EXERCISE NO. : 9

CLOSED LOOP PNEUMATICS
PID CONTROLLERS

DATE: 03-11-2020

Reg. No. : RA1711018010101

LAB PREREQUISITES:

None

PREREQUISITE KNOWLEDGE:

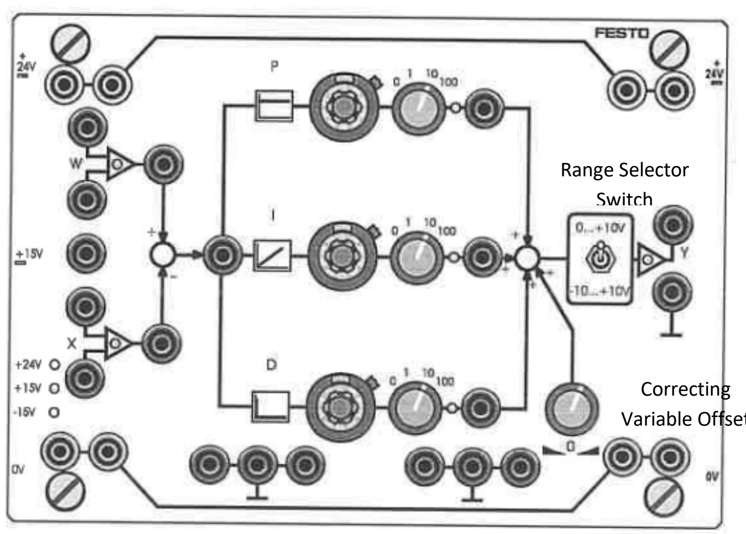
Fundamentals of Festo FluidSIM.

OBJECTIVES:

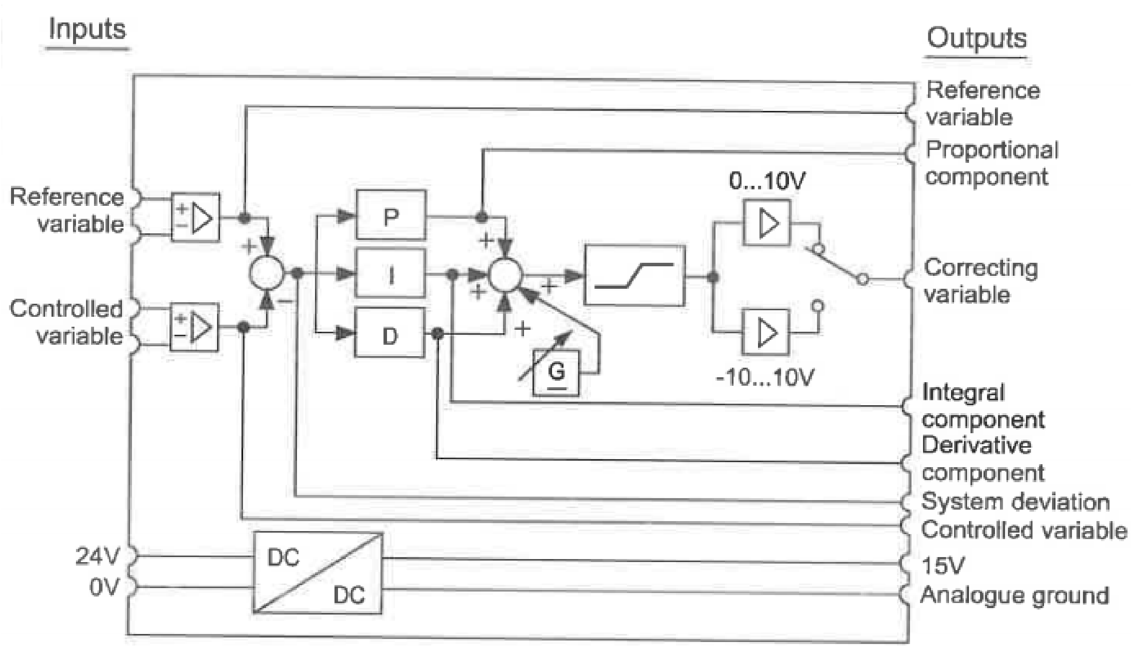
- Understand the basics of PID Controllers
- Understand the PID controller hardware in the laboratory
- To set the parameters of PID controller using an empirical method
- To assess the transient response of a closed loop circuit with a PID controller

THEORY

Key Information related to Festo PID Controller:




EduTrainer®
FESTO
24V
W
15V
X
+24V
+15V
-15V
0V
P
I
D
0 1 10 100
0 ... +10V
-10V ... +10V
Y


Inputs
Outputs
Reference variable
Controlled variable
24V
0V
P
I
D
G
DC
DC
0...10V
-10...10V
Reference variable
Proportional component
Correcting variable
Integral component
Derivative component
System deviation
Controlled variable
15V
Analogue ground

The controller card requires a power supply of 24 V. This voltage is converted internally to +/- 15 V and fed to the card electronics. The two voltages are electrically isolated from each other, i.e. the controller card has two zero potentials, (analogue ground and power-supply ground 0 V).

Analogue and power-supply ground must never be connected together, since this may cause interference to signals. The 15 V voltage can be tapped by means of a special socket. This should be used together with analogue ground as the sensor power supply. This ensures that noise signals are reduced to a minimum.

One *signal input* each is provided on the controller card for the reference variable and controlled variable. Both these inputs are differential inputs, i.e. only the difference between the input signals is processed further. This differential signal can be measured against analogue ground.

Both inputs are fitted with *filters* to suppress interference.

Overloads are indicated by light-emitting diodes (LEDs). An overload occurs when a permissible voltage limit is exceeded (in this case approx. +/- 10 V).

At a *summation point* following the signal inputs, the controlled variable is deducted from the reference variable and fed to the controller as a deviation.

All three controller branches can be switched off and on independently, allowing different combinations to be produced. The individual controller branches can be adjusted by means of potentiometers and rotary switches.

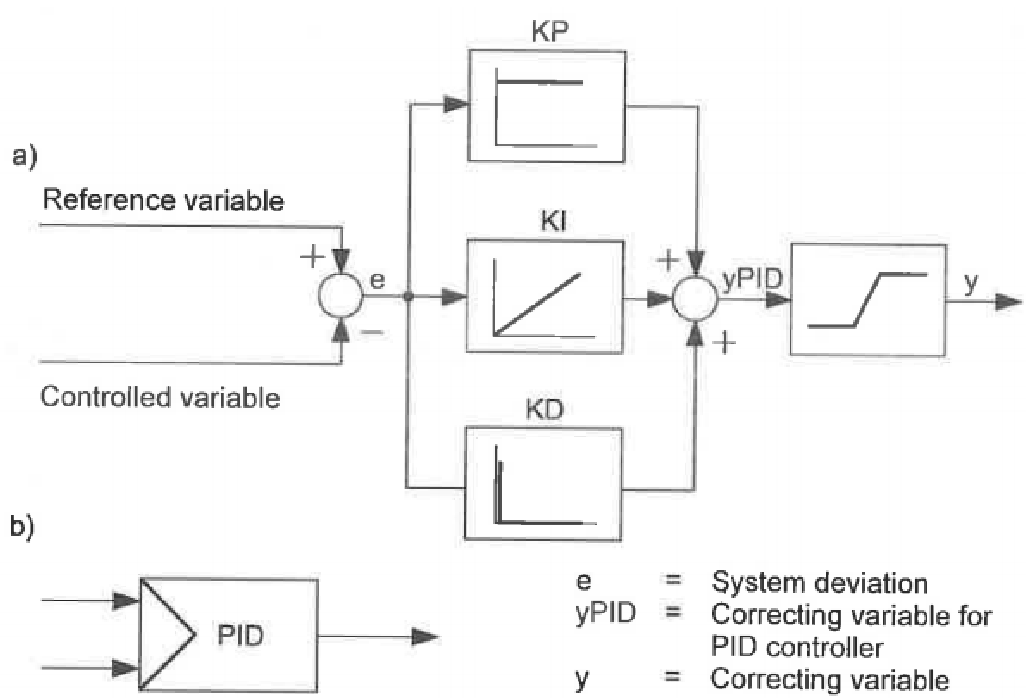
The controlled signals can be measured against analogue ground at individual measuring sockets. All three signals are added together at a summation point.

The signals generated by the controller components are processed on the output side to match them to the final control element which follows. This is carried out using a correcting variable offset, a voltage limiter and a range selector switch.

The *correcting variable offset* allows constant voltages to be applied to the control signal, in order for example to compensate for the zero-point shifts of final control elements. The summation point adds the signals from the controller branches and the correcting variable offset.

Depending on their design, final control elements will require different ranges of *energisation voltage*. Dynamic valves generally operate in the range of 0..10 V or –10 ...10 V. The *range selector switch* converts the controller signals into the desired energisation voltage range. Any output voltage overload which may occur is indicated by an LED.

BASICS OF PID CONTROLLER



The characteristic data of a PID controller are the coefficients KP, KI and KD and the times Tn and Tv. The integral-action time can be determined from the transition function using a tangent construction (see

Controller type	*Advantages*	*Disadvantages*
P controller	Fast	Steady state system deviation
I controller	No steady state system deviation	Slow, tendency to oscillation
PI controller	Fast,no steady state system deviation	Tendency to oscillation
PD controller	Very fast	Steady state system deviation
PID controller	Very fast, no steady state system deviation	——

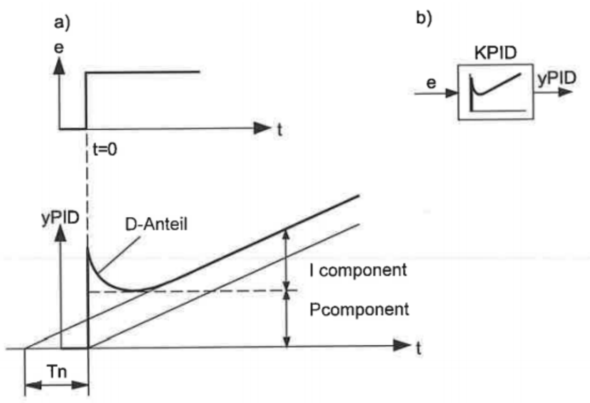
PID controller on controller card

With the PID controller, the three correcting signals of the proportional-action, integral-action and derivative-action controllers are added together at the summation point. Signals are generated in a similar way to those of a PI or PD controller.

The parameters of industrial PID controllers can be set in two different ways:

1. *Setting of the coefficients KP, KI and KD.*
2. *Setting of the integral-action time Tn and derivative-action time Tv.*

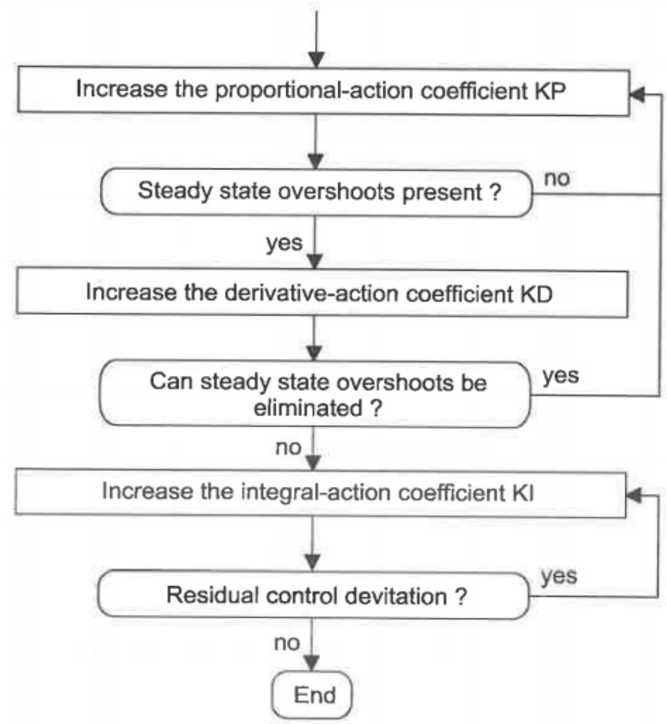
Both methods have both advantages and disadvantages. The first method will be used to adjust the PID controller in the present case. This has the advantage that the effect of the coefficients can be investigated selectively.



EMPIRICAL PARAMETERIZATION OF A PID CONTROLLER

The setting of a PID controller requires experience of commissioning. In order to make this work easier, a well-proven method for the parametri-sation of a PID controller is described below.

- Assemble the closed-loop control circuit
- Check the circuit
- Switch on the electrical power supply
- Switch on the compressed air
- Check the control direction and change if necessary
- Initialise the controller
  (set all parameters and the correcting variable offset to zero
- Set the range selector switch (-10 ... + 10 V or 0 ... +10 V
- Apply a step-change reference variable signal
- Adjust the correcting variable offset to compensate for assymmetries

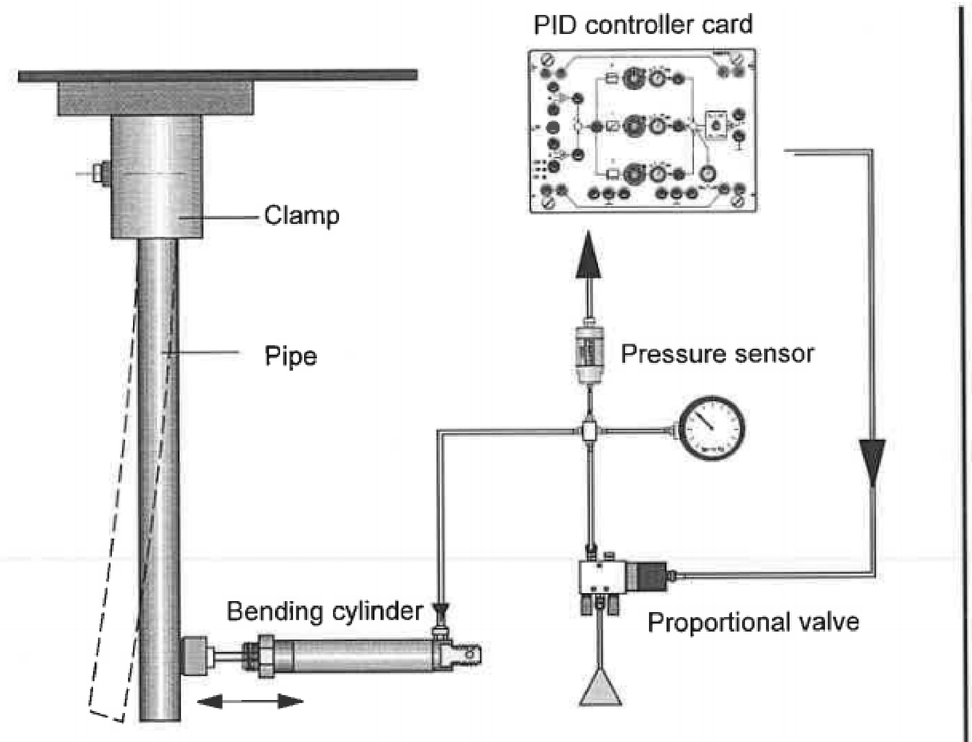


The procedure shown in the flow chart can be used only in cases where it is permissible to bring a closed-loop control circuit into oscillation during the setting operation.

TASK 1 – PROBLEM DESCRIPRION – BENDING MACHINE

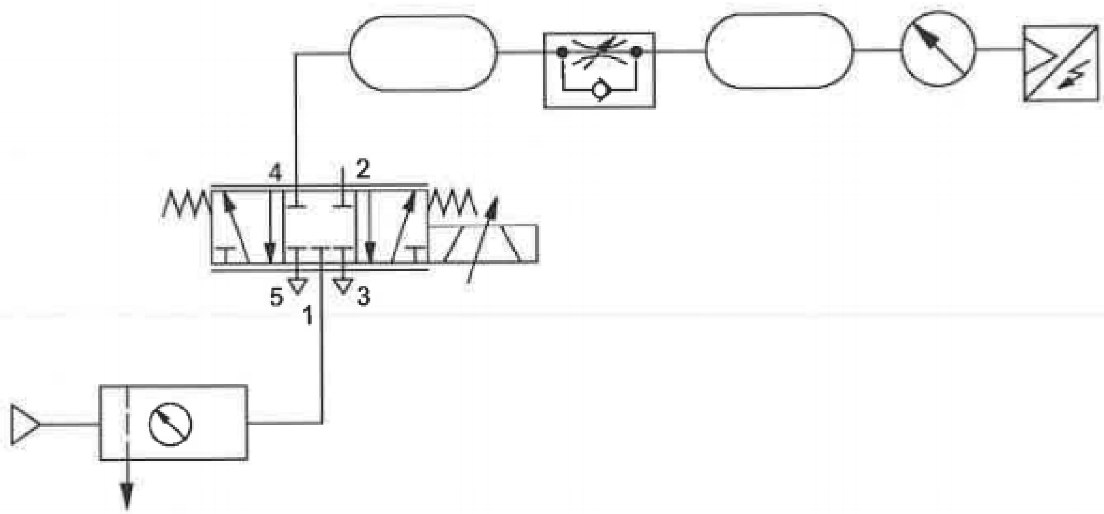
A bending machine is used to bend metal pipes of various diameters. The angle to which the clamped pipe is bent is determined by the stroke of the bending cylinder. The bending operation is matched to the characteristic data for the metal pipe (diameter, wall thickness, material). A bending force (or in other words cylinder pressure) is then used which is suitable for these data. A defined pressure must be present in the cylinder chamber during the advance stroke of the bending cylinder. This is ensured through the use of a closed-loop pressure control system.

The bending machine is to be operated with a closed-loop pressure control circuit incorporating a PID controller.

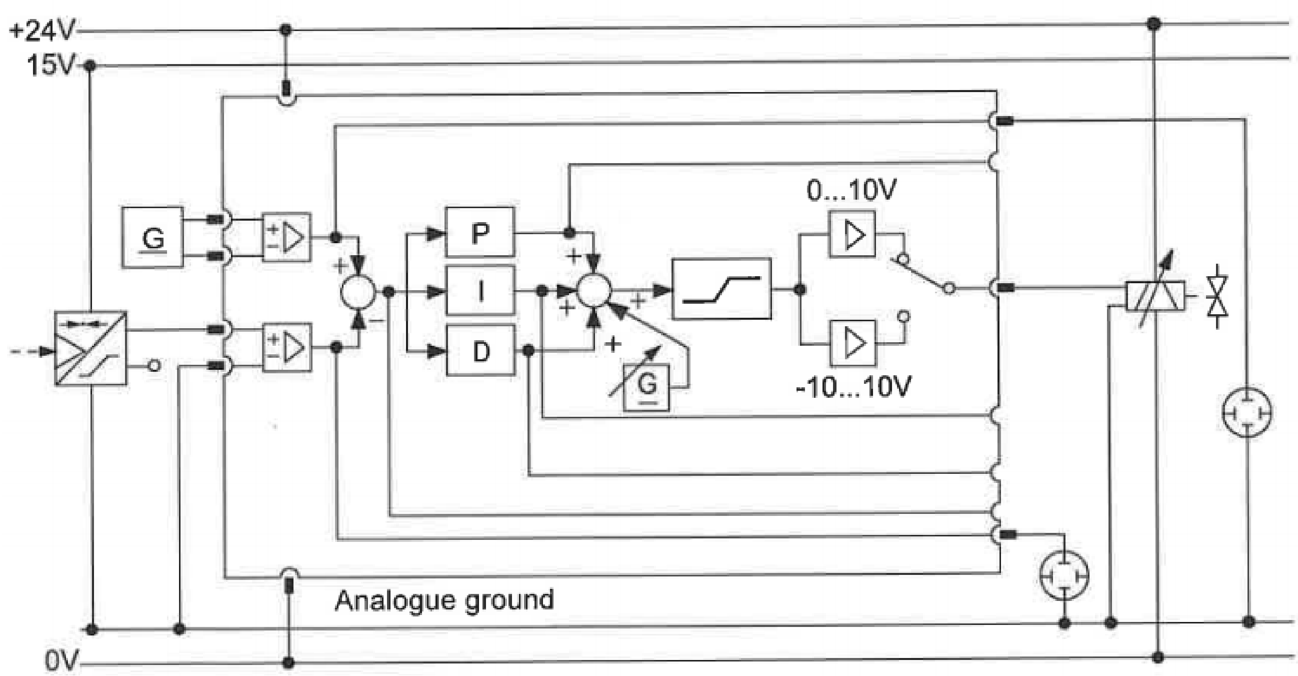


The execution of the experiment is made up of the following steps:

1. Assembly and commissioning of the closed-loop control circuit
2. Investigation of the transient response of the closed-loop control circuitwith a PD controller
3. Investigation of the transient response of the closed-loop control circuit with a PID controller



Pneumatic Circuit



Electrical Circuit

INVESTIGATION OF THE TRANSIENT RESPONSE WITH A PD CONTROLLER

Commission the closed-loop control circuit with PD controller. Proceed in accordance with the flow chart shown in Fig. A14.1. Note the following additional instructions:

- Set the range selector switch to [0 ... 10 V].
- Select a square-wave reference variable signal.
  Offset 3 V, amplitude 1 V. The frequency should be approx. 0.1 Hz.
- Display the reference variable and the controlled variable on the oscilloscope.
- Note the optimised controller coefficients.
- Enter the optimised controller coefficients and the characteristic data into the prepared table.
- Now set the derivative-action coefficient KD to zero.
- Once again measure and record the characteristic data.
- Compare the parameters and characteristic data of the P and PD controllers.

In your measurements, consider only the upper range of the reference variable (4 V).

INVESTIGATION OF THE TRANSIENT RESPONSE WITH A PID CONTROLLER

- The control system will now be optimised by adding an I controller.
- Use the optimised PD coefficients from step 2.
- Increase the integral-action coefficient KI.
- Measure the characteristic data. Compare these with the data for the PD controller.
- Draw the controlled variable curve for the case in which KI is increased to considerably above the optimised value (KI = approx. 40).

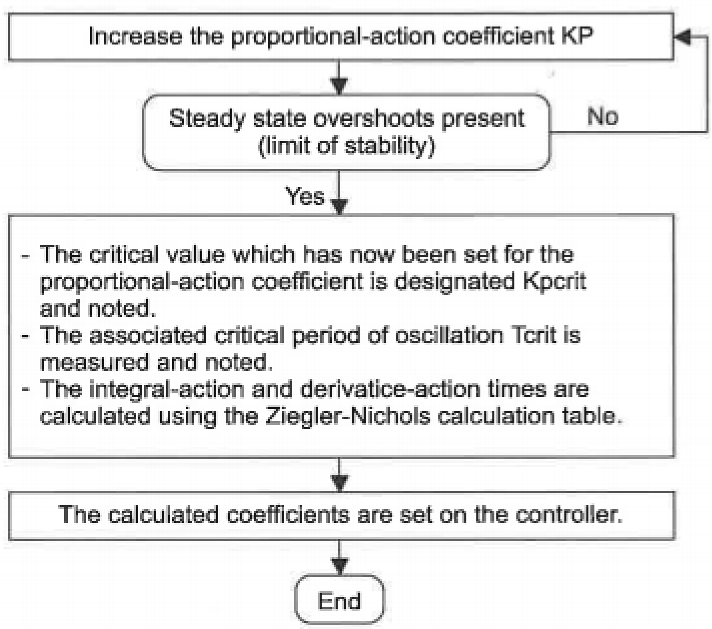
BASICS OF ZIEGLAR-NICHOLS METHOD

Setting parameters using the Ziegler-Nichols method

As a complement to empirical parametrisation, a number of standard methods have been developed. One method which uses objective criteria to produce suitable controller parametrisation is the "Ziegler-Nichols method".

The flow chart below explains the procedure for the parametrisation of a controller using the Ziegler-Nichols method:

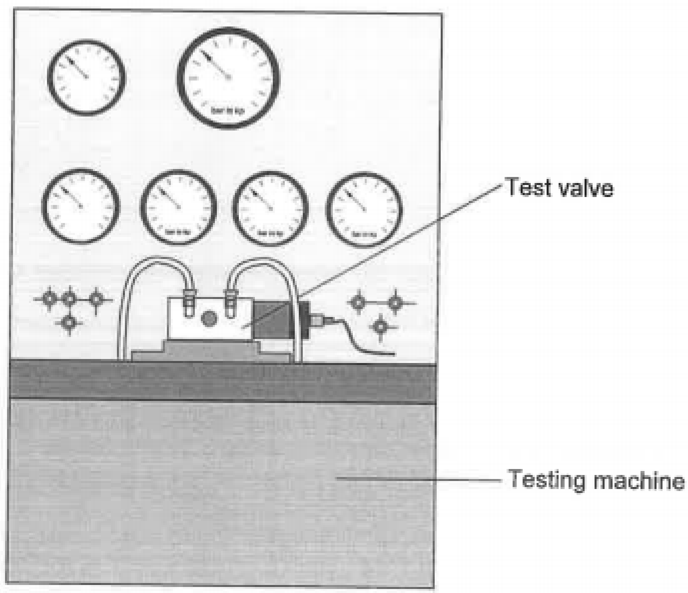
Parametrisation using the Ziegler-Nichols method



TASK 2 – PROBLEM DESCRIPTION – TESTING MACHINE

The flow rate of pneumatic valves is to be tested. For this purpose, test valves are clamped into a testing machine and fed with compressed air.

The valve flow rate and leakage rates represent controlled systems with different runtime performance which influence the test pressure. A PID control system is used to maintain the test pressure at a constant value during the measurement.



Measurements should be taken on the testing machine in the following order:

1. Assembly of the closed-loop control circuit
2. Setting the controller for a controlled system without a delay
3. Setting the controller for a controlled system with a delay
4. Setting the controller for a controlled system with a leak

ASSEMBLY OF CLOSED LOOP CONTROL CIRCUIT

The assembly for the testing machine consists of the following closed-loop control circuit components:

- Voltage generator
- PID controller card
- Proportional valve
- One-way flow control valve (1V3)
- Solenoid valve
- Pressure gauge
- Signal input unit
- Pressure sensor

The test valves are simulated by two different controlled systems. The controlled systems differ in their time constants:

- A short piece of tubing (length approx. 100 mm) as a low-delay controlled system
- Two compressed-air reservoirs connected in series and separated by a one-way flow control valve (1V2) to act as a controlled system with a delay.

A storage oscilloscope should be used to measure the voltage signals.

The one-way flow control valve (1V3) is used to simulate a variable fault. The valve must be switchable. It is therefore connected in series with the solenoid valve.

- First assemble a circuit incorporating the short piece of tubing and set the control direction.
- Set a pressure of 6 bar.

SETTING OF CONTROLLER FOR A CONTROLLED SYSTEM WITHOUT DELAY

- Input a square-wave reference variable with an offset of 3 V and an amplitude of 1 V. A low frequency should be selected (approx. 0.1 Hz).

Use the Ziegler-Nichols method to commission a P controller. Proceed as follows:

- Determine the critical gain KPcrit and the period of oscillation Tcrit which results. Select a suitable small time base on the oscilloscope (e.g. 10 ms).
- Use the settings table to calculate the coefficient KP for a P controller.
- Set this value on the controller.
- Then use the step response to determine the characteristic data.

In your measurements, always consider the higher value for the reference variable (4 V).

- Use the settings table to calculate the proportional-action coefficient KP and the integral-action time Tn for a PI controller.
- Use these to calculate the integral-action coefficient KI:

$$KI = \frac{KP}{Tn}$$

- Set this value on the controller.
- Then use the step response to determine the characteristic data Ta, xm and estat for the PI controller.

SETTING OF CONTROLLER FOR A CONTROLLED SYSTEM WITH DELAY

- Assemble the closed-loop pressure control circuit incorporating a controlled system subject to a delay (twin-reservoir system).
- Do not actuate the solenoid valve for the time being.
- Set the parameters of the P controller as described in step 2. Due to the lower oscillation amplitude, a larger division (0.5 V/division) should be selected on the oscilloscope.
- Then calculate the parameters for a PID controller.

$$KI = \frac{KP}{Tn}$$

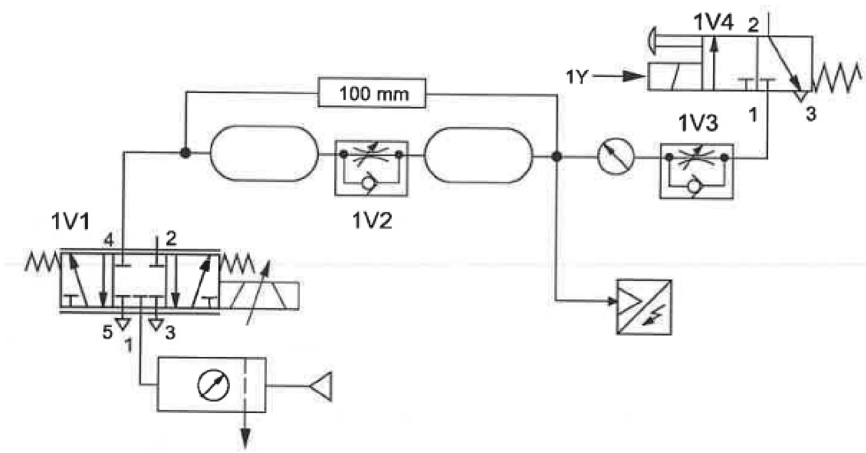
$$KD = KP \cdot Tv$$

- Set these values on the controller.
- Use the step responses to determine the characteristic data Ta, xm and estat for the P and PID controllers.

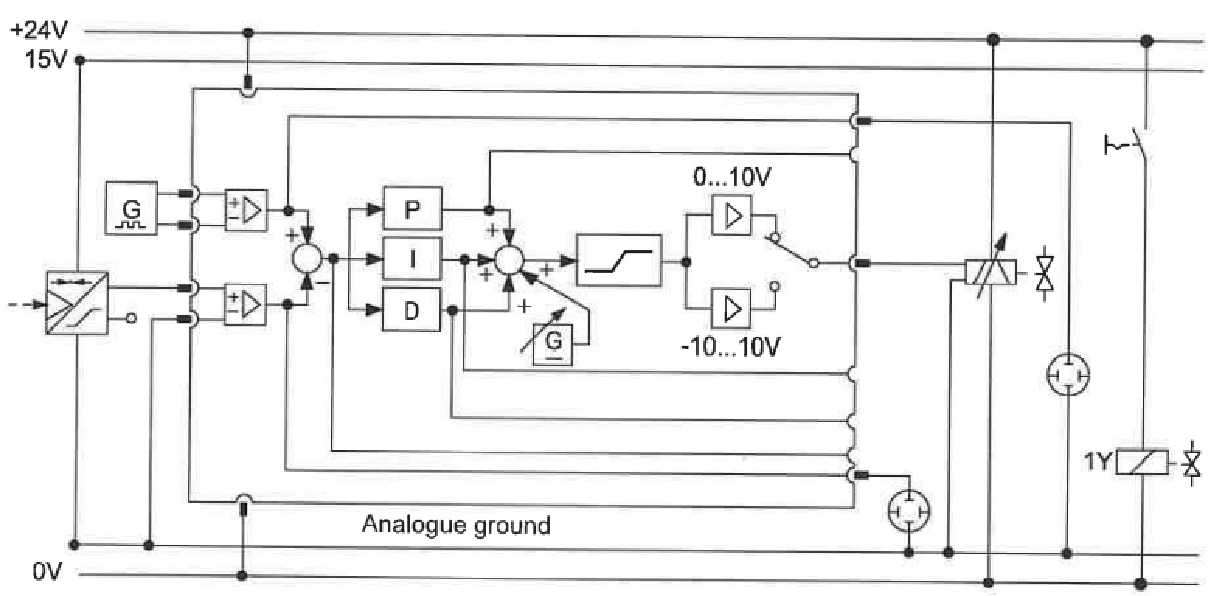
SETTING OF CONTROLLER FOR A CONTROLLED SYSTEM WITH A LEAK

An interference variable will now be applied to the closed-loop pressure control circuit (twin-reservoir system).

- Set the flow control valve to approximately half open. Open the solenoid valve.
- Use the Ziegler-Nichols method to commission the PID closed-loop control circuit.
- Determine the characteristic data.



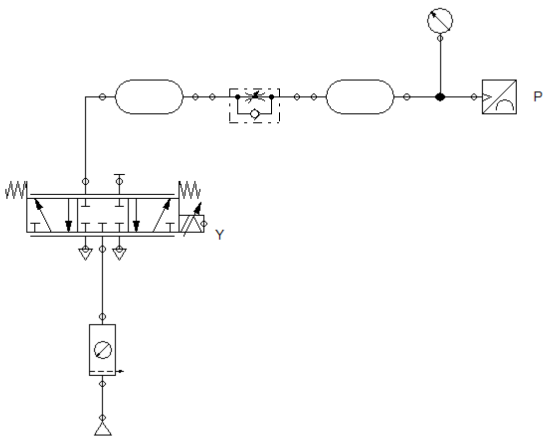
Pneumatic Circuit Diagram



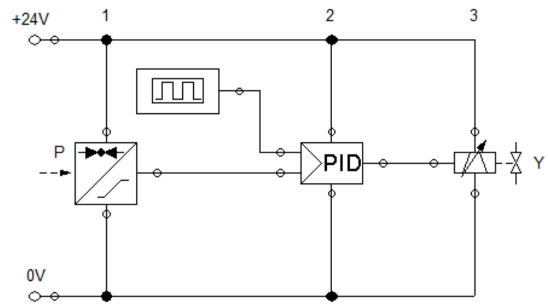
Electrical Circuit Diagram

EXERCISE TASKS

Task 1: Investigation of the Transient Response of the closed loop control circuit using a PID controller



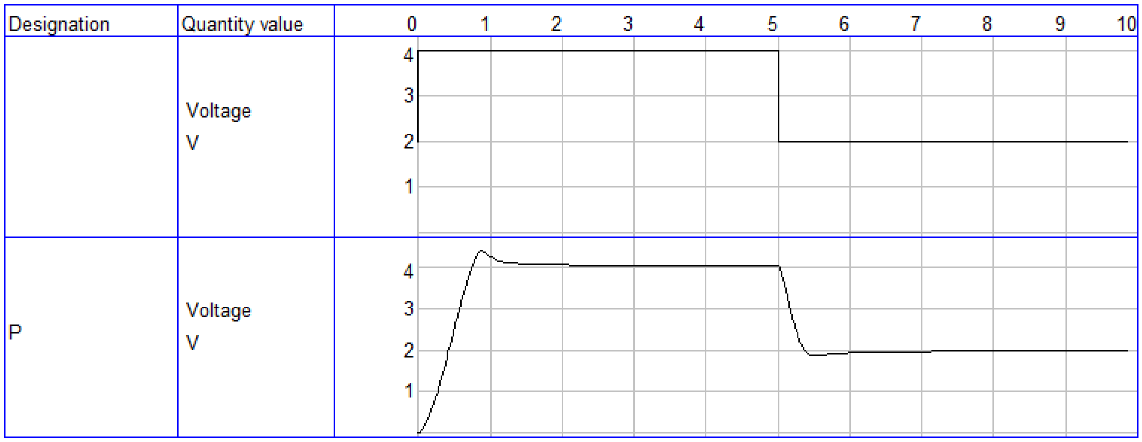
Pneumatic Circuit



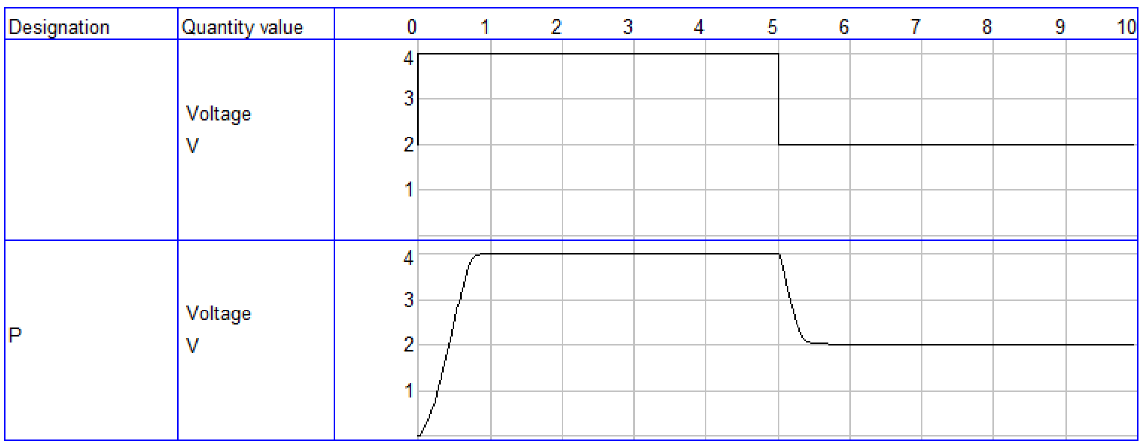
Electrical Circuit

- Fill in the entries of the table below:

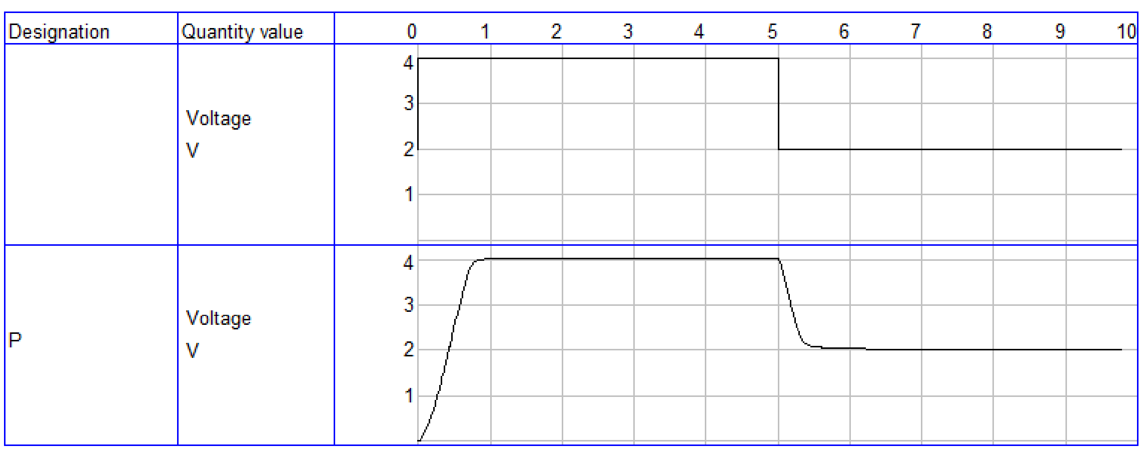
Characteristic Data	**Controller**		
	P	**PD**	**PID**
Proportional-action coefficient K_P	3	11	10.5
Integral-action coefficient K_I	0	0	0.1
Derivative-action coefficient K_D [ms]	0	1000	1000
Settling Time T_a [ms]	3225	884	873
Overshoot Amplitude x_m [mV]	390	0	0
Steady-state system deviation e_{state} [mV]	30	0	0



P-Controller



PD-Controller



PID-Controller

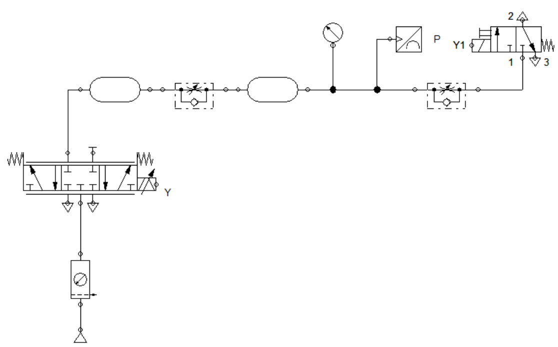
- **Is the closed-loop control circuit still stable after the derivative action coefficient K_D is switched off in the PD controller implementation?**

Ans: *The transient response of the simulated closed loop system was unstable and oscillated before attaining steady state value. For a real system, a simple P-controller would either leave a finite steady error (if gain is a small value) or oscillate (for a larger gain) by driving the final control element from one direction to the other.*

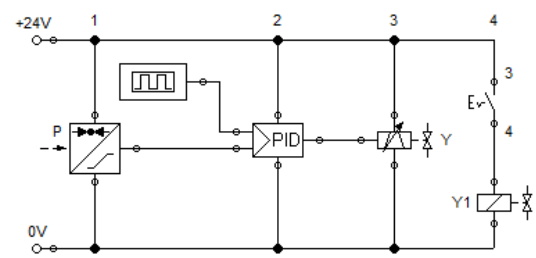
- **Which type of controller gives the smallest overshoot amplitude. Justify why?**

Ans: *In terms of overshoot, both PD and PID controllers were able to produce zero-overshoot in simulation. It is evident that since the simulated system doesn't exhibit any damping or disturbance, the integral controller is not very necessary, just a simple PD-controller is able to achieve similar performance. However, practical elements will exhibit such characteristics and hence PID controller will be more desirable in such cases.*

Task 2: Setting the Controller for a Controlled System

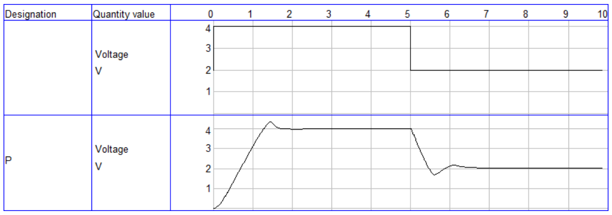


Pneumatic Circuit

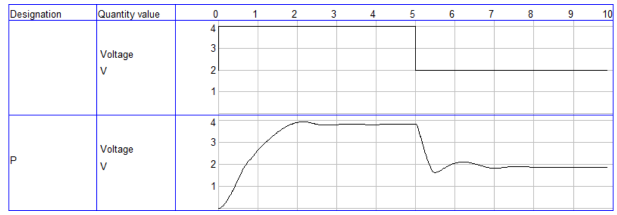


Electrical Circuit

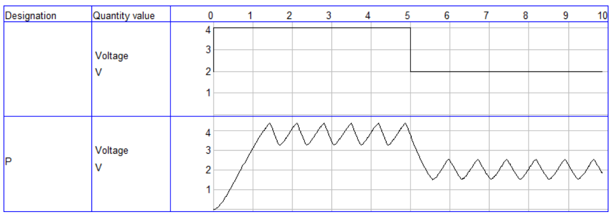
Characteristic Data	**Controller**		
	P	**PI**	**PID**
Proportional-action coefficient K_P	5	5	15.6
Integral-action coefficient K_I	0	535	3.9
Derivative-action coefficient K_D	0	0	15.6



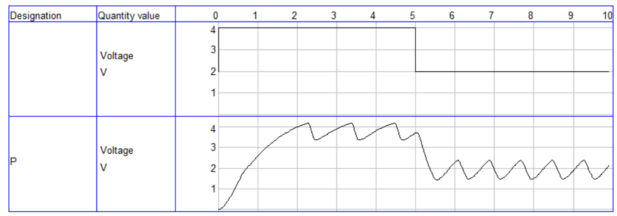
P-Controller [Without Leak]



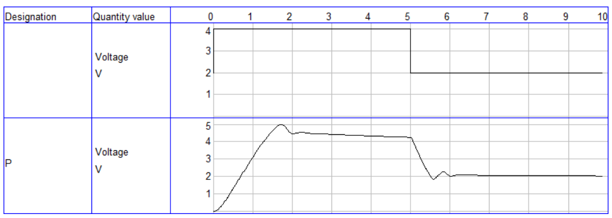
P-Controller [With Leak]



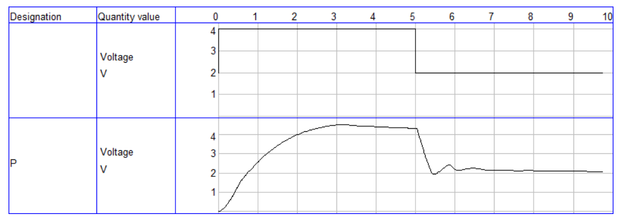
PI-Controller [Without Leak]



PI-Controller [With Leak]



PID-Controller [Without Leak]



PID-Controller [With Leak]

- **Which controller gave the better result for the system with and without leak? State the reason.**

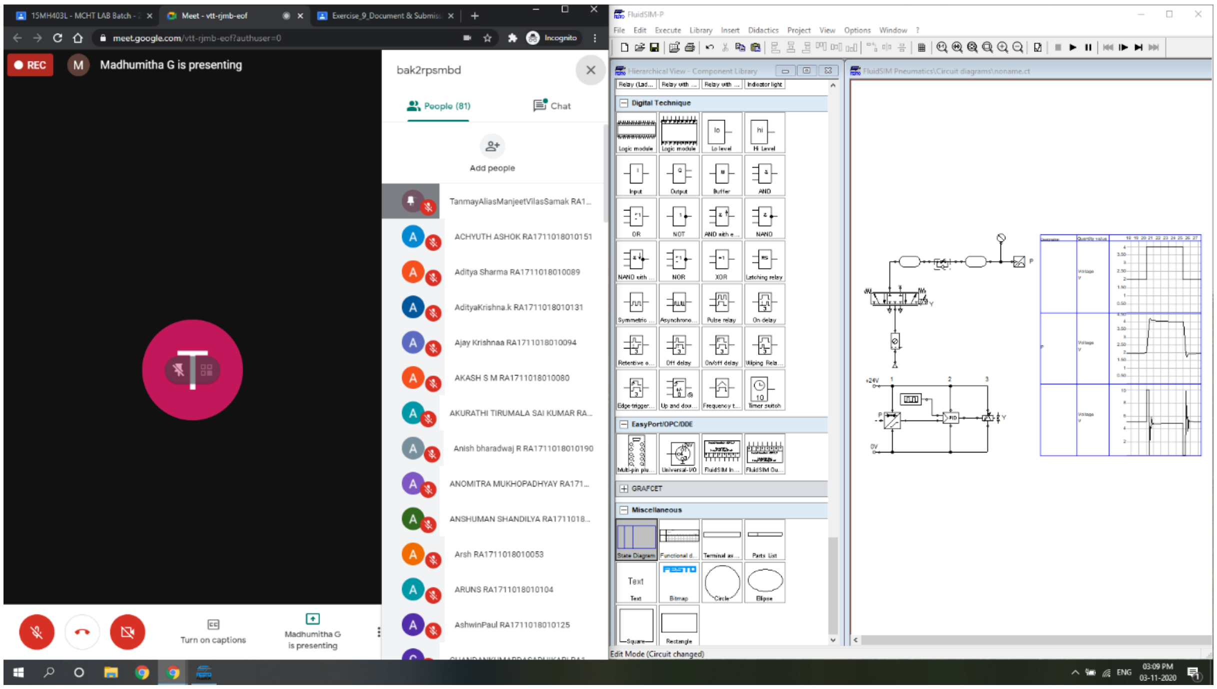
Ans: *The PID controller with the given set of gains was the most efficient in controlling the system with and without leak. The P-controller, although looks good in simulation, is not recommended in practical applications, owing to its nature of either leaving a steady-state error (for lower gain) or producing oscillations (for higher gain). The integral gain of PI controller was very high, which forced the system to overcompensate for the accumulated error, thereby swinging back and forth the setpoint – the behaviour got even worse with leakage. The PID controller had a similar response to that of the simple P controller, however, it is practically more robust than the P controller alone as it can dampen the oscillations and take action on accumulated error to improve steady-state performance. Furthermore, with proper tuning of the gains, the response of PID controlled system can be improved greatly.*

DELIVERABLES

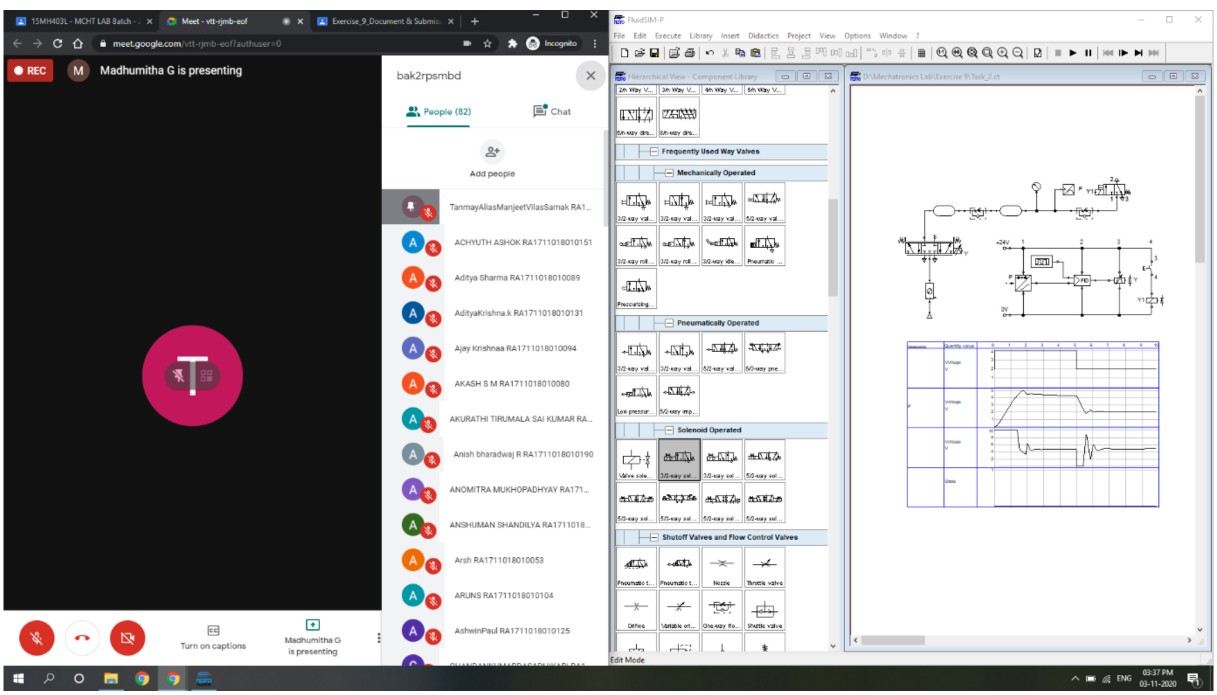
- Filling of table fields and descriptive answers for the questions under each task.

LAB SESSION SCREENSHOTS

Task 1:



Task 2:



INFERENCE

The working of a proportional valve (introduced in the last experiment) was studied/revised from both theoretical and practical viewpoints. A closed loop electro-pneumatic circuit to control the pressure of a twin accumulator system (resembling bending and valve testing machine setups) was constructed and simulated using Festo FluidSIM.

The voltage setpoint to the solenoid of the proportional DCV was a square wave of frequency = 0.1 Hz, amplitude = 1 V, and offset = 3 V, to control the system pressure. The signal generator voltage (input) was not directly comparable against the system pressure as the physical units of these two quantities were not identical. Nonetheless, the analog pressure sensor output in terms of voltage was directly comparable against the signal generator voltage, since the two had same voltage scale.

The theory of PID controller was understood and a simulated PID controller card was used to regulate the system pressure in the aforementioned tasks. The effect of proportional, integral and derivative gains (K_P, K_I and K_D) was analysed by observing the transient response of the controlled variable (pressure).

For task 1, the controller gains were tuned to get minimum (or no) overshoot, minimum steady-state error and quick settling time for P, PD and PID controllers. For task 2 on the other hand, the given controller gains we fed into the simulated PID controller card and the system response was observed in each case (P, PI and PID controllers). Finally, the results were reported along with the corresponding state diagrams for signal generator (setpoint) and pressure sensor voltages.