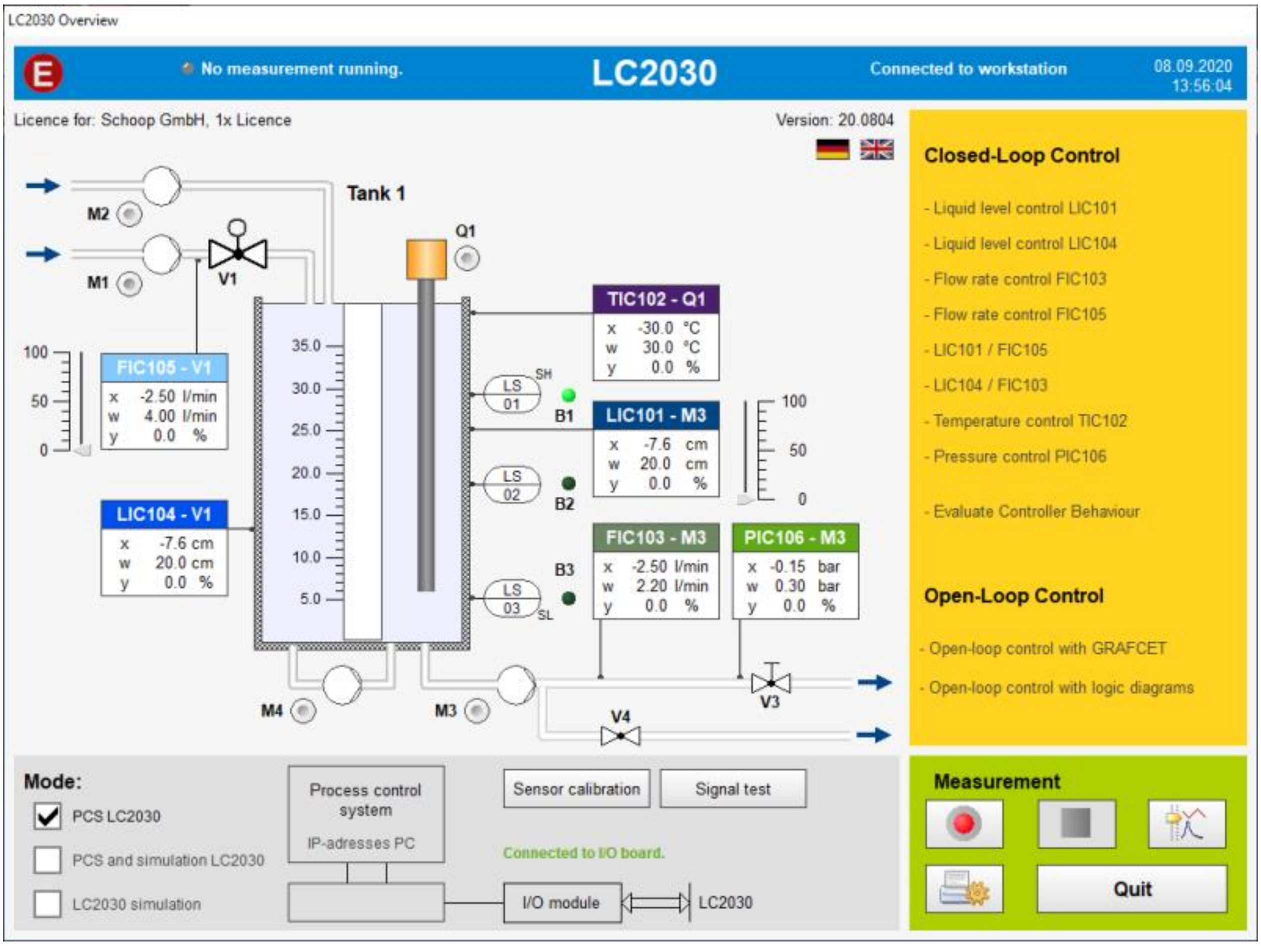
TASKS AND SOLUTIONS
LC2030 – TRAINING



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1 TASKS – OPEN-LOOP CONTROL WITH GRAFCET

1.1 INTRODUCING EXAMPLE WITH DETAILED DESCRIPTION, TASK: LIGHT CHAIN

TASK 1.1.1: Create a Grafcet diagram, which turns on the lamps P1, P2, P3 one by one, and switches off again after 5 seconds. The process is started by pressing switch HS1.

SOLUTION WITH DETAILED DESCRIPTION

To create a Grafcet plan, you have to press the "Build/Execute" button, for example, from Grafcet page 1. It is the Grafcet editor with a blank page.

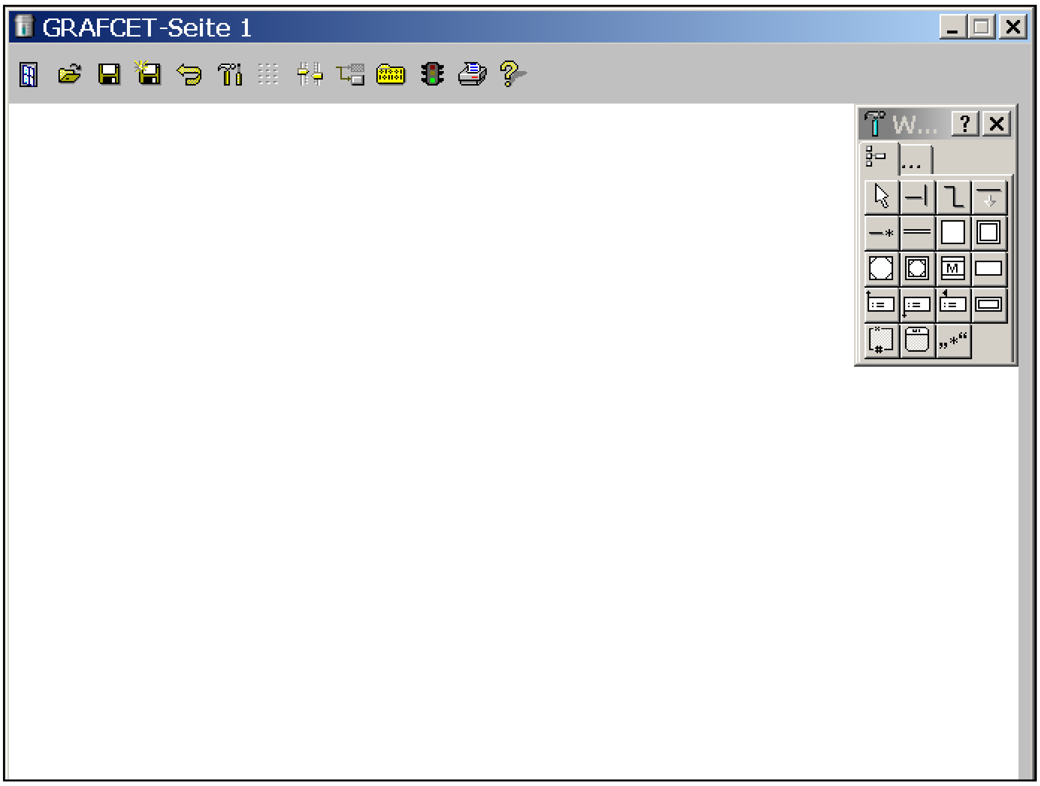


Fig. 1: Grafcet editor with blank page 1

Create the following plan by selecting the corresponding elements (initial step, steps, continuous effective actions, transitions) from the toolbox and place them in the editor.

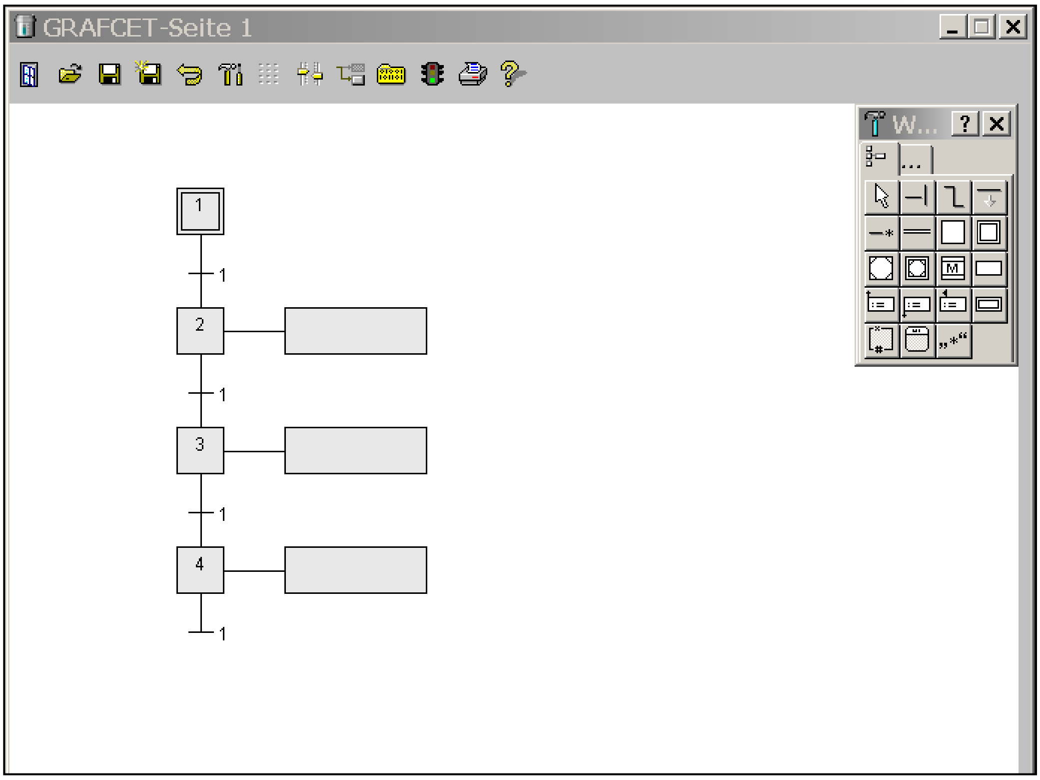


Fig. 2: Grafcet plan with light chain

To set the continuous actions, double-click the blocks. The following dialog appears (Illustration 3)

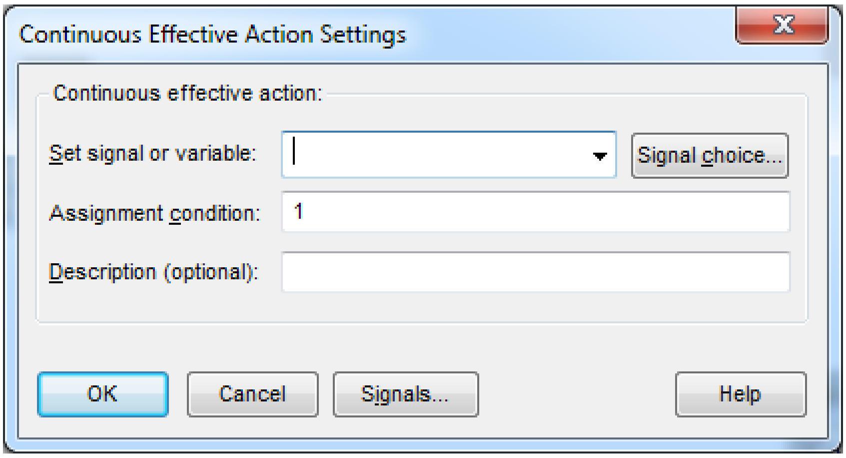


Fig. 3: Setting dialog for continuous action

By pressing the signal choice you get a dialog, in which you can select lamp P1

(Click the plus sign in front of the group lamps or control bin.).

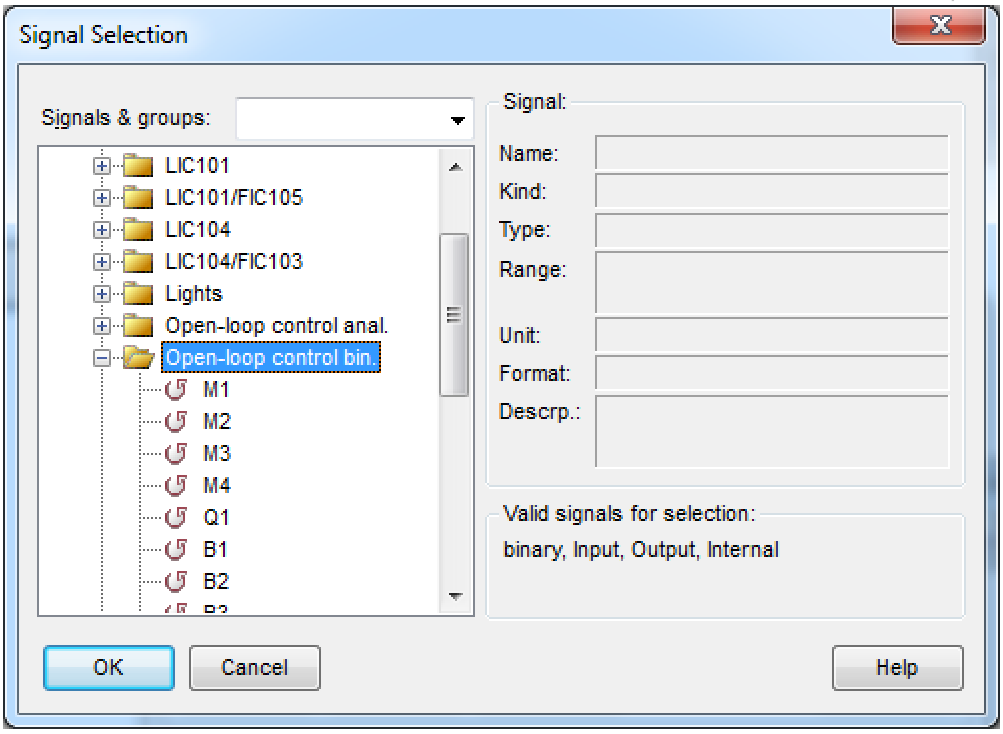


Fig. 4: Alarm changing

By double-clicking on P1 or selecting P1 and pressing OK, the signal P1 is entered into the continuous action. Continue with the other two continuous actions and select P2 and P3.

To set the transitions, double-click the transition. The following dialogue appears.

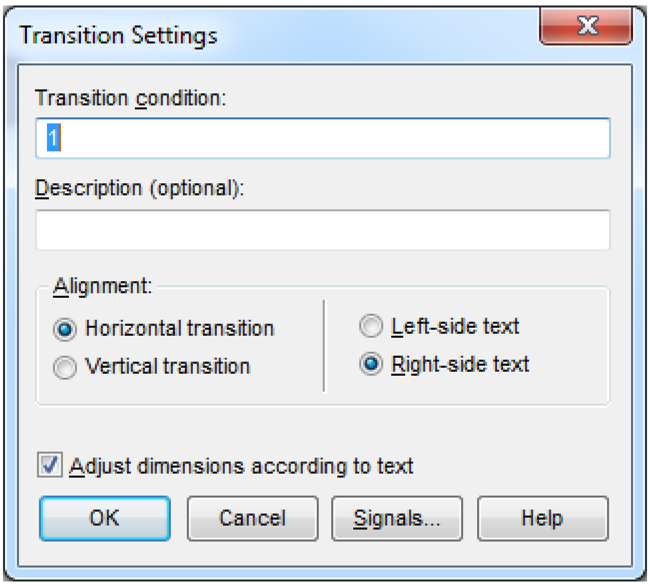


Fig. 5: Setting transitions

Since the lamps should light up only when the HS1 switch is pressed, enter HS1 for the first transition after the initial step 1 for the transition condition.

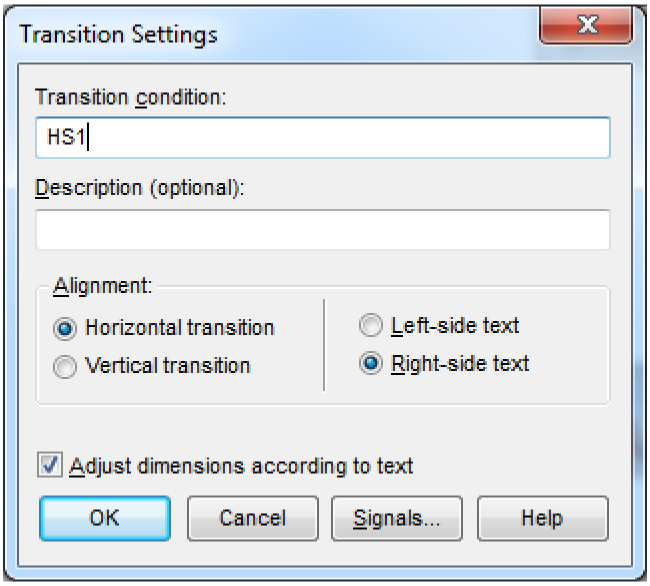


Fig. 6: transition condition HS1

The lamps should light for 5 seconds. Therefore the transition condition 5s / X2 must be entered after step 2 (fig. 8). 5s / X2 means that the transition condition is suffused (forwarded) if step 2 was active for exactly 5 seconds. Correspondingly, you can set the transitions according to steps 3 and 4.

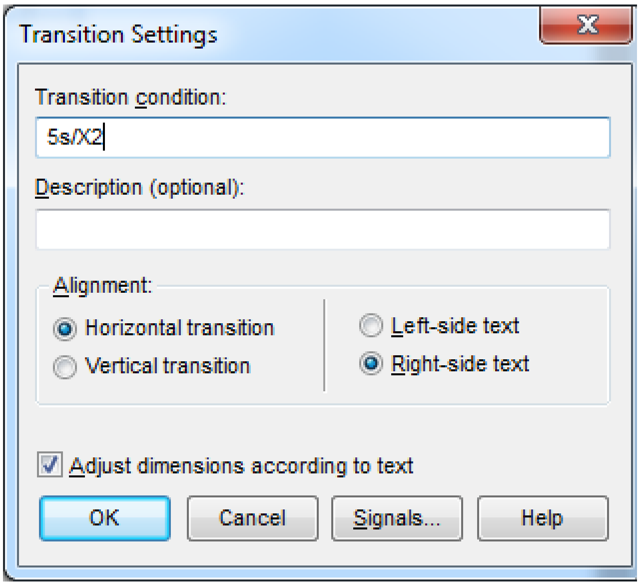


Fig. 7: Transition condition: 5 seconds delay after step 2

This will give you the following Grafcet plan for the lighting chain.

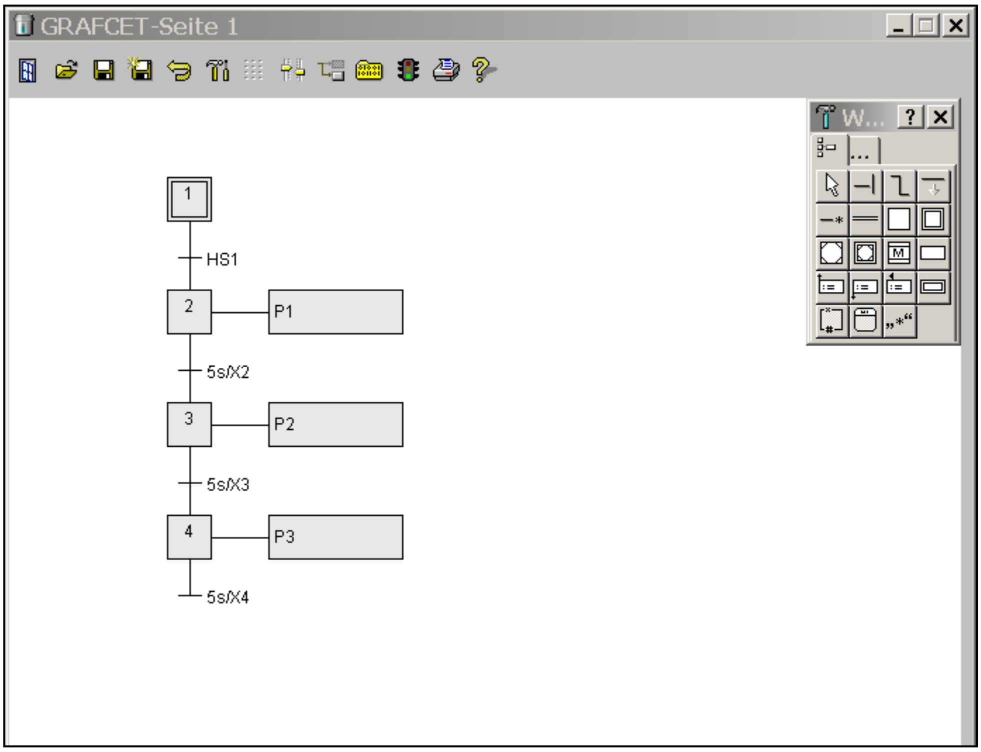
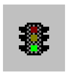


Fig. 8: Grafcet plan for lighting chain



By clicking the traffic light, the Grafcet page is checked and if no errors are detected, the page is executed (Grafcet view).

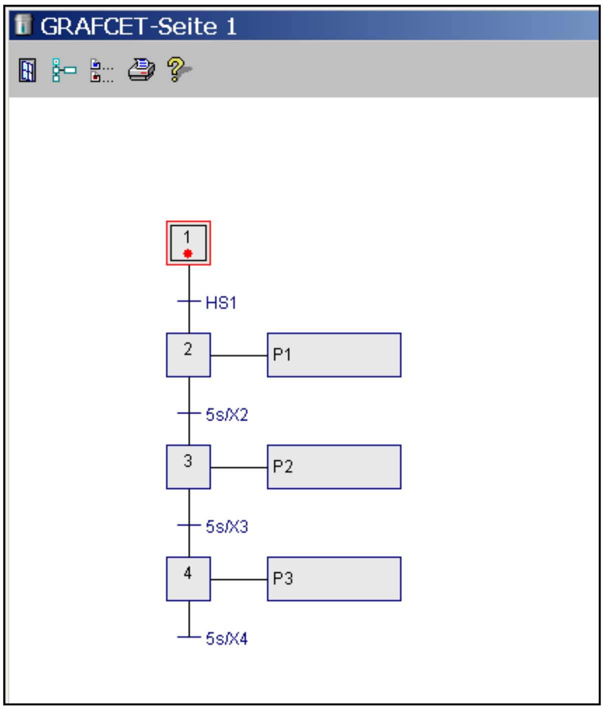


Fig. 9: Grafcet view for lighting chain

If you now press switch HS1 in the process screen, step 2 is set. The continuous action from step 2 sets the signal P1. That’s why lamp 1 shines.

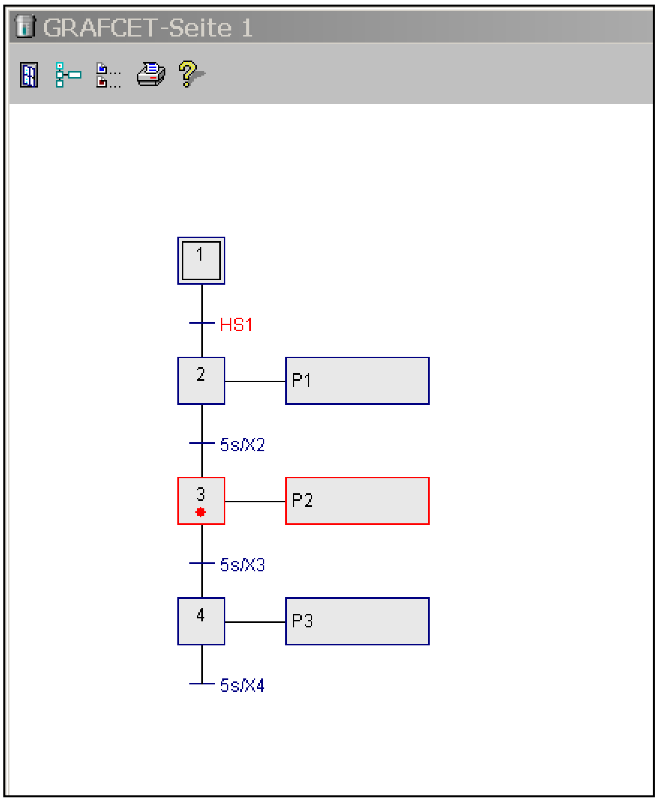
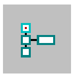


Fig. 10: Light chain (order of events)

The second transition 5s / X2 is satisfied when step 2 was active for 5 seconds. Step 3 is set directly and lamp 2 is switched on. Lamp 1 turns off because it is linked to step 2 via the continuous action.

The process continues. If step 4 has been set for 5 seconds, the final transition is satisfied. Thereby, step 4 is reset and the lamp 3 is turned off.



To restart the process, the initial step must be initialized via Grafcet (the button in the upper button bar).

In order for the light chain to go through endlessly, the task needs to be extended.

TASK 1.1.2: Let the light chain go through until the switch HS1 is switched off again. The light chain should continue to the end and then stop.

You must extend the Grafcet plan for this task.

Close the Grafcet view by pressing the button close active sub window.

You return to the Grafcet editor and you are able to change the Grafcet plan there.

Expand the plan as follows.

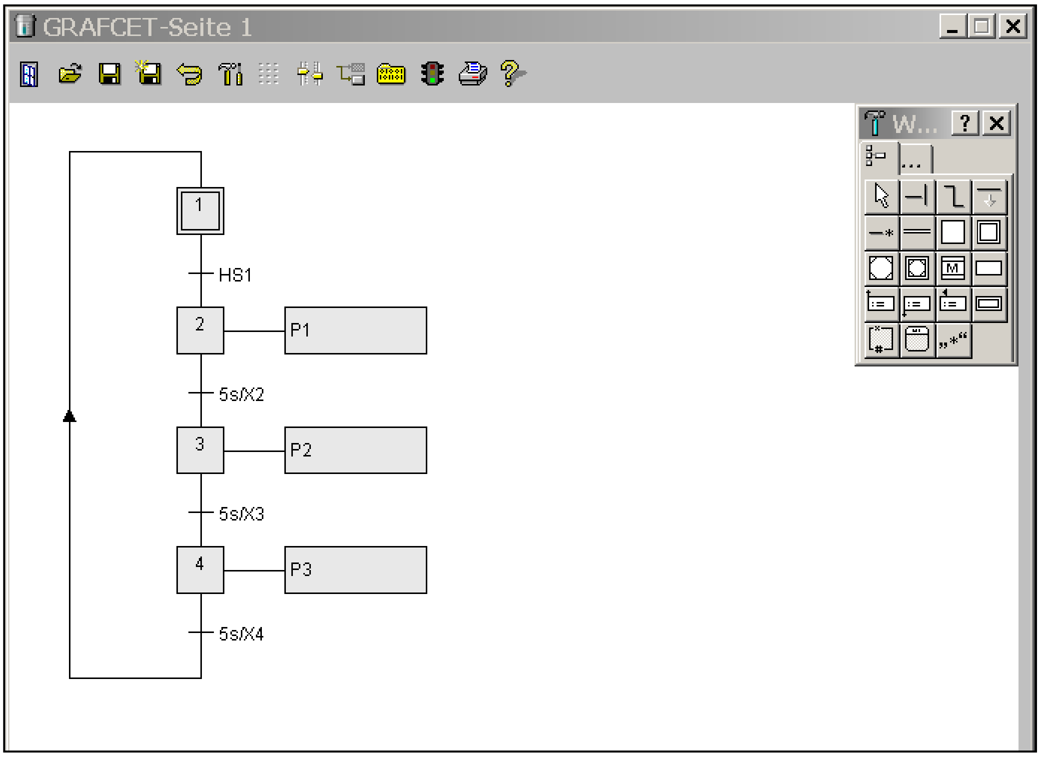


Fig. 11: Light chain

If you activate this Grafcet plan by the traffic light, the lamps P1, P2 and P3 will be switched on and off for 5 seconds until the switch HS1 is switched off.

TASK 1.1.3: Start the light chain with an initial transition without using an initial step. The light chain should be terminated by a final transition. The initial transition is to be fulfilled by setting the switch HS1.

The initial transition that starts the Grafcet plan should be edge-controlled (or the condition must be reset in the first step) so that the transition is not permanently fulfilled and the first step is set again and again.

The positive edge is entered with *^HS1* in the transition.

For solving the problem 3, you could create the following Grafcet plan (Fig. 13)

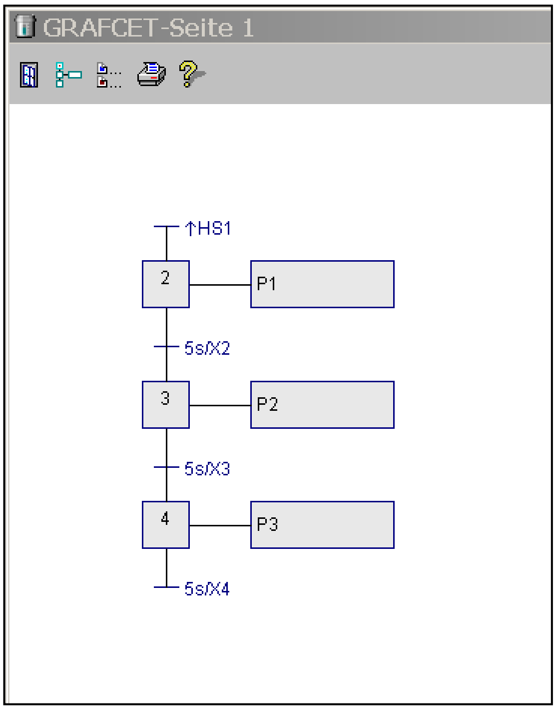


Fig. 12: Grafcet plan without initial step

After the Grafcet page has been activated by the "traffic light", the Grafcet control is executed immediately, and by pressing the switch HS1, the flow goes to the first step (step 2).

TASK 1.1.4: Allow the lamp P1 to flash exactly ten times for one second before the circuit is terminated. Use the free signal Parameter1. The HS4 button is used to start the circuit again and again when it has passed.

In the Grafcet chart shown below, the analogue signal parameter1 is set to 0 in the initial step. In step 2, parameter1 is incremented by 1 and lamp P1 is turned on. Via the transitions *parameter1> 10* or *parameter1 <= 10*, it is decided whether to go back to step 2 or whether the initial step is set again.

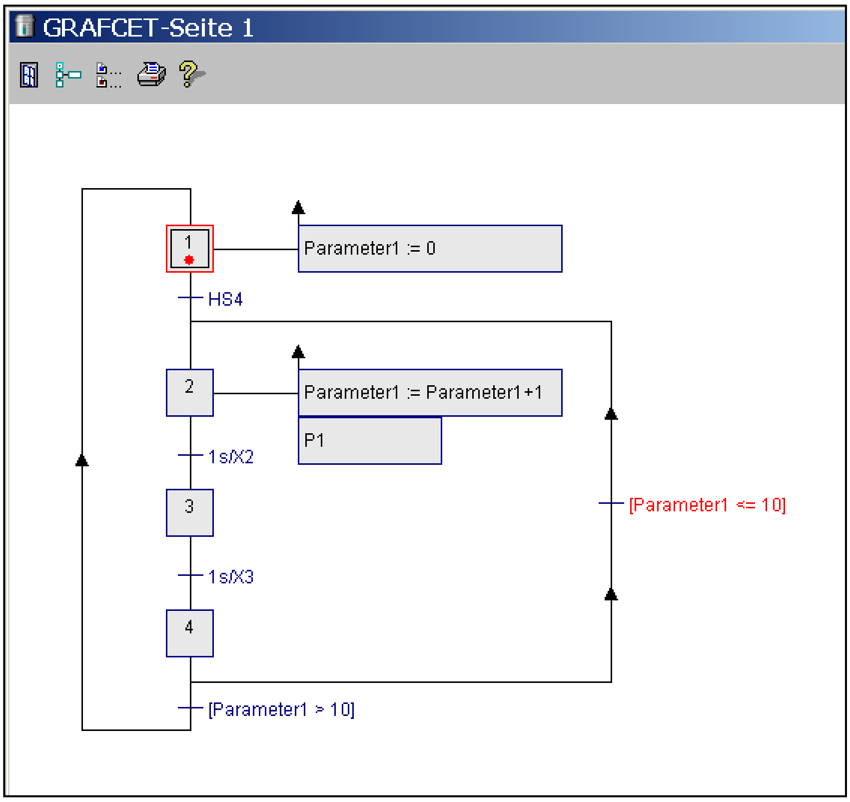


Fig. 13: Counting with Grafcet

1.2 TASK LIGHT CHAIN

TASK 1.2.1: Expand the light chain so, that each lamp lights for a second in the order red, yellow, green, yellow if HS1 is pressed.

SOLUTION

The solution with a Grafcet plan could, for example, look like the following:

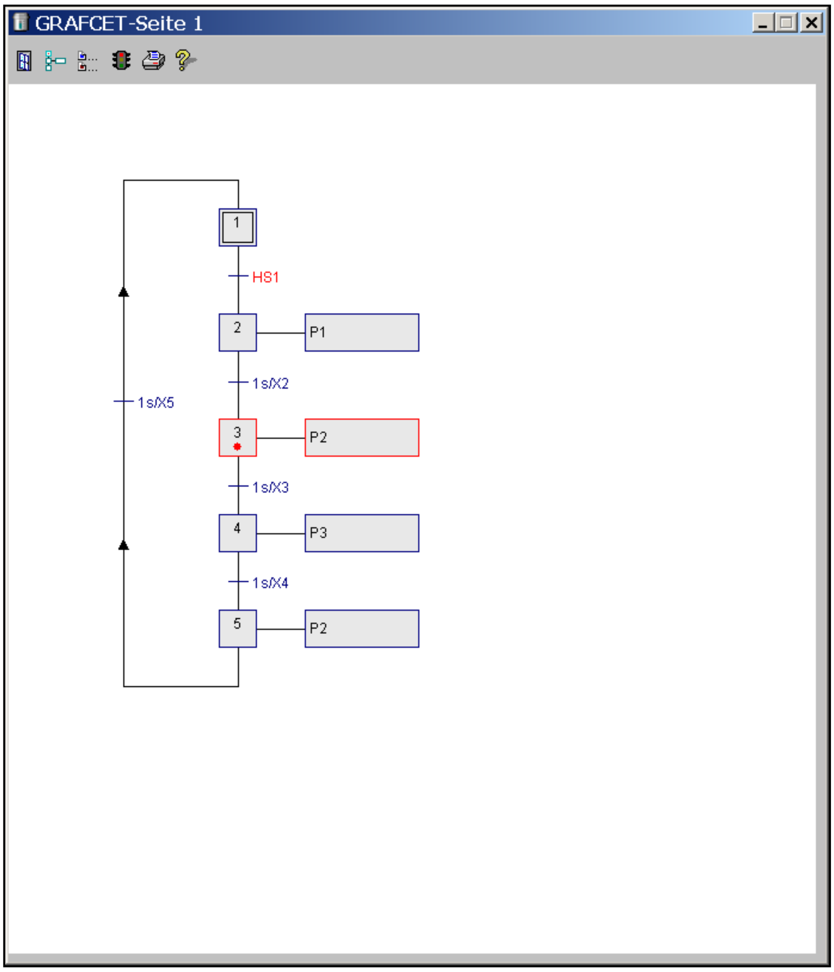


Fig. 14: Light chain

When HS1 is pressed, the sequence begins in the order red, yellow, green, yellow and starts again at the initial step until HS1 is no longer pressed

TASK 1.2.2: Extend the lighting chain so that by pushing switch HS2 all lamps turn off and the step sequence goes back to the initial step. (Tip: use Sub-Grafcet and forced control)

SOLUTION

Define your light chain as a Sub-Grafcet. Reset the Sub-Grafcet to the initial step by a forced command.

The solution with a Grafcet plan could, for example, look like the following:

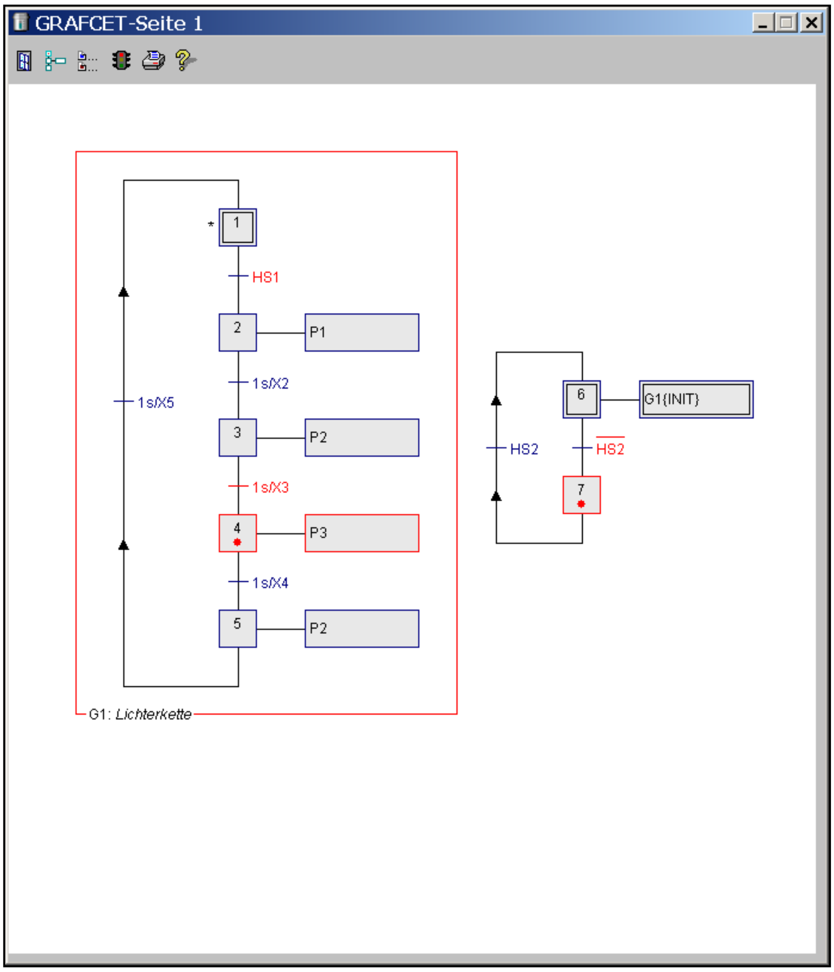


Fig. 15: Turning off the light chain with a forced control

If *HS2* is not pressed, the Grafcet map immediately moves from the initial step 6 to the step 7 and thus releases the Sub-Grafcet *G1*. If *HS2* is pressed, step 6 is set again. Thus, the forcible command forces the Sub-Grafcet *G1* to its initial step 1, and the sequence of the string of lights is stopped.

1.3 TASK – TRAFFIC LIGHT CONTROL

TASK 1.3.1: Create a traffic light control

Switch the traffic light circuit on or off with the HS1 switch. At the traffic light control, first set the red light for 10 seconds (set P1 to 1). Then the yellow light is switched on for 3 seconds (P2 to 1). The red and yellow lights must then be switched off at the same time and the green light should be switched on (P1, P2 to 0 and P3 to 1). The green light should remain on for 12 seconds. The green light then turns out while the yellow light is switched on for 4 seconds, before the cycle begins again with the red light.

SOLUTION

The solution with a Grafcet plan could, for example, look like the following:

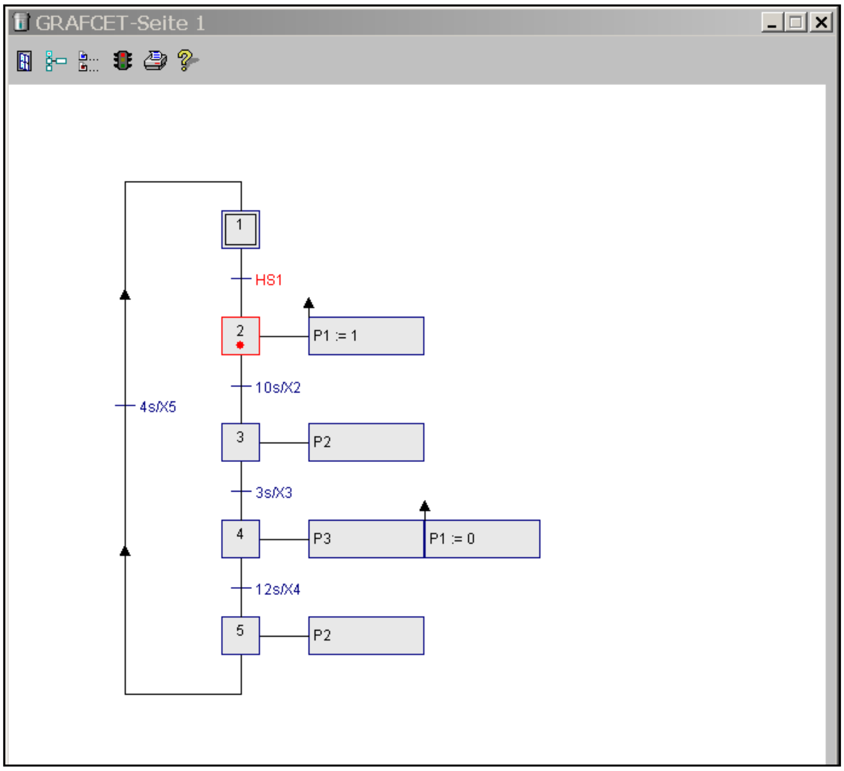


Fig. 16: Traffic light control

To enable the red lamp and the yellow lamp to light simultaneously, the red lamp has been set to 1 in this Grafcet chart (activated in step 2, P1 is set to 1). In step 4, the red lamp is switched off again by the saving action when activated (P1 is set to 0). The yellow lamp P2 is set to 1 by the continuous action in step 3 and is set to 0 when the step 3 is exited. Overall, the desired behaviour results.

TASK 1.3.2: The traffic light control of task 1.3.1 is to be expanded:

The traffic light cycle may only be started when the switch HS1 has been actuated. If the stop switch HS2 is pressed, the traffic light turns off immediately. Only when the switch HS2 is no longer pressed and the switch HS1 has been actuated, the traffic light circuit should restart.

SOLUTION

The solution with a Grafcet plan could, for example, look like the following:

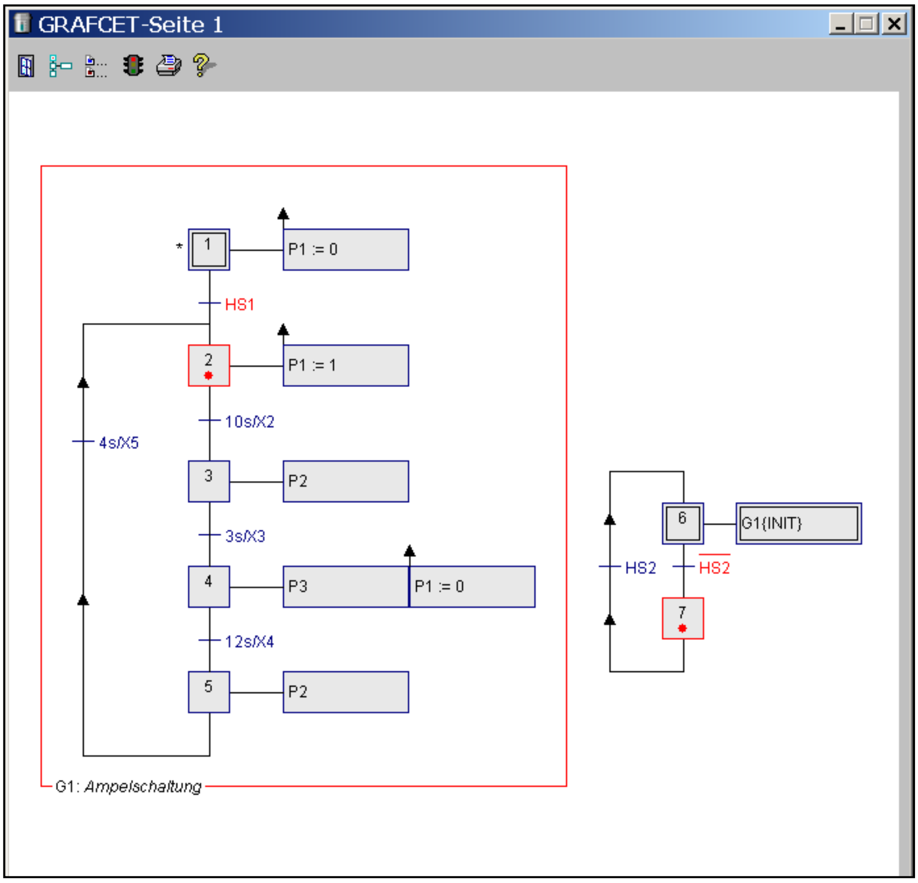


Fig. 17: Traffic light control with stop switch

By the forced control in step 6, the Sub-Grafcet *G1* traffic light control is initialized, meaning it is forced in the initial step 1. If *HS2* is not pressed (has the value 0), the control goes to step 7 and releases the Sub-Grafcet *G1*. The traffic light in the Sub-Grafcet starts again when the switch *HS1* has been pressed. Because switching on the red lamp *P1* with a *stored effective action on activation*, the lamp P1 must be switched off in the initialization step of the Sub-Grafcet G1

TASK 1.3.3

Flashing of the green light, when green phase is over:

In Austria the green lamp starts to flash when the green phase is over. Extend the circuit of task 1.3.2 so that the green lamp is on for 10s, then flashes for 5s before the yellow lamp is on (use *Inclusion Step*).

SOLUTION

The solution with a Grafcet plan with *Inclusion Step* could, for example, look like the following:

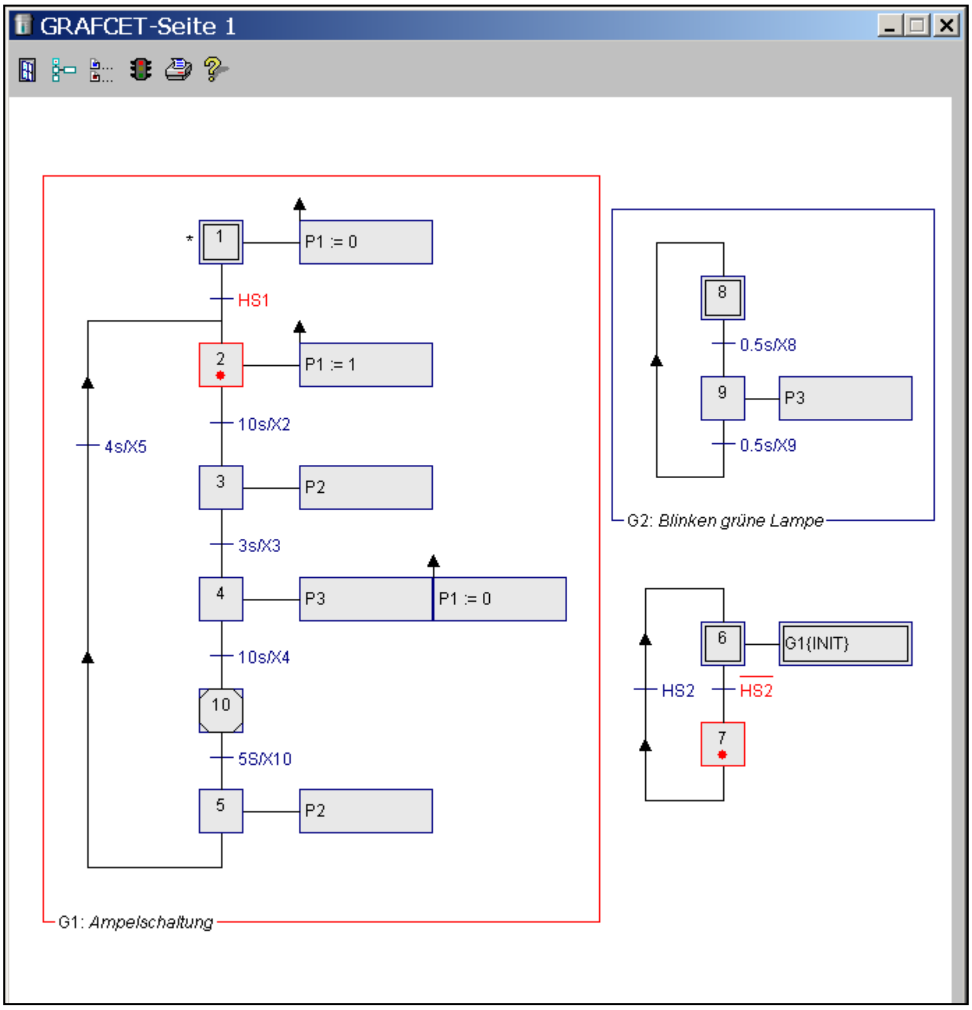


Fig. 18: Traffic light control with flashing green light

In this solution, the flashing green light is realized with the Sub-Grafcet *G2*, which is called up via *Inclusion Step*. The *Inclusion Step 10* starts the Sub-Grafcet *G2*. If the *concluding step* is exited, the *Sub-Grafcet* is terminated, that means, all steps of the *Sub-Grafcet* will reset.

1.4 TASKS WITH SWITCHES AND PUSH BUTTONS

TASK 1.4.1: Try to turn on the *P1* lamp by pressing the button *HS4* and turn the lamp off by pressing the button again.

SOLUTION

The solution with a Grafcet plan could, for example, look like the following:

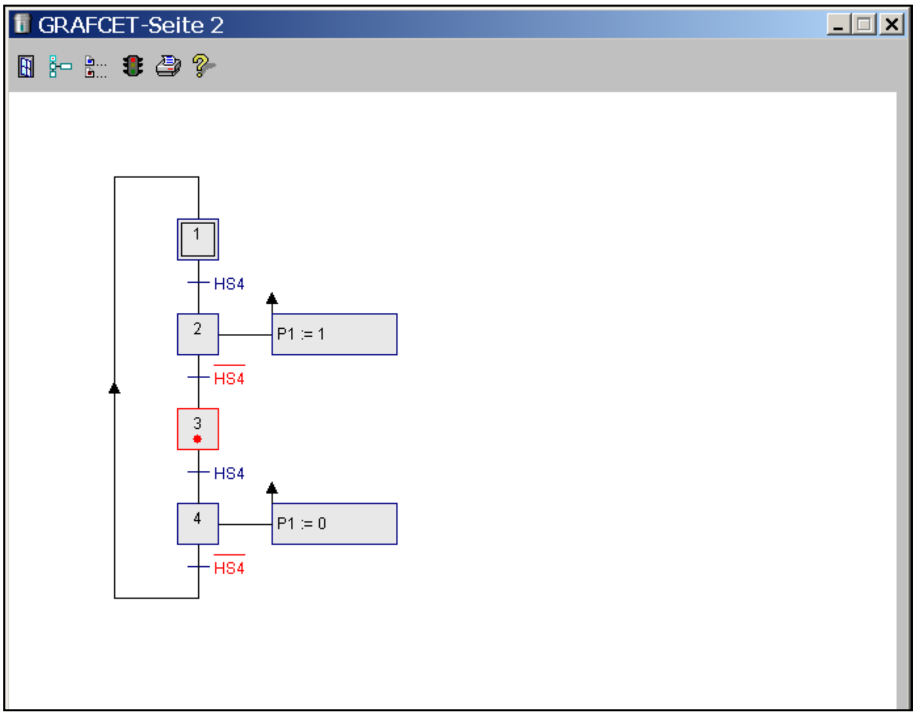


Fig. 19: On and off switching lamp *P1* with push button *HS4*

After initialisation, the Grafcet plan is in step 1 and waits for transition *HS4*. If *HS4* is pressed, step 2 is activated and the lamp *P1* is activated by means of the *stored effective action*. If the button is released, transition *!HS4* (not HS4) is fulfilled, the Grafcet goes to step 3. The lamp remains on since it was "stored" set in step 2.

Pressing *HS4* again causes the control to go to step 4, in which by a *stored effective action P1* is set 0 and thus lamp *P1* is turned off.

TASK 1.4.2:

Create a Grafcet diagram which enables you to switch pumps *M1, M2, M3* and *M4* and heating rod *Q1* on and off using the switches / push buttons *HS1, HS2, HS3, HS4* and *HS5*.

SOLUTION

The Grafcet plan might look like this. Switching on and off of M4 and Q1 using pushbuttons HS4 and HS5 could also be solved, as shown in task 1.4.1.

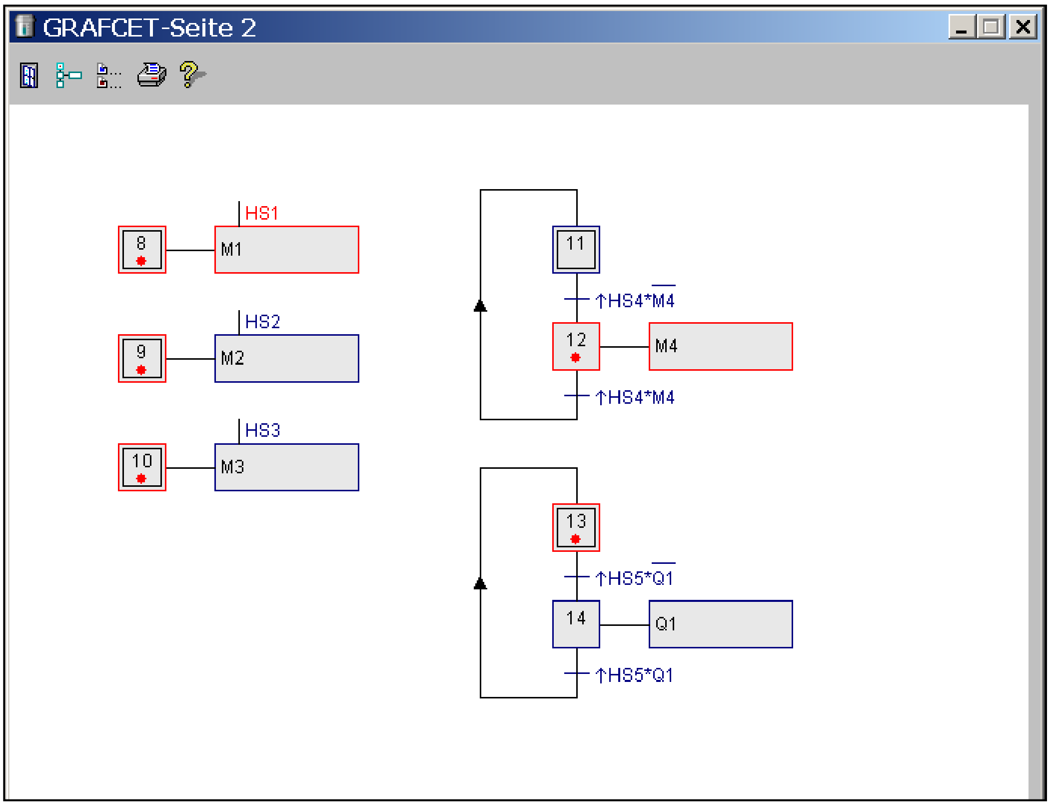


Fig. 20: Grafcet plan for manual operation of the aggregates

TASK 1.4.3: Extend the manual control so that no overflow can occur, meaning pumps M1 and M2 are switched off when level sensor B1 is exceeded. For pump M3, perform a dry-running protection. It may only run if level is not below sensor B3. Pump M4 and the heating rod Q1 may only be connected if the filling level is above B2.

SOLUTION

A solution may look like the following.

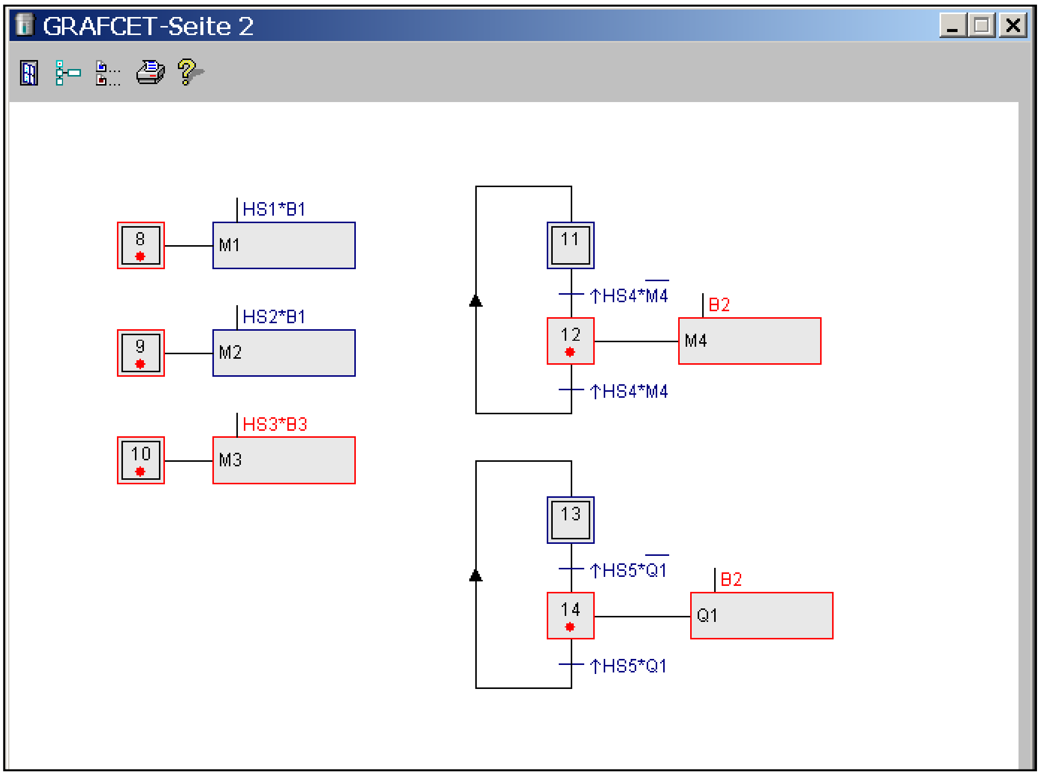


Fig. 21: Grafcet plan for manual operation with overflow and dry-running protection

TASK 1.4.4: On a second page, create a Grafcet chart that displays the fill level "Full" or "Empty" through lamps P1 and P2. P1 indicates empty state when fill level is below B3. If fill level is above B1, lamp P2 should display "Full". Evaluate all three sensor conditions for both displays due to safety reasons.

SOLUTION

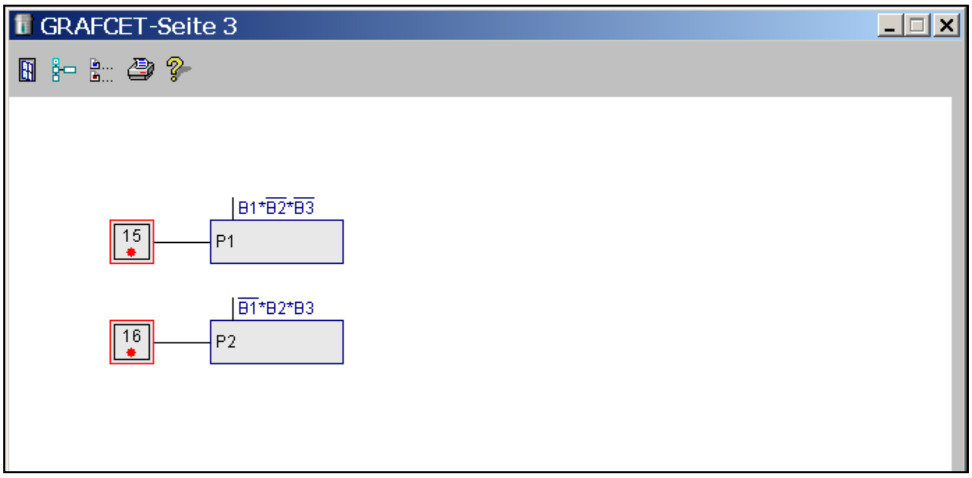


Fig. 22: Display level "Full" and "Empty" with the help of lamps P1 and P2

TASK 1.4.5: Change the circuit, so that the lamps start flashing when "Blank" or "Full" is indicated.

SOLUTION

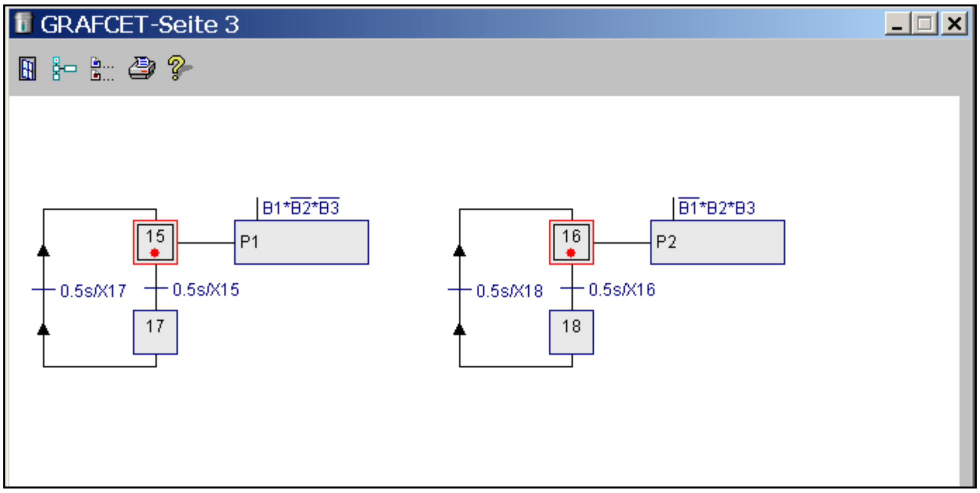


Fig. 23: The fill level "Full" or "Empty" is indicated by flashing lamps

1.5 OPERATION STORAGE TANK

TASK 1.5.1: Create a Grafcet diagram, which allows you to switch pumps M1 and M2 on and off using switches HS1 and HS2. Following automatic sequence is to be implemented for pump M3:

- If upper level switch B1 is exceeded, the pump is started with a control signal of 5% (FI103.y = 5)
- Every 5 seconds, the control signal should be increased by 5% until a maximum of 100% is reached
- Pump M3 is switched off when the lower level sensor B1 is underrun
- To test Grafcet diagram, turn on pumps M1 and M2 using switches HS1 and HS2.

SOLUTION

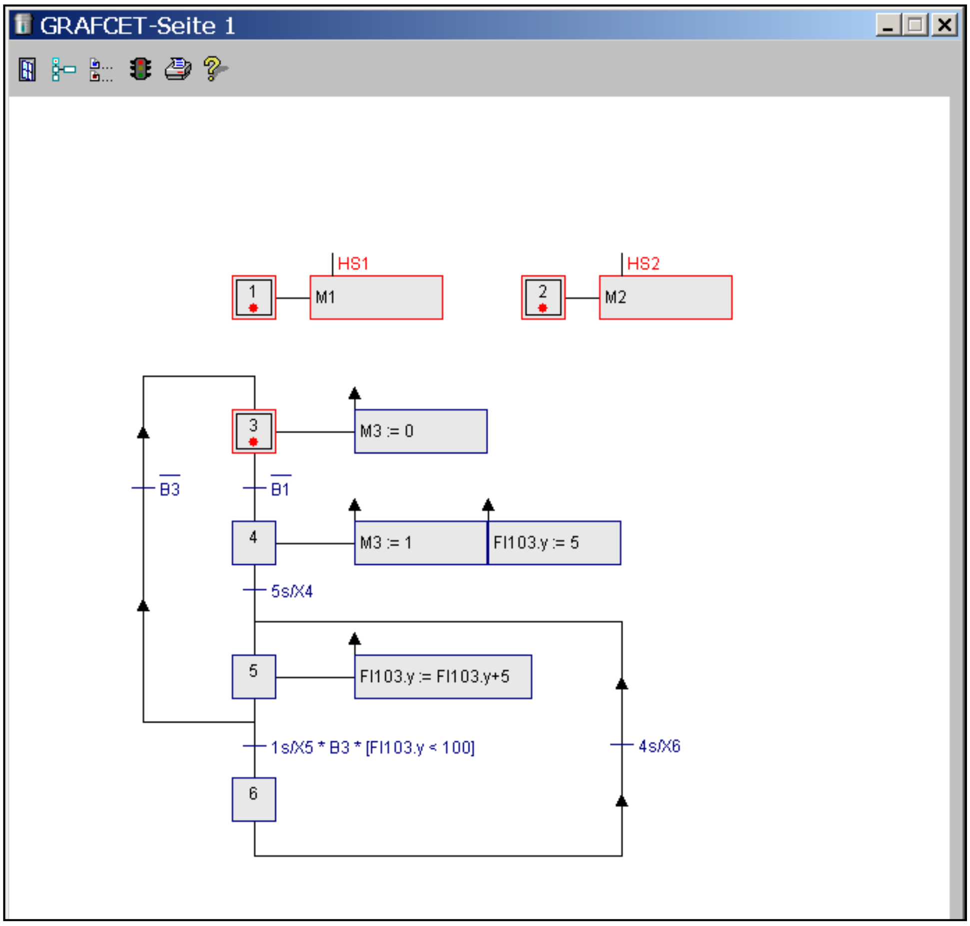


Fig. 24: Pump M3 control

To prevent the control from stepping transiently to step 6, a time delay of 1s after step 5 was provided and thus a delay of 4s after step 6.

TASK 1.5.2:

To ensure that there is always enough water in the container, pumps M1 and M2 should continuously run when they have been enabled by switches HS1 or HS2 and filling level is below medium level switch B2.

If the level is between medium level switch B2 and upper level switch B1, only pump M1 should run. Pump M1 must be enabled by HS1.

Above level switch B1, none of the feed pumps M1 and M2 is allowed to run.

To test the circuit, pump M3 should have the behaviour from task 1.5.1.

SOLUTION

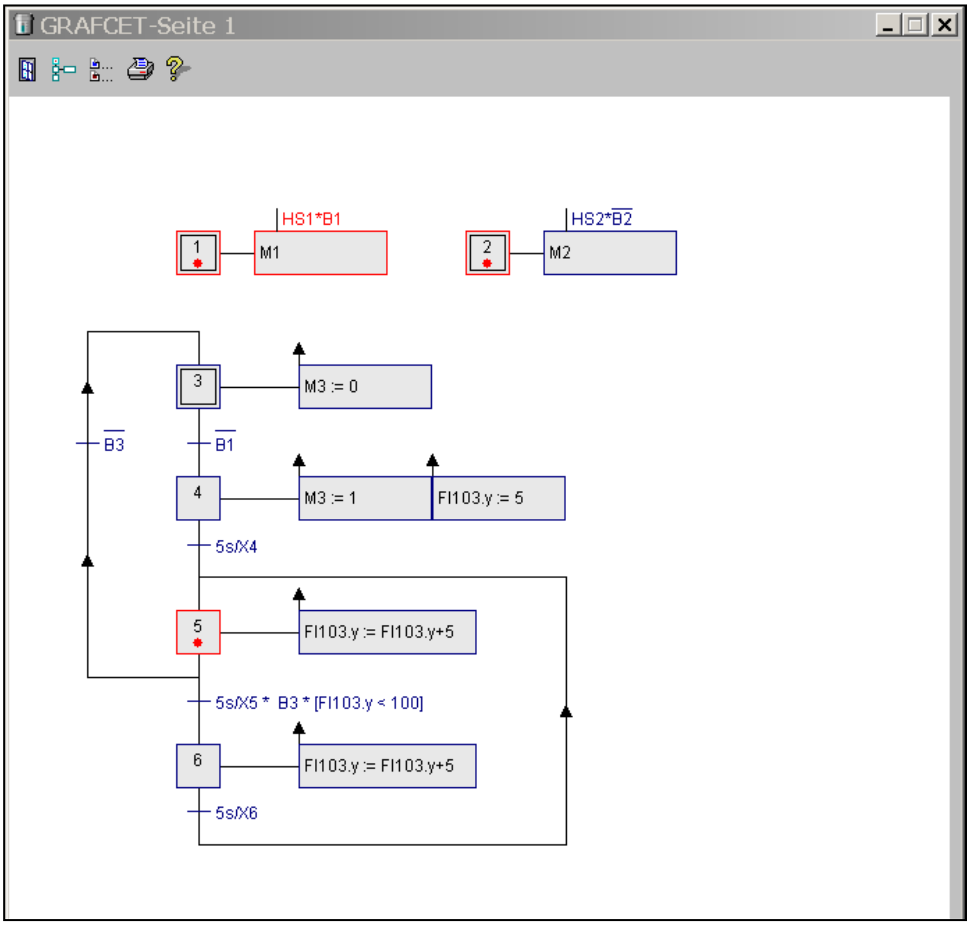


Fig. 25: Control of pumps 1 and 2

Instead of the diagram from Fig. 25, also the Grafcet diagram from Fig. 25 could also be taken for pump M3.

Since the filling level fluctuates, the level switches flicker at the corresponding filling levels. To prevent the pumps from being switched on and off several times, the task is extended.

TASK 1.5.3: To conserve the pumps, they should not be switched on and off quickly.

When turned on, they must remain on for 5s before they can be turned off again. When turned off, they must remain off for 5s before they can be turned back on.

Expand the Grafcet plan accordingly.

SOLUTION

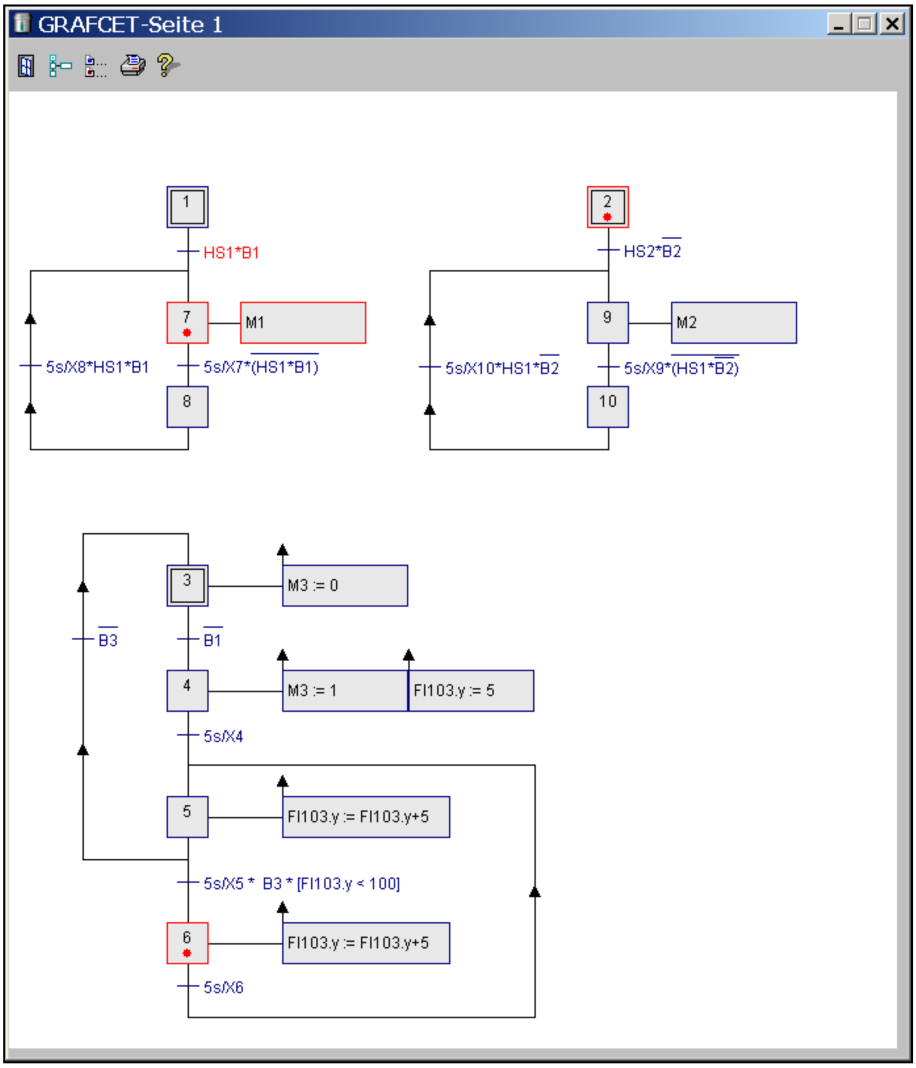


Fig. 26: Control of pumps 1 and 2 with time delay

TASK 1.5.4: In addition to the above circuit, pump 3 may only run when it has been enabled via switch HS3. If HS3 is not pressed, pump 3 is switched off and the Grafcet diagram goes into the basic position.

SOLUTION

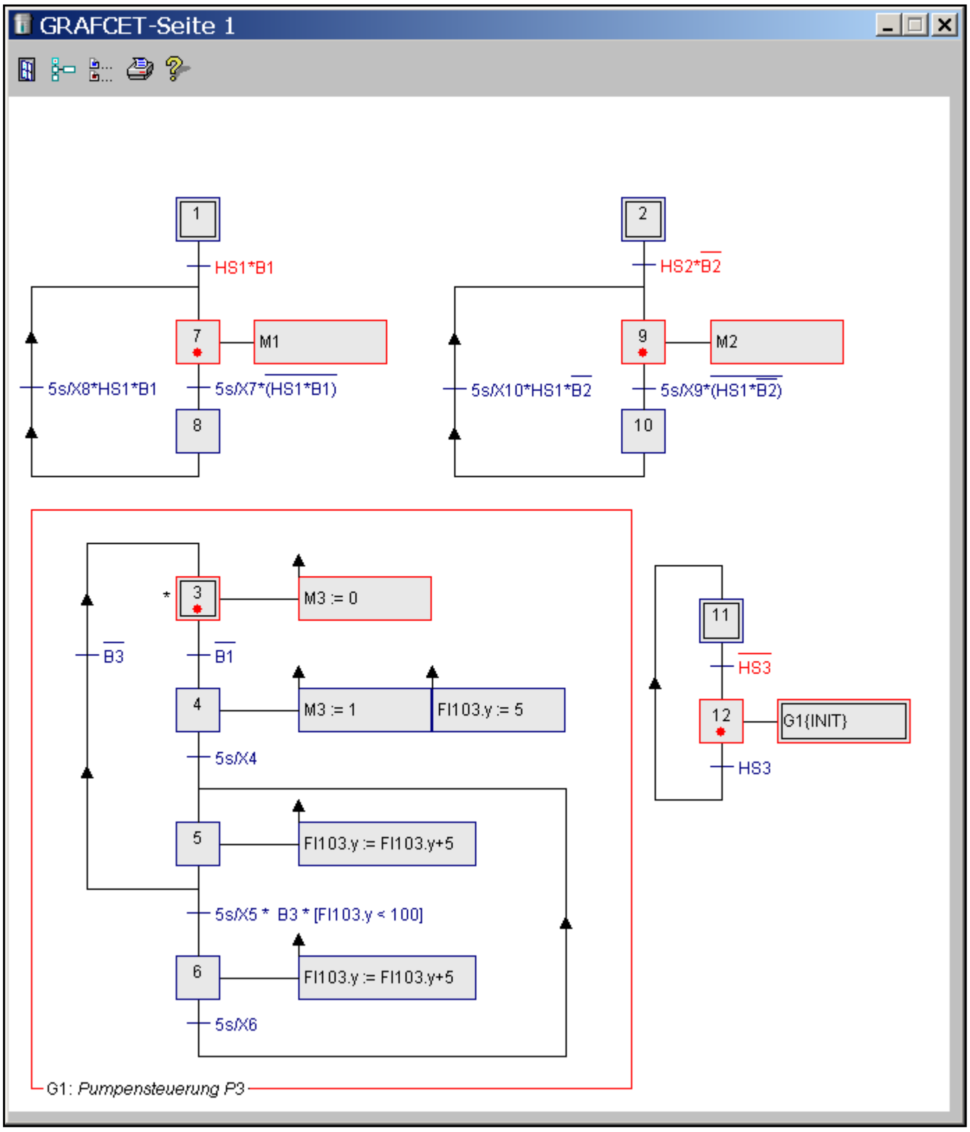


Fig. 27: Activation of pump 3

1.6 PRODUCTION MIXING REACTOR

Consider container B1 as a mixing reactor. Two components can be added via pumps 1 and 2. Pump 4 is used to mix the two components. The mixture can be heated with heating rod Q1. The end product is released with pump 3.

TASK 1.6.1: Create following production process for the mixing reactor:

- The production process may only be started if the filling level is below B3,
- Simultaneous start of pumps M1 and M2,
- If level switch B2 is reached, pump M1 is switched off and circulation pump M4 is switched on. Pump M2 should continue for 20s.
- After pump M2 has been stopped, heating rod Q1 is switched on for 40s.
- After heating rod Q1 is turned off, wait 30s before M3 starts emptying the tank.

- Pump M3 is switched on for emptying the tank. Control signal FI103.y of the pump is set to 100%.
- If level is below B3, circulation pump M4 is switched off and pump M3 is set to basic load (FI103.y = 0).
- The drainage pump M3 should continue to run for 3s before it is switched off.

Use parallel branching in Grafcet for switching on and off the feed pumps or circulation pump.

SOLUTION

A solution example might look like this

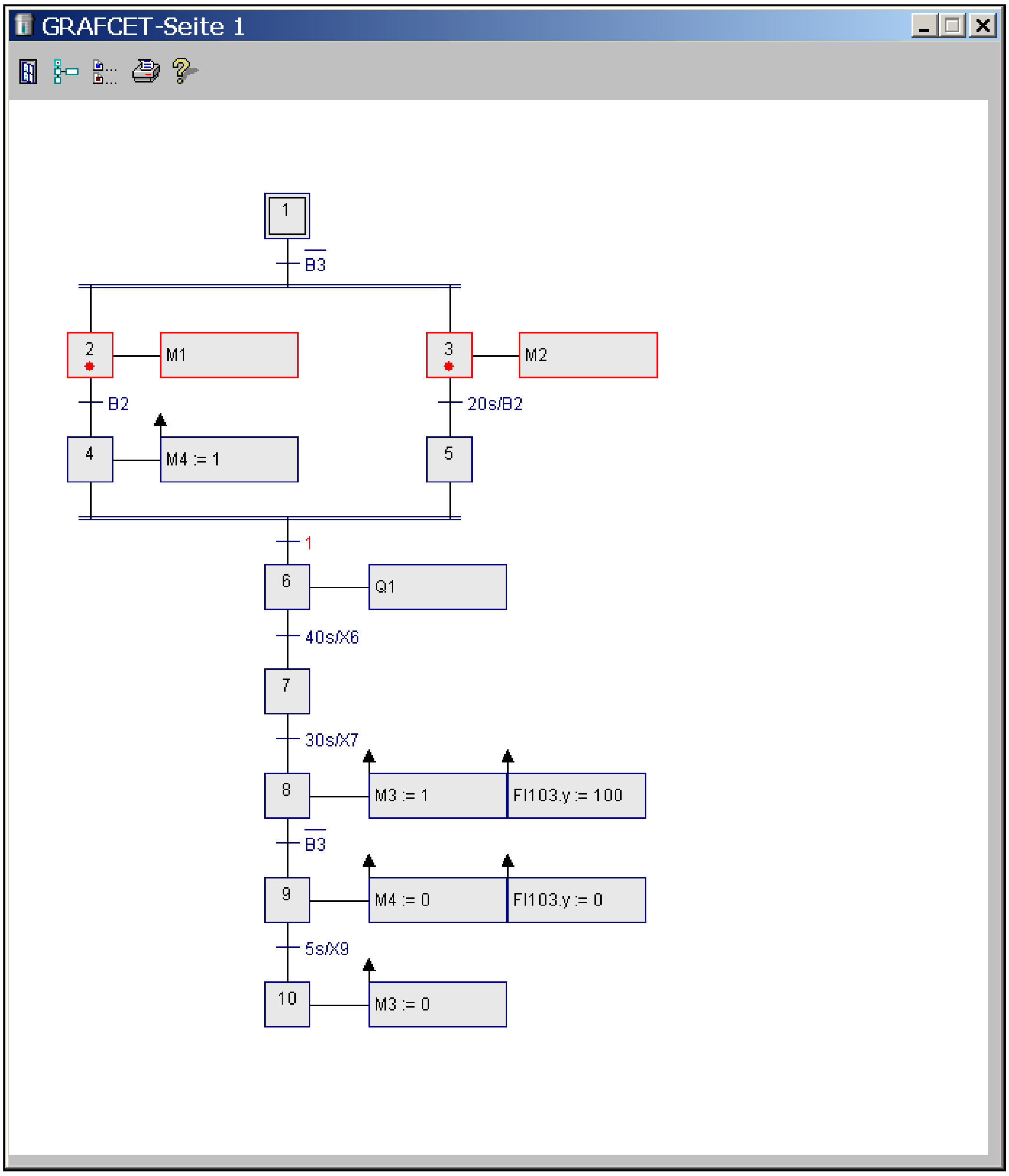


Fig. 28: Simple production process

TASK 1.6.2: Expand the flow as follows:

- Define the production process as a macro.
- The production process may only be started when HS1 switches from 0 to 1 (rising edge).
- If the tank is not empty, it should be emptied before the production process is started as a macro.
- In order to ensure pumps M3 and M4 are be switched off at start-up, they should be set to 0 in the initial step.

SOLUTION

An exemplary solution is the Grafcet plan shown below

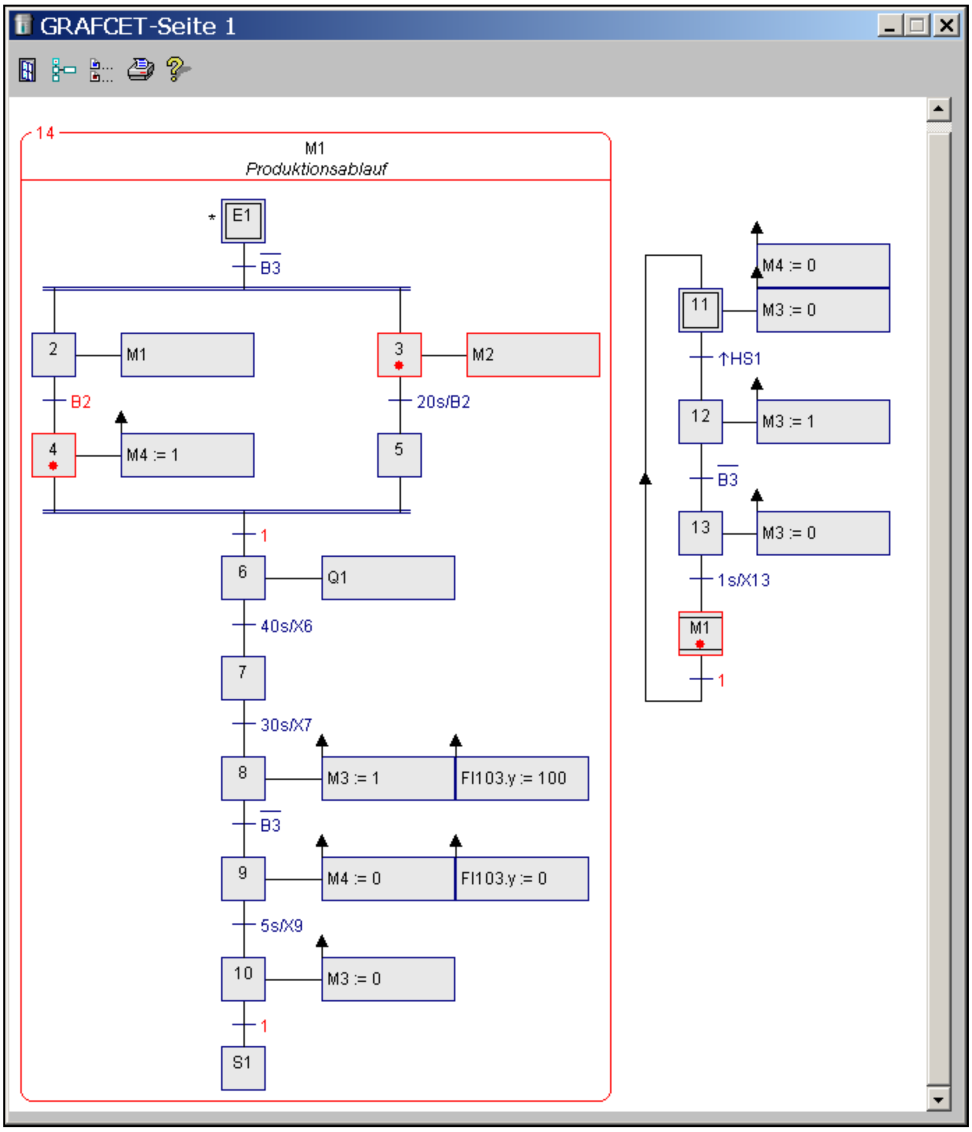


Fig. 29: Production sequence with macro and start via HS1

TASK 1.6.3: Extend the sequence by an emergency stop switch (HS3):

- HS3 must be 1 to start process.
- If HS3 is triggered (HS3 is 0) all pumps and the heating rod are switched off. The process should start again from the beginning. To start, HS1 must be pressed again (rising edge from 0 to 1)
- Note: Use Sub-Grafcet and the Forced Control.

SOLUTION

One solution would be the following Grafcet plan.

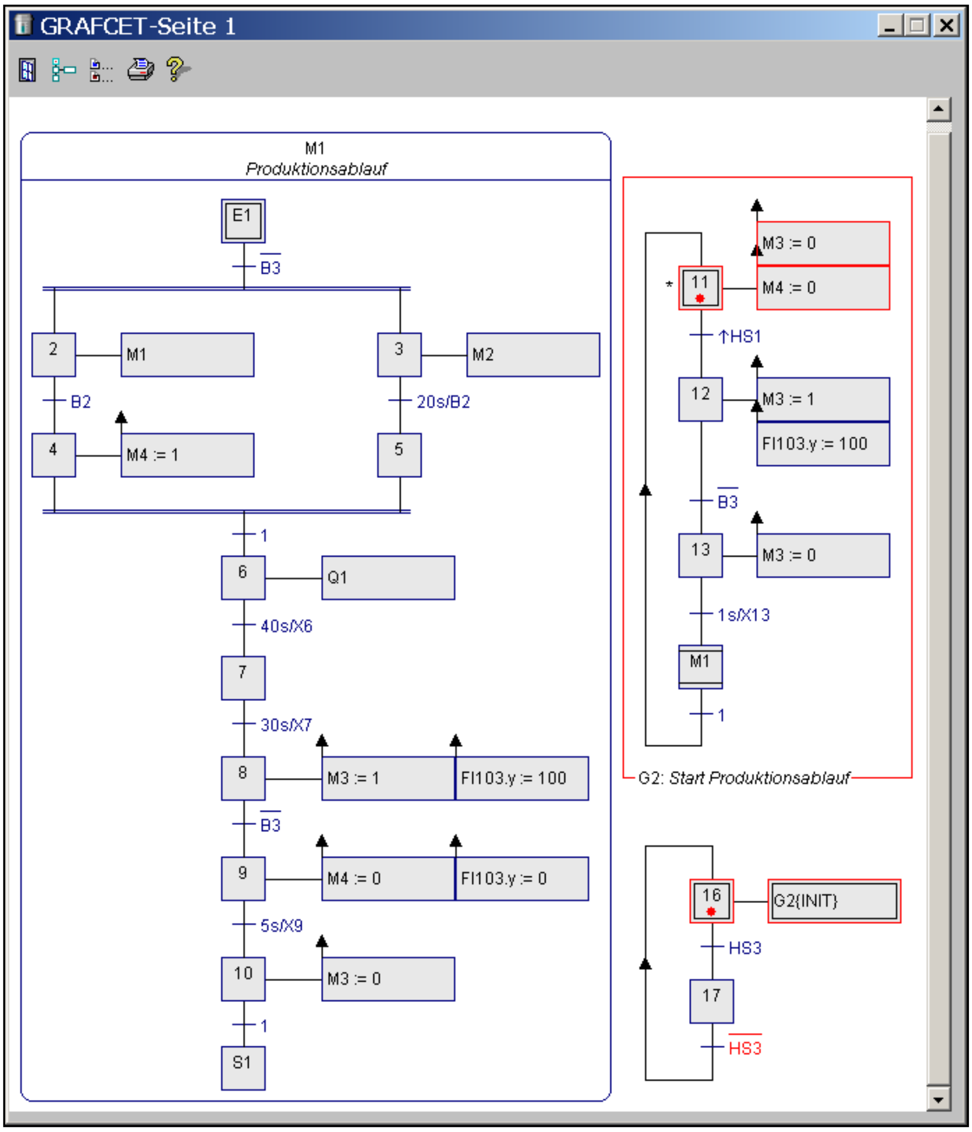


Fig. 30: Emergency stop for production process

Instead of placing macro, Sub-Grafcet, and parent control on one page, the Grafcet can also be distributed to multiple pages.

2 KEYBOARD LAYOUT FOR GRAFCET - TERMS

Following keys are used for the Grafcet terms:

- + Or operator
- * And operator
- ! Not operator
- ^ Raising edge
- \^ Falling edge
- [a comp b] Statement, e.g. [C> = 5]
- 0 False
- 1 True

Statements with analogue signals must be set explicitly in square brackets.

Example: [Fill level> 70] * !ValveA,

The term is 1 (true) if the analogue signal fill level has a value greater than 70 and the binary signal ValveA has the value 0

3 TASKS – CONTROL WITH LOGIC DIAGRAMS

3.1 COMMISSIONING OF THE PLANT WITH MANUAL CONTROL

The system is initially to be tested in manual operation in order to test the performance of the pumps. The hand valves of the feed pumps should be set differently for this purpose. Open hand valve of pump M1 almost fully and hand valve of pump M2 half. In the simulation, you can enter e.g. 75% and 60% in *View simulated LC2030*. You can also perform the tasks with the default setting for both pumps of 75%. The hand valve of drainage pump M3 should be fully open.

For switching the pumps on and off, a circuit according to task 3.1.1 is to be created.

TASK 3.1.1: Pump M1 should be switched on and off with switch HS1, pump M2 with HS2 and pump M3 with HS3.

SOLUTION

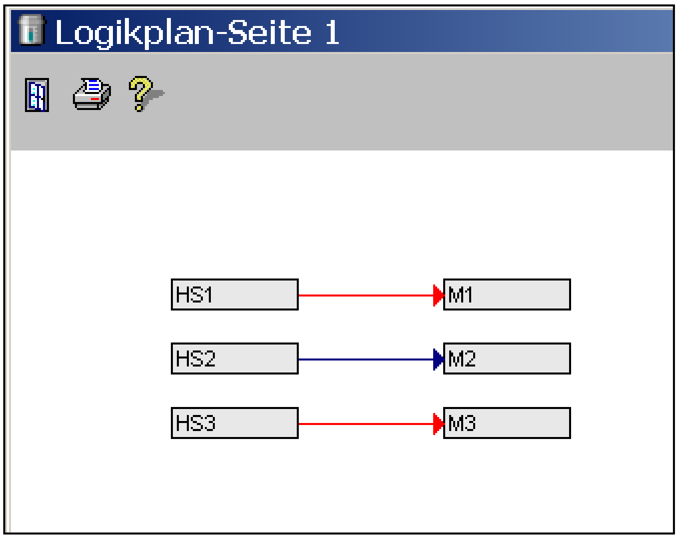


Fig. 31: Switching pumps M1, M2, M3 on and off by switches HS1, HS2, HS

TASK 3.1.2: Test the performance of the pumps in manual mode. To do this, fill the tank only with pump M1 or only with pump M2. Measure the required filling time and enter it into the table. Determine the pump flow rates from the data.

Pump	Delivery time for a container volume of 7,887 L	Pump flow rate
M1		
M2		

SOLUTION

With a special valve position on the real system, the following times were obtained.

Pump	Delivery time for a container volume of 7,887 L	Pump flow rate
M1	345s	22,86 cm^3/s
M2	250s	31,5 cm^3/s

TASK 3.1.3: Switch on pump M3. Try to always keep a sufficient supply in the tank with the pumps M1 and M2. Check the change of level in the trend diagram. Observe the switching contacts and signals of the sensors LS1 to LS3. (Vary the control signal for pump3 FI103.y between 0% and 100% by using the slider beside the display).

3.2 DISPLAY OF EMPTY OR FULL WITH LIGHT DETECTORS / GATE CIRCUIT

Indicator light P1 and light P2 should indicate the "full" or "empty" condition of the tank. Indicator light P1 indicates empty state when level is below the lower sensor. If level is above upper sensor, light P2 indicates "full". Evaluate all three sensor conditions for both displays due to safety reasons.

TASK 3.2.1: Develop and test a lighting circuit as described above. Write down the corresponding function equations. Only gate circuits (AND, OR, NOT) with any number of inputs can be used for the control design.

SOLUTION

The functional equations are:

$$P1 = \overline{B1} \wedge B2 \wedge B3$$
$$P2 = B1 \wedge \overline{B2} \wedge \overline{B3}$$

Gate circuit:

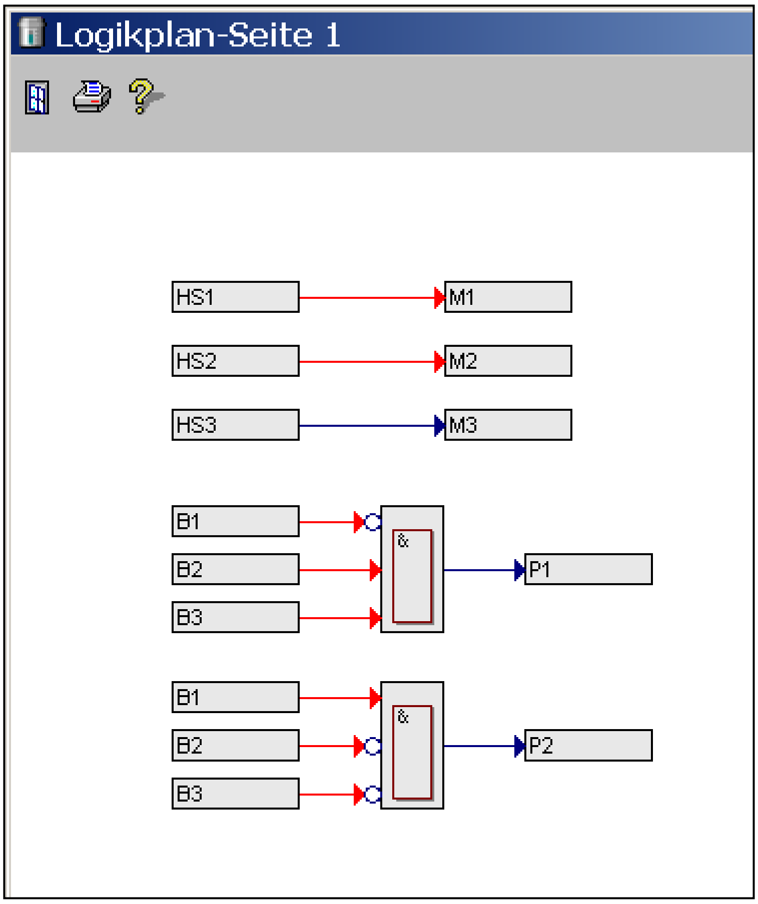


Fig. 32: Display tank "full" or "empty" by the indicators P1 and P2

TASK 3.2.2: Develop a circuit for the luminaires according to the following

SPECIFICATION:

LEVEL	Display by:
above B1	*P1* and *P2* lights
between B1 and B2	*P2* lights
between B2 and B3	*P1* lights
below B3	*P3* lights

SOLUTION (Gate circuit)

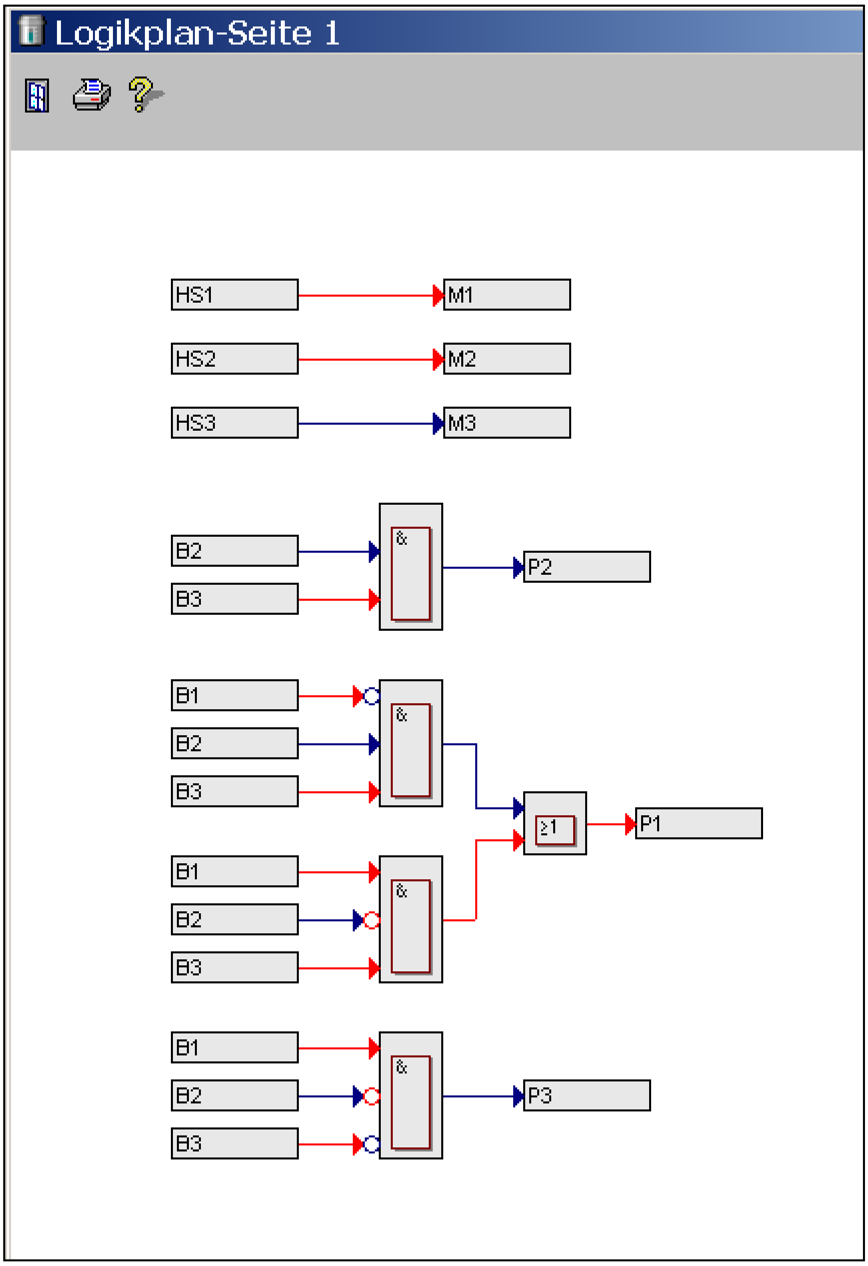


Fig. 33: Display of level via the indicator lights using the level switches

3.3 DISPLAY OF A SENSOR ERROR / GATE WITH SIMPLIFICATION

In the event of a line break at the sensor connections, faulty displays and thus malfunctions of the pumps can occur. Unrealistic combinations of sensor signals indicate such disturbances and could be detected and displayed by monitoring circuits.

TASK 3.3.1: Enter in the following table all combinations of sensor signals. Under "Level", enter the state of the respective combination. Mark all unrealistic combinations as “Sensor Errors”.

B3	B2	B1	Level	Sensor Error	P3

SOLUTION

B3	B2	B1	Fill level	Sensor error	P3
0	0	0		ERROR!	1
0	0	1	EMPTY		0
0	1	0		ERROR!	1
0	1	1		ERROR!	1
1	0	0		ERROR!	1
1	0	1	ALMOST EMPTY		0
1	1	0	FULL		0
1	1	1	ALMOST FULL		0

TASK 3.3.2: Develop and test a circuit which indicates all "sensor errors" by light P3. Check the circuit by simulating sensor errors.

Note: For the real system, simply pull the cables of the level switches out of the sockets to create a sensor error. In the simulation, press the button *sensor error* and simulate the error.

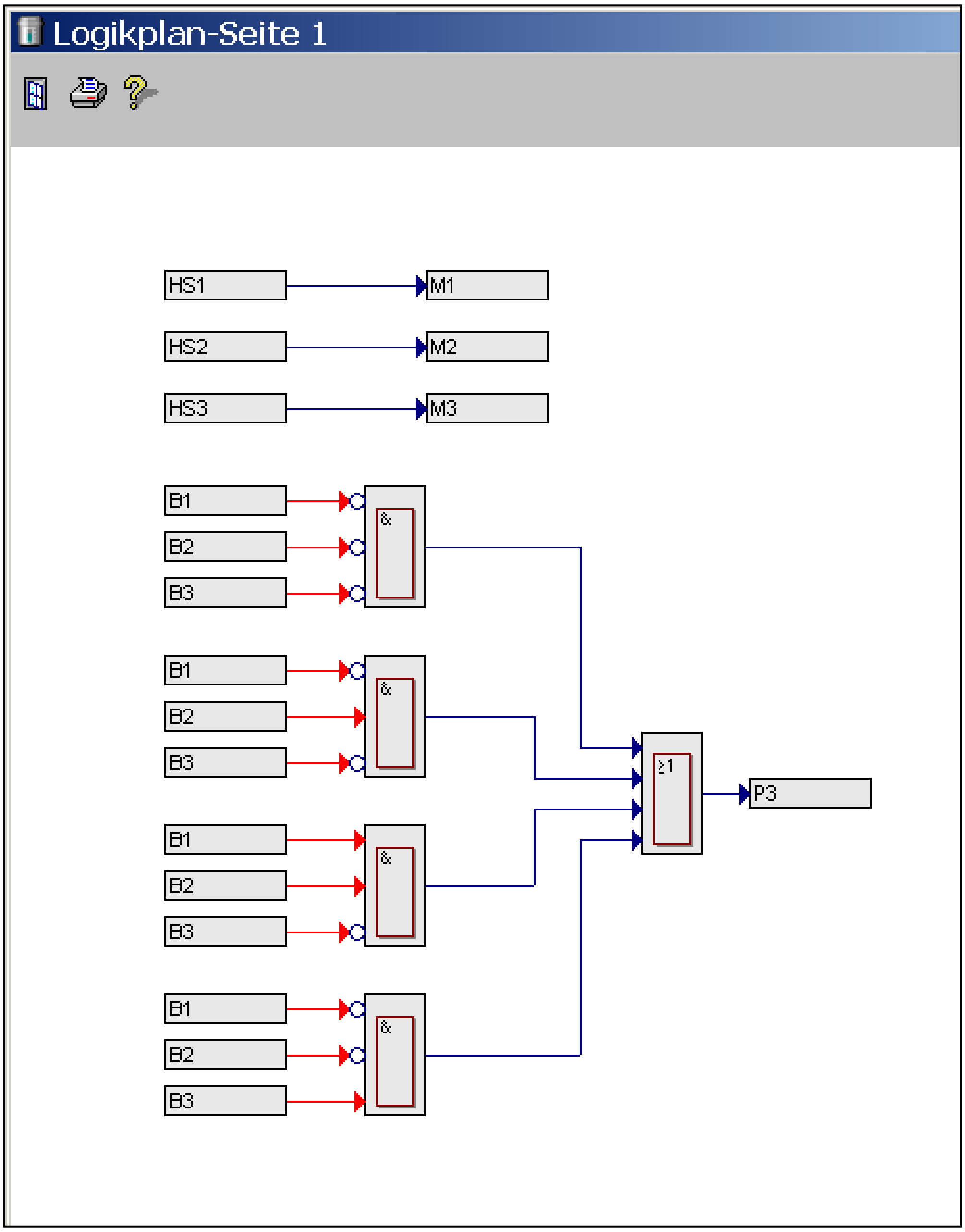


Fig. 34: Display of sensor errors via indicator light P3

TASK 3.3.3: Simplify the circuit if possible. Use e.g. a Karnaugh map.

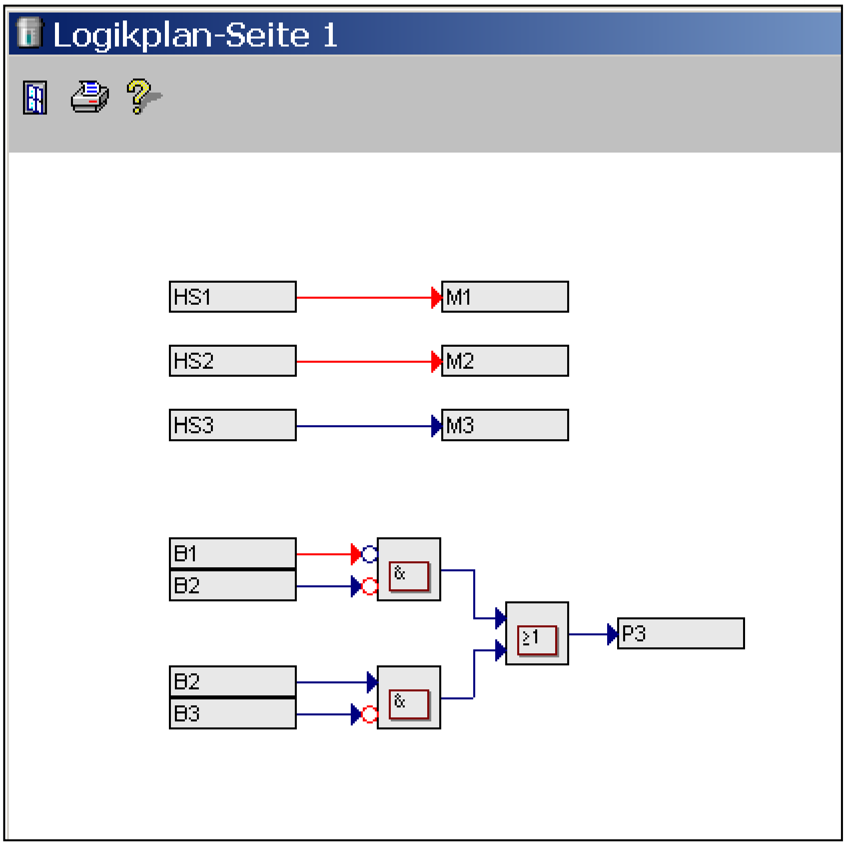


Fig. 35: Simplified circuit for indicating sensor errors via the P3 indicator

Note: To switch pumps M1, M2, M3 via switches HS1, HS2, HS3 for testing the circuits, the circuitry required for this purpose has to be indicated in the upper part of the logic diagrams.

3.4 PUMP CONTROL GATES

The level-dependent control of the inflow quantity is to be effected automatically by means of a circuit. The conditions for the operation of pumps M1 and M2 are established in the following table:

Fill level	Running pumps
Above B1	none
Between B1 and B2	Pump M1
Between B2 and B3	Pump M2
Below B3	Pumps M1 and M2

Note: To test the following circuits, pump M3 must be switched on and off. Switch pump M3 on and off as described in section 3.3 using switch HS3. You can change the speed of pump M3 using the slider next to the display field.

TASK 3.4.1: Enter into the function table, for which sensor signals pumps M1 and M2 are switched on and write down the function equations.

B3	B2	B1	M1	M2

SOLUTION

B3	B2	B1	M1	M2
0	0	0	0	0
0	0	1	1	1
0	1	0	0	0
0	1	1	0	0
1	0	0	0	0
1	0	1	0	1
1	1	0	0	0
1	1	1	1	0

Functional equations

$$M1 = (B1 \wedge \overline{B2} \wedge \overline{B3}) \vee (B1 \wedge B2 \wedge B3)$$
$$M2 = (B1 \wedge \overline{B2} \wedge \overline{B3}) \vee (B1 \wedge \overline{B2} \wedge B3)$$

TASK 3.4.2: Develop the previously specified pump control. Take advantage of the possibilities of simplification and test the solution.

SOLUTION

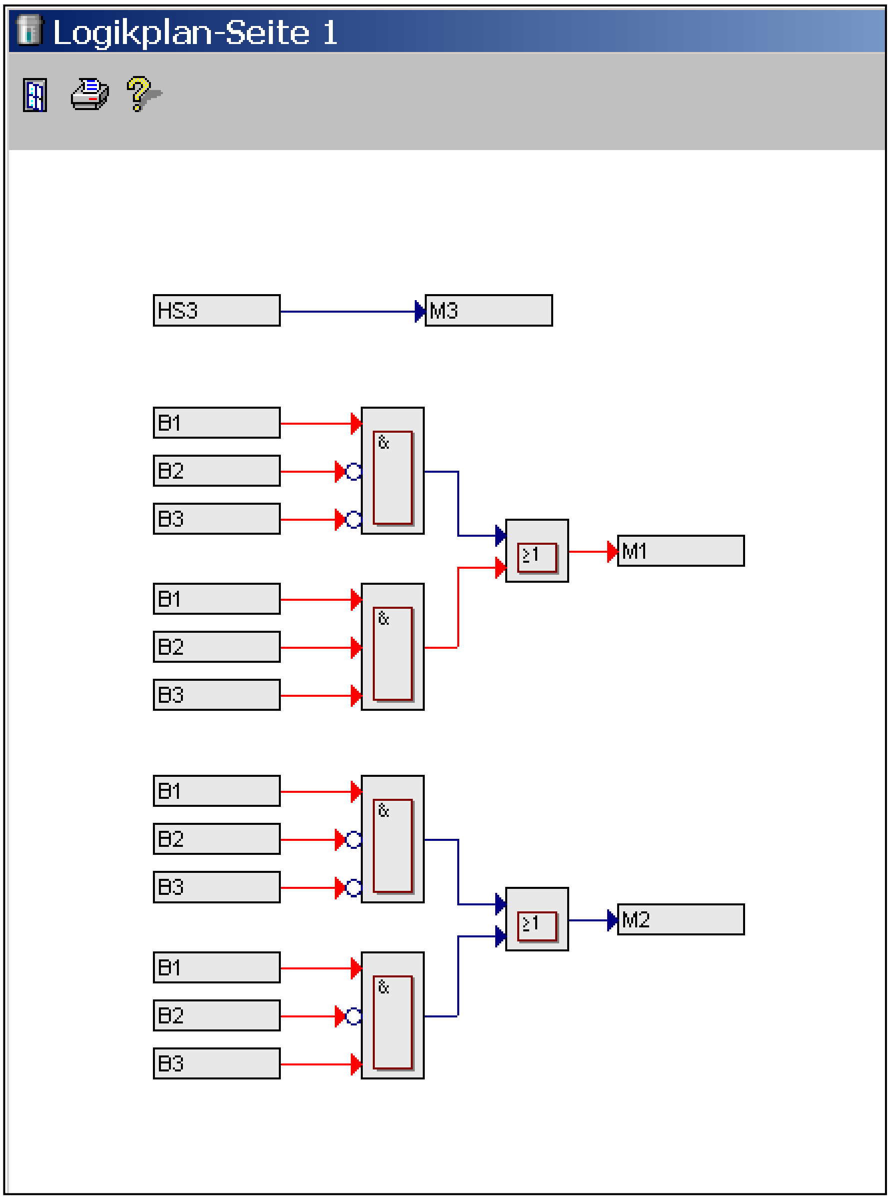


Fig.36 Circuit for the automatic operation of pumps M1 and M2

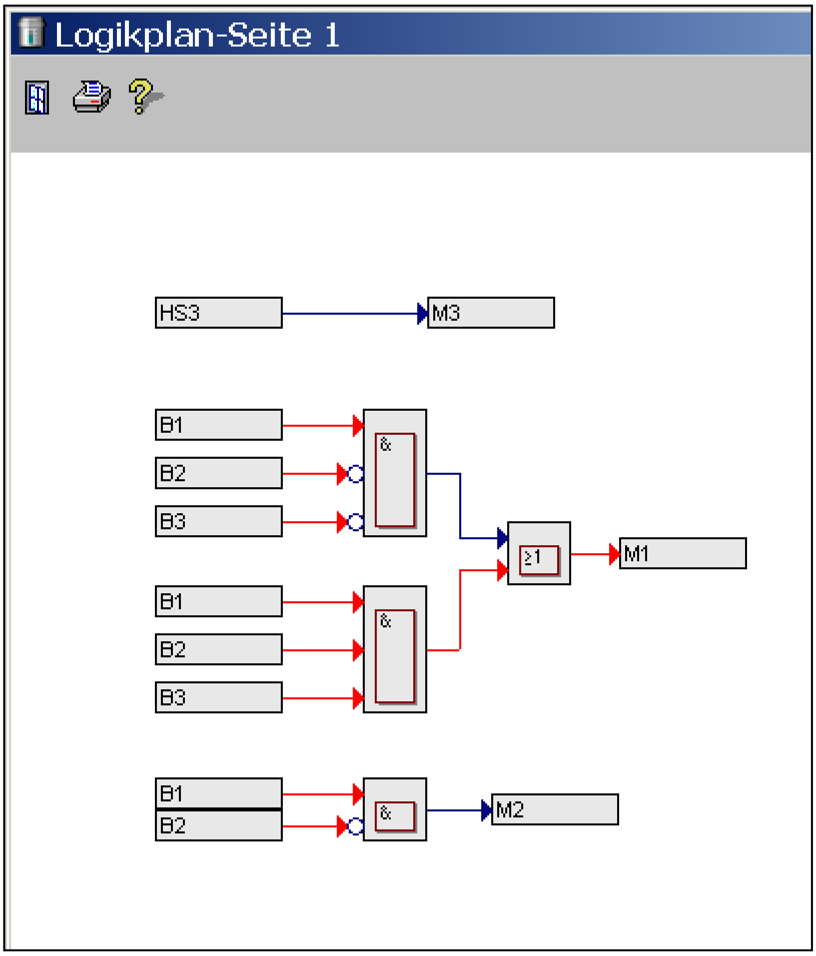


Fig.37 Simplified circuit for the automatic operation of pumps M1 and M2

TASK 3.4.3: Test the circuits by switching on pump M3 via switch HS3 and then use the slider next to the flow indicator to vary the flow rate.

Since the filling level fluctuates, the level switches flicker at the corresponding filling levels. This results in a high switching frequency of the pumps. This is solved in a later task by the use of on / off delay timers.

TASK 3.4.4:

The developed pump control is later to be realized with ICs. To avoid having to use too many (and different) ICs, it is useful to engage only one type of gate (e.g., NAND's) in the circuit design. Draw the tested circuit so that only NANDs with 2 inputs (as in IC 7400) are used. Try to use as few ICs as possible.

SOLUTION

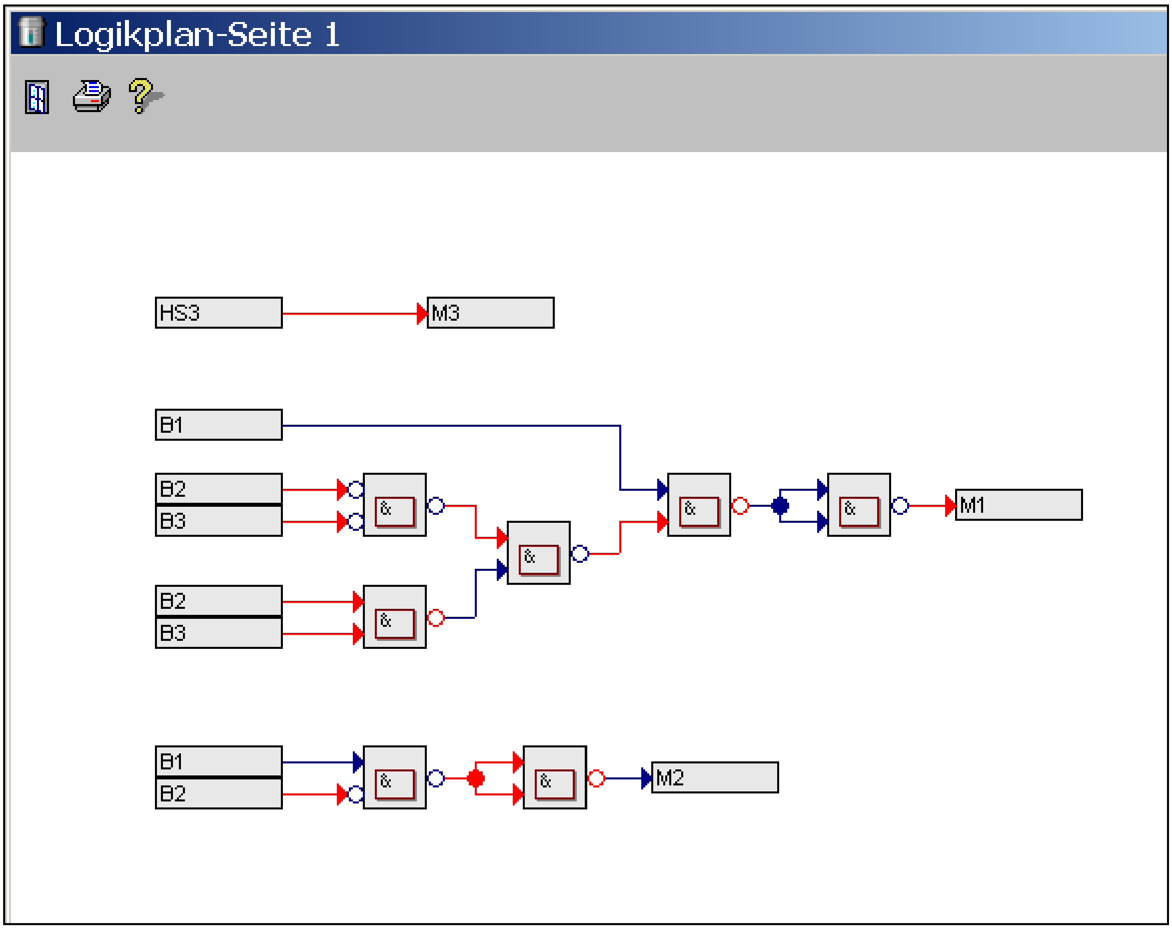


Fig.38: Circuit of NANDs for the automatic operation of pumps M1 and M2

3.5 CONTROL OF PUMP 3 VIA A PUSH BUTTON

Pump M3 should be switched on or off using push button HS5.

Develop a circuit or implement the circuit as specified in the solution. In order for the circuit to work, you must also use the on / off delay timer and the edge block (binary trigger block) for this task.

TASK 3.5.1: Develop a circuit with an RS (RS flip-flop), which allows you to switch pump M3 on and off using the button.

SOLUTION

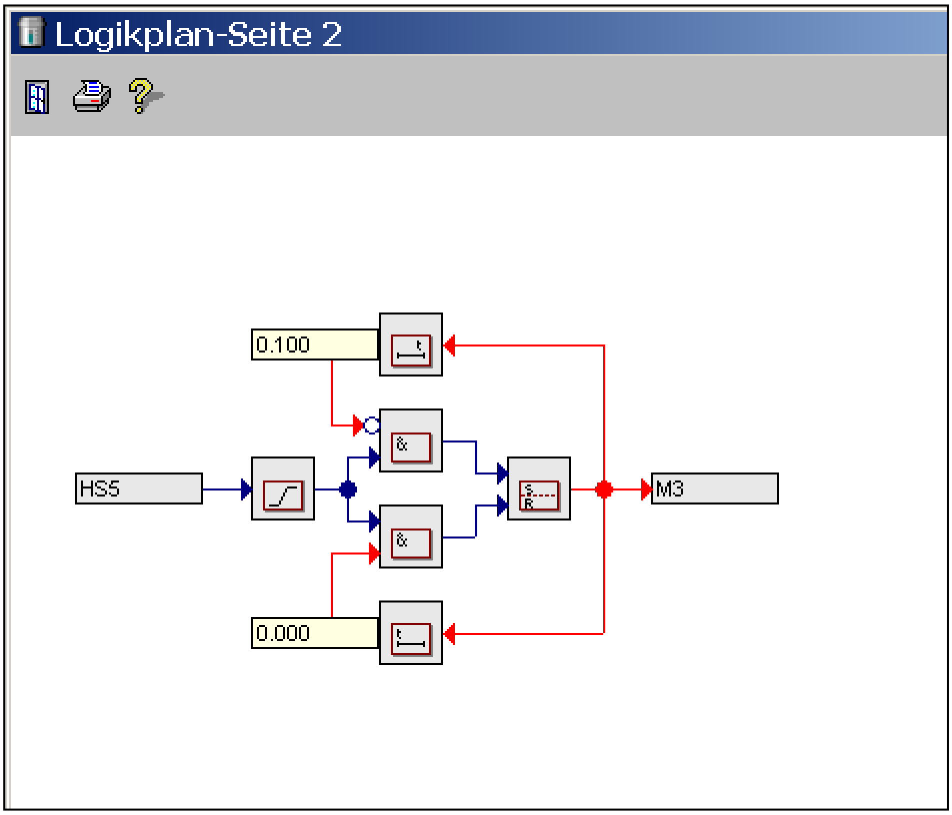


Fig.39 Switching pump M3 on and off via push button HS5

3.6 INSTRUCTIONS WITH NORMALLY CLOSED / NORMALLY OPEN CONTACT

There are 3 switches and 2 buttons available in the control panel. Pumps M1 and M2 are to be switched on and off via switches HS2 and HS3. Switch HS1 is used as an emergency stop switch.

Normally closed: NC

Normally open: NO

Operating element	function	switch	button	NC	NO
HS1	Emergency stop	X		X	
HS2	M1	X			X
HS3	M2	X			X
HS4			X		
HS5	M3		X		

These control elements are to be used with the level sensors for the control.

TASK 3.6.1:

Use control elements for the described tasks:

- If emergency stop switch is actuated, it locks and switches off all actuators.
- If no emergency stop occurs, the pumps can additionally be switched on manually using HS2 and HS3, in addition to automatic control.

Push button HS5 is used to switch pump M3 on and off for testing the circuit as in task 3.5.

Extend the circuit from task 3.4.2 according to the functions described above.

SOLUTION

The circuit for pump M3 is implemented on the logic plan page 2 as in task 3.5.1 (Fig.39).

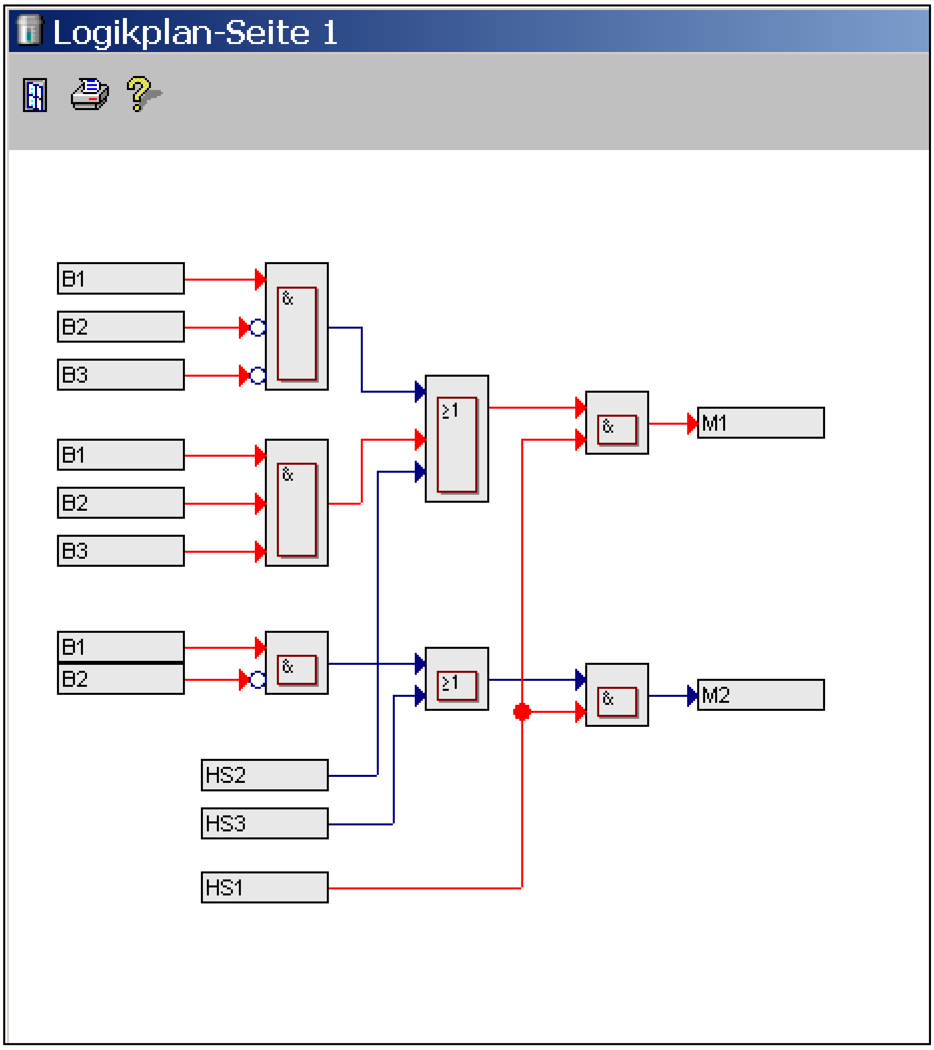


Fig.40 Emergency stop switch (HS1) and switch for additional operation of the pumps

3.7 CONTROL WITH PUSH BUTTONS / INTRODUCTION RS-MEMORIES

The operation of the pump control is to be changed to pushbutton operation. The functions of the control elements are as follows.

Operating element	Function	Switch	Button	NC	NO
HS1	Emergency stop	X		X	
HS2	MS	X			X
HS3		X			X
HS4	Start		X		X
HS5	Stop		X		X

The operation part of the control and the pump control unit should be developed separately. Light P1 is to be used for this purpose. Light P1 indicates the state "System ON".

The main switch is labelled MS.

TASK 3.7.1:

The following functions are to be implemented with gates and RS memories:

- The system stays switched off without the main switch (MS) switched on.
- If the emergency stop switch is activated, the system also switched off.
- The system is only switched on when the start button is pressed while MS is active.
- The Stop button switches off the system at any time.

SOLUTION

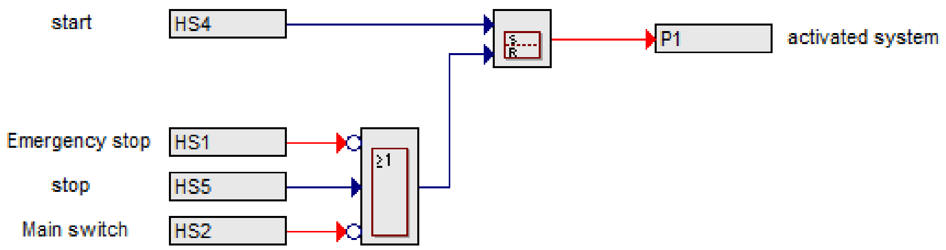


Fig.41: Control "System ON"

TASK 3.7.2: Check the logic diagram for operational safety:

- Is there a restart protection after a power failure?
- Is switching off the system (MS, Stop, Emergency Stop) guaranteed?
- How does the system respond to line breakage at the control elements?

SOLUTION

- Is there a restart protection after a power failure?

  Yes !

- Is switching off the system (MS, Stop, Emergency Stop) guaranteed?

  Yes !

- How does the system react to line breakage at the control elements?

  Power break at main switch (MS): *System switches off*

  Power break at stop switch: *System cannot switch off*

  Power break at emergency stop: *System switches off immediately*

TASK 3.7.3: Is there any need for changes to the controls?

SOLUTION : The stop button should be designed as a normally closed contact (NC contact). Since buttons cannot be selected as normally closed, switch HS3 is used instead of the push button.

TASK 3.7.4: Press switch HS3 as a stop button and use it as an NC contact. Change the circuit accordingly.

SOLUTION

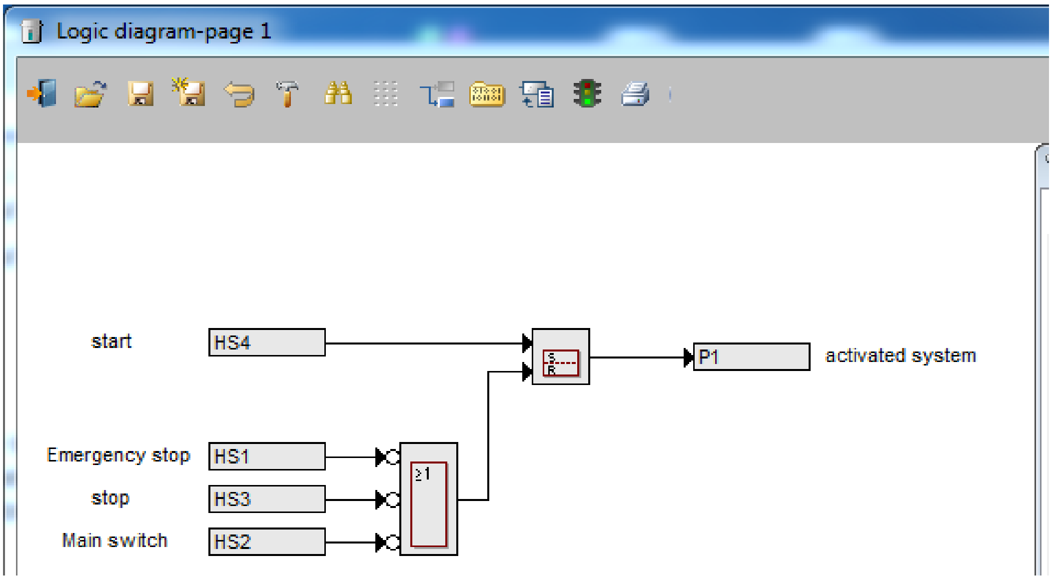


Fig.42 Consider cable breakage at the stop switch

3.8 PUMP CONTROL WITH MEMORIES AND GATES

Switching pumps M1 and M2 on and off is done by setting and resetting RS memories. If the levels for both switching commands are different, a high switching frequency is avoided.

The pumps should be switched on and off according to the following description:

- If the tank is filled above the uppermost sensor, no pump is running.
- If the level falls below B2, M2 switches on.
- If the level falls below the lowest sensor, both pumps M1 and M2 are running.
- If the level rises above the medium sensor B2, pump M1 is switched off.

TASK 3.8.1: Enter all combinations of input signals into the function table. In columns M1 and M2, enter S (set) or R (reset) for each level switch combination.

B3	B2	B1	M1	M2

SOLUTION

B3	B2	B1	M1	M2
0	0	0		
0	0	1	S	S*
0	1	0		
0	1	1		
1	0	0		
1	0	1		S
1	1	0		R
1	1	1	R	

* Switching on pump M2 is also necessary here if the tank is empty and the system is restarted.

TASK 3.8.2: Develop and test the circuit.

SOLUTION

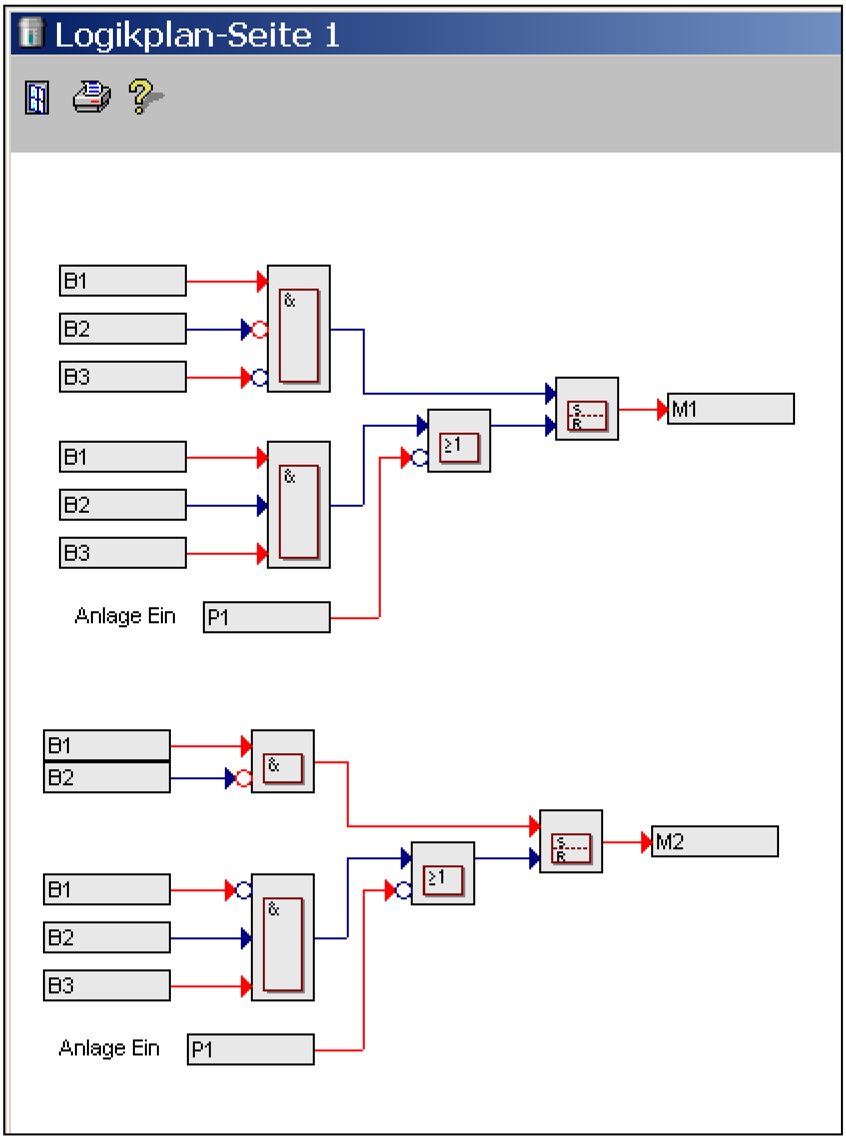


Fig.43 Switching the pumps on and off via RS-memory

To generate the signal P1 ("System ON"), use the function diagram of logic plan page 2 (task 3.7.4, Fig.42).

To test the circuit, you must switch the pump on and off. Use the logic plan of Task 3.5.1 (Fig.39).

3.9 ERROR MESSAGE WITH RECEIPT

In the event of a breakdown, the given circuit outputs an alarm signal via horn and / or indicator light.

The message can be "Acknowledged" with a button.

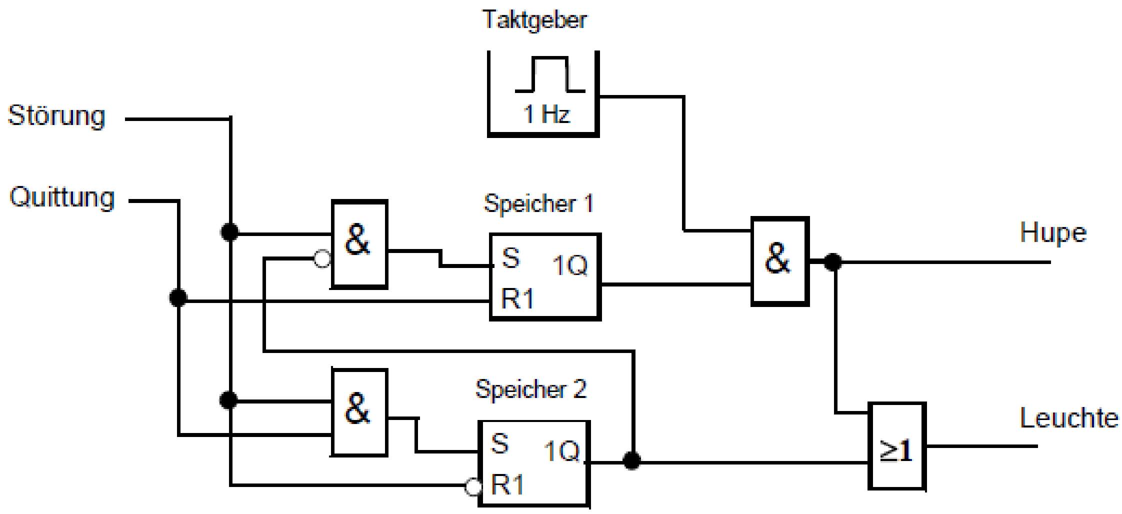


Fig. 44 Alarm signal via horn and / or indicator light.

TASK 2.9.1: Describe in the table below the effects on the two memories, the horn and the indicator, when

a) An error message arrives (fault = "1"),

b) This signal is terminated again (fault = "0") and

c) Afterwards an acknowledgment is made (acknowledgment = "1")

d) The error is present (fault = "1") and the acknowledgment is pressed (acknowledgment = "1")

Solution table:

	Memory 1	Memory 2	Horn	Indicator
Task a				
Task b				
Task c				
Task d				

SOLUTION

	Memory 1	Memory 2	Horn	Indicator
Task a	set	not set	horns in intervals	flashes
Task b	set	not set	horns in intervals	flashes
Task c	not set	not set	off	off
Task d	not set	set	off	on

TASK 3.9.2: Extend the circuit for signalling a sensor error by the function shown above with the following specifications:

- Acknowledgment should be possible via the button HS4.
- Use light P2 as the horn and light P3 as the indicator light.

Note: Use the light signal P1 as a marker to internally transmit the sensor error.

SOLUTION

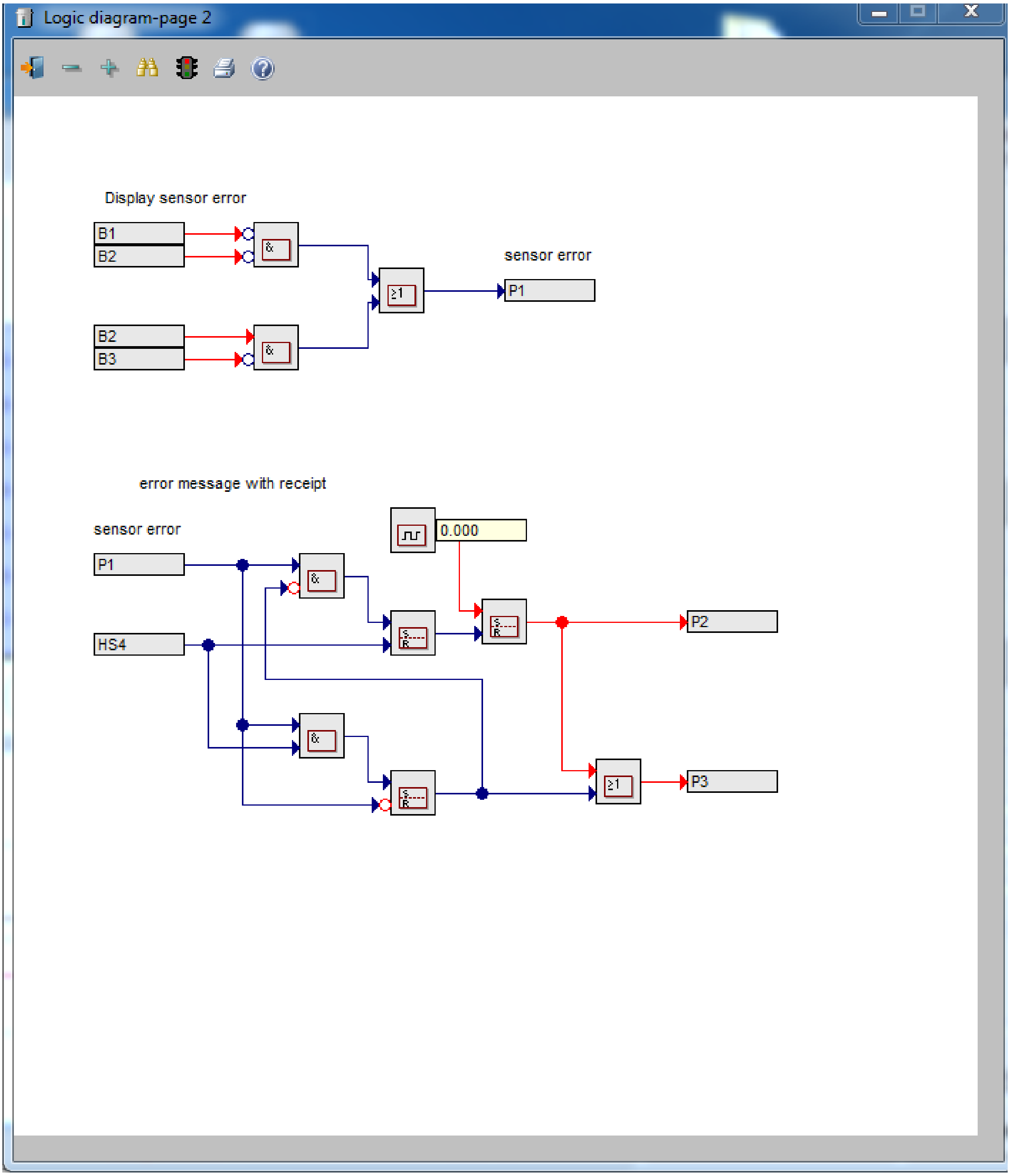


Fig.45 Error acknowledgment

3.10 CONTROL WITH TIMER

To avoid load peaks by switching both pumps on at the same time, the control is to be extended by a time delay.

TASK 3.10.1: Since the M1 and M2 can be switched on at the same time, the switch-on signal for pump M1 is to be delayed by 5s by means of a timer. Modify the circuit developed in Exercise 2.8.2 according to these conditions.

SOLUTION

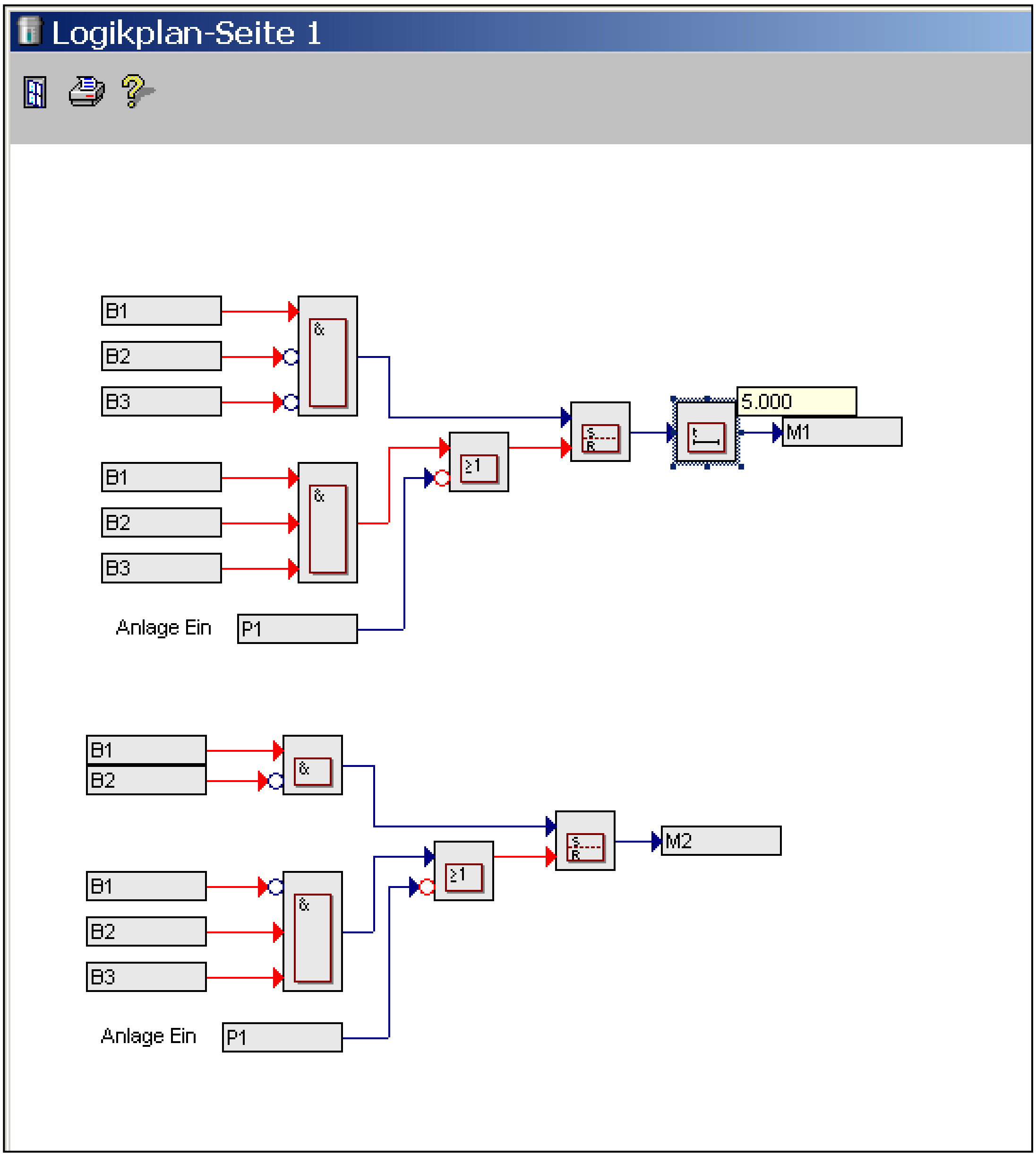


Fig.46 Pump control with switch-on delay timer

TASK 3.10.2: The upper sensor limits the filling capacity of the container to approx. 80%. A time control should ensure that during the filling process pump P2 is switched after 8s delayed.

SOLUTION

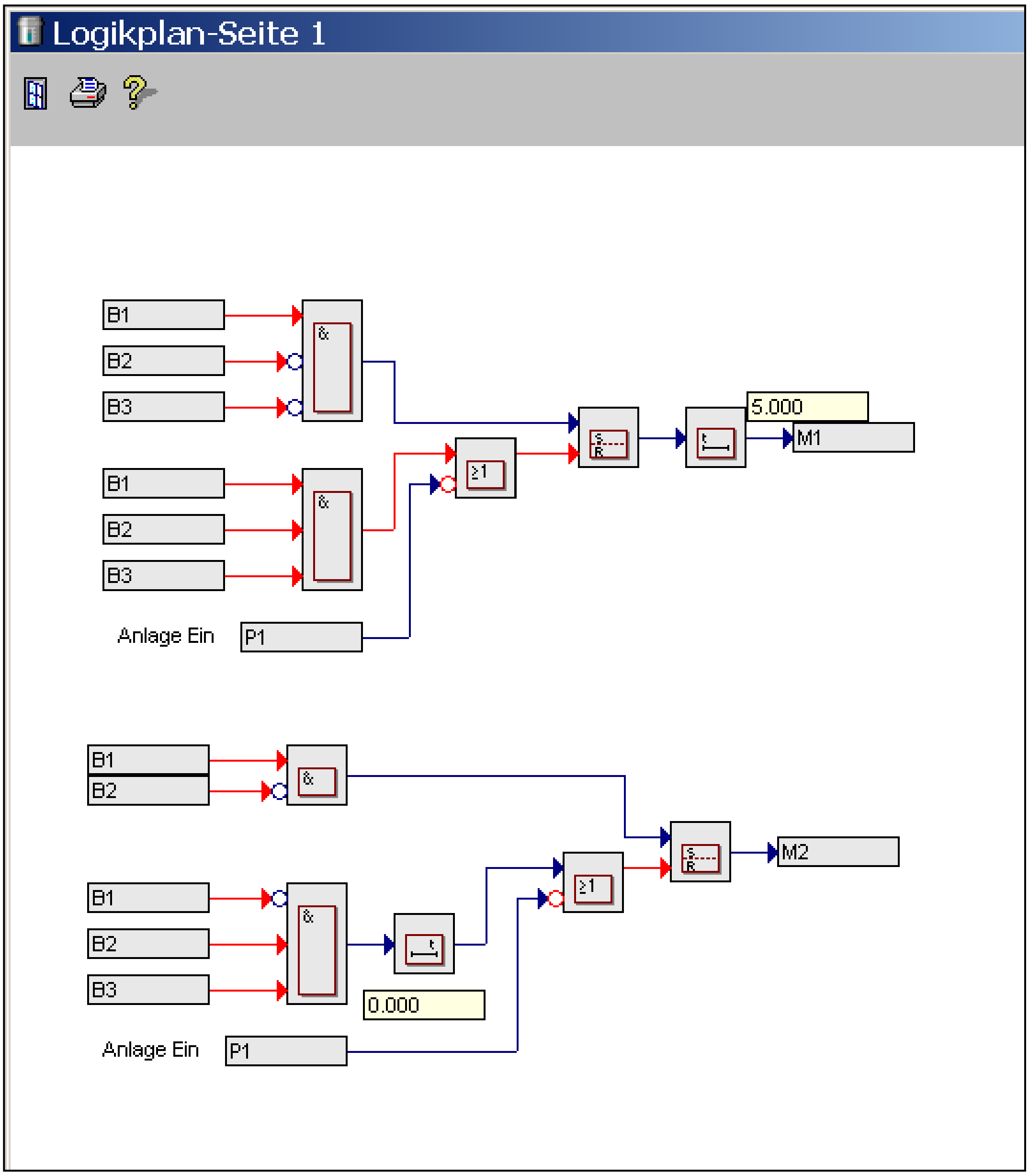


Fig.47 Pump control with switch-on and switch-off delay

3.11 MIXED OPERATION WITH RS-STORES

The storage tank is to be used for the automatic filling and mixing of two liquids. The container is emptied afterwards. The following steps are to be carried out one after the other:

1. The container is filled up to sensor B2 via pump M1. Pump M1 should then be switched off.
2. Subsequently, the filling is continued through M2 and meanwhile pump M4 is switched on for mixing.
3. When level switch B1 is reached, pump M2 should still continue for 5s and pump M4 for 20 seconds.
4. When all pumps have been switched off, pump M3 should empty the tank.

The sequence should fulfil the following additional conditions:

- The system can only be operated with the main switch HS (switch HS3) pressed.
- The emergency stop switch (switch HS1) switches off all steps and actuators.
- If the system is in the basic position (all pumps off, level below sensor B3), the start sequence can be started via START button (HS4). Make the basic setting visible by turning on the P3 lamp.
- The STOP switch (HS2) can reset the steps at any time and switch off the actuators.

TASK 3.10.1: Develop the above described control with RS memories.

SOLUTION

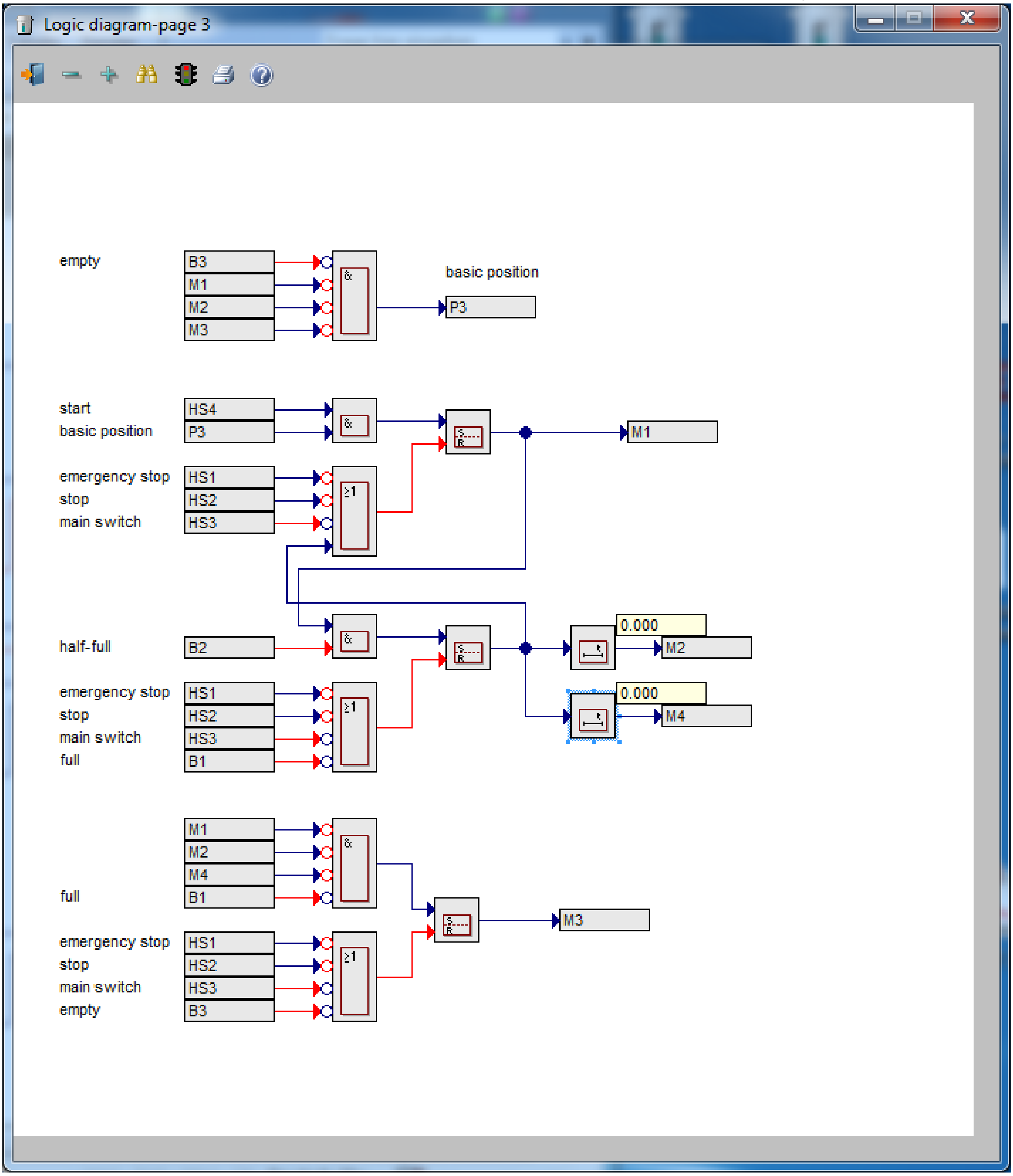


Fig.48 Pump control for mixed operation

4 TASKS CONTROL TECHNOLOGY

4.1 INTRODUCTION

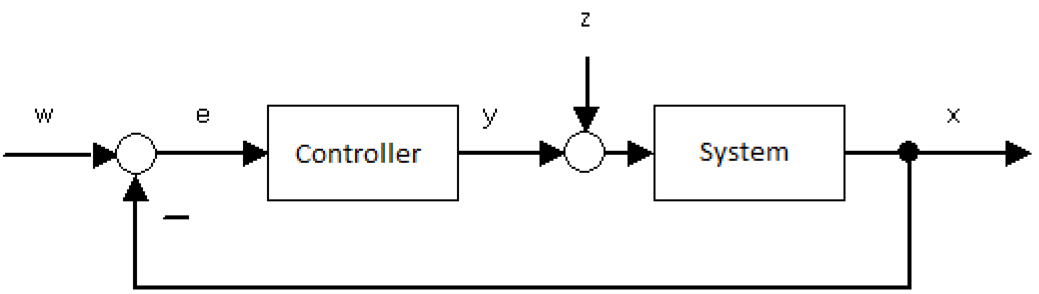
With the LC2030 work station or with the simulated system you can carry out various types of different regulations

- Liquid level control (via inflow and outflow)
- Flow control (via inflow and outflow)
- Temperature control
- Pressure control

All of the following tasks refer to LIC101 level control (drain), flow control FIC103 (drain) and temperature control TIC102.

The goal in control technology is that a controller is able to bring the actual value to the desired value by adjusting an actuating signal after an acceptable time. The response to set point changes (guidance control) or to disturbance influences (disturbance value control) is distinguished here. In both cases, the controller attempts to bring the actual value back to the set point value.

The standard control loop looks as follows in the signal flow chart:



The actual value x is compared with the desired value w and the difference e is entered into the controller. The controller outputs a manipulated variable y to the system with which it attempts to influence the system so that the actual value is equal to the set point value after a settling phase. The occurrence of a disturbance z, of course, influences the system and thereby changes the actual value x. This also changes the difference between set point and actual value. The controller reacts and with the control signal influences the system.

In the normal case, the minus sign is next to the input of the actual value (e = w - x) during the set point / actual value comparison. However, it can also be at the input of the set point value (e = x - w). Where the minus sign is placed depends on whether the control signal is to be increased if the set point is greater than the actual value or vice versa. If the control signal y has to increase while the set point value is greater than the actual value, then the minus sign at the summation point is next to the input of the actual value,

Designations:

Reference variable (set point) w

The reference variable (set point) is the task variable to be followed by the control (the actual value). It is fed from the outside and is not affected by the control

Control variable (actual value) x

The control variable is the magnitude of the control path which is recorded for the purpose of the control and is compared with the reference variable (set point value). The aim of the control is that after a certain time (transient response), the control variable equals the value of the reference variable.

System deviation e

The system deviation is the difference between the reference variable and the control variable

$e = w - x$

Correcting variable y

The actuating signal is the output variable of the controller and input variable of the system (the process).It transmits the controlling effect and influences the process.

Disturbance variable z

A disturbance variable is an externally acting variable on the system. The control variable is thereby changed and the controller tries to correct the change.

There are two types of rules:

Guidance control

The reference variable (set point) is changed and the controller must attempt to bring the control variable (actual value) to the new reference value by influencing the control signal.

Disturbance control

The system and thus the control variable are changed by disturbances. The controller must try to correct the disturbance by changing the control signal so that after a certain time the control variable again equals the value of the reference variable.

4.2 RECORDING THE PUMP CURVE

The liquid level and the flow rate are controlled by the controllable pump M3. By examining the characteristics of the pump M3 one gets an impression of the behaviour of the system. It is also clear that the flow rate of the system is not only dependent on the speed of the pump, but also on the liquid level.

TASK 4.2.1: Record the characteristics for pump M3 by recording the flow rate from the flow meter and enter the values in the following table.

Speed / Delivery height	100%	80%	60%	40%	20%
10 cm					
15 cm					
20 cm					
25 cm					
30 cm					
35 cm					

SOLUTION

The task was performed with the simulated plant. In the overview, you can go to the simulation settings page, using "View simulated LC2030 " and "Parameters", and adjust the flow rates of the pumps M1 and M3.

If you want to adjust the simulated flows to the flow rates of your real system, determine the maximum flow rate of pump M1 at 100% opening of the valve and 5cm level or the maximum flow rate of pump M3 at 100% speed and the level of approx.. 35cm and enter these values on the parameter page at the corresponding location.

Thus the behaviour of the simulated flows will be in the same dimension of the real plant.

Fig.49 shows the settings for the following tests. In particular, the maximum flow of M1 should be set at 3.75 l / min and of M3 to 5 l / min. You can access the page from the overview page by clicking on "View simulated LC2030 " and then pressing "Parameters".

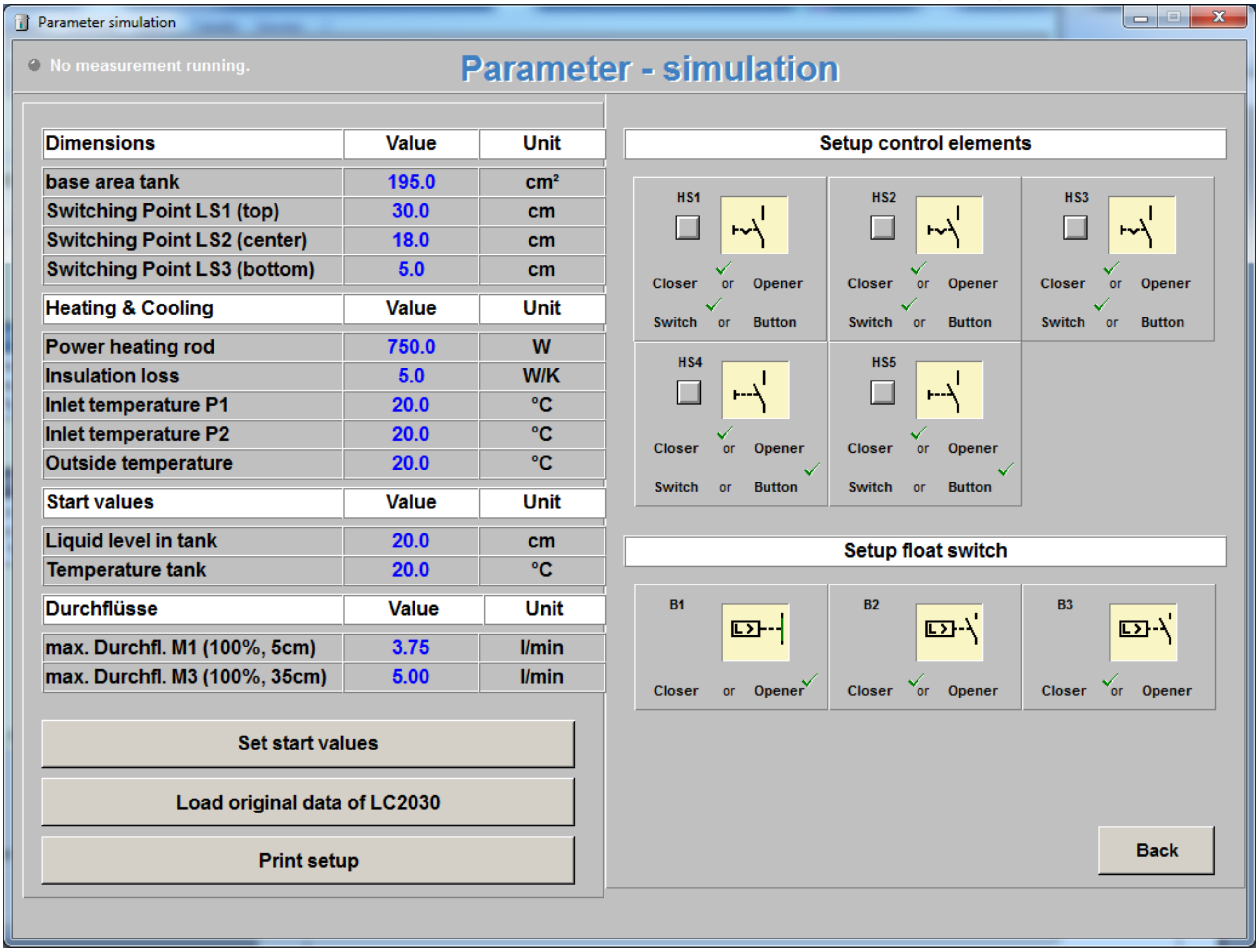


Fig.49: Parameter settings of the simulated system

It is best to perform the experiment on the LC2030 training page. Set the control signal y (speed of the pump) to the desired speed, start the pump and enter the flow rates for the corresponding liquid levels and rotational speeds into the table.

Speed / Delivery height	100%	80%	60%	40%	20%
10 cm	4,89	3,72	2,55	1,38	0.30
15 cm	4,91	3,77	2,63	1,49	0,36
20 cm	4,93	3,82	2,71	1,61	0,50
25 cm	4,94	3,87	2,79	1,72	0.65
30 cm	4,96	3,92	2,88	1,83	0,79
35 cm	4,98	3,97	2,96	1,95	0,94

This experiment clearly shows that the flow rate of pump M3 is dependent on the filling level. This means for the later level and flow control that the behaviour of the control will be dependent on the level in the tank. For this reason, a specific operating point is often determined in the control technology in which the control is being carried out. The operating point of this plant can be chosen freely, e.g. for level control at 20cm. Since the behaviour of plants or control systems is often different in different operating points, different optimal controller parameters for the different operating points will also result.

TASK 4.2.2: Develop a strategy to determine the flow rate from the change in the level and tank base area.

SOLUTION

Measure the time for changing the level between 15cm to 5cm, 25cm to 15cm, etc. for different pump speeds .Determine how many litres fit in 10cm difference in level and calculate the flow rate from the litres and time.

4.3 LIQUID LEVEL CONTROL LIC101

Go to Level Control page LIC101. Here you can operate the control in manual or automatic mode, select the controller type and set the controller parameters.

First, the control circuit is to be determined in principle.

TASK 4.3.1: Formulate what should be controlled, by what it is controlled and what disturbances take an influence.

SOLUTION

The level should be controlled via drain. The flow rate can be influenced by adjusting the speed of pump M3. Disturbances are the switching on and off of the inflow pumps M1 and M2 or the changing of the manual valves in the inlet or the adjustment of the controllable valve V1 downstream of pump M1.

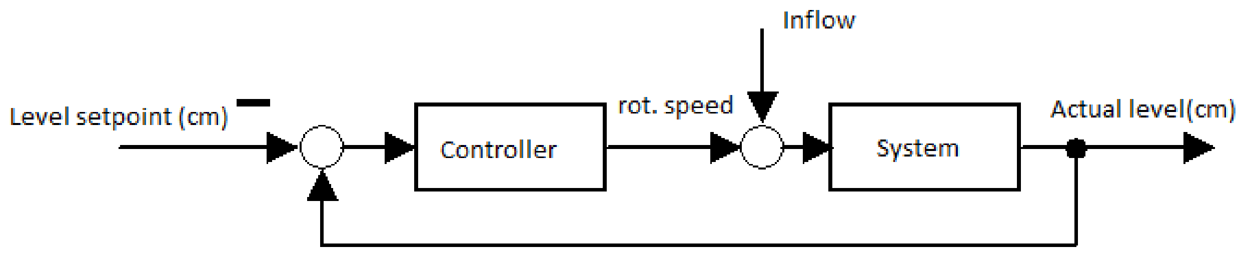
TASK 4.3.2: For this control loop, determine the set point, the actual value, the actuating signal and the disturbance variable, and specify the respective units.

SOLUTION

Set point:	Target level in cm
Actual value:	Measured fill level in cm
Control variable:	Speed of pump M3 in %
Disturbance:	Feed of pumps M1 and M2 in l / min

TASK 4.3.3: Create a flow chart (block structure) for the liquid level control.

SOLUTION



In this case the minus sign has to be before the input of the set point.

If the level set point is greater than the actual filling level, the speed of the controllable pump must be reduced so that less fluid flows through the drain. The output of a controller becomes smaller if a negative controller difference goes into the controller. As a result, the rotational speed decreases and the level in the container increases.

If the actual filling level is greater than the nominal filling level, the speed of the controllable pump must increase, in order to flow more out of the container via the drain. The output of the controller is increased when a positive controller difference is entered into the controller. As a result, the rotational speed becomes greater and the filling level in the container drops.

TASK 4.3.4: Since the level signal fluctuates greatly when the feed pumps or the drain pump are running, it is useful to smooth the signal for the control. This is achieved by switching on the low-pass filter (corresponds to a Pt1 behaviour). Change the time constant of the low-pass filter and observe the behaviour of the smoothed signal. Describe the behaviour for different time constants.

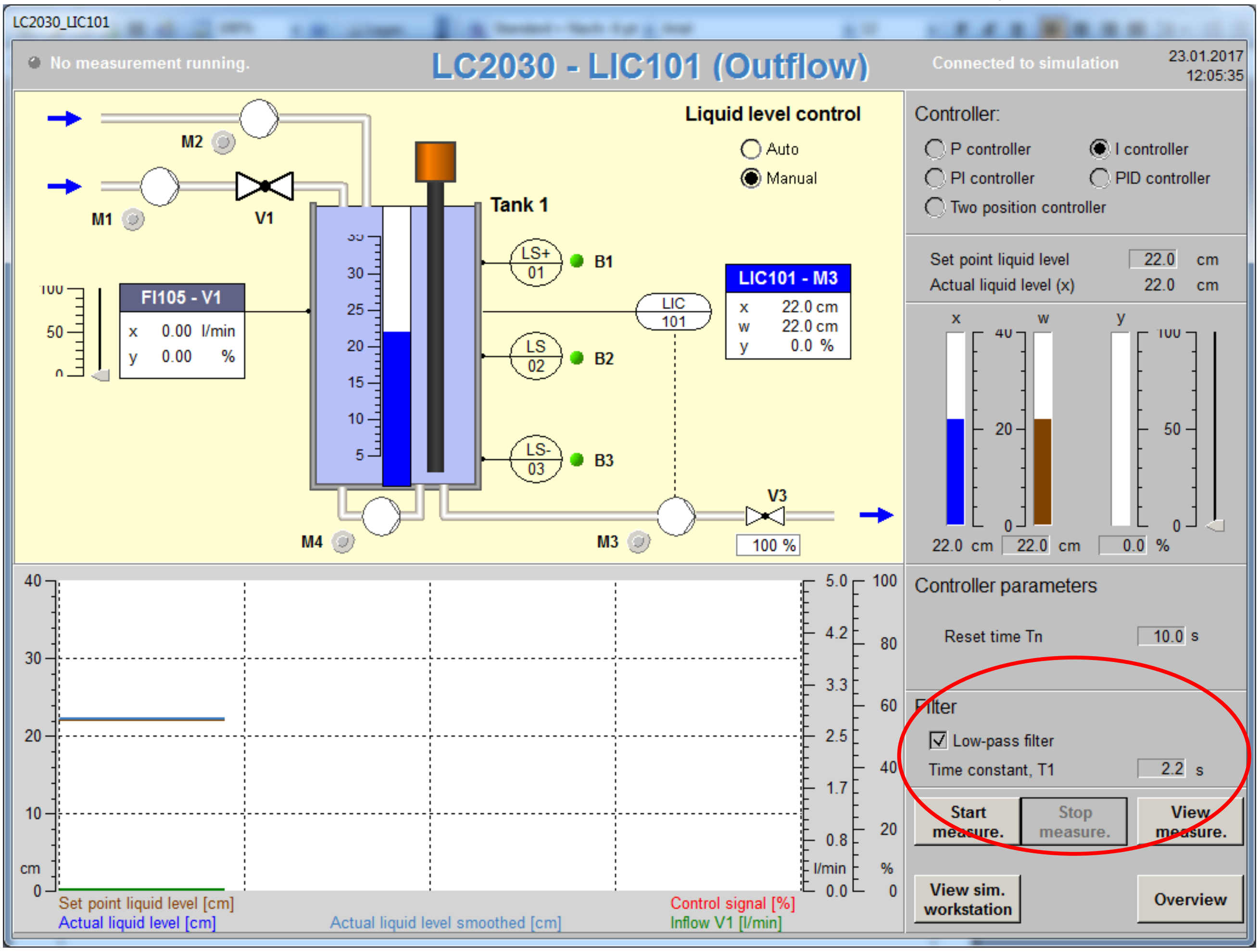


Fig. 50: Switching on the low-pass filter to smooth the level signal

SOLUTION

The larger the time constant, the better the signal is smoothed, but the slower the signal follows the original signal.

In Fig. 51: Smoothed level signal with the time constant 5s and 0.5sa time constant of 5 s was selected in the first half of recording and a time constant of 0.5 s was selected in the second half of recording. As can be seen clearly, in the second half the smoothed signal follows the original signal better, but it varies more.

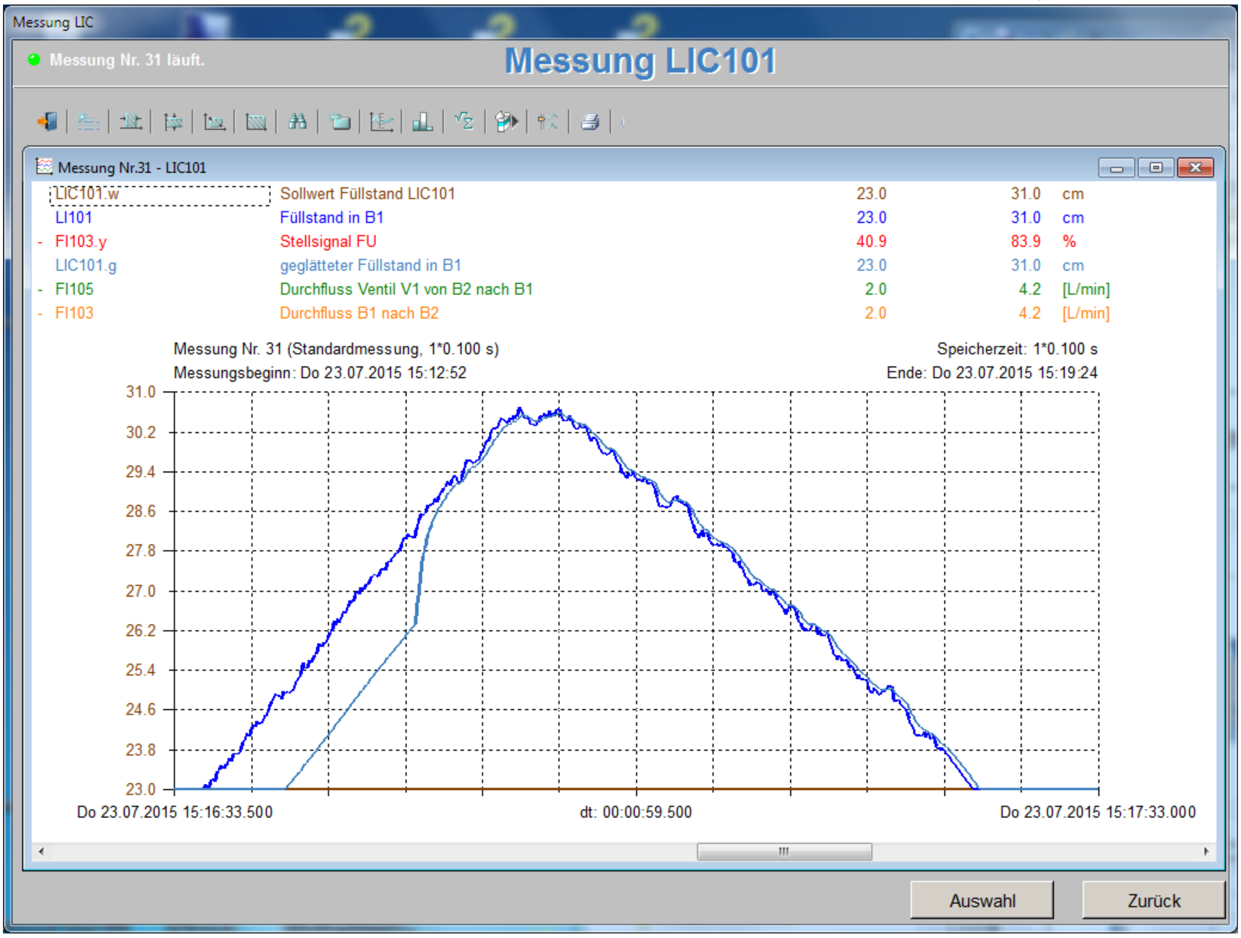


Fig. 51: Smoothed level signal with the time constant 5s and 0.5s

TASK 4.3.5: Set the circuit to manual control and switch on the two pumps M1 and M3. Set valve V1 to 100%. Specify a level set point (for example, 20cm) and try to bring the actual level to the desired level by adjusting the actuating signal y (speed of pump M3 from 0 - 100%).

NOTE: Turn on the low pass filter and set it to 2.2s. Try to correct the smoothed level signal. Start the measurement with the related button. You can then view the recorded measurements later using the *Measurement View*, and thus assess your ability to "play controller".

4.3.1 EXAMINATION OF LEVEL CONTROL LIC101 WITH THE P CONTROLLER

First, level control with P controller is to be investigated. To do this, turn on pumps M1 and M3 and set the controller to "Auto". The low-pass filter should be switched on and set to 2.2s.

In the simulated plant, the maximum flow rate of M1 should be set to 3.75 l / min and the one of pump M3 should be set to 5 l / min. Valve V1 behind pump M1 is opened to 80%.

The following tasks were performed with the simulated system and the above settings.

TASK 4.3.6: Set the level set point to 20cm and the gain of the P controller to 0.2. Wait until the smoothed actual level no longer changes. Describe the behaviour of the control.

SOLUTION

Pump M1 delivers more into the tank than pump M3 pumped out. The tank overflows.

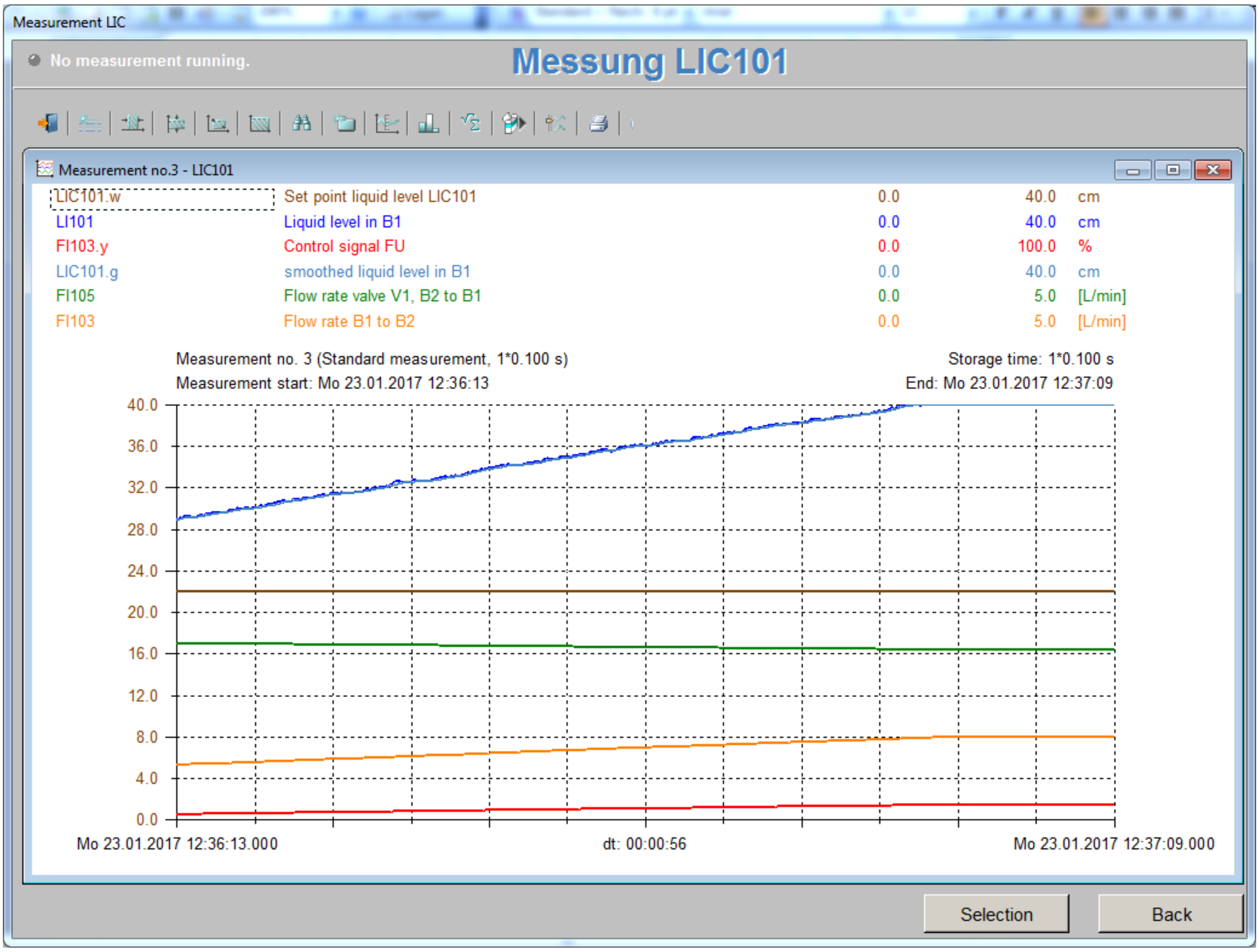


Fig. 52 Tank overflowing when being controlled with P controller

TASK 4.3.7:

Set the gain of the P controller to 4 and observe the behaviour. Describe the behaviour of the control, in particular the relationship between the actual level and the desired level (actual value and set point value).

SOLUTION

The tank is does no longer overflow. The actual level, however, does not reach the desired level.

TASK 4.3.8: Increase the gain of the P controller to 6 and wait until the control loop has settled. Describe the behaviour of the control system, in particular the relationship between the actual level and the desired level. Then increase the gain to 25 and observe the control loop.

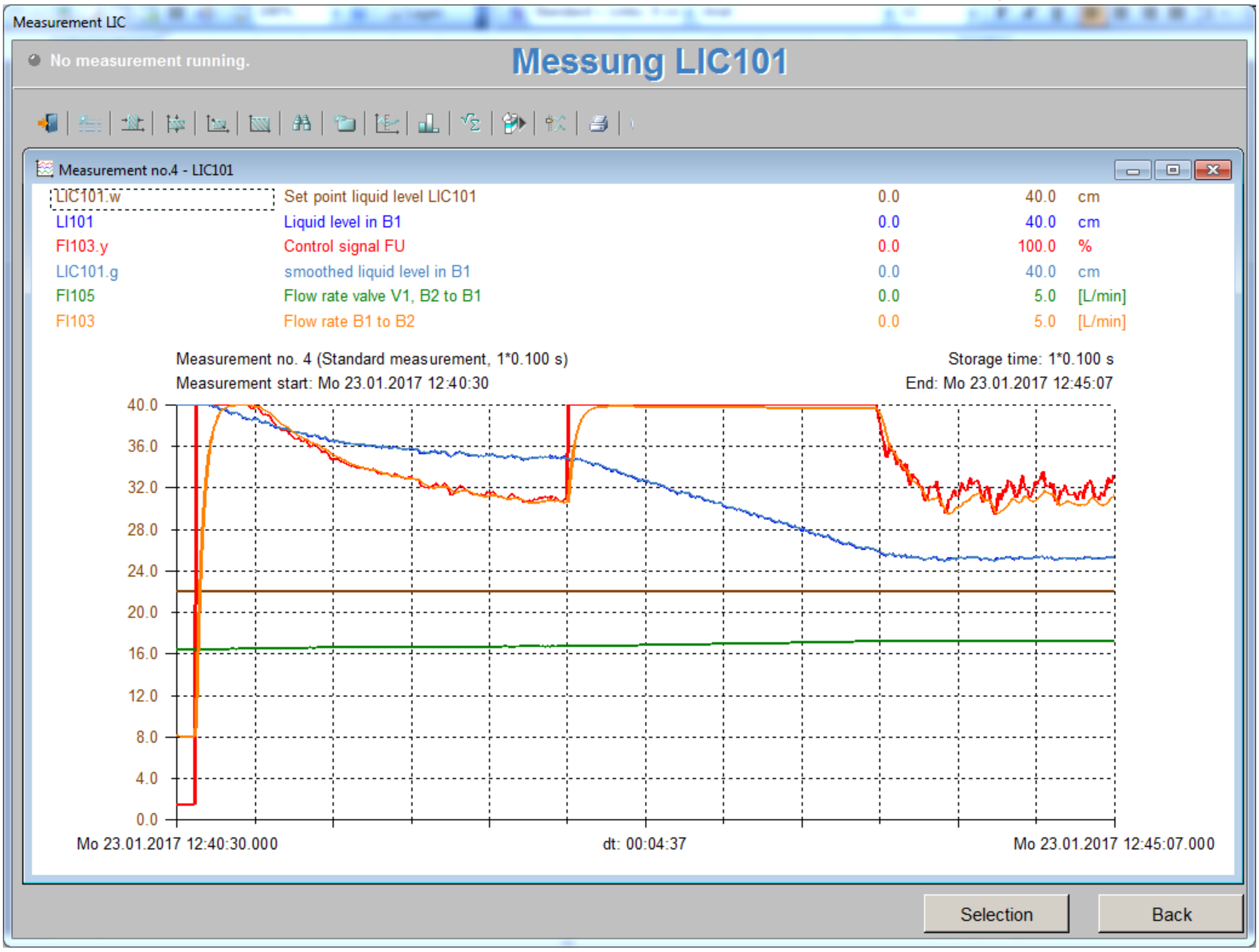


Fig. 53: Level control with P controller with an increase of gain (brown line: set point; blue line: actual value)

SOLUTION

The actual level does not reach the desired level. The difference between the actual level and the desired level (control difference) becomes smaller as the gain of the P controller increases.

The P controller is therefore not suitable for completely adjusting without control difference. Even with a gain of 25, a difference of about 2.5cm remains.

TASK 4.3.9: Turn off the low-pass filter with a gain of 25. Describe what happens.

SOLUTION

The actual level is no longer smoothed. As a result, and by the high gain, the control becomes very unsteady. The control signal fluctuates strongly and thus mechanically loads pump M3.

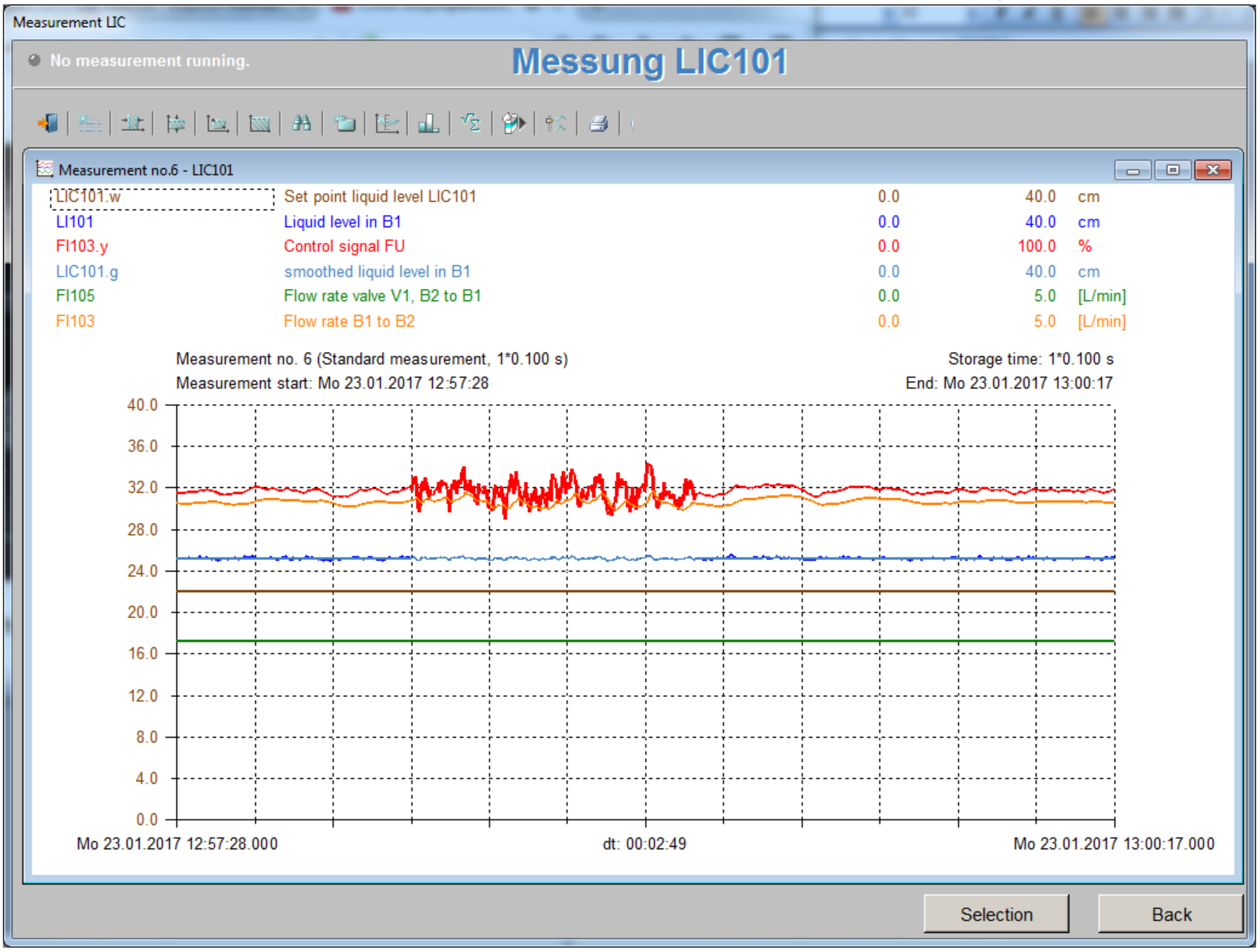


Fig. 54: Level control with P controller (gain 25) with low-pass filter on and off

4.3.2 EXAMINATION OF LEVEL CONTROL LIC101 WITH THE I CONTROLLER

Switch on the two pumps M1 and M3 again, select the I-controller and switch control to "Auto". The low-pass filter should be switched on and set to 2.2s.

In the simulated system, the maximum flow rate of M1 is set at 3.75 l / min and that of pump M3 is set to 5 l / min (*View simulated LC2030*). Valve V1 behind pump M1 is opened to 80%.

The following tasks were performed with the simulated system and the above settings.

TASK 4.3.10: Set the reset time of the I controller to 5s and the set point to 20cm. Observe the control loop and describe it´s behaviour.

SOLUTION

The control circuit begins to perform a permanent oscillation. The controller does not manage to bring the actual level to the desired level. The control loop is unstable.

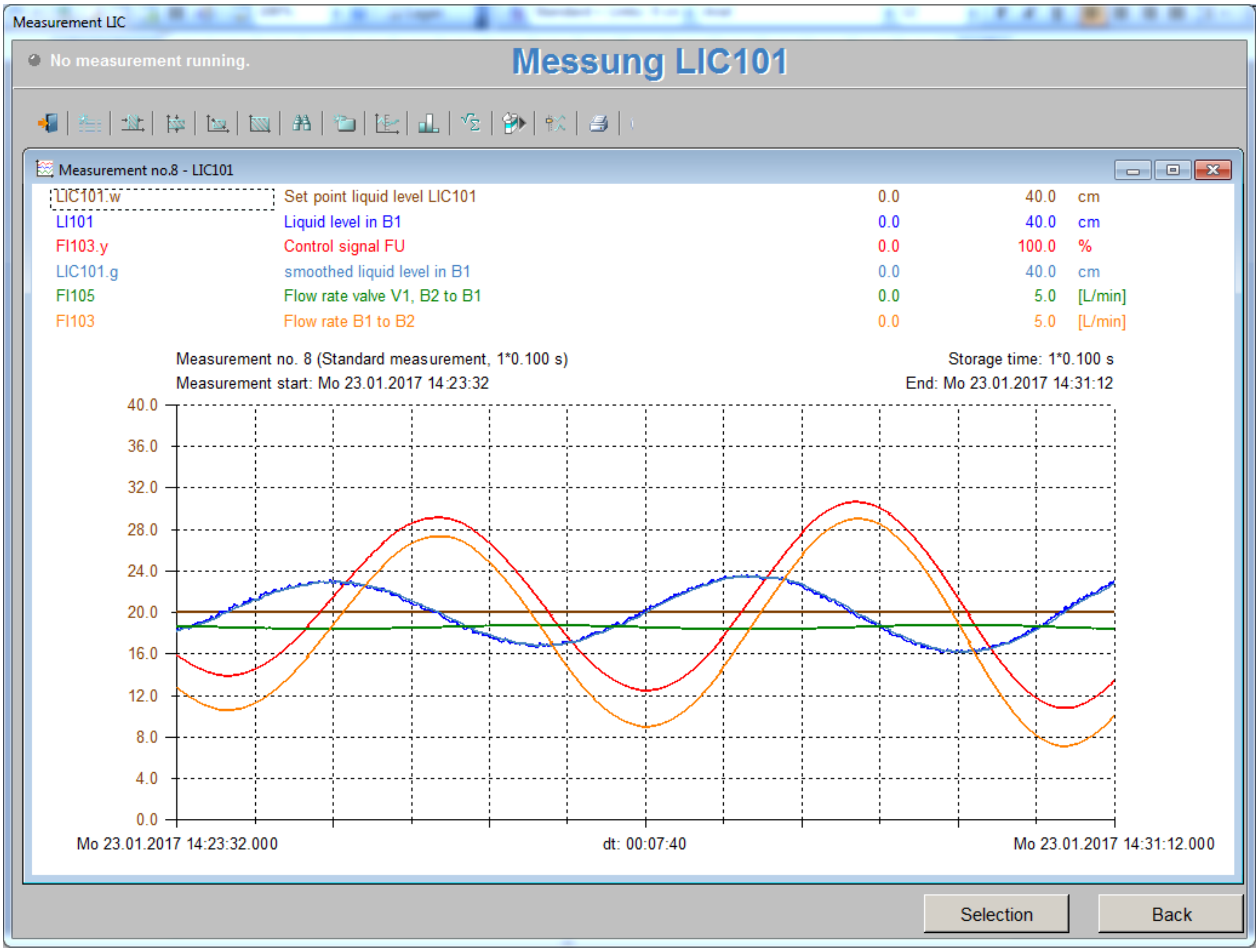


Fig. 55: Level control with I-controller

TASK 4.3.11: Increase the integral time of the I-controller from 5s to 15s. Observe the control loop and describe its behaviour.

SOLUTION

The control circuit becomes stable at greater reset times, but only after hours.

The I controller is not suitable for level control.

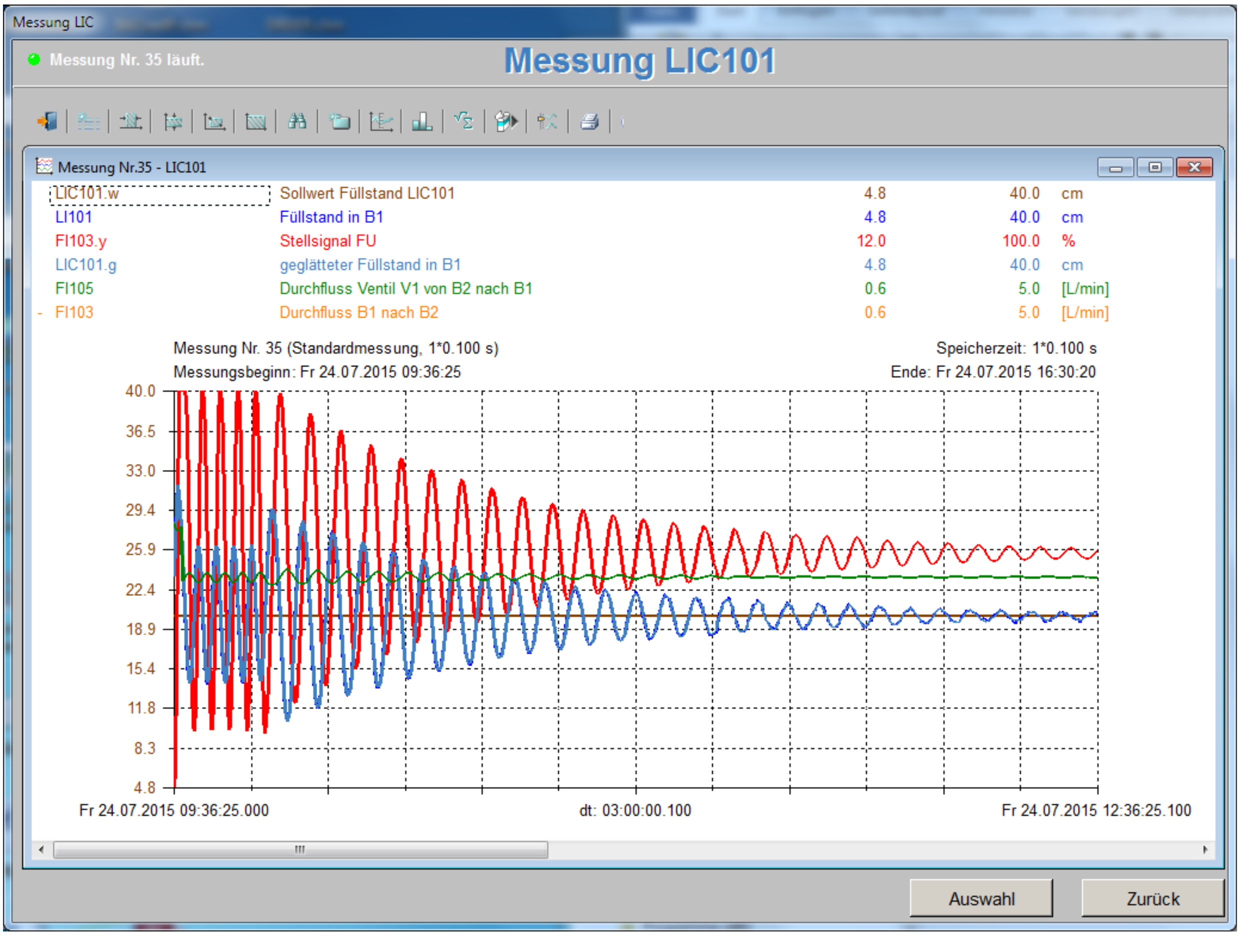


Fig. 56: Level control with I-controller and increase of the integral time from 5s to 15s

4.3.3 EXAMINATION OF THE LEVEL CONTROL LIC101 WITH PI CONTROLLER

Switch on the two pumps M1 and M3 again, select the PI controller and switch it to "Auto". The low-pass filter should be switched on and set to 2.2s.

In the simulated system, the maximum flow rate of M1 is set to 3.75 l / min and that of pump M3 is set to 5 l / min (*View simulated LC2030*). Valve V1 behind the pump M1 is opened to 80%.

The following tasks were performed with the simulated system and the above settings.

TASK 4.3.12: Set the gain to 2 and the reset time to 5s. The level set point is set to 20cm. Observe the control loop and describe it´s behaviour.

SOLUTION

Likewise to the I controller, the control circuit carries out a continuous oscillation, which decreases very slowly. The behaviour is not sufficient for a control because the actual value gets too slow to the set point.

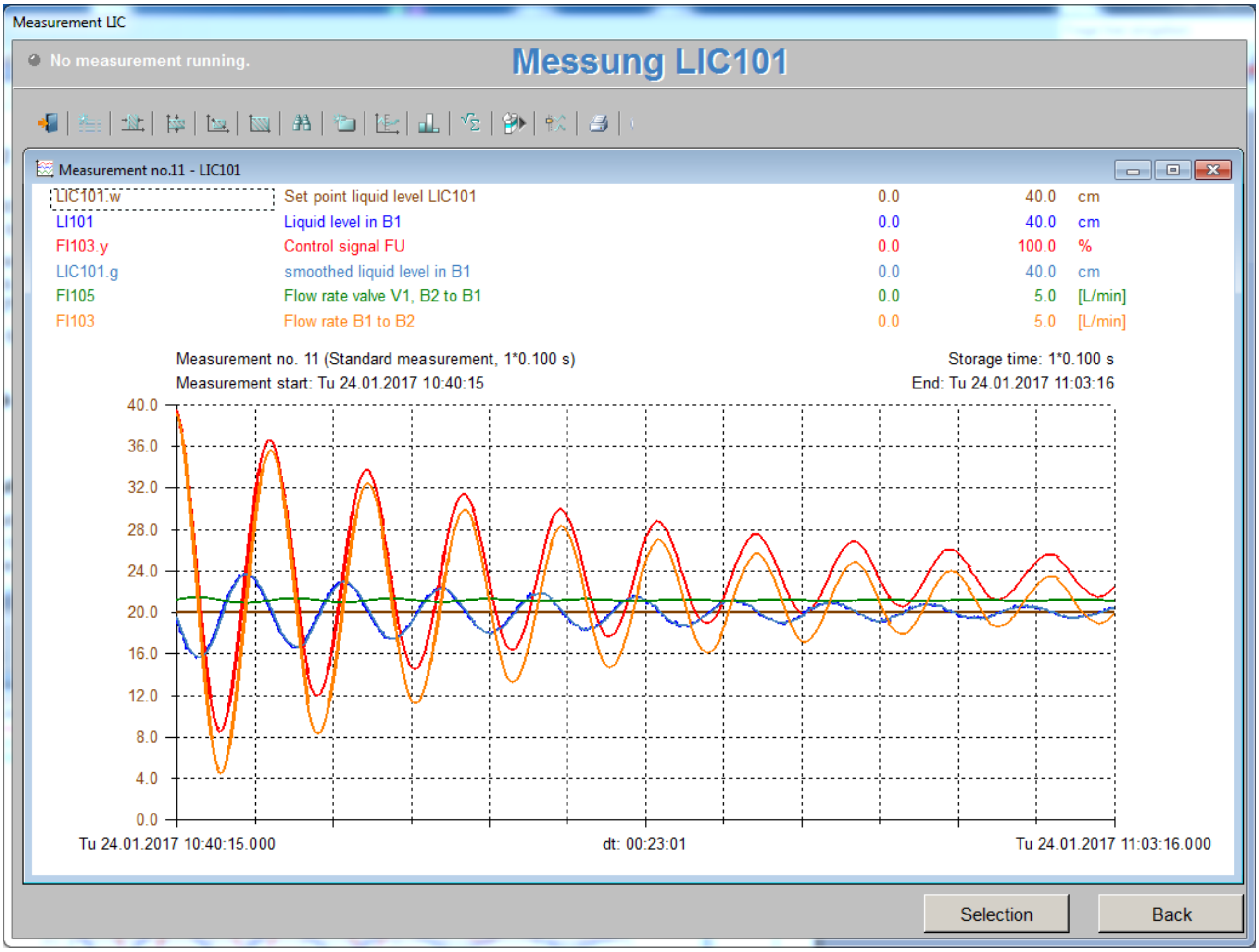


Fig. 57: Level control with PI controller, reset time 5s, gain 2

TASK 4.3.13: Increase the gain to 20, leave the reset time at 5s. Describe the behaviour of the control loop.

SOLUTION

The control loop oscillates faster. It still takes a long time until the oscillation subsides, or it looks as if the control circuit is performing a steady-state oscillation. The behaviour is not sufficient for a control because the actual value gets too slow to the set point.

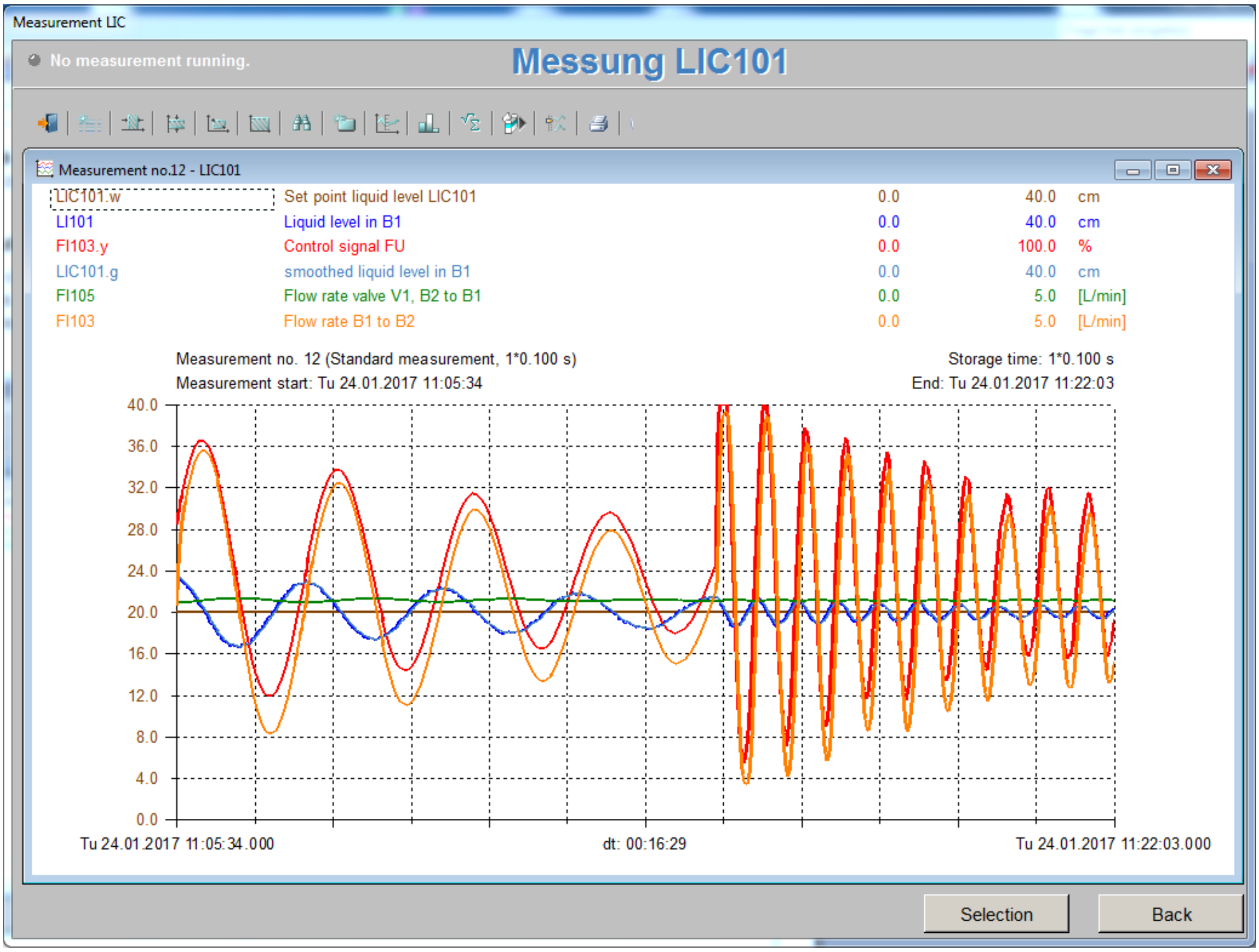


Fig. 58: Level control with PI controller, integral action time 5s, Gain was increased from 2 to 20

TASK 4.3.14: Set the reset time from 5s to 2s and observe the behaviour of the control circuit.

SOLUTION

After the reset time has been changed, the control circuit becomes rapidly unstable and begins to oscillate. It then performs a permanent oscillation.

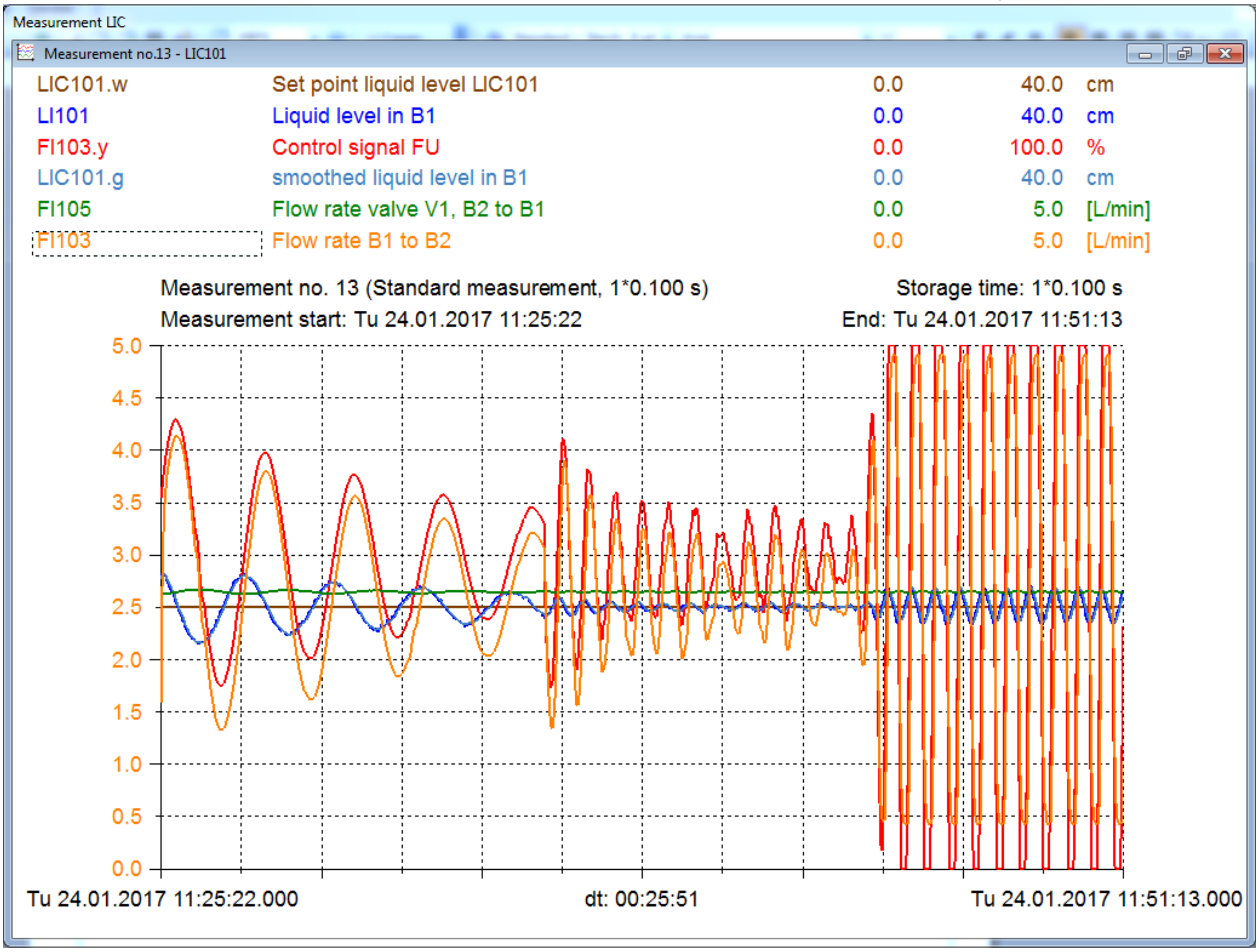


Fig. 59: Level control with PI controller, gain 20, Integral time was set from 5s to 2s

TASK 4.3.15: Try to find parameters by which the control loop is stable and the actual level quickly settles to the desired level by changing the gain and the reset time stepwise.

SOLUTION

Selection of the parameters e.g.: Reset time 15s, gain 20.

By adjusting the parameters to the values given above, the control loop becomes stable and the actual level swings quickly into the desired filling level.

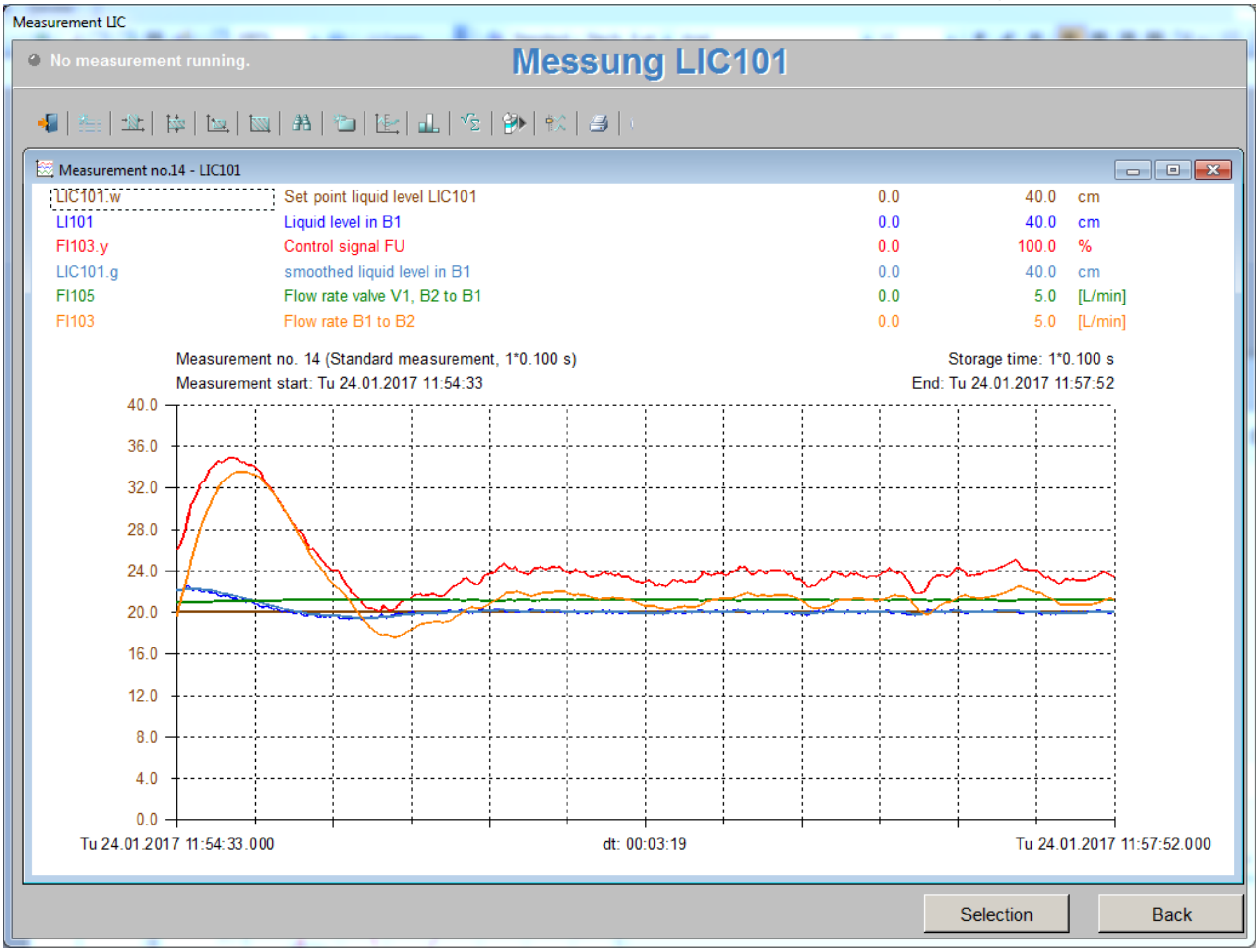


Fig. 60: Level control with PI controller, reset time 15s, gain 20

TASK 4.3.16: Use the parameters specified above to perform a set point jump from 20cm to 25cm. Observe and describe the behaviour of the control circuit to the set point jump (conduct behaviour).

SOLUTION

After a certain settling phase, the actual level reaches the desired level. The objective of the control that the actual value reaches the set point value was fulfilled in a reasonable time.

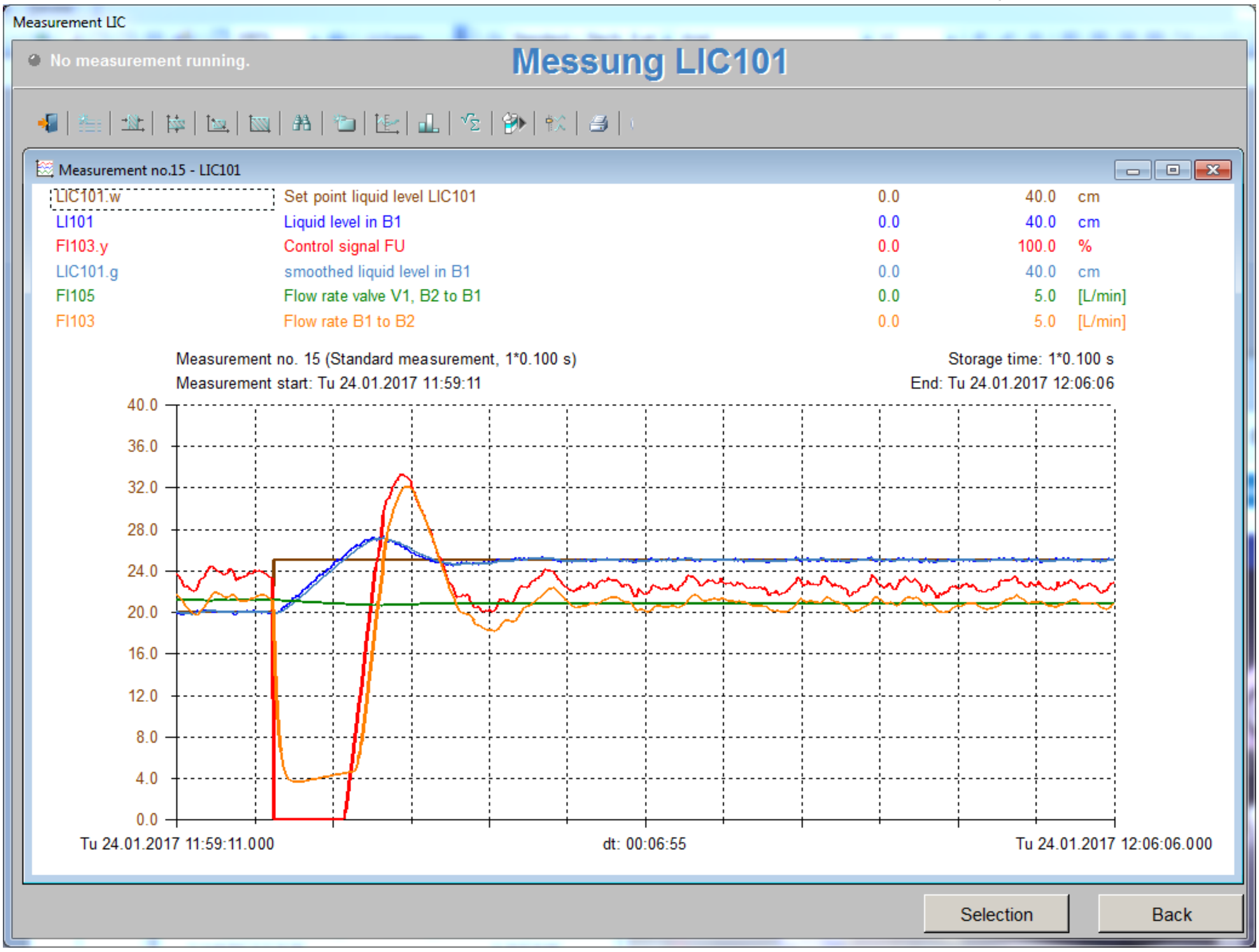


Fig. 61: Level control with PI controller, set point jump from 20 to 25

TASK 4.3.17: Indicate a disturbance by setting valve V1 downstream of pump M1 from 80% to 50%. Observe and describe the behaviour of the control circuit for a disturbance value change (disturbance behaviour).

SOLUTION

Because the inflow decreases, the outflow rate must also drop (the speed of the pump M3 is reduced), to keep the actual level at the desired level. With the parameters set above, the PI controller adjusts the actual level back to the desired level after a short settling phase.

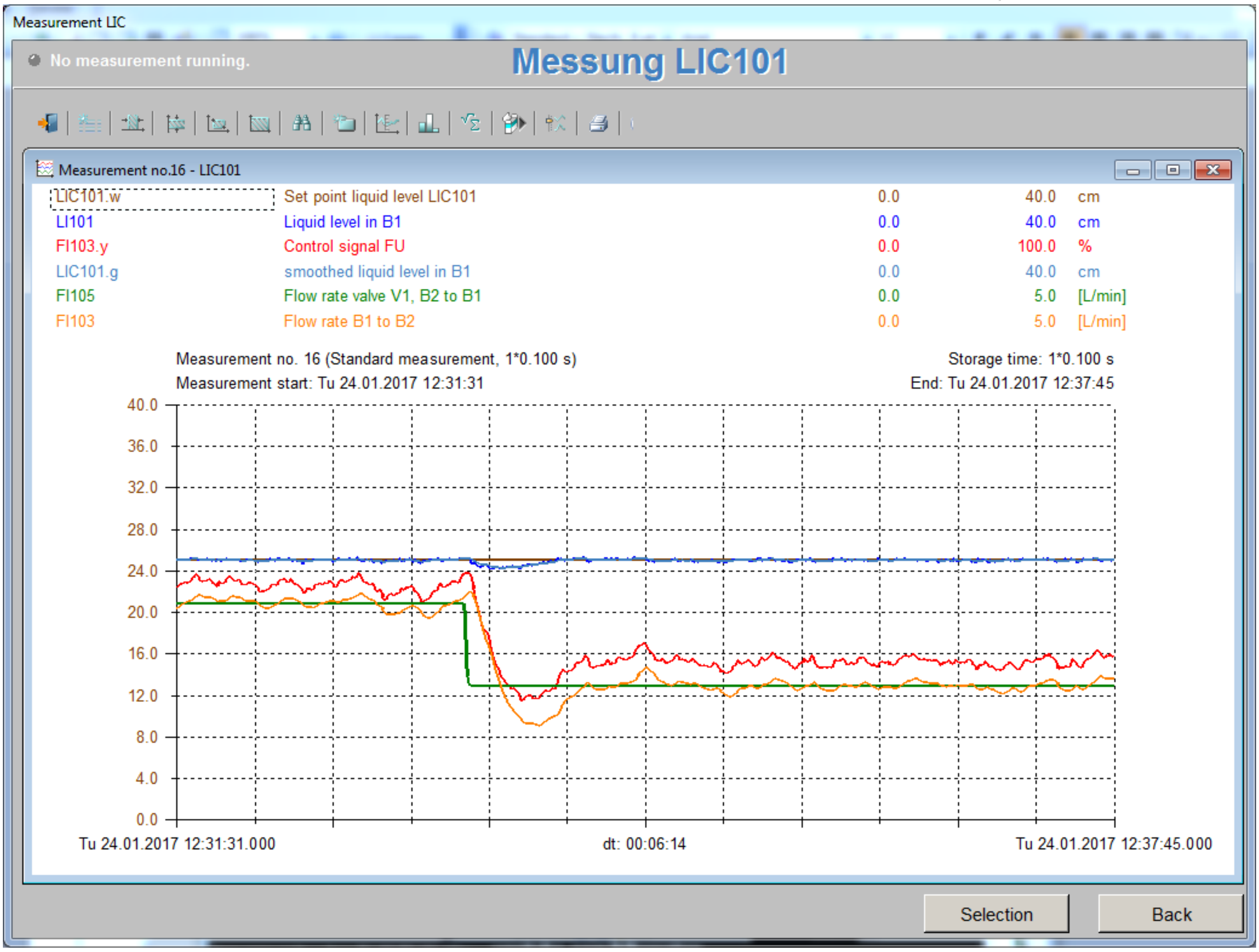


Fig. 62: Level control with PI controller, disturbance value jump

TASK 4.3.18: What happens when you turn off the low-pass filter? Observe and describe the behaviour of the control loop.

SOLUTION

Due to the high gain and the noise of the actual level, the control becomes very restless. The control signal (speed of pump M3) fluctuates strongly and thus mechanically loads pump M3.

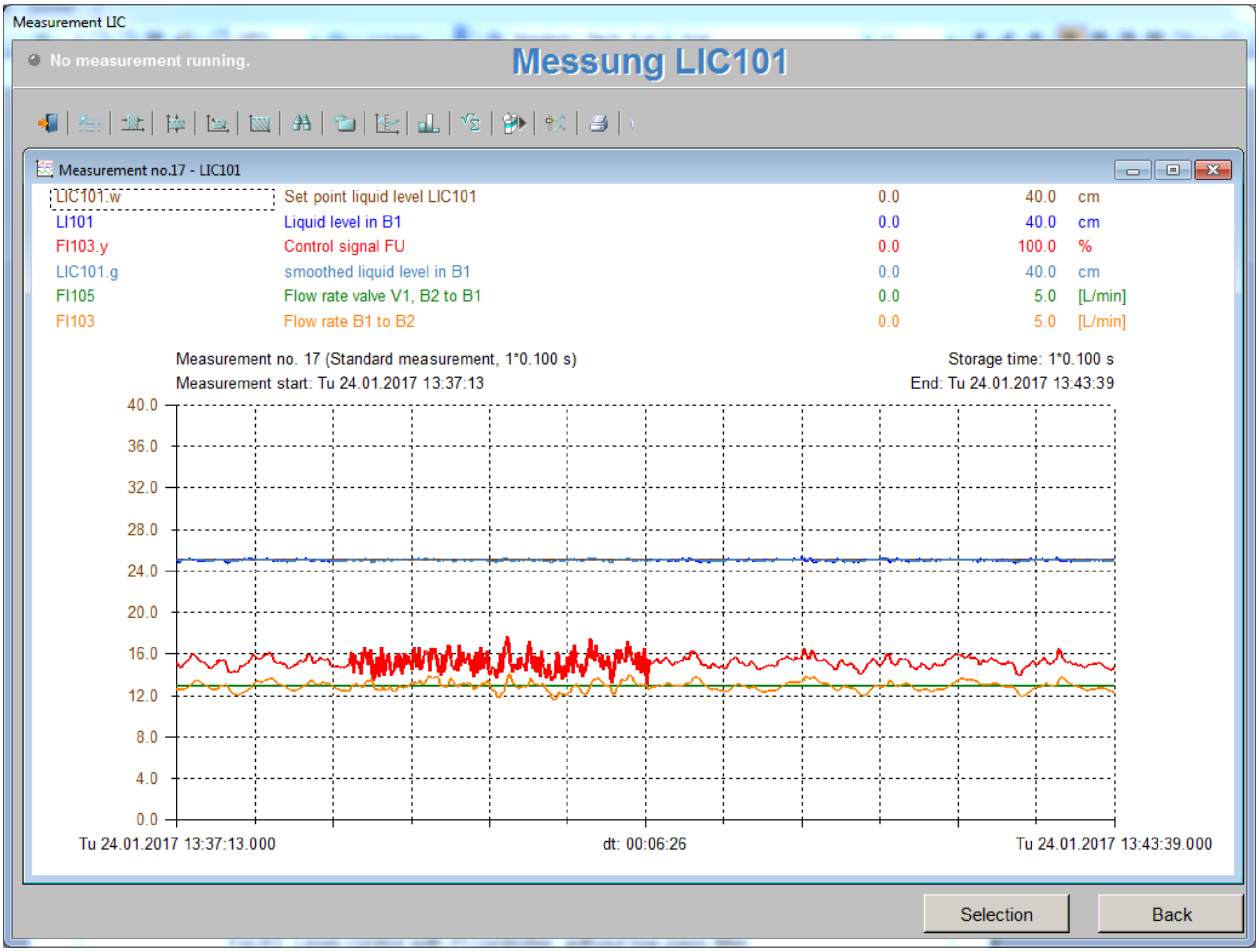


Fig. 63: Level control with PI controller, without low-pass filter

The experiments above with the PI controller show that the transient response of the control circuit is dependent on the selected controller parameters. Thus, the control circuit has been e.g. unstable at the gain 2 and the reset time 2s, while the control circuit showed an acceptable transient response at a gain of 20 and the reset time of 15s as well for guidance control as for disturbance value control.

4.3.4 EXAMINATION OF LEVEL CONTROL LIC101 WITH PID CONTROLLER

Switch on the two pumps M1 and M3 again, select the PID controller and switch control to "Auto". The low-pass filter should be switched on and set to 2.2s.

In the simulated system, the maximum flow rate of M1 is set to 3.75 l / min and that of pump M3 is set to 5 l / min (*View simulated LC2030*). The valve V1 behind the pump M1 is opened to 80%.

The following tasks were performed with the simulated plant and the above settings.

TASK 4.3.19: Set the following parameters: Gain 2, reset time 5s, derivative time 1s. Switch on the 2 pumps and switch the control to automatic. The level set point is set to 20cm. Observe the control loop and describe it´s behaviour.

SOLUTION

The control loop oscillates for a long time with these parameters. This control is not acceptable, since it takes too long before the actual level reaches the desired level.

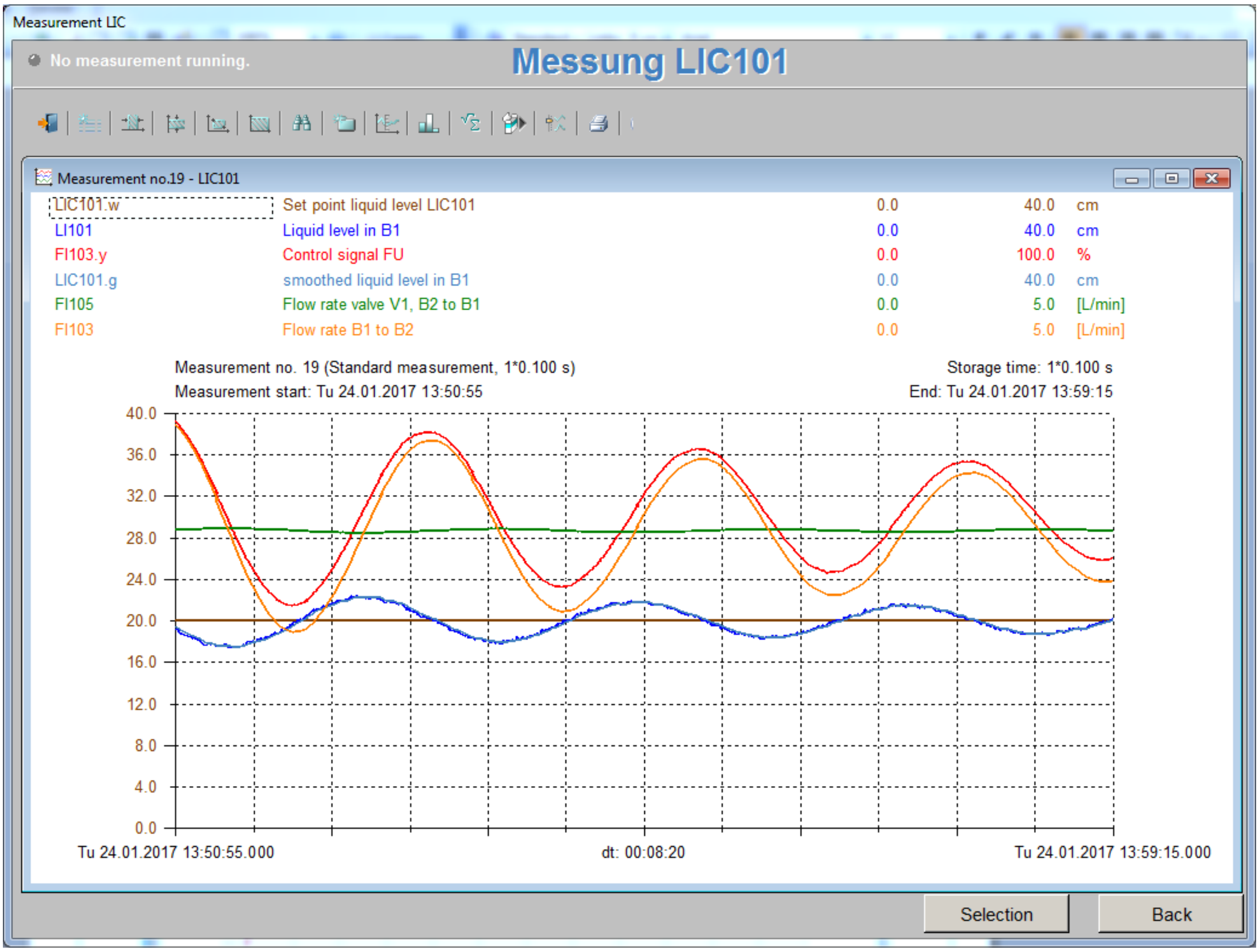


Fig. 64: Level control with PID controller and badly set parameters

TASK 4.3.20: Try to stepwise change the gain, the reset time and the derivative time so that the control loop settles in an acceptable time, meaning that the actual level settles at the desired level.

SOLUTION

Choose e.g. the following parameters: Gain 20, reset time 15s, derivative time 1s

With these parameters, the actual level rises very quickly to the desired level in the case of the still highly oscillating control circuit. Due to the high gain, the control signal FI103.y becomes more and more restless.

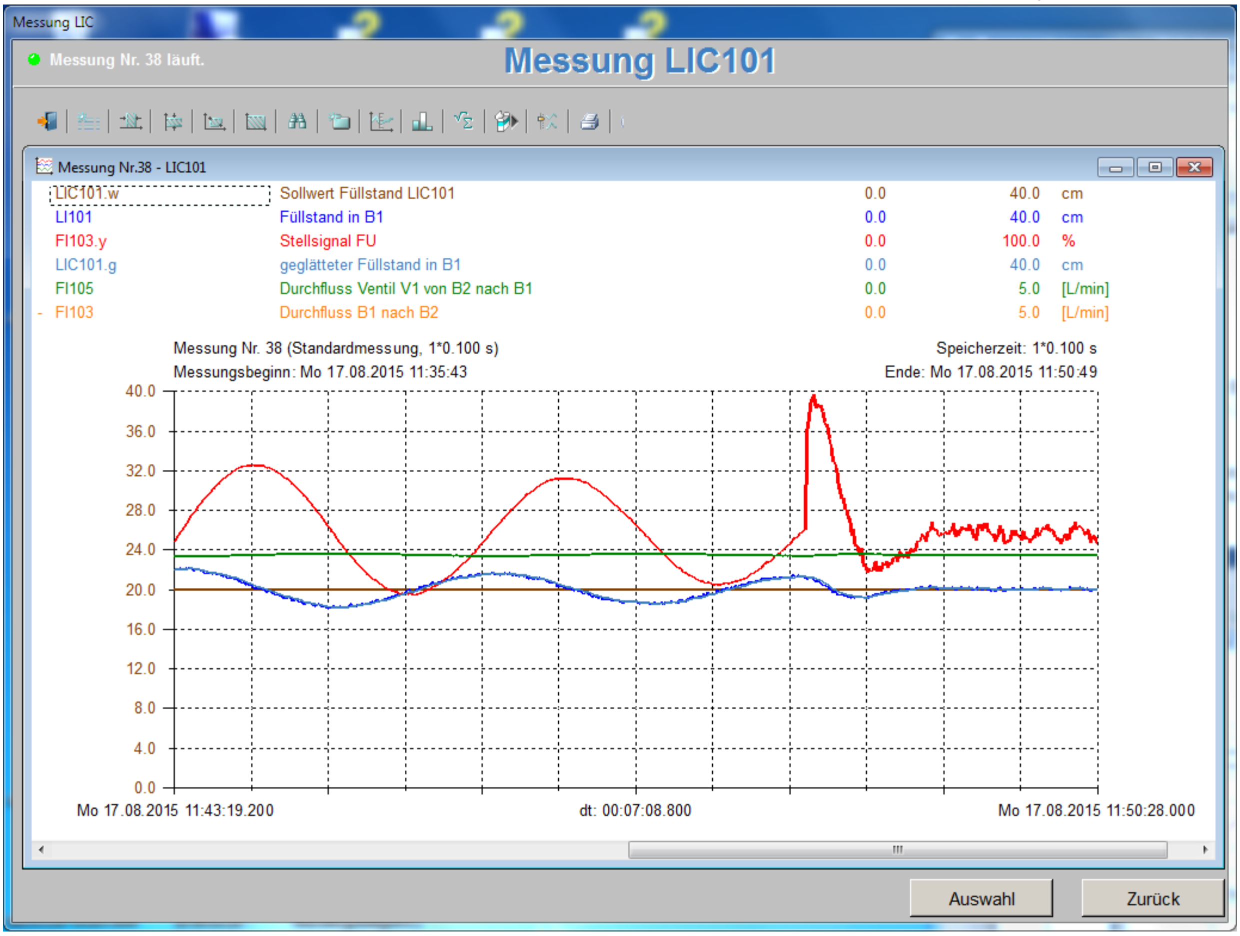


Fig. 65: Level control with PID controller and the above parameters

TASK 4.3.21: Use the PID controller and the parameters set above to set the target value from 20cm to 25cm (guidance behaviour).

SOLUTION

With the parameters defined above, the controller manages to control the circuit in an acceptable time during set point changes.

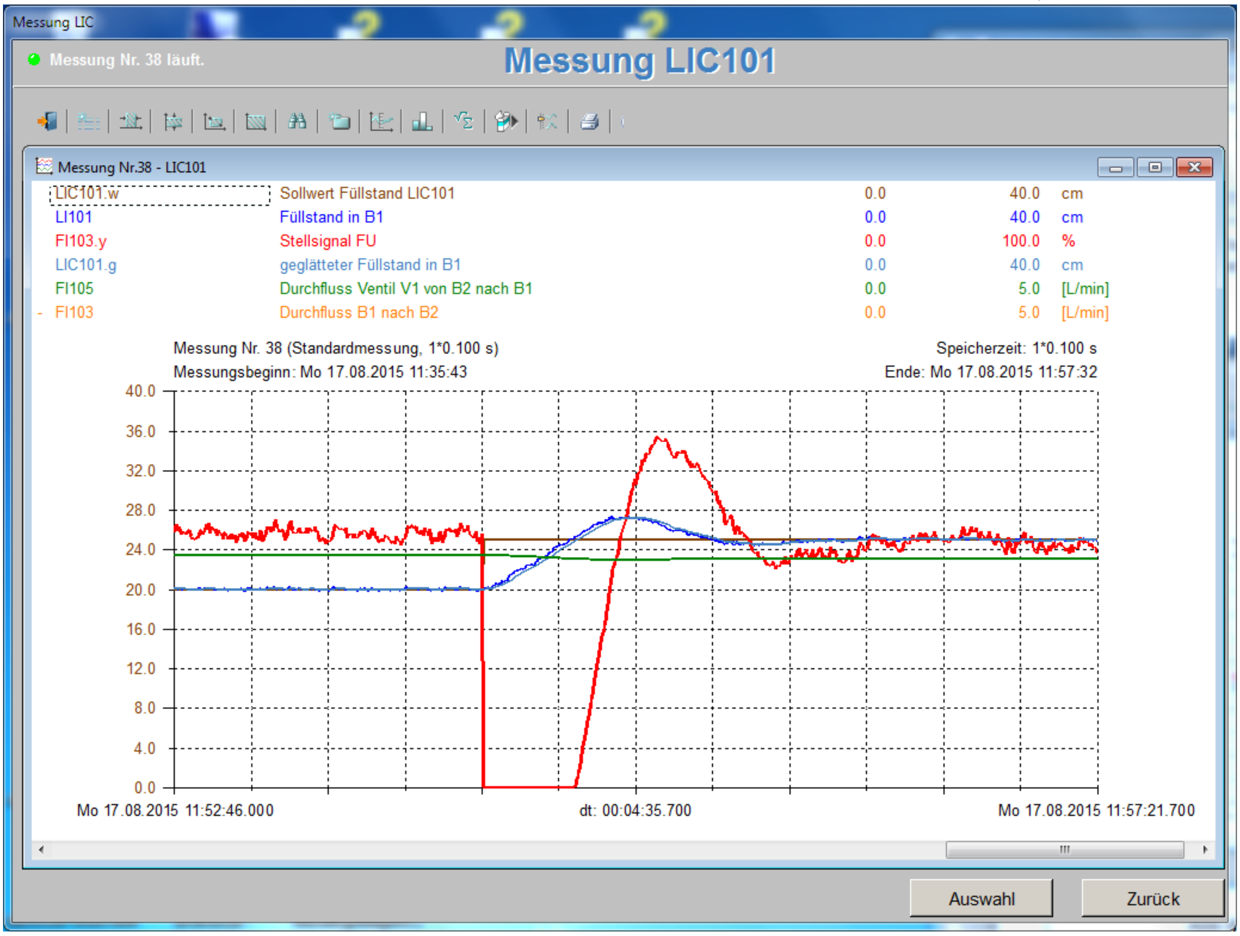


Fig. 66: Level control with PID controller, guidance behaviour

TASK 4.3.22: Wait until the control loop is steady. Then set a disturbance by changing the valve position from V1 from 80% to 50% (malfunction). Describe the behaviour of the control loop.

SOLUTION

With the parameters determined above the controller quickly compensates for the disturbance.

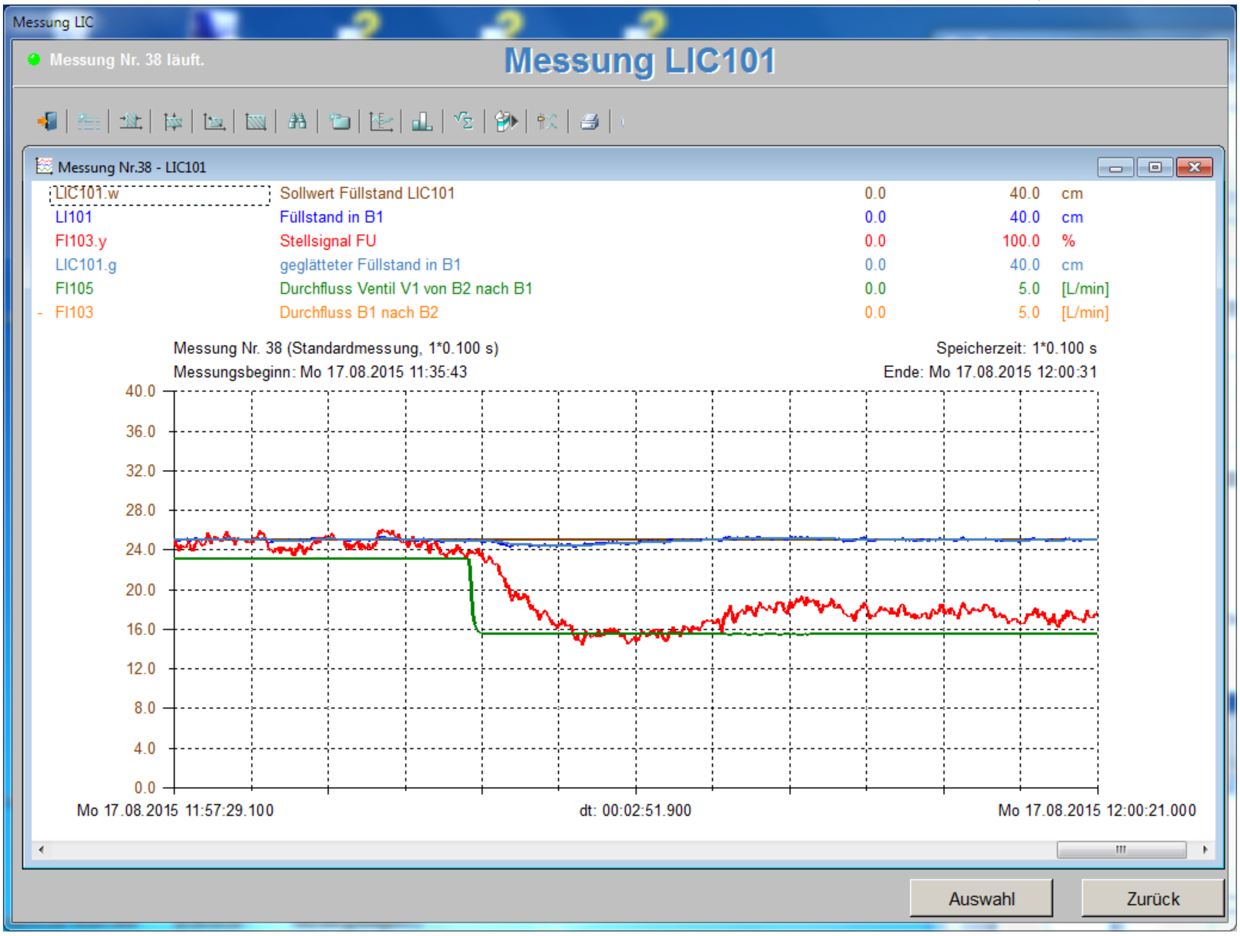


Fig. 67: Level control with PID controller, disturbance value behaviour

TASK 4.3.23: Describe what happens when you switch of the low-pass filter in the above scheme.

SOLUTION

Due to the high gain and the D-component (derivative time) of the PID controller, the noise of the actual level is amplified and the control becomes even more unstable than with the PI controller. The control signal (speed of the pump M3) changes very quickly and thus mechanically loads the pump.

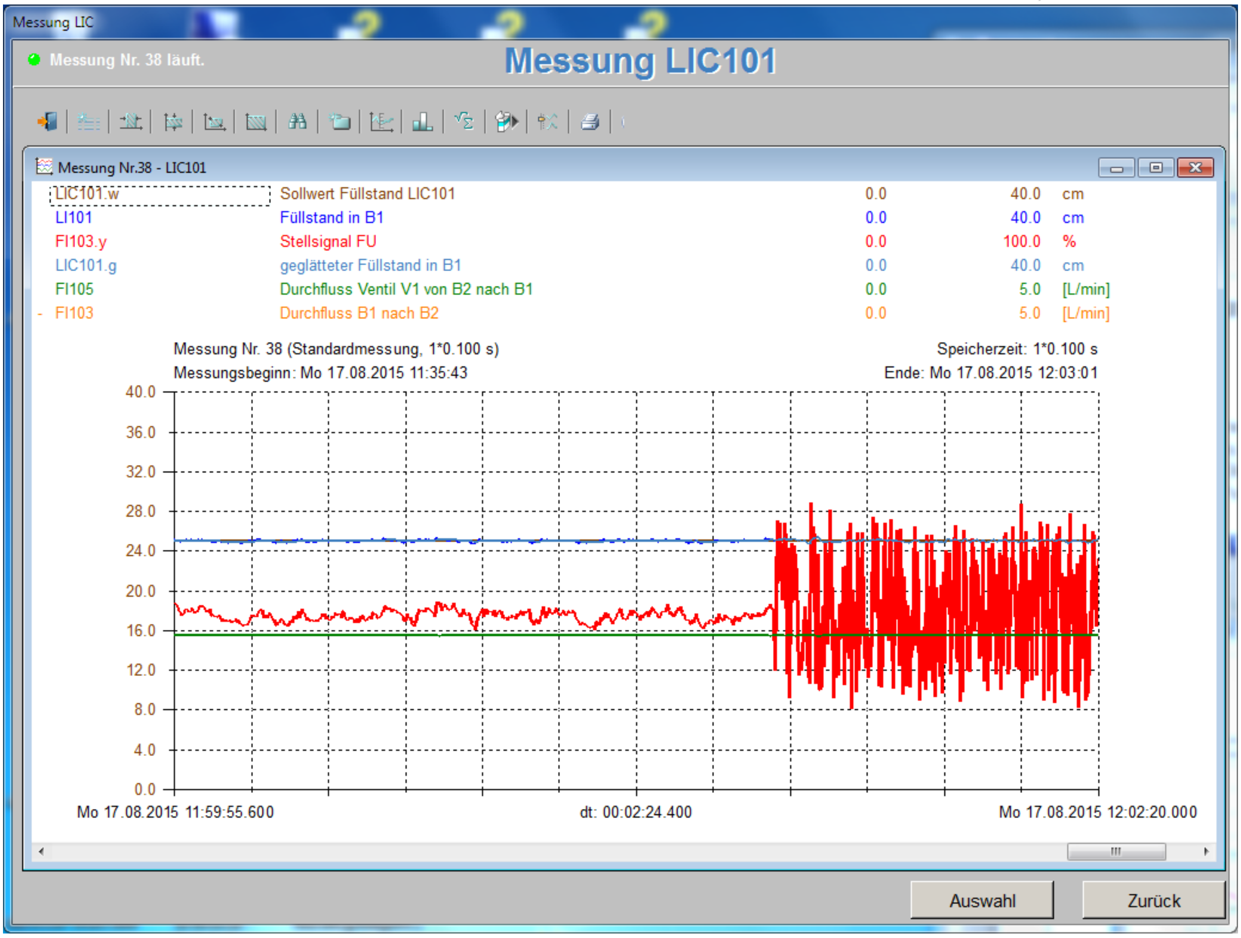


Fig. 68: Level control with PID controller, without low-pass filter

4.3.5 EXAMINATION OF LEVEL CONTROL LIC101 WITH TWO POSITION CONTROLLER

Switch back on the two pumps M1 and M3, select the two position controller and switch control to "Auto". The low-pass filter should be switched on and set to 2.2s.

In the simulated system, the maximum flow rate of M1 is set to 3.75 l / min and that of pump M3 is set to 5 l / min (*View simulated LC2030*). Valve V1 behind pump M1 is opened to 80%.

The following task was performed with the simulated plant and the above settings.

TASK 4.3.23: Follow the loop and describe its behaviour.

SOLUTION

If the actual level is below the desired level, the two position controller switches the speed of pump M3 to the minimum (0%). If the actual level is above the set point level plus the hysteresis, the controller switches the speed of pump M3 to maximum (100%). The control circuit always oscillates with the two position controller depending on the hysteresis around the level set point.

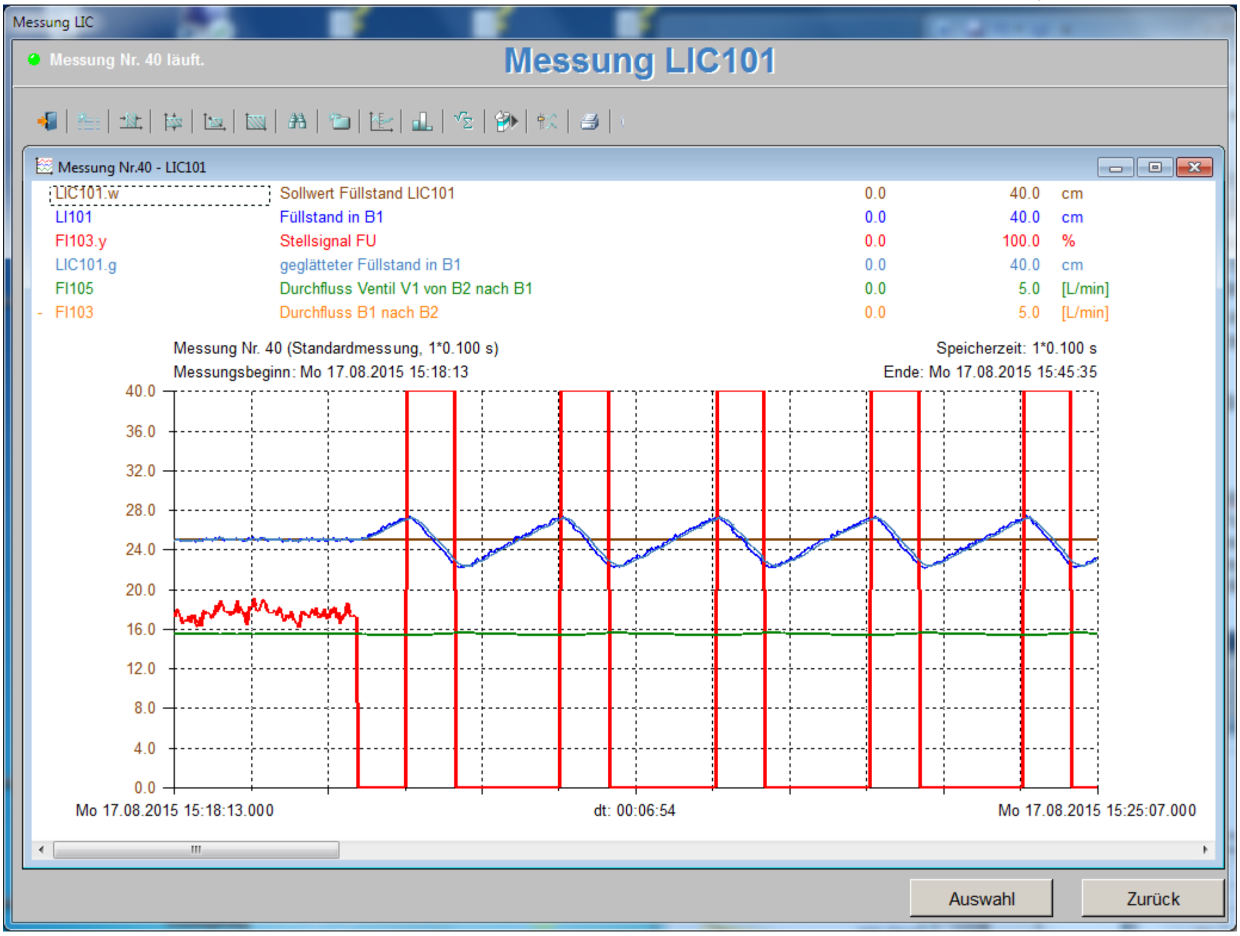


Fig. 69: Level control with two position controller

4.3.6 CONTROLLER ADJUSTMENT METHODS

In addition to the problem of selecting the appropriate controller for the control loop, control technology also has the problem of finding suitable controller parameters for the selected controller.

There are various control setting methods in the literature which support the user in the selection of the controller parameters. In these methods, the control system is examined and, depending on the behaviour of the control system, controller parameters are proposed. These methods are based on empirical studies. The suggested parameters are therefore not necessarily the optimal parameters. Often, however, these are parameters with which the control loop can be operated well in practice.

Some known controller adjustment methods are:

- Ziegler/Nichols I and II
- Chien/Hrones/Reswick
- T-Sum-Rule according to Kuhn
- Oppelt
- Method of maximum rate of rise (For temperature systems according to Müller)
- Setting rules of thumb

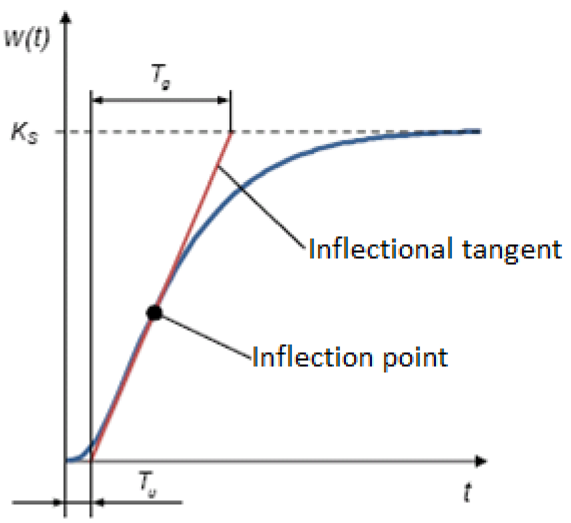
In the following, investigations are carried out using the regulator rules according to Chien / Hrones / Reswick and the rules of thumb.

4.3.7 METHOD ACCORDING TO CHIEN/HRONES/RESWICK

In the process of Chien / Hrones / Reswick, the step response is examined for a set point jump (unit jump) of the system. For this purpose, your control loop must be in a stable operating point. You must set the controller to "Manual" and the actuating signal and the control variable must not change. Provide a jump-like change of the control signal by 1 and watch the behaviour of the system.

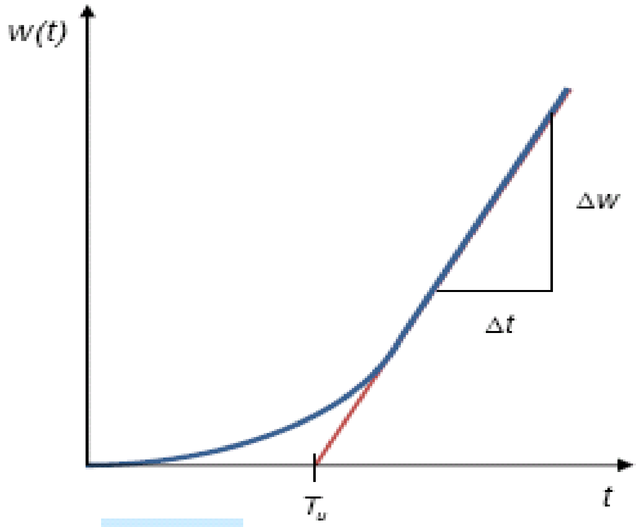
A system with compensation has approximately the following behaviour on a unit jump of the actuating signal (sudden change of the control signal by 1):

Determination of Tu and Tg from a guidance jump of a system with compensation



You can use this step response to determine the parameters Ks, Tg and Tu as shown in the figure above. The change in the control path Ks results from the sudden change of the control signal by 1. If you make a larger manipulated variable change, you must divide the resulting gain value of the path by changing the manipulated value so that you get Ks.

If you have a system without compensation, the following behaviour will result in a unit jump of the control signal:



$$K_{is} = \frac{\Delta w}{\Delta t}$$

Here you can determine K_{is} as the slope of the tangent and T_u as the intersection of the tangent with the time axis. From K_{is}, calculate the time constant T_i by $T_i = 1 / K_{is}$.

Variables:

T_u	Period of delay
T_g	Recovery time of the controlled system
K_s	Transfer coefficient of the control section with compensation
K_{is}	Transfer coefficient of the control loop without compensation

The controller parameters are determined from the setting table according to Chien / Hrones / Reswick:

Controller	Quality criteria			
	Overshoot of 20% to opposite site		Aperiodic control behaviour	
	disturbance	guidance	disturbance	guidance
P	$K_P \approx \frac{0{,}7}{K_S} \cdot \frac{T_g}{T_u}$	$K_P \approx \frac{0{,}7}{K_S} \cdot \frac{T_g}{T_u}$	$K_P \approx \frac{0{,}3}{K_S} \cdot \frac{T_g}{T_u}$	$K_P \approx \frac{0{,}3}{K_S} \cdot \frac{T_g}{T_u}$
PI	$K_P \approx \frac{0{,}7}{K_S} \cdot \frac{T_g}{T_u}$ $T_n \approx 2{,}3 \cdot T_u$	$K_P \approx \frac{0{,}6}{K_S} \cdot \frac{T_g}{T_u}$ $T_n \approx T_g$	$K_P \approx \frac{0{,}6}{K_S} \cdot \frac{T_g}{T_u}$ $T_n \approx 4 \cdot T_u$	$K_P \approx \frac{0{,}35}{K_S} \cdot \frac{T_g}{T_u}$ $T_n \approx 1{,}2 \cdot T_g$
PID	$K_P \approx \frac{1{,}2}{K_S} \cdot \frac{T_g}{T_u}$ $T_n \approx 2 \cdot Tu$ $T_v \approx 0{,}42 \cdot T_u$	$K_P \approx \frac{0{,}95}{K_S} \cdot \frac{T_g}{T_u}$ $T_n \approx 1{,}35 \cdot T_g$ $T_v \approx 0{,}47 \cdot T_u$	$K_P \approx \frac{0{,}95}{K_S} \cdot \frac{T_g}{T_u}$ $T_n \approx 2{,}4 \cdot T_u$ $T_v \approx 0{,}42\, T_u$	$K_P \approx \frac{0{,}6}{K_S} \cdot \frac{T_g}{T_u}$ $T_n \approx T_g$ $T_v \approx 0{,}5 \cdot T_u$

For systems without compensation instead of $\frac{T_g}{K_S \cdot T_u}$ use $\frac{1}{K_{IS} \cdot T_u}$

[The table has been adopted from: E. Samal, Ground plan of practical control engineering, Oldenbourg]

If you have a system without compensation, you must use the expression *1 / (K_{is} * T_u)* in the table instead of the expression *T_g / (K_s * T_u)* and replace the time constant T_g with *T_i = 1 / K_{is}*.

4.3.8 CONTROLLER SETTINGS OF THE FILLING LEVEL CONTROL LIC101 ACCORDING TO CHIEN/HRONES/RESWICK

The level system is a system without compensation. In order to be able to switch on a set point jump, the system must be in a stable operating point. For operating point, select. 20 cm.

To get a stable system (i.e. control variable x and the control signal y do not change any more), the inflow must be equal to the outflow. Since it will be very difficult to manually adjust the control signal by keeping the level at 20cm with a constant control signal, you can select the PI controller and try to keep the level constantly at 20cm after a settling phase . Finally the control signal must not fluctuate anymore.

The following investigations were carried out with the simulated plant and the above settings.

For this experiment, only switch on pump M1 and pump M3 and set valve V1 to 100%. The maximum flow rate of M1 should be set to 3.75 l / min and that of pump M3 should be set to 5 l / min (*View simulated LC2030*).

Then switch the controller to manual and give a manipulated value jump of e.g. 20% (a jump from 75% to 55% in Fig. 70).

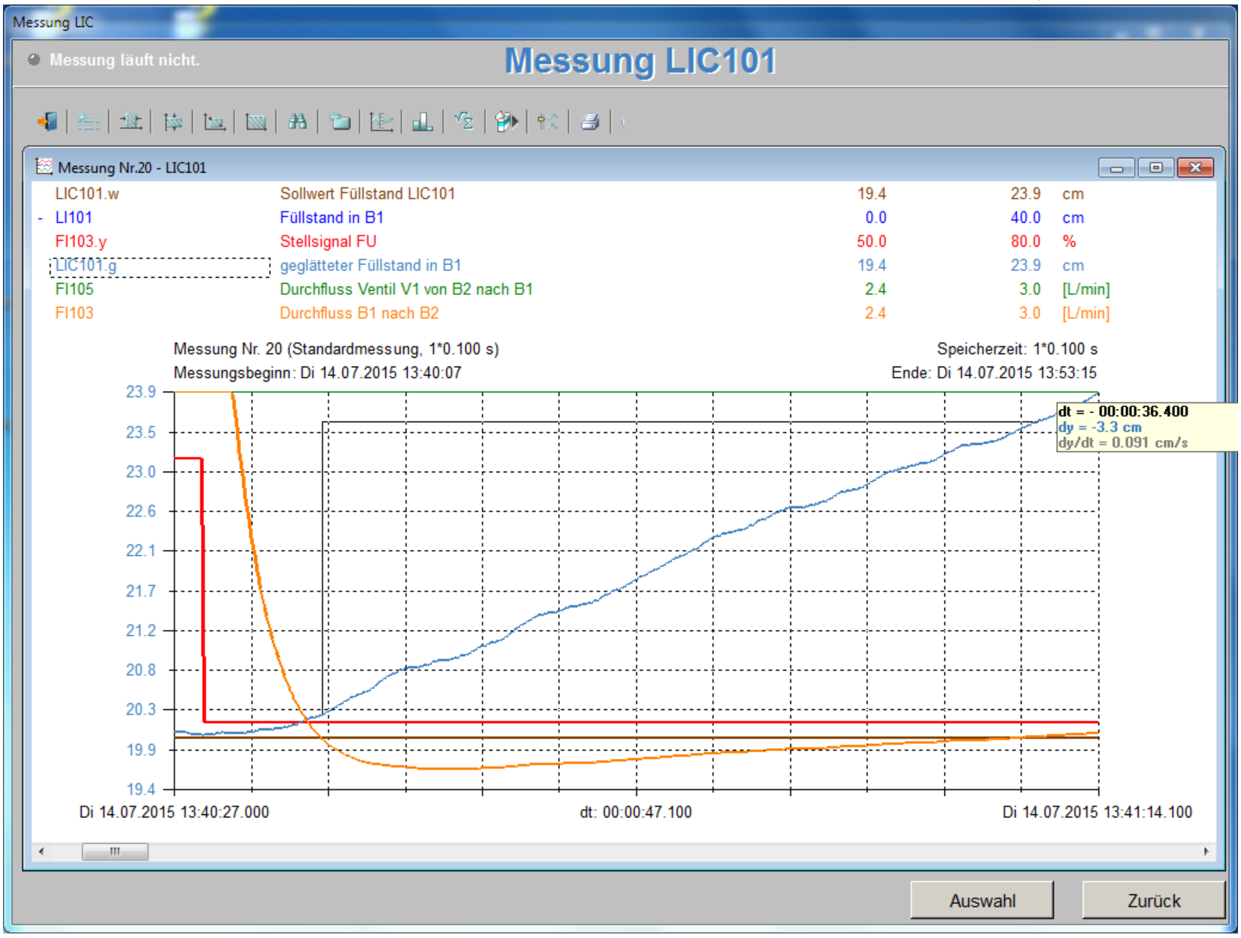


Fig. 70: Actuating variable jump from 75% to 55%

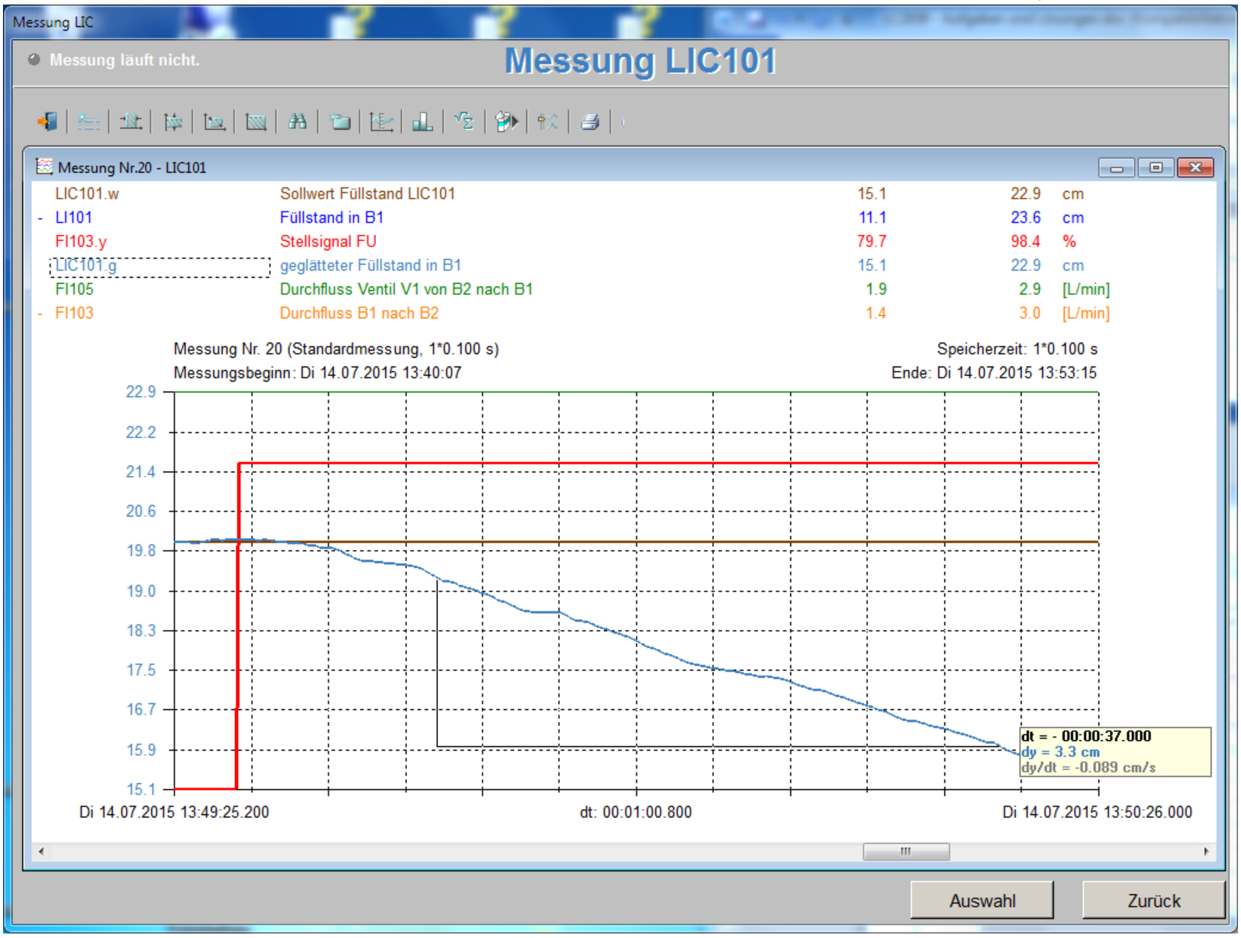


Fig. 71: Step response to a actuating value jump from 75% to 95%

TASK 4.3.24: Determine Tu for both step responses and take the average to calculate Kis and Ti.

SOLUTION

In Fig. 70 and Fig. 71 you can measure T_u and K_{is}. In Fig. 70, a T_u of about 3s was obtained, while in Fig. 71 about 4.5s were measured. The slope of the straight line in Fig. 70 is approx. 0.091 while in Fig. 71 approx. 0.089 were measured. Thus the slope can be assumed as approximately 0.09 for both cases.

Since we have set a jump of 20% we get

$K_{is} = 0,09 / 20 = 0,0045$

And with that

$T_i = 1/K_{is} = 222,23s$

Measured was

$T_u = 3s$ (In Fig. 70 with the negative jump of the control signal)

or.

$T_u = 4,5s$ (In Fig. 71 with the positive jump of the control signal)

TASK 4.3.25 Calculate controller parameters for guidance control with PI-controller from the table with 20% overshoot.

SOLUTION

For the PI controller, the following controller parameters for the behaviour result from the table at 20% overshoot:

$$K_p = 0.6 * T_g/(K_s*T_u) = 0,6 * 1/(K_{is}*T_u)$$

and

$$T_n = T_g = T_i$$

Thus, for Fig. 70, we obtain the negative jump of the control signal:

PI-Controller: $K_p = 0,6 * 1/(0,0045*3) = 44,5$ and $T_n = 222s$

Thus, for Fig. 71, we obtain the positive jump of the control signal:

PI-Controller: $K_p = 0,6 * 1/(0,0045*4,5) = 29.6$ and $T_n = 222s$

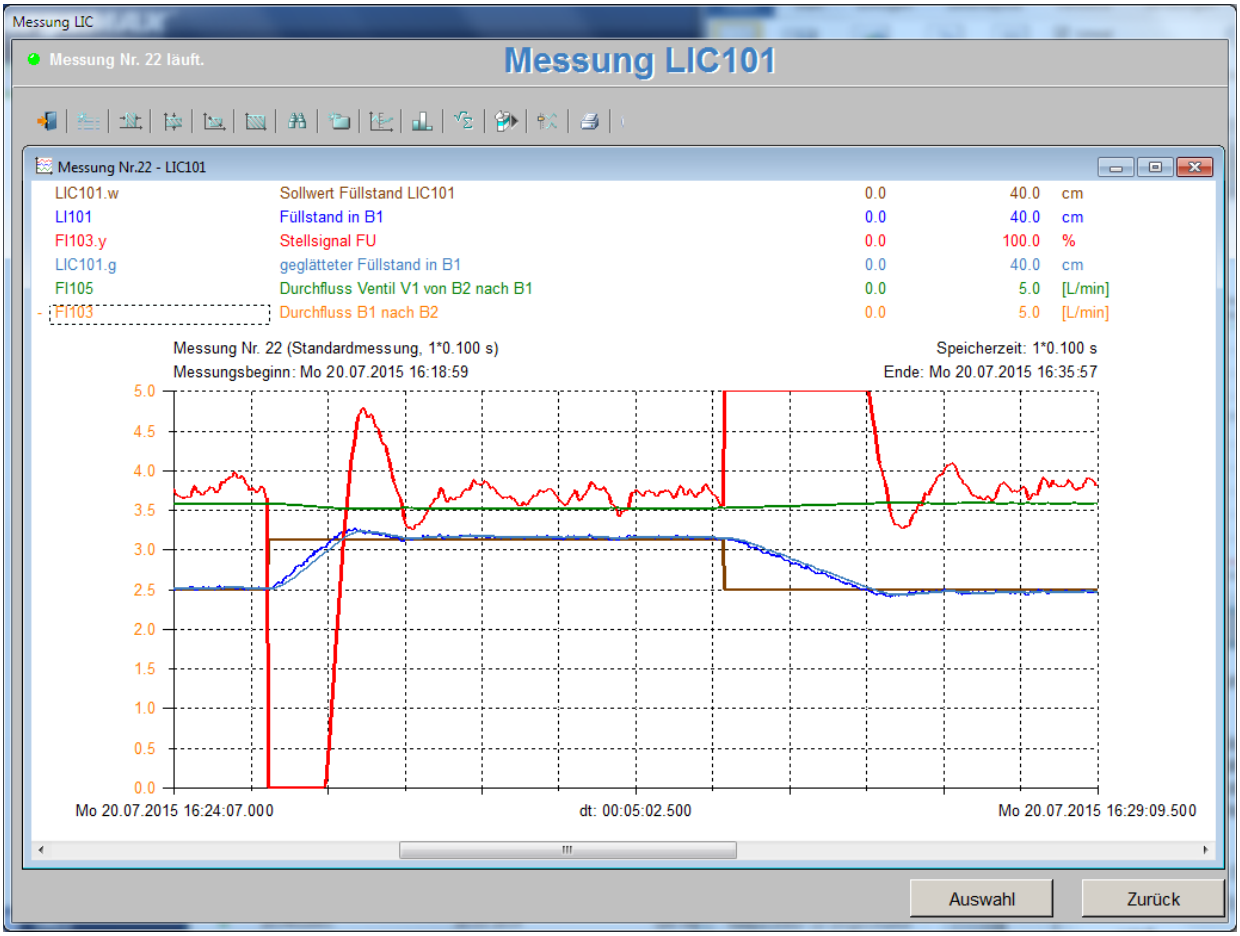


Fig. 72 PI controller according to Chien / Hrones / Reswick for guidance jump with 20% overload with gain Kp = 44.5

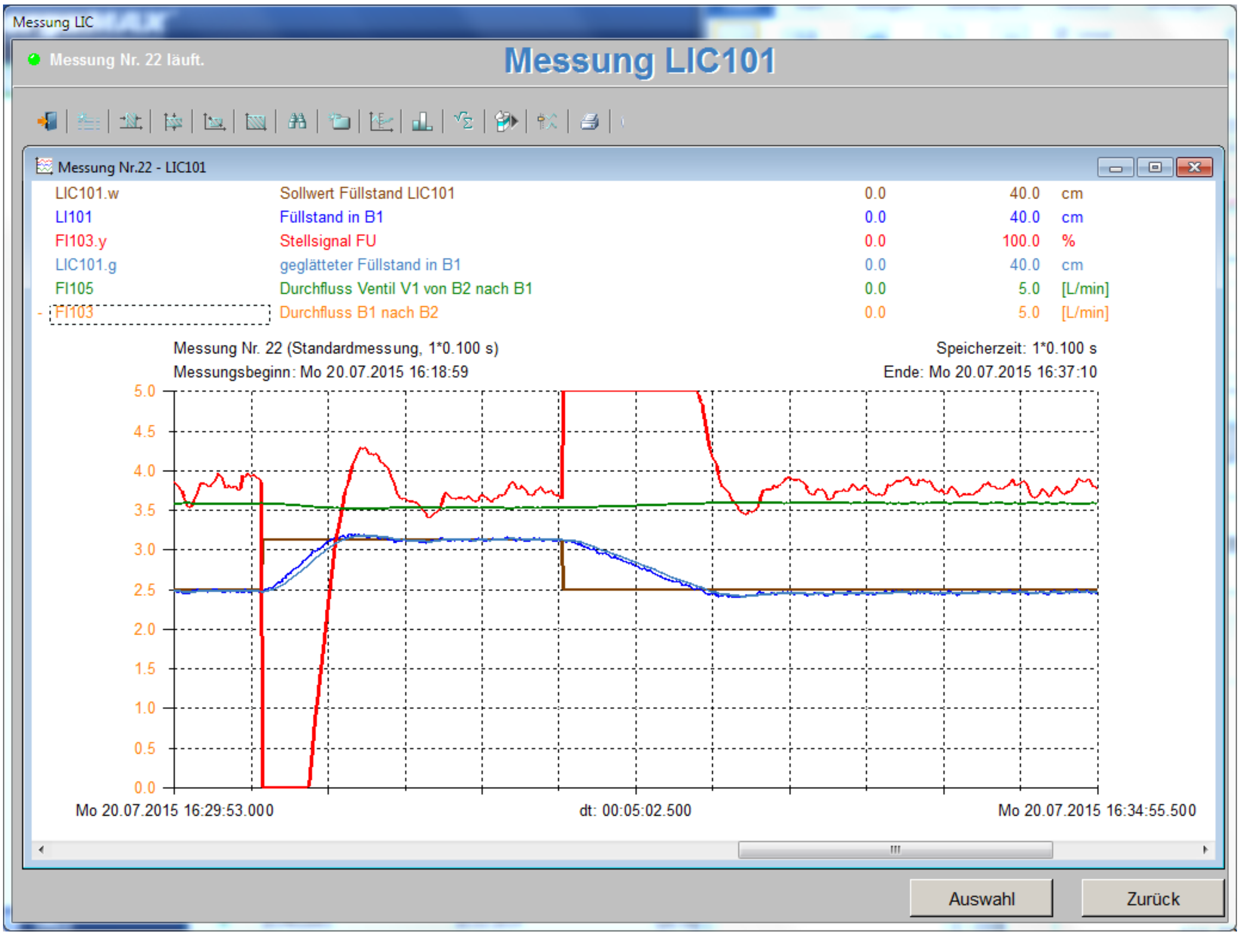


Fig. 73: PI controller according to Chien / Hrones / Reswick for guidance jump with 20% overload, upper image, lower image with Kp = 29.6

In each case, a set point jump was made from a 20cm level to 25cm or from 25cm to 20cm.

In Fig. 72, the gain Kp = 44.5 was selected and the gain in Fig. 73 was 29.6. The reset time Tn was 222 s.

With both gains and the set reset time, a reasonable transient response is obtained. The actual level reaches the new nominal level comparatively quickly with a small overshoot.

TASK 4.3.26: Calculate controller parameters for guidance control with PI-controller without overshoot.

SOLUTION

The following controller parameters result from the table for the behaviour without overshoot (aperiodic case):

$$K_p = 0.35 * T_g/(K_s*T_u) = 0,35 * 1/(K_{is}*T_u)$$

and

$$T_n = 1,2 * T_g = 1,2 * T_i$$

For $T_u = 3s$ we get:

PI-Controller: $K_p = 0{,}35 * 1/(0{,}0045*3) = 26$ and $T_n = 1{,}2 * 222s = 266s$

For $T_u = 4{,}5s$ we get:

PI-Controller: $K_p = 0{,}35 * 1/(0{,}0045*4{,}5) = 17$ and $T_n = 1{,}2 * 222s = 266s$

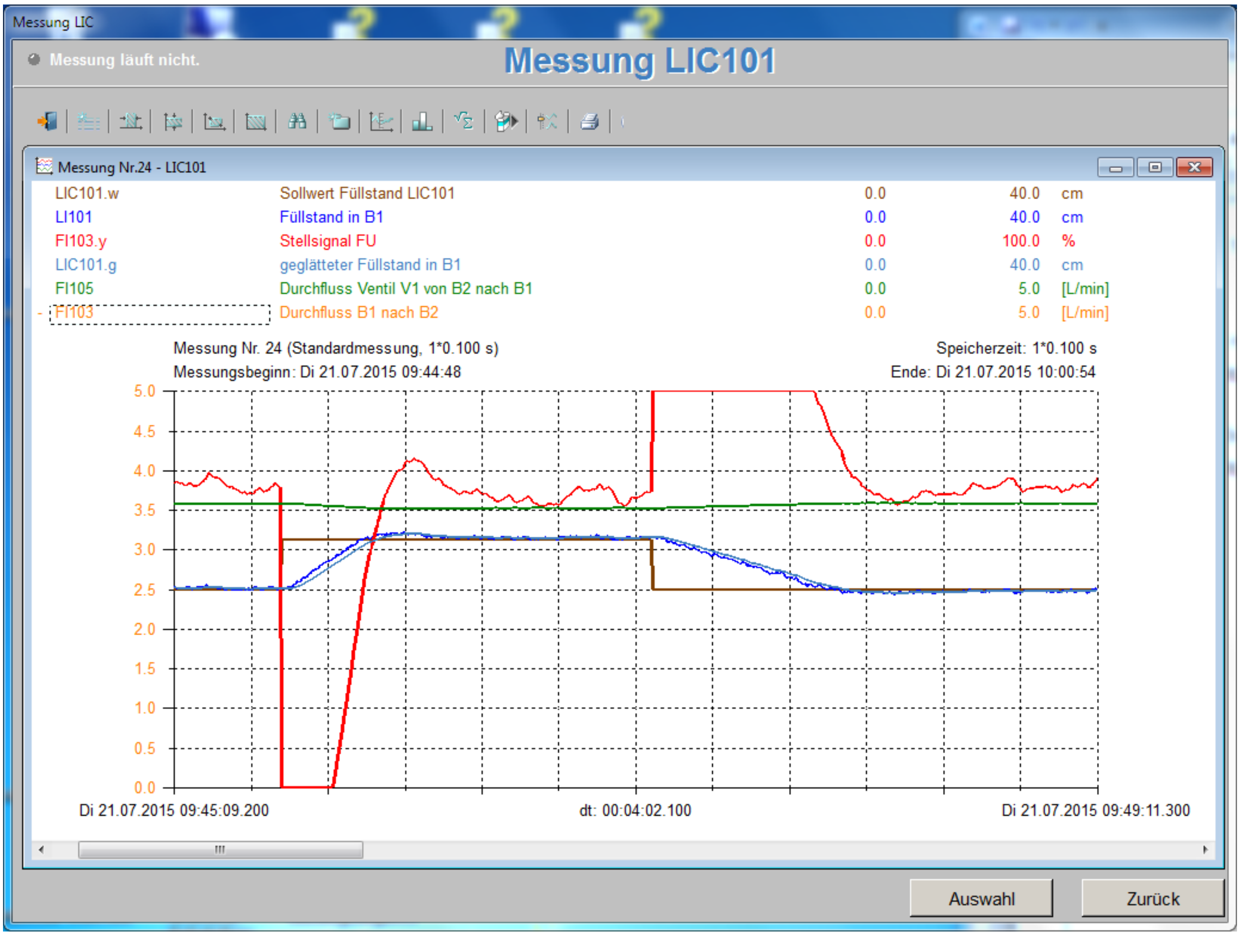


Fig. 74 PI-controller according to Chien / Hrones / Reswick for guide jump without overflow upper image with gain Kp = 26

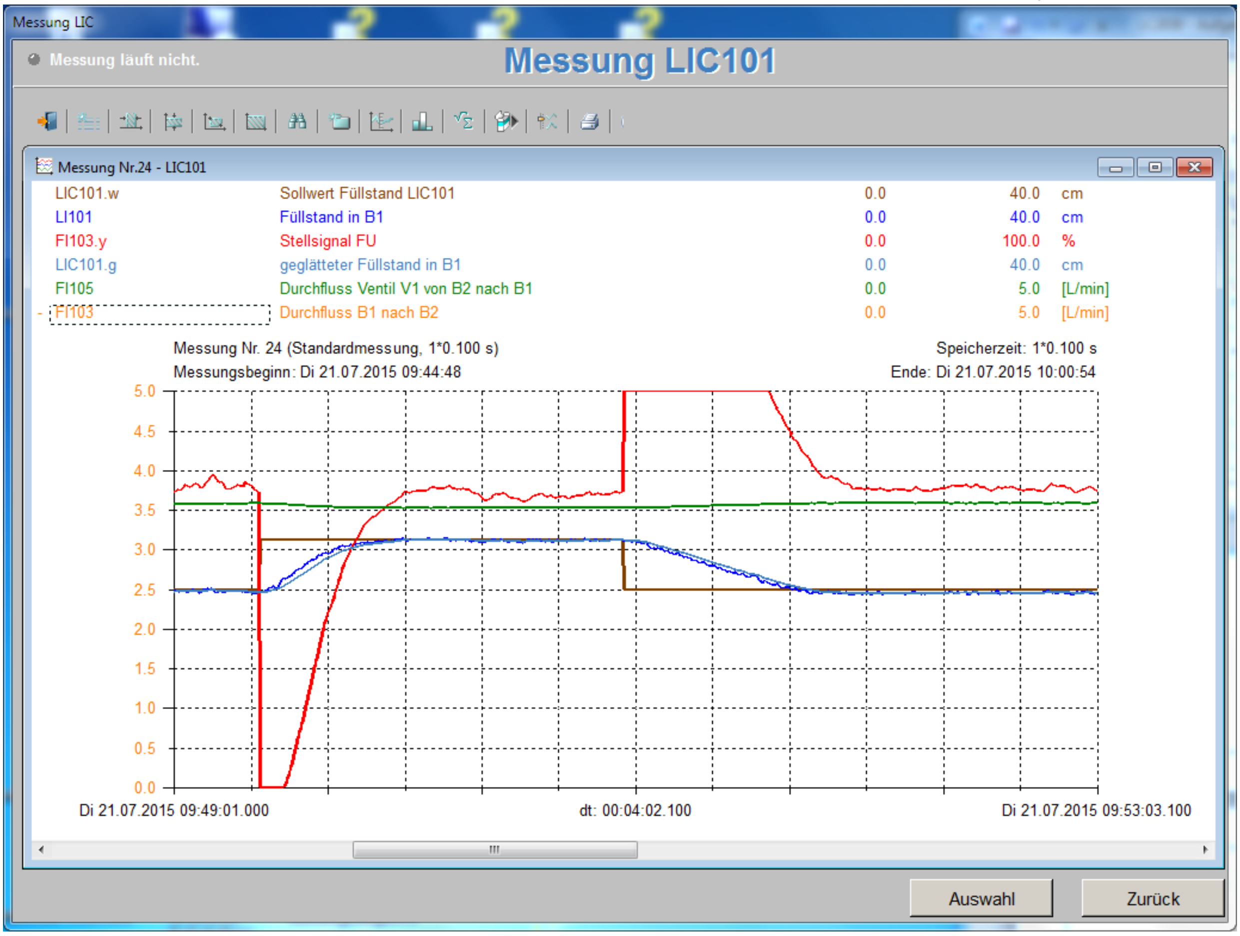


Fig. 75: PI-controller according to Chien / Hrones / Reswick for guide jump without overflow upper image with gain Kp = 17

In each case, a set point jump was made from a 20cm level to 25cm or from 25cm to 20cm.

In Fig. 74 the gain is Kp = 26 and in Fig. 75 the gain is Kp=17. The reset time Tn was 266 seconds.

In Fig. 74 with the gain Kp = 26, the control oscillates minimally. In Fig. 75, the actual level reaches the new set point without overshoot.

The controller parameters determined by the Chien / Hrones / Reswick are well suited for initial controller settings. However, not all criteria is fulfilled, such as, e.g. Fig. 74, the actual value oscillates over the set value, although the asymptotic case has been selected for the calculation of the controller parameters. This is, due to the empirical method, where the determination of the delay time T_u, the compensation time T_g and the transmission coefficient K_s or K_{is} is inaccurate.

TASK 4.3.27: Calculate controller parameters for disturbance control with PI controller with 20% overshoot.

SOLUTION

The following controller parameters are obtained for the disturbance behaviour with 20% overshoot:

For $T_u = 3s$ we get:

PI-Controller: $K_p = 0,7 * 1/(0,0045*3) = 52$ and $T_n = 2,3 * 222s = 510s$

For $T_u = 4,5s$ we get:

PI-Controller: $K_p = 0,7 * 1/(0,0045*4,5) = 35$ and $T_n = 2,3 * 222s = 510s$

The disturbance was generated by setting the valve from 100% to 50% and from 50% to 100%.

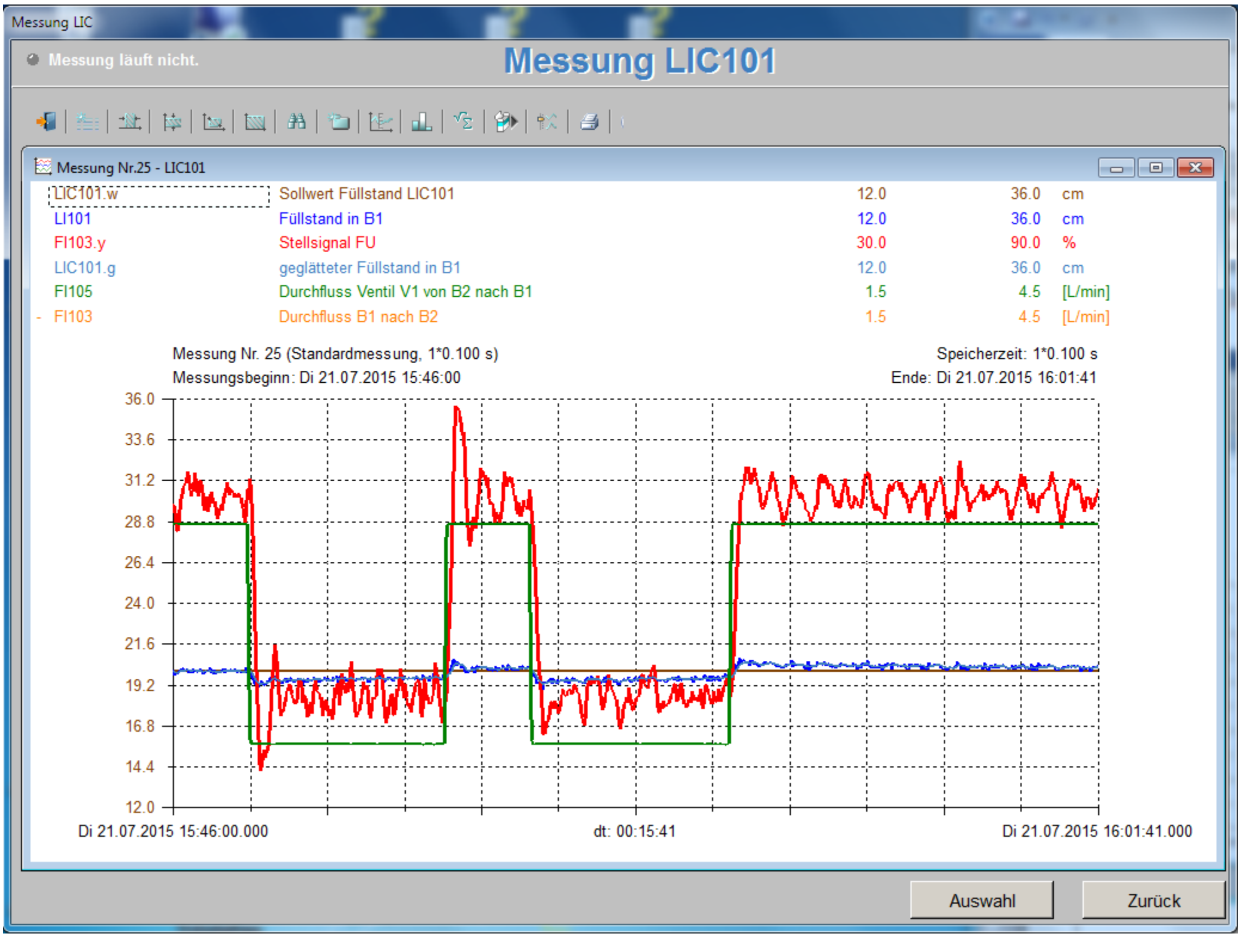


Fig. 76: PI-controller according to Chien / Hrones / Reswick for disturbance behaviour with overshoot

As can be seen in Fig. 76 and Fig. 77, the controller parameters according to Chien / Hrones / Reswick are suitable for the disturbance behaviour of the control circuit.

Since the controller parameters for the disturbance and guidance behaviour are completely different, it is always important to determine whether the control circuit is primarily to react to set point or to disturbance value changes during the design of a control loop.

If both set point changes and disturbances occur during control, a compromise must be found for the controller parameters.

Fig. 77 shows the behaviour on a disturbance (valve V1 was switched from 100% to 50% and from 50% to 100%) with the parameters for the guidance behaviour with 20% overflow.

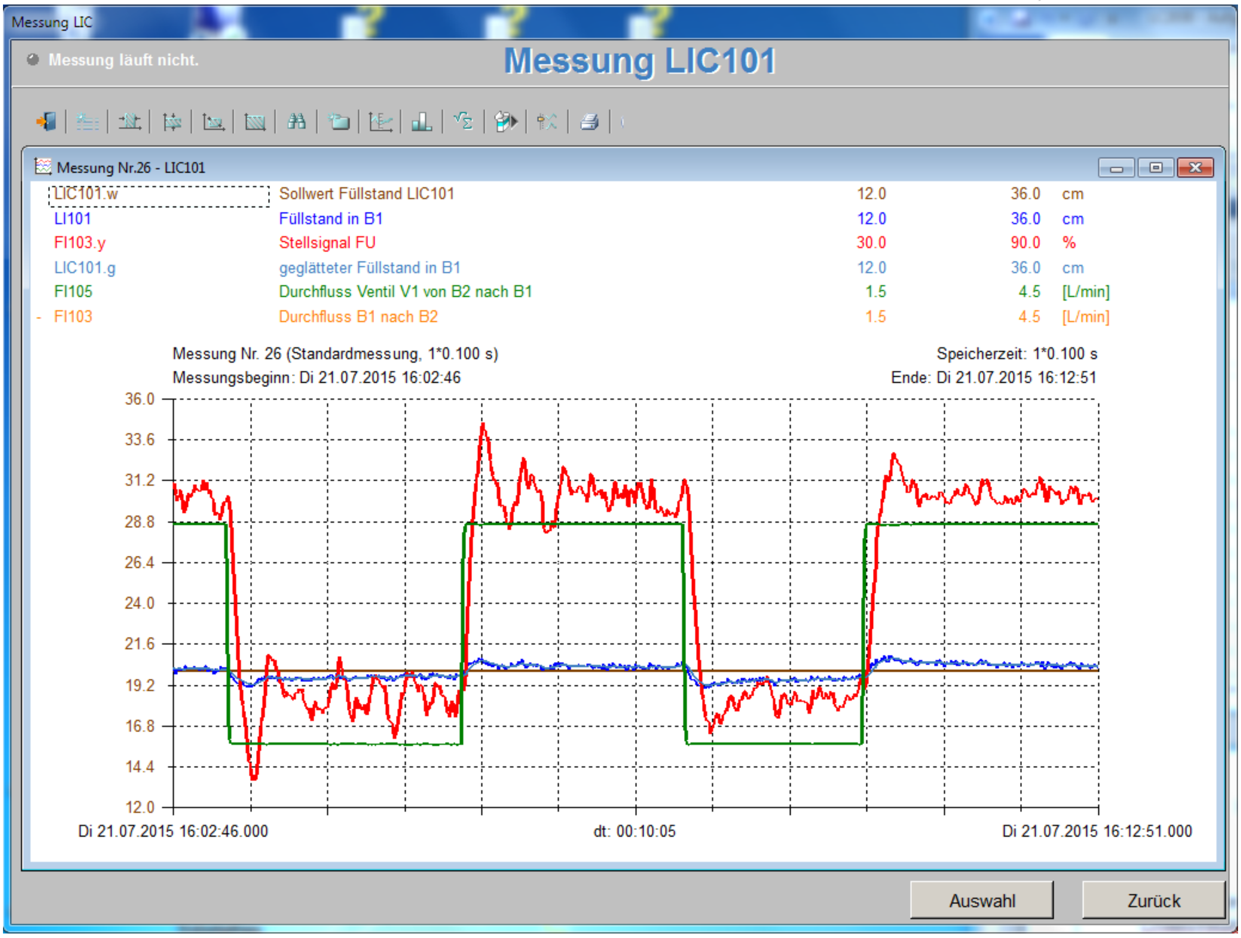


Fig. 77: PI-controller according to Chien / Hrones / Reswick for disturbance behaviour with overshoot (Kv = 44,5, Tn = Ti = 222s in the first part or. Kv = 29,6, Tn = Ti = 222s in the second part)

As is shown in the transient response to the disturbance, in this case the adjusted parameters of the guidance behaviour are also suitable for compensating disturbances.

This is not always the case.

TASK 4.3.28 Calculate controller parameters dor disturbance control with PID controller from the table without overshoot

SOLUTION

If the task is to correct disturbances and set point changes, a compromise between the two controller parameter sets must generally be found. If the control circuit is o be controlled with a PID controller following parameters result for guidance behaviour without overshoot.

Parameters:

For $T_u = 3s$:

PID: $K_v = 0,6 * 1/ (K_{is}*T_u) = 0,6 * 1 / (0,0045*3) = 44,5$

$T_n = Ti = 222s$

$T_v = 0,5 * T_u = 0,5 * 3s = 1,5s$

For $T_u = 4,5s$:

PID: $K_v = 0{,}6 * 1 / (K_{is} * T_u) = 0{,}6 * 1 / (0{,}0045 * 4{,}5) = 29{,}6$

$T_n = T_i = 222s$

$T_v = 0{,}5 * T_u = 0{,}5 * 4{,}5s = 2{,}25s$

Fig. 78 and Fig. 79 show that the PID controller is suitable for this control, but the control signal fluctuates very strongly. This is due to the noisy control variable and the D component of the controller.

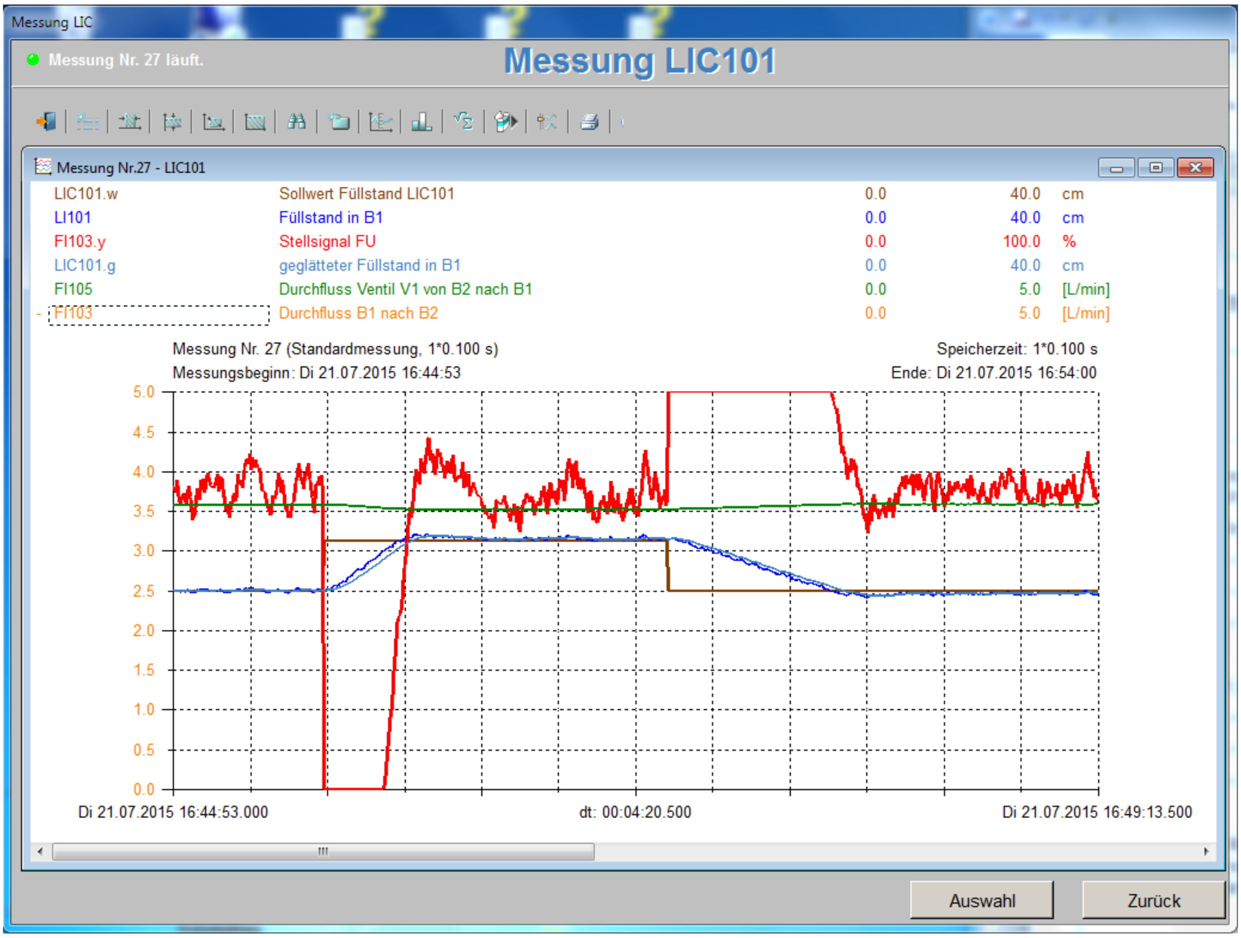


Fig. 78: PID controller according to Chien / Hrones / Reswick for guide jump without overshoot, with Kp = 44.5 and Tv = 1.5s

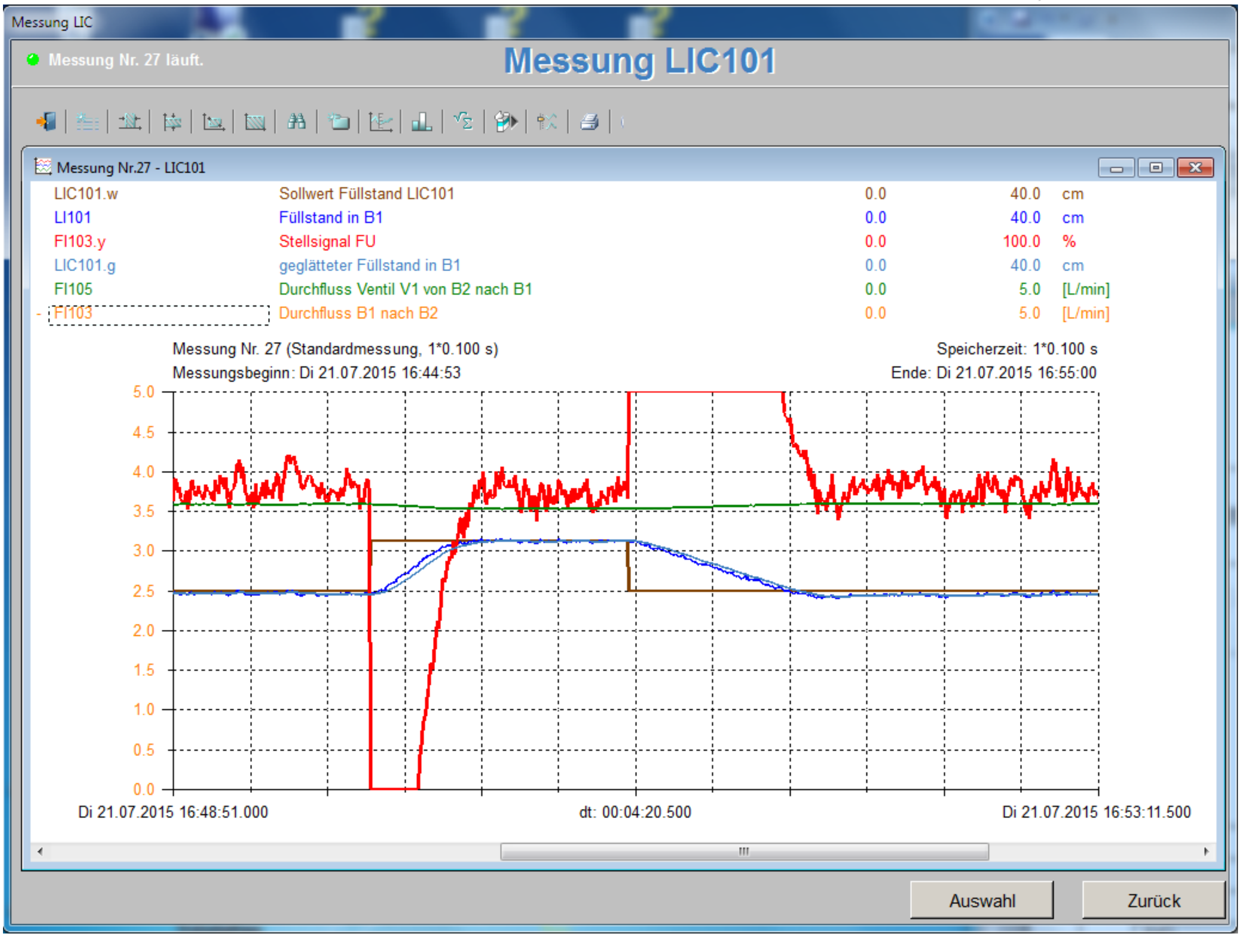


Fig. 79: PID controller according to Chien / Hrones / Reswick for guide jump without overshoot, with Kp = 29.6 and Tv = 2.25s

4.3.9 CONTROLLER SETTINGS ACCORDING TO RULE OF THUMB FOR SYSTEMS WITHOUT BALANCING

The following rules of thumb were taken from the book by Josef Uphaus, Grundlagen der Regelungstechnik, Dümmler Verlag.

Controller	Kv	Tn	Tv
P	0,5 * 1 / (Ki*Tu)		
PI	0,42 * 1 / (Ki*Tu)	5,8 * Tu	
PID	0,4 * 1 / (Ki*Tu)	3,2 * Tu	0,8 * Tu

TASK 4.3.28 Calculate controller parameters for disturbance behaviour from above table.

SOLUTION

K_i (K_{is}) and T_u get determinated as described in Chapter 4.3.8.

This results in the following parameters for the PI controller:

$K_v = 0{,}42 * 1 / (0{,}0045 * 3) = 31,$ $\qquad T_n = 5{,}8 * 3 = 17{,}4s$ *or.*

$K_v = 0{,}42 * 1 / (0{,}0045 * 4{,}5) = 20,$ $\qquad T_n = 5{,}8 * 4{,}5 = 26{,}1s$

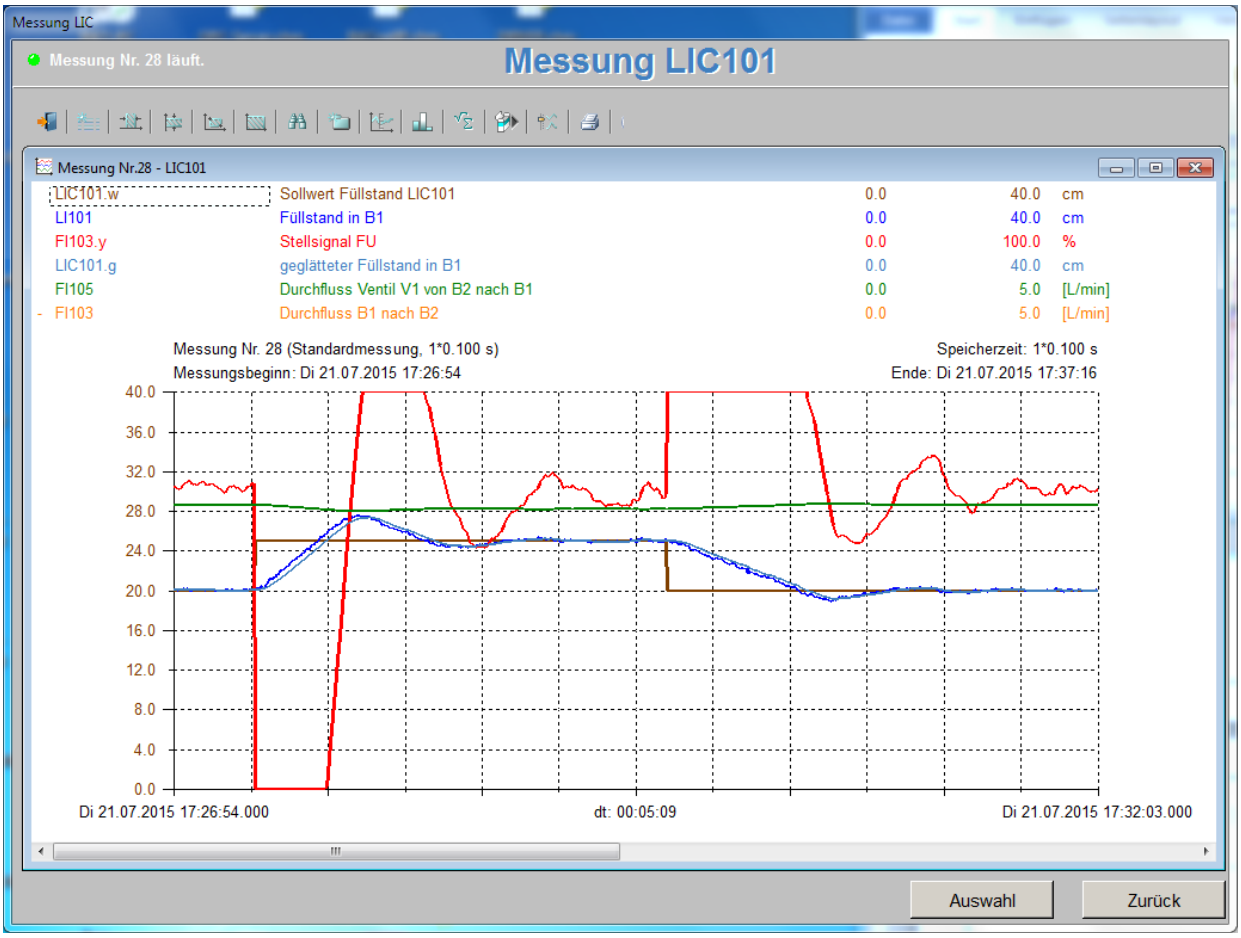


Fig. 80 PI-controller, setting according to rules of thumb, guide behaviour with Kp = 31 and Tn = 17,4s

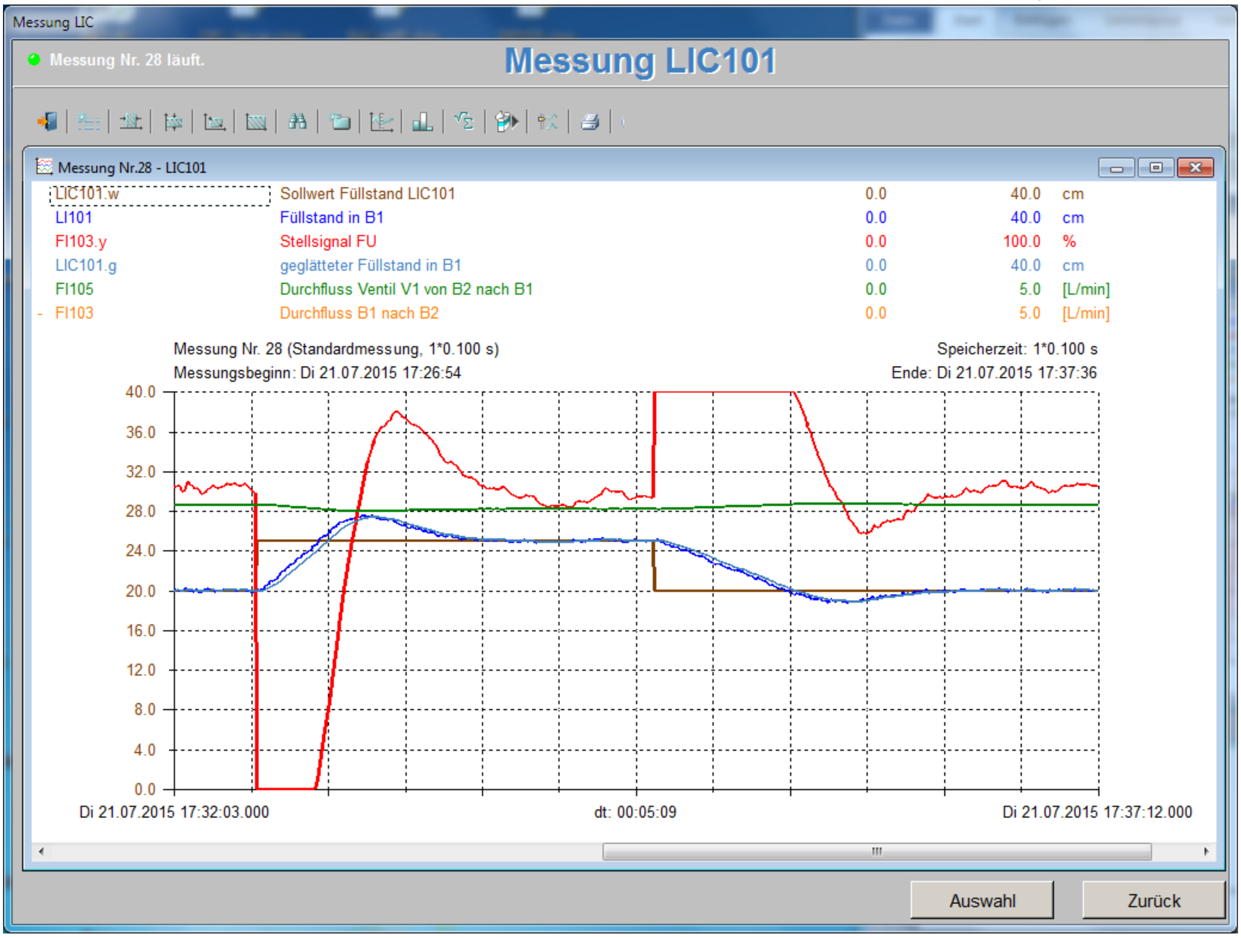


Fig. 81: PI-controller, setting according to rules of thumb, guide behaviour with Kp = 20 and Tn = 26,1s

With the controller settings selected above, the following behaviour results when switching on a disturbance (inflow valve V1 from 100% to 50% or from 50% to 100%).

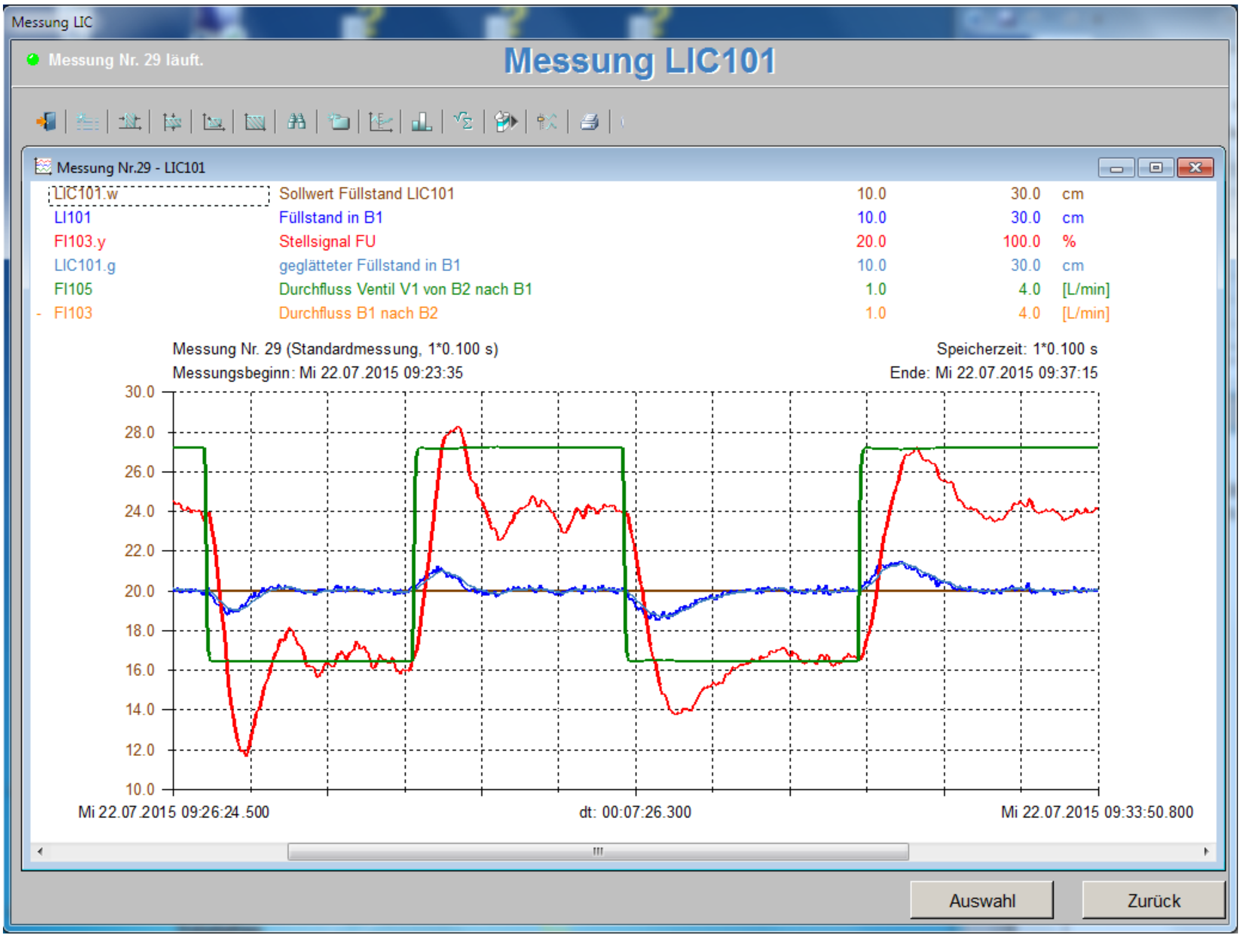


Fig. 82: PI-controller, set according to rules of thumb, disturbance behaviour, left half with Kp = 31 and Tn = 17,4s, right half with Kp = 20 and Tn = 26,1s

The parameters obtained according to the rules of thumb for the PI controller are partly acceptable for the correction of the guidance and the disturbance behaviour. The behaviour is much poorer than with the parameters according to the rules of Chien / Hrones / Reswick.

As can be seen from the above-described methods, very different controller parameters are obtained depending on the method, on the accuracy of the measurement and on the operating point or the direction of the manipulated variable jump.

This clearly shows that controller adjustment methods do not provide optimal controller parameters, but they help to obtain control suitable parameters. In the normal case, a reasonable control behaviour will be achieved with them.

4.4 FLOW CONTROL FIC103

Go to the *Flow Rate Control FIC103*. Here, you have the options of operating the controller in manual or automatic mode, selecting the controller type and setting the controller parameters.

The following tasks were performed with the simulated system. In the simulated system, the maximum flow rate of M1 is set to 3.75 l / min and that of pump M3 is set to 5 l / min (*View simulated LC2030*).

First, the control circuit is to be determined in principle.

TASK 4.4.1: Formulate what should be controlled, by what it is controlled and what disturbances take an influence.

SOLUTION

The flow should be controlled by means of the adjustable pump M3. The flow rate is influenced by adjusting the speed of the pump M3. The manual valve in the drain is available as a disturbance variable.

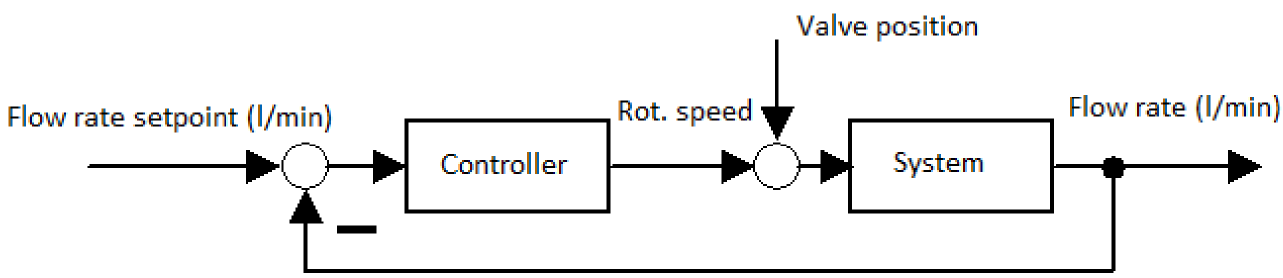
TASK 4.4.2: For this control loop, determine the set point, the actual value, the actuating signal (manipulated variable) and the disturbance variables, and specify the respective units.

SOLUTION

Set point value:	Flow in l / min.
Actual value:	Measured flow in l / min.
Actuating variable:	Rotational pump speed M3 in %.
Disturbance:	Valve position of the hand valve in the drain in %.

TASK 4.4.3: Create a flow chart (block structure) for the flow control.

SOLUTION



TASK 4.4.4: In flow control the measuring signal (actual flow) can also be smoothed. This is achieved by switching on the low-pass filter (corresponds to a Pt1 behaviour). Change the time constant of the low-pass filter and observe the behaviour of the smoothed signal. Describe the behaviour of different time constants.

SOLUTION

Since the measured flow hardly fluctuates, one should select 0.5s as a time constant or switch off the filtering.

If the filtering is switched on, the greater the time constant of the filter, the slower the smoothed signal follows the original signal (see level control solution to task 4.3.4).

As stated in section 4.2 (Recording the pump´s characteristic curve), the flow rate depends on the level in the tank. This behaviour is to be investigated again in Problem 4.4.5

TASK 4.4.5: Fill the tank up to the maximum with the pumps M1 and M2. Turn off the two pumps. Set control signal y to 75% and switch on pump M3. Describe the behaviour.

SOLUTION

The flow rate decreases with the decrease of the level even though the control signal for the speed of the pump remains constant.

This again shows that the behaviour of the system is dependent on the operating point.

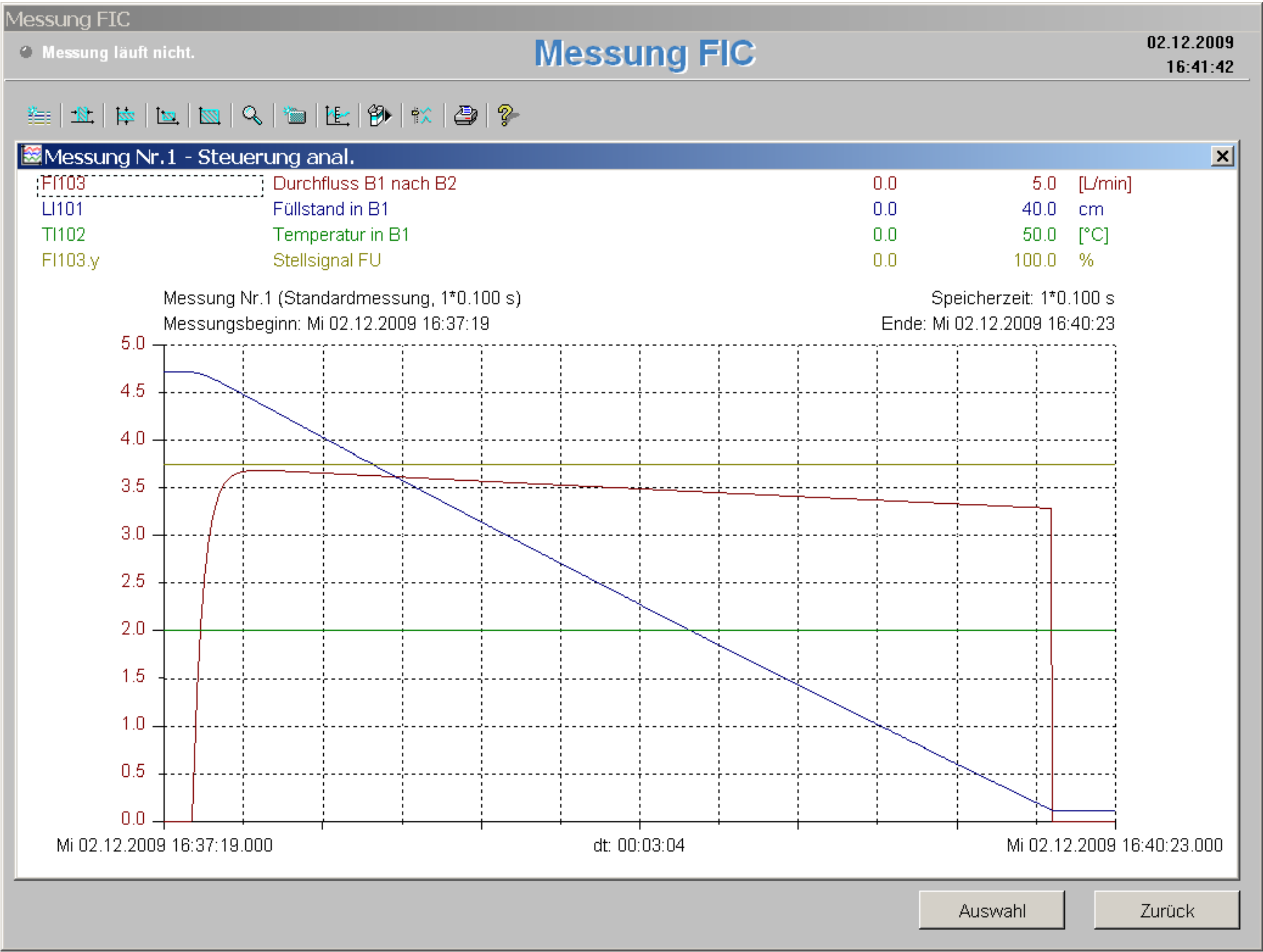


Fig. 83: At constant speed flow decreases with the level

TASK 4.4.6: Set the control circuit to manual and switch on the three pumps M1, M2, and M3. Specify a desired flow rate (for example 3 l / min) and try to manually adjust the actual flow to the set flow by adjusting the control signal y (speed of pump M3 from 0 - 100%).

NOTE**:** Turn on the low pass filter and set it to 0.5s. Try to control the smoothed flow signal. Switch on the measurement via *Start measurement*. You can then view the recorded measured values later using the *Measurement View*, and thus assess your ability to "play controller".

4.4.1 INVESTIGATION OF FLOW CONTROL FIC103 WITH P-CONTROLLER

First, the flow control with the P controller is to be investigated. Switch on the pumps M1 and M2 and fill the tank up to the overflow. Ensure that during the following tests inflow is greater than outflow. This means that you are in a defined operating point (maximum level of the container, overflow).

Set the low-pass filter to 0.5s. Select the P controller, set the set point to 3 l / min, turn on pump M3 and set the control to Auto.

The following tasks were performed with the simulated system. In the simulated plant, the maximum flow rate of M1 was set to 3.75 l / min and that of pump M3 to 5 l / min (*View simulated LC2030*).

TASK 4.4.7: Set the set point to 3 l / min and the gain of the P controller to 5. Observe the behaviour and describe it. Consider, in particular, the relationship between actual flow and set point flow (actual value and set point).

SOLUTION

The actual value does not reach the set point. The difference between the actual value and the set point is very large (approx. 2 l / min).

TASK 4.4.8: Increase the gain of the P controller by 10, and observe the behaviour of the control loop. Describe the behaviour of the control, in particular the relationship between the actual flow and the desired flow.

SOLUTION

When the gain of the P controller is increased, the difference between the actual value and the set point value decreases. However, the actual flow does not reach the desired flow.

The P controller is therefore not suitable to completely vanish the control deviation.

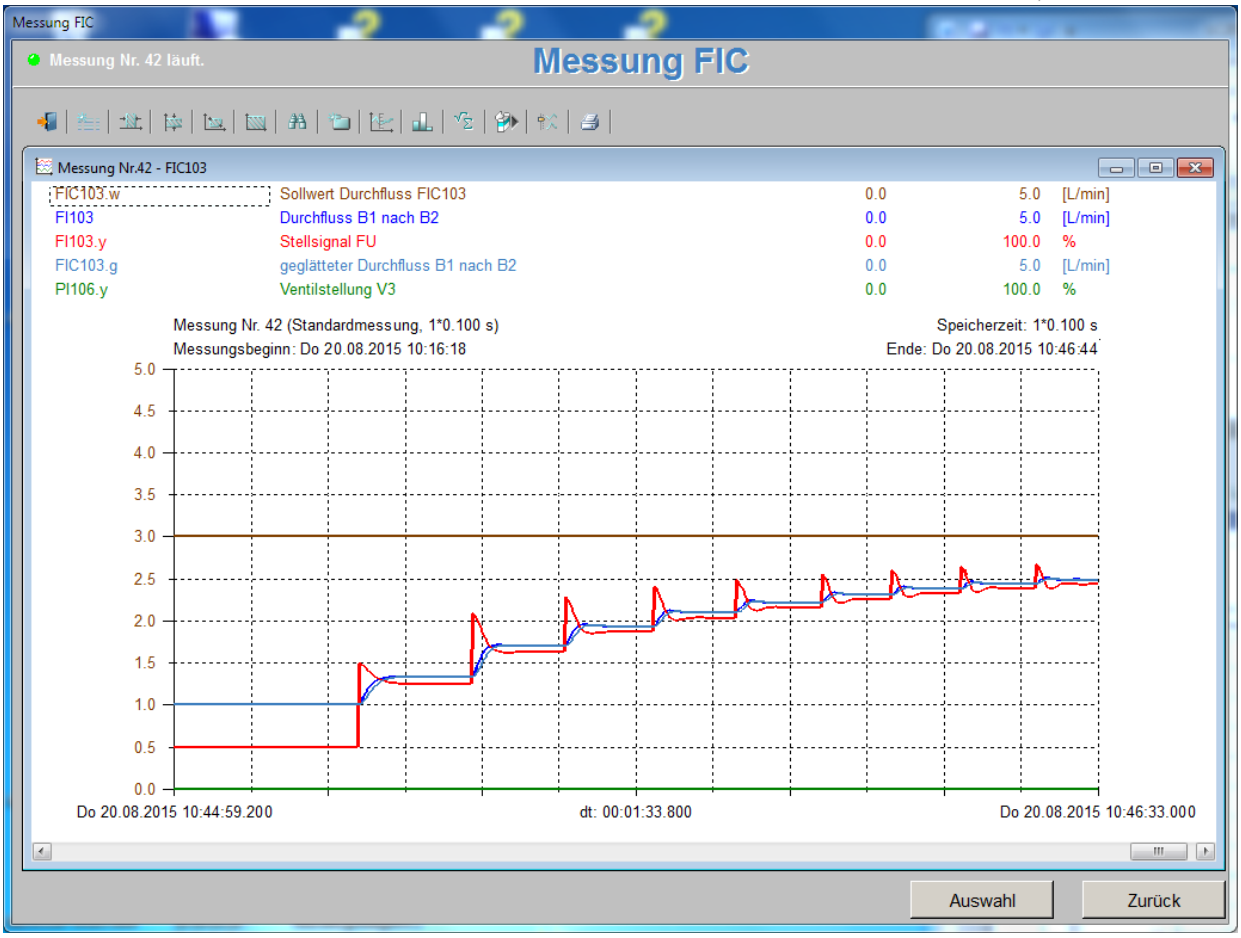


Fig. 84: Stepwise increase in the gain of the P controller during flow control

4.4.2 INVESTIGATION OF FLOW CONTROL FIC103 WITH I CONTROLLER

Switch on the three pumps again, select the I controller and switch it to "Auto". The low-pass filter should be switched on and set to 0.5s.

The following tasks were performed with the simulated plant and the above settings.

TASK 4.4.9: Set the reset time of the I controller to 1s and the set point flow to 3 l / min. Observe the control loop and describe its behaviour.

SOLUTION

The actual flow rate slowly reaches the desired flow without overshoot. The I controller makes it possible to control the system. However, the adjustment takes a very long time.

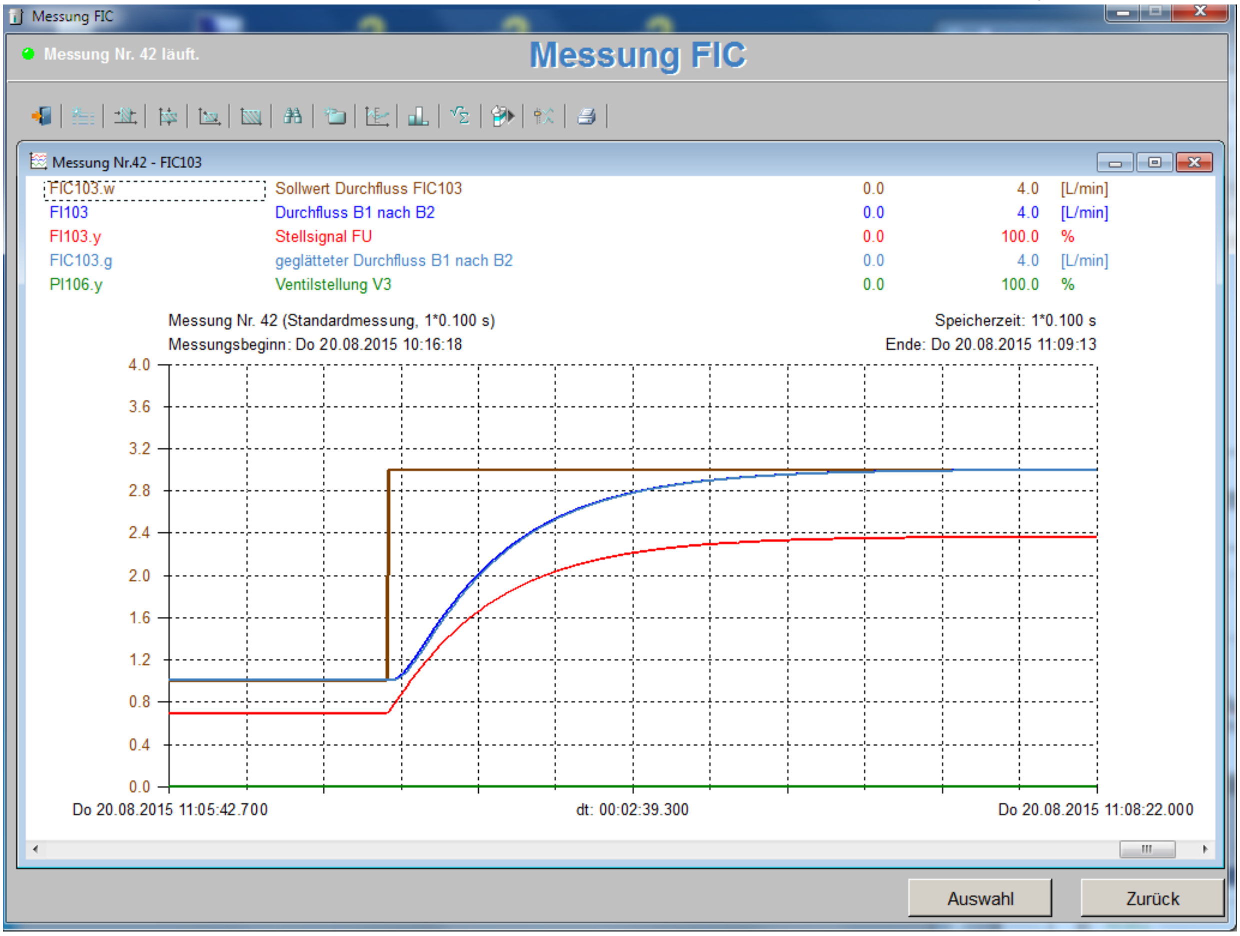


Fig. 85: Flow control with I controller

TASK 4.4.10: Increase the reset time of the I-controller step by step and adjust the set point every time between 3 l / min and 2.5 l / min. Observe the control loop and describe its behaviour.

SOLUTION

The greater the reset time is selected, the slower the control loop is adjusted.

4.4.3 EXAMINATION OF THE FLOW CONTROL WITH THE PI CONTROLLER

Switch on the three pumps again, select the PI controller and switch it to "Auto". The low-pass filter should be switched on and set to 0.5s.

The following tasks were performed with the simulated plant and the above settings.

TASK 4.4.11: Set a gain of 15 and a reset time of 4s. The desired flow rate is set to 1l/min. Wait until the control loop is steady. Then enter a set point jump from 1l/min to 3l/min. Observe the control loop and describe its behaviour.

SOLUTION

The actual value reaches the new set point faster with the PI controller than with the I controller.

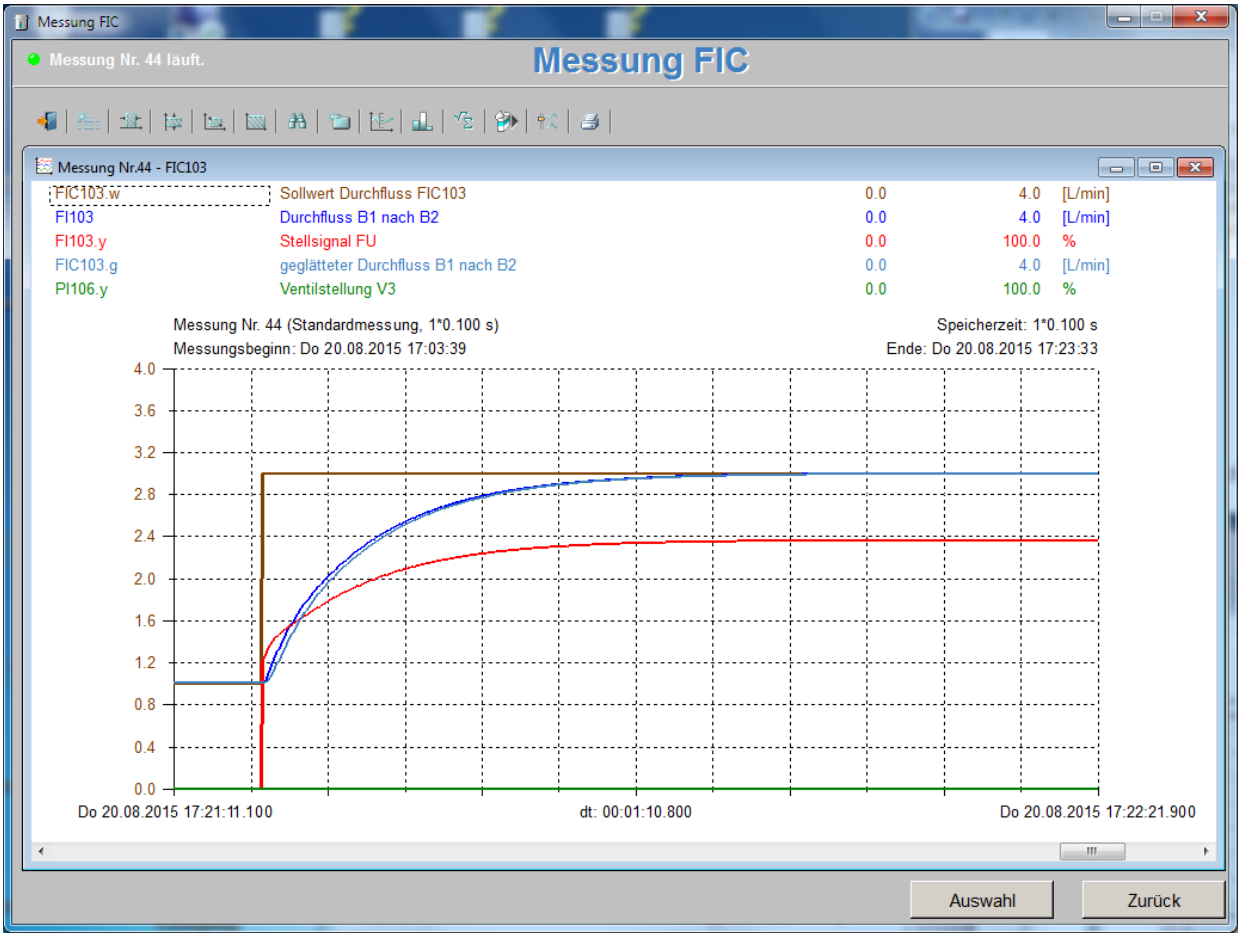


Fig. 86: Flow control with PI controller, reset time of 4s, gain 15

TASK 4.4.12: Increase the gain to 30, leave the reset time at 4s. Describe the behaviour of the control loop.

SOLUTION

The control circuit swings to the new set point faster.

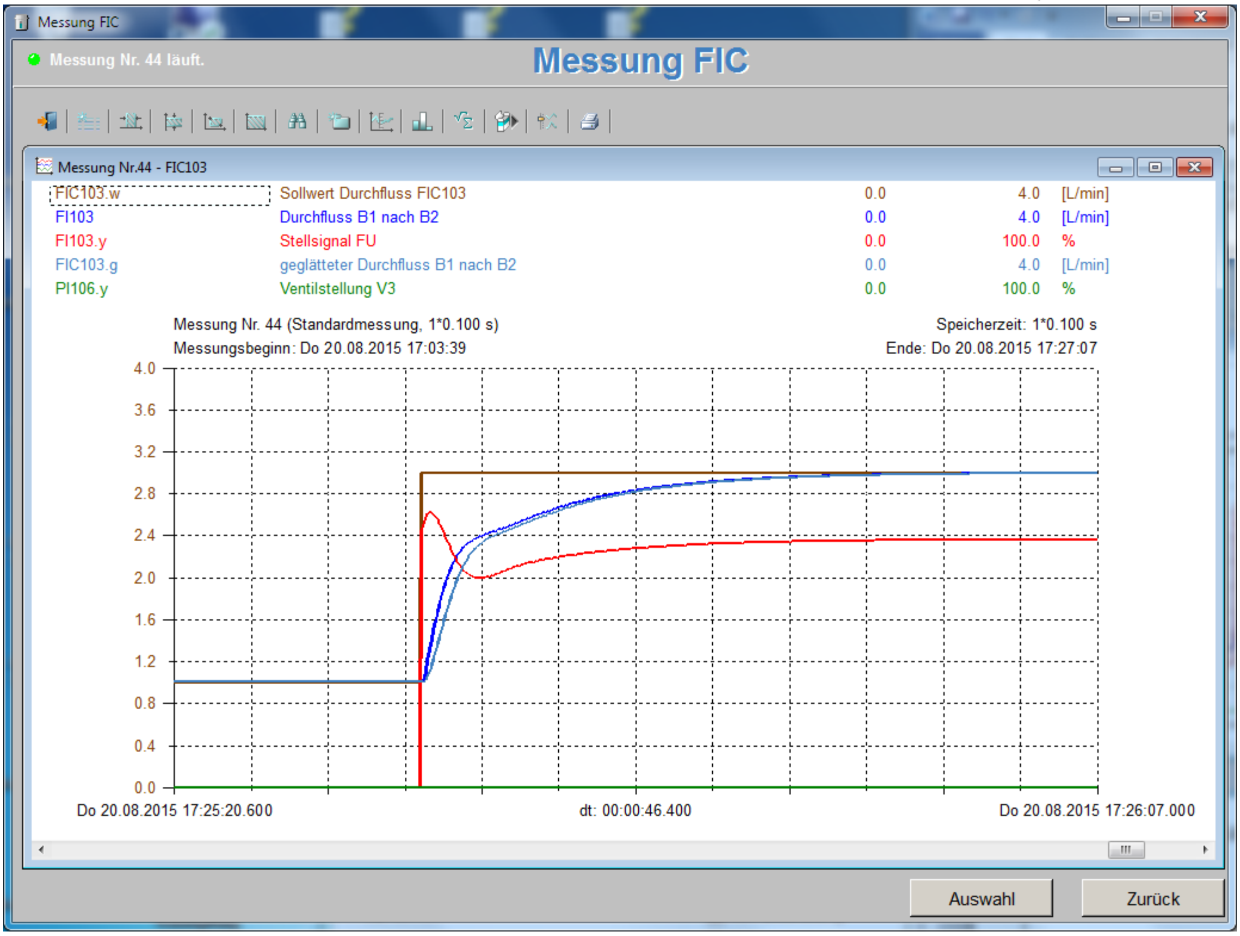


Fig.87: Flow control with PI controller, integral action time of 4s, gain 30

TASK 4.4.13: Try to find parameters by stepwise changing the gain and the reset time, with which the control loop remains stable and the actual flow rate meets as quickly as possible to the desired flow rate. Provide a set point jump from 1 to 3 for each attempt.

SOLUTION

Selection of the parameters e.g.: Reset time = 1s, gain 30

In the above-mentioned selection of the parameters, the control circuit has a quick transient oscillation, but with overshoot.

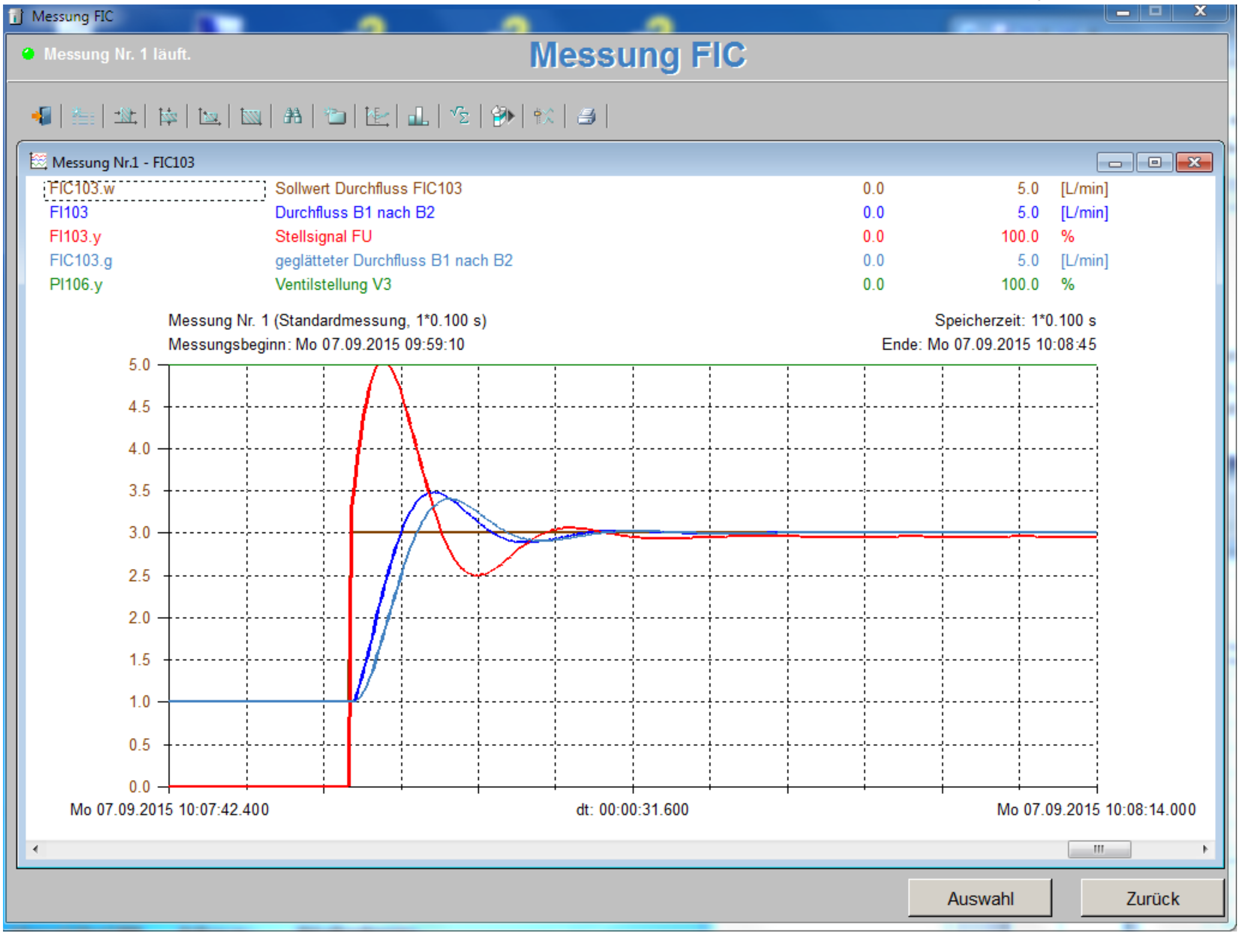


Fig.88: Flow control with PI controller, reset time 1s, gain 30

TASK 4.4.14: Let the control loop settle to 1l/min. Set as parameter 35 for gain and 2 for reset time. Specify a set point jump from 1 l / min to 3 l / min. Observe and describe the behaviour of the control loop to the set point jump (guidance behaviour).

SOLUTION

The actual value goes without overshooting to the new set point.

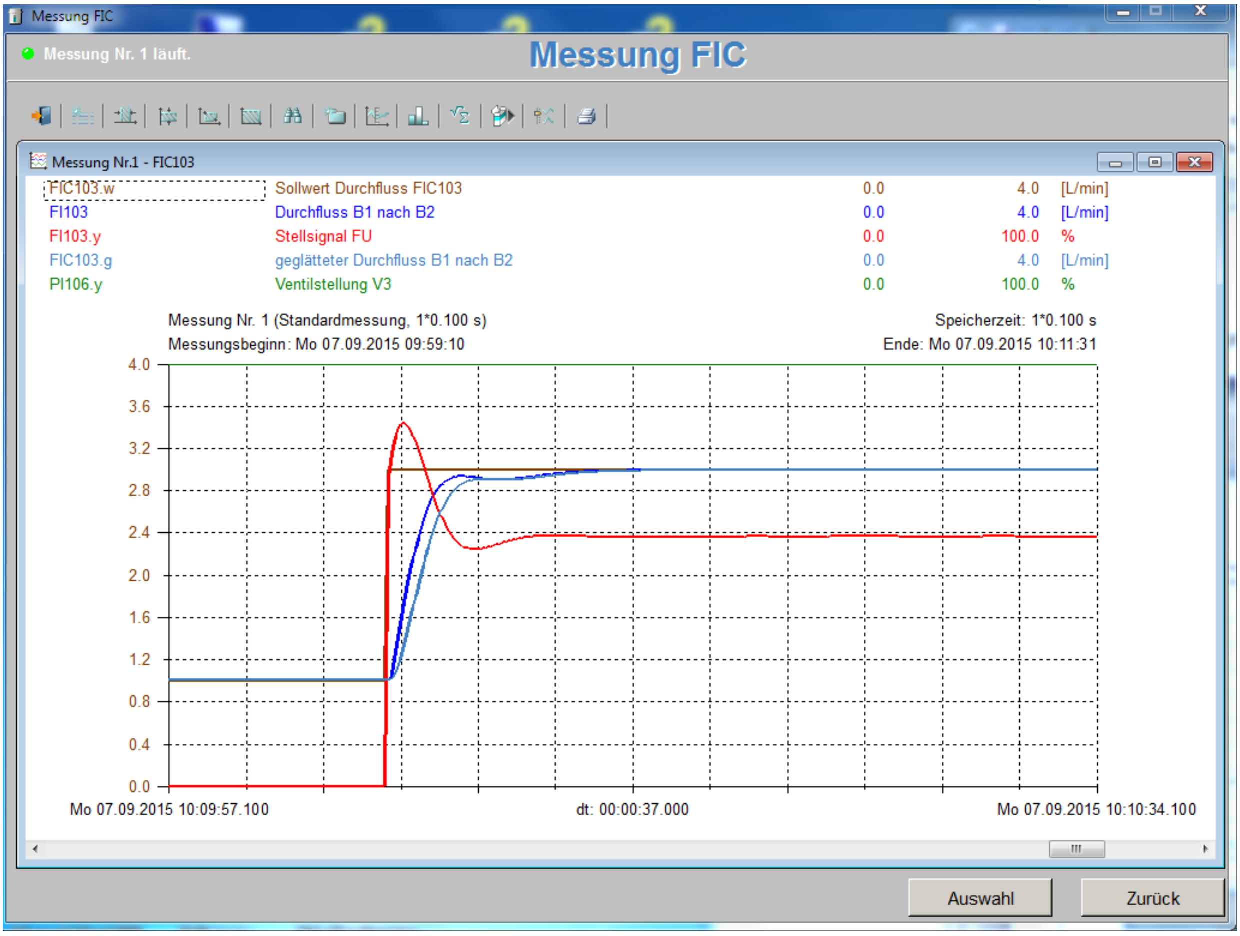


Fig.89: Flow rate control with PI controller, set point jump

TASK 4.4.15: Indicate a disturbance by setting the manual valve behind the M3 pump to 80%. Observe and describe the behaviour of the control loop for a disturbance value jump (disturbance behaviour).

SOLUTION

The disturbance is adjusted, the actual value returns to the set point value after a certain time. To achieve this, the controller had to increase the speed of pump M3.

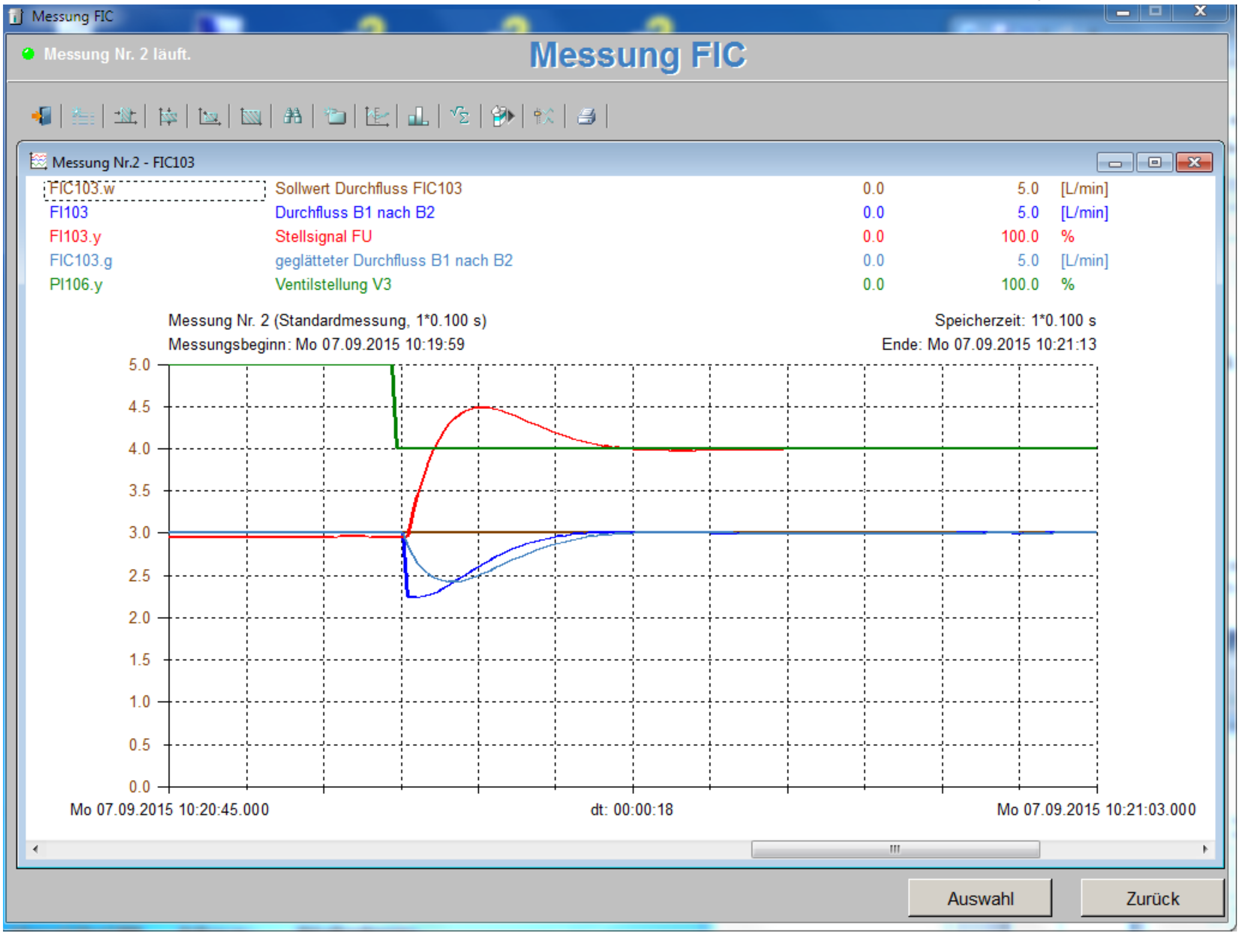


Fig.90: Flow control with PI controller, disturbance value jump

4.4.4 EXAMINATION OF FLOW CONTROL FIC103 WITH PID CONTROLLER

Switch on the three pumps again, select the PID controller and switch it to "Auto". The low-pass filter should be switched on and set to 0.5s.

The following tasks were performed with the simulated plant and the above settings.

TASK 4.4.16: Set the following parameters: Gain = 10, reset time = 5s, derivative time = 1s and as set point 2.5 l / min. Set the set point to 1 l / min. Wait until the system is steady. Change the set point from 1 l / min to 3.0 l / min. Observe the control loop and describe its behaviour.

SOLUTION

The actual value reaches the set point without overshoot. However, it takes a comparatively long time until the actual value reaches the set point.

It is important to note the peak of the actuating signal during the sudden change of the set point. The D component of the controller generates this peak.

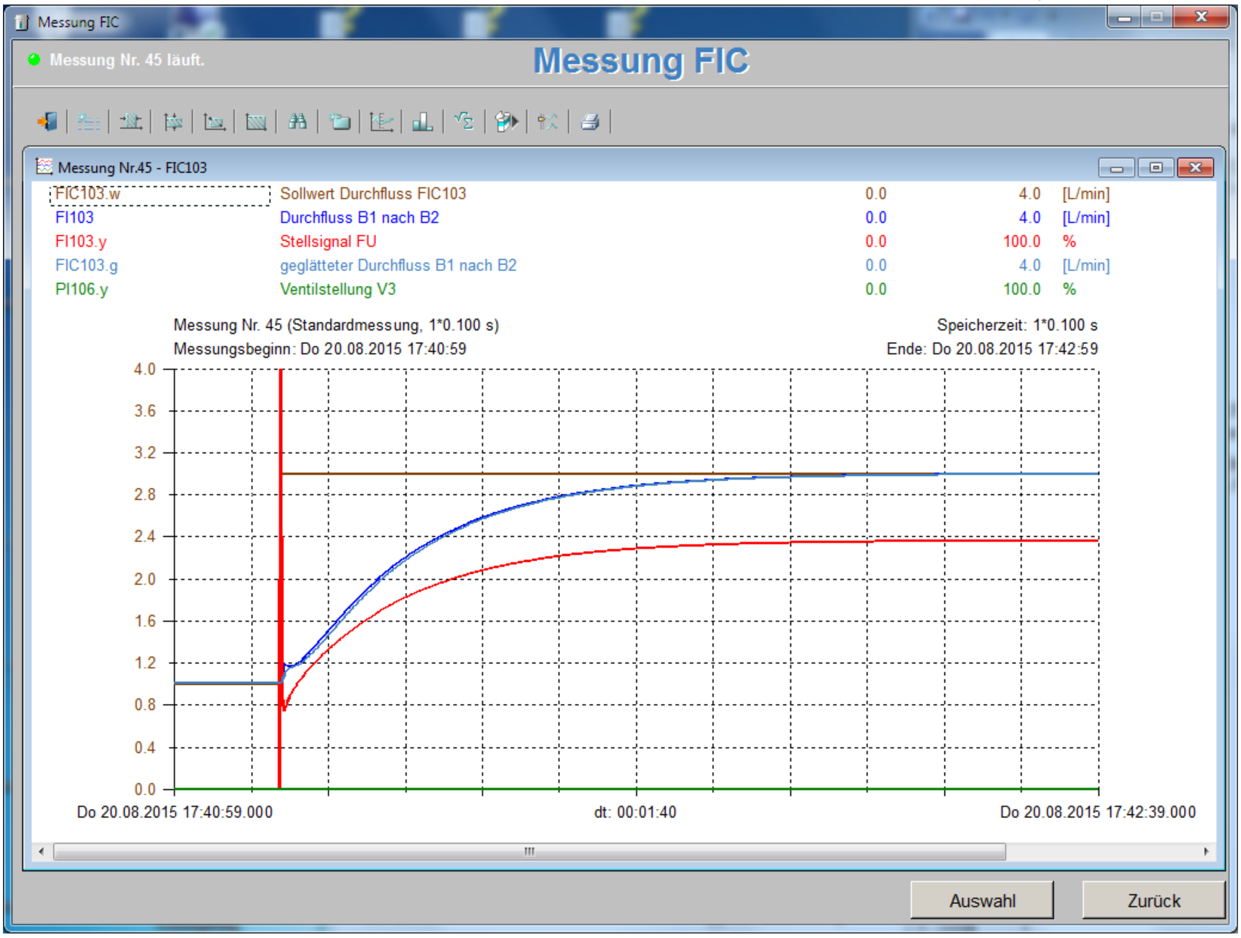


Fig.91: Flow control with PID controller, slow settling

TASK 4.4.17: Determine the parameters by stepwise changing gain, reset time and derivative time so that the control loop settles as quickly as possible.

SOLUTION

The actual value quickly reaches the set point, but the control circuit swings over using the following parameters.

Parameters: gain = 30, reset time = 2s, derivative time = 2s

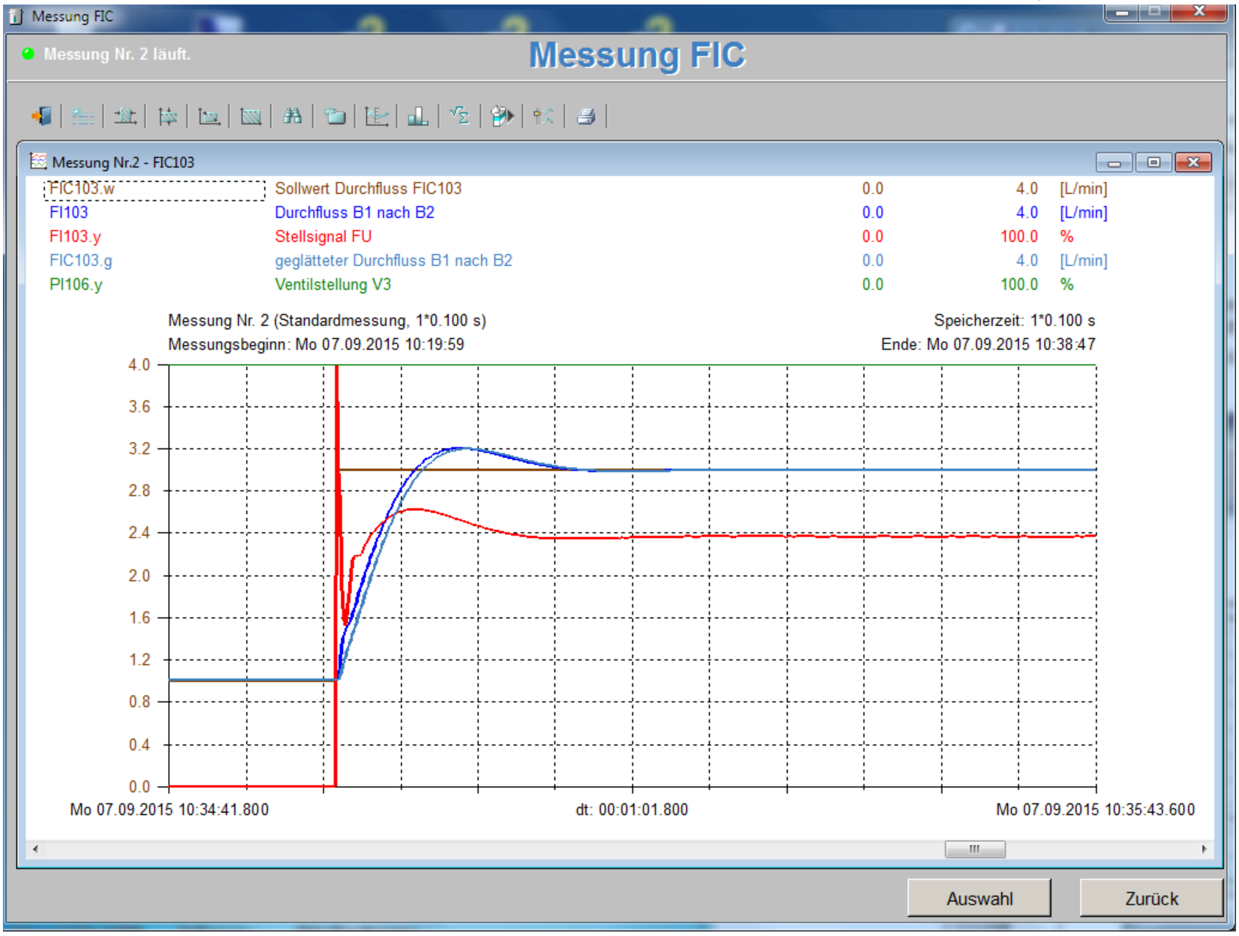


Fig.92: Flow control with PID controller and the above parameters, guidance behaviour

TASK 4.4.18: Wait until the control loop has settled at 3.0 l / min with the above parameters. Then switch on a disturbance by adjusting the hand valve behind pump M3 to 80% (disturbance). Describe the behaviour of the control loop.

SOLUTION

With the parameters defined above, the controller manages to bring the actual value back to the desired value. Thus the disturbance is adjusted.

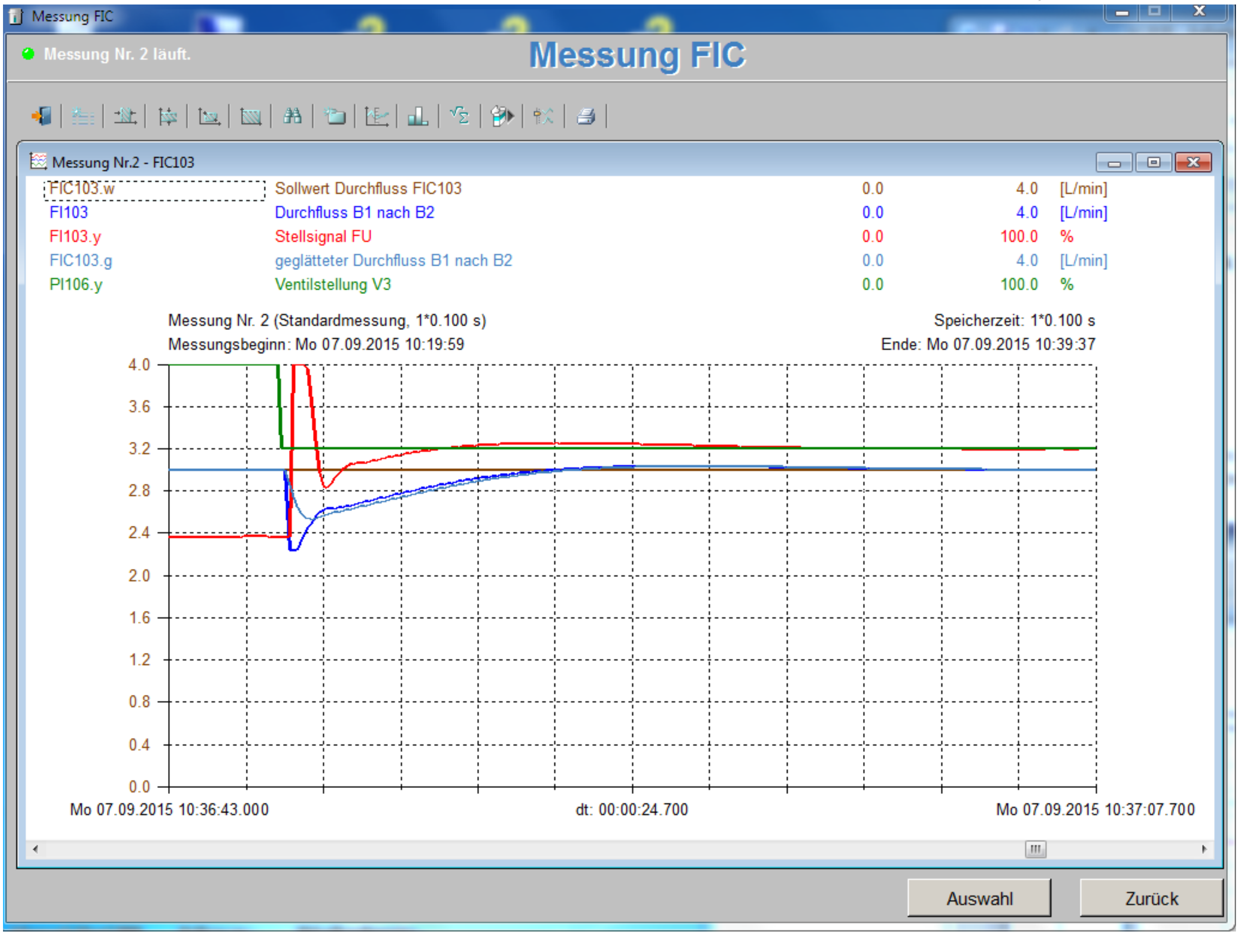


Fig.93: Level control with PID controller, disturbance behaviour

4.4.5 EXAMINATION FLOW CONTROL FIC103 WITH TWO POSITION CONTROLLER

Switch back on the three pumps, select the two position controller and switch it to Auto. The low-pass filter should be switched on and set to 0.5s.

The following tasks were performed with the simulated plant and the above settings.

TASK 4.3.21: Select 0.2 as hysteresis for the two position controller. Observe the control loop and describe its behaviour.

SOLUTION

The actual value fluctuates around the set point value with the hysteresis of 0.2. The speed of pump M3 switches back and forth quickly between 0% and 100%.

The controller uses the smoothed flow as the control variable. You can see clearly how the smoothed signal follows the original signal FI103 time-delayed.

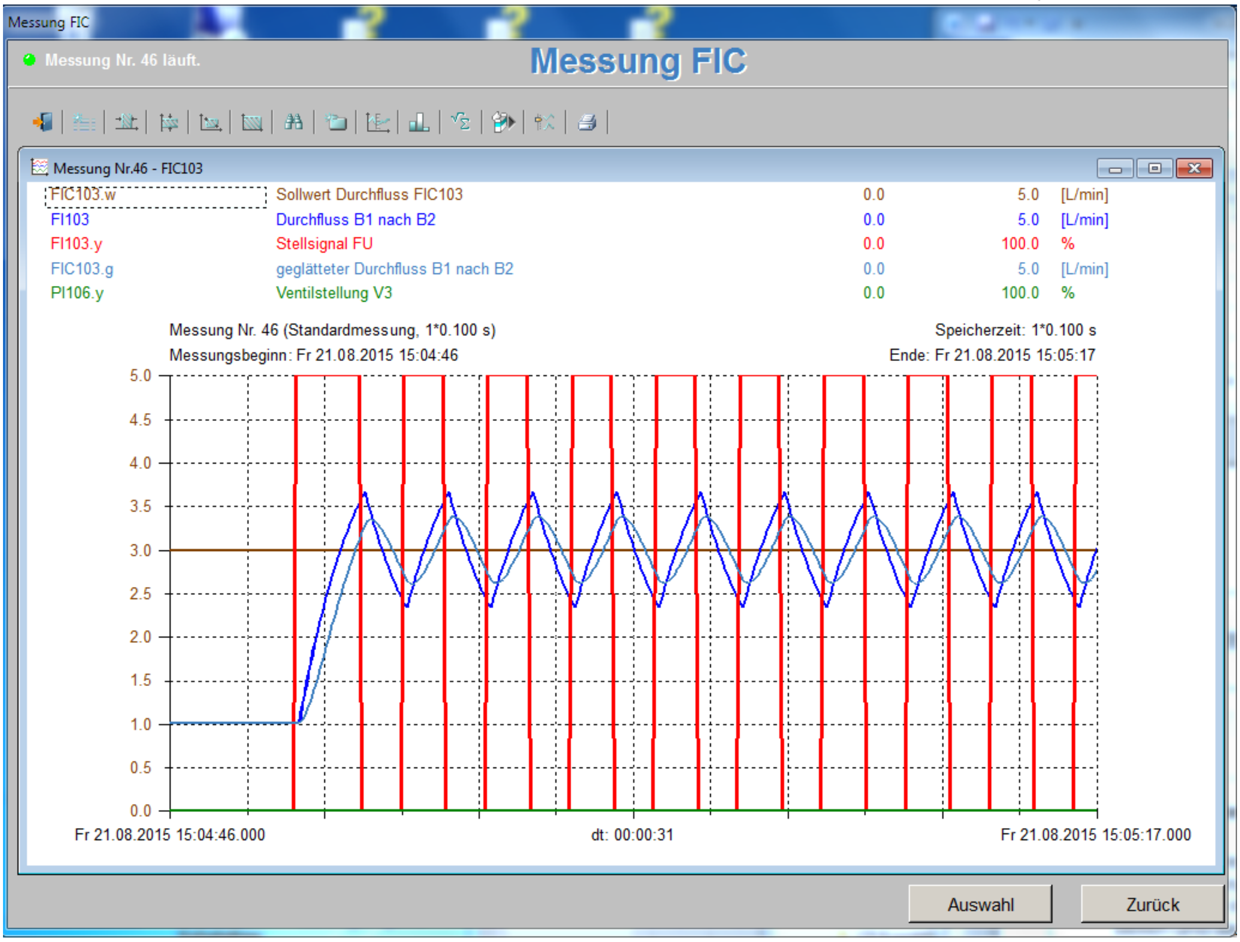
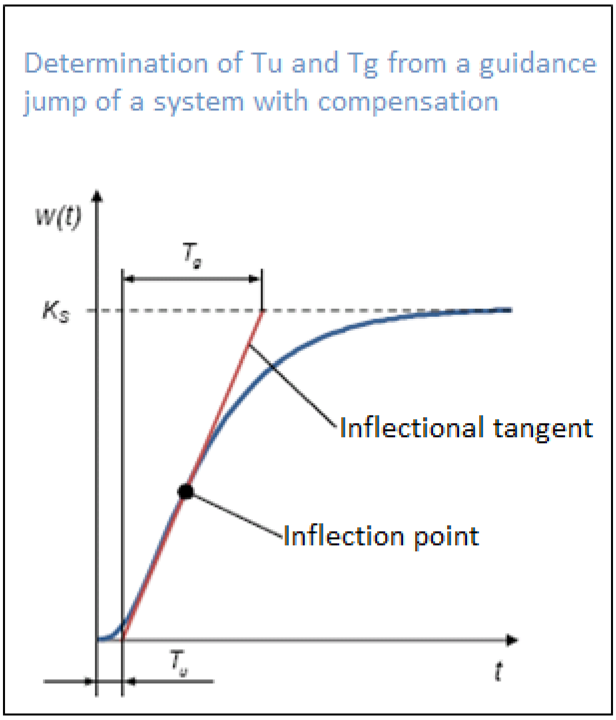


Fig.94: Flow control with two position controller

4.4.6 PROCEDURE ACCORDING TO CHIEN / HRONES / RESWICK FOR CONTROLLED SYSTEMS WITH COMPENSATION

In the process of Chien / Hrones / Reswick, the step response is examined for a set point jump (unit jump) of the system. For this purpose, your control loop must be in a stable operating point. You must set the controller to "Manual" and the actuating signal and the control variable must not change. Provide a jump-like change of the control signal by 1 and watch the behaviour of the system.

A system with compensation has approximately the following behaviour on a unit jump of the actuating signal (sudden change of the control signal by 1):



You can use this step response to determine the parameters Ks, Tg and Tu as shown in the figure above. The change in the control path Ks results from the sudden change of the control signal by 1. If you make a larger manipulated variable change, you must divide the resulting gain value of the path by changing the manipulated value so that you get Ks.

It means:

T_u	Effective dead time
T_g	Compensation time of the control system
K_S	Transfer coefficient of the control system with compensation

The controller parameters can then be calculated from the setting table according to Chien / Hrones / Reswick:

Controller	Quality criteria			
	Overshoot of 20% to opposite site		Aperiodic control behaviour	
	disturbance	guidance	disturbance	guidance
P	$K_P \approx \frac{0,7}{K_S} \cdot \frac{T_g}{T_u}$	$K_P \approx \frac{0,7}{K_S} \cdot \frac{T_g}{T_u}$	$K_P \approx \frac{0,3}{K_S} \cdot \frac{T_g}{T_u}$	$K_P \approx \frac{0,3}{K_S} \cdot \frac{T_g}{T_u}$
PI	$K_P \approx \frac{0,7}{K_S} \cdot \frac{T_g}{T_u}$ $T_n \approx 2,3 \cdot T_u$	$K_P \approx \frac{0,6}{K_S} \cdot \frac{T_g}{T_u}$ $T_n \approx T_g$	$K_P \approx \frac{0,6}{K_S} \cdot \frac{T_g}{T_u}$ $T_n \approx 4 \cdot T_u$	$K_P \approx \frac{0,35}{K_S} \cdot \frac{T_g}{T_u}$ $T_n \approx 1,2 \cdot T_g$
PID	$K_P \approx \frac{1,2}{K_S} \cdot \frac{T_g}{T_u}$ $T_n \approx 2 \cdot Tu$ $T_v \approx 0,42 \cdot T_u$	$K_P \approx \frac{0,95}{K_S} \cdot \frac{T_g}{T_u}$ $T_n \approx 1,35 \cdot T_g$ $T_v \approx 0,47 \cdot T_u$	$K_P \approx \frac{0,95}{K_S} \cdot \frac{T_g}{T_u}$ $T_n \approx 2,4 \cdot T_u$ $T_v \approx 0,42\, T_u$	$K_P \approx \frac{0,6}{K_S} \cdot \frac{T_g}{T_u}$ $T_n \approx T_g$ $T_v \approx 0,5 \cdot T_u$

For systems without compensation instead of $\frac{T_g}{K_S \cdot T_u}$ use $\frac{1}{K_{IS} \cdot T_u}$

[The table was adopted from: E. Samal, Grundriss der praktische Regelungstechnik, Oldenbourg]

4.4.7 ADJUSTMENT OF FLOW CONTROL FIC103 ACCORDING TO CHIEN / HRONES / RESWICK

The flow control system is a system with compensation. In order for you to switch on a control signal jump, the track must be in a stable operating point. For operating point, select e.g. 2.5 l / min.

Allow the tank to overflow so that you always have the same conditions.

Wait until the control loop is steady. Switch the controller to manual and set a value of 10% (a jump from 48.9% to 58.9% in Fig.).

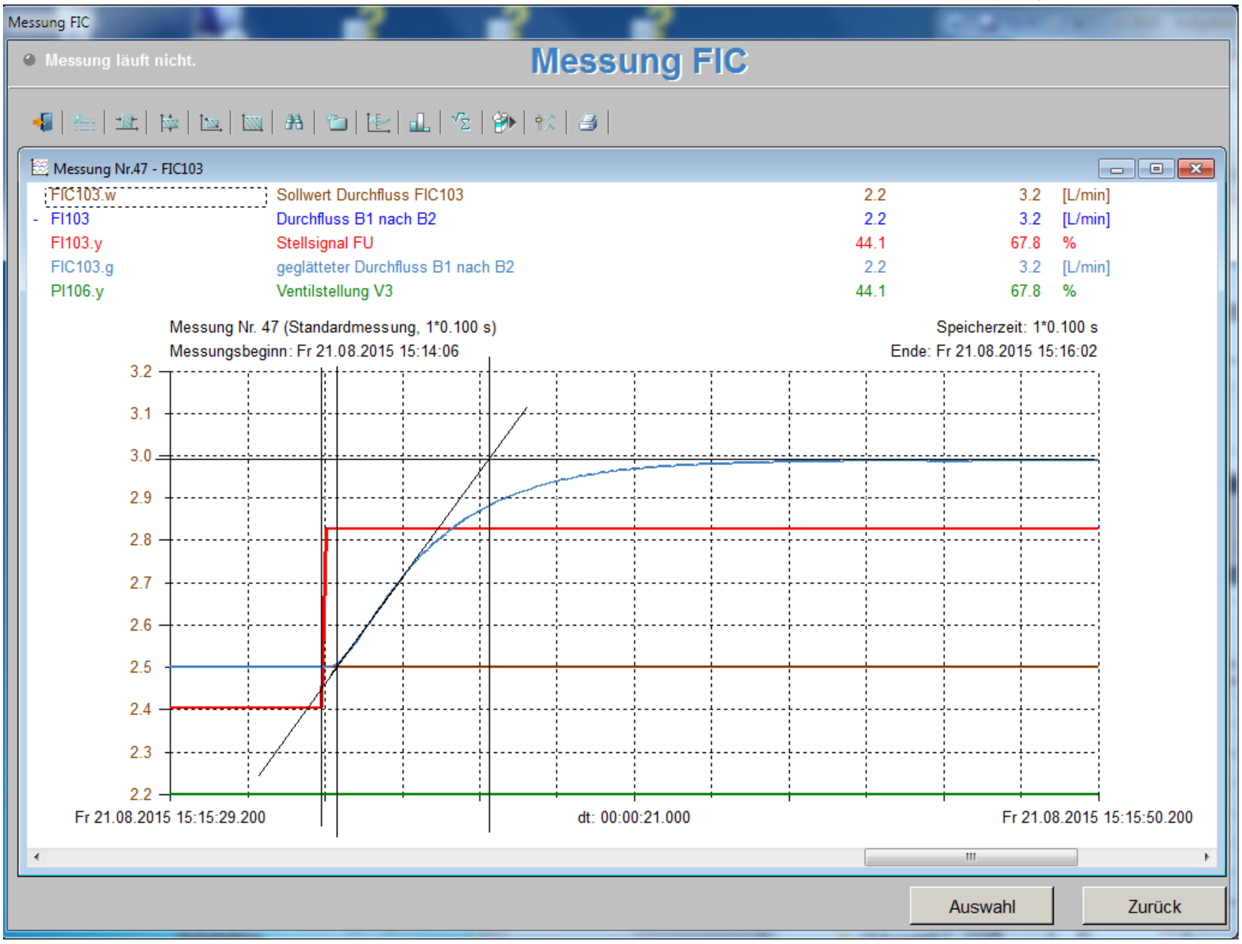


Fig.95: Jump response to a change in the value from 48.9% to 58.9%

TASK 4.4.19 Determine Tu, Tg and Ks.

SOLUTION

In Fig.95, you can measure T_u, T_g and K_s.

The following values are obtained: $T_u = 0.4s$, $T_g = 3.1s$, $K_s = 0.5 / 10 = 0.05$.

The slope of the straight line is approximately 0.16.

TASK 4.4.20 Calculate controller parameters for guidance control from the table with 20% overshoot.

SOLUTION

Thus, following controller parameters for the guidance behaviour result from the table with approx. 20% overshoot:

PI: $K_p = 0.6 * T_g / (K_s * T_u) = 0.6 * 3.1 / (0.05 * 0.4) = 93$

$T_n = T_g = 3.1s$

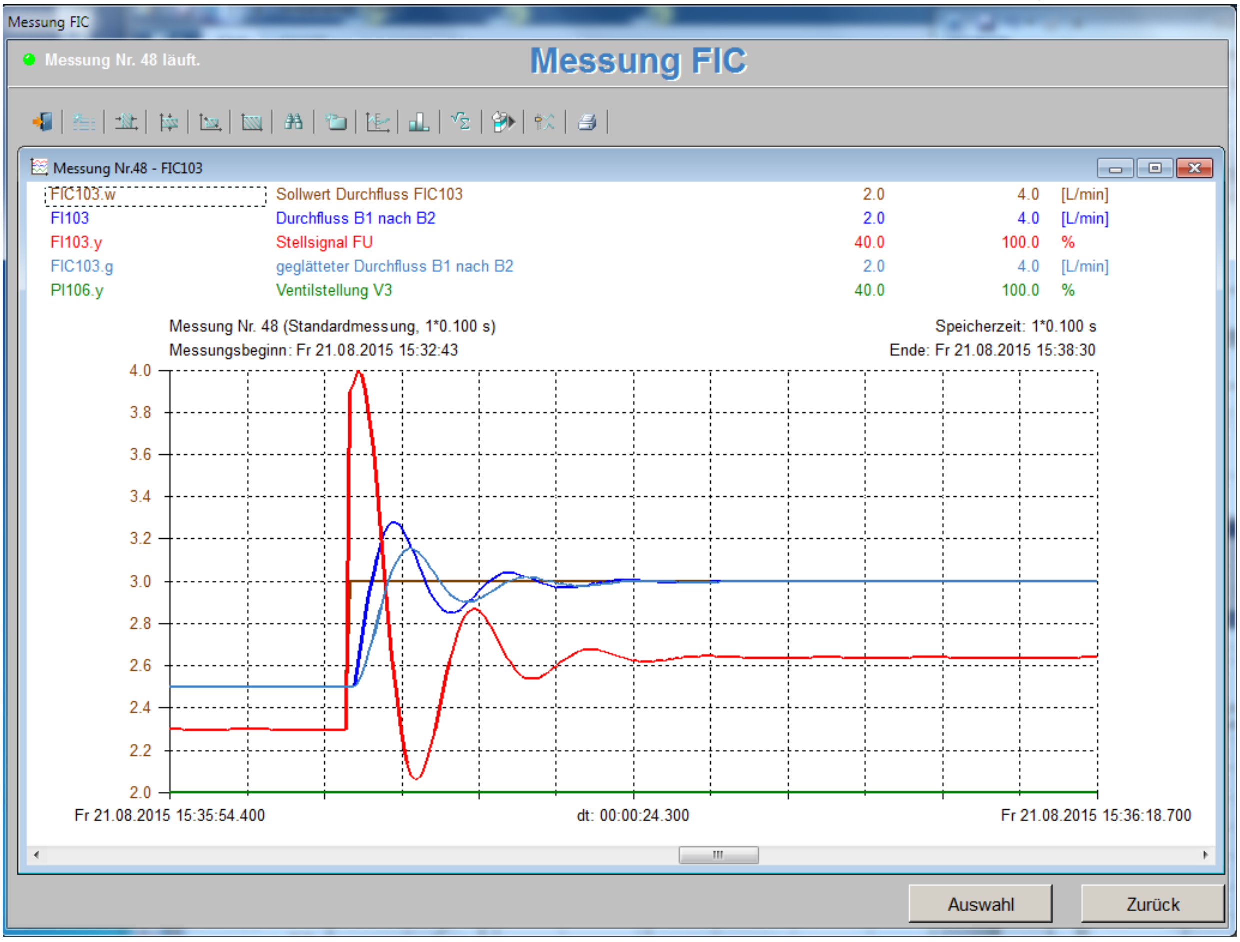


Fig.96: PI controller according to Chien / Hrones / Reswick for guidance jump with 20% overshoot

A set point change was defined from 2.5 l / min to 3 l / min.

As can be seen from the transient response, the actual value oscillates over 20% above the set point value (the controlled variable is the smoothed flow rate FIC103.g). This is due to the fact that the measurement of T_g and T_u is inaccurate. On the other hand, controller adjustment methods are empirical methods that react differently for each system and therefore do not always behave as expected.

TASK 4.4.21 Calculate controller parameters for guidance control from the table without overshoot.

SOLUTION

The following controller parameters result as controller parameters for the behaviour without overshoot:

PI: $K_p = 0.35 * T_g / (K_s * T_u) = 0.35 * 3.1 / (0.05 * 0.4) = 54.25$

$T_n = 1.2 * T_g = 1.2 * 3.1s = 3.72s$

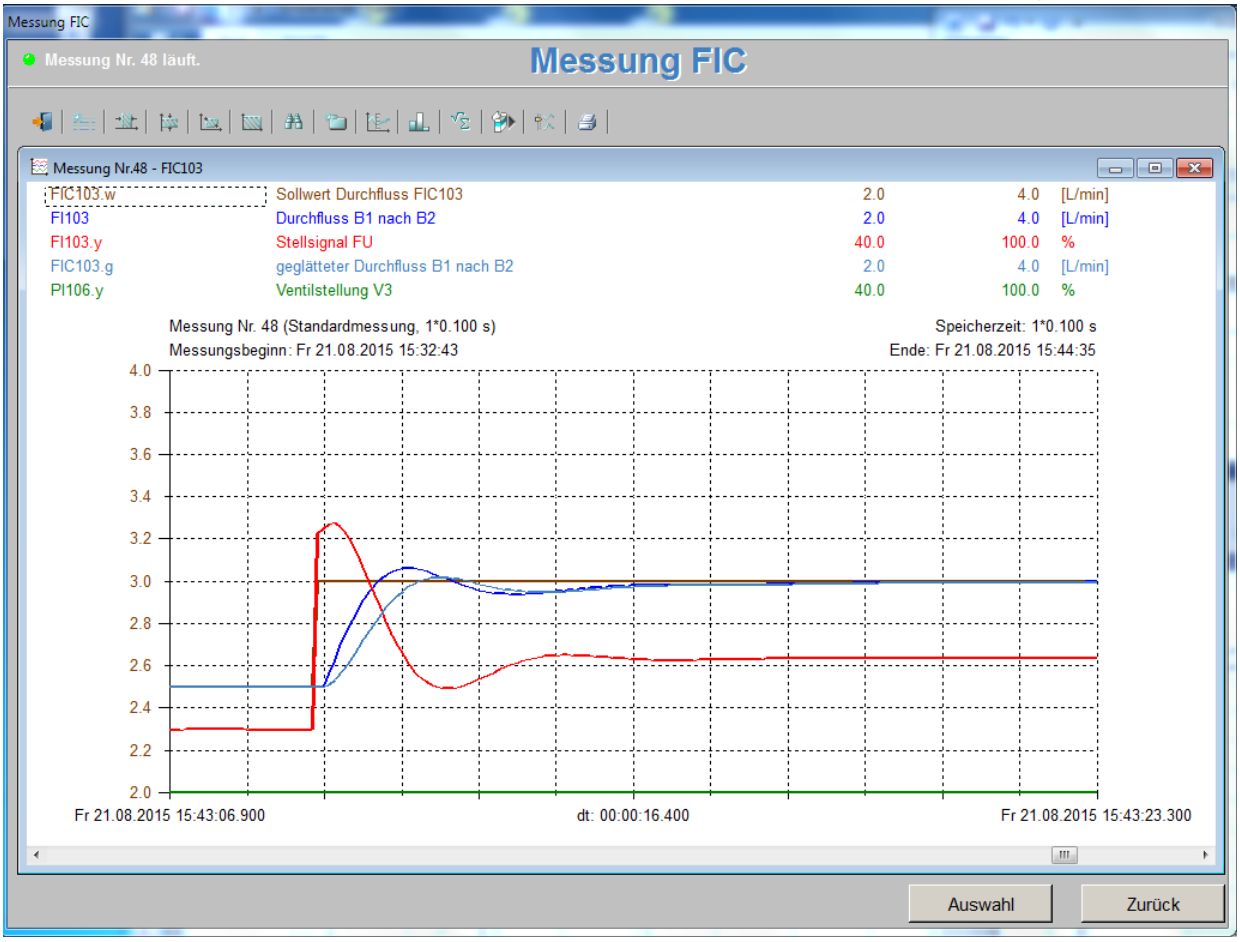


Fig.97: PI controller to Chien / Hrones / Reswick for leading jump without overshoot

A set point change was defined from 2.5 l / min to 3 l / min.

The control variable is again the smoothed flow FIC103.g.

As can be seen, the control loop slightly oscillates, although the parameters for the aperiodic course have been chosen. The reason for the overshoot can be explained as above.

Please note that the smoothed signal FI103.g was used to determine the controller parameters. In Fig.97, you must therefore consider the transient response of the light blue signal (FI103.g). The overshoot of this signal is limited.

TASK 4.4.22 Calculate controller parameters for disturbance control from the table with 20% overshoot.

SOLUTION

The following controller parameters are obtained for the disturbance behaviour with 20% overshoot:

PI: $K_p = 0.7 * T_g / (K_s * T_u) = 0.7 * 3.1 / (0.05 * 0.4) = 108.5$

$T_n = 2.3 * T_u = 2.3 * 0.4 = 0.92s$

The disturbance was generated by adjusting the hand valve behind the pump M3 to 80%.

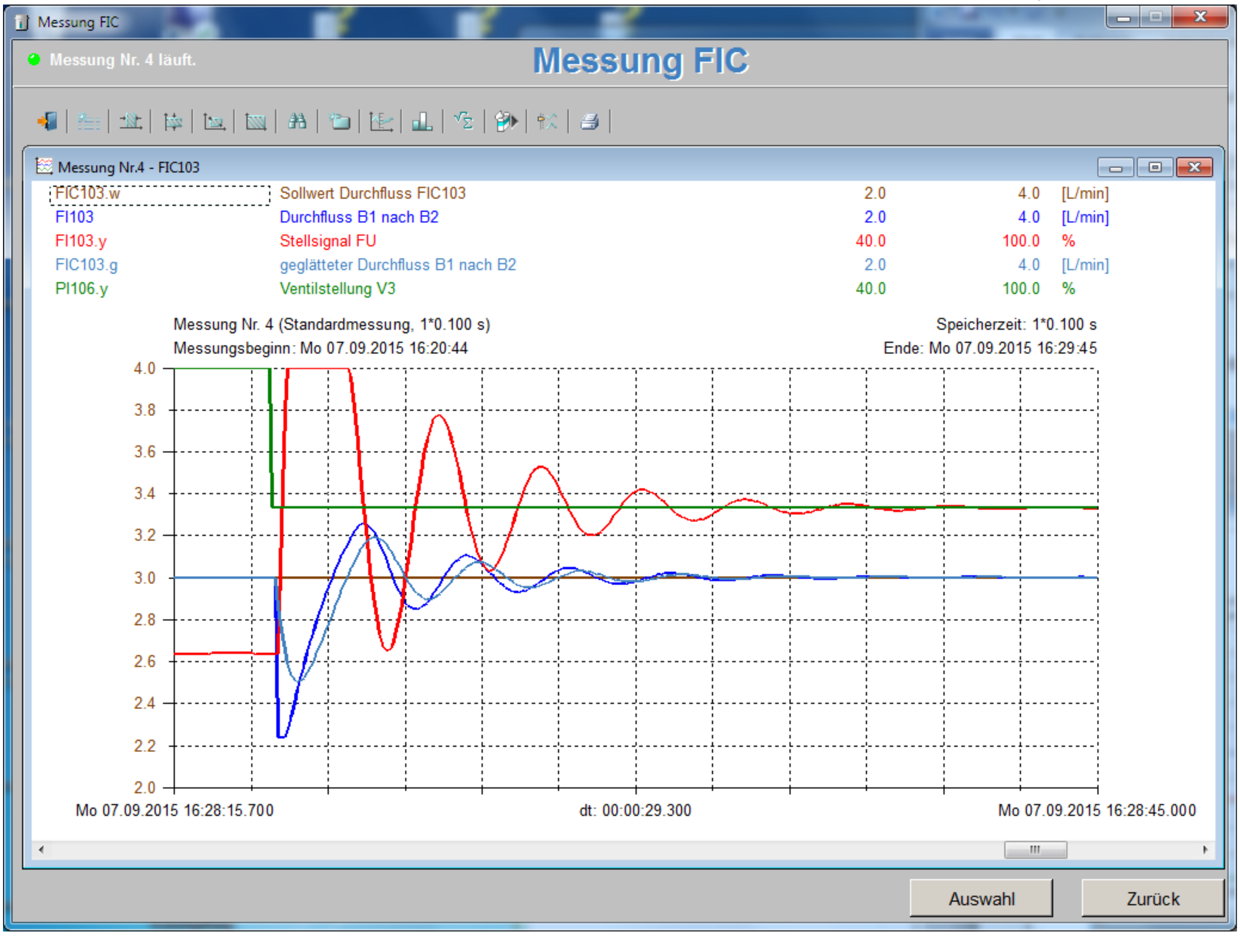


Fig.98: PI controller according to Chien / Hrones / Reswick for disturbance behaviour with overshoot

TASK 4.4.23 Calculate controller parameters for disturbance control from the table without overshoot.

SOLUTION

The following controller parameters result for the disturbance behaviour with the aperiodic course:

PI: $K_p = 0.6 * T_g / (K_s * T_u) = 0.6 * 3.1 / (0.05 * 0.4) = 93$

$T_n = 4 * T_u = 4 * 0.4 = 1.6s$

The disturbance was generated by adjusting the hand valve behind pump M3 to 80%.

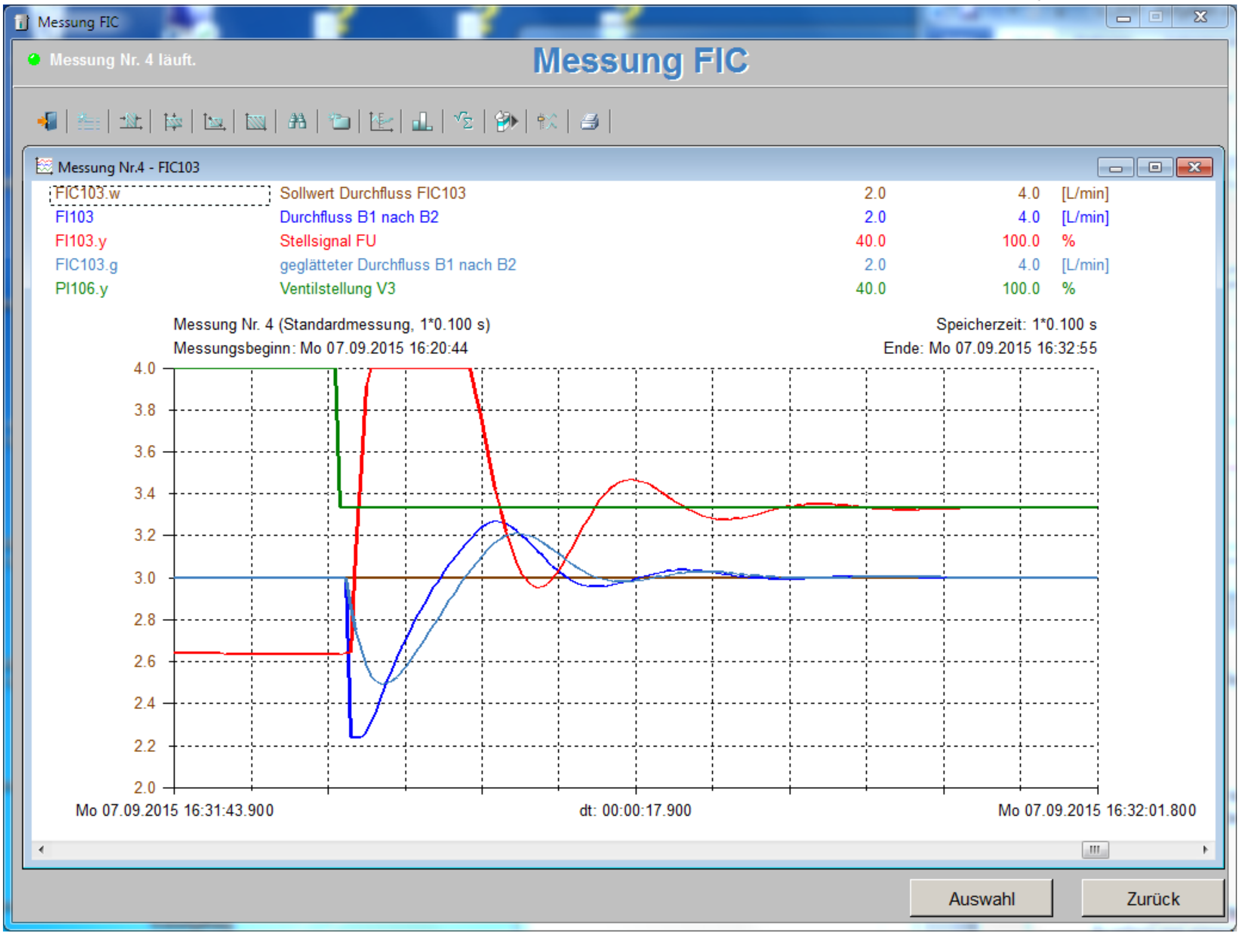


Fig.99: PI controller according to Chien / Hrones / Reswick for disturbance behaviour with aperiodic behaviour

Again, it can be seen that the disturbance is not aperiodically adjusted. However, here, the actual value goes back to the set point with less overshoot.

The controller parameters for the disturbance and guidance behaviour are different. When designing a control circuit, it must be determined whether the control circuit is primarily to react to set point or to disturbance value changes.

If both the set point changes and the disturbances occur during control, a compromise must be found for the controller parameters.

TASK 4.4.24 Calculate controller parameters for PI controller which are suitable for guidance and disturbance control. Apply a step from 2.5l/min to 3l/min and a disturbance)manual valve from 100% to 80%).

SOLUTION

Fig.100 shows the behaviour on a guidance jump from 2.5 l / min to 3 l / min and on a disturbance (manual valve from 100% to 80%) with the parameters:

$K_p = 55$, $T_n = 2.5s$

This corresponds roughly to the controller parameters for the conduct behaviour with aperiodic settling.

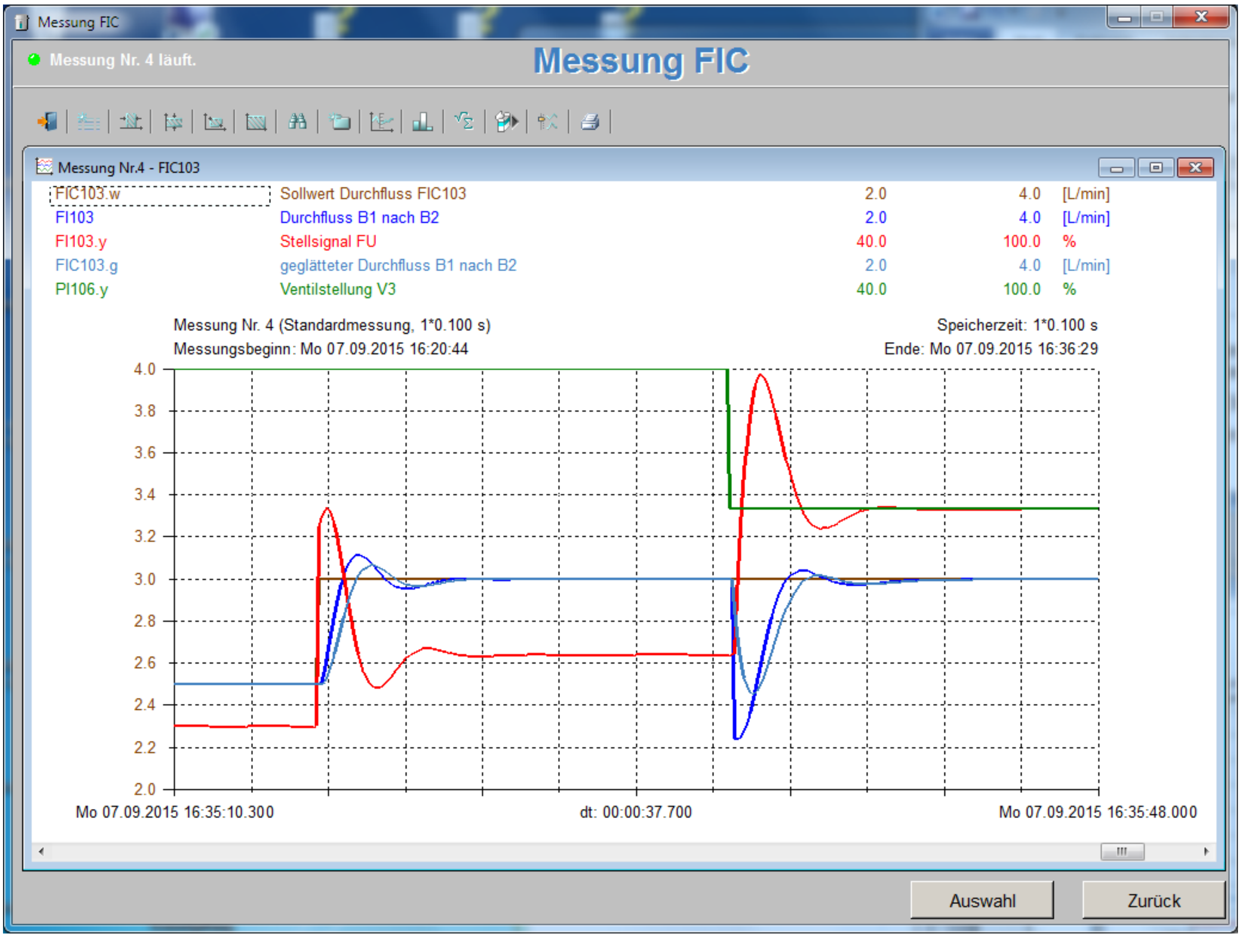


Fig.100: PI controller with controller parameters for disturbance and guidance behaviour

If, therefore, the task is to correct disturbances and set point changes, These controller parameters work as a compromise.

TASK 4.4.25 Calculate controller parameters for guidance with PID controller control from the table without overshoot.

SOLUTION

If the control circuit is to be controlled with the PID controller, the following controller parameters are obtained as controller parameters for the control behaviour without overshoot:

PID: $K_p = 0.6 * T_g / (K_s * T_u) = 0.6 * 3.1 / (0.05 * 0.4) = 93$

$T_n = T_g = 3.1s$

$T_v = 0.5 * T_u = 0.2s$

As can be seen in Fig.101, the PID controller reacts quickly to a set point change. However, the control circuit also overshoots with these parameters, although they were determined for the aperiodic case. Also a disturbance can be well adjusted with these parameters.

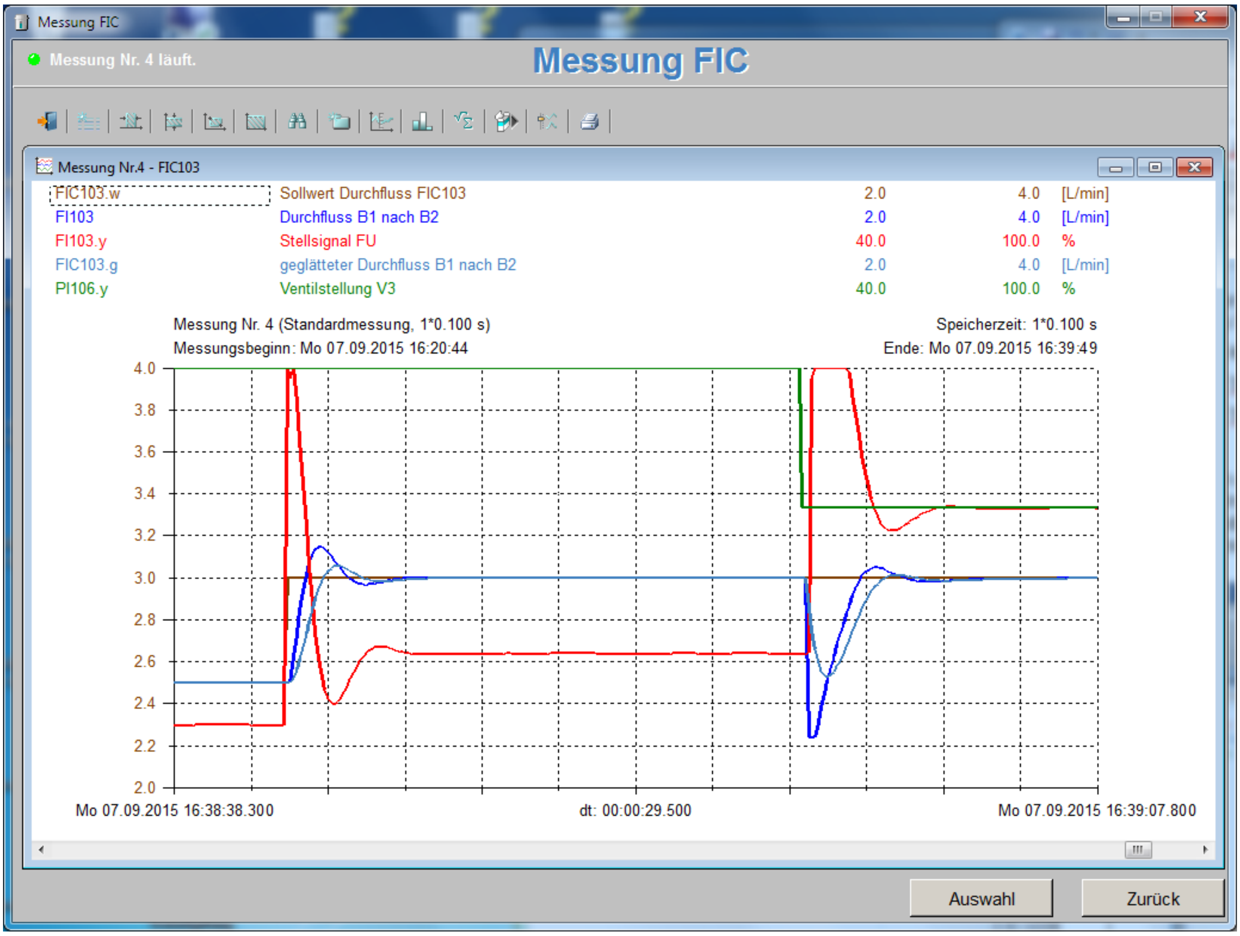


Fig.101: PID controller according to Chien / Hrones / Reswick for guidance jump without overshoot on set point change and disturbance

If you select the PID controller instead of Tv = 0.2 s Tv = 2 s, you get the following behaviour (Fig. 102). The control circuit becomes unstable.

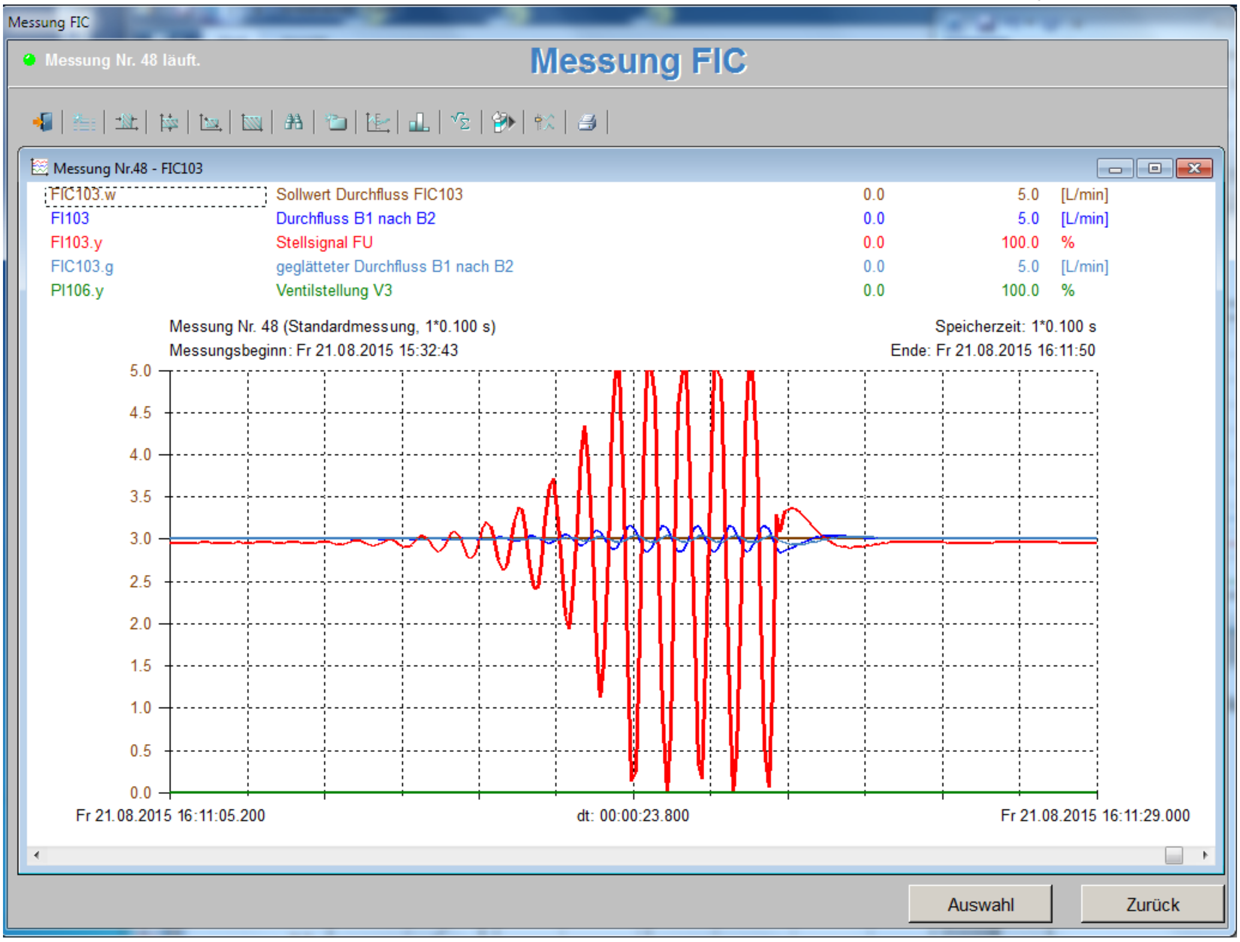


Fig. 102 Unstable control circuit due to high derivative time

In Fig. 102, only the derivative time Tv was set from 0.2 s to 2 s.

The control loop began to swing and became unstable. After the derivative time was again changed to 0.2 s, the control became stable.

4.5 TEMPERATURE CONTROL TIC102

Go to *Temperature Control*. Here, you have the options of operating the control in manual and automatic mode, selecting the controller type and setting the controller parameters. P, PI, PID and two position controller are available as controllers.

The temperature is controlled by means of a heating rod. The heating power of the heating rod cannot be adjusted analogously. It can only be switched on or off. If the control is to be performed analogously, a pulse-width-modulated control must be implemented or a two position control can be used.

The heating rod is locked so that it can only be switched on when the container is at least half full (level switch *B2* reached).

A time interval (cycle time) is defined for the pulse width modulated control in which the heating rod is switched on or off as a function of the control signal of the controller.

If you set the temperature control to Auto, the heating rod is switched on and off as follows: Depending on the control signal (0-100%), the heating rod is switched on and off proportionally in the specified time interval of the pulse width modulation (cycle time).

If pump *M4* is switched on during the simulation, the simulation behaves as if there is a cooler in the circulating line. The temperature of the water cools down faster with pump *M4* switched on.

The following tasks were performed with the simulated system.

The level was 20 cm and pumps M1, M2 and M3 were switched off.

First, the control circuit is to be determined in principle.

TASK 4.5.1: Formulate what should be controlled, by what it is controlled and what disturbances take an influence.

SOLUTION

The temperature of the water in the tank should be controlled by means of the heating rod. The temperature is influenced by switching the heating rod on and off. An inflow pump can be connected as a disturbance variable.

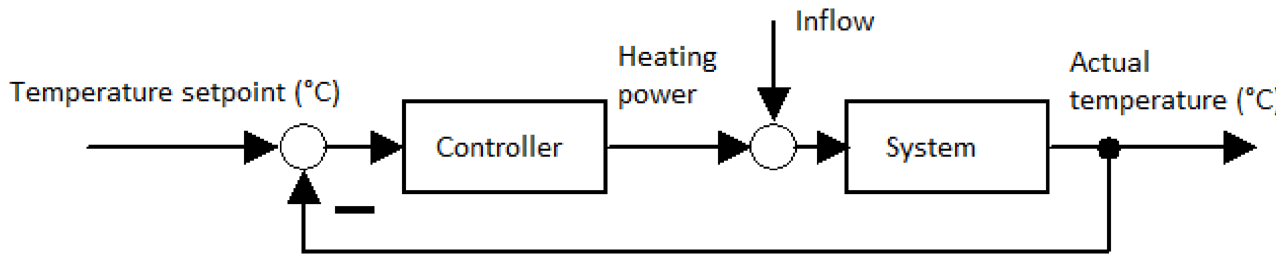
TASK 4.5.2: For this control loop, determine the set point, the actual value, the actuating signal (manipulated variable) and the disturbance variable, and specify the respective units.

SOLUTION

Set point:	Temperature set point in ° C
Actual value:	Measured water temperature in the container in ° C
Manipulated variable:	Heating power, heating element switched on or off
Disturbance:	Inflow through pump M1 or M2 in l / min

TASK 4.5.3: Create a signal flow plan (block structure) for temperature control.

SOLUTION



TASK 4.5.6: Set the control loop to manual and try to reach a given temperature set point by adjusting the control signal y.

4.5.1 EXAMINATION TEMPERATURE CONTROL TIC102 WITH P CONTROLLER

Examine the temperature control using the P controller.

The following tasks were performed with the simulated plant and the above settings. The circulating pump M4 is not switched on. The time for pulse width modulation is 10 sec. The level should be at 20cm.

TASK 4.5.7: Choose manual regulation. The actual temperature is 20 ° C. and the desired temperature is set to 30 ° C. Set the gain of the P controller to 5 and switch the control to Auto. Observe the behaviour. Describe the behaviour of the control. Consider, in particular, the relationship between actual temperature and temperature set point (actual value and set point).

SOLUTION

The actual value does not reach the set point. The difference between actual value and set point is approx. 1.2 °C. It takes very long until the actual value goes to its final value.

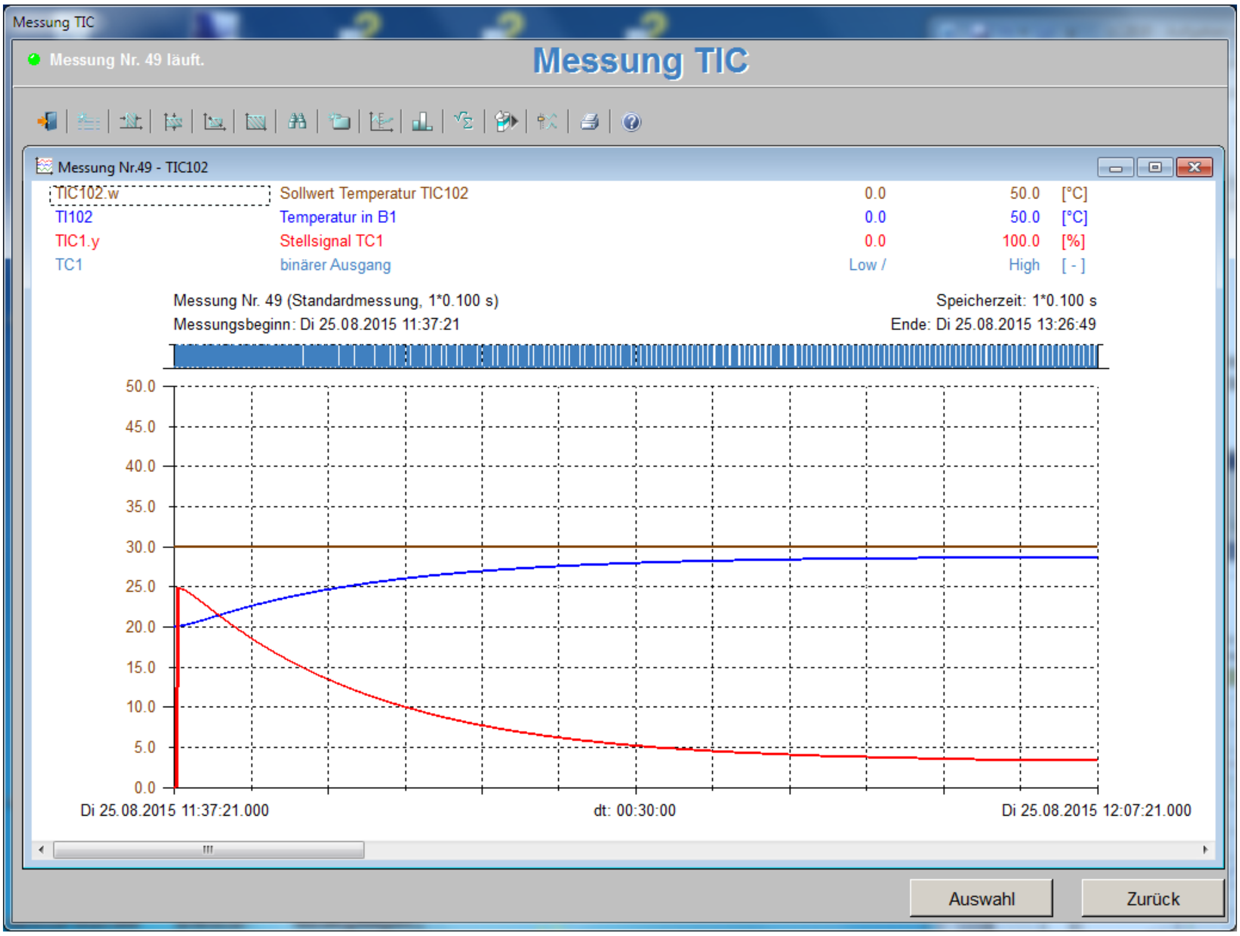
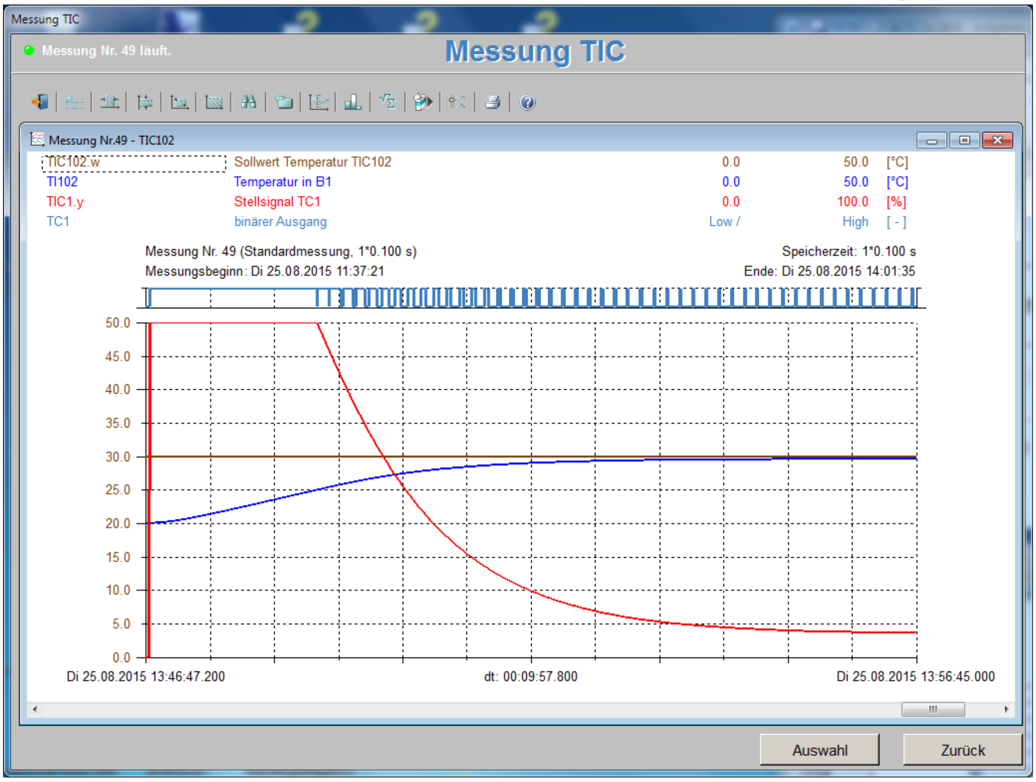


Fig.103 Temperature control, P controller with gain 5

TASK 4.5.8: Increase the gain of the P controller to 20 and to 50 and observe the behaviour. Describe the behaviour of the control. Consider, in particular, the relationship between actual temperature and set point temperature (actual value and set point).



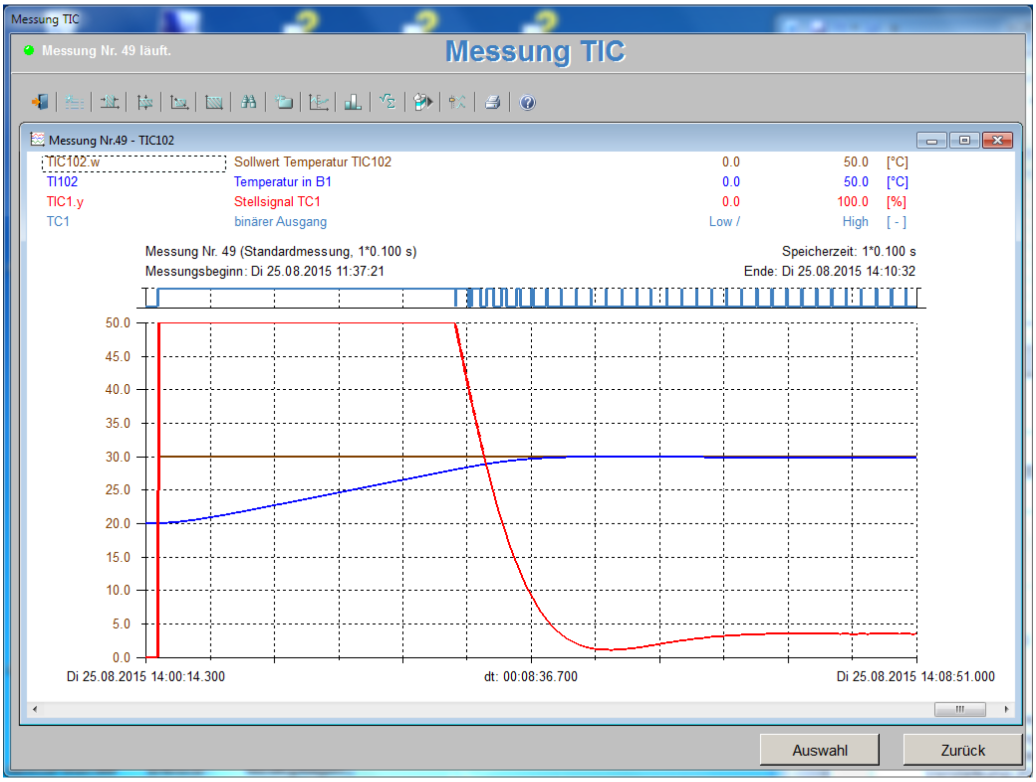


Fig.104 Temperature control with P controller, gain of 20 and 50

SOLUTION

The P controller controls the actual value almost to the set point with these high gains. For the gain of 20, the difference between the actual value and the set point is approx. 0.4 °C and the gain of 50 is approx. 0.1 °C. The actual value goes to its new end value without overshoot (with gain 20) or with a small overshoot (with gain 50). Since the difference between the actual value and the set point with these gains is low, the P controller is suitable with the pulse-width-modulated temperature control for many requirements. The larger the gain, the faster the actual value goes into its new end value.

If you select the gain even greater, e.g. 500, the actual value oscillates over the set point.

If the tests carried out above are carried out with pump M4 switched on and with the cooler (Fig.105), the transient response time is longer as the cooler additionally cools the water to be heated. There results also a larger difference between the actual value and the set point.

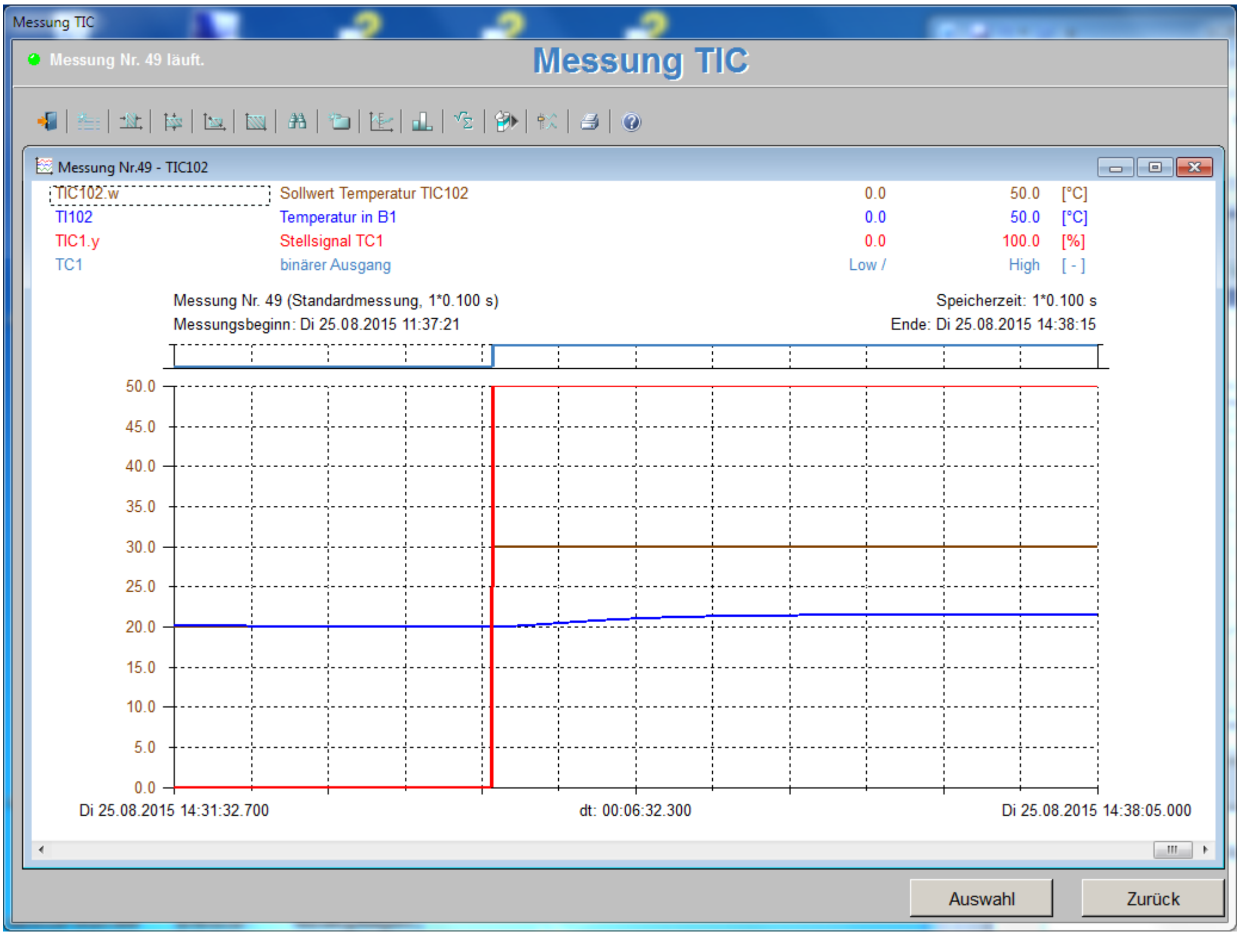


Fig.105 Temperature control with P controller, gain 500, activated pump M4, cooling capacity 100%

4.5.2 EXAMINATION OF THE TEMPERATURE CONTROL WITH THE PI CONTROLLER

Wait until the temperature in the container is constant (e.g., 20 ° C). If you are working with the simulated system, you can use *View simulated LC2030* and *Parameters* to *Set start* and bring the simulated system to a defined initial state with a temperature in the tank of 20 °C.

Pump M4 is switched on for the following tasks and the cooling capacity is set to 50%. The level should be set to 20cm.

TASK 4.5.9: Set a gain of 50 and a reset time of 10s. Increase the set point from 20 °C to 30 °C. Observe the control loop and describe its behaviour.

SOLUTION

The actual value goes over the new set point with the PI controller and then begins to oscillate. Since the temperature cools very slowly, it takes a long time until the actual value reaches the set point again. By the pulse width modulation and the adjusted parameters, the control loop starts to oscillate.

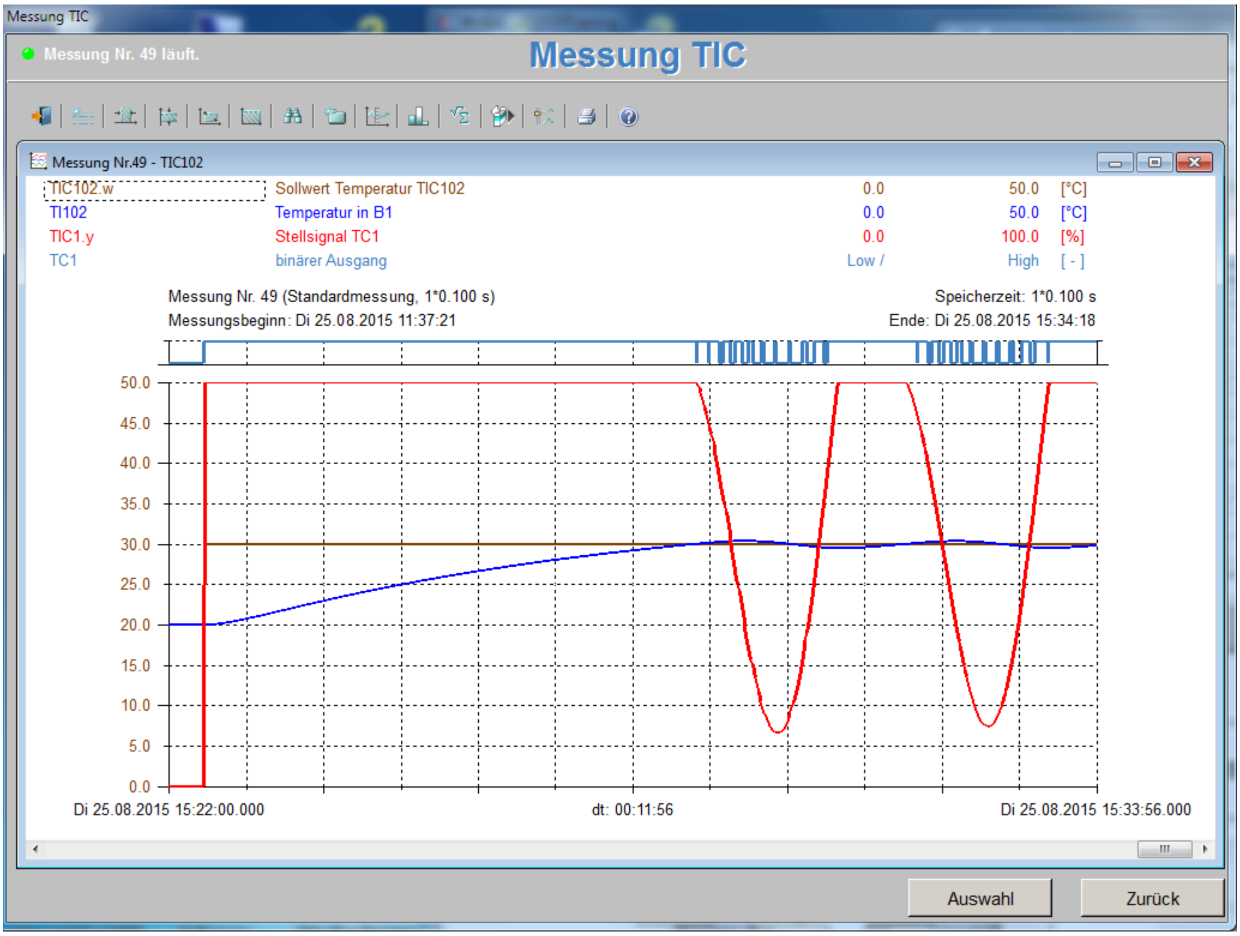


Fig.106 Temperature control with PI controller, reset time of 10s, gain 50

TASK 4.5.10: Change the parameters of the PI controller and try to get to the set point faster without overshooting.

SOLUTION

Gain and reset time must be increased, e.g. Gain 80 and reset time 100.

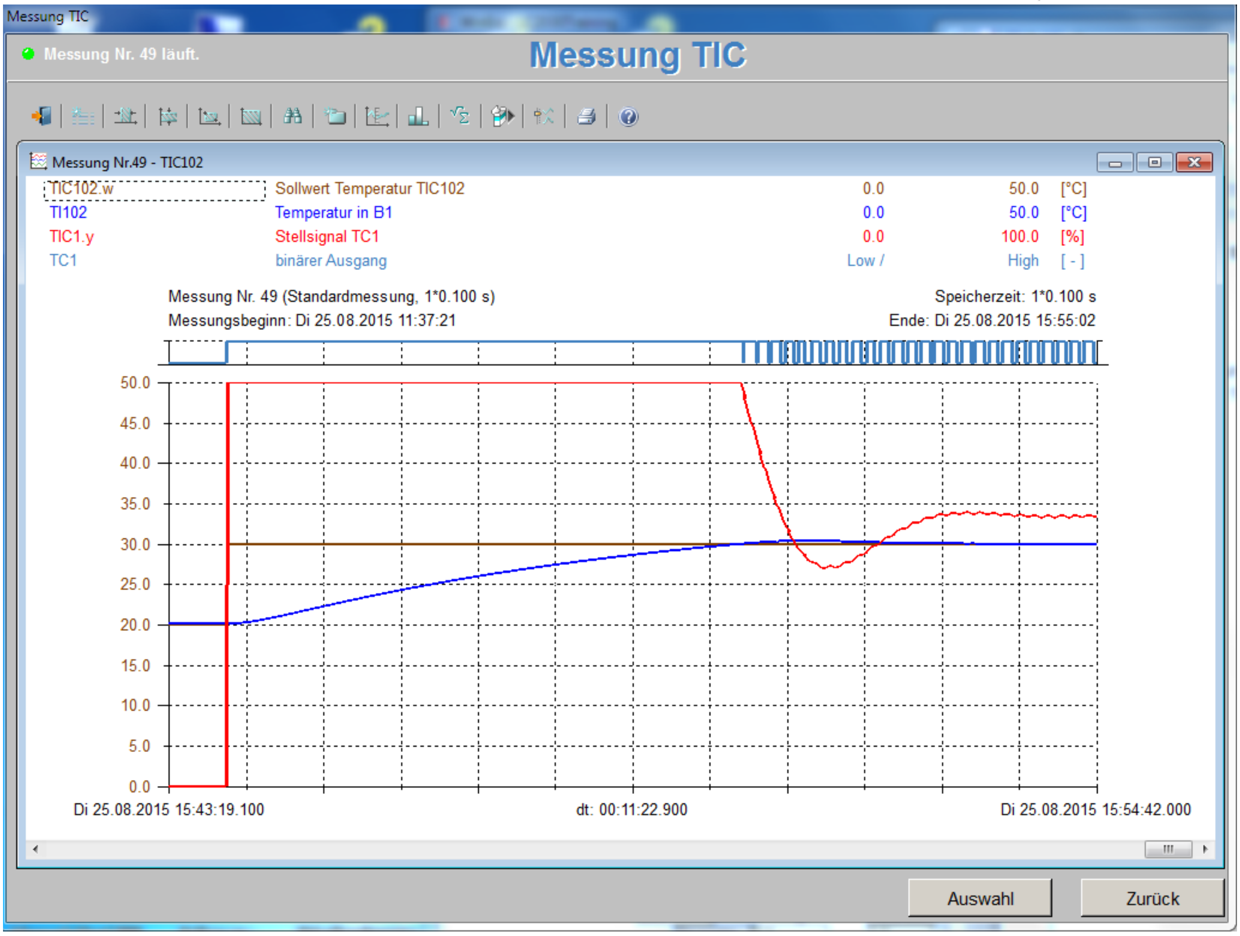


Fig.107: Temperature control with PI controller, reset time of 100s, gain 80

4.5.3 EXAMINATION OF TEMPERATURE CONTROL TIC102 WITH PID CONTROLLER

Wait until the temperature in the tank is constant (e.g., 20 ° C). If you are working with the simulated system, you can use *View simulated LC2030* and *Parameters* to *Set start* and bring the simulated system to a defined initial state with a temperature in the tank of 20 °C.

Pump M4 is switched on for the following tasks and the cooling capacity is set to 50%. The level should be set to 20cm.

TASK 4.5.11: Set the following parameters: Gain = 50, reset time = 10s, derivative time = 2s. Provide a set point jump from 20 °C to 30 °C. Observe the control loop and describe its behaviour.

SOLUTION

The actual value goes over the new set point value and then begins to oscillate. Since the temperature in the vessel cools very slowly without a cooler, it takes a long time for the actual value to reach the set point again. By the pulse width modulation and the adjusted parameters, the control loop starts to oscillate.

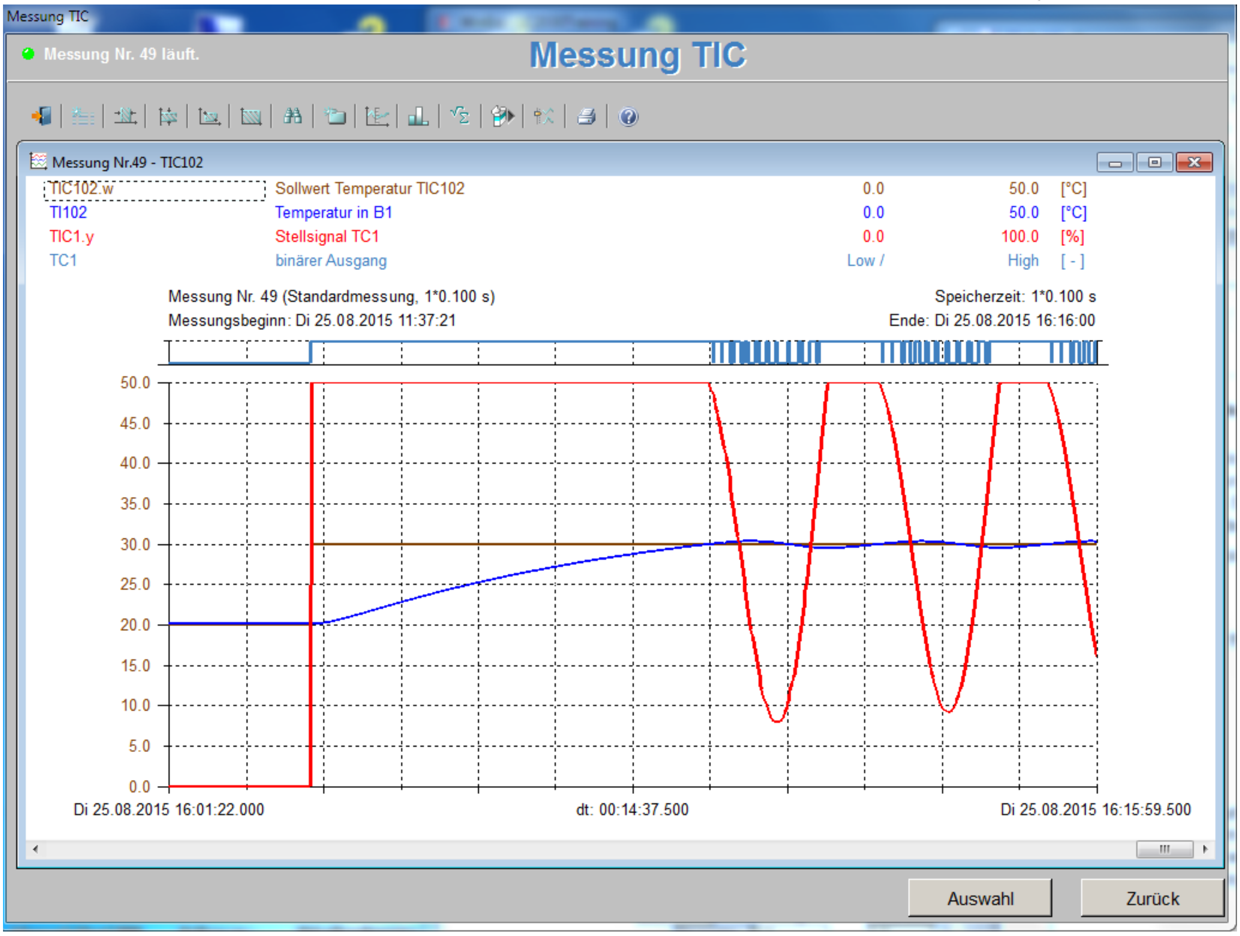


Fig.108: Temperature control with PID controller, gain 50, reset time 10s, derivative time 2s

TASK 4.5.12: Change the parameters of the PID controller and try to reach the set point quickly and without overloading with the actual value.

SOLUTION

Increase gain, reset time and derivative time (gain 80, reset time 100s, derivative time 3s).

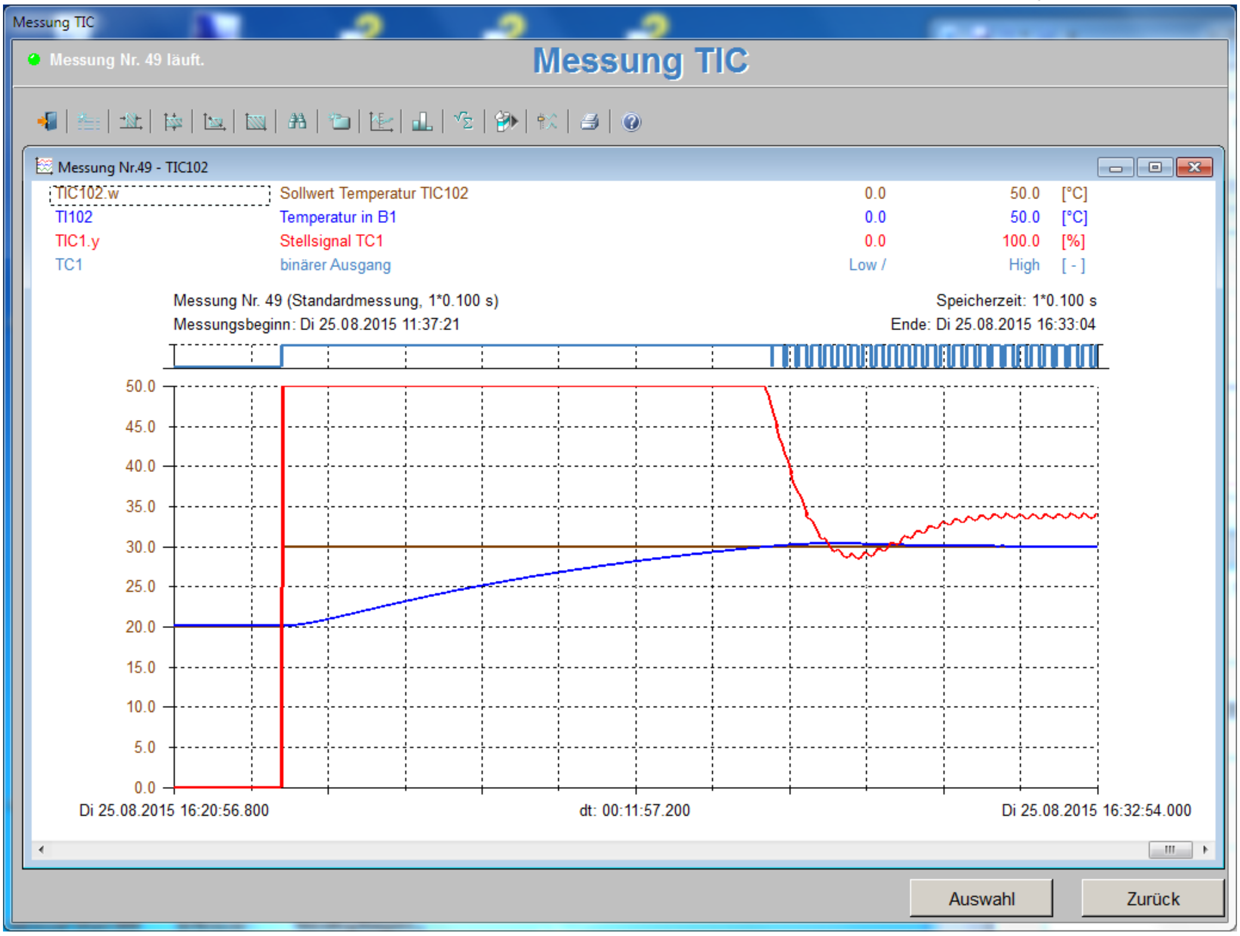


Fig. 109 Temperature control with PID controller, gain 80, reset time 100s, derivative time 3s

4.5.4 EXAMINATION OF TEMPERATURE CONTROL TIC102 WITH TWO POSITION-CONTROLLER

Wait until the temperature in the container is constant (e.g., 20 ° C). If you are working with the simulated system, you can simulate the LC2030 view and set the parameters by pressing start values to bring the simulated system to a defined initial state with the temperature in the vessel 20 ° C.

The pump M4 is not switched on in the following task. The level should be set to 20cm .

TASK 4.5.13: Choose a hysteresis of 0,2 for the two-position-controller and enter a set point jump from 20 °C to 30 °C. Observe the control loop and describe its behaviour.

SOLUTION

The actual value oscillates around the set point with the hysteresis of 0,2. Because the heating rod still has a heat capacity even when switched of the water becomes warmer than 30,2°C. The actuating signal switches between 0% and 100%. Thus the heating rod is switched on and off.

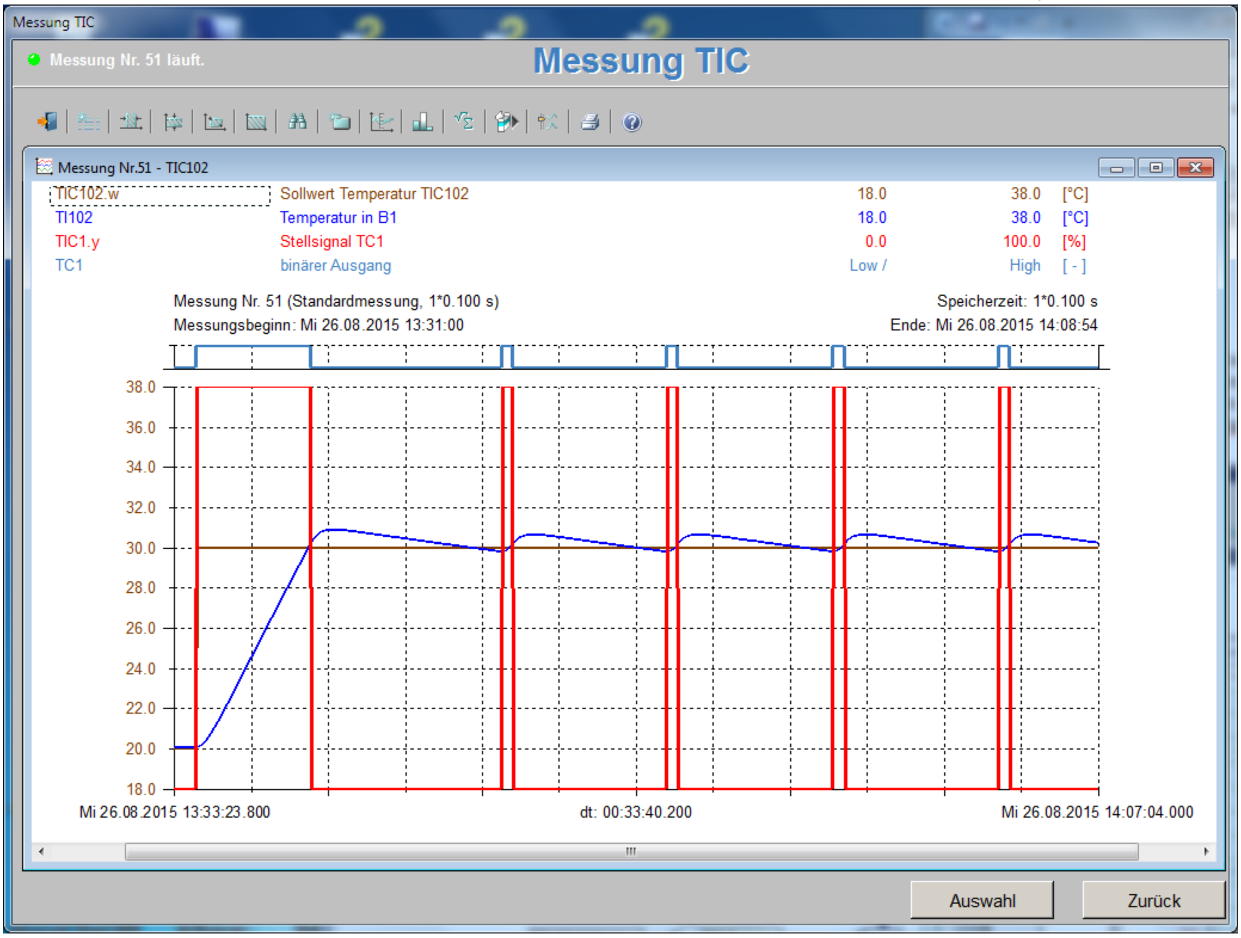


Abb.110 Flow rate control with two position controller

4.5.5 CONTROLLER SETTING PROCEDURE FOR TEMPERATURE SYSTEMS ACCORDING TO MÜLLER

In the method of Müller, the step response on a control value jump is examined. For this purpose, your control loop must be in a stable operating point. You must set the controller to manual mode and the actuating signal and the control variable must not change. Provide a sudden change of the control signal and observe the behaviour of the temperature range.

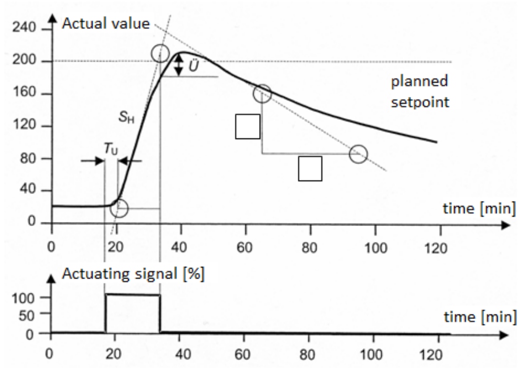
Circulating pump M4 is switched off.

To determine the controller parameters, delay time T_u and slope *Sh* are required.

Method of Maximum Increase Speed (for Temperature Systems (acc. Müller)

Approach: test function = square function

I. Initial temperature of the system Room temperature
II. Actuating jump 100%
III. Wait until temperature is app. 10% below operating point
IV. Reduction of actuating signal to 0%
V. Determination of slope S_H from $S_H = \triangle x / \triangle t$



VI. Determination of controller parameters according to following table:

Controller type	K_{PR}	TN	TV
P	$100/(S_H \cdot T_U)$		
PI	$83/(S_H \cdot T_U)$	$4 \cdot T_U$ [s]	
PD	$120/(S_H \cdot T_U)$		$0{,}2 \cdot T_U$ [s]
PID	$220/(S_H \cdot T_U)$	$2 \cdot T_U$[s]	$0{,}4 \cdot T_U$ [s]

Fig.111 Method of the maximum increase speed according to Müller (from a course "Regelungstechnik" by Prof. Hass, Hochschule Bremen)

The controller parameters can be calculated from the setting table according to Müller using T_u and *Sh*.

For our range, the following behaviour (Fig. 107) results in a actuating value jump.

TASK 4.5.14 Calculate T_u and *Sh*.

SOLUTION

From this the T_u and *Sh* can be determined:

T_u = 18.3, Sh = 0.048

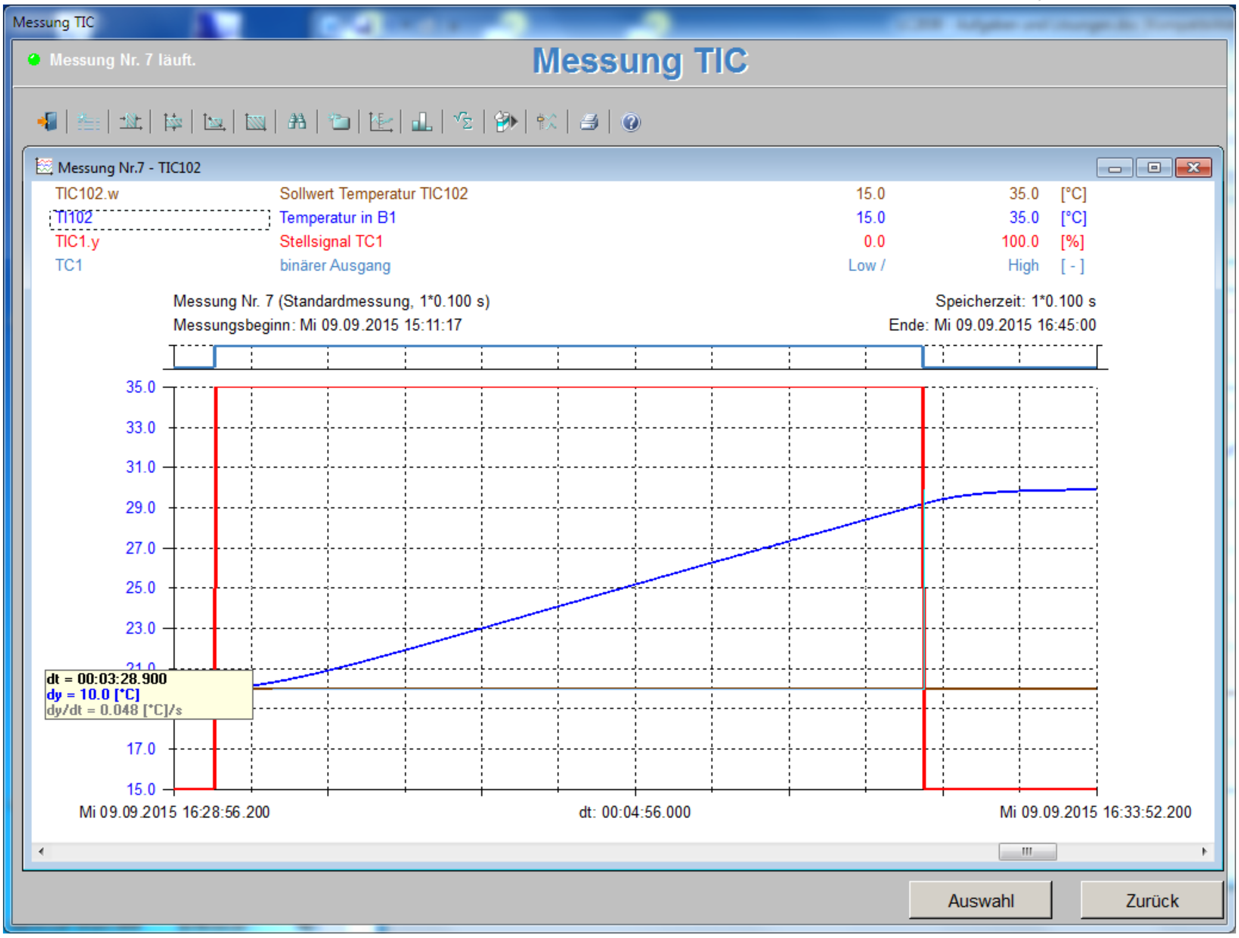


Fig.112: System response for determining the parameters according to Müller

TASK 4.5.14 Calculate controller parameters for PI controller and PID controller from the table and examine the transient response.

SOLUTION

The following controller parameters are calculated:

PI: $K_p = 83 / (Sh * T_u) = 83 / (0.048 * 18.3) = 83.9$

$T_n = 4 * T_u = 4 * 18.3 = 73.2s$

PID: $K_p = 220 / (Sh * T_u) = 220 / (0.048 * 18.3) = 250.5$

$T_n = 2 * T_u = 2 * 18.3 = 36.6s$

$T_v = 0.4 * T_u = 0.4 * 18.3 = 7.3s$

As can be seen clearly from the actuating variable jump (Fig.113), the temperature increases even though the heating element has been switched off at 29 ° C. This is due to the heat capacity the heating element has stored. In the real system, this overshoot is even more extreme than in the simulated system.

The pump M4 is switched off and the level is set to 20cm.

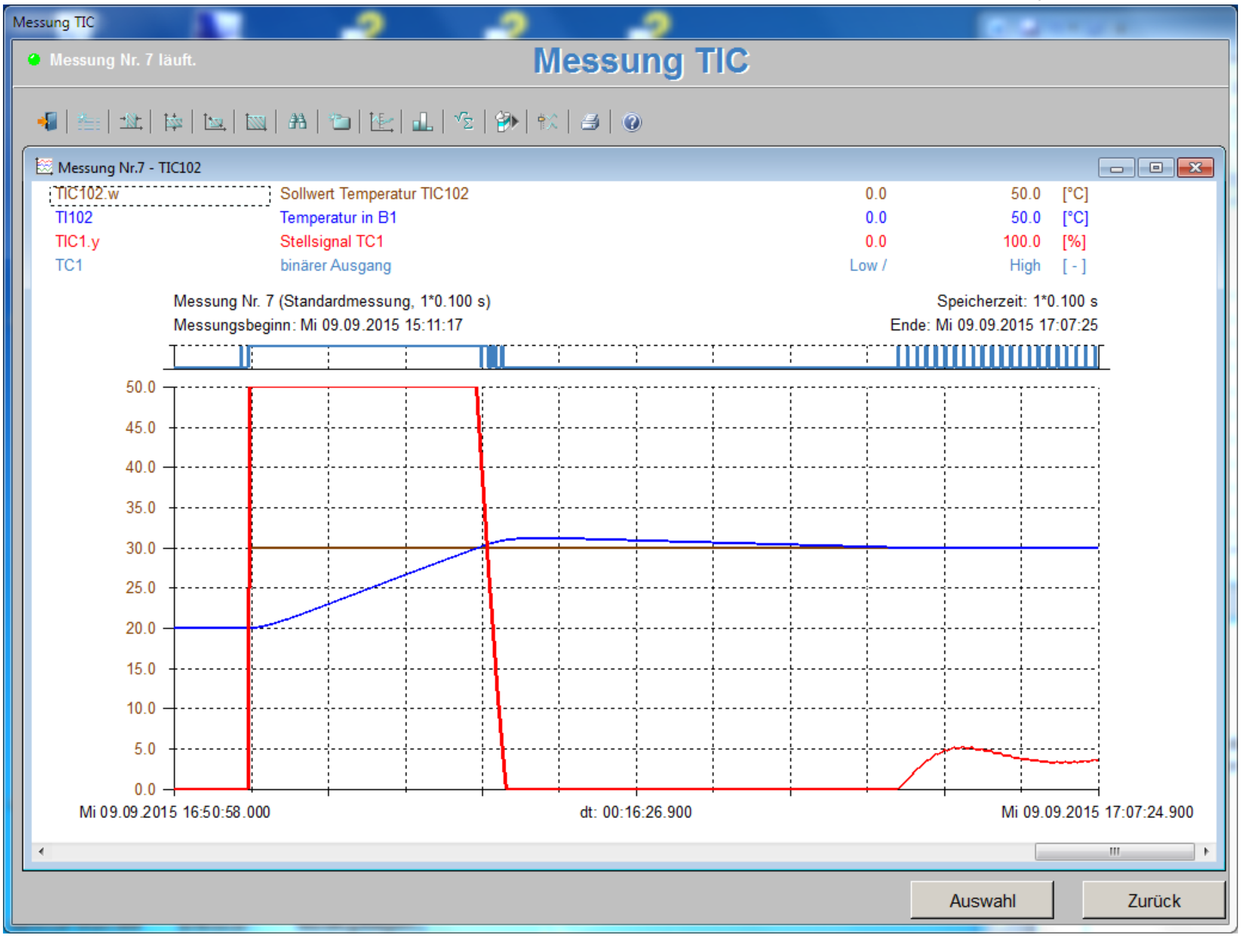


Fig.113: PI controller according to Müller, gain 83.9, reset time 73.2

The control loop oscillates (the actual value becomes greater than the set point value). The actual value then reaches the set point and the actual value is kept at the set point with slight overshoot.

For the PID controller with the parameters according to Müller, the following settling occurs (Fig.114).

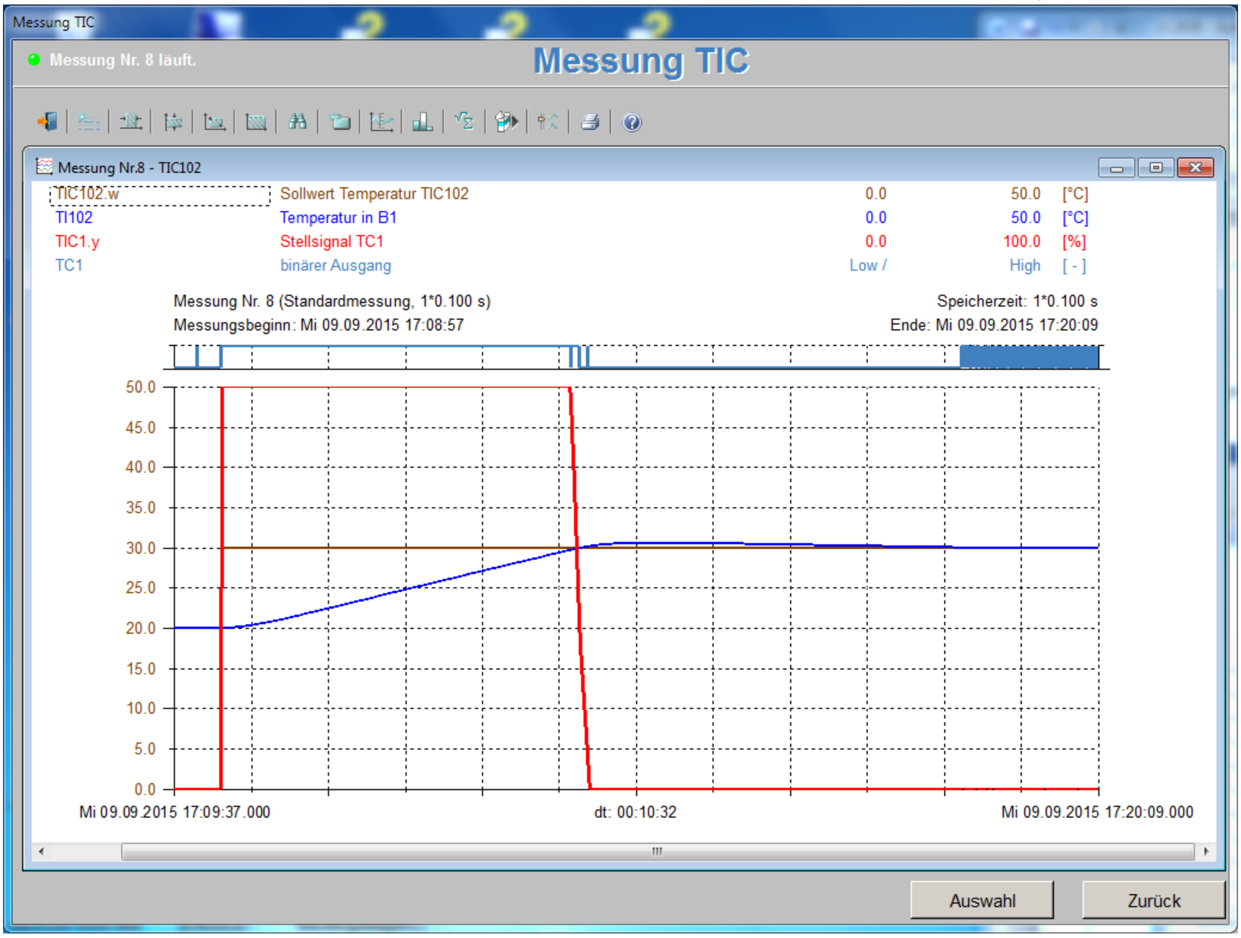


Fig.114: PID controller according to Müller, gain 250.5, reset time 73.2s, derivative time 7.3s

The actual value goes to the set point with overshoot. After the actual value has reached the set point, the actual value is kept well at the set point. The actual value is held by rapid pulsing of the heating element, as can be seen on the binary signal TC1 at the top of the diagram (Fig.114).

The settling of the actual value to the nominal value with the PID controller is faster than with the PI controller.

Information regarding errors, inaccuracies and expansion options are highly appreciated!

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