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. Mohieddine Jelali, Priv.-Doz.)

____

(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:	**55**
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:

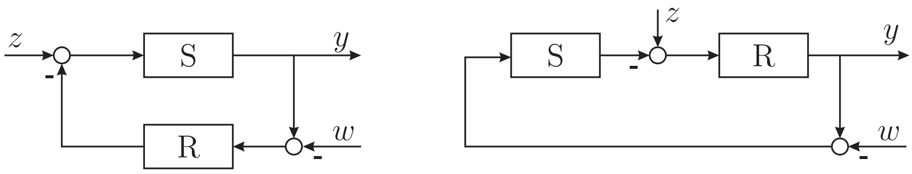
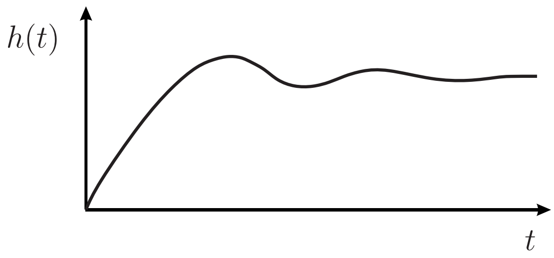
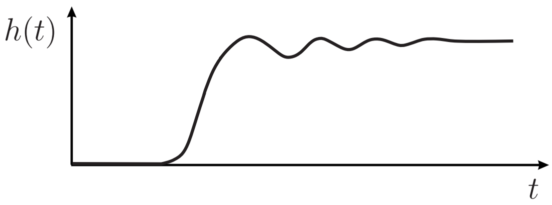
   i) For correct answers of exam task parts the desired number of points will be given.
   ii) For noncorrect answers of exam task parts the desired number of points will be counted negative.
   iii) No answering will neither lead to positive nor to negative points.
   iv) The points of the task will be summarized. The whole number can not be smaller than zero.

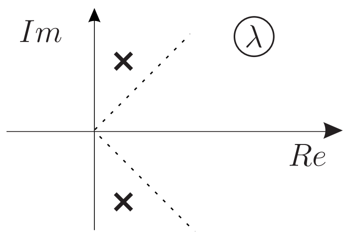
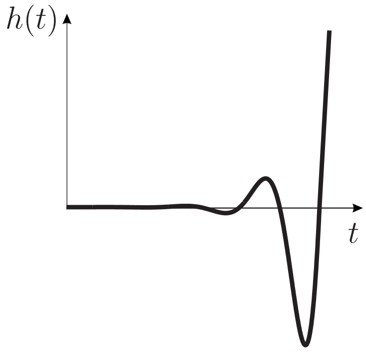
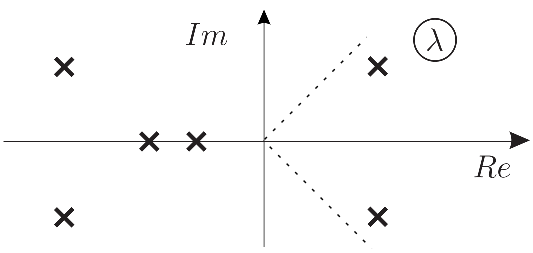
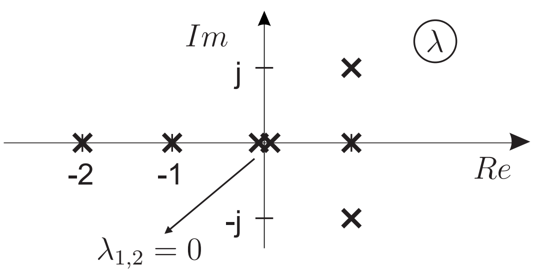
2) If in the exam tasks no information is given for the valid range of numbers for time constants or masses etc.: take for time constants (in sec.), for masses (in kg) positive numbers.

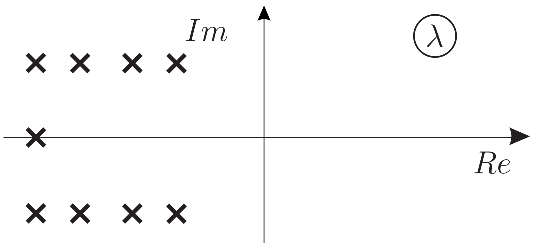
3) If in the exam tasks no information is given for applying negative or positive feedback: use the usual negative feedback.

Problem 1 (30 Points)

1a) (2 × 5 × 1 Point, 10 Points)
Which of the following statements are true and which are false?

No.	Task/Question/Judgment	True	False
A.1)	The systems A and B are identical with respect to their I/O-behavior.  A B	○	○
A.2)	At a transfer system with the input signal $u(t) = a\sin(3\omega t)$ the output $y(t) = a\sin(3\omega t - \varphi_0)$ is measured. The system has nonlinear transfer behavior.	○	○
A.3)	The amplitude of the input of a transfer system is tripled. The output of this system changes also, in detail the frequency of the output is tripled. The observed frequency is identical to the frequency of the input signal. The observed output time response is certainly delayed with respect to time. Such behavior can only occur in nonlinear systems.	○	○
A.4)	A linear system of second order with damping $D > 1$ can show the following step response behavior. 	○	○
A.5)	A system of second order with damping $D < 1$ and time delay connected after the system can show the following step response behavior. 	○	○

No.	Task/Question/Judgment	True	False
B.1)	A system with the eigenvalue distribution  can show the following behavior.  	○	○
B.2)	The SISO system with the eigenvalue distribution  has 2 stable eigenvalues with the damping $D = 1$.	○	○
B.3)	A system of two interconnected systems in series is considered. The eigenvalues of the system 1 are: $\lambda_1 = 0$; $\lambda_2 = -1$; $\lambda_3 = 1$. The eigenvalues of the system 2 are: $\lambda_1 = 0$; $\lambda_2 = -1 \pm j$; $\lambda_3 = -2$. The interconnected systems show the following eigenvalue distribution:  	○	○

No.	Task/Question/Judgment	True	False
B.4)	A system with the eigenvalue distribution  is asymptotically stable.	○	○
B.5)	The weighting function $g(t)$ of linear systems can be determined from a measured step response $h(t)$ in practice.	○	○

1b) (2 × 5 × 1 Point, 10 Points)

The following differential equations of two systems are given.

System I) $\frac{1}{\omega_0^2}\ddot{u} + \frac{2D}{\omega_0}\dot{u} + u = K[\frac{1}{T_I}\int(y-w)dt + (y-w)]$

System II) $T_1\dot{u} + u = K[T_D(\dot{y}-\dot{w}) + (y-w)]$

Two measured step response behaviors are illustrated in Figure 1.1. Evaluate the statements in the following tables.

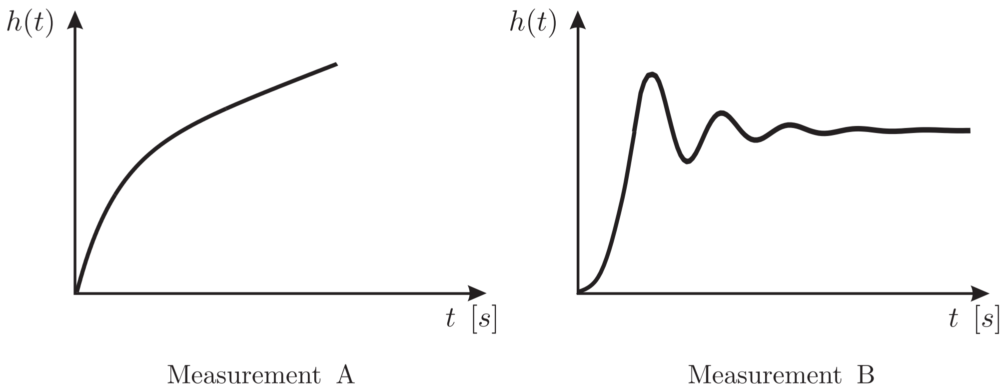


Figure 1.1: Step responses of two different systems

No.	Task/Question/Judgment	True	False
A.1)	System I is a PIT_2-system.	◯	◯
A.2)	System II can not show a oscillatory behavior.	◯	◯
A.3)	The step response of System I with $D > 0$ and $\omega_0 > 0$ is limited.	◯	◯
A.4)	Measurement B shows the step response of a system of 2. or higher order.	◯	◯
A.5)	Measurement A shows the step response of a PIT_1-system with $T_1 > T_I$.	◯	◯

☐

No.	Task/Question/Judgment	True	False
B.1)	Measurement A shows that the underlying system is a system including an integral part.	◯	◯
B.2)	Measurement A corresponds to System II.	◯	◯
B.3)	Measurement B corresponds to System I.	◯	◯
B.4)	In case of applying a controller for P-plant (proportional plant), measurement A shows the behavior of the controller, which is suitable for the complete compensation of the control error.	◯	◯
B.5)	Considering an undamped system, measurement B shows the system behavior that can execute continuous oscillations.	◯	◯

☐

1c) (5 × 1 Point, 5 Points)
The mathematical model of a novel solar-electro-mechanical SILLY-system, which is suggested for a patent by its developer, is described accordingly to the patent application by the equations

$$L\ddot{x}_2 = I_1 - I_2,$$
$$I_1 = Q(x_1 - x_2), \text{ and}$$
$$I_2 = R\dot{x}_2 + Cx_2$$

with the variables

$x_{1,2}$: work,
$\dot{x}_{1,2}$: power,
I_1 : coulomb force,
I_2 : photon flux,
L : electric charge,
Q : volume,
R : light intensity, and
C : degrees of freedom of the radial bearing.

Evaluate the statements in the following tables.

No.	Task/Question/Judgment	True	False
1)	The transfer behavior of the input variable x_1 to the output variable x_2 is described by $$\frac{L}{Q+C}\ddot{x}_2 + \frac{R}{Q+C}\dot{x}_2 + x_2 = Qx_1.$$	○	○
2)	The transfer behavior can be classified as PDT_2-behavior.	○	○
3)	The transfer behavior of the system with the input variable x_1, the output variable x_2, and the state space vector $x = \begin{bmatrix} x_2 \\ \dot{x}_2 \end{bmatrix}$ is described by the state space representation $$\begin{bmatrix} \dot{x}_2 \\ \ddot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -\frac{Q+C}{L} & -\frac{R}{L} \end{bmatrix} \begin{bmatrix} x_2 \\ \dot{x}_2 \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{Q}{L} \end{bmatrix} x_1$$ $$y = \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} x_2 \\ \dot{x}_2 \end{bmatrix}.$$	○	○
4)	For the parameters L, Q, R, and C of the transfer behavior of the system the following values are assumed: $L = 1$, $Q = 2$, $R = 4$, and $C = 2$. The considered system shows undamped behavior ($D = 0$).	○	○
5)	The considered mechanical system with the parameters from 1c)4) has the eigenvalues $\lambda_{1,2} = -3$.	○	○

☐

1d) (2 Points)
Illustrate the function $u(t) = -1(t) + \delta(t-1) + 2 \cdot 1(t-2) - 2 \cdot 1(t-4) - \delta(t-4)$ graphically.

1e) (3 Points)
For a control loop at the stability bound, the following time response is measured as shown in Figure 1.2.

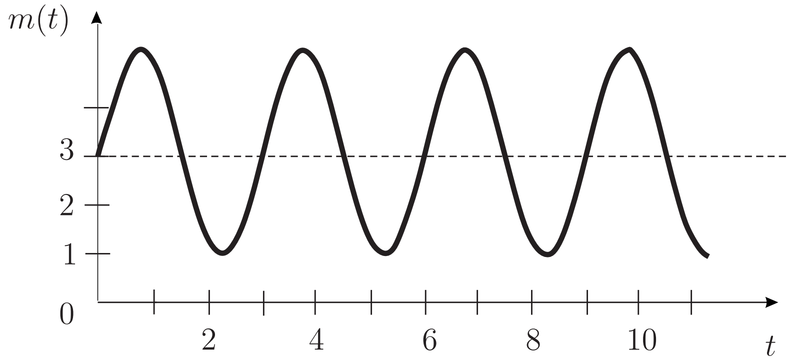


Figure 1.2: Measurement

1e) i) (2 Points)
Approximate the time response with a mathematical description, from which the detailed constant value as well as the detailed frequency of the measured signal can be seen.

1e) ii) (1 Point)

Change the signal $m(t)$ into a signal $y(t)$ with zero-mean behavior using an offset-signal $n(t)$. (A signal with zero-mean behavior has a mean value = 0). State according to the following block diagram, how this can be achieved respectively how the signal $n(t)$ has to be chosen.

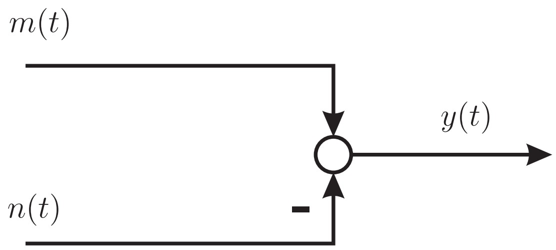


Figure 1.3: Block diagram

∑

Problem 2 (25 Points)

2a) (3 × 1 Point, 3 Points)
Which of the following statements are true and which are false?

No.	Task/Question/Judgment	True	False
1)	The following I/O-description shows a time variant system behavior: $$m\ddot{y} + d(t)\dot{y} + K(y)y = u.$$	○	○
2)	The I/O-description above shows a linear I/O-behavior.	○	○
3)	The system described by $$A = \begin{bmatrix} 0 & 1 \\ k & -d \end{bmatrix}, \quad B = \begin{bmatrix} 0 \\ 0.5 \end{bmatrix}, \quad C = \begin{bmatrix} 0 & 1 \end{bmatrix}, \text{ and } \quad D = 0$$ is identical to the I/O-description $$2\ddot{y} + 2d\dot{y} - 2ky = u,$$ where y is measured.	○	○

☐

2b) (11 Points)

The block diagram of a plant and a controller consisting of three transfer elements with w, z_1, and z_2 as inputs and y as output is given (refer to Figure 2.1).

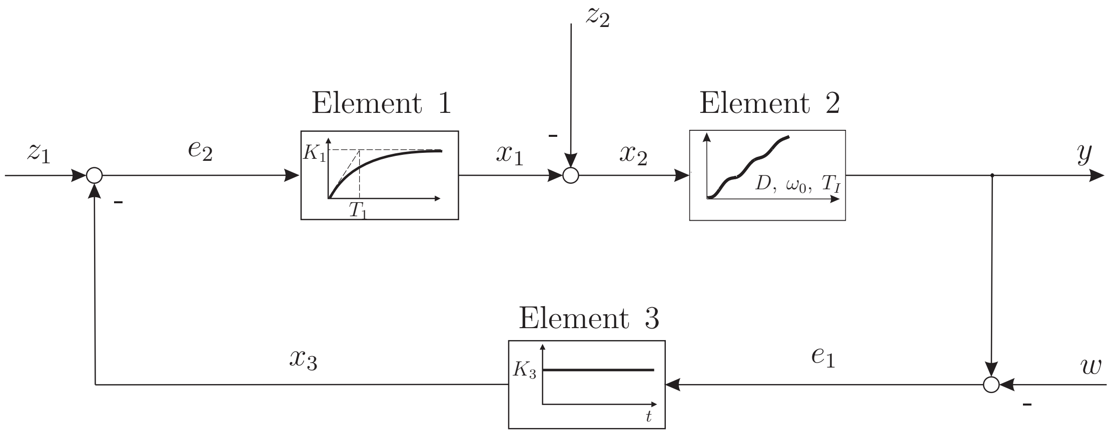


Figure 2.1: Block diagram of a system

2b) i) (1.5 Points)

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

2b) ii) (4.5 Points)

Determine the differential equation of the transfer behavior $z_1 \rightarrow y$ in standard form and classify the resulting transfer behavior.

For further considerations, assume the following differential equations for the elements 1 to 3 as

Element 1: $\dot{x}_1 + \frac{1}{2}x_1 = e_2,$

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

Element 3: $\frac{1}{5}x_3 = e_1.$

2b) iii) (2 Points)
Determine the differential equation of the transfer behavior with respect to the desired value ($w \to y$) in standard form.

2b) iv) (3 Points)

For this task the behavior of $y(t)$ is assumed as

$$\ddot{y}(t) + 0.2\dot{y}(t) + y(t) = z_1(t) + z_2(t) + w(t)$$

for $z_1(t) = w(t) = 0$ and $z_2(t) = 2 \cdot 1(t) + 1(t-1)$.
Sketch the behavior of $y(t)$.
Hint: Draw both components at first separately and than add them together.

2c) (6 Points)
The complex I/O-behavior of a novel actor is shown in Figure 2.2.

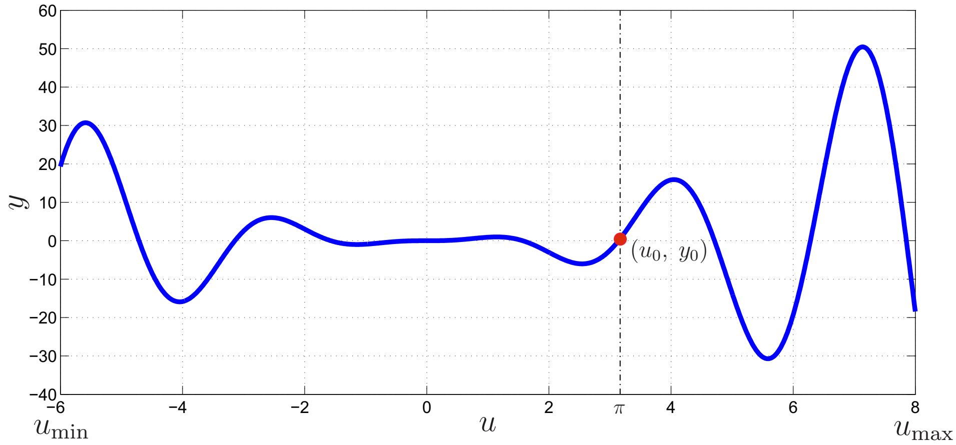


Figure 2.2: I/O-behavior of a novel actor

The mathematical description of the I/O-behavior is

$$y = u^2 \cdot \sin(2u),$$

where $u \in [u_{min},\ u_{max}]$.

2c) i) (2 Points)
Determine graphically the linearized behavior for $y = Ku$ around the working point π. Determine therefore K.

2c) ii) (2 Points)

Is the mentioned nonlinearized I/O-behavior a dynamic I/O-behavior? State reasons.

2c) iii) (2 Points)

For the safety operation of the actor it is necessary to limit the deviation to max. 10% from the linearized characteristic line to the original one.

Show graphically the tolerance range of the output y of the actor beginning with the working point ($u_0 = 6.5$ and $y_0 = 17.75$).

Determine graphically the corresponding tolerance range of the input of the actor $[u_{min},\, u_{max}]$ according to the linearized characteristic line.

It is important that you hereby draw clearly and unequivocally the intersections for the determination of the tolerance limits.

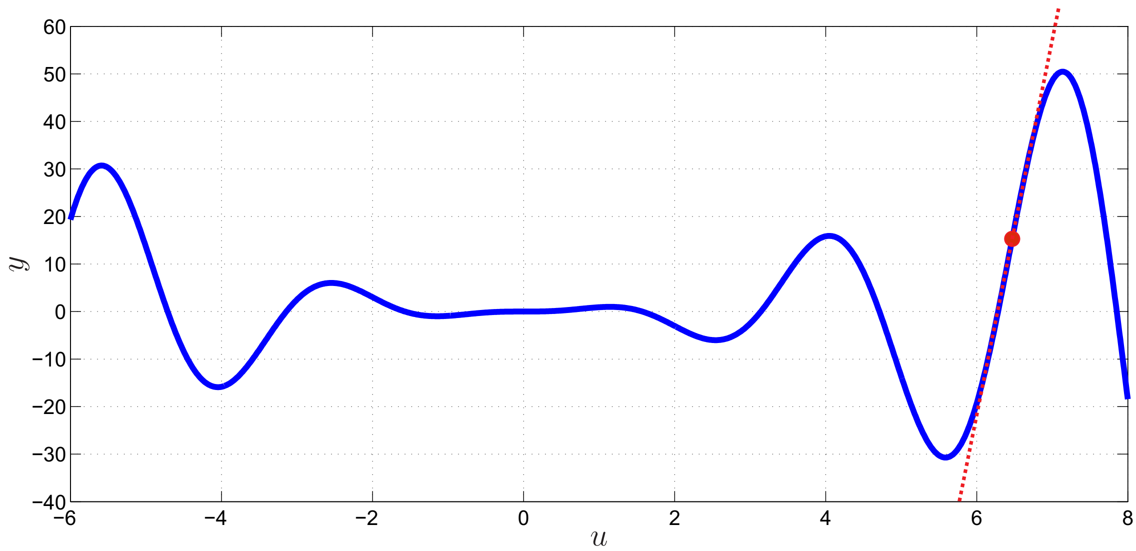


Figure 2.3: I/O-behavior of a novel actor

2d) (5 Points)
The system behavior of a plant should be determined experimentally. The step response of the plant is measured and illustrated in Figure 2.4.

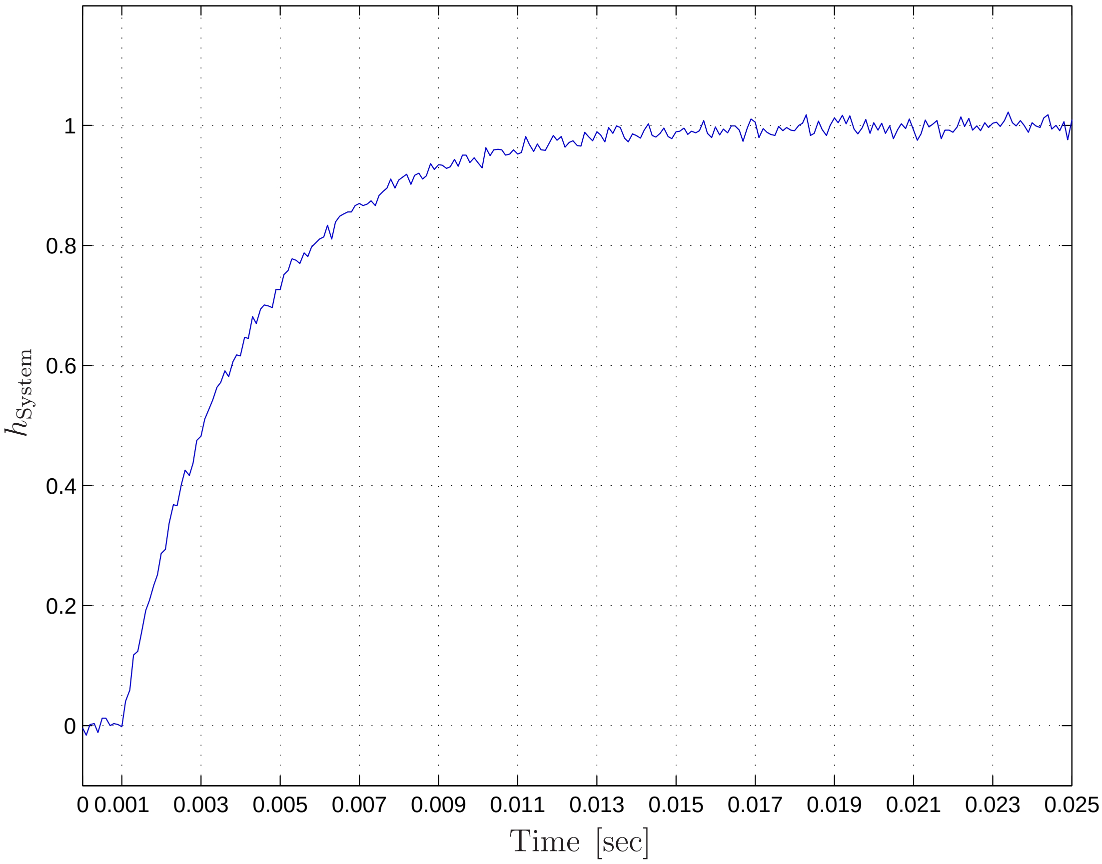


Figure 2.4: Experimentally determined step response of the system

2d) i) (1 Point)
Classify the step response behavior of the system neglecting the measurement noise. Determine the readable parameters of the describing differential equation from the figure.

A PD-controller (K_r, T_d) should be applied to the plant above. The whole system is connected with negative feedback.

2d) ii) (1 Point)
Sketch the corresponding block diagram and denote the characteristic graphical representation as well as all necessary characteristic data into the block diagram.

2d) iii) (3 Points)

The resulting disturbance response is given according to a system change as

$$\tilde{T}_1\dot{y} + y = \tilde{K}_1(u + \tilde{T}_D\dot{u}).$$

Please give qualitatively how to set up the system parameters $\tilde{T}_1$ and $\tilde{K}_1$ for a best possible behavior.

$\sum$