MIDDLE EAST TECHNICAL UNIVERSITY

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

PROCESS CONTROL LABORATORY

EXPERIMENT 3: LEVEL CONTROL SYSTEM WITH ELECTRONIC CONTROLLER

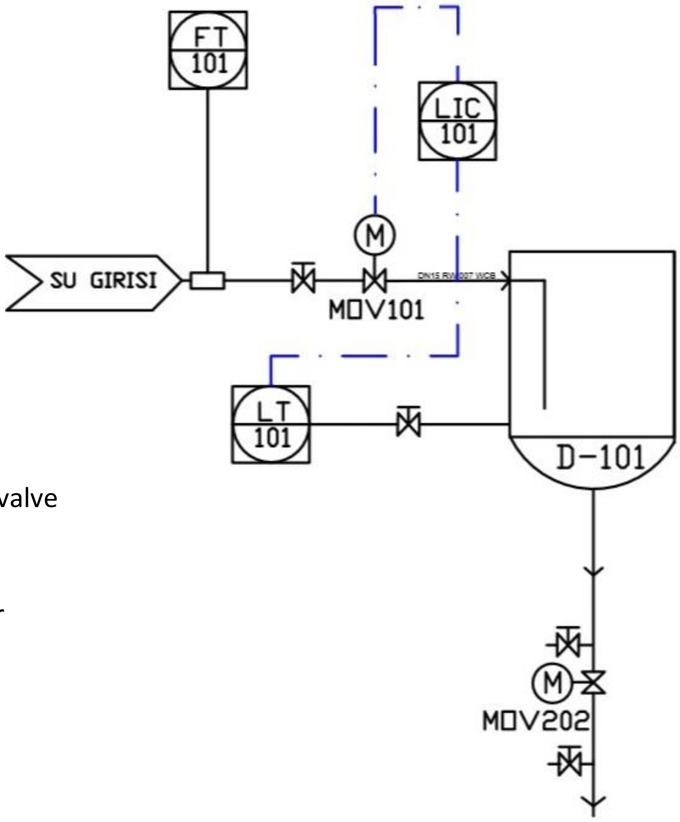
I. Objective

The objective of this experiment is to model and control a level process while getting familiar with an industrial Distributed Control System (DCS) and with various components involved in the control mechanism.

II. Information

General:

A related piping and instrumentation diagram (P&ID) for the water level process is shown in Figure 1. Lines in this diagram represent hydraulic connections. Dashed lines represent the control loop.



D101 : Water Tank
M : Motor actuated valve
MOV101 : Valve 1
MOV202 : Valve 2
LT101 : Level transmitter
FT101 : Flow transmitter
LIC101 : Level Controller

Figure 1. P&ID for the water level process.

The Level Transmitter:

A Honeywell differential pressure transducer featuring piezoresistive sensor technology with model number STD700 is utilized to measure the level of the water in the tank. The pressure signal acquired by the transmitter is proportional to the level of the water in the tank. Therefore, the level information can be obtained by processing the pressure output.

The transmitter outputs a DC voltage between 1 and 5 Volts corresponding to 0% and 100% of the max process value that it can measure, respectively. The relation between the percentage process value and the level of the water is illustrated in Figure 2.

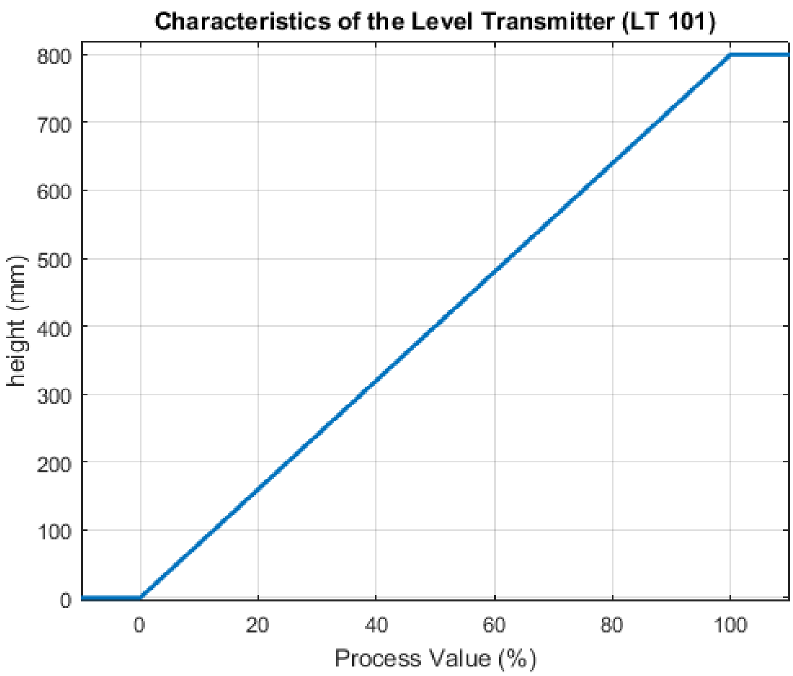


Figure 2. Characteristics of the level transmitter.

The Control Valve:

In this experiment, an Electric Linear Valve Actuator, with model number ML7421A, of Honeywell is employed to control the flow of the water into the tank. As is evident from its name, an electrical signal (current or voltage) connected to the unit, controls the position of the stem of the valve. The control valve essentially consists of two main parts, namely an actuator and a valve. A synchronous motor with a worm gear serves as the actuator. The drive of the synchronous motor is converted into linear motion of the stem by using the transmission. Consequently, the amount of flow through the control valve is controlled by changing the linear position of the valve stem. In addition, there are internal force sensors employed to switch off the actuator precisely when the nominal stem force is reached via installed microswitches.

The relation between the valve position and the output flow is depicted in Figure 3.

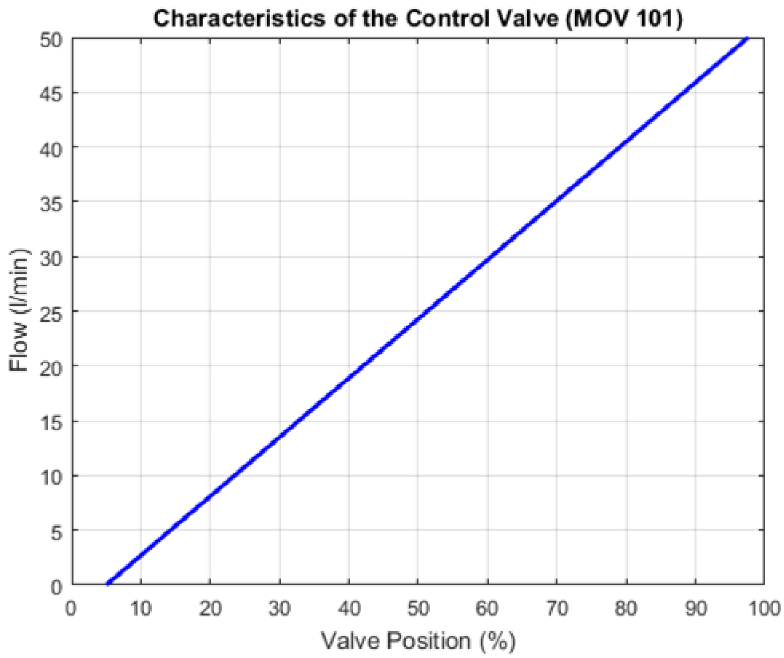


Figure 3. Characteristics of the control valve.

The Flowmeter:

A flowmeter (flow transmitter) of Honeywell named as ‘VersaFlow Vortex’, as denoted by FT101 in the schematic, is included in the experimental setup to detect the amount of input water flow to the tanks. It is essentially a vortex flow meter which is used to measure the volumetric flow of gases, vapours and liquids at completely filled pipes.

The measuring principle is based on the Karman vortex street. The measuring tube contains a bluff body, behind which vortex shedding occurs. The frequency f of the vortex shedding is proportional to the flow rate v. The nondimensional Strouhal number S describes the relationship between vortex frequency f, width b of bluff body and the mean flow velocity v:

$$f = (S \, . \, v) / b$$

The functional principle of vortex flowmeter is shown in Figure 4. The vortex frequency is recorded at the sensor and evaluated at the converter.

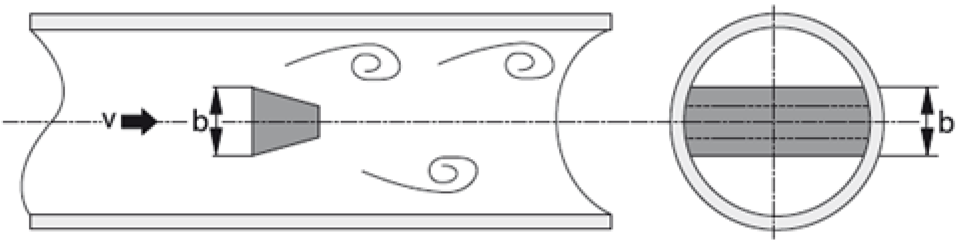


Figure 4. Functional principle of vortex flowmeter

Process and the control loop:

The water level process in this experiment is given in the simplified diagram in Figure 5. Here, q_i is the input flow, R is hydraulic resistance and q_o is the output flow that is dependent on the water height h. A is the area of the tank.

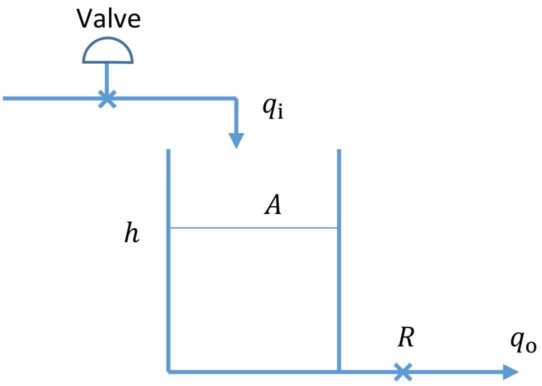
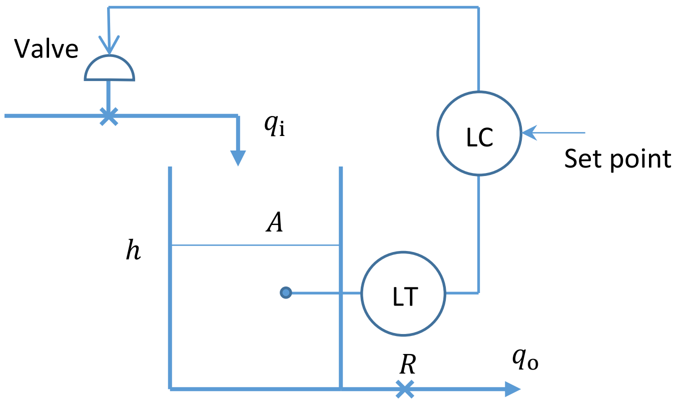


Figure 5 Water level process.

The controller is connected in such a way that valve opening is manipulated as shown in Figure 6.

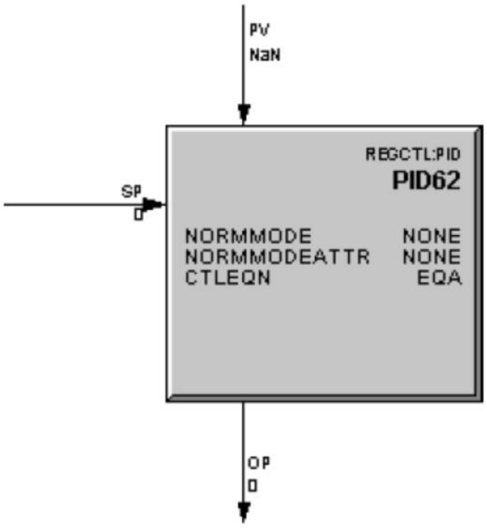


LT: Level transmitter; LC: Level controller

Figure 6 Water level process with controller

PID Controller

The PID block is a regulatory control block that operates as a proportional-integral-derivative (PID) controller. It supports the Ideal form of calculating the PID terms. The Ideal form is often called the digital-computer version of the PID controller. The PID block looks like this graphically:



The PID block has two analog inputs - a process variable (PV) and a set point (SP). The difference between PV and SP is the error and this block calculates a control output (OP) that should drive the error to zero.

The following equations are supported:

• **Equation A**: Proportional, Integral, and Derivative (PID) on the error

$$CV = K * L^{-1}\left[\left(1+\frac{1}{T_1 s}+\frac{T_2 s}{1+aT_2 s}\right)*\left(PVP_s - SPP_s\right)\right]$$

• **Equation B**: Proportional and Integral (PI) on the error and Derivative (D) on changes in PV

$$CV = K * L^{-1}\left[\left(1+\frac{1}{T_1 s}+\frac{T_2 s}{1+aT_2 s}\right)* PVP_s - \left(1+\frac{1}{T_1 s}\right)* SPP_s\right]$$

In Equation A, all three terms (Proportional, Integral, Derivative) act on the error (PV-SP), while in equation B the proportional and integral terms act on the error (PV-SP) and the derivative term acts on changes in PV. Equation B is used to eliminate derivative spikes in the control action as a result of quick changes in SP.

III. Preliminary Work

1. Considering Figure 5, derive an expression for the water height h assuming the outflow rate is $q_o = h/R$.

2. Assuming the input is q_i and the output is h, derive the transfer function of the process (in s-domain).

3. Considering Figure 5 and Figure 6, draw the block diagram of the overall process, showing all the elements and variables clearly.

a) Derive the overall transfer function assuming P-control is applied.

b) Derive the overall transfer function assuming PID-control is applied.

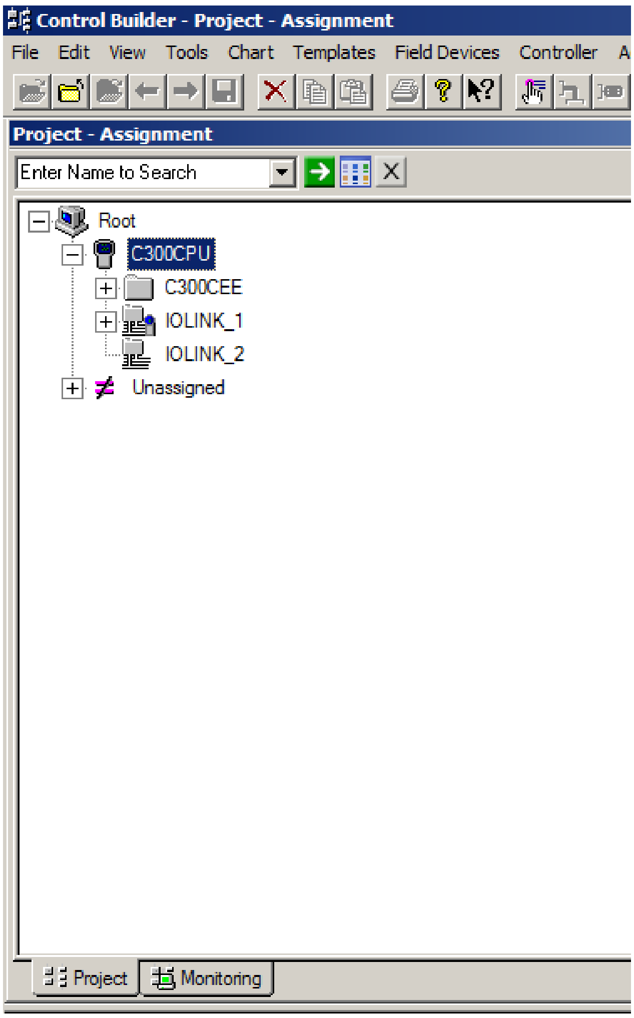
4. For regulation control, calculate the offset in the water level when P control is applied.

5. How is the offset affected when integral action is included? What can be the disadvantage of a poorly designed PI control?

6. What is the advantage of derivative action? Considering noisy measurements for the level transmitter, what is the disadvantage of derivative action? Propose a method to handle noisy measurement case for PID control.

IV. Experimental Procedure

1. Open Configuration Studio from the Desktop.
2. From the screen select ODTUsys and press connect.
3. Select Servers -> ODTUSRV -> Control Strategy
4. Under the tab of Process Control Strategies, select "Configure Process Control Strategies."
5. Control Builder Screen is open.
6. Under the Project-Assignment tab select Project. This is the tab where we define the control modules in the controller environment.
7. Under C300CPU you can see C300CEE and IOLINK_1. C300CEE is the control execution environment and IOLINK_1 represents the input-output links of the system.
8. Close all the control module pages in the middle of the screen, if there are any.
9. Right click C300CPU and select "Load with contents." Press Continue.
10. Select both of the checkboxes in the screen and select "OK." This action loads all the control modules defined in the project to the monitoring side.
11. Select the monitoring tab. Right click C300CEE and select "Change State..."
12. From CEE Command select COLDSTART. Select OK. You can observe that all three of the blocks under C300CPU turn into green. This means that we can read the input-output relations from the control cabinet.



13. Now we can control the system. For this purpose we will use a predefined user interface.

14. From the desktop, select Station. Click on ODTU→ODTU from top menu bar to open the screen "ODTU.htm". Repeat this last step at any point during the experiment should you need to come back to this screen.
15. Click on Station→Log on… from the top menu bar. Enter "mngr" as the password. This shall set what you see in the bottom right side of the page from Oper to Mngr. You are not allowed to change the values in the screen if you don't do this. If you are not able to interact with the screen during following steps, repeat this to log on again.
16. To see the name of the components, click the button labeled as "GOSTER" at the top left side of the Station screen.
17. In this experiment, we will control the water level of the tank D101 with the help of MOV101 and MOV202. The controller circuit is called LIC101. You can reach the controller from this box circled in Figure 7.
18. The tank D101 should be initially empty. If it is empty and you are getting non-zero measurements, the level transmitter LT101 should be recalibrated. To do this, open the top cover of LIC101 (not through the SCADA software but physically), hit enter, navigate with up and down errors to find the option Zero Correct. Select and confirm it with enter, and close the top cover.

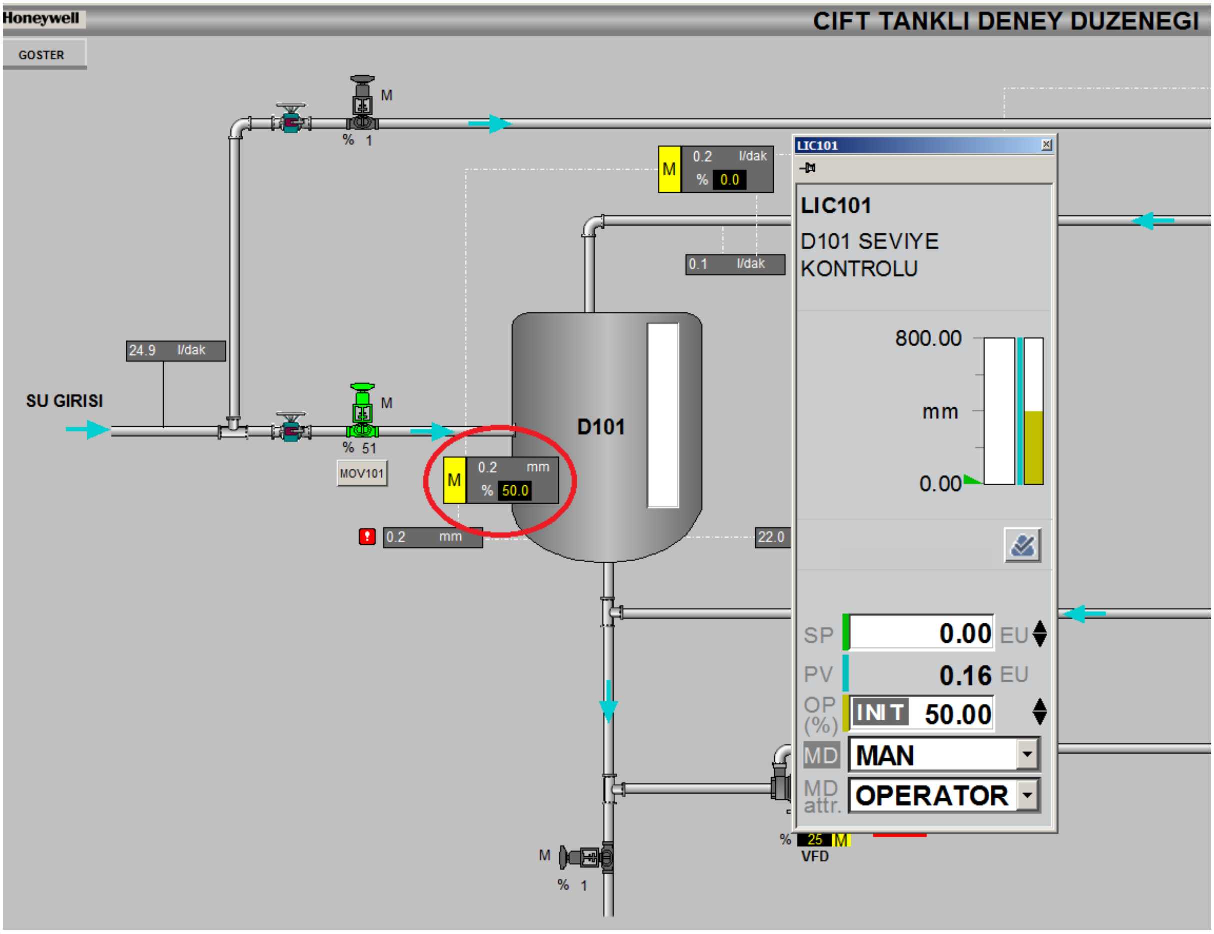


Figure 7. Demonstration of LIC 101

Proportional control

19. From Station screen, click on MOV202 which is the valve at the left bottom side of the screen and from the faceplate open the valve at its %100 value. Now, the water level at the tank is a first order system.

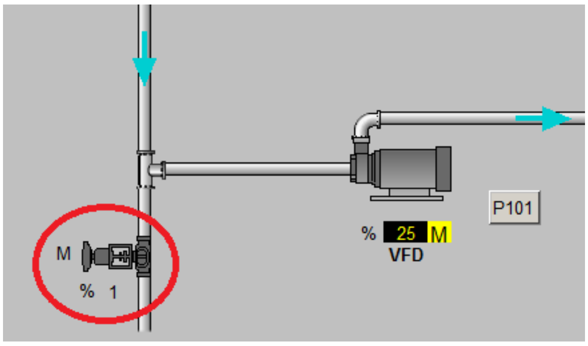


Figure 8. Demonstration of MOV 202

20. Click on MOV101 which is the valve shown in the Figure 9. You can adjust the water level manually to bring it to approximately to 100mm. Then close the valve.

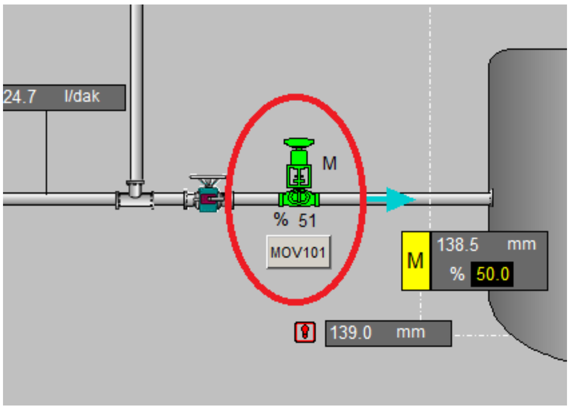


Figure 9. Demonstration of MOV 101

21. Change the mode of MOV101 valve from MAN to CAS. Now, the valve is controlled by LIC101.
22. Double click on LIC 101 shown in Figure 7. The faceplate shown in Figure 10 is opened. Click on the Set Point tab. Check the option Enable PV tracking so that when the controller is in MAN mode, set point SP is equal to the process value PV. This is a necessary step to make the controller function properly.
23. Click on the Loop Tune tab and PID tuning button. In the faceplate select Overall gain as 10.
24. Select the mode as AUTO. Bring the set point to 300 mm. Record for at least 10 min.

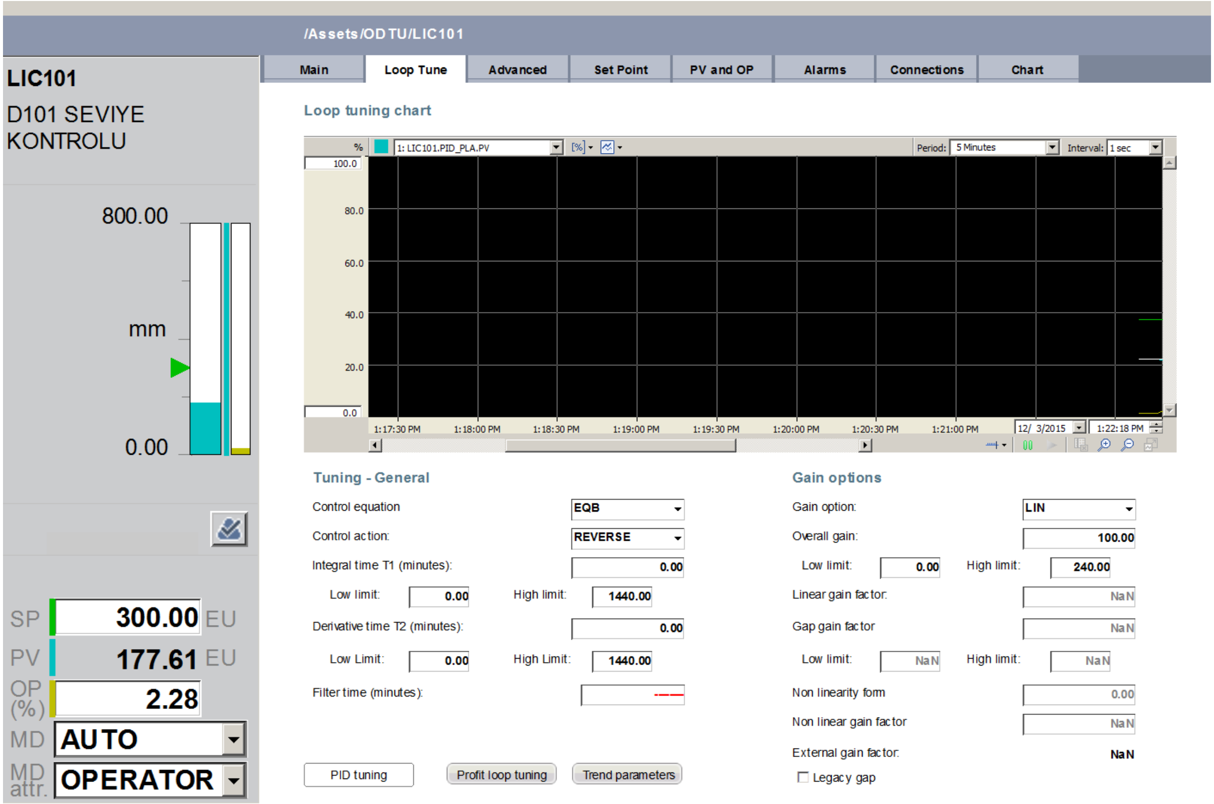


Figure 10. Faceplate for LIC 101

PI control:

25. For the PID control, we will use Equation B defined in the preliminary work.
26. We will assume that the water level at the tank has reached 300mm.
27. Open the LIC101 faceplate.
28. Change the mode form AUTO to MAN. Now, the MOV101 valve is controlled by the user. Close the valve by entering 0 to the OP.
29. Select the Loop Tune tab.
30. You can tune your PID by selecting the button PID Tuning.
31. Adjust the controller parameters as:

    K : 10, TI : 5 min, TD : 0 min

32. Turn on the automatic mode, bring the set point to 400 mm. Record for at least 10 min.

PID Control:

33. Repeat steps 27 and 28. Wait for the water level to drop down to 30 cm.
34. Set the controller parameters as:

    K : 10, TI : 5 min, TD : 1 min

35. Turn on the automatic mode, bring the set point to 40 cm, and record the transient response to this set point change.
36. Turn on the manual mode and bring the level of water to 30 cm.
37. Set the controller parameters as:

    K : 10, TI : 5 min, TD : 100min

38. Repeat step 35.

V. Conclusions

Write down your general conclusions and comments on this experiment.