Reading-up-time

For reviewing purposes of the problem statements, there is a "reading-up-time" of **10 minutes** prior to the official examination time. During this period it is **not** allowed to start solving the problems. This means explicitly that during the entire "reading-up-time" no writing utensils, e.g. pen, pencil, etc. at all are allowed to be kept on the table. Furthermore the use of carried documents, e.g. books, (electronic) translater, (electronic) dictionaries, etc. is strictly forbidden. When the supervisor refers to the end of the "reading-up-time" and thus the beginning of the official examination time, you are allowed to take your utensils and documents. Please **then**, begin with filling in the **complete** information on the titlepage and on page 3.

Good Luck!

LAST NAME	
FIRST NAME	
MATRIKEL-NO.	
TABLE-NO.	

Klausurunterlagen

Ich versichere hiermit, dass ich sämtliche für die Durchführung der Klausur vorgesehenen Unterlagen erhalten, und dass ich meine Arbeit ohne fremde Hilfe und ohne Verwendung unerlaubter Hilfsmittel und sonstiger unlauterer Mittel angefertigt habe. Ich weiß, dass ein Bekanntwerden solcher Umstände auch nachträglich zum Ausschluss von der Prüfung führt. Ich versichere weiter, dass ich sämtliche mir überlassenen Arbeitsunterlagen sowie meine Lösung vollständig zurück gegeben habe. Die Abgabe meiner Arbeit wurde in der Teilnehmerliste von Aufsichtsführenden schriftlich vermerkt.

THE ABOVE REQUIRED STATEMENTS AS WELL AS THE SIGNATURE ARE MANDATORY AT THE BEGINNING OF THE EXAM.

Duisburg, ______________ (Date) ________________________________ (Student's signature)

Falls Klausurunterlagen vorzeitig abgegeben: ______________Uhr

Bewertungstabelle

Aufgabe 1	
Aufgabe 2	
Gesamtpunktzahl	
Angepasste Punktzahl	
%	
Bewertung gem. PO in Ziffern	

____

(Datum und Unterschrift 1. Prüfer, Univ.-Prof. Dr.-Ing. Dirk Söffker)

____

(Datum und Unterschrift 2. Prüfer, Prof. Dr.-Ing. Yan Liu)

____

(Datum und Unterschrift des für die Prüfung verantwortlichen Prüfers, Söffker)

Fachnote gemäß Prüfungsordnung:

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
1,0	1,3	1,7	2,0	2,3	2,7	3,0	3,3	3,7	4,0	5,0
sehr gut		gut			befriedigend			ausreichend		mangelhaft

Bemerkung: ____

Attention: Give your answers to ALL problems directly below the questions in the exam question sheet.

You are NOT allowed to use a pencil and also NOT red color (red color is used for corrections).

This exam is taken by me as a
☐ mandatory (Pflichtfach)
☐ elective (Wahlfach)
☐ prerequsite (Auflage)
subject (cross ONE option according to your own situation).

Maximum achievable points:	**70**
Minimum points for the grade 1,0:	**95%**
Minimum points for the grade 4,0:	**50%**

General hints:

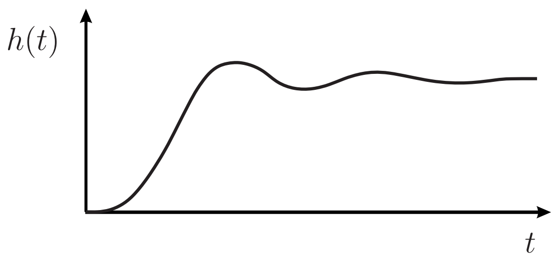
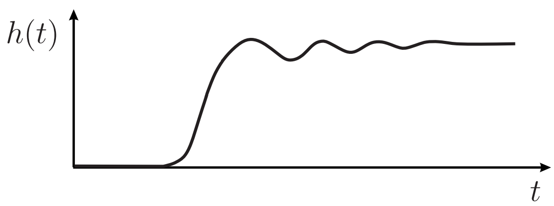
1) For the multiple-choice and multiple-choice-similar tasks the following rules are effective:
   - i) For correct answers of exam task parts the desired number of points will be given.
   - ii) For noncorrect answers of exam task parts the desired number of points will be counted negative.
   - iii) No answering will neither lead to positive nor to negative points.
   - iv) The points of the task will be summarized. The whole number can not be smaller than zero.

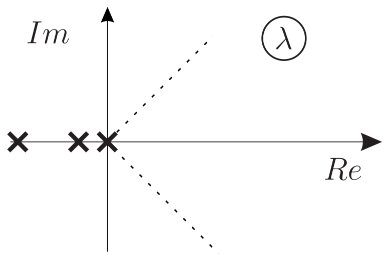
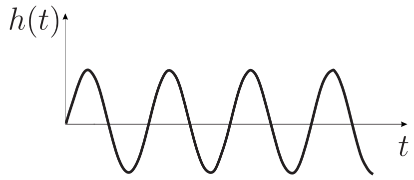
2) If in the exam tasks no information is given for the valid range of numbers for time constants or masses etc.: take for time constants (in sec.), for masses (in kg) positive numbers.

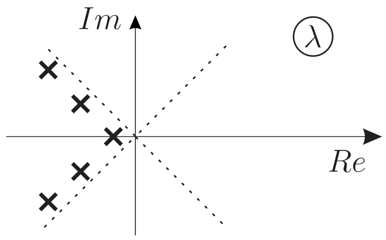
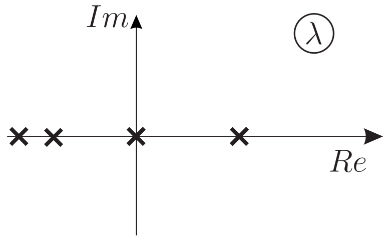
3) If in the exam tasks no information is given for applying negative or positive feedback: use the usual negative feedback.

Problem 1 (40 Points)

1a) (3 × 5 × 1 Point, 15 Points)
Which of the following statements are true and which are false?

No.	Task/Question/Judgment	True	False
A.1)	The difference between an open loop control and a closed loop control is the position of the disturbance.	◯	◯
A.2)	Using an input signal $u(t) = a\sin(\omega t)$ for a system yields to the output $y(t) = b\sin(3\omega t - \varphi_0)$. The system has nonlinear transfer behavior.	◯	◯
A.3)	The step response is the response of a system to the dirac delta function $u(t) = \delta(t)$ as input.	◯	◯
A.4)	A linear system of second order with damping $D < 1$ can have the following step response. 	◯	◯
A.5)	A system of second order with damping $D < 1$ can have the following step response. 	◯	◯

No.	Task/Question/Judgment	True	False
B.1)	A typical I/O-description $$y^{(n)} + a_{n-1}y^{(n-1)} + ... + a_1 y + a_0 = K[u(t) + \frac{1}{T}\int u\ dt]$$ describes a MIMO-system.	○	○
B.2)	Due to the feedback, an open loop control is capable to compensate the influence of disturbances.	○	○
B.3)	The linearization of the equation $$f(x, y) = 2yx^2 - \sin(y) + xy$$ around the working point $(x_0, y_0) = (1, 0)$ results in $$f(x, y) = 2y.$$	○	○
B.4)	The amplitude of the input from a transfer system is doubled. The output of this system changes correspondingly. Concretely the frequency of the output is doubled. Such behavior can only occur in nonlinear systems.	○	○
B.5)	A system with the eigenvalue distribution  shows the following behavior. 	○	○

No.	Task/Question/Judgment	True	False
C.1)	For the modal canonical form, the system matrix A is transformed into a diagonal matrix.	○	○
C.2)	For linear systems, the transfer behavior with respect to the desired value and with respect to the disturbance can be analyzed separately.	○	○
C.3)	A system with the eigenvalue distribution  is asymptotically stable.	○	○
C.4)	A system with the eigenvalue distribution  is boundary stable.	○	○
C.5)	Second order transfer elements described by $T_2\ddot{y} + T_1\dot{y} + y = Ku,$ can be able to oscillate depending on the setting parameters T_1 and T_2.	○	○

1b) ($2 \times 5 \times 1$ Point, 10 Points)
The eigenvalues of the I/O-behavior from two different linear systems without time delay are illustrated in Figure 1.1. Two measured weighting functions $g(t)$ are shown in Figure 1.2. Evaluate the statements in the following tables.
Hint: The weighting function is the derivative of the step response.

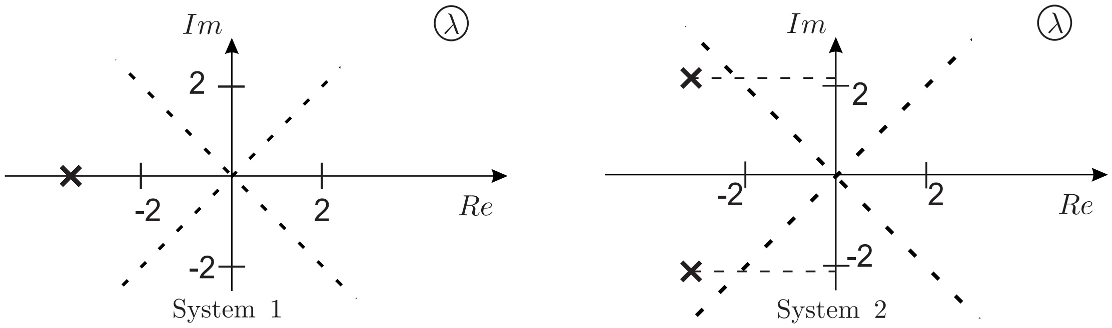


Figure 1.1: Eigenvalue distribution of two different systems

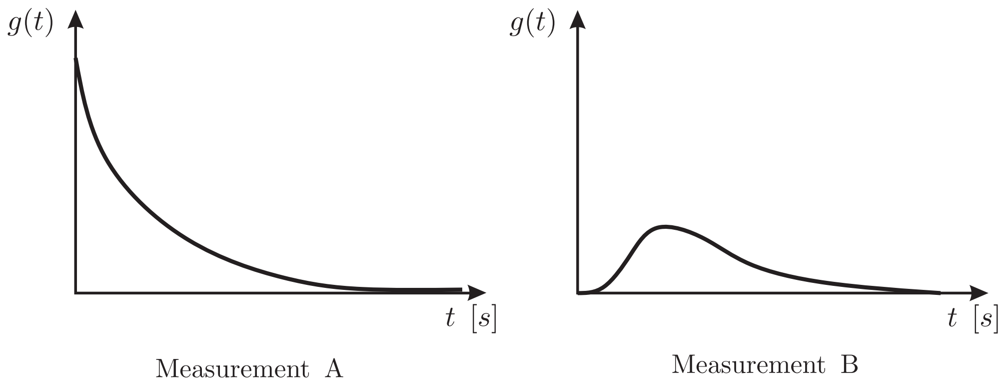


Figure 1.2: Weighting functions of two different systems

No.	Task/Question/Judgment	True	False
A.1)	System 1 can be described by $$\dot{y} + y = K(\frac{1}{T_\mathrm{I}}\int u\,dt).$$	◯	◯
A.2)	System 2 corresponds to a system with a damping $D > 1$.	◯	◯
A.3)	System 1 is asymptotically stable.	◯	◯
A.4)	Measurement B shows a damping behavior with $D \geq 1$.	◯	◯
A.5)	Measurement A shows transfer behavior with time delay.	◯	◯

☐

No.	Task/Question/Judgment	True	False
B.1)	Measurement A could correspond to the behavior of a PT_1-system.	◯	◯
B.2)	Measurement A corresponds to System 1.	◯	◯
B.3)	Measurement B corresponds to System 2.	◯	◯
B.4)	From the eigenvalue distribution of System 1 and 2, it can be concluded clearly that the systems have an identical static gain K.	◯	◯
B.5)	Connecting a time delay system in series with System 2, Measurement A can be obtained.	◯	◯

☐

1c) (5 × 2 Points, 10 Points)
The mathematical model of a mechanical system (Figure 1.3) is described by the equations

$$
\begin{aligned}
m\ddot{x}_2 &= F_1 - F_2, \\
F_1 &= c(x_1 - x_2), \text{ and} \\
F_2 &= d\dot{x}_2 + cx_2
\end{aligned}
$$

with the variables

$x_{1,2}$: position,
$\dot{x}_{1,2}$: velocity,
F_1 : spring force,
F_2 : damping force + spring force,
c : spring stiffness,
d : damping constant, and
m : mass.

Evaluate the statements in the following tables.

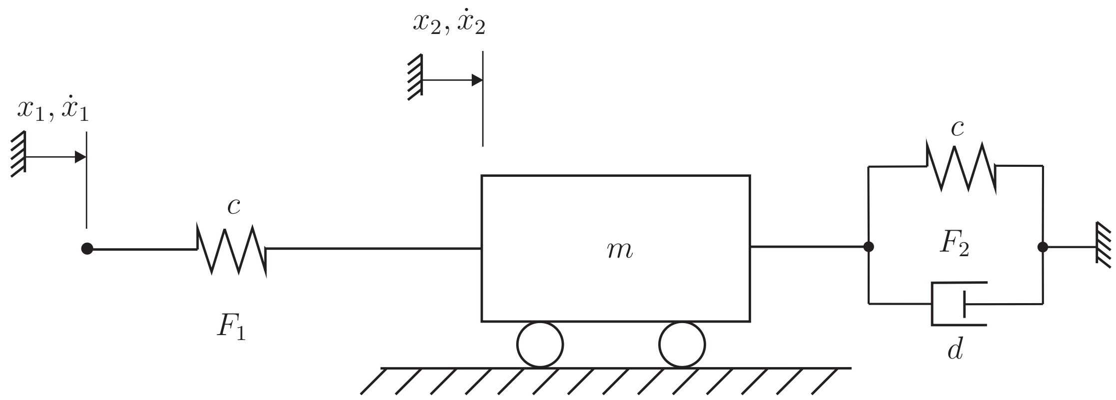


Figure 1.3: Model of a mechanical system

No.	Task/Question/Judgment	True	False
1)	The transfer behavior from the input value x_1 to the output value x_2 is described by $$\frac{d}{c}\ddot{x}_2 + \frac{m}{c}\dot{x}_2 + x_2 = \frac{1}{2}x_1.$$	○	○
2)	The transfer behavior can be classified as PDT_2-behavior.	○	○
3)	The transfer behavior of the mechanical system with the input value x_1, the output value x_2, and the state space vector $x = \begin{bmatrix} x_2 \\ \dot{x}_2 \end{bmatrix}$ is described by the state space representation $$\begin{bmatrix} \dot{x}_2 \\ \ddot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -\frac{2c}{m} & -\frac{d}{m} \end{bmatrix} \begin{bmatrix} x_2 \\ \dot{x}_2 \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{c}{m} \end{bmatrix} x_1$$ $$y = \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} x_2 \\ \dot{x}_2 \end{bmatrix}.$$	○	○
4)	For the parameters c, d, and m of the transfer behavior of the mechanical system the following values are assumed: $c = 2$, $m = 1$, and $d = 4$. The considered system behavior shows oscillations ($D < 1$).	○	○
5)	The considered mechanical system with the parameters from 1c)4) has the eigenvalues $\lambda_{1,2} = -2$.	○	○

□

1d) (2 Points)
Illustrate the function $u(t) = 3 \cdot 1(t-1) - 2 \cdot 1(t-2) + 1 \cdot 1(t-3)$ graphically.

1e) (3 Points)

For a control loop at the stability bound, the following behavior, shown in Figure 1.4, is measured. The gain of the P-controller was observed as 1.2.

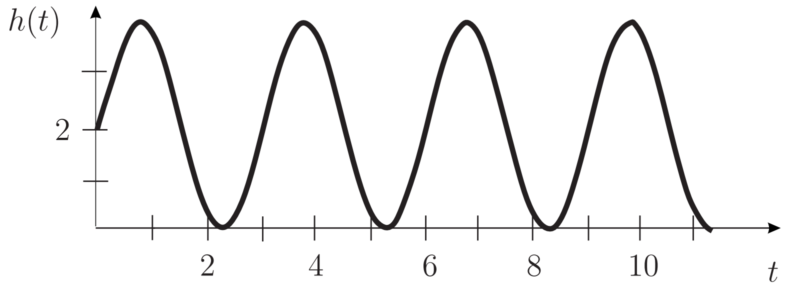


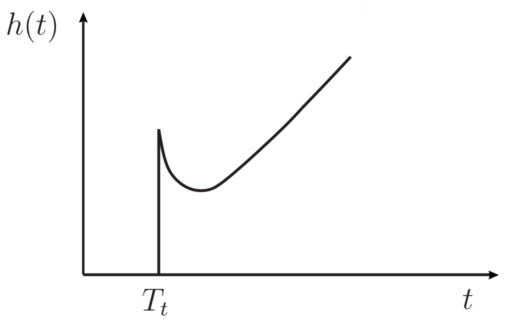
Figure 1.4: Measurement

Calculate the parameters K, T_I, and T_D of a PID-controller, that are chosen similarly as the ITAE-optimization.

Σ

Problem 2 (30 Points)

2a) (3 × 2 Points, 6 Points)
Which of the following statements are true and which are false?

No.	Task/Question/Judgment	True	False
1)	From the description of the state behavior given by $$x(t) = \phi(t)x_0(t=0) + \int_{t=0}^{t} \phi(t-\tau)bu(\tau)d\tau,$$ the time response of the output $y(t)$ can be calculated by $y(t) = Cx(t)$. For an asymptotically stable and proportional system behavior $\phi(t)$, the free motion $y_{\text{frei}}(t \to \infty)$ shows a stationary behavior with $y_{\text{frei}}(t \to \infty) = 0$.	○	○
2)	The system described by $$A = \begin{bmatrix} 0 & 1 \\ k & -d \end{bmatrix}, \quad B = \begin{bmatrix} 0 \\ 1 \end{bmatrix}, \quad C = \begin{bmatrix} -1 & 0 \end{bmatrix}, \quad \text{and} \quad D = 0$$ is identical to the I/O-description $$\ddot{y} - d\dot{y} + ky = u,$$ where y is measured.	○	○
3)	The system with  can be classified as $\text{PIDT}_1\text{T}_\text{t}$-behavior.	○	○

2b) (10 Points)
The block diagram of a system consists of three transfer elements with w and z as inputs and y as output (refer to Figure 2.1).

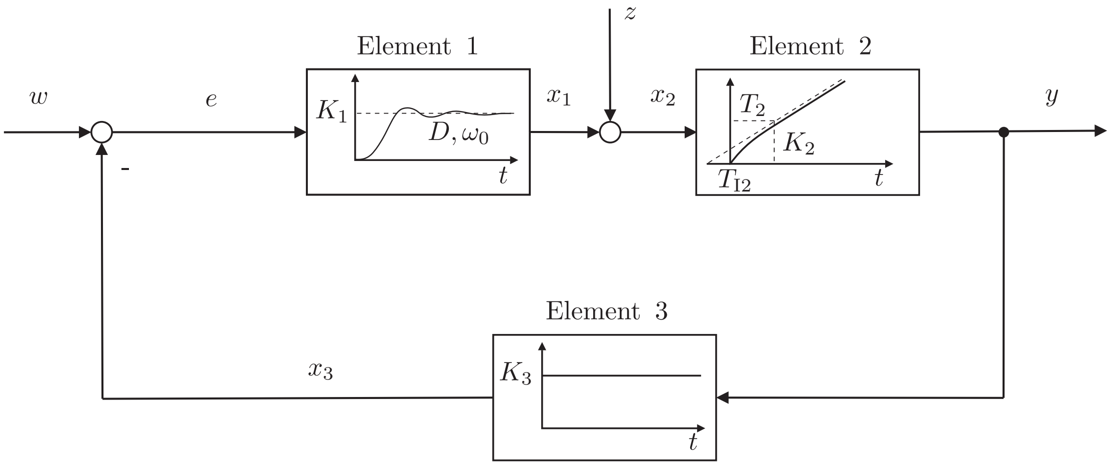


Figure 2.1: Block diagram of a system

i) (3 Points)
Classify the transfer element behavior (type of individual transfer element behavior) of the Elements 1 to 3 and give the corresponding differential equations in standard form, which is suitable for classification, using the given notations from Figure 2.1.

For further considerations, assume the following differential equations for the Elements 1 to 3:

Element 1: $\frac{1}{2}\ddot{x}_1 + \dot{x}_1 + \frac{1}{2}x_1 = e$,

Element 2: $\dot{y} + y = \int x_2 \, dt$, and

Element 3: $\frac{1}{5}x_3 = y$.

ii) (3 Points)
Determine the differential equation of the transfer behavior with respect to the desired value ($w \to y$) in standard form.

iii) (3 Points)
Determine the differential equation of the transfer behavior with respect to the disturbance ($z \to y$) in standard form.

iv) (1 Point)
Determine the static gain K_{S} of the transfer behavior in stationary behavior with respect to the desired value.

2c) (4 Points)
The experimentally determined characteristic curve $f(u)$ is given in Figure 2.2.

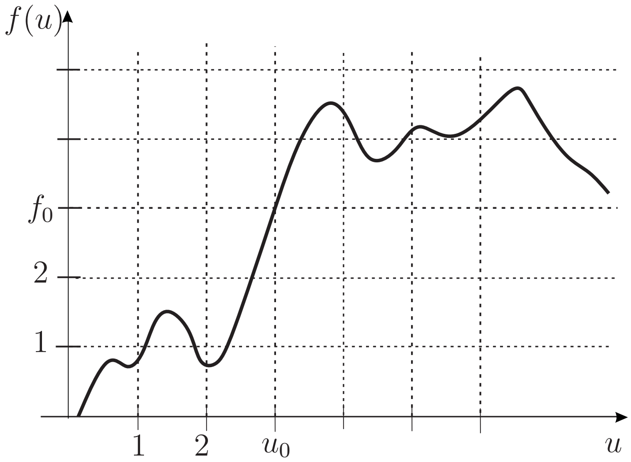


Figure 2.2: Characteristic curve

The dynamic of the system is described by $\dot{y} = f(u) - 2y$.

i) (2 Points)
Determine the linearized behavior between $f(u)$ and u around the working point (u_0, f_0) with $f(u) = Ku$ in linearized coordinates of the working point. Please pay attention to the scaling of the axes.

ii) (2 Points)
Give the linearized behavior of the system as differential equation in standard form with suitable coefficients and classify the system behavior.

2d) (2 × 5 × 1 Point, 10 Points)
The block diagram of a transfer system is given (see Figure 2.3).
Answer the following questions related to the mentioned system.

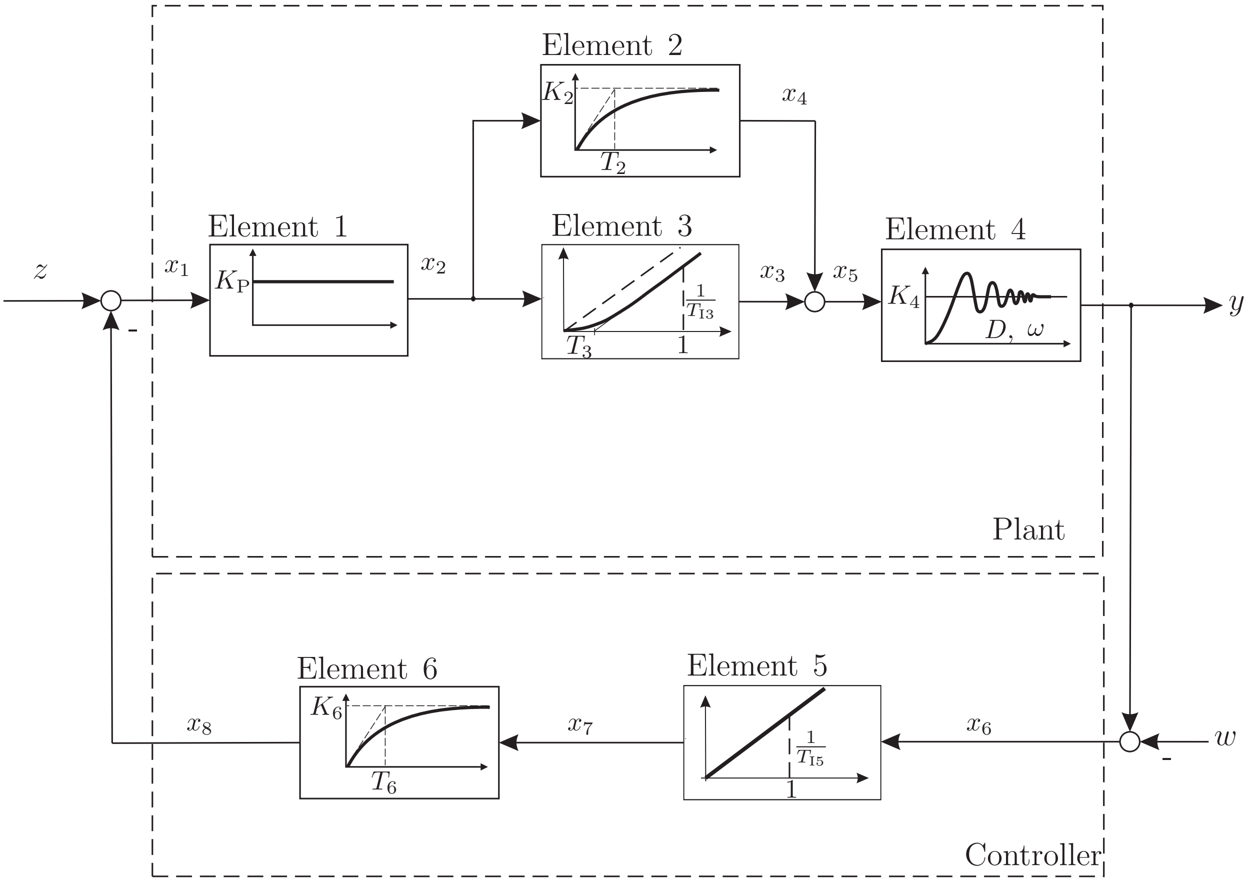


Figure 2.3: Block diagram

No.	Task/Question/Judgment	True	False
A.1)	Element 6 is a system with proportional behavior.	○	○
A.2)	Element 3 is an IT_3-system.	○	○
A.3)	The system behavior from x_2 to x_5 does not contain time delay.	○	○
A.4)	The system behavior from x_6 to x_8 can be described by $$T_6\dot{x}_8 + x_8 = K_6(x_6 + \frac{1}{T_{I5}}\int x_6 dt).$$	○	○
A.5)	Element 3 is boundary stable.	○	○

No.	Task/Question/Judgment	True	False
B.1)	Depending on the parameter T_{I5}, Element 5 is able to oscillate.	◯	◯
B.2)	Assume that the system behavior from $x_1 \rightarrow y$ can be described by a proportional behavior. The given choice of the Elements 5 and 6 is suitable for stationary accurate control of the system.	◯	◯
B.3)	Element 4 shows a behavior that is not corresponding to the linear theory due to the variable frequency in the instationary behavior.	◯	◯
B.4)	The Ziegler-Nichols approach can be applied for a setting of the controller (Element 5 and Element 6).	◯	◯
B.5)	Assuming the plant is a PT_1-system which is described by $T_1\dot{y} + y = K_{\mathrm{P}}x_8$. In combination with the shown controller (Element 5 and Element 6) the open loop ($x_6 \rightarrow y$) can be classified as a PIT_2-system behavior.	◯	◯

☐

$\sum$ ☐