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)

____

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

General hints:

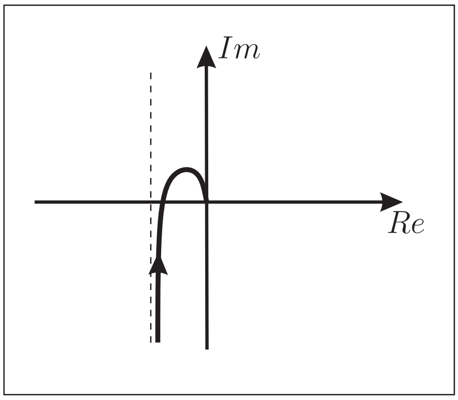
1) For the multiple-choice and multiple-choice-similar tasks the following rules are effective:
   i) For correct answers of exam task parts the desired number of points will be given.
   ii) For noncorrect answers of exam task parts the desired number of points will be counted negative.
   iii) No answering 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.

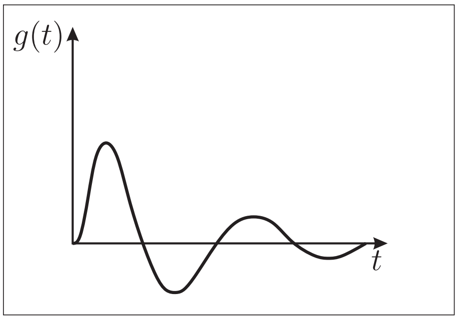
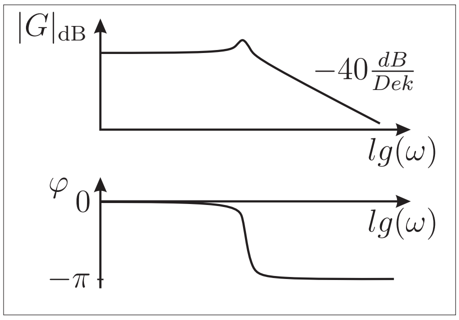
2) If in the exam tasks no information is given for the valid range of numbers for time constants or masses etc. : take for time constants (in sec.), for masses (in kg) positive numbers.

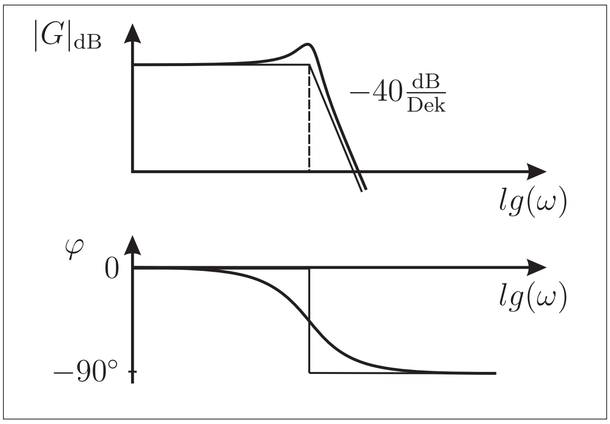
3) If in the exam tasks no information is given for applying negative or positive feedback: use the usual negative feedback.

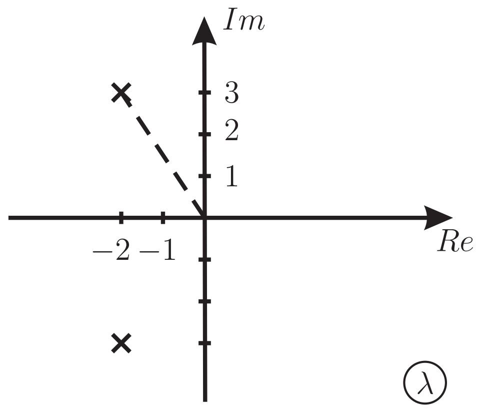
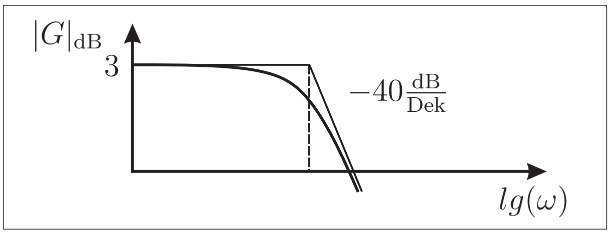
Problem 1 (35 Points)

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

No.	Task/Question/Judgement	True	False
A.1)	The polar plot of a system with IT_1-transfer behavior corresponds to the following figure. 	○	○
A.2)	The functions step function, impulse function, and ramp function are typical output behaviors in control engineering.	○	○
A.3)	The general algorithm of the Fourier transformation for a function $f(t)$ is $\mathcal{F}\{f(t)\} = \int_0^t f(t)e^{-\omega t}\,dt$.	○	○
A.4)	The polar plot contains the information about amplitude and phase behavior of the bode diagram, at least qualitative.	○	○
A.5)	The zeros of a $PIDT_1$-transfer behavior $G(s) = \frac{10[1+\frac{1}{3}s+\frac{2}{3s}]}{2s+1}$ are $s_{n1} = -1$ and $s_{n2} = -\frac{1}{2}$.	○	○

No.	Task/Question/Judgement	True	False
B.1)	The following figures are describing a structurally equivalent transfer behavior (Hint: $g(t) = \frac{\mathrm{d}h(t)}{\mathrm{d}t}$):   	○	○
B.2)	The system $A = \begin{bmatrix} 0 & 1 \\ -1 & -1 \end{bmatrix}$, $B = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$, $C = \begin{bmatrix} 0 & 1 \end{bmatrix}$ is described by $G(s) = \frac{s}{s^2+s+1}$ in frequency domain.	○	○
B.3)	The Laplace transformed $U(s)$ of $u(t) = 3 \cdot 1(t-1) + 2 \cdot 1(t-2) - 1(t-3)$ is $U(s) = \frac{3}{s}e^{-s} + \frac{2}{s}e^{-2s} - \frac{1}{s}e^{-3s}$.	○	○
B.4)	The I/O-behavior in frequency domain of a PI-transfer element is described by the equation $y(s) = K(1 + \frac{1}{T_I s})u(s)$.	○	○
B.5)	Due to the different stability analysis, an I/O-behavior can be unstable in time domain and stable 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 PIT_1-system has the transfer function $G(s) = \frac{5(1+2s)}{8s+1}$.	○	○
C.3)	Considering a time delay, the system description of the system in 1a)C.2) leads to a nonlinear system behavior.	○	○
C.4)	Assume a transfer system with PDT_1-transfer behavior with the coefficients $K = 2$, $T_1 = 3$, and $T_D = 4$. The static final value is $y(t \to \infty) = 6$ for step excitation with $u(t) = 3 \cdot 1(t)$.	○	○

No.	Task/Question/Judgement	True	False
C.5)	Following, the eigenvalue distribution of a system is given.  The corresponding behavior in the Bode-diagram is shown in the following. 	○	○

1b) (12 Points)
The following approximated behavior of a Bode-diagram has to be analyzed.

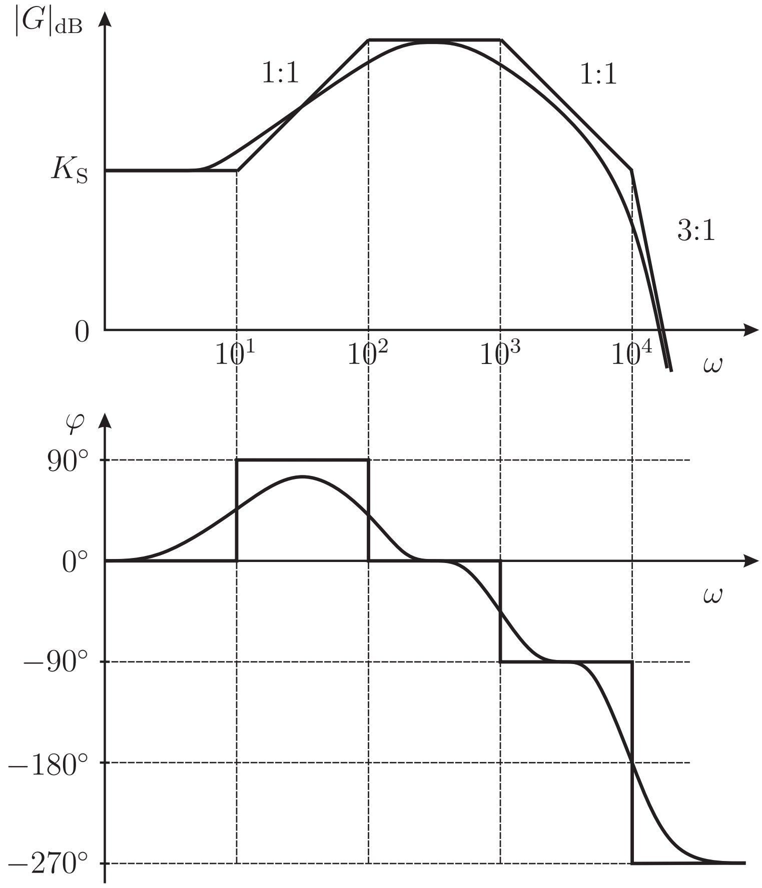


Figure 1.1: Bode-diagram

1b) i) (3 Points)
Classify the system behavior as proportional, differential, or integral. State reasons for your decision using the amplitude and/or the phase behavior.

1b) ii) (4 Points)
Draw the qualitative polar plot in the range from $\omega = 0$ to $\omega = \infty$.

1b) iii) (1 Point)
Is the shown system a minimum-phase system (Yes/No and why)?

1b) iv) (1 Point)
Is the shown system a stable system (Yes/No and why)?

1b) v) (3 Points)
Calculate the transfer function $G(s)$ of the given system in standard form.

1c) (8 Points)

The transfer function of a plant is given by

$$G_{\mathrm{S}}(s) = \frac{K}{\frac{1}{\omega_0^2}s^2 + \frac{2D}{\omega_0}s + 1}.$$

In order to improve the dynamic behavior, a PI-controller with

$$G_{\mathrm{R}}(s) = K(1 + \frac{1}{T_{\mathrm{I}}s}).$$

should be used with negative feedback.

Assume $\frac{1}{T_{\mathrm{I}}} < \omega_0$ and $D < \frac{\sqrt{2}}{2}$.

1c) i) (6 Points)

Draw the Bode-diagram (real and approximate behavior) of the open loop qualitatively and give all qualitatively determinable parameters (pole/zero position, phase values, ...).

1c) ii) (1 Point)
Draw the amplitude and phase margin for the given open loop in case of closed loop graphically in the given polar plot.

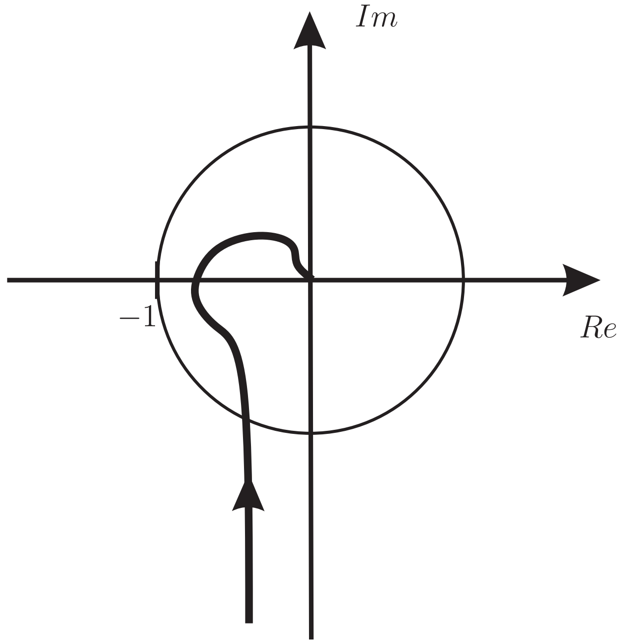


Figure 1.2: Polar plot

1c) iii) (1 Point)
Is the controlled system a system with good and stable control behavior?
Why/why not?

$\sum$

Problem 2 (30 Points)

2a) (1 × 5 × 1 Point, 5 Points)
Evaluate the statements in the table below.

No.	Task/Question/Judgement	True	False
1)	The consideration of time delay for the mathematical description of transfer functions is done by multiplication of the transfer function without time delay with $e^{-T_\mathrm{t}s}$, where T_t denotes the additional time delay, e.g. in seconds.	○	○
2)	A system is described by $$G(s) = \frac{1+\frac{2}{s}}{(s+5)(s+4)(s+3)}.$$ The I/O-behavior of the system is asymptotically stable.	○	○
3)	A system with integral behavior can be controlled without any problems using a controller with integral behavior.	○	○
4)	It is $$g(t) = ag_1(t) + bg_2(t),$$ $$\mathcal{L}\{g(t)\} = a\mathcal{L}\{g_1(t)\} + b\mathcal{L}\{g_2(t)\}.$$	○	○
5)	It is $$\mathcal{L}^{-1}\{G(s)\} = \int h(t)\mathrm{d}t.$$	○	○

□

2b) (17 Points)
The transfer behavior of a human-machine-system should be determined experimentally. The dynamic of the machine (plant) is measured and shown as Bode-diagram in Figure 2.1.

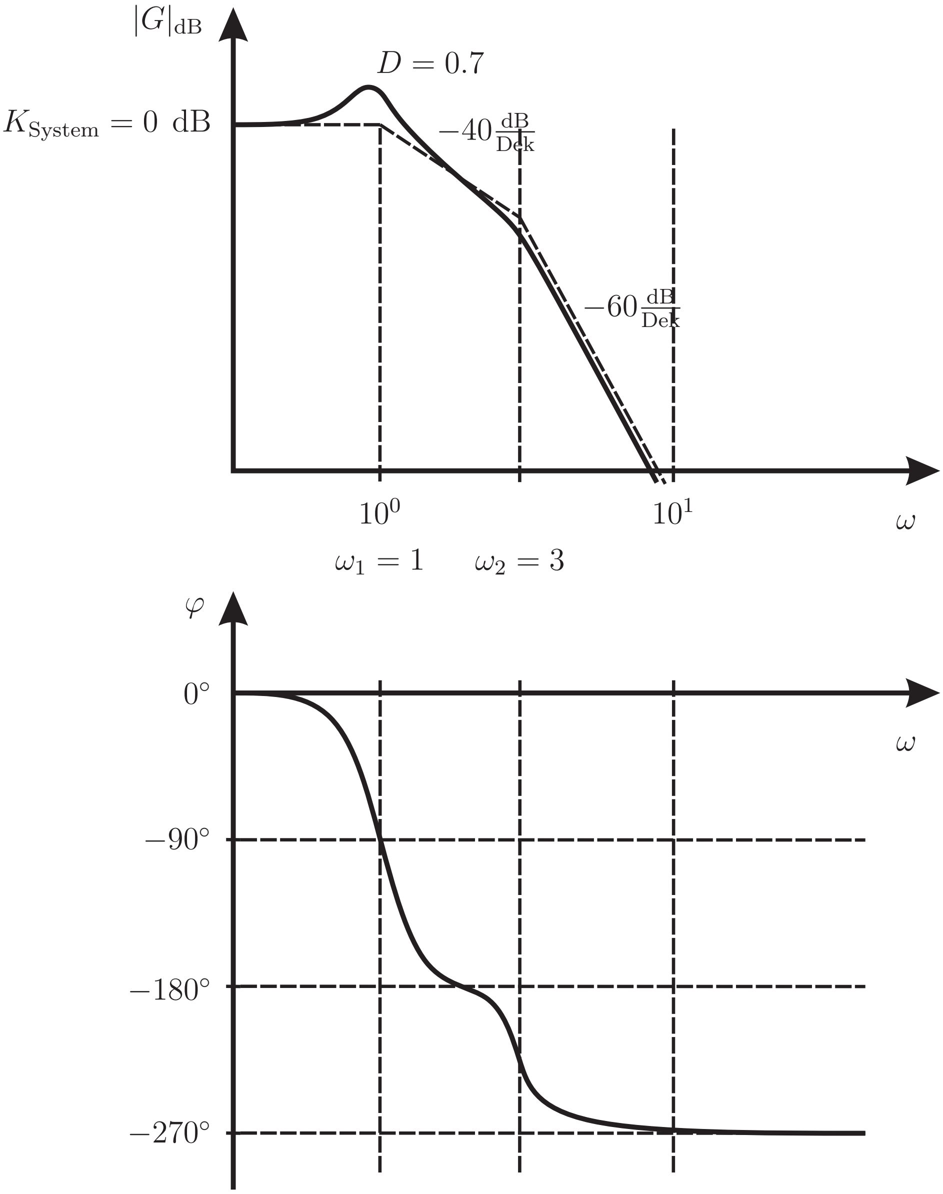


Figure 2.1: Frequency response of the plant

The behavior of the human is described by

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

with $T_{\text{D}} = 0.2$ sec, $T_1 = 0.7$ sec, and $T_{\text{t}} = 0.7$ sec and is used as controller.

2b) i) (4 Points)
Determine the transfer function of the open loop. Is the open loop stable? Is the open loop a minimum-phase system? State reasons.

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

$$G_{\mathrm{S}}(s) = \frac{1}{(s^2 + 8s + 52)(s + 7)}$$

and the controller is assumed as

$$G_{\mathrm{human}}(s) = K_{\mathrm{M}} \cdot e^{-T_{\mathrm{t}} s}.$$

2b) ii) (7 Points)
Determine the root locus of the system. Therefore draw the complete root loci for $T_t = 0$ sec. Determine the exact root loci centre and bifurcation points.

2b) iii) (1 Point)
How many instable eigenvalues/poles does the closed loop have for very large gains?

2b) iv) (1 Point)

The human is replaced by a controller only showing anticipative behavior. This controller is described by

$$\tilde{G}_{\text{human}}(s) = (1 + T_{\text{D}} s).$$

At the same time, it is assumed that the real pole of the plant becomes unstable. Could the anticipative acting human stabilize the system behavior? State reasons.

2b) v) (1 Point)
How does the system behave for large K concerning stability and vibration capability?

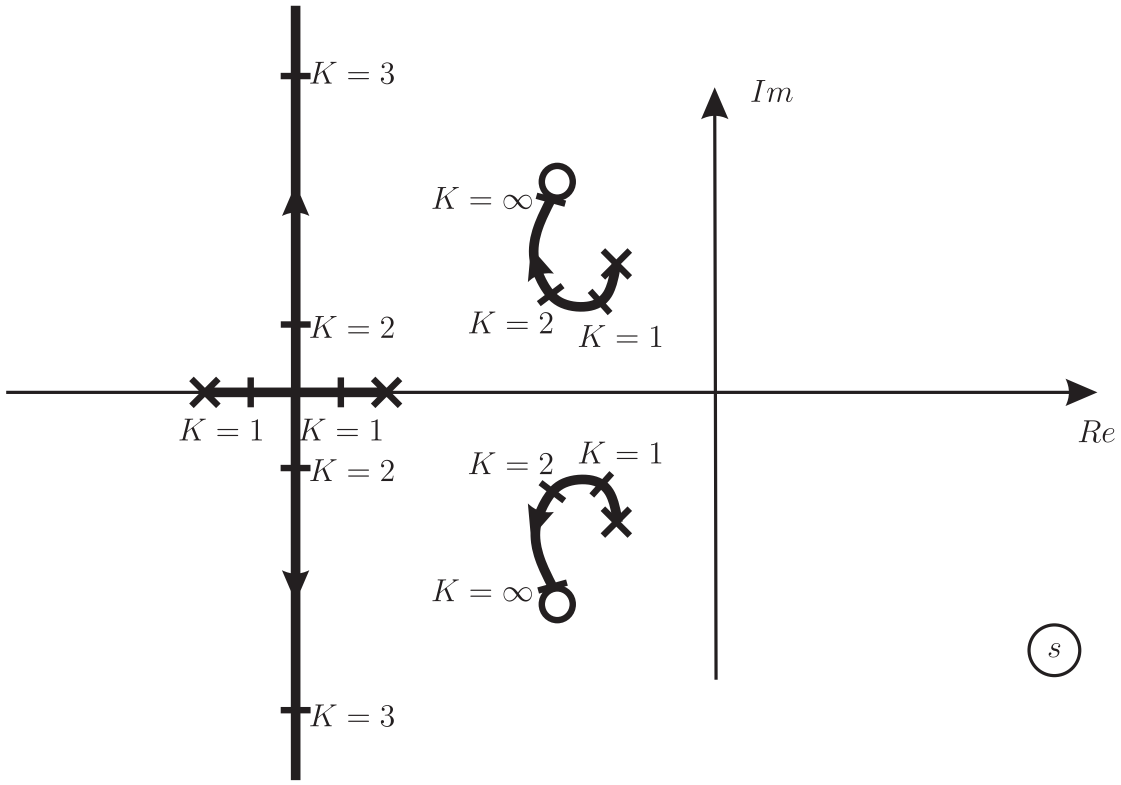
2b) vi) (1 Point)
How would, regarding the mathematical properties of the transmission behavior in the frequency range, the human behavior be designed, so that for large K no oscillations occur?

2b) vii) (1 Point)

Is the assumed or as necessary extended behavior causal? State reasons.

2c) (8 Points)

2c) i) (1 Point)
Judge the dynamic behavior of the closed loop with regard to K using the given root locus. Could the system show unstable behavior? State reasons.

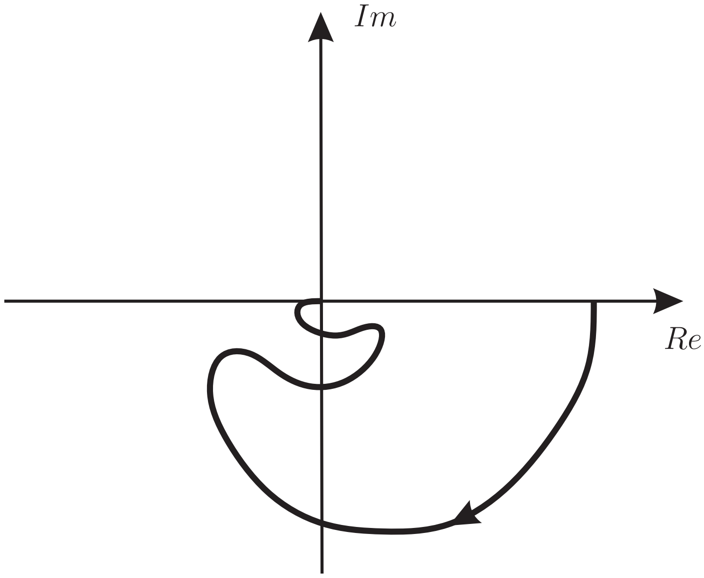


2c) ii) (2 Points)
For which K does the system have the highest damping? State reasons.

2c) iii) (1 Point)
Are there more poles than zeros? If so, how many?

2c) iv) (4 Points)

The system shown in 2c)i) has the following polar plot.



Draw the complete nyquist plot for the given system. Mark the principle area boundaries for different ranges of the gain $K \in [-\infty, +\infty]$.

$\sum$

Problem 3 (15 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.

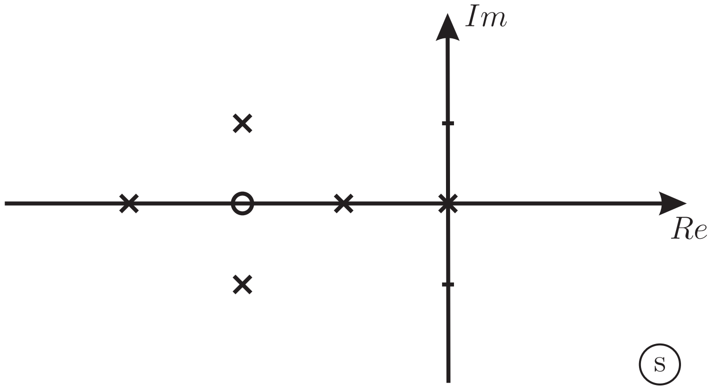


Figure 3.1: Pole/zero-plot

Evaluate the statements in the tables below.

No.	Task/Question/Judgement	True	False
A.1)	The uncontrolled system is boundary stable.	○	○
A.2)	The open loop is asymptotically stable.	○	○
A.3)	The closed loop has no poles in the origin for small control gains.	○	○
A.4)	A behavior with $D < \frac{\sqrt{2}}{2}$ could 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)	The phase shift of the open loop is $-90°$ for $\omega = 0$.	○	○
B.2)	By adding a simple positive zero, the system can be stabilized for arbitrary gains.	○	○
B.3)	Instead of the zero in 3a)B.2), a zero placed very far to the left is added. This changes fundamentally the overall system behavior of the closed loop regarding to the stability behavior.	○	○
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 $G_R = (s+1)(s+2)$ could stabilize the PIT_3-system.	○	○

☐

3b) (5 Points)

A minimal-phase system is given with the amplitude behavior as shown in Figure 3.2.

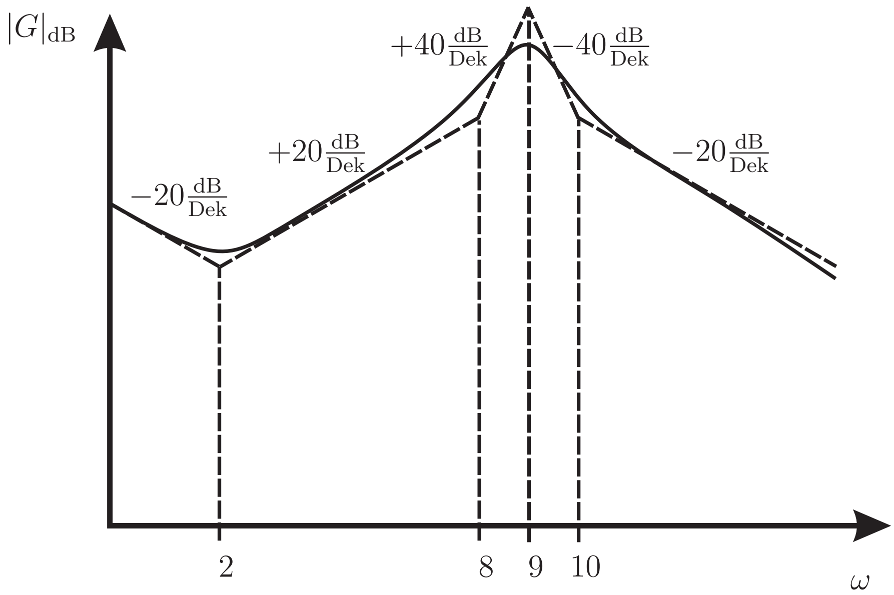


Figure 3.2: Amplitude behavior

3b) i) (2 Points)

Is the system a system with time delay? How can this behavior be recognized respectively why is it a system with/without time delay?

3b) ii) (3 Points)

Draw the phase shift behavior (real and approximate behavior) qualitatively using numerical values for frequency and phase corresponding to the amplitude behavior in Figure 3.2.

$\sum$