match up the individual components of the hydraulic power unit with the corresponding numbers in the drawing.

<table>
<thead>
<tr>
<th>Component no.</th>
<th>Component (designation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Drain screw</td>
</tr>
<tr>
<td>3</td>
<td>Suction chamber</td>
</tr>
<tr>
<td>2</td>
<td>Suction tube</td>
</tr>
<tr>
<td>10</td>
<td>Vent with air filter</td>
</tr>
<tr>
<td>4</td>
<td>Moderating plate</td>
</tr>
<tr>
<td>8</td>
<td>Filling filter</td>
</tr>
<tr>
<td>9</td>
<td>Fill-level indicator, maximum fill-level</td>
</tr>
<tr>
<td>7</td>
<td>Fill-level indicator, minimum fill-level</td>
</tr>
<tr>
<td>1</td>
<td>Motor and pump</td>
</tr>
<tr>
<td>11</td>
<td>Return</td>
</tr>
<tr>
<td>5</td>
<td>Return chamber</td>
</tr>
</tbody>
</table>
2. Calculating the volumetric flow rate of a hydro pump

**Information**
Displacement volume \( V \) (also known as delivery rate or pump capacity) is a measure of the pump’s size. It designates the liquid volume which is delivered by the pump per revolution (or stroke).

The volume of liquid delivered per minute is referred to as the volumetric flow rate \( q \) (delivery rate). This results from displacement volume \( V \) and speed in RPM \( n \):

\[
q = n \cdot V
\]

– Calculate the delivery rate of a gear pump.

**Given**
- Speed \( n = 1450 \text{ rpm} \)
- Displacement volume \( V = 2.8 \text{ cubic cm (per revolution)} \)

**Sought**
- Delivery rate \( q \) in l/min

**Calculation**

\[
q = n \cdot V = 1450 \text{ min}^{-1} \cdot 2.8 \text{ cm}^3 = 4060 \text{ cm}^3 \text{ min}^{-1} = 4.06 \text{ dm}^3 \text{ min}^{-1} = 4.06 \text{ l/min}
\]
3. Calculating the efficiency of a hydro pump

**Information**

Pumps convert mechanical power into hydraulic power, which always involves power loss that's expressed in terms of efficiency.

Effective power $P_{\text{hyd}}$ generated by the pump depends upon operating pressure $p$ and effective delivery rate $q_{\text{eff}}$. Effective power is calculated with the equation:

$$P_{\text{hyd}} = p \cdot q_{\text{eff}}$$

Volumetric efficiency is the relationship between the pump's effective delivery rate and its theoretically calculated delivery rate.

$$\eta_{\text{vol}} = \frac{q_{\text{eff}}}{q_{\text{th}}}$$

$$q_{\text{th}} = V_{\text{th}} \cdot n$$

$$q_{\text{eff}} = V_{\text{th}} \cdot n \cdot \eta_{\text{vol}}$$

Calculate the efficiency of a hydro pump.

**Given**

- Speed $n = 1450$ rpm
- Displacement volume $V = 6.5$ cubic cm (per revolution)
- Effective delivery rate $q_{\text{eff}} = 8.6 \frac{1}{\text{min}}$ at 100 bar

**Sought**

Efficiency $\eta_{\text{vol}}$

**Calculation**

$$q_{\text{th}} = 6.5 \text{ cm}^3 \cdot 1450 \text{ min}^{-1} = 9.4 \frac{1}{\text{min}}$$

$$\eta_{\text{vol}} = \frac{q_{\text{eff}}}{q_{\text{th}}} = \frac{8.6 \frac{1}{\text{min}}}{9.4 \frac{1}{\text{min}}} = 0.92 = 92 \%$$
4. Selecting a hydraulic power unit

**Information**
Excerpts from three data sheets for hydraulic power units are included below. Select the power unit which fulfils the following conditions:
- Drive motor with 230 V nominal voltage
- Frequency: 50 Hz
- Delivery rate at nominal speed: 2.2 l/min
- Weight without oil: max. 20 kg

<table>
<thead>
<tr>
<th>General</th>
<th>HA-5L-230-50</th>
<th>HA-5L-110-60</th>
<th>HA-20L-400-50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length</td>
<td>580 mm</td>
<td>580 mm</td>
<td>580</td>
</tr>
<tr>
<td>Width</td>
<td>300 mm</td>
<td>300 mm</td>
<td>300</td>
</tr>
<tr>
<td>Height</td>
<td>180 mm</td>
<td>180 mm</td>
<td>180</td>
</tr>
<tr>
<td>Weight</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Empty</td>
<td>19 kg</td>
<td>19 kg</td>
<td>19 kg</td>
</tr>
<tr>
<td>Filled with oil</td>
<td>24 kg</td>
<td>24 kg</td>
<td>29 kg</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Electrical data</th>
<th>HA-5L-230-50</th>
<th>HA-5L-110-60</th>
<th>HA-20L-400-50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor</td>
<td>Alternating current, single-phase</td>
<td>Alternating current, single-phase</td>
<td>Alternating current, 3-phase</td>
</tr>
<tr>
<td>Nominal power</td>
<td>650 W</td>
<td>550 W</td>
<td>550 W</td>
</tr>
<tr>
<td>Nominal voltage</td>
<td>230 V</td>
<td>110 V</td>
<td>400 V</td>
</tr>
<tr>
<td>Frequency</td>
<td>50 Hz</td>
<td>60 Hz</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Nominal speed</td>
<td>1320 rpm</td>
<td>1680 rpm</td>
<td>1390 rpm</td>
</tr>
<tr>
<td>Protection</td>
<td>IP 20</td>
<td>IP 20</td>
<td>IP 20</td>
</tr>
<tr>
<td>Duty cycle</td>
<td>50%</td>
<td>50%</td>
<td>100%</td>
</tr>
</tbody>
</table>
Which hydraulic power unit have you chosen? Give reasons for your selection.

The hydraulic power unit with the designation HA-5L-230-50 was selected. It fulfils the following specified conditions:

- Drive motor with 230 V nominal voltage
- Frequency: 50 Hz
- Delivery rate at nominal speed: 2.2 l/min
- Weight without oil: max. 20 kg
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Exercise 17: Loading and offloading buckets ............................................................... 145
Exercise 1:
Setting up a hydraulic workstation

■ Learning objectives
After completing this exercise:
- You'll be familiar with the setup and function of a hydro pump.
- You'll be familiar with the most important characteristics of a hydro pump.
- You'll be able to select a hydraulic power unit on the basis of specified requirements.

■ Description of the problem
A new hydraulic workstation needs to be set up in the training department. Size NG 4 components are used. Maximum operating pressure is limited to 6 MPa (60 bar). A 230 V AC electrical outlet is available. A suitable hydraulic power unit must be selected.

■ Layout
Exercise 1 – Setting up a hydraulic workstation

Name: ___________________________ Date: ____________ © Festo Didactic 551141

Work assignments
1. Describe the setup and function of a hydro pump.
2. Calculate the volumetric flow rate of a hydro pump.
3. Calculate the efficiency of a hydro pump.
4. Select a hydraulic power unit on the basis of specified requirements.

Work aids
- Books of tables
- Textbook: Basic principles of hydraulics and electrohydraulics
- Component data sheets
- FluidSIM® H design and simulation software
- Web-based training: Hydraulics

1. Setup and function of a hydro pump

Information
Hydro pumps are displacement pumps which function on the basis of “suction and displacement”. We differentiate amongst three basic types of hydro pumps on the basis of displacement volume:
- Constant displacement pump: Constant displacement volume
- Variable displacement pump: Adjustable displacement volume
- Control pump: Displacement volume is controlled on the basis of pressure, volumetric flow rate and power

The hydro pump generates volumetric flow (but no pressure). The delivery rate per revolution and the drive speed dictate the pump’s delivery rate which is specified in liters per minute.

Pressure only occurs as the result of resistance to pump delivery, for example flow resistance, load resistance and pressure relief valve settings. Pressure is specified in MPa or bar.
a) Describe the function of the gear pump shown in the figure.

Gear pump – cutaway view, 1: trapped fluid, 2: pressure chamber, 3: suction chamber

_______________________________________________________________________________________
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_______________________________________________________________________________________
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_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________
b) Name the circuit symbol shown below and briefly describe the function of the components.

Hydraulic power unit – circuit symbol

_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________

Name: __________________________________ Date: ____________ © Festo Didactic 551141
c) Match up the individual components of the hydraulic power unit with the corresponding numbers in the drawing.

<table>
<thead>
<tr>
<th>Component no.</th>
<th>Component (designation)</th>
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<tbody>
<tr>
<td>1</td>
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<td>9</td>
<td>Motor and pump</td>
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<td>10</td>
<td>Return</td>
</tr>
<tr>
<td>11</td>
<td>Return chamber</td>
</tr>
</tbody>
</table>

Hydraulic power unit – schematic diagram
2. Calculating the volumetric flow rate of a hydro pump

**Information**

Displacement volume \( V \) (also known as delivery rate or pump capacity) is a measure of the pump’s size. It designates the liquid volume which is delivered by the pump per revolution (or stroke).

The volume of liquid delivered per minute is referred to as the volumetric flow rate \( q \) (delivery rate). This results from displacement volume \( V \) and speed in RPM \( n \):

\[
q = n \cdot V
\]

– Calculate the delivery rate of a gear pump.

**Given**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td>( n = 1450 ) rpm</td>
</tr>
<tr>
<td>Displacement</td>
<td>( V = 2.8 ) cubic cm (per revolution)</td>
</tr>
</tbody>
</table>

**Sought**

Delivery rate \( q \) in l/min

**Calculation**
3. Calculating the efficiency of a hydro pump

**Information**
Pumps convert mechanical power into hydraulic power, which always involves power loss that's expressed in terms of efficiency.

Effective power \( P_{\text{hyd}} \) generated by the pump depends upon operating pressure \( p \) and effective delivery rate \( q_{\text{eff}} \). Effective power is calculated with the equation:

\[
P_{\text{hyd}} = p \cdot q_{\text{eff}}
\]

Volumetric efficiency is the relationship between the pump's effective delivery rate and its theoretically calculated delivery rate.

\[
\eta_{\text{vol}} = \frac{q_{\text{eff}}}{q_{\text{th}}}
\]

\[
q_{\text{th}} = V_{\text{th}} \cdot n
\]

\[
q_{\text{eff}} = V_{\text{th}} \cdot n \cdot \eta_{\text{vol}}
\]

- Calculate the efficiency of a hydro pump.

**Given**

- Speed \( n = 1450 \text{ rpm} \)
- Displacement volume \( V = 6.5 \text{ cubic cm (per revolution)} \)
- Effective delivery rate \( q_{\text{eff}} = 8.6 \frac{\text{l}}{\text{min}} \text{ at 100 bar} \)

**Sought**

- Efficiency \( \eta_{\text{vol}} \)

**Calculation**
4. Selecting a hydraulic power unit

Information
Excerpts from three data sheets for hydraulic power units are included below. Select the power unit which fulfils the following conditions:
- Drive motor with 230 V nominal voltage
- Frequency: 50 Hz
- Delivery rate at nominal speed: 2.2 l/min
- Weight without oil: max. 20 kg

<table>
<thead>
<tr>
<th>Dimensions</th>
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<th>HA-20L-400-50</th>
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<tbody>
<tr>
<td>Length</td>
<td>580 mm</td>
<td>580 mm</td>
<td>580 mm</td>
</tr>
<tr>
<td>Width</td>
<td>300 mm</td>
<td>300 mm</td>
<td>300 mm</td>
</tr>
<tr>
<td>Height</td>
<td>180 mm</td>
<td>180 mm</td>
<td>180 mm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Weight</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Empty</td>
<td>19 kg</td>
<td>19 kg</td>
<td>19 kg</td>
</tr>
<tr>
<td>Filled with oil</td>
<td>24 kg</td>
<td>24 kg</td>
<td>29 kg</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>General</th>
<th>HA-5L-230-50</th>
<th>HA-5L-110-60</th>
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</thead>
<tbody>
<tr>
<td>Motor</td>
<td>Alternating current, single-phase</td>
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<td>Alternating current, 3-phase</td>
</tr>
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<td>550 W</td>
</tr>
<tr>
<td>Nominal voltage</td>
<td>230 V</td>
<td>110 V</td>
<td>400 V</td>
</tr>
<tr>
<td>Frequency</td>
<td>50 Hz</td>
<td>60 Hz</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Nominal speed</td>
<td>1320 rpm</td>
<td>1680 rpm</td>
<td>1390 rpm</td>
</tr>
<tr>
<td>Protection</td>
<td>IP 20</td>
<td>IP 20</td>
<td>IP 20</td>
</tr>
<tr>
<td>Duty cycle</td>
<td>50%</td>
<td>50%</td>
<td>100%</td>
</tr>
<tr>
<td>Hydraulic data</td>
<td>HA-5L-230-50</td>
<td>HA-5L-110-60</td>
<td>HA-20L-400-50</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>--------------</td>
<td>-------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Medium</td>
<td>Mineral oil, recommended: 22 cSt (sq. mm/s)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pump design</td>
<td>External gear pump</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geometric delivery rate</td>
<td>1.6 cubic cm</td>
<td>1.6 cubic cm</td>
<td>1.6 cubic cm</td>
</tr>
<tr>
<td>Delivery rate at nominal speed</td>
<td>2.2 l/min</td>
<td>2.7 l/min</td>
<td>2.2 l/min</td>
</tr>
<tr>
<td>Operating pressure</td>
<td>0.5 to 6 MPa (5 to 60 bar)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Settings</td>
<td>Manual</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pressure gauge indicating range</td>
<td>0 to 10 MPa (0 to 100 bar)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pressure gauge quality class</td>
<td>1.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oil tank capacity</td>
<td>Approx. 5 l</td>
<td>Approx. 5 l</td>
<td>Approx. 10 l</td>
</tr>
<tr>
<td>Return filter filtration grade</td>
<td>90 µm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Connection</td>
<td>One quick coupling socket each for P and T, one coupling for the line to the storage tank, one connection for the discharge measuring receptacle</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Which hydraulic power unit have you chosen? Give reasons for your selection.

_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________