EXERCISE NO. : 8

CLOSED LOOP PNEUMATICS

STATUS CONTROLLER

DATE: 27-10-2020

Reg. No. : RA1711018010101

PREREQUISITE KNOWLEDGE:

- Fundamentals of pneumatics and its basic components.
- Fundamentals of FluidSIM software for simulation of pneumatic and electrical circuits.

OBJECTIVES:

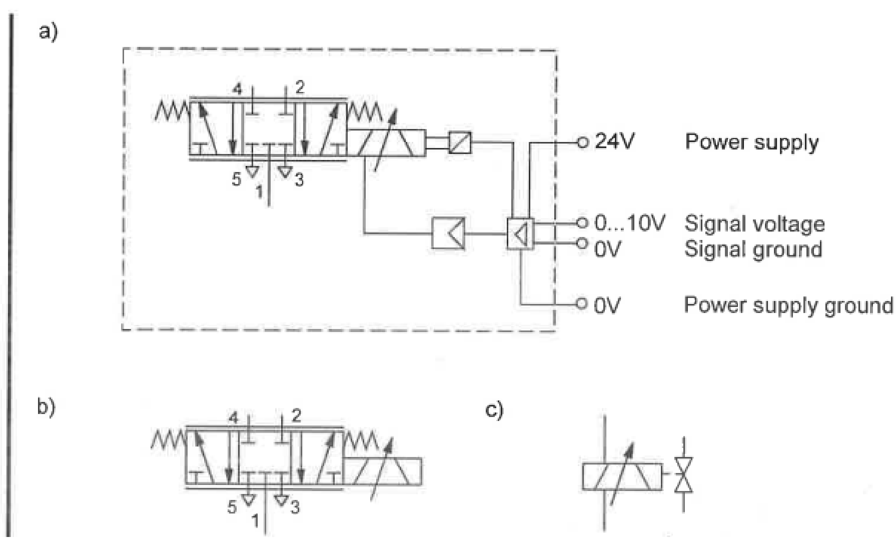
- To be able to set the parameters of a status controller
- To get familiarized with the influence of controller coefficients

THEORY:

5/3 Proportional Valve

The 5/3-way proportional valve used here has five pneumatic ports and three main spool positions. A plunger-armature actuator acts directly on a control spool. This controls the flow rate through the valve when energised appropriately. The valve incorporates a closed-loop control system which gives improved accuracy.

Fig. A6.1: Connection diagram and pneumatic and electrical symbols for 5/3-way proportional directional control valve



A signal voltage of between 0 and 10 V is used to *energise* the valve. The relationship between the energisation voltage and the valve flow rate is as follows:

Table A6.2:

Energisation voltage	*Flow rate*
0 V	Full flow rate between 1 and 2 or 4 and 5
0 ... 5 V	Reduced flow rate between 1 and 2 or 4 and 5
5 V	Closed mid-position
5 ... 10 V	Reduced flow rate between 1 and 4 or 2 and 3
10 V	Full flow rate between 1 and 4 or 2 and 3

The valve requires a power supply of 24 V.

Linear Potentiometer

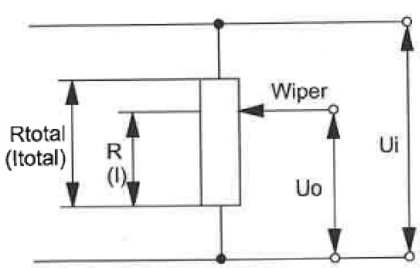
A linear potentiometer can be used to measure lengths and distances. The potentiometer converts the physical variable "position" into an electrical voltage. This is carried out using the principle of a voltage divider. With this principle, an input voltage Ue is applied to a total resistance Rtotal. The output voltage Ua of the potentiometer can be calculated using the voltage divider formula:

$$Uo = Ui \cdot \frac{R}{R\,total}$$

Since the resistance component R is proportional to the wiper position l, the voltage divider formula can be replaced by the expression

$$Uo = Ui \cdot \frac{l}{l\,total}$$

The motion of the wiper produces a change in the resistance component R. The output voltage Ua varies in proportion to the resistance component.



Ui	= Input voltage
Uo	= Output voltage
Rtotal	= Total resistance
R	= Resistance component
ltotal	= Total length
l	= Wiper position

Fig. A17.1:
Schematic representation of linear potentiometer

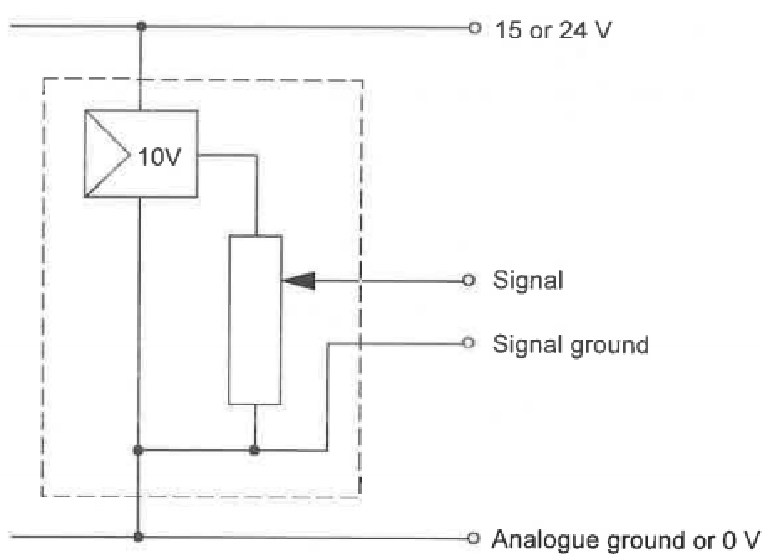
The linear potentiometer used here is connected in series with additional electronic circuitry to prevent damage to the potentiometer by crossed connections.

The potentiometer has an electrical length of 450 mm. A voltage of between 0 and 10 V appears at the sensor output, depending on the wiper position. The supply voltage must be between 15 and 24 V. The additional electronics converts this voltage into a constant supply voltage of 10 V for the potentiometer.

The potentiometer has four electrical connections:

- Power supply 24 V (or 15 V)
- Power supply ground 0 V (or analogue ground)
- Signal voltage
- Signal ground

Fig. A17.2: Electrical connection diagram for linear potentiometer



Within the closed-loop control circuit, the potentiometer should always be connected to the 15 V power supply and the analogue ground of the controller card. Only in this way can it be ensured that electrical interference is kept to a minimum.

Linear Axis (Rod-less Cylinder)

The linear actuator used here consists of a rodless cylinder which acts via a interlocking connection between piston and carrier to drive a slide with through guide rods. The axis has a stroke of 450 mm. The piston diameter D of the cylinder is 25 mm.

The slide is fitted with a driver which actuates the wiper of the linear potentiometer.

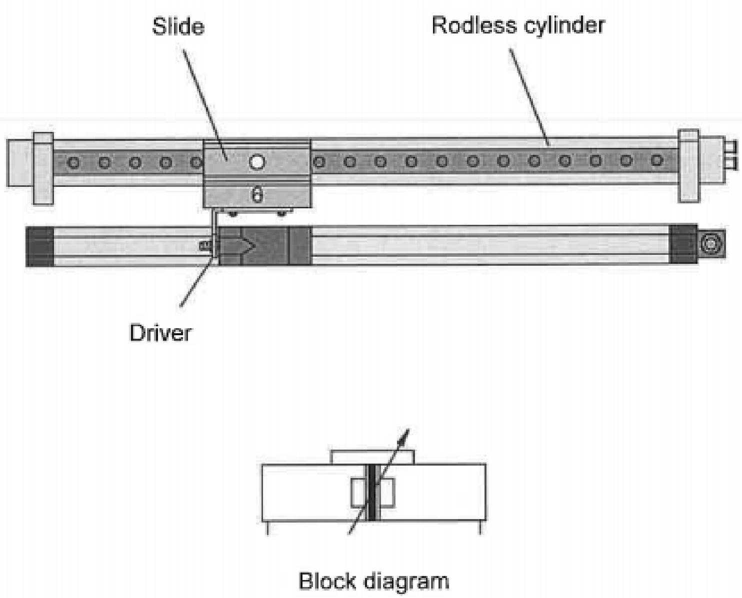


Fig. A17.3: Schematic representation of pneumatic linear axis

In controlled systems, it is a disadvantage if pneumatic cylinders are fitted with end-position cushioning, since this impairs the control behaviour of the system.

The stroke of the linear potentiometer should be greater than that of the cylinder in order to prevent mechanical overload of the potentiometer in the end positions. The mechanical stroke of the potentiometer used here is approx. 450 mm.

Status Controller

Status controllers have proved extremely useful for the closed-loop control of pneumatic linear axes.

The status controller used here processes three status variables:

- The system deviation e (also known as the position deviation)
- The velocity $\dot{x}$ and
- The acceleration $\ddot{x}$

of the slide.

Since it is extremely complex in hardware terms to measure all three status variables with sensors, only the position is measured. The velocity and acceleration are generated from the position variable using derivative-action controllers.

Fig. A18.1 shows the block diagram for the status controller used here.

Certain controlled systems cannot be controlled adequately with a PID controller. Status controllers are used in these cases.

In order to determine which variables are looped back in the status controller, a mathematical model of the controlled system is created. The number of status variables corresponds to the order of the model. Each status variable is measured and looped back. In the case of a second-order model, for example, two variables must be looped back.

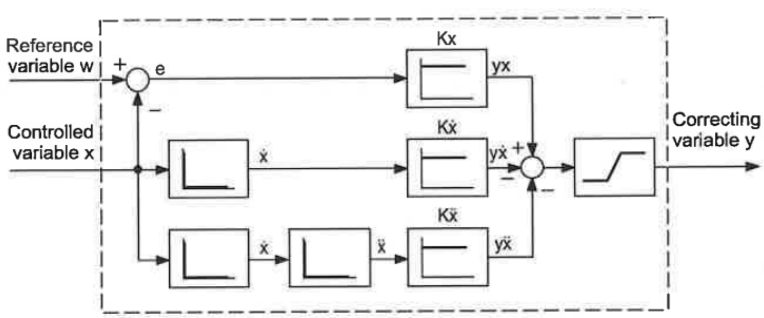


Fig. A18.1: Block diagram for status controller

e = Position deviation	Kx = Position coefficient	yx = Position correcting variable
$\dot{x}$ = Velocity	K$\dot{x}$ = Velocity coefficient	y$\dot{x}$ = Velocity correcting variable
$\ddot{x}$ = Acceleration	K$\ddot{x}$ = Acceleration coefficient	y$\ddot{x}$ = Acceleration correcting variable

Mode of operation of a status controller

The status controller has a separate controller branch for each status variable. Status controllers for pneumatic actuators thus have a triple-loop controller structure:

Position controller

The reference variable and controlled variable are fed to a summation point and subtracted from each other. The resulting position difference e is multiplied by the position coefficient Kx. The position correcting variable yx is calculated as follows:

$$yx = Kx \cdot e$$

The position controller is identical to the P controller.

Velocity controller

The velocity controller consists of a derivative-action controller which converts the controlled variable x into the velocity value $\dot{x}$ and multiplies it by the velocity coefficient $K\dot{x}$.

$$y\dot{x} = K\dot{x} \cdot \dot{x}$$

Acceleration controller

The acceleration controller consists of two derivative-action controllers which convert the controlled variable x into the acceleration value $\ddot{x}$ and multiplies this by the acceleration coefficient $K\ddot{x}$.

$$y\ddot{x} = K\ddot{x} \cdot \ddot{x}$$

The correcting signal components of these controller branches are added at a summation point. The velocity and acceleration signals are incorporated into this operation with a negative sign. The correcting signal thus produced then passes through a limiter circuit.

Design of status controller card

The status controller card has a similar design to the PID controller card. Figs. 18.2a and b show the front panel and the electrical connection diagram for the status controller.

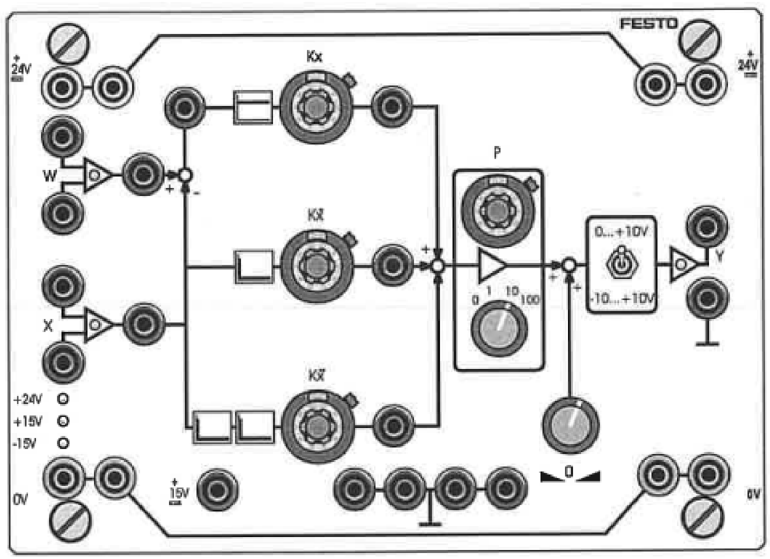
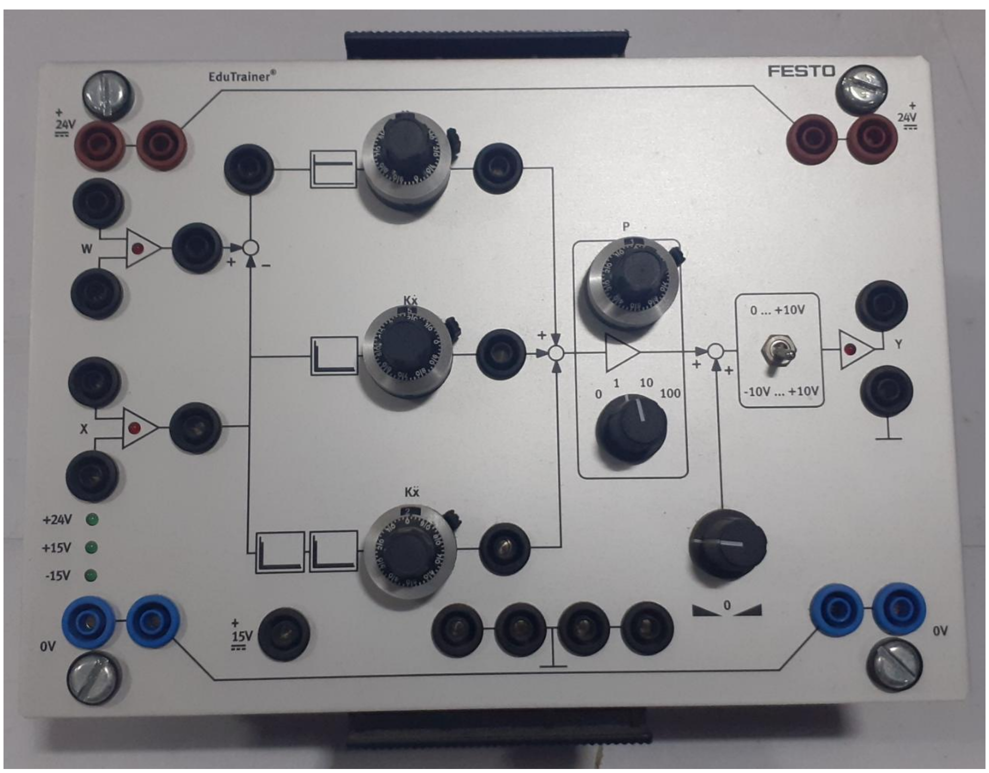


Fig. A18.2a: Front panel of status controller card



Festo Status Controller

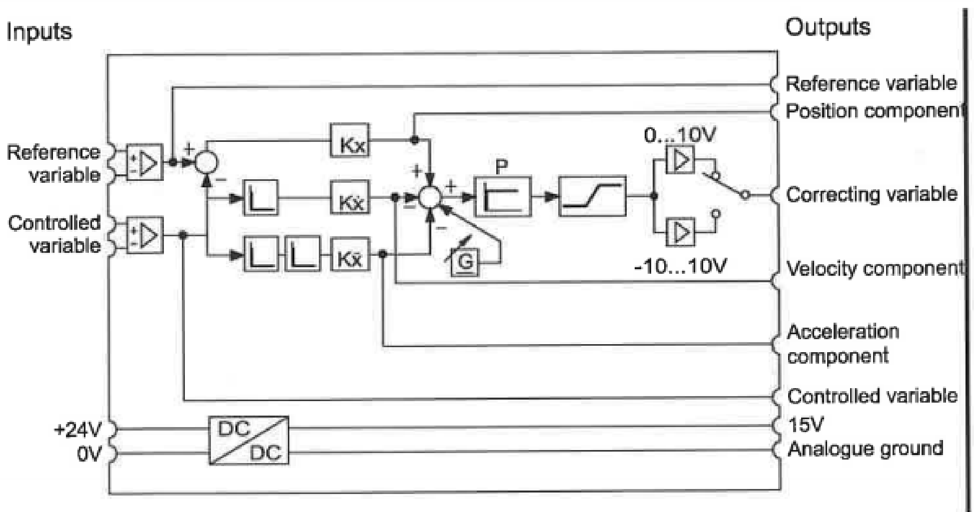


Fig. A18.2b: Electrical connectiondia-gram for status controller card

In contrast to the PID controller card, the status controller card has a rotary potentiometer and a rotary switch which allow adjustment of an overall gain coefficient P for the correcting signal.

Closed-loop control of a pneumatic positioning actuator

A pneumatic positioning actuator is one of the types of controlled systems which cannot be controlled adequately with a standard controller. A pneumatic positioning actuator is a controlled system without compensation which is capable of oscillation.

A third-order model will generally be selected for a pneumatic positioning actuator. It will then be necessary to loop back three variables in the status controller. The following three variables are generally selected:

The position s of the piston

The velocity v of the piston

The acceleration a of the piston.

The controller is accordingly known as a triple-loop controller.

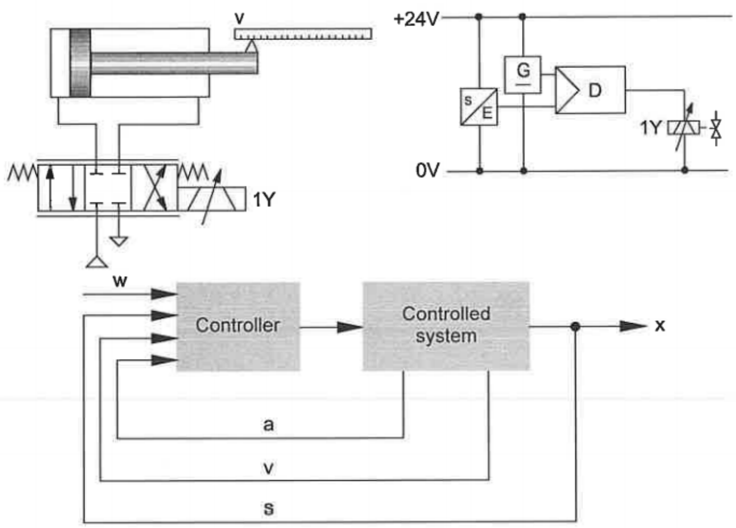


Fig. 3.22:
Closed-loop control circuit for a pneumatic positioning actuator

Differentiation

Pneumatic positioning actuators are equipped with a positional transducer.

In order to reduce costs, the velocity and acceleration are not measured with sensors. These must be calculated from the position by differentiation.

Controller equation

The following overall equation results for the calculation of the correcting variable:

$$y = KX\,(w - x) - K\dot{X} \cdot d\,\frac{x}{dt} \cdot d\,\frac{x}{dt} - K\ddot{X}\,\frac{d^2x}{dt^2}$$

Fig. B3.23 shows the associated signal flow diagram.

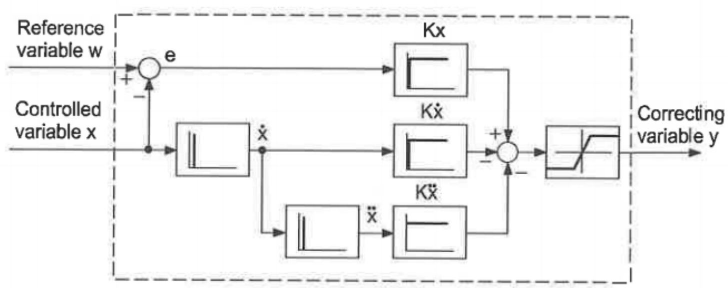


Fig. B3.23:
Signal flow diagram for triple-loop status controller

e = Position difference
$\dot{x}$ = Velocity
$\ddot{x}$ = Acceleration

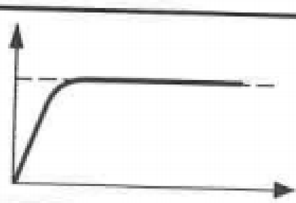
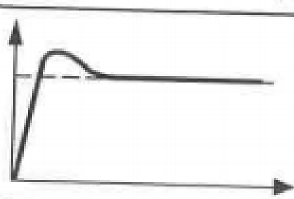
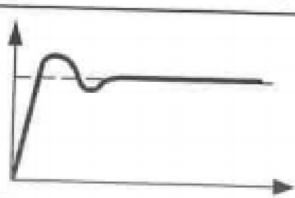
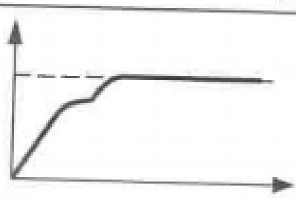
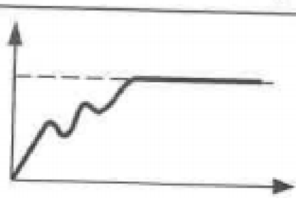
Kx = Position coefficient
K$\dot{x}$ = Velocity coefficient
K$\ddot{x}$ = Acceleration coefficient

Status controller in a closed-loop position control circuit

The parameters of a status controller are set in accordance with the same quality criteria as for a PID controller:

- Short settling time Ta
- No or only small overshoot amplitude xm
- Small steady-state system deviation estat

Table A19.1 shows various transient responses which may be obtained with poor status controller settings. Details are given in each case of how the controller coefficients must be changed in order to obtain a better transient response.

Case	Transient responce	Description	Measures
I		Optimum	None
II		Overshoot	Reduce $K\dot{x}$
III		Overshoot with forward swing	Reduce Kx or increase $K\dot{x}$ or increase $K\ddot{x}$
IV		One forward swing	Reduce $K\dot{x}$
V		Several forward swings	Reduce $K\dot{x}$ or increase $K\ddot{x}$

Preparatory work

- 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

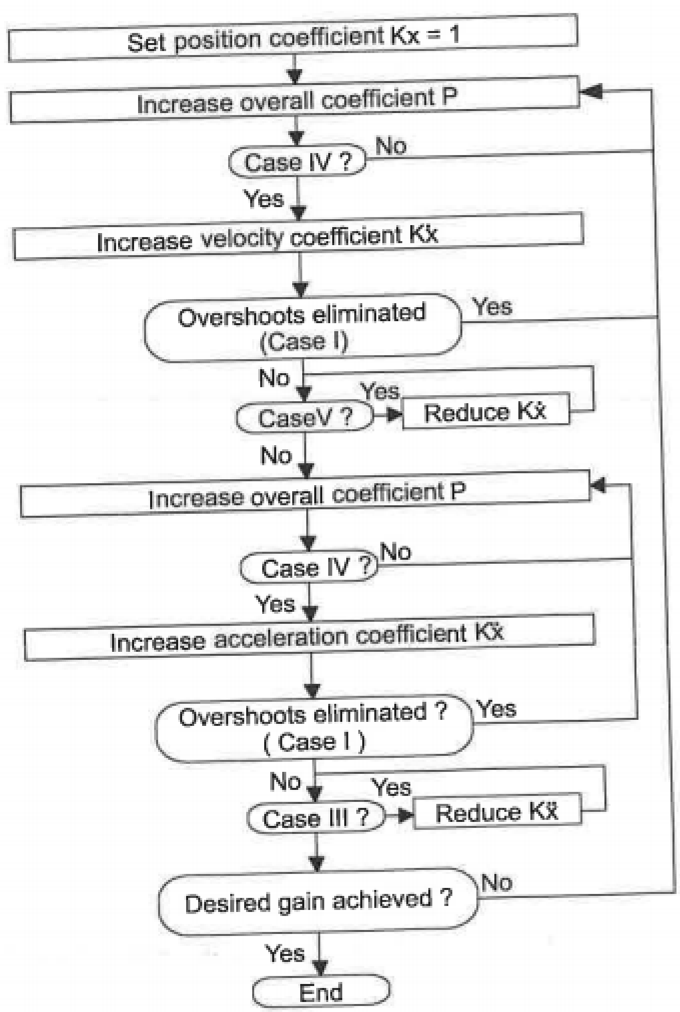


Fig. A19.1:
Flow diagram for empirical parametrisation of a status controller

TASK 1 – POSITION CONTROL OF A PNEUMATIC CYLINDER IN A DEBURRING APPLICATION

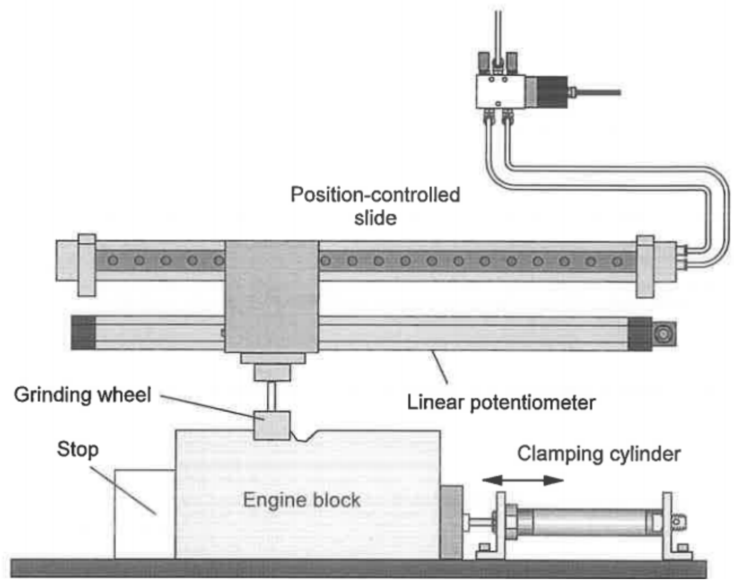
Problem description

Blocks for car engines are produced in a foundry. The blocks are trimmed and deburred after casting. For this purpose, they are fed to a deburring station on a conveyor belt. The blocks are clamped to allow trimming to be carried out.

A grinding wheel is mounted on a slide. This slide is driven by a controlled linear axis. The grinding wheel is guided along the edges of the engine blocks.

The closed-loop control circuit for the linear axis must be assembled, adjusted and then tested.

Fig. A19.2: Positional sketch



Assembly and Commissioning of Closed Loop Circuit

The closed-loop control circuit consists of the status controller, the control valve and the linear axis. A voltage generator is used to produce the reference variable. A storage oscilloscope is recommend for the measurement and display of signals.

In order to commission the closed-loop control circuit, proceed as follows:

- Assemble the circuit in accordance with the circuit diagrams.
- Set all controller coefficients and the correcting variable offset to zero.
- Set the range selector switch to [0 ... 10 V].
- Switch on the electrical power supply.
- Switch on the compressed air.

Investigation of Transient Response for Various Coefficients

- Set a step-change reference variable: frequency: = 0.5 Hz, offset: = 5 V, amplitude: = 1 V.
- Check that the slide oscillates symmetrically about its mid-position.
- If necessary, use the correcting variable offset to reduce the steady-state system deviation.
- Set the specified controller coefficients.
- Relate the transient responses to the cases shown in Fig. A19.1.
- Draw the curves for the reference and controlled variables. Use the prepared graph for this purpose.

Parameterization of the Controller Using Empirical Method

Parametrise the status controller as follows:

- Set a step-change reference variable: frequency: = 0.5 Hz, offset: = 5 V, amplitude: = 1 V.
- Initialise the controller (all values set to zero).
- Set a position coefficient Kx = 1.
- Set the velocity coefficient $K\dot{x}$ and the acceleration coefficient $K\ddot{x}$. Proceed as shown in the flow chart (Fig. A19.2). Use the experience which you have gained from step 2.
- Measure and record the characteristic data.

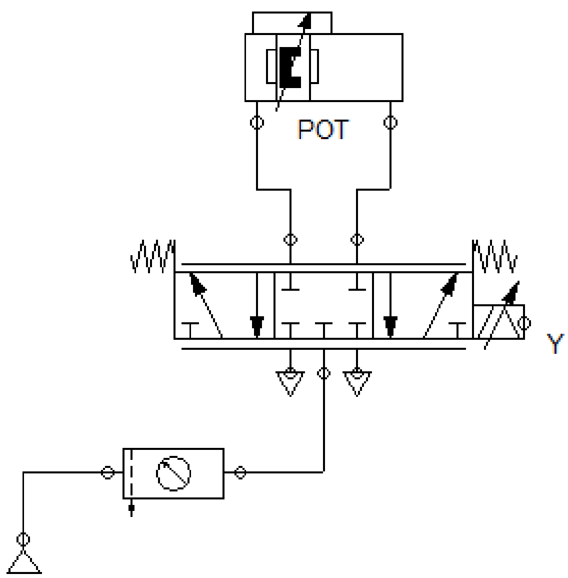
Use the following specifications for the rod-less cylinder

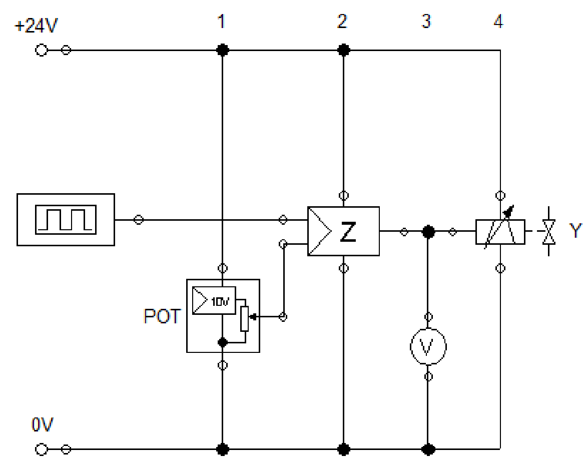
Specification	Value
Type	Double acting cylinder, Piston rod-less cylinder with slide, Adjustable Cushioning
Stroke	450mm
Piston Diameter	25mm

DELIVERABLES

TASK 1

- Pneumatic and Electrical circuit diagrams





(a) Pneumatic Circuit Diagram

(b) Electrical Circuit Diagram

- Investigation of the transient response for various coefficients.
  - Present the state diagram of the controlled variable for the following cases to understand the influence of the respective coefficients.
  - **Case 1**:

Table A19.2: Influence of position coefficient Kx:

Controller coefficients			
K_x	$K_{\dot{x}}$	$K_{\ddot{x}}$	p
0.4	0	0	8.5
0.7	0	0	8.5

Designation	Quantity value	0 1 2 3 4 5 6 7 8 9 10
POT	Position mm	

Case 1.1 $[K_x = 0.4, K_{\dot{x}} = 0.0, K_{\ddot{x}} = 0.0, P = 8.5]$ – Overshoot with one forward swing

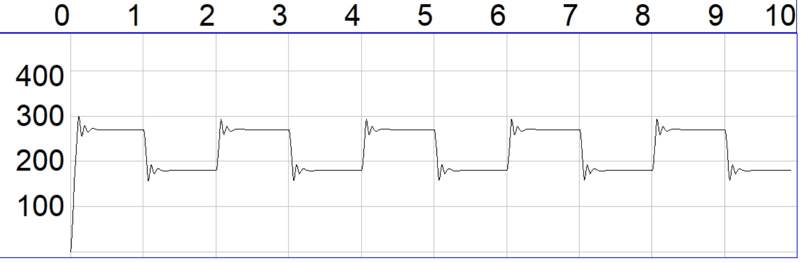
Designation	Quantity value	0 1 2 3 4 5 6 7 8 9 10
POT	Position mm	

Case 1.2 $[K_x = 0.7, K_{\dot{x}} = 0.0, K_{\ddot{x}} = 0.0, P = 8.5]$ – Overshoot with two forward swings

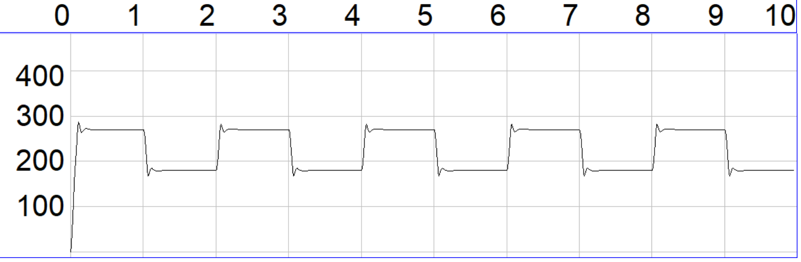
- **Case 2**:

Table A19.3: Influence of velocity coefficient $K\dot{x}$:

Controller coefficients			
Kx	$K\dot{x}$	$K\ddot{x}$	p
1	2.5	0	8.5
1	7	0	8.5

Designation	Quantity value	0 1 2 3 4 5 6 7 8 9 10
POT	Position mm	

Case 2.1 $[K_x = 1.0, K_{\dot{x}} = 2.5, K_{\ddot{x}} = 0.0, P = 8.5]$ – Overshoot with two forward swings

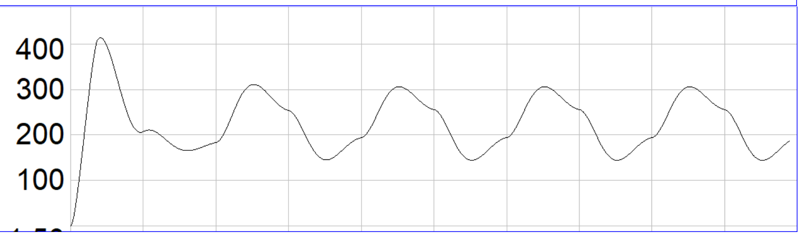
Designation	Quantity value	0 1 2 3 4 5 6 7 8 9 10
POT	Position mm	

Case 2.2 $[K_x = 1.0, K_{\dot{x}} = 7.0, K_{\ddot{x}} = 0.0, P = 8.5]$ – Overshoot with slight forward swing

- **Case 3**:

Table A19.4: Influence of acceleration coefficient $K\ddot{x}$:

Controller coefficients			
Kx	$K\dot{x}$	$K\ddot{x}$	p
0.4	0	10	8.5

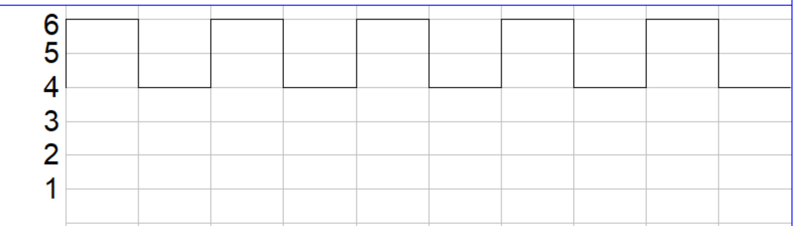
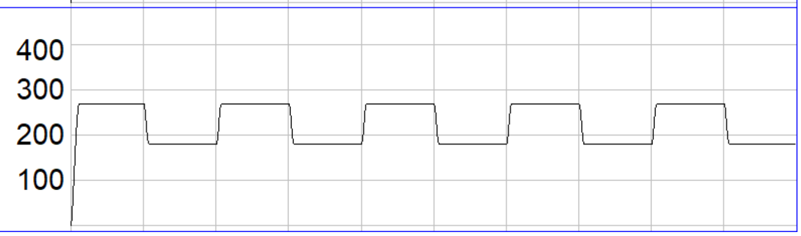
Designation	Quantity value	0 1 2 3 4 5 6 7 8 9 10
POT	Position mm	

Case 3 $[K_x = 0.4, K_{\dot{x}} = 0.0, K_{\ddot{x}} = 10, P = 8.5]$ – Overshoot with one forward swing

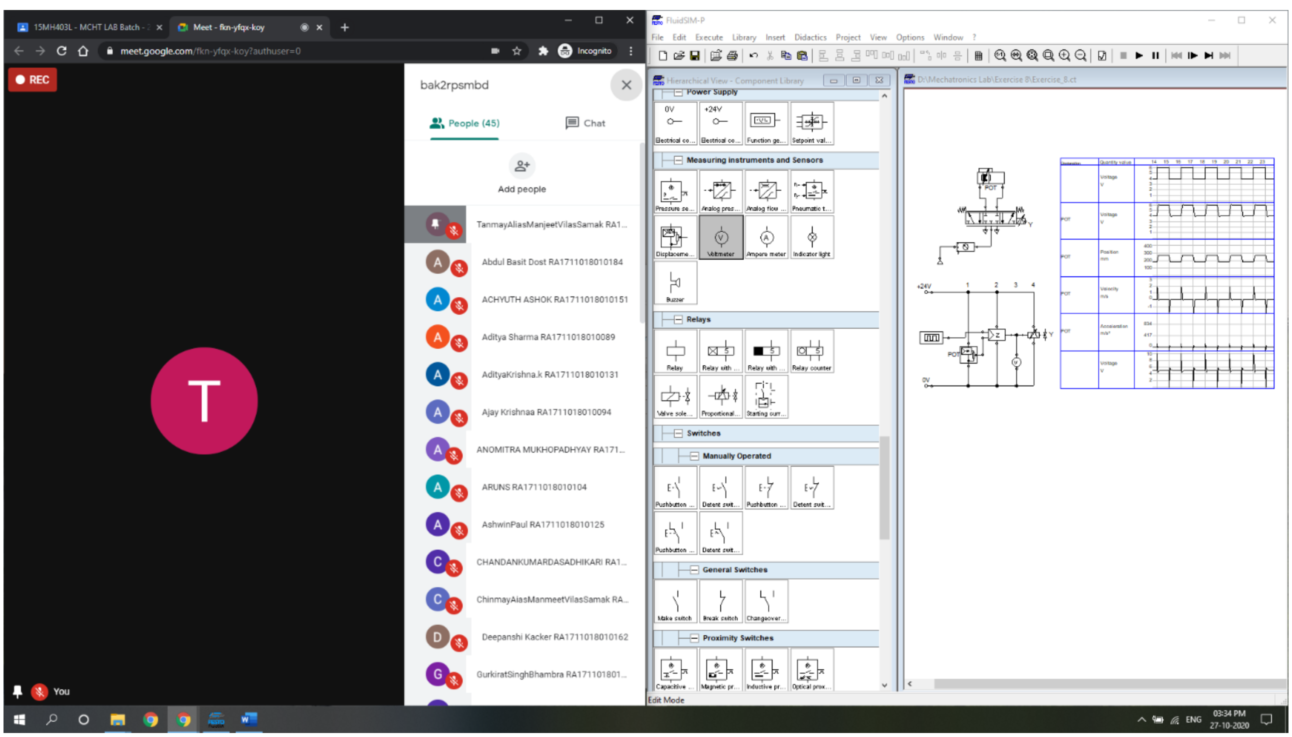
- Parameterization of status controller using the empirical method. Note the values which have been set for the characteristic data to obtain a minimum or no overshoot, minimum steady-state error and quick settling time.

Characteristic Data	Values
Overall Gain	25
Position Coefficient	1.8
Velocity Coefficient	27
Acceleration coefficient	0.1

- Present the state diagram of the generator, displacement encoder and position of the piston.

Designation	Quantity value	0 1 2 3 4 5 6 7 8 9 10
	Voltage V	
POT	Voltage V	
POT	Position mm	

LAB SESSION SCREENSHOT



INFERENCE

The working of a proportional valve was studied from both theoretical and practical viewpoints. A closed loop electro-pneumatic circuit to control the position of a double-acting rodless cylinder was constructed and simulated using Festo FluidSIM.

The voltage setpoint to the solenoid of the proportional DCV was a square wave of frequency = 0.5 Hz, amplitude = 1 V, and offset = 5 V, to control the valve spool proportionately about its mean position (@5V). The signal generator voltage (input) was not directly comparable against the piston position of the double-acting rodless cylinder as the physical units of these two quantities were not identical. Nonetheless, the displacement encoder (linear potentiometer) output in terms of voltage was directly comparable against the signal generator voltage, since the two had same voltage scale.

The theory of status controller was understood and a simulated status controller was implemented to control the position of a double-acting rodless cylinder. The effect of position, velocity and acceleration coefficients K_x, $K_{\dot{x}}$ and $K_{\ddot{x}}$ respectively was analysed by observing the transient response of the controlled variable (piston position of the double-acting rodless cylinder). Finally, the coefficients were tuned to get minimum (or no) overshoot, minimum steady-state error and quick settling time. The coefficient values were reported along with the corresponding state diagrams for signal generator (input), displacement encoder (feedback) and position of the piston (output).