ELEC-C8201 Control and Automation
Exam 12. 4. 2022

- *Write your name and student number to all answer sheets.*
- *There are six (6) problems, and each must be answered.*
- *No literature except the Laplace transformation table is allowed. A calculator is allowed.*
- *The Laplace transformation table must be returned, if you have received it from the exam supervisor.*
- *NOTE:* ***Your solutions must contain enough information to show, how you have solved the problems****. Calculator can only be used as a calculation tool. Solutions cannot be based on output from calculator ("I used the calculator and got the result that..." is not a solution).*

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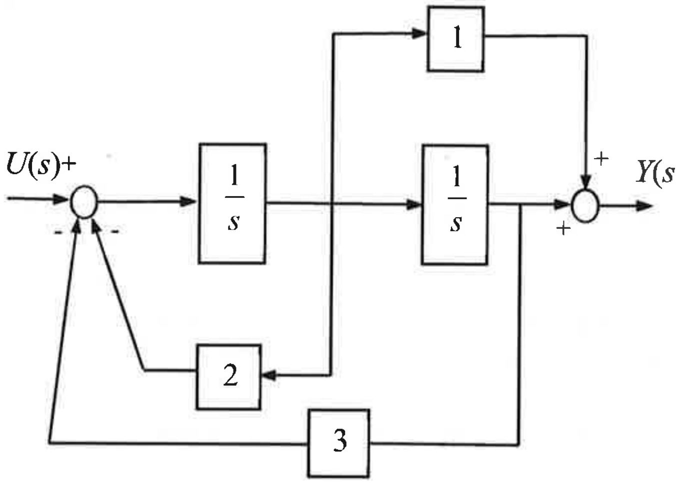
1. Determine the closed-loop transfer function of the system shown below. What are the zeros and poles?



[6 + 4p]

2. Let an unstable process be $G(s) = \dfrac{1}{s-1}$. Use negative feedback and the controller $K_P \dfrac{1+T_i s}{T_i s}$, where the tuning parameters K_P and T_i are positive constants.

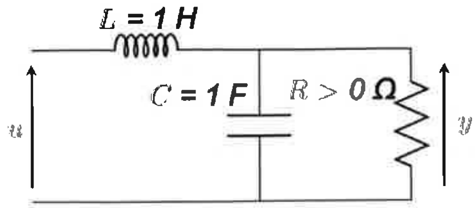
a) What name does the controller have? For what parameter choices we get a *P*-controller? [3p]

b) Can the process be stabilized and if so for what parameter values does this succeed? [3p]

c) Can the process be stabilized by a *P*-controller only? If it can, will there be a permanent control error, when a step input enters the reference. Compare to the controller in part b.
[4p]

(Turn over)

3. The transfer function of RLC circuit below is given by $G(s) = \frac{Y}{U} = \frac{1}{LCs^2 + (L/R)s + 1}$



a) Find the poles of the transfer function as a function of the resistance, R. [1p]

b) Is G(s) asymptotically stable for any value of R? Justify your answer. [2p]

c) Consider the step input voltage u = V. Find the steady-state output. [2p]

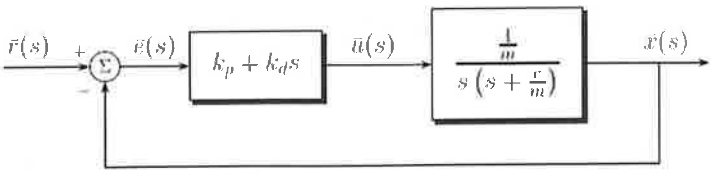
d) Consider R = 1 Ω. Sketch the Bode and Nyquist diagrams of G(s) and estimate the gain margin. [5p]

4. Consider a car moving along a straight line. Car position, velocity and acceleration at time t are denoted by $x(t)$, $\dot{x}(t)$ and $\ddot{x}(t)$, respectively. The position and velocity are zero at $t = 0$. The dynamics of the car satisfy the balance of forces $m\ddot{x}(t) + c\dot{x}(t) = u(t)$. Parameter $m > 0$ is the mass of the car, $c > 0$ is the damping coefficient and $u(t)$ is the force exerted on the car by the engine.

a) Show that the transfer function $G(s)$ from $\bar{u}(s)$ to $\bar{x}(s)$ is given by [3p]

$$G(s) = \frac{\frac{1}{m}}{s\,(s + \frac{c}{m})}$$

b) Consider the cruise-control system shown below



For m = 1 and c = 1:

i) Show that the closed-loop transfer function T(s) from $\bar{r}(s)$ to $\bar{x}(s)$ is given by [2p]

$$T(s) = \frac{k_p + k_d s}{s^2 + (1 + k_d)s + k_p}$$

ii) For $k_d = 0$, find $k_p > 1/4$ to achieve a damping ratio equal to 0.5. [2p]

iii) Is integral control action necessary to be included in the cruise-control system? Justify your answer. [3p]

5. Two double-acting cylinders are composed into a system as shown in Figure 1, *a* such that if both cylinders are extended, they can collide in the middle.

The desired behavior of the system:

The initial position of the system is as shown in Figure 1, *a*, and both buttons are enabled, indicated by the lamps lighting behind them. Upon pressing of either button, both cylinders shall retract to the home positions and be ready to further requests (i.e., with the buttons enabled).

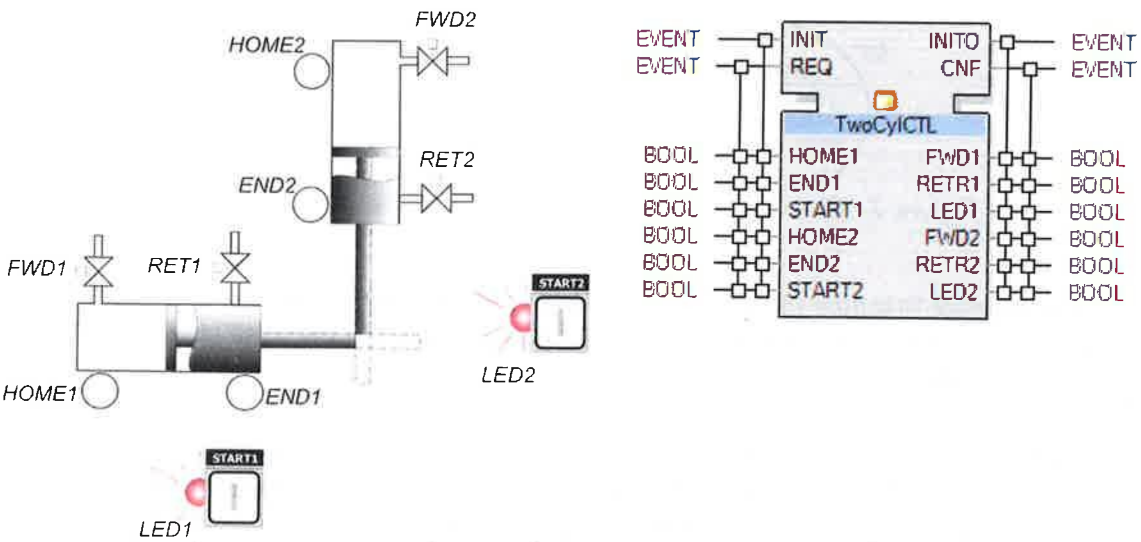
- Upon pressing of button START1, the horizontal cylinder shall make one trip to its end position and then return.
- Upon pressing of button START2, the vertical cylinder shall make one trip to its end position and return.

During the trip of either cylinder, both buttons shall be disabled, indicated by the absence of light behind both buttons. To avoid the collision, if one cylinder is moving forward, the other shall remain still.
In case if a button is pressed while the other cylinder is moving, the light behind the button shall go on for a short time (a single, but visible, blink).

List of the system's variables is as follows:

List of inputs and outputs

Controller inputs		**Controller outputs**	
Name	*Description*	*Name*	*Description*
HOME1	Left position of cylinder 1	FWD1	Open push valve of cylinder 1
END1	Right position of cylinder 1	RET1	Open pop valve of cylinder 1
HOME2	Left position of cylinder 2	FWD2	Open push valve of cylinder 2
END2	Right position of cylinder 2	RET2	Open pop valve of cylinder 1
START1	Button to start cylinder 1	LED1	Lamp behind the START1 button
START2	Button to start cylinder 2	LED2	Lamp behind the START2 button



a) *b)*

Figure 1. a) System of two pneumatic cylinders. b) Interface of its controller function block.

a) Develop controller of the system as a Moore state machine. [6p]

(Turn over)

b) Implement the state machine as an ECC of the basic function block, whose interface is shown in Figure 1, *b*. [4p]

6. Moore state machine of the oven controller is presented in Figure 2.

Legend and declaration:
T1: timer
The notation ->T1.IN(t#15s) means "start timer T1 for 15 seconds", and T1.Q is the logic flag of the timer, which becomes true after the timer has expired.
Note that the Stop button is normally closed.

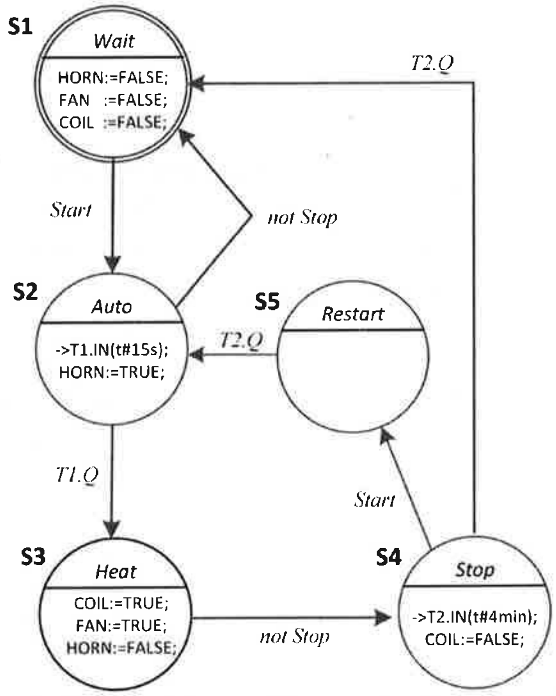


Figure 2. Moore state machine controller of the oven.

a) Implement the state machine in Structured Text (or pseudocode), using the IF-THEN-ELSE method. To start timers, use exactly same notation as it is used in the state machine, i.e. ->T1.IN(t#15s); [6p]

b) What is the *minimum* time the state machine can make the path from state S3 to state S1 if the safety button STOP was pressed only once? Since STOP is a normally closed contact, when pressed, the value of the corresponding signal becomes FALSE. [2p]

c) What is the *maximum* time the state machine can make the path from state S4 to state S3, if the START button was pressed before the timer T2 has expired? [2p]