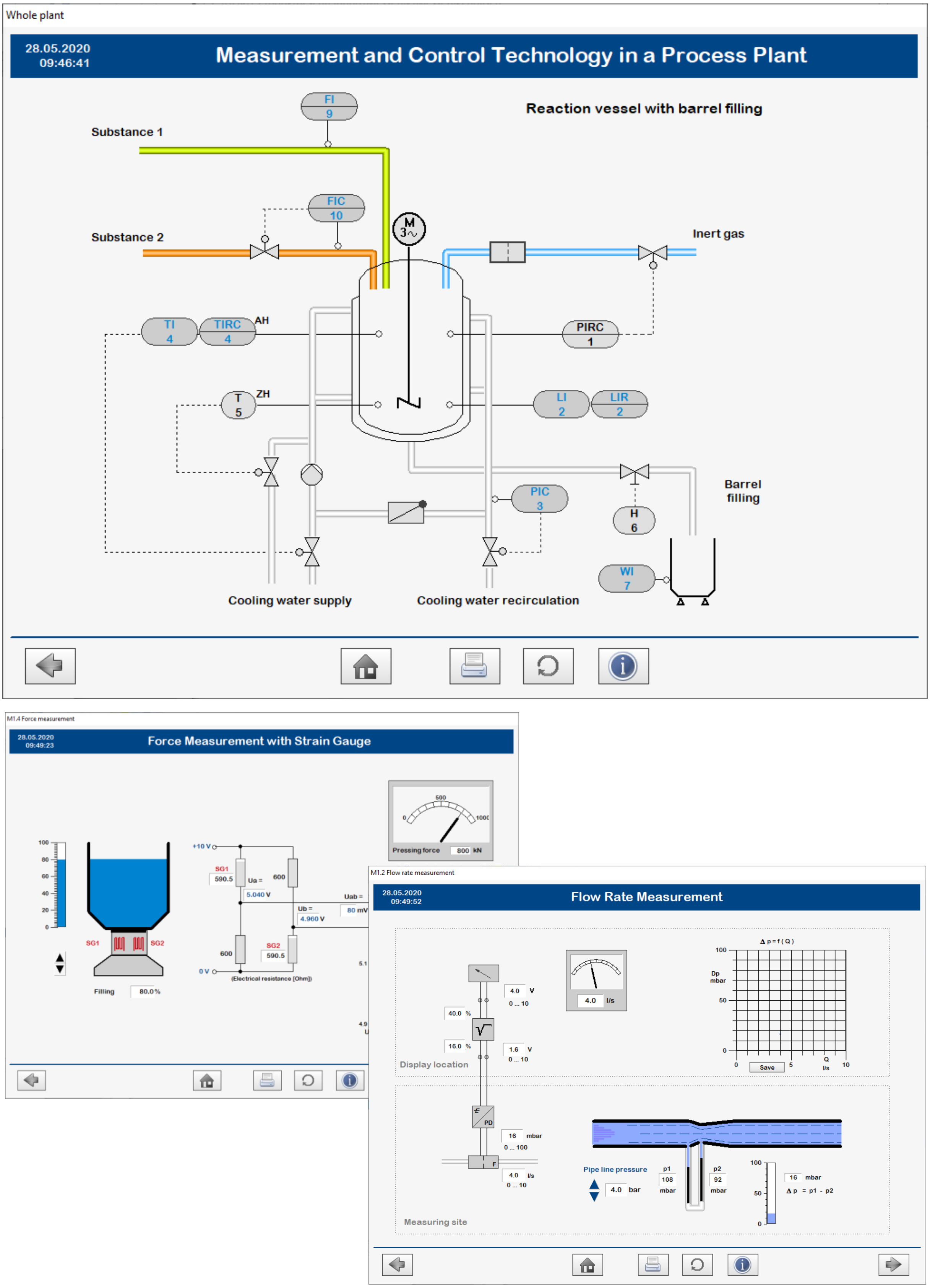
Methods of Measurement Technology in a Process Plant



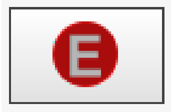
Version 20.0511

Inhalt

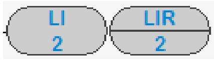
Operating instructions

The start window for this course is always the overview. The program should also be exited from this page by clicking *End* button.

For information on the WinErs program and on the practical course on measurement techniques, click on the button for the "WinErs" symbol.



You may change to the individual pages of the course by clicking on the subject. The example for process engineering on page 1 shows a reaction vessel with barrel filling. Here, the measuring methods simulated in the course are indicated with the "cycle standard" symbol (with possible additional exercises). By clicking on the cycle symbols you can change directly to the respective work sheet..

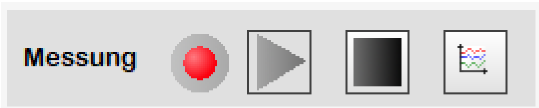


All the work sheets have a control bar on the bottom.

The arrows lead to back tot he previous page or forward to the next subject-relevant page. The home symbol always leads to the overview. Use the printer symbol to print the current page (set up printer on "start page"), the reset button is for initial adjustments and with the info button the manual opens (.pdf).

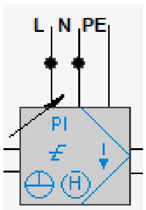
Additionally some pages have a measurements control bar:

- display: "Running measurement" (red point)
- start measurement,
- stop measurement, and
- display diagram;



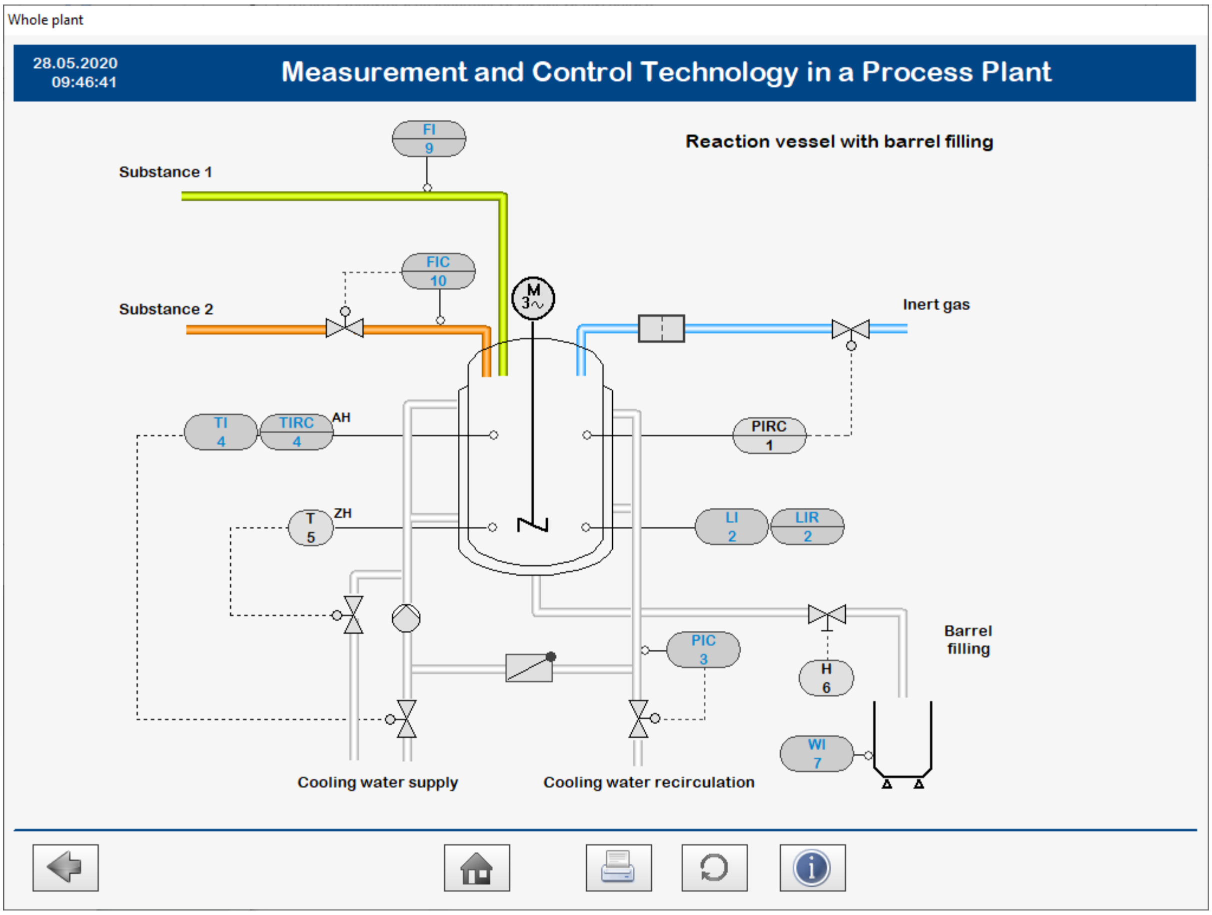
The work sheets allow additional operations in the simulation. The measured physical variables can be changed step-by-step with the arrow keys. The arrow key must be activated with the left mouse button. (The mouse cursor changes into a manual symbol over an activated button.) If the left mouse button is pressed constantly, the values independently change in the selected direction.

On the individual pages of the course, some system parts can be "opened" via the manual symbol of the mouse cursor. Example: In the displayed controller symbol, the setpoint, the gain, the reset time etc. can be set.



Example Plant

In this course, several measuring methods are demonstrated in a model system covering the field of measurements. The transfer of the measured values and the handling of measuring transformers and standardised signals are simulated. The co-operation of measuring and actuating signals in a complete control loop can be studied on a model of a flow control system.



First, the system (reaction vessel with barrel filling) is shown in an overview containing the measurement points and the control loops. The meaning of the symbols represented as "standard circles" can be analysed first.

When the process is simulated, a brief note on the measurement point circle is displayed (when the mouse cursor remains on the symbol). It is also possible to change to the respective methods of measurement with a left mouse click.

Measurement Methods

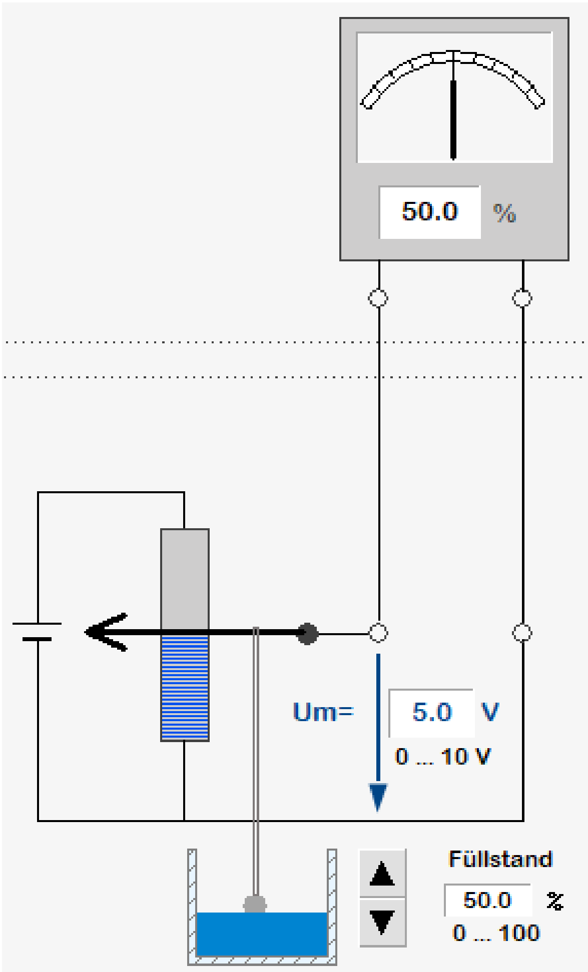
Level Measurement

Various methods of measurement are used to measure the liquid levels in industrial systems. In the set-up selected for this simulation, a float is used.

Measuring principle

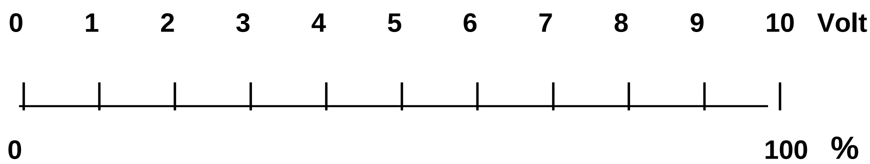
A float is connected to the slider on a potentiometer via a linkage. The slider is moved via the resistor corresponding to the liquid level (0 ... 100%). Therefore, there is a partial resistance between the lower connection on the resistor and the slider position, which corresponds to the liquid level (in %). Since the (overall) resistance applies to a voltage of U = 10V, a voltage of 0 ... 10 V proportional to the liquid level can be measured on the slider and advanced to the display.

When the measuring instrument has a range of 10 V, the indicated voltage value (0...10V) can be converted into a proportional liquid level (0 ... 100%).



Tasks

1. The indicating instrument has a linear scale for the voltage values of 0 to 10 Volt. Enter the values for the direct display of the liquid level (in %) below the scale.



2. Using caculations, check the value of the measured voltage (Um) for different liquid levels. The overall resistance of the potentiometer is 1kOhm. (The effect of the indicating instrument is not taken into consideration!)

   Calculation:
   Lower partial resistance of the potentiometer (Rm):

$$R_m = R_{ges} * \text{Level} / 100$$

Measuring-circuit voltage (Um):

$$U_m = U_{ges} * R_m / R_{ges}$$

When you work with real indicating instruments and larger transmission paths, the effect of the internal resistance of the measuring instrument must be taken into consideration. The current passing the measuring cables causes measuring inaccuracies:

- Voltage drop due to the line resistance,
- Temperature effect due to the line resistance.

On the following page, the voltage signal is converted into a current signal to transmit the measured value over a long distance. The measuring errors mentioned above can be eliminated with these measures. (Also see: "Standardised signals in the measuring chain")

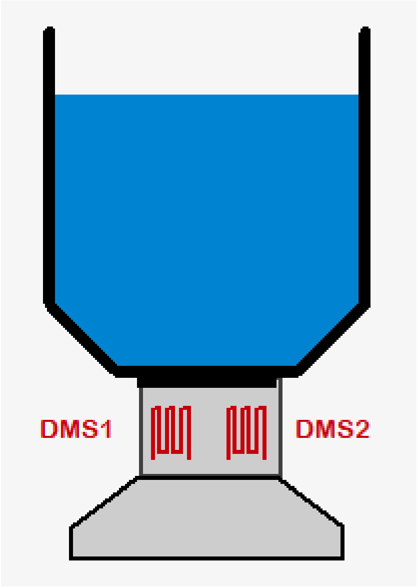
Force measurement

The liquid level in a container is determined by measuring the weight. Therefore, the storage stamps on the container are equipped with strain gauges.

Measuring principle

The resistance in an electrical conductor depends on the length and the cross-section of the conductor and other factors. When the conductor is compressed, its length decreases and its cross-sectional area increases. Both changes lead to a reduction of the electrical resistance.

When this electrical conductor in the shape of a strain gauge (SG) is solidly connected to an elastic material (e.g. steel), the (forced) elastic deformation can be measured via the changing electrical resistance.



Tasks

1. Determine the resistance of the strain gauge

   without load (Level: 0%): .... Ohm, and with

   maximum load (Level: 100%): .... Ohm.

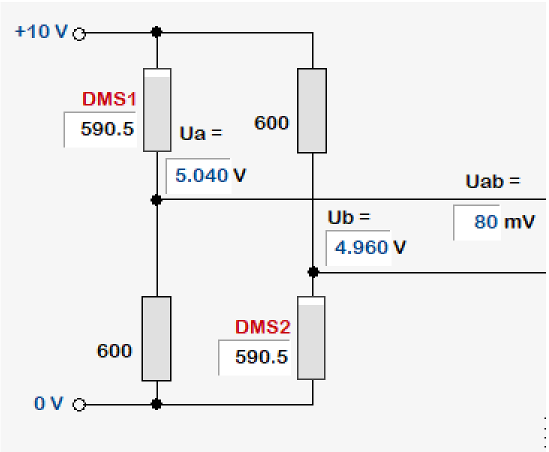
2. What is the maximum change in resistance? .... Ohm

3. What is the maximum relative change? .... %

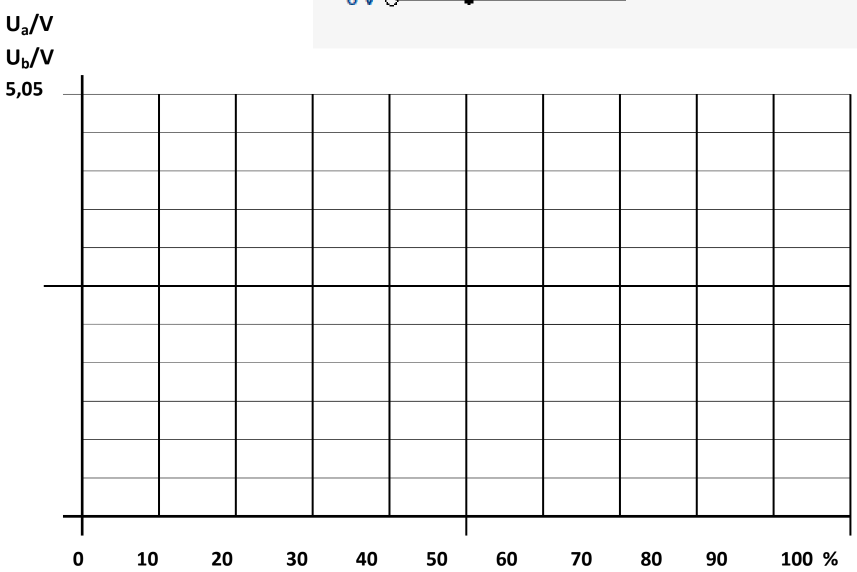
When the change in resistance is used to indicate the causing force directly, the indication is very inaccurate due to the low relative change. The use of a bridge circuit with one or more strain gauges leads to higher indication accuracy.

Function of bridge circuit:

When a constant voltage is applied to the series connection (left voltage divider) of a strain gauge (top) and a resistor (bottom), the strain gauge voltage drops when the strain gauge resistance is reduced. The residual voltage (U_a) increases proportionally. In the right voltage divider, the strain gauge is connected below the resistance, so that the voltage U_b decreases.



4. Draw the measurement points for the voltages Ua and Ub into the diagram. Read the voltage values for levels between 0 and 100%.



The "bridge voltage" ($U_{ab} = U_a - U_b$) between the two voltage dividers is intensified and used for the display.

The "bridge voltage" (Uab = Ua – Ub) between the two voltage dividers is intensified and used for the display.

4. *Determine the bridge voltage Uab*

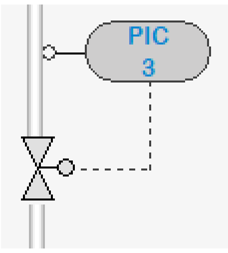
   without load (level: 0%): .... mV, and with

   maximum load (level: 100%): .... mV.

5. *What is the maximum change in voltage? .... mV*

6. *What is the maximum relative change? .... %*

Pressure Measurement

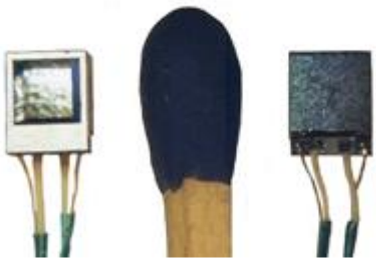


The pressure in a pipe is measured, indicated and controlled. The measuring principle with a capacitive sensor is simulated and the measured values are displayed and registered.

Measuring principle

Two conductive surfaces are separated by a dielectric. The capacitance of this arrangement depends, among other factors, on the gap between the two surface areas. When the gap is reduced due to an acting pressure or force, the capacitance increases. A measuring amplifier converts the capacitance into a voltage that is proportional to the acting force.

The figure on the right shows capacitive sensors (compared to the top of a match).



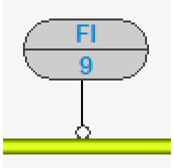
The pressure in the pipe acts upon a diaphragm and creates a force that is proportional to the surface area:

$$F = p * A$$

The force displaces the diaphragm and is transmitted to the sensor. The measuring amplifier converts the capacitance into a standardised electrical signal (here: 0 ... 10V), which is used for the display or the registration.

Flow Rate Measurement

The flow rate in a pipe is measured and indicated. The differential-pressure method has been selected from the possible methods of measurement.



Measuring principle

Narrows in pipes for flowing liquids increase the flow velocity and decrease the static pressure. When the pressure is measured before and in the pipe narrowing the pressure difference can be used to determine the flow velocity and the flow rate. In the simulation, a Venturi pipe has been used as a narrow.

In the initial state, the pipe pressure is 4 bar and therefore causes a flow rate of 4 l/s. A pressure difference of 16 mbar can now be measured on the differential-pressure transducer.

Tasks 1

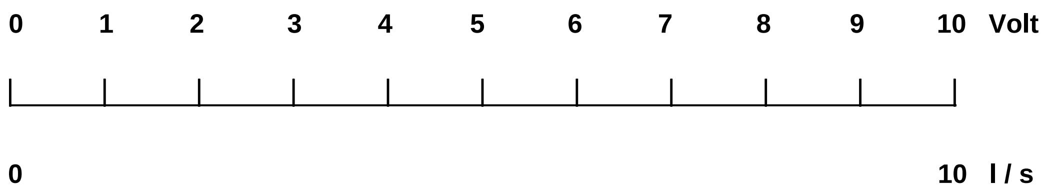
1. Change the pipe pressure, so that the flow rate rises to double the amount, which is 8 l/s. What pressure difference is measured now?
2. How can you formulate the dependence of the pressure difference on the flow rate?
3. Change the pipe pressure between 0 and 10 l/s with the pipe pressure. Observe the figure in the diagram. (You may "freeze" the display by clicking on the "Save" button.)

The measured pressure difference is used to indicate the flow rate. First, the pneumatic signal must be converted into a standardised electrical signal.

An electrical voltmeter for the (standard) range of 0 to 10 V is available for the display of the flow rate. The pressure range of 0 to 100 mbar (corresponding to a flow rate of 0 to 10 l/s) must be transmitted to a voltage range of 0 to 10 V.

Tasks 2

4. Increase the flow rate step by step from 0 to 10 l/s and read the respective voltage values (directly behind the measuring transformer).
5. Enter the values for the respective flow rates on the scale from 0 to 10 Volt.



6. What is the special feature of this scale division?

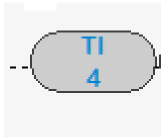
If the linear division of the volt scale is also to be valid for the flow rate, a root extractor must be integrated in the measuring chain. The r.m.s. ratio between the pressure difference and the flow rate is "linearised" by the root extractor.

(The square-root extraction can only be checked computationally when percentage values are used for the calculation.)

>> possibly continue with: Standardised signals in the measuring chain

Temperature measurement Pt100 (Display at Site)

The temperature in a container is measured with a Pt100 resistor and indicated near the measurement point with a pointer instrument.



Measuring principle:

Current passes an electrical circuit containing a voltage source, a Pt100, a connection cable and an indicating instrument. When the temperature on the Pt100 changes, the current and the display also change. The instrument has been selected and adjusted, so that the pointer is on the zero when the container temperature is 0 °C. When the temperature is 100 °C, the value is indicated with a full pointer deflection. The line resistance of 1 Ohm (for 20°C) was taken into consideration when the indicator was adjusted.

Tasks 1

1. Record the characteristic curve ($R = f(\vartheta)$ for the Pt100 between 0 and 100°C,
2. Describe the PTC performance for metals,
3. Use the formula for the NTC resistance,
4. Check the current values for different operating points.

In systems to protect against mechanical, chemical and other environmental influences, the Pt100 resistor is only used in combination with a protective tube. Since the thermal conduction from the measured medium to the platinum wire is delayed, the display is also delayed when the container temperature (presumably) changes abruptly.

Tasks 2

1. Observe the time response of the display when the temperature changes.
2. Abruptly change the container temperature between 50 and 100°C. After which time does the instrument indicate the correct temperature value?

The resistance of the connection cable has constantly been 1 Ohm. When the cable is near heat sources, however, the line temperature is higher than 20°C. The rise of the ambient temperature can be simulated with the arrow buttons.

Tasks 3

1. Observe and calculate the effect of the temperature rise on the line resistance,
2. Observe the indicated container temperature and determine the absolute and the percentage error,
3. Describe the relation between the measuring accuracy, the line length and the ambient temperature.

Temperature measurement Pt100 (Display in Control Room)

The temperature measured in a container is not indicated spot-on, as in the first example, but in a separate control room. The measured value is also used as the actual value for an existing temperature control.

The measured value must therefore be transmitted free of errors and unaffected by any environment influences over a longer line. The circuit shown in the previous example is not suitable for this purpose.

Measuring Principle of a Four-conductor Circuit

A constant current (here: 1 mA) from a current source passes the Pt100 thermistor and generates a measuring voltage which is proportional to the actual resistance. This measuring voltage is transmitted to a (high-resistive) measuring transformer via an additional pair of conductors. Since the measured current passing this additional pair of conductors is almost zero, effects caused by the line resistance (and therefore also the ambient temperature) are insignificant.

The measuring transformer uses measured voltage to form a standardised signal (here between 4 and 20 mA), which can also be transmitted without transmission errors over long distances.

Tasks

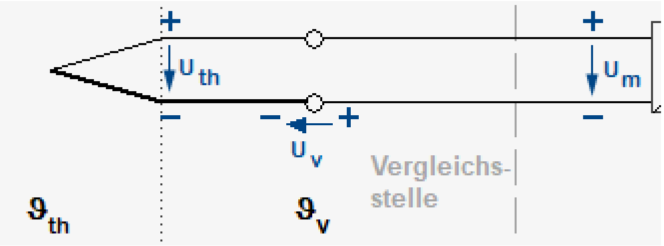
1. The constant current can experimentally be switched off by clicking on the "Constant current ON/OFF" button. Observe the measured voltage.
2. Display the relation between the standardised signal (4 to 20 mA) and the measured temperature (0 to 100 °C) in a diagram.

Temperature Measuring with a Thermocouple

The temperature determined with a thermocouple used as a sensor is transmitted to a survey station and indicated (amongst others).

Measuring principle

A thermocouple consists of two wires made from different materials. When connected, the two metals generate a temperature-dependent "thermal" e.m.f. When the wires of the thermocouple are connected to the connection cable for the measuring transformer, (at least) one further thermocouple is formed, so that another thermal e.m.f. ("voltage reference") is generated. Only the difference between the two thermal e.m.f. can be used for the measurement.



In the illustrated example, the thermocouple consists of copper (+) and constantan (-). Constantan is the thick line in the right figure. At a measured temperature of 100 °C (and 0 °C on the reference point), the thermocouple generates a thermal e.m.f. of 4.25 mV. To simplify the calculation, this value is assumed to be 5 mV in the simulation.

When adjusting the temperature display, a reference point temperature of 20 °C is assumed. If the measured temperature is now 80 °C, the measured voltage is:

$$U_m = U_{th} - U_v = 4mV - 1mV = 3mV$$

The indicating instrument must be set, so that 80 °C are indicated instead of 60 °C (the reference temperature must be added).

In the top circuit, the reference point is near the measurement point. This way the reference temperature increases when the container temperature rises.

Tasks 1

1. Check the indicated thermal e.m.f. and the illustrated calculation.
2. Determine the display errors when the container temperature is 200 °C.

In the bottom circuit, an equalising cable is used for the connection of the thermocouple. These special cables consist of the same materials as the thermocouple. The junction to a normal copper cable and therefore the reference point is further away from the measurement point. The reference temperature does not therefore deviate much from the room temperature of 20 °C.

Tasks 1

1. Check the indicated thermal e.m.f. values and the illustrated calculation.
2. Determine the indication error when the container temperature is 200 °C.

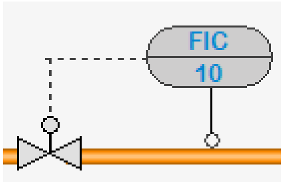
On the next page of the course, a circuit is simulated in which the temperature of the reference point is kept constant. Ice water would be useful to guarantee a reference temperature of 0 °C. In industrial installations, it is more useful to use a reference point heater with temperature control (e.g. for 50 °C).

Tasks

3. Adjust several reference temperatures and check the display.
4. Determine the indication error when the container temperature is 200 °C.

Transducers and Standard Signals

Standardised Signals in the Measuring Chain



The left figure illustrates the measuring circuit: The flow rate in a pipe is measured and displayed in the survey station. The measured value is also used as the actual value for the control of the flow rate.

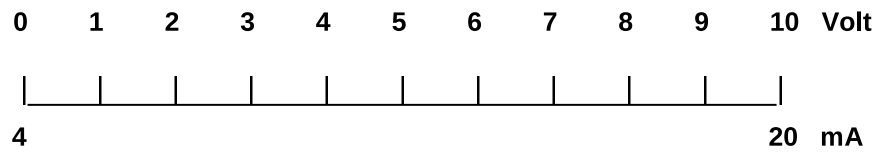
Form the measurement point for the flow rate (in the system) to the point of display (in the survey station), the measured value must be transmitted over a long distance.

When using a voltage signal that corresponds to the flow rate (e.g. standard range of 0 to 10 V), among other factors, the line resistance in the measurement current circuit has an effect on the display. Temperature influences on the transmission line may lead to measuring errors. For long distances, a current signal is therefore often used for the transmission of the measured values. The measured value (range : 0 to 100%) is converted into current (standard range, e.g. 0 to 20 mA), which is transmitted independently from the line resistance.

When a measured value of 0% is indicated in the survey station, in case of a standardised signal of 0 to 20 mA (or 0 to 10 V) it is not possible to distinguish between an actually measured value of 0% and a potential broken line. For safety reasons, a "live zero" is often used. When the standardised signal is 4 to 20 mA, a current of 4 mA passes even when the measured value is 0%. When the current flow drops to 0 mA, a line fault becomes obvious.

Tasks

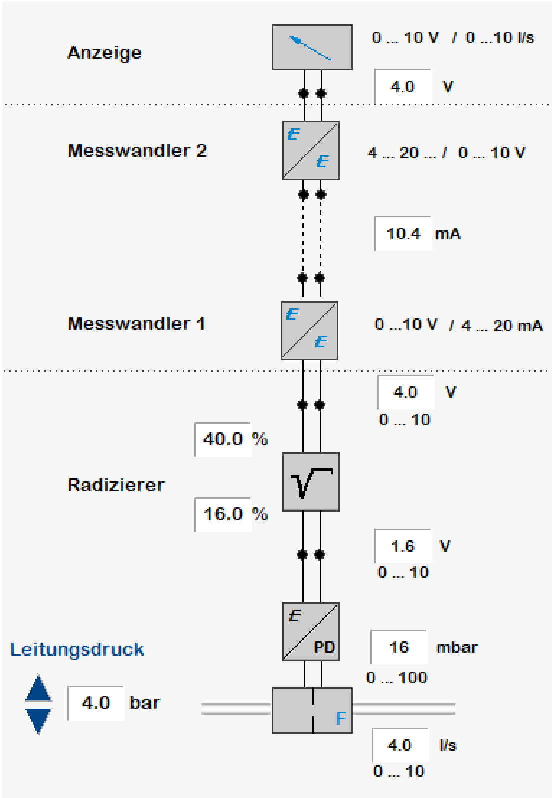
1. Change the flow rate (0 to 10 l/s) and therefore the voltage signal behind the root extractor step-by-step from 0 to 10 V. Determine the respective current value for the standard range between 4 and 20 mA. Enter the current values in the scale.



2. Find a solution for the following exercises by calculating. Then check the results in a simulation:
   a. What current value do you get for a flow rate of 8 l/s?
   b. The current is 10 mA (standard range of 4 o 20 mA). What is the respective flow rate?

Selecting the Measuring Transformer (Transducer)

The illustrated measuring chain shows possible stations, which a measuring signal passes from the measuring point (below) to the display in the survey station (top).



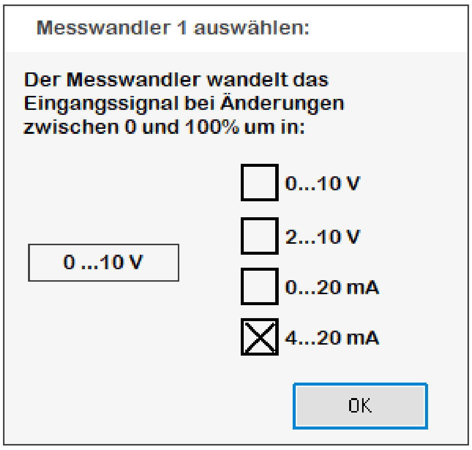
First, the flow rate is measured with the differential-pressure method.

The differential pressure is converted into a proportional voltage.

The r.m.s. dependence of the differential pressure on the flow rate is "linearised" with the following root extractor.

For the transmission over long distances, the voltage signal can be converted into a proportional current signal by selecting a suitable measuring transformer (1).

In the survey station, a further measuring transformer adapts the signal to the indicating instrument (2).



The operating ranges can be selected with a left mouse click on measuring transformer 1, measuring transformer 2 or the indicating instrument.

The operating ranges correspond to the ranges for the standardised electrical signals. When the range for the output signal on the 1st measuring transformer does not correspond to the range for the input signal for the following measuring transformer, the transmission is incorrect.

Invalid combinations are marked red.

Task

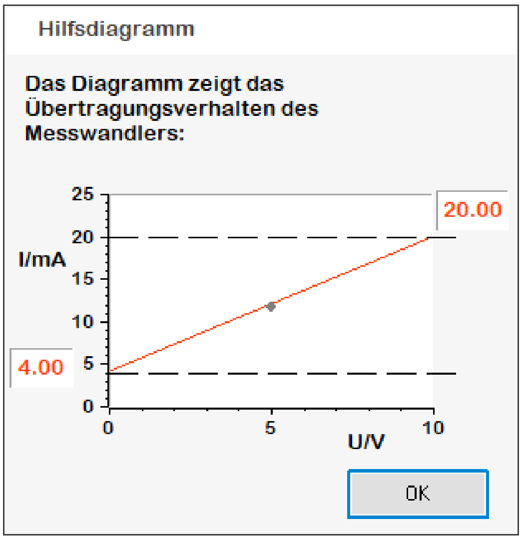
3. Select the standardised signal ranges. Then determine several values in the measuring chain for the preset flow rate and check them in a simulation.

Adjust Transducer

Measuring transformers can, due to ageing, incorrect use, temperature influences or other factors, cause inaccuracies when the signals are converted. For more accurate measurements it is therefore necessary to adjust the measuring transformer.

Open the diagram window, which shows the characteristic curve for the measuring transformer by clicking on the button

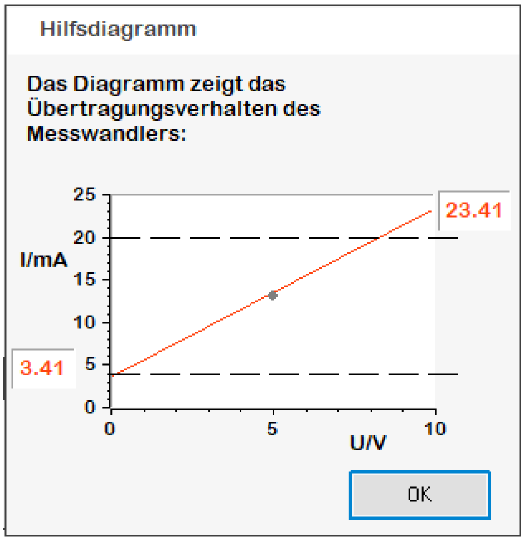
Transmission behaviour.



If the measuring transformer is correctly adjusted, the characteristic curve is between 4 mA (for U = 0 V) and 20 mA (for U = 10 V).

In the simulation, the measuring transformer can be adjusted with the button

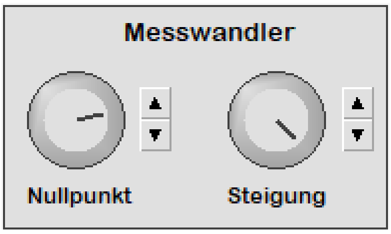
Transducer ok



To adjust the measuring transformer, change the response with the button

Transducer shifted

Tasks



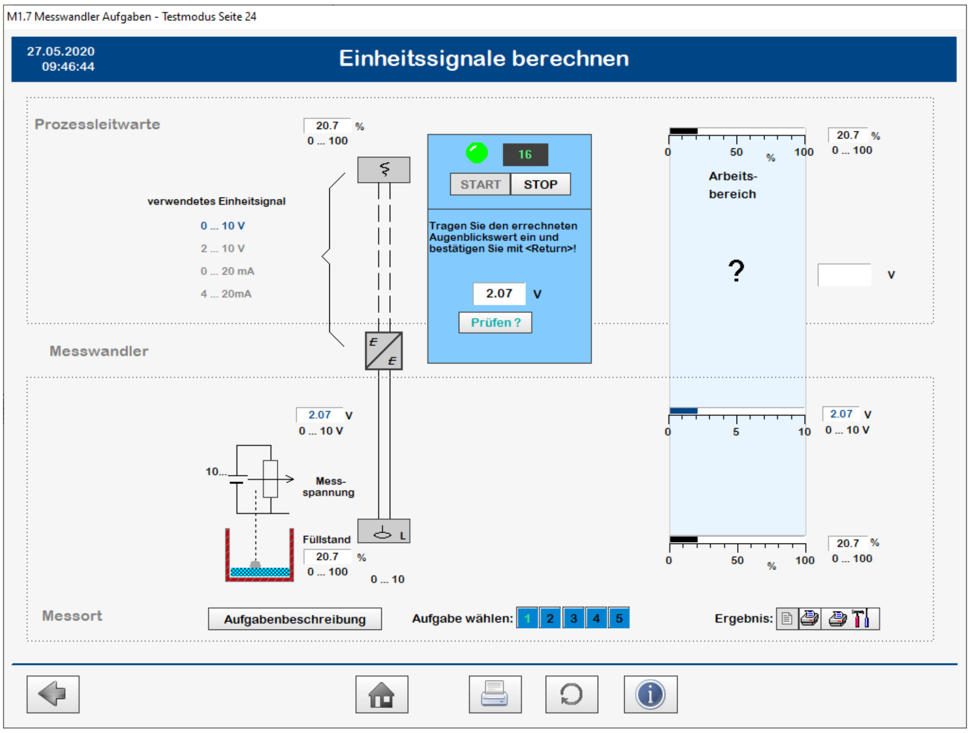
1. To adjust the measuring transformer, set the zero and the incline of the characteristic curve.
2. First, set a lower limit for the transformer of 4 mA with the "Zero" adjuster.
3. Then set the top limit of 20 mA with the "Incline" adjuster.
4. Since the zero has been readjusted by the last step, an accurate setting must be achieved in several steps of adjustment.

Calculate Standard Signals

To check the performance of a transducer, it is necessary be able to calculate standard signals. According to section “Standard signals of a measuring chain” the calculation may be practised interactively.

The values needed for the calculation are regenerated every time the page is opened. Wenn calculated values are entered, the result can be check with according button. If the entered value differs more than 1% from the internal result, the outcome is negative.

All tasks can be repeated. If all tasks are successfully solved, all task numbers are displayed green.



Tasks

1. Choose a task number.
2. Calculate the used standard signal for the actual value.
3. Enter the value into the result field and confirm with <Return>!

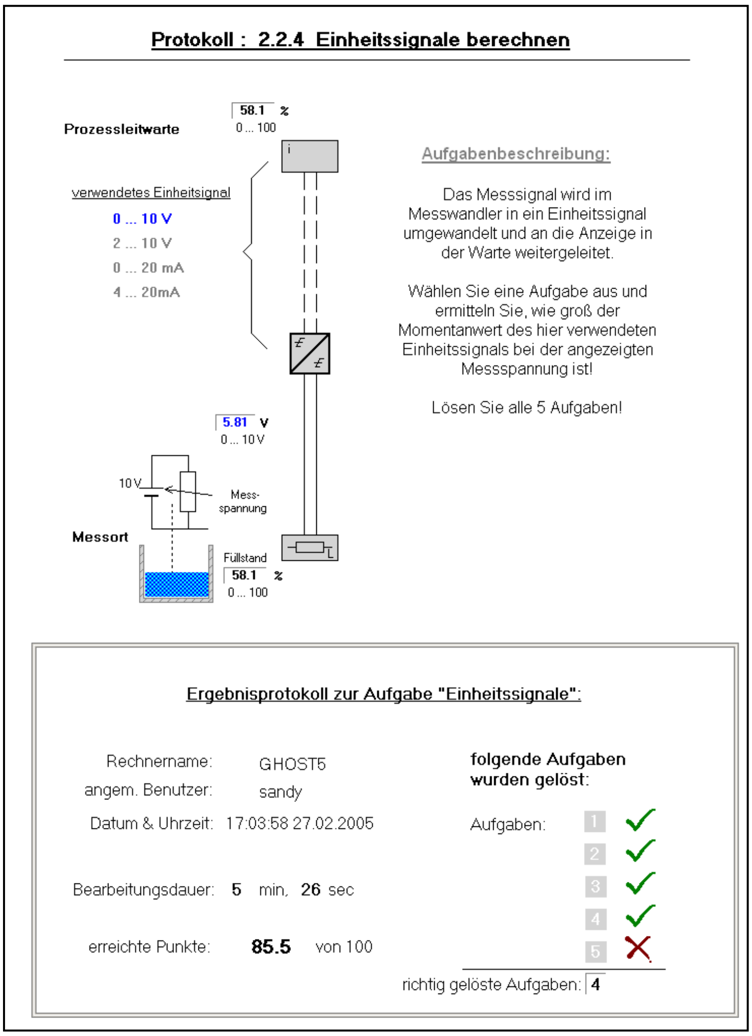
Test exercises

All results and the exercise time can be stored, protocolled and evaluated. Test result is an evaluation on a scale from 0 to 100 points.

With *Start* the exercise time begins. The test is finished with *Stop.* A protocol is stored, which ca be viewed or printed with following buttons

<u>Basis of evaluation</u>

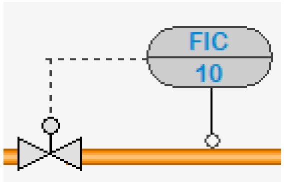
There are 20 point for each correct answer. The usual time for one exercise is 3min. If the editing time is very short up to 10 points are added. If the total editing time is longer than 15min points are deducted.



Closed Loop Control

Flow Rate Control

In the illustrated system (measurement point 10), the flow is measured and indicated for the flow rate control. In the controller, the actual value is compared to the setpoint value and processed to the manipulated variable according to the controller settings. The control valve changes the volume rate of flow with the manipulated variable.

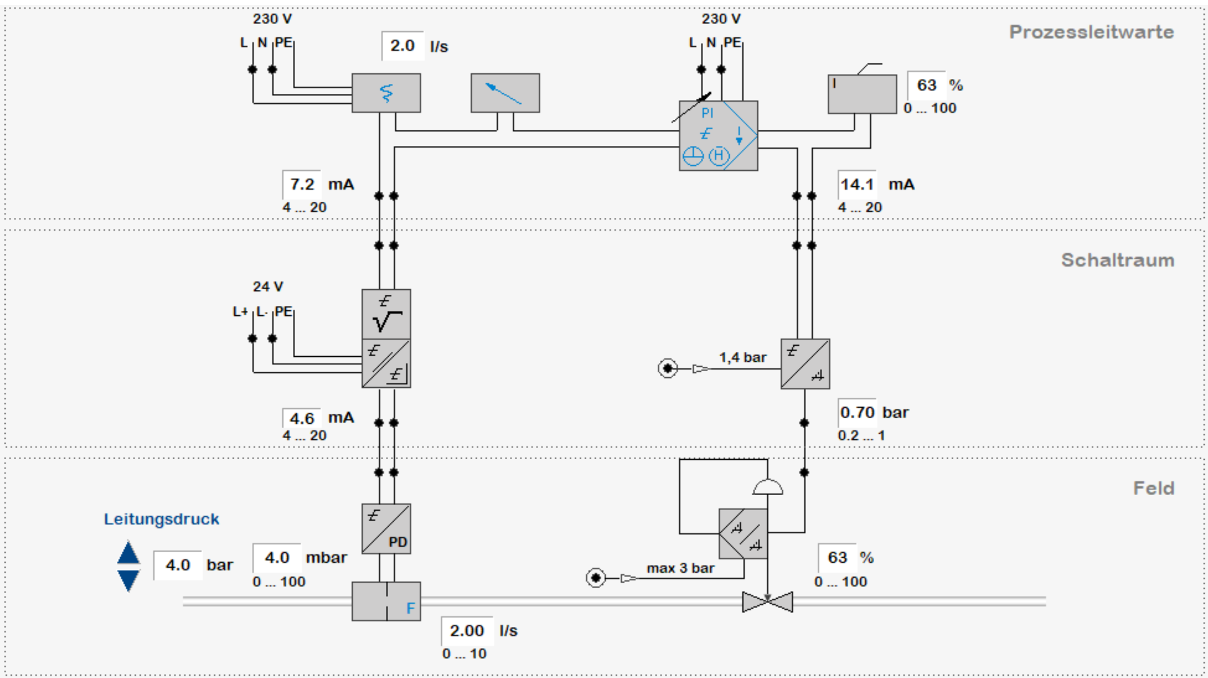


Eine detaillierte Darstellung des Regelkreises mit den Geräteanschlüssen erfolgt im EMSR-Stellenplan.

The ICE plan shows a detailed image of the control loop with the connections for the equipment.

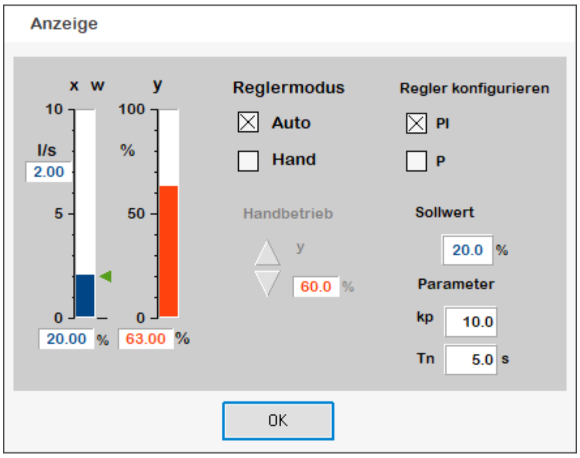
The physical variable measured in the system ("Field") is transmitted via intermediate stations (e.g. switchroom) to the process control room to be indicated and registered. In the controller, the measured controlled variable ("Actual value") is compared to the (adjustable) setpoint value. According to the selected controller type and the set parameters, the actuating signal is formed with the "control error".

The selected universal controller operates with standardised input and output signals (here: 4 to 20 mA). To activate the controller valve, this signal is converted into a differential-pressure signal (0.2 to 1 bar).



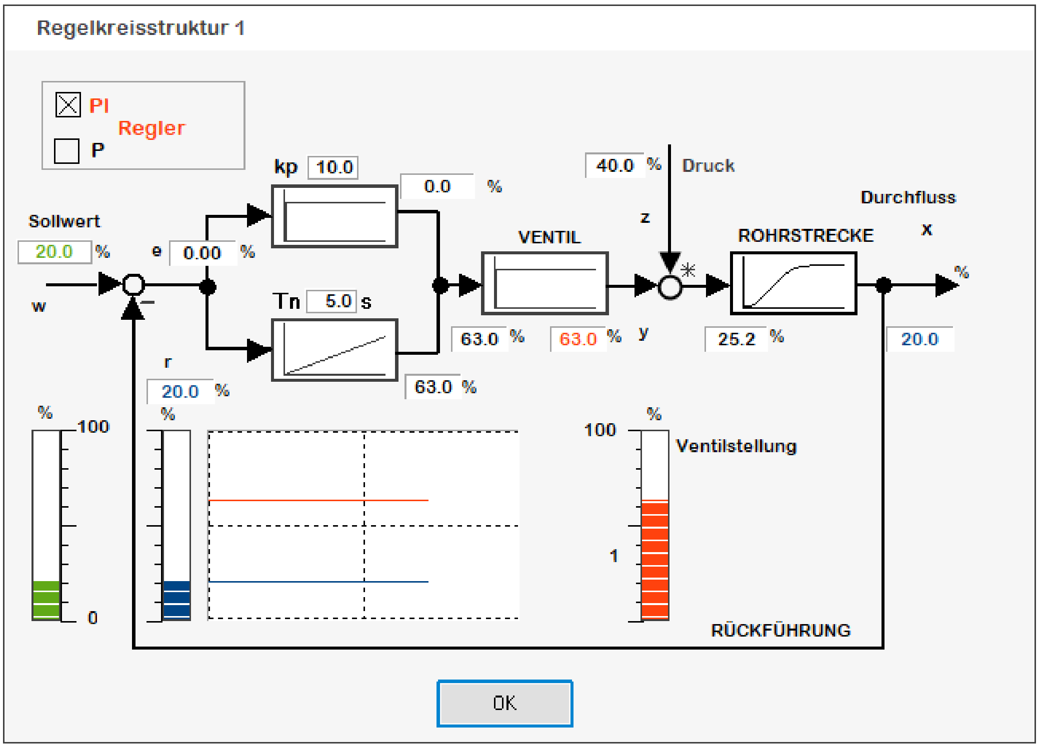
The actual signal values (fields with white background) can be observed to analyse the control response. Some components in the control loop (differential-pressure sensor, indicator, controller) can be opened with a left mouse click.

In this diagram, the controller can be set corresponding to a universal controller.

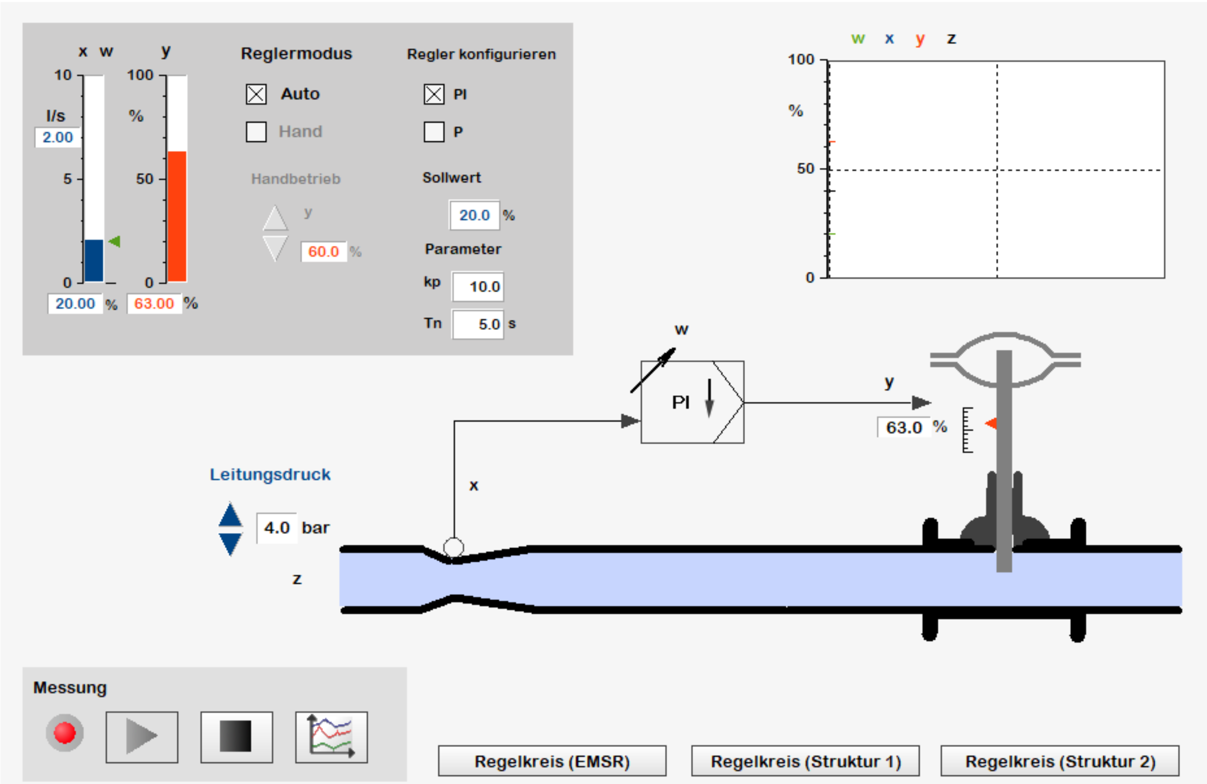


Initially, the control loop is in a stable, steady state. These settings can later be reset by clicking on the "Initial setting" button.

The automatic control structure for the control loop opens up by clicking on the "Control loop (structure)" button. This display field also allows you to change the controller parameters and the setpoint value.



It is also possible to select a very simple, "graphical" image of the control loop ("Control loop (simple)" button), which also allows you to set the controller parameters.



Suggestions to familiarise yourself with the subject of flow rate control

1. Adjusting the flow manually:

Working steps:

- Adjust the initial settings (button).
- Open the controller diagram.
- Adjust the manual actuating variable (60%) to the controller actuating variable (63%) with the arrow keys.
- Now change from AUTO to MANUAL mode. (The flow will not change!)
- Increase the flow rate to 2.5 l/s by changing the manual actuating variable. Which value have you selected for the actuating variable?

Y_{Manual} = ...%

2. Manual Control

Working steps:

- Adjust the initial settings.
- Open the controller diagram.

- Adjust the manual actuating variable (60%) to the controller actuating variable (63%) with the arrow keys.
- Now change from AUTO to MANUAL mode. (The flow will not change!)
- Open the window "Set pipe pressure" by clicking on the "Line pressure" button.
- Increase pipe pressure for 1 bar (by clicking the button „Apply pressure jump“).
- Change controlling variable until you get the initial value of the flow rate (2 l/s).

y_{Manual} = ...%

- Open the window "Set pipe pressure" by clicking on the "Line pressure" button.
- Select "Low fluctuation".
- Open the controller diagram.
- Try to keep the setpoint for the flow rate constant (e.g. 2 l/s) by changing the actuating variable (ymanual). (Compare the actual value (blue bar) to the setpoint value (green arrow) in the controller diagram).
- Then open the diagram image and check the quality of your efforts.

We would appreciate it if you could inform us about any errors, inaccuracies, possible extensions and ... !

Please e-mail to: info@schoop.de

For further information about our trainings or the SCADA system WinErs please contact:

Ingenieurbüro Dr.-Ing. Schoop GmbH
Riechelmannweg 4
D-21109 Hamburg
Tel.: 040 / 754 922 30
www.schoop.de
Email: info@schoop.de