Workbook
EduKit PA
Project kit
Process automation

With CD-ROM
Use for intended purpose

This system and the workbook have been developed and produced exclusively for training and further education in the field of process automation and technology. The respective training companies and/or trainers must ensure that all trainees observe the safety precautions which are described in the accompanying manuals.
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 system 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.

Order no. 563971
Revision level: 04/2009
Authors: Bernhard Schellmann, Hans Kaufmann
Editors: Jürgen Helmich, Klaus Kronberger
Graphic design: Doris Schwarzenberger
Layout: 05/2009

© Festo Didactic GmbH & Co. KG, 73770 Denkendorf, 2013
Internet: www.festo-didactic.com
e-mail: did@de.festo.com

© Adiro Automatisierungstechnik GmbH, 73734 Esslingen, 2013
Internet: www.adiro.com
E-mail: info@adiro.com

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.
The purchaser shall be entitled to use the work to train his/her staff at the purchaser's site/location and shall also be entitled to use parts of the copyright material as the basis for the production of his/her own training documentation for the training of his/her staff at the purchaser's site/location with acknowledgement of source and to make copies for this purpose. In the case of schools/technical colleges and training centres, the right of use shall also include use by school and college students and trainees at the purchaser's site/location for teaching purposes.
The right of use shall in all cases exclude the right to publish the copyright material or to make this 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 site/location.
Entitlement to other rights relating to reproductions, copies, adaptations, translations, microfilming and transfer to and storage and processing in electronic systems, no matter whether in whole or in part, shall require the prior consent of Festo Didactic GmbH & Co. KG.
# Table of contents

**Introduction**
- Training content .................................................. 9
- Learning objectives ................................................. 6
- References to German school syllabi and vocations .......... 6
- Obligations of the trainees ........................................ 11
- Risks associated with the modular production system ...... 11
- Guarantee and liability ............................................. 11
- Use for intended purpose ........................................... 12
- Safety precautions .................................................. 12
- Transport ............................................................. 14
- Unpacking ............................................................. 14
- Scope of delivery .................................................... 14
- Visual inspection ..................................................... 14
- Maintenance .......................................................... 15
- Updates ............................................................... 15

**Part A – Plant construction**

1. Process description ................................................. A-3
2. Planning ............................................................. A-9
3. Installation .......................................................... A-43
4. Commissioning ..................................................... A-47
5. Marketing and sales .............................................. A-51
6. Evaluation of learning objectives for plant construction ... A-55

**Part B – Practice-based learning: manual measurement, open-loop and closed-loop control**

1. Manual measurement ............................................. B-3
2. Manual open-loop control ....................................... B-13
4. Evaluation of learning objectives for manual measuring, open-loop and closed-loop control ... B-47
Part C – Practice-based learning: automated measurement, open-loop and closed-loop control

1. Basic principles .................................................................................................................. C-3
2. Automated measurement .................................................................................................. C-13
3. Automated open-loop control ........................................................................................ C-25
4. Automated closed-loop control ...................................................................................... C-41
5. Evaluation of learning objectives for automated measurement, open-loop and closed-loop control .................................................................................................................. C-59

Part D1 – Plant construction with solutions

1. Process description ........................................................................................................... D1-3
2. Planning ............................................................................................................................ D1-9
3. Installation ....................................................................................................................... D1-43
4. Commissioning ............................................................................................................... D1-47
5. Marketing and sales ......................................................................................................... D1-51
6. Evaluation of learning objectives for plant construction ................................................ D1-55

Part D2 – Practice-based learning: manual measurement, open-loop and closed-loop control with solutions

1. Manual measurement ...................................................................................................... D2-3
3. Manual control ............................................................................................................... D2-37
4. Evaluation of learning objectives for manual measurement, open-loop and closed-loop control .................................................................................................................. D2-47

Part D3 – Practice-based learning: automated measurement, open-loop and closed-loop control with solutions

1. Basic principles ................................................................................................................ D3-3
2. Automated measurement .................................................................................................. D3-13
3. Automated open-loop control ........................................................................................ D3-25
4. Automated closed-loop control ...................................................................................... D3-41
5. Evaluation of learning objectives for automated measurement, open-loop and closed-loop control .................................................................................................................. D3-59
Introduction

Festo Didactic’s process automation and technology learning system is aimed at various educational backgrounds and vocational requirements. The systems and stations included with the modular production system for process automation (MPS® PA) facilitate training and vocational education which is based on real-life company situations. The hardware comprises industrial components specifically prepared for this purpose.

The process automation project kit provides you with a suitable, practical system with which you can convey key competencies including:

- Social
- Technical
- Procedural

In addition, teamwork, willingness to cooperate and organisational skills are also part of the training.

The learning modules focus on realistic project phases. These include:

- Planning
- Installation
- Wiring
- Commissioning
- Operation
- Open-loop control technology
- Closed-loop control technology
- Maintenance
- Troubleshooting

Training content

The following subject areas are covered:

- Mechanical
  - Mechanical layout of a system
- Process engineering
  - Read and prepare flowcharts and documentation
  - Piping connections for process engineering components
  - System analysis
- Electrical engineering
  - Create electrical circuit diagrams
  - Correct wiring of electrical components
- Sensor technology
  - Correct use of sensors
  - Measurement of non-electrical, process engineering and control technology quantities
- Commissioning
  - Initial commissioning of a process system
  - Initial commissioning of a controlled system
• Open-loop control technology
  – Controlling actuators
  – Relay circuits
• Closed-loop control technology
  – Fundamentals of closed-loop control technology
  – Expansion of measuring chains into closed-loop control circuits
  – Analysis of regulated systems
  – Use of regulators
• Troubleshooting
  – Systematic troubleshooting of a process system
  – Inspection, maintenance and servicing of process systems

■ **Learning objectives**
• Become familiar with the setup and the mode of operation of the fill-level system.
• Read and expand flow diagrams.
• Read and expand simple electrical circuit diagrams.
• Become familiar with the setup and mode of operation of a pressure gauge.
• Become familiar with the setup and mode of operation of a pump.
• Become familiar with the setup and mode of operation of a flow sensor.
• Record and analyse characteristic curves.
• Become familiar with the terms “open-loop control” and “closed-loop control”.
• Become familiar with the concepts of discontinuous control (2-step control) and continuous control.
• Become familiar with the essential work steps in the field of plant construction, from planning to operation.

■ **References to German school syllabi and vocations**

<table>
<thead>
<tr>
<th>Type of school</th>
<th>Planning, engineering, assembly, marketing</th>
<th>Commissioning, production system</th>
<th>Open-loop control technology</th>
<th>Closed-loop control technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary schools, 10th grade</td>
<td>SU 2</td>
<td>SU 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vocational secondary schools, 9th grade</td>
<td>SU 2, 4</td>
<td>SU 2, 4</td>
<td>SU 2, 4</td>
<td>SU 4</td>
</tr>
<tr>
<td>Vocational secondary schools, 10th grade</td>
<td>SU 1</td>
<td>SU 1</td>
<td>SU 2</td>
<td>SU 2</td>
</tr>
</tbody>
</table>

SU = syllabus unit
### Vocations according to learning content

<table>
<thead>
<tr>
<th>System engineer</th>
<th>LC 7</th>
<th>LC 8, 9</th>
<th>LC 10, 11</th>
<th>LC 10, 11</th>
</tr>
</thead>
<tbody>
<tr>
<td>System technician, sanitary, heating and air-conditioning</td>
<td>LC 5, 6</td>
<td>LC 7</td>
<td>LC 10</td>
<td>LC 10</td>
</tr>
<tr>
<td>Chemical laboratory technician</td>
<td></td>
<td></td>
<td>LC 12</td>
<td>LC 12</td>
</tr>
<tr>
<td>Chemical technician</td>
<td>LC 4</td>
<td>LC 4, 5</td>
<td>LC 8</td>
<td>LC 5, 8</td>
</tr>
<tr>
<td>Electronics technician</td>
<td>LC 6</td>
<td>LC 3</td>
<td>LC 7</td>
<td></td>
</tr>
<tr>
<td>Electronics technician for automation</td>
<td>LC 10</td>
<td>LC 10</td>
<td>LC 6, 7</td>
<td>LC 10</td>
</tr>
<tr>
<td>Qualified personnel for water supply technology</td>
<td>LC 4, 13</td>
<td>LC 4</td>
<td>LC 4, 14</td>
<td>LC 4, 14</td>
</tr>
<tr>
<td>Precision mechanic</td>
<td></td>
<td>LC 8, 16a</td>
<td>LC 8, 16a</td>
<td></td>
</tr>
<tr>
<td>Industry mechanic</td>
<td>LC 6</td>
<td></td>
<td>LC 13</td>
<td></td>
</tr>
<tr>
<td>Mechatronics technician</td>
<td>LC 10</td>
<td>LC 9</td>
<td>LC 4, 7</td>
<td>LC 7</td>
</tr>
<tr>
<td>Pharmaceuticals technician</td>
<td></td>
<td>LC 7</td>
<td></td>
<td>LC 7</td>
</tr>
<tr>
<td>Process technician for glass technology</td>
<td></td>
<td></td>
<td>LC 9</td>
<td>LC 13</td>
</tr>
</tbody>
</table>

LC = learning content

---

### Diagram

**Basic stage**

- Introduction
  - Training content
  - Syllabi/vocations
  - Diagram
  - Room layout
  - Notes for the operating company

- Plant manufacturing
  - 1. Process description
  - 2. Planning
  - 3. Installation
  - 4. Commissioning
  - 5. Marketing and sales

**Advanced level**

- Practice based learning: manual MSR
- Practice based learning: automated MSR

Teachware, EduKit PA process automation project kit including evaluation of learning objectives
Hardware flow chart, EduKit PA process automation project kit
Sample room layout
Classification into groups within the product range

Important note
The fundamental prerequisites for the safe use and trouble-free operation of the EduKit PA project kit include knowledge of basic safety precautions and safety regulations. This workbook includes the most important instructions for the safe use of the EduKit PA project kit. In particular, the safety precautions must be adhered to by all persons working with the EduKit PA project kit. Furthermore, all pertinent rules and regulations for the prevention of accidents, which are applicable at the respective location of use, must be adhered to.
Obligations of the operating company
The operating company undertakes to allow only those persons to work with the EduKit PA project kit who:
- are familiar with the basic regulations regarding work safety and accident prevention and have been instructed in the use of the EduKit PA project kit, and
- have read and understood the section concerning safety and the safety precautions.
- In the event that the EduKit PA project kit is not monitored by the operating company itself, an appropriate person must be designated who, on the basis of his technical qualifications, is capable of evaluating the functionality of the station as well as the dangers which result therefrom, for himself and all trainees.

All staff should be tested at regular intervals on their safety-awareness at work.

Obligations of the trainees
All persons who have been entrusted to work with the EduKit PA project kit undertake to complete the following steps before beginning work:
- Read the section on safety and the safety precautions in this manual
- Familiarise themselves with basic regulations regarding work safety and accident prevention
- Familiarise themselves with the specific dangers associated with compressed air, without which the equipment would not be feasible, and accordingly ensure their own safety
- Disconnect the station from mains power when cleaning work or inspections are requested by the person in charge.

Risks associated with the modular production system
The EduKit PA project kit is laid out in accordance with the latest state-of-the-art technology as well as recognised safety rules. Nevertheless, life and limb of the user and third parties may be at risk and the machine or other property may be damaged during its use.
The EduKit PA project kit may only be used:
- For its intended purpose
- When its safety functions are in perfect order

Faults which may impair safety must be eliminated immediately!

Guarantee and liability
Our “general terms and conditions of sale and delivery” always apply. These are made available to the operating company no later than upon conclusion of the sales contract. Guarantee and liability claims resulting from personal injury and/or property damage are excluded if they can be traced back to one or more of the following causes:
- Use of EduKit PA project kit for other than its intended purpose
- Incorrect assembly, commissioning and/or operation of EduKit PA project kit
• Use of the EduKit PA project kit with defective safety equipment or with incorrectly attached or non-functioning safety and protective equipment
• Non-compliance with instructions included in the manual with regard to transport, storage, assembly, commissioning, operation, maintenance and setup of the EduKit PA project kit
• Inadequate monitoring of system components which are subject to wear
• Improperly executed repairs
• Disasters resulting from the influence of foreign bodies and acts of God

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 system 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.

### Use for intended purpose

This station has been developed and manufactured exclusively for training and vocational education in the fields of automation and technology. The respective training companies and/or trainers must ensure that all trainees observe the safety precautions which are described in the accompanying manuals.

Use for intended purpose also encompasses:
• Compliance with all instructions included in the manual
• Completion of inspection and maintenance tasks

### Safety precautions

#### General
• Trainees should only work at the station under the supervision of a trainer.
• Observe specifications included in the data sheets for the individual components and in particular all safety instructions!
• Teachers and trainers must be capable of assessing the experiments they supervise or execute with electrical energy, as well as any potential danger using their knowledge and training (e.g. with regard to their own specialty, regulations and standards).

#### Electrical
• Electrical connections must only be established and interrupted in the absence of voltage!
• Use low-voltage only (max. 24 V DC).
• Correct polarity must be assured when connecting certain electrical components, especially sensors. These components may be destroyed in the event of polarity reversal or short-circuiting.
• Electrical components are pre-wired at the factory, and are mounted onto an H-rail for direct attachment to the rectangular profile. Alternatively, they can be shipped unwired as a kit. In either case, wiring work must only be carried out by qualified personnel.
- Do not pour water over any electrical components. If water is inadvertently poured over electrical components, switch supply power off immediately. The entire system must be inspected for possible damage by a teacher or trainer in this case.
- Avoid overloading the digital outputs with excessive current. Maximum current consumption of the actuators used must be determined before they are connected.

**Pneumatics**
- Set system pressure to a value between 3 and 6 bar to operate the 2-way ball valve with a pneumatic semi-rotary actuator. Do not exceed the maximum permissible pressure of 800 kPa (8 bar).
- Do not activate compressed air until all of the tubing connections have been completed and secured.
- Do not disconnect tubing while under pressure.

**Mechanical**
- Mount all of the components onto the profile plate.
- Make sure that piping and screw connections are carefully secured.

**Process engineering**
- Always fill the lower tank in the voltage-free state!
- Switch the 24 V DC supply power off and disconnect the power supply unit from the power supply (230 V DC).
- Use potable tap water (recommended), which ensures long-term, maintenance-free operation of the system.
- The maximum permissible operating temperature of +65° C for the tank must not be exceeded.
- The maximum permissible operating pressure of 0.5 bar for the liquid in the tubing may not be exceeded.
- The pump must not be allowed to run dry. The pump must not be used with seawater, contaminated liquids or viscous media.
- Empty the liquid from the system by opening the drain valve after completing the experiments or before changing the piping layout.
- Inspect the liquid and replace it at least once a week if contaminated.
- Clean the system as required, but in any case at least once a week. Do not use aggressive cleaning materials or scouring agents.
- The liquid ages if the system is left at a standstill for a lengthy period of time. Always empty the tanks and the piping before leaving the system at a standstill for a long period of time.
- No liquids must be allowed to remain in the system for long periods of time, because this may result in the growth of bacteria such as the so-called legionellae.
### Technical data, system

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. operating pressure in piping</td>
<td>50 kPa (0.5 bar)</td>
</tr>
<tr>
<td>Power supply for the station</td>
<td>24 V DC / 4.5 A</td>
</tr>
<tr>
<td>Profile plate</td>
<td>350 x 200 mm</td>
</tr>
<tr>
<td>Station height: with one tank</td>
<td>670 mm</td>
</tr>
<tr>
<td></td>
<td>with two tanks</td>
</tr>
<tr>
<td></td>
<td>1090 mm</td>
</tr>
<tr>
<td>Inside dimensions of the Systainer</td>
<td>490 x 360 x 272 mm (H x W x D)</td>
</tr>
<tr>
<td>Volumetric flow rate of the pumps</td>
<td>0 to 6 l/min.</td>
</tr>
<tr>
<td>Clean water tank</td>
<td>Max. 3 litres</td>
</tr>
<tr>
<td>Flexible piping system</td>
<td>DN15 (Ø 15 mm)</td>
</tr>
</tbody>
</table>

### Transport

The EduKit PA project kit is shipped in a Systainer. The freight forwarder and Festo Didactic must be notified without delay of any damage that occurred in transit.

### Unpacking

Carefully remove the filler material from the Systainer when unpacking the project kit. When unpacking the project kit, make sure that none of the parts are damaged. Examine the station for possible damage after unpacking. The freight forwarder and Festo Didactic must be notified of any damage without delay.

### Scope of delivery

Check delivered items against the packing slip and your purchase order. Festo Didactic must be notified of any deviations without delay.

### Visual inspection

Each time the system is started up, it must first be inspected visually. Perform the following inspections before starting the EduKit PA project kit:

- Inspect electrical connections and wiring.
- Check piping, pipe connectors and pneumatic components, including tubing for correct fitting, leak-proof sealing and condition.
- Check mechanical and pneumatic components for visible defects (cracks, loose connections etc.).

Eliminate any damages discovered during inspection before starting the station!

All regulations and instructions must be adhered to in order to ensure correct operation of the EduKit PA project kit.
Maintenance
The EduKit PA project kit is largely maintenance free. The following steps should be carried out at regular intervals:
- Clean the entire project kit with a soft, lint-free cloth and check components for freedom of movement.
- Inspect liquid for contamination! The liquid may age if the project kit is left unused for any length of time.
- The system should be drained completely if it is not used for a long period of time.

Updates
Current information on and supplements to the technical documentation for the EduKit PA project kit are available on the Internet at www.festo-didactic.de/Service/MPS.
### 3. Installation

#### 3.1 Work safety

**Information**

Work instructions specify in detail how certain steps have to be carried out. Work instructions are tied to a specific process, a product or a workstation. They form the basis for ensuring that quality standards are met when the company's employees carry out their respective tasks. Initial basic instruction on safety in the workplace and how each person should comply must be completed before specific work instructions are handed out.

Observe the safety precautions in the introduction!

<table>
<thead>
<tr>
<th>Subject of instruction</th>
<th>Date</th>
<th>Instructed person (signature)</th>
<th>Supervisor (signature)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. General instructions at the fill-level system</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Instructions on handling liquids</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Instructions for electrical components</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Electrical start-up must only be carried out by appropriately trained personnel.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. General introduction to: Workshop use Goods in/out Working at a PC Internet and e-mail Telephone system</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Accident prevention regulations specified by trade associations for precision and electrical engineering apply.
### 3.2 Preassembly, mechanical

**Information**
The components must now be assembled in accordance with the specifications in the assembly plan.

**Task**
- Complete the mechanical preassembly of the components of the fill-level system first. Supplement the assembly plan you created in the chapter on “Planning” by assigning assembly procedures to components. Use the technical drawings of the components as an assembly guideline. Engineering drawings of the individual components are included on CD-ROM.
- Write down the assembly times in the assembly plan prepared earlier and modify it if necessary if you use different steps or discover better alternatives.

### 3.3 Pre-wiring, electrical

**Information**
The components are preassembled in accordance with the basic electrical setup plan.

**Task**
- First of all, the electrical components are pre-wired. Proceed in accordance with the layout you have already created. Follow the circuit diagram with regard to wiring. Then attach the electrical components to the H-rail.
Write down the assembly times and modify the assembly plan if necessary if you use different steps or discover better alternatives. Make a note of any changes to the assembly plan.

### 3.4 Final assembly with component labelling

**Information**
All the mechanical and electrical components are put together in the final step.

**Task**

- During final assembly, screw or clamp all the mechanical and electrical components to the profile plate and the rectangular profiles and connect the electrical components to each other (see CD-ROM).
- Supplement the components list with the component designations in accordance with the PI flow diagram and the electrical circuit diagram. Write the designations of the components onto the adhesive labels and attach them to the respective system components.
### Component list per PI flow diagram

<table>
<thead>
<tr>
<th>Item no.</th>
<th>Graphical symbol</th>
<th>Meaning of the graphical symbol</th>
<th>Identification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><img src="p101.png" alt="Graphical symbol" /></td>
<td>Measuring point for pressure measurement with display (component: pressure gauge)</td>
<td>PI103</td>
</tr>
<tr>
<td>2</td>
<td><img src="fi101.png" alt="Graphical symbol" /></td>
<td>Tank, container (2)</td>
<td>B101, B102</td>
</tr>
</tbody>
</table>

### Components list based on electrical circuit diagram

<table>
<thead>
<tr>
<th>Item no.</th>
<th>Graphical symbol</th>
<th>Meaning of the graphical symbol</th>
<th>Identification</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td><img src="indicator.png" alt="Graphical symbol" /></td>
<td>Indicator light, start</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td><img src="s1.png" alt="Graphical symbol" /></td>
<td>Electrical pushbutton, start</td>
<td>S1</td>
</tr>
<tr>
<td>12</td>
<td><img src="pushbutton.png" alt="Graphical symbol" /></td>
<td>Electrical pushbutton, start</td>
<td>S2</td>
</tr>
<tr>
<td>13</td>
<td><img src="relay.png" alt="Graphical symbol" /></td>
<td>Relay</td>
<td>S3</td>
</tr>
<tr>
<td>14</td>
<td><img src="relay.png" alt="Graphical symbol" /></td>
<td>Relay</td>
<td></td>
</tr>
</tbody>
</table>
1. Manual measurement

1.1 Project task: bath recirculation

1.1.1 Task description

Information
Typical recirculating processes are used in all baths where liquids have to be filtered. For example, leisure time applications include swimming pools and technical applications include acid baths and galvanising plants. As the filter becomes more and more contaminated, resistance in the piping system increases upstream of the filter in proportion to the degree of contamination. When a specified pressure is exceeded, the filter must be cleaned or replaced. The relationship between resistance (degree of valve opening) and pressure is determined by experimentation.

Task
- Modification in accordance with the PI flow diagram: modify the basic setup with two tanks so that the experiments for manual measurement can be done using a single tank. Stopcock V103 represents the filter for the purpose of the experiment. Filter permeability is simulated by opening and closing the valve.
1.1.2 Setting up the system, inspection

Modify the piping layout in accordance with the photograph. Remove the piping to the upper tank and insert blanking plugs into each of the push-in T-connectors.

Close stopcock V105.

Check to make sure that all piping connections are correct.

Check the piping connections to the impeller pump.

Make sure that the pressure gauge is installed directly downstream of the pump!

Fill tank B101 with 3 litres of water.

Connect the system to the power supply unit (24 V DC).

Test execution:
Stopcocks V103 and V102 are fully open and V105 is fully closed. The control switch is turned to the ON position and the pump delivers water. Stopcock V103 is closed successively in the test setup.

After the experiment has been completed, pull out the main plug and remove the 4 mm safety cable from the power supply unit.

The water must be drained from the system via stopcock V105 after testing.
### 1.1.3 Experiment: mechanical pressure measurement

Fill the tank and then start the pump. Stopcock V103 is open at first and is gradually closed. Stopcock V103 represents the filter for the purpose of experimentation. Filter permeability is simulated by opening and closing the valve.

- Read pump pressure from the pressure gauge.
- Observe the volumetric flow rate at the sight glass in the flow meter.

#### Resistance (degree of valve opening) and pressure

<table>
<thead>
<tr>
<th>Degree of valve opening as percentage, V 103</th>
<th>p, [bar]</th>
<th>Q [l/min.]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td>80%</td>
<td>0.32</td>
<td></td>
</tr>
<tr>
<td>60%</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>40%</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td>20%</td>
<td>0.22</td>
<td></td>
</tr>
<tr>
<td>Closed</td>
<td>0.32</td>
<td></td>
</tr>
</tbody>
</table>
1.1.4 Evaluation and findings

Task

- **Plot the pressure measured in the piping system relative to the degree of valve opening on the graph:**

![Graph](image.png)

- **How are pressure and volumetric flow rate within a piping system influenced when resistance within the piping system is continuously increased?**

- **Why doesn't pressure continue to rise after the stopcock has been fully closed?**

- **Explain how an impeller pump works.**
- Why is it important to ensure that there’s no air in the pump?

- Which types of pumps can be used in the field of process technology? Use information from various manufacturers in order to research your answer. Create a table with typical characteristics, as well as technical data and the range of applications, for a given type of pump.

<table>
<thead>
<tr>
<th>Pump type (section drawing)</th>
<th>Characteristics, technical data, range of applications</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### 1. Manual measurement

<table>
<thead>
<tr>
<th>Pump type (section drawing)</th>
<th>Characteristics, technical data, range of applications</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
1.2 Project task: mixing system

1.2.1 Task description

Information
The ingredients fed to a mixing system are usually required in the defined quantity. Mixing systems of this sort are used, for example, to mix cement. A corresponding amount of water must be fed to the cement mixer in order to produce a specified concrete mix. The quantity is time-controlled. A prerequisite is that a constant volumetric flow rate must be maintained, e.g. 60 litres per hour.

The relationships between resistance (degree of stopcock opening), the delivered amount of water and the required amount of time can be determined by means of an experiment. Run the experiment using the existing test setup with one tank.
### 1.2.2 Experiment: flow measurement

The relationships between resistance (degree of stopcock opening) and volumetric flow rate, as well as the amount of water delivered within a specific period of time will be examined. In doing so, we'll look into the question of how long it takes to pump 2 litres of water into the upper tank with various degrees of opening at stopcock V103.

#### Task

- Read the volumetric flow rate at the sight glass in the flow meter.
- Set volumetric flow rate to the required flow rate.
- Fill the upper tank.
- Measure the time it takes for the water level to rise from the 0.5 to the 2.5 litre mark.
- Enter measured time in the table.

<table>
<thead>
<tr>
<th>Q [l/hr.]</th>
<th>Time [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td></td>
</tr>
<tr>
<td>300</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td></td>
</tr>
</tbody>
</table>

Volumetric flow rate per unit of time
1. Manual measurement

1.2.3 Evaluation and findings

Task

– Plot the measured time values and the volumetric flow rate settings on the graph.

![Graph showing volumetric flow rate vs. time in seconds]

– Describe your observations on the experiment in a few short sentences:

_________________________________________________________________________________________
_________________________________________________________________________________________
_________________________________________________________________________________________
_________________________________________________________________________________________

– How long would it take to pump 150 litres of water if the flow rate were set to 90 litres per hour?

_________________________________________________________________________________________
_________________________________________________________________________________________
_________________________________________________________________________________________
_________________________________________________________________________________________
1. Manual measurement

– It takes 0.033 hours to fill the tank to the 2 litre mark. Calculate the volumetric flow rate for any desired setting for stopcock V101 with the help of the measured time value. Check the selected volumetric flow rate against the results of your calculation.
4.2 Project task: controlling the fill level using a continuous controller

4.2.1 Task description
If no system deviation is permissible within the control circuit, continuous controllers must be used. Continuous controllers are characterised by, for example, an analogue manipulated variable in the event that the sensor has generated an analogue signal. Depending on the control function, the manipulated variable is calculated by means of various mathematical formulas.

Schematic diagram of a control circuit with a continuous controller
A fill-level system with open outlet (PT1 performance), for example, is used within the control circuit.

The following controller functions (selection) could be used:

<table>
<thead>
<tr>
<th>Controller</th>
<th>Graphic symbol</th>
<th>Function</th>
</tr>
</thead>
</table>
| P controller | ![P graph]  
$y = kp \cdot e$
kp = adjustable amplification factor  
e = system deviation $w - x$ |
| I controller | ![I graph]  
$y = esum \cdot TA/Ti$
Adjustable integral time (Ti)  
esum = sum of system deviation $e$
System deviation $e$ is added up during each cycle. |
| PI controller | ![PI graph]  
$Y = kp \cdot (e + esum \cdot TA/Tn)$
Adjust $kp$ and reset time (Tn)  
$TA =$ sampling time, programme cycle time |
| PID controller | ![PID graph]  
$Y = kp \cdot (e + esum \cdot TA/Tn + (e - e_{alt}) \cdot Tv/TA)$
Adjust derivative time (Tv),  
e_{alt} = system deviation from the previous cycle |

Note
The pump must be operated in the analogue mode for continuous control. Control voltage from the EasyPort to the motor control is between 0 and 10 V. Changeover relay K1 must be set with $A2 = 1$ to this end.
4. Automated closed-loop control

4.2.2 Experiment: controlling the fill level with a continuous controller

In this experiment the fill level will be controlled with a continuous controller. In the example included in the chapter entitled “Manual control of fill level”, the fill level was kept constant by varying the power supply unit’s output voltage. The manipulated value will now be read out by the software. The experiment should be carried out with four different controllers.

Various settings must be entered in order to test the performance of the control circuit. In order to be able to draw any conclusions, it’s always advisable to change only one parameter at a time and then conduct the experiment. The settings included in the following table are suggestions.

– Start the software and open the “Continuous control” menu.
– Check the software settings: set changeover relay A2 = 1 and specify the setpoint.
– Carry out the experiment with P, I and PI controllers.
– Add your observations to the table.

Depending on the software revision level, the setpoints may also have to be entered in a sub-window.
4.2.3 Experiment: controlling the fill level using a proportional controller

**Note**
Empty B102 before each start-up!

- Select each of the values listed below and carry out the experiment.
- Document your observations.

<table>
<thead>
<tr>
<th>No.</th>
<th>Setpoint w, physical</th>
<th>Setpoint w (standardised)</th>
<th>Amplification kp</th>
<th>Disturbance variable z, hand valve V103</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 litre</td>
<td>0.3</td>
<td>0.5</td>
<td>10% open</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1 litre</td>
<td>0.3</td>
<td>2</td>
<td>10% open</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1 litre</td>
<td>0.3</td>
<td>10</td>
<td>10% open</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1 litre</td>
<td>0.3</td>
<td>5</td>
<td>0% open</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1 litre</td>
<td>0.3</td>
<td>5</td>
<td>20% open</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>2 litres</td>
<td>0.2</td>
<td>5</td>
<td>100% open</td>
<td></td>
</tr>
</tbody>
</table>

Sample solution for fill-level control with a P controller
4. Automated closed-loop control

Task

– Which characteristics is the control circuit (P controller, PT1 system) displaying?

_________________________________________________________________________________________
_________________________________________________________________________________________
_________________________________________________________________________________________

4.2.4 Experiment: controlling the fill level using an integral controller

Note
Empty B102 before each start-up.

Software setup
The manipulated value of the I controller is calculated as follows:

\[ Y = \text{total of all system deviation (e:sum) } \times \text{sampling time (TA) } \div \text{integral action time (Ti)} \]

This formula makes it clear that \( Y \) is quickly changed by the controller when \( Ti \) is small, and \( Y \) is changed slowly, i.e. the controller is sluggish, when \( Ti \) is large. Make sure that \( Ti \) does not drop to 0, otherwise \( Y \) would be undefined in this case. Switch the software to “I controller”.

The physical setpoint depends on the size of the tank and whether the unit of measure of the fill level will be in litres or in mm.
Select each of the values listed below and carry out the experiment.
Document your observations.

<table>
<thead>
<tr>
<th>No.</th>
<th>Setpoint w, physical</th>
<th>Setpoint w (standardised)</th>
<th>Integral action time (Ti)</th>
<th>Disturbance variable z, hand valve V103</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>–</td>
<td>0.3</td>
<td>1</td>
<td>10% open</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>–</td>
<td>0.3</td>
<td>0.5</td>
<td>10% open</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>–</td>
<td>0.3</td>
<td>0.1</td>
<td>10% open</td>
<td></td>
</tr>
</tbody>
</table>

**Note**

It is possible that no stabilisation occurs in an actual system and that continuous oscillation takes place.

Sample solution for controlling the fill-level with an I controller
Task

– What is the effect of integral time?

_________________________________________________________________________________________

_________________________________________________________________________________________

_________________________________________________________________________________________

– What can we say about system deviation?

_________________________________________________________________________________________

_________________________________________________________________________________________

_________________________________________________________________________________________

_________________________________________________________________________________________

4.2.5 Experiment: controlling the fill level using a proportional-integral controller (parallel P and I components)

In order to take advantage of the positive characteristics of both the P and the I controller, the two will be combined. This can be done in two different ways:

The controllers are connected in parallel in the combination shown on the left and in series in the combination on the right. In actual industrial practice, the combination shown on the right is used in accordance with DIN 19226.

Note
Empty B102 before each start-up.

– Select each of the values listed below for the PI (DIN) controller and carry out the experiment.
– Document your observations.
Sample solution for controlling the fill-level with a PI controller

**Task**

- What can we say about reset time \( T_n \)?

- What can we say about system deviation?