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	
Aufgabe 3	
Gesamtpunktzahl	
Angepasste Punktzahl	
%	
Bewertung gem. PO in Ziffern	

____

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

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

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(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).

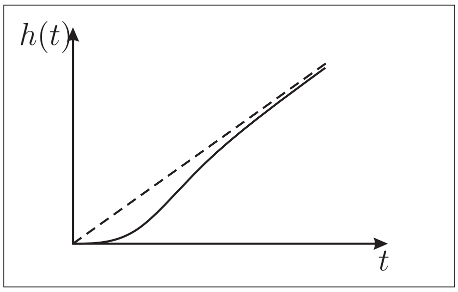
Maximum achievable points:	**80**
Minimum points for the grade 1,0:	**95%**
Minimum points for the grade 4,0:	**50%**

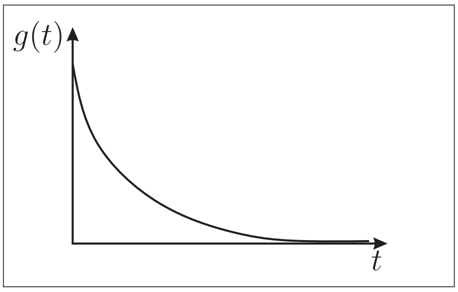
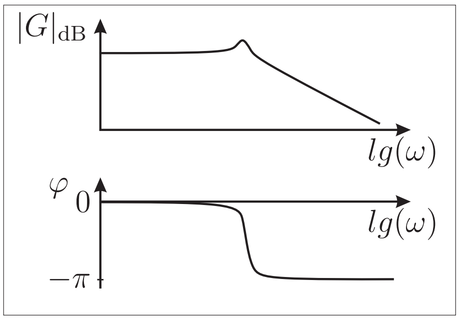
General hints:

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.

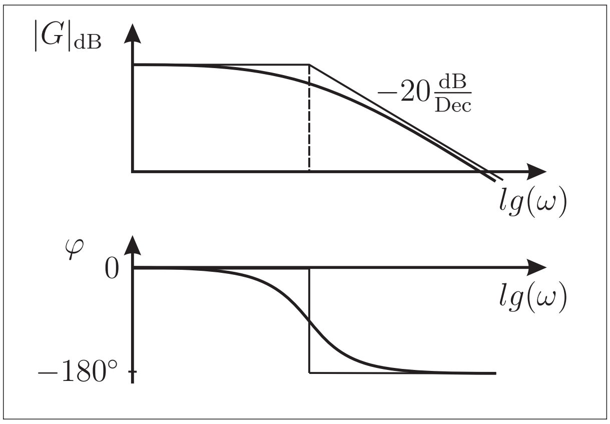
Problem 1 (32 Points)

1a) (3 × 5 × 1 Point, 15 Points)
Which of the following statements are true and which are false? (All underlying relationships have been discussed as part of the lecture control engineering.)

No.	Task/Question/Judgement	True	False
A.1)	The transfer function of a system with IT_2-transfer behavior is $G(s) = \dfrac{1}{s(s+1-j)(s+1+j)}$. The step response of the system corresponds to the following figure: 	○	○
A.2)	A system is not able to oscillate with a negative damping.	○	○
A.3)	The general algorithm of the Laplace transformation for a function $f(t)$ is $\mathcal{L}\{f(t)\} = \int_0^{\omega} f(t)e^{-\omega t}\,d\omega$.	○	○
A.4)	The Bode-diagram contains the information about amplitude behavior and phase shift of the transfer behavior.	○	○
A.5)	A transfer element with PIT_1-behavior has no zeros.	○	○

No.	Task/Question/Judgement	True	False
B.1)	The following figures are describing an identical transfer behavior (Hint: $g(t) = \frac{\mathrm{d}h(t)}{\mathrm{d}t}$):  	○	○
B.2)	State space models are possible descriptions in time domain and frequency domain.	○	○
B.3)	The function $f(t) = \left[\frac{1}{4}t\sin(2t) + \sin(2t) - 2t\cos(2t)\right] \cdot 1(t)$ can be described in frequency domain as $F(\omega) = \frac{\omega + 16}{(\omega^2+4)^2}$.	○	○
B.4)	The I/O-behavior in frequency domain of a PI-transfer element can be described by the equation $y(s) = K(1 + \frac{1}{T_I s})u(s)$.	○	○
B.5)	Due to the different stability analysis, a stable I/O-behavior in time domain can be unstable in frequency domain.	○	○

☐

No.	Task/Question/Judgement	True	False
C.1)	A system with a so-called double pole can show the following frequency behavior: 	○	○
C.2)	The I/O-behavior of a $\mathrm{PDT_1T_t}$-system has the transfer function $G(s) = \frac{(1+3s)\cdot e^{-sT_t}}{T_1 s + 1}$. It is a minimum-phase system.	○	○
C.3)	Neglecting the time delay, the system description of the system in 1a)C.2) leads to a linear system behavior.	○	○
C.4)	The stimulation of a system with certain frequencies and with a damping of $D = 0.5$ can lead to a resonance.	○	○
C.5)	A stable system is also a minimum-phase system.	○	○

1b) (17 Points)
The transfer function of a plant is given by

$$G_{\mathrm{S}}(s) = \frac{12(s+1)}{(2s^2+s+2)(s+2)}.$$

The plant should be controlled with negative feedback. The controller has the transfer function

$$G_{\mathrm{R}}(s) = \frac{1}{s+2}.$$

i) (2 Points)
Determine the transfer function and the static gain K_{S} of the open loop.

ii) (4 Points)
Classify the transfer behavior of the complete system with respect to the desired value ($w \rightarrow y$).

For the following tasks iii) and iv), the transfer function with respect to the desired value is assumed as

$$\tilde{G}_{\mathrm{W}}(s) = \frac{K_{\mathrm{P}}(5+s)}{s^3 + (8+K_{\mathrm{P}})s^2 + 7s + 15K_{\mathrm{P}}} \quad \text{with} \quad K_{\mathrm{P}} > 0.$$

iii) (6 Points)
For which values of $K_{\mathrm{P}} > 0$ is the transfer behavior with respect to the desired value asymptotically stable? State reasons.

iv) (5 Points)
Calculate the stationary final value and the remaining control difference for the desired value $w(t) = a \cdot 1(t)$.

$\sum$

Problem 2 (31 Points)

2a) (1 × 3 × 1 Point, 3 Points)
Evaluate the statements in the table below.

No.	Task/Question/Judgement	True	False
1)	Time delay elements affect the amplitude behavior by an additional amplitude increase of T_t, with T_t as time delay.	○	○
2)	A system is described by $$G(s) = \frac{1+\frac{2}{s}}{(s+3)(s+4)(s+5)s}.$$ The I/O-behavior of the system is asymptotically stable.	○	○
3)	A system with proportional behavior should be controlled stationary accurate. This goal can be achieved easily by integrating an integral part in the feedback.	○	○

□

2b) (23 Points)
The transfer behavior of a human-machine-system should be determined experimantally. The frequency behavior of the human-machine-system (plant) is measured and shown in Figure 2.1.

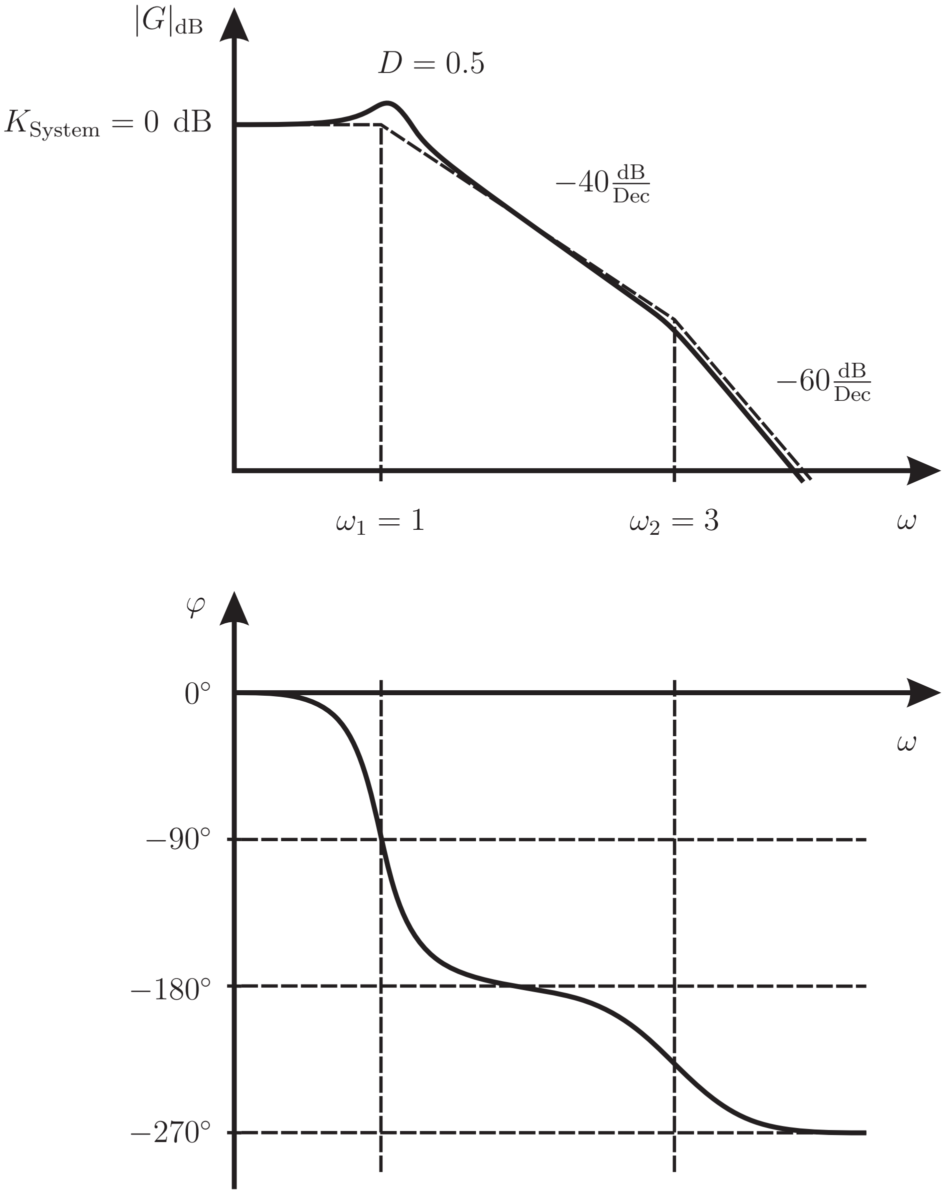


Figure 2.1: Frequency behavior of the plant

The behavior of the human is described by

$$G_{\mathrm{Mensch}}(s) = \frac{K_{\mathrm{M}}}{1 + T_1 s} \cdot e^{-T_{\mathrm{t}} s}$$

with $T_1 = 0.4$ sec and $T_{\mathrm{t}} = 0.1$ sec and is used as controller.

i) (3 Points)
Determine the transfer function of the open loop. Is the open loop stable? State reasons.

For the following tasks ii)-v), the transfer function of the plant is assumed as

$$G_{\mathrm{S}}(s) = \frac{1}{(\frac{1}{4}s^2 + \frac{1}{2}s + 1)(\frac{1}{5}s + 1)}.$$

The controller is still the human with $G_{\mathrm{Mensch}}(s)$.

ii) (8 Points)
Draw the Bode-diagram qualitatively (real and approximated behavior) of the open loop for $K_{\mathrm{M}} = 1$ and plot the amplitude margin and the phase margin into the Bode-diagram.

iii) (4 Points)
Discuss the stability of the closed loop according to K using the root locus method.

iv) (4 Points)
Calculate the remaining control difference for the desired value $w(t) = 1(t)$.

v) (4 Points)
The human is replaced by a new controller with D-behavior. Discuss the stability of the closed loop with the new controller according to K.

2c) (1 × 5 × 1 Point, 5 Points)
A system with the transfer function

$$G(s) = \frac{K}{s(s^2 + \tilde{D}s + 1)}$$

should be controlled with negative feedback by a D-controller with the time constant T_D. Evaluate the statements in the table below.

No.	Task/Question/Judgement	True	False
1)	The controlled system shows a stationary accurate difference for the transfer behavior with respect to the desired value of $e(t \to \infty) = \dfrac{1}{1 + KT_\text{D}}$ with the input signal $w(t) = 1(t)$.	○	○
2)	The transfer behavior with respect to the desired value is stationary accurate for small $\tilde{K} = KT_\text{D}$.	○	○
3)	The parameter $\tilde{D}$ of the plant affects the oscillating behavior of the closed loop.	○	○
4)	The parameter T_D of the plant affects the oscillating behavior of the closed loop.	○	○
5)	For large values of $\tilde{K} = KT_\text{D}$, the distance between the poles and the imaginary axis ($\lvert Re\left\{s_i\right\}\rvert$) decreases for all s_i of the system.	○	○

$\sum$

Problem 3 (17 Points)

3a) (2 × 5 × 1 Point, 10 Points)
A system with PIT_3-behavior is controlled by a controller with PT_1-behavior (negative feedback). The pole/zero-plot of the open loop is given in Figure 3.1.

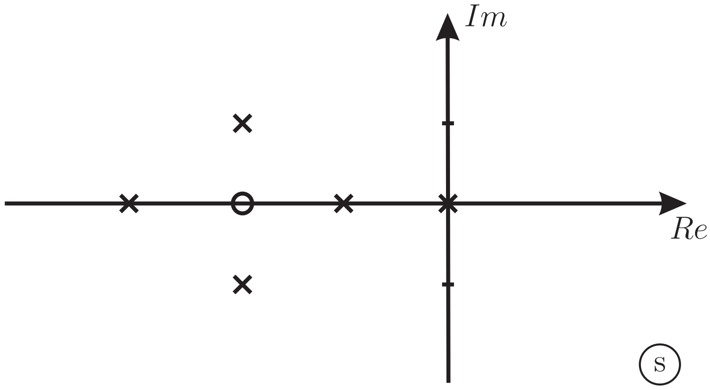


Figure 3.1: Pole/zero-plot

Evaluate the statements in the tables below.

No.	Task/Question/Judgement	True	False
A.1)	The uncontrolled system is not asymptotically stable.	○	○
A.2)	The open loop is unstable.	○	○
A.3)	The closed loop is unstable for large values of the control gain.	○	○
A.4)	An asymptotically stable behavior can be obtained by a suitable control parameter tuning.	○	○
A.5)	According to the gain K, the closed loop does not have any conjugate complex poles.	○	○

For each statement in the following table take the given PIT_3-plant and the PT_1-controller as background for your considerations.

No.	Task/Question/Judgement	True	False
B.1)	By adding a negative zero, the system can be stabilized for arbitrary gains.	○	○
B.2)	Instead of the zero in 3a)B.1), a zero at $s_n = 4$ is added. This changes fundamentally the overall system behavior of the closed loop.	○	○
B.3)	The PT_1-controller is replaced by a minimal-phase PDT_2-controller. This changes fundamentally the overall system behavior of the closed loop compared to the PIT_3-plant controlled by PT_1-controller.	○	○
B.4)	The closed loop with the controller in 3a)B.3) is not able to oscillate for all control gains.	○	○
B.5)	In principle, a controller of the type $G_R = (s + T)$ with $T > 0$ could stabilize the PIT_3-system.	○	○

□

3b) (7 Points)
A minimal-phase system is given with the amplitude behavior shown in Figure 3.2. The system is controlled by a P-controller with $K_\mathrm{P} = 1$.

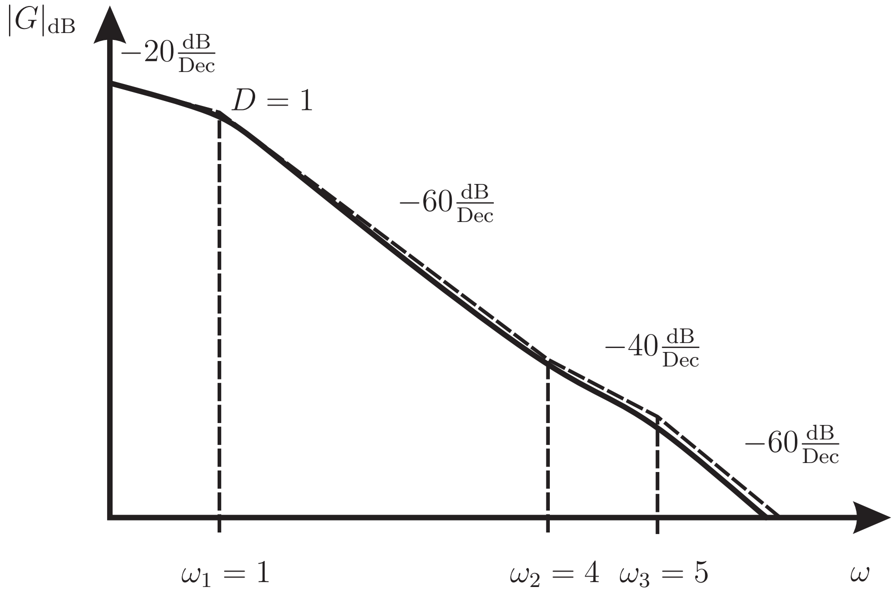


Figure 3.2: Amplitude behavior

i) (2 Points)
Determine the poles and zeros of the open loop.

ii) (5 Points)
Draw the phase shift behavior qualitatively (real and approximated behavior) and draw the polar plot of the open loop.

$\sum$