Period of Examinations
Winter Semester 2019 / 2020

HOCHSCHULE RHEIN-WAAL
Rhine-Waal University of Applied Sciences

Study Course: **Mechanical Engineering / Mechatronic Systems Engineering / Electrical and Electronics Engineering / Electronics**

Module Title: **Controls**

Examination Part: **Controls**

Points: 100

Duration: 120 Minutes

Please write legibly!

Date: ____________________

Family Name : ____________________ ____________________________

First Name: ____________________ Signature (Student)

Student No.: ____________________

FOR INTERNAL USE ONLY:

Question Number	Tick Questions Attempted	Points	Question Number	Tick Questions attempted	Transfer Points
1		/ 10	13		
2		/ 10	14		
3		/ 8	15		
4		/ 16	16		
5		/ 14	17		
6		/ 18	18		
7		/ 7	19		
8		/ 17	20		
9	Bonus points from laboratory WS 2019/20	/ 10	21		
10			22		
11			23		
12			24		
	SUM			TOTAL	/ 100

Graded by		Checked by

Final Grade

Regular grading key.	
Adjusted grading key. (Please add the adjusted grading key to the exam-results)	

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Points:

Question 1: **10**

Mark the correct answers / statements with a cross. For each correct cross you will receive 1 point, each cross which is not correct will subtract 1 point from the total score. The total score for question 1 cannot be negative.

a) An unstable system given in state-space form
- ○ is not observable.
- ○ can be stabilized when it is controllable.
- ○ can be stabilized only when it is controllable and observable.
- ○ is not controllable.

b) The poles of the observer for a closed-loop system
- ○ are located between the eigenvalues of the matrix $\boldsymbol{A}-\boldsymbol{BK}$ and the imaginary axis.
- ○ have to be located left to the eigenvalues of the matrix $\boldsymbol{A}-\boldsymbol{BK}$.
- ○ have to be equal to the eigenvalues of the system matrix $\boldsymbol{A}$.
- ○ are equal to the eigenvalues of the matrix $\boldsymbol{A}-\boldsymbol{LC}$.

c) An emergency stop switch is designed as a NC (normally closed) switch instead of a NO (normally open) switch, because
- ○ it is easier to produce, thus cheaper.
- ○ a NO switch cannot be connected to a PLC.
- ○ the PLC program can be simplified.
- ⊗ of safety reasons in case of a cable break.

d) The Down-counter CTD
- ○ considers a priority of the reset input.
- ⊗ contains a reset input which has to be assigned in a logic program (input definition mandatory, not optionally).
- ○ resets the actual counted value, when the count down input CD goes from 1→0.
- ○ sets the actual counted value to zero, when the defined counted value (threshold) has been achieved.

e) A time discrete system with the two poles $p_{1,2} = 0.8 \pm 0.56j$

- O is boundary stable for a sampling time $T = 1\ [sec]$.
- ☒ is stable.
- O is not controllable.
- O has a weak stability margin.

f) A time discrete system with the transfer function $G(z) = \frac{z}{z+4-4.5\ e^{-T}}$

- O is stable for a sampling time $T = 1\ [sec]$.
- O is unstable for any sampling time.
- ☒ is stable for a sampling time $T = 0.1\ [sec]$.
- O is representing the difference equation $y(k) + (4 - 4.5\ e^{-T})\ y(k-1) = u(k)$.

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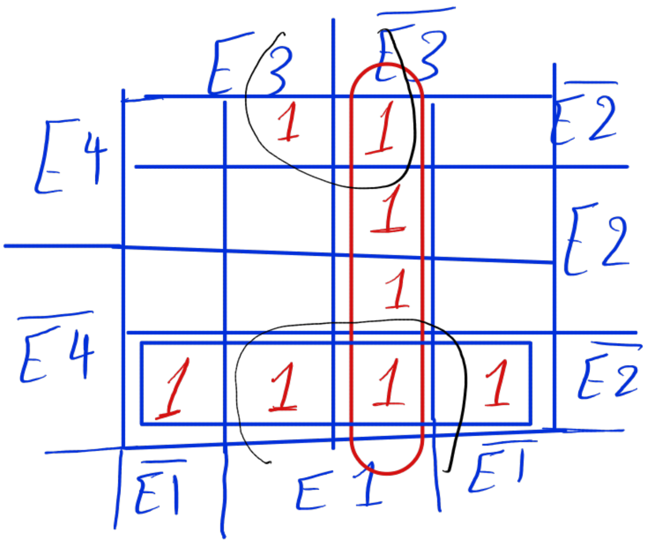
Question 2: Points: 10

The output setting of a logical system is realized by four inputs A, B, C, D. The logic can be described through the Boolean equation

$$Y = A\bar{B}\bar{C}D + \bar{A}\bar{B}\bar{C}\bar{D} + AB\bar{C}\bar{D} + A\bar{B}CD + \bar{A}\bar{B}C\bar{D} + AB\bar{C}D + A\bar{B}\bar{C}\bar{D} + A\bar{B}C\bar{D}$$

a) Find the optimized/minimum Boolean equation.
b) Sketch the corresponding function block diagram (FBD).



$Y = A \cdot \bar{C} + \bar{B}\bar{D} + \bar{B}A$

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Question 3:

Points: **8**

Transfer the given logic gate circuit with the inputs $A, B,$ and C and the outputs Y and Z, according to figure 3.1, to a corresponding ladder diagram (LAD).

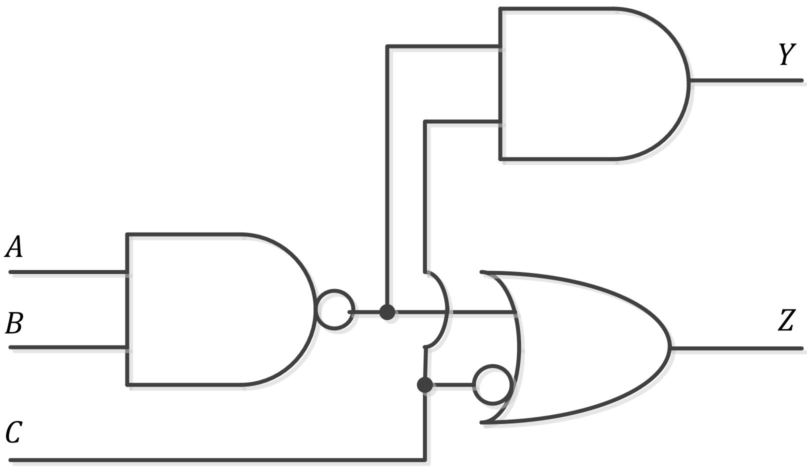
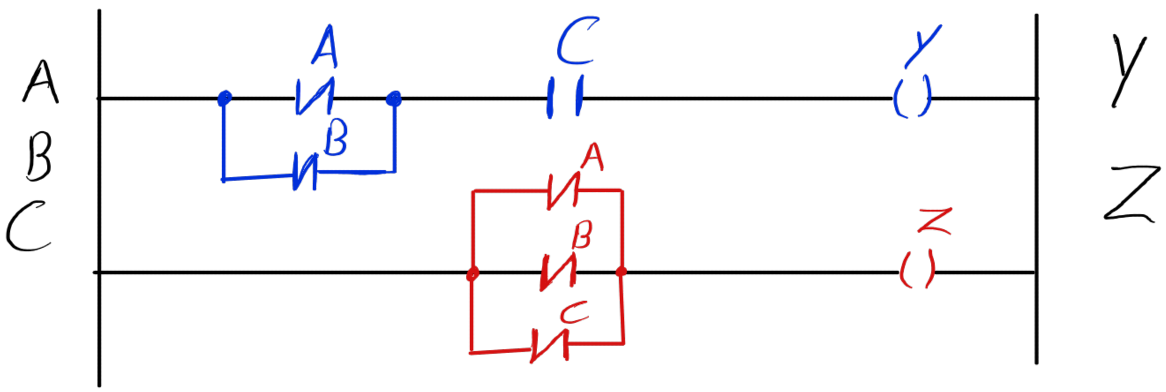


Figure 3.1: Logic gate circuit

$$Y = \overline{(A \cdot B)} \cdot C = (\overline{A} + \overline{B}) \cdot C = (\overline{A} \cdot C) + (\overline{B} \cdot C)$$

$$Z = \overline{(A \cdot B)} + \overline{C} = (\overline{A} + \overline{B}) + \overline{C} = \overline{A} + \overline{B} + \overline{C}$$



Points:

Question 4: 16

A packaging line is automated by use of a PLC. Figure 4.1 shows the hardware arrangement and consists of a NO start button, a NC stop button, a motor 1 to activate the main belt, and a proximity switch detecting the cans going into the packaging station. The specific sequence is as follows, when the start button is pushed.

1. The main belt is activated (by motor M1) and remains active, even when the start button is no longer pressed.
2. A proximity switch detects cans going into the packaging station.
3. Within 20 seconds (after activation according to task 1), 10 cans have to be in the packaging station, detected by the proximity switch. If this is not the case, the belt is shut off and will not be able to start again for another 30 seconds.
4. When 10 cans have passed the proximity switch, the 20 second timer for the next 10 cans is reset and the process continues.
5. The process continues and remains activated as long as the stop button is pressed. In that case the process shall stop immediately.

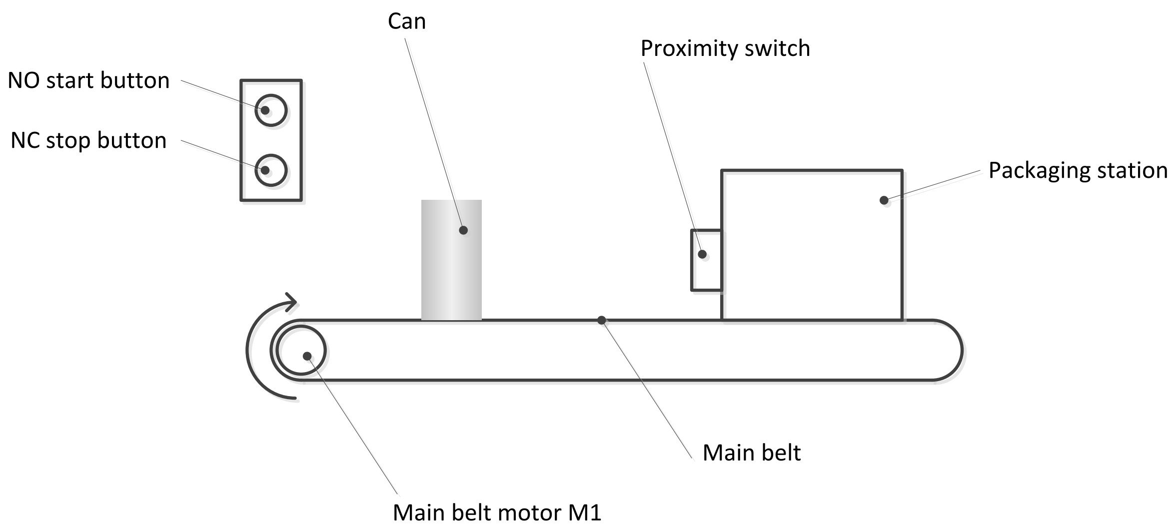


Figure 4.1: Packaging line

Develop and create the logic using a Ladder Diagram (LAD).

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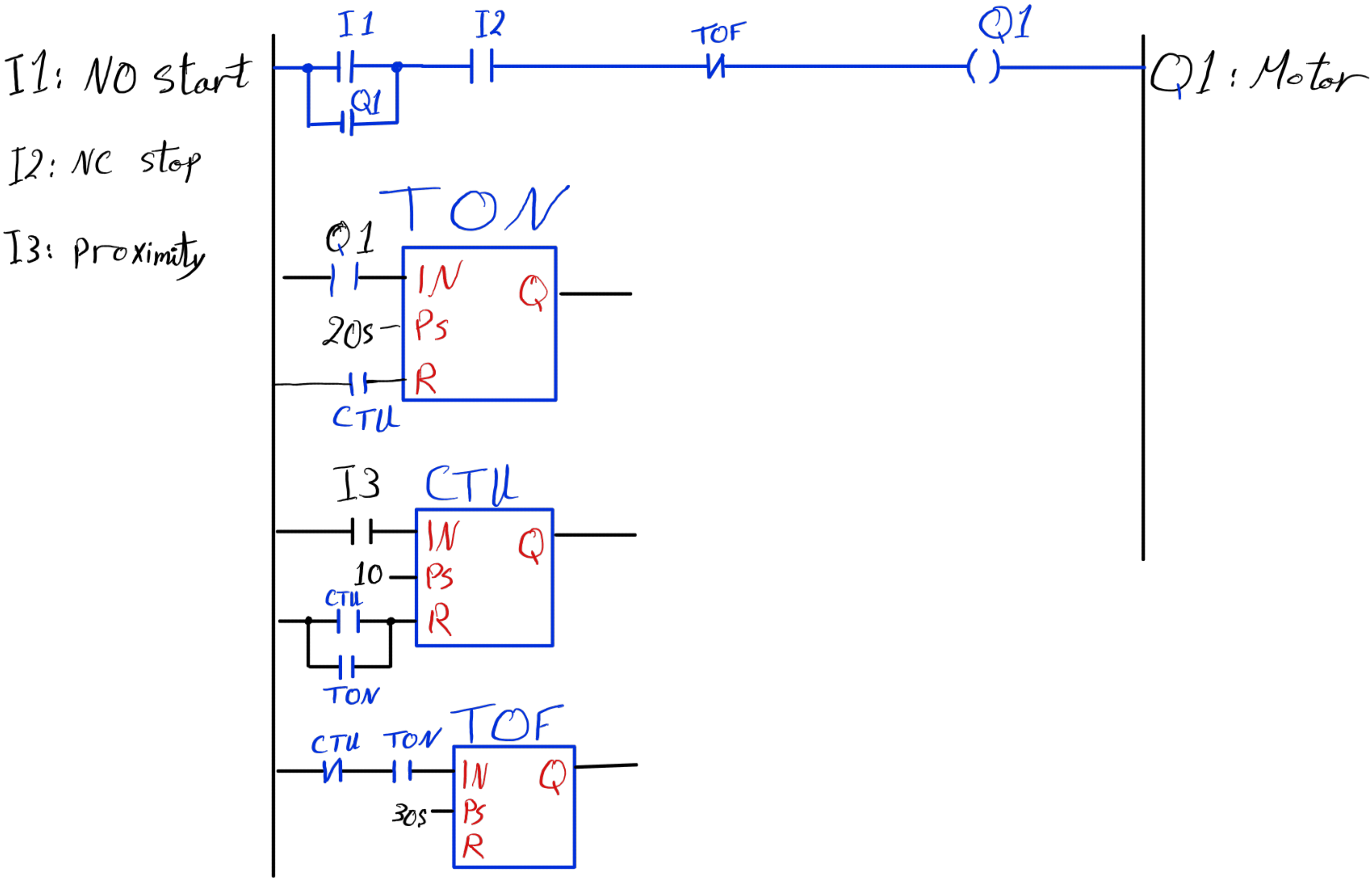
I1: NO start
I2: NC stop
I3: proximity
I1
I2
TOF
Q1
Q1
Q1: Motor
TON
Q1
IN
Q
20s
Ps
R
CTU
I3
CTU
IN
Q
10
PS
CTU
R
TON
CTU
TON
TOF
IN
Q
30s
PS
R

Points:

Question 5: **14**

A system is characterized through the set of equations

$$2\,\ddot{x}_1(t) + 6\,x_1(t) = 8\,u_1(t)$$
$$\dot{x}_2(t) + a\,x_2(t) + 10\,\dot{x}_1(t) = 2\,u_1(t) + b\,u_2(t)$$
$$y(t) = 2\,x_1(t) + 5\,u_2(t)$$

where y is the output variable and u_1 and u_2 are the input variables.

a) Formulate a state-space model of the system and determine the matrices $\boldsymbol{A}$, $\boldsymbol{B}$, $\boldsymbol{C}$, and $\boldsymbol{D}$.
b) Formulate a condition for the coefficients a and b, so that the system is stable.

Points:

Question 6: 18

A system is defined through the state space model

$$\dot{\boldsymbol{x}}(t) = \boldsymbol{A}\,\boldsymbol{x}(t) + \boldsymbol{B}\,u(t)$$
$$y(t) = \boldsymbol{C}\,\boldsymbol{x}(t) + D\,u(t)$$

with $\boldsymbol{A} = \begin{bmatrix} 0 & 4 \\ 1 & 8 \end{bmatrix}, \boldsymbol{B} = \begin{bmatrix} 2 \\ 0 \end{bmatrix}, \boldsymbol{C} = \begin{bmatrix} 1 & 0 \end{bmatrix}$ and $D = 0$

a) Convert the state space model into a state space model in phase variable canonical form.
b) Is the given system controllable? Please explain.

In the following the system is controlled by a state space controller with the feedback vector $\boldsymbol{K}$.

c) Calculate the feedback vector $\boldsymbol{K}$, so that the closed-loop system has the poles at $p_{1,2} = -6 \pm j$.

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Question 7: Points: 7

A plant with a IT1 characteristic and a transfer function $G_P(s) = \frac{1}{s(0.1s+1)}$ is excited by the input signal $\tilde{u}_{zoh}(t)$ as shown in the block diagram, figure 7.1. The digital signal $\tilde{u}_{zoh}(t)$ is generated out of $u(t)$ by using a sampler and a zero-order hold element. The input signal $u(t)$ is shown in the graph, figure 7.2.

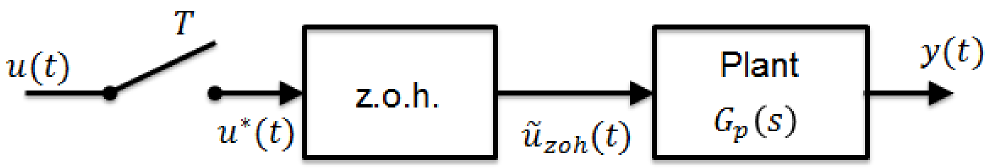

Figure 7.1: Block diagram of signal flow

a) Draw the signal $u^*(t)$ into the graph of figure 7.2, when the sampling time of the sampler is $T = 0.2\ s$.
b) Draw the signal $\tilde{u}_{zoh}(t)$ into the graph of figure 7.2, when the sampling time of the sampler is $T = 0.2\ s$.
c) Using the signal $\tilde{u}_{zoh}(t)$ from task b), sketch the output of the plant $y(t)$ into the graph of figure 7.2.

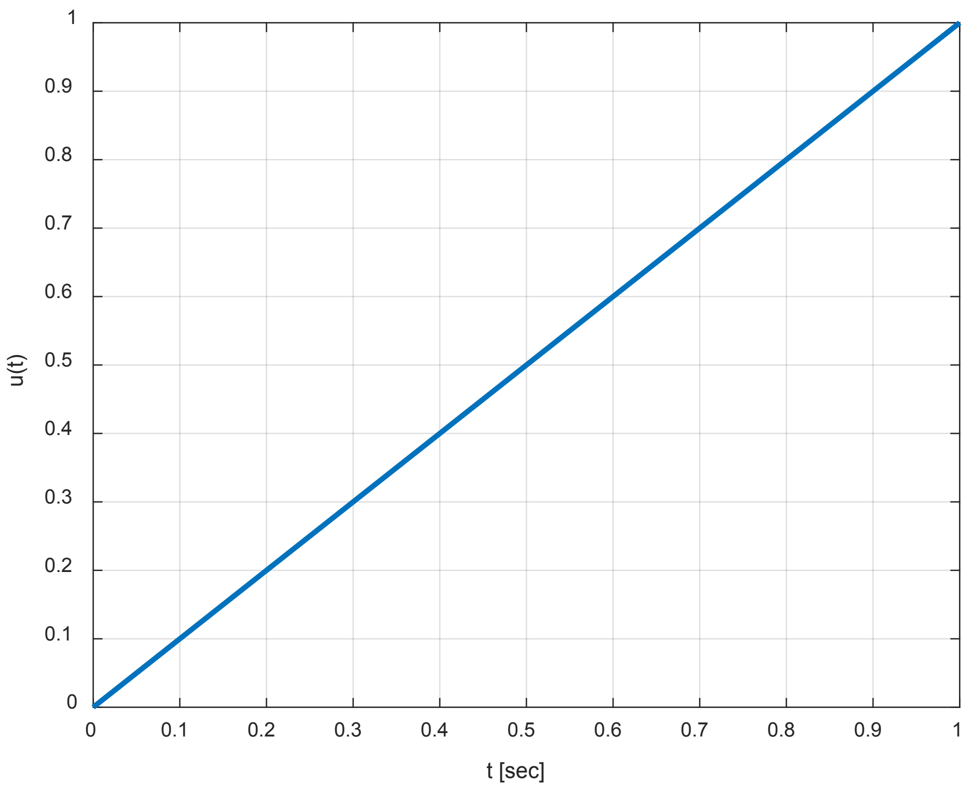

Figure 7.2: Input signal

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Points:

Question 8: **17**

A closed-loop sampled system with the reference input $r(t)$ and the actual output $c(t)$, as shown in block diagram fig. 8.1, consists of a system with the transfer function $G_1(s)$ in the feedforward path, a zero-order-hold in the feedforward path, two samplers which are synchronized with the sampling time T, and a system with the transfer function $H(s)$ in the feedback path.

The following transfer functions are given:

$G_1(s) = \frac{5}{s}$ and $H(s) = \frac{10}{s+10}$

$\tilde{G}(z) \cdot H(z) \neq \tilde{G}H(z)$

$\tilde{G}(s) = \frac{1-e^{-sT}}{s} \cdot \frac{5}{s}$

If this is not there $G_{CL}(z) = \frac{\tilde{G}(z)}{1+\tilde{G}H(z)}$

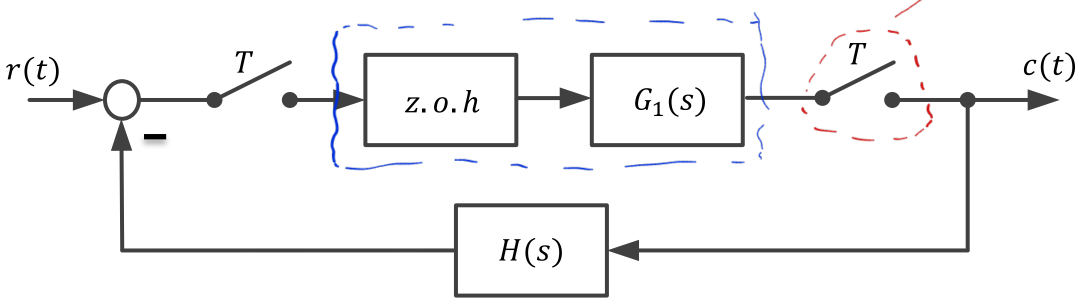

Figure 8.1: Block diagram of closed-loop system

a) Find the sampled-data transfer function $G(z) = \frac{C(z)}{R(z)}$ of the closed-loop system as a function of the sampling time T. *Hint: Check the sampler arrangement!*

b) Is the sampled closed-loop system stable for $T = 10\ [ms]$? Please explain.

$$\tilde{G}(z) = \mathcal{Z}\{1-e^{-sT}\} \cdot \mathcal{Z}\left\{\frac{5}{s^2}\right\} = \frac{\cancel{z-1}}{\cancel{z}} \cdot \frac{5T\cancel{z}}{(z-1)^{\cancel{2}}}$$

$$\boxed{\tilde{G}(z) = \frac{5T}{z-1}}$$

$$H(z) = \mathcal{Z}\left\{\frac{10}{s+10}\right\} = \frac{10z}{z-e^{-10T}}$$

$$G_{CL}(z) = \frac{C(z)}{R(z)} = \frac{\tilde{G}(z)}{1+H(z)\cdot\tilde{G}(z)} = \frac{\frac{5T}{z-1}}{1+\frac{50Tz}{(z-1)(z-e^{-10T})}} = \frac{\frac{5T}{\cancel{z-1}}}{\frac{z^2-z-e^{-10T}z+50Tz+e^{-10T}}{\cancel{(z-1)}(z-e^{-10T})}}$$

$$\boxed{G_{CL}(z) = \frac{5T(z-e^{-10T})}{z^2+z(50T-e^{-10T}-1)+e^{-10T}}}$$

Good luck!