UNIVERSITÄT DUISBURG-ESSEN
Fakultät für Ingenieurwissenschaften, Abt. Maschinenbau und Verfahrenstechnik
Lehrstuhl Steuerung, Regelung und Systemdynamik
Control Engineering February 13th, 2018

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 writing utensils. 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 zurückgegeben habe. Die Abgabe meiner Arbeit wurde in der Teilnehmerliste von Aufsichtsführenden schriftlich vermerkt.
Durch die Teilnahme versichere ich, dass ich prüfungsfähig bin. Bei Krankheit werde ich die Klausur vorzeitig beenden und unmittelbar eine Ärztin/einen Arzt aufsuchen.

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	
Die Bewertung gem. PO in Ziffern ist der xls-Tabelle bzw. dem Papierausdruck zu entnehmen.	

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

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(Datum und Unterschrift 2. Prüfer, Prof. Dr.-Ing. Mohieddine Jelali, Priv.-Doz.)

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

Fachnote gemäß Prüfungsordnung: (alternativ: siehe xls-Tabelle bzw. beigefügter Papierausdruck)

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
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:	**60**
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 tasks with individual evaluation of subtasks, the following applies: Only correct answers are evaluated with the intended number of points.
   ii) The points achieved in a subtask are summed up.
   iii) Unless explicitly stated otherwise, only one of the given solution options is correct.
   iv) If subtasks contain more than two answer options and only one solution exists: The marking of multiple answer options is interpreted as a non-response due to the not clear declaration of intention. As a result, no points can be given in this case.

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 (27 Points)

1a) (3 × 5 × 1 Point, 15 Points)
Mark the correct solution in the following statements. (All underlying relationships have been discussed as part of the lecture control engineering.)

A1) (1 Point)
The Laplace transformation is a special Fourier transformation. Besides the “preprocessing of the signal” with the damping term $e^{-\delta t}$, so that $\tilde{f}(t) = f(t)e^{-\delta t}$, the transformation of $f(t)$ is only executed one-sided leading to the transformation
$\mathcal{L}\{f(t)\} = \mathcal{F}_{spec}(j\omega) = \int\limits_{t=0}^{t=\infty} \tilde{f}(t)e^{-j\omega t}\, dt$
which is available as $\mathcal{L}\{f(t)\}$

- ◯ at the moment t of consideration.
- ◯ as a description of the entire signal.
- ◯ after completion of the execution of the integration (for the end of integration).

A2) (1 Point)
In frequency domain the signal $u(t) = 1(t - 15) + 2\delta(t)$ can be described as

- ◯ $u(s) = \frac{-15}{s}(e^{-s} + 2s)$.
- ◯ $u(s) = \frac{1}{s}(e^{-15s} + 2)$.
- ◯ $u(s) = \frac{1}{s}(e^{-15s} + 2s)$.

A3) (1 Point)
Transfer functions are descriptions

- ◯ in time domain.
- ◯ in frequency domain.
- ◯ in time and frequency domain.

A4) (1 Point)

The signal $y(s) = G(s)u(s)$ with $G(s) = T_\mathrm{D}s + 1$ and $u(s) = \frac{1}{s}$ describes with $y(s) = T_\mathrm{D} + \frac{1}{s}$ the step response behavior of a

- ○ PI-system.
- ○ PD-system.
- ○ PID-system.

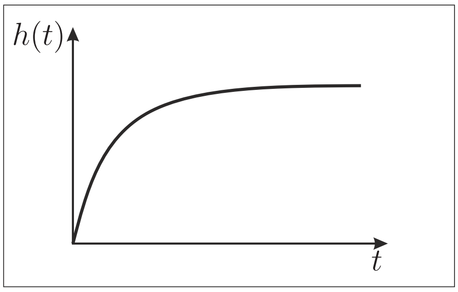
A5) (1 Point)

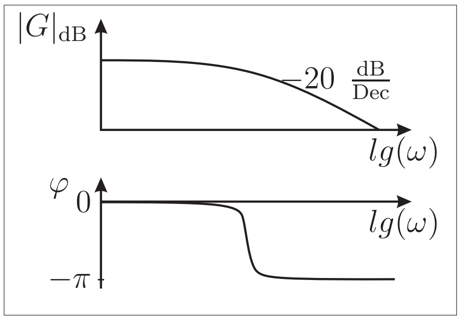
The root locus describes the location of

- ○ the stable poles depending on the gain of the system. The location of unstable poles is not described here.
- ○ all poles depending on the gain of the system. The location of unstable poles is also described here.
- ○ the unstable poles depending on the gain of the system. The location of stable poles is not described here.

B1) (1 Point)

The following figures describe a principally identical transfer behavior:

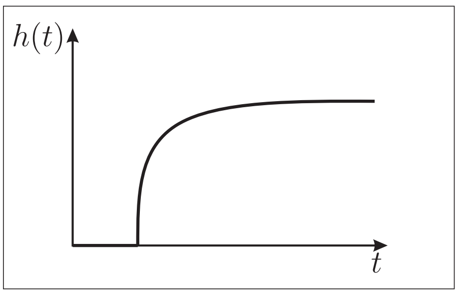


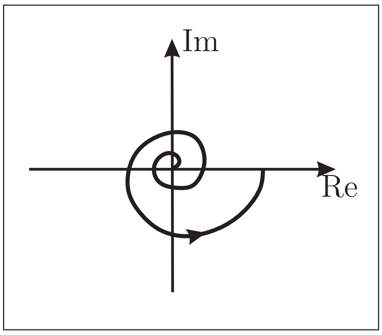


- ◯ No, because the gradient does not have to be $-20\ \frac{\text{dB}}{\text{Dec}}$.
- ◯ No, because the phase of $-\pi$ for large frequencies is not correct.
- ◯ Yes, because everything is correct and the system is a PT_1-system.
- ◯ Yes, because everything is correct and the system is a PT_2-system.

B2) (1 Point)

The following figures describe a principally identical transfer behavior:





- ◯ Yes, because the shown time delay behavior can exactly be represented by the polar plot.
- ◯ No, because there are no such curls in a polar plot.
- ◯ No, because the given course (on the curl) is not correct.
- ◯ No, because the shown infinite phase shift can not be represented by the finite time delay.

B3) (1 Point)
The Nyquist curve describes

- ◯ similar to the Bode diagram the frequency-dependent amplitude (gain) and phase behavior.
- ◯ depending on the gain K the stability behavior of an open loop in context with general or special Nyquist criterion.
- ◯ depending on the gain K the stability behavior of a closed loop in context with general or special Nyquist criterion.

B4) (1 Point)
For the calculation of the transfer function the knowledge of the initial values for $f(t=0)$ to $f^{(n-1)}(t=0)$ with n as highest output derivative order is

- ◯ not necessary.
- ◯ necessary.
- ◯ in specific cases necessary.

B5) (1 Point)
The Laplace transformation $y(s)$ of the system behavior described by $\dot{y}(t)+y(t)=1(t)$ is

- ◯ not identical
- ◯ identical
- ◯ in general not numerically determinable

for the both cases $\dot{y}(t=0)=0$ and $\dot{y}(t=0)=1$ with $y(t=0)=0$.

☐

C1) (1 Point)
Based on the

- ◯ eigenvector orientation
- ◯ eigenvalue location
- ◯ eigenvalues only in combination with the eigenvectors

the state stability of a linear, time invariant system can be evaluated.

C2) (1 Point)
A closed-loop system described by $G(s) = \dfrac{s+5}{s^2+2s+5}$ is charged with the reference signal $w(t) = 1(t)$. For $t \to \infty$ the system is

- ◯ stationary accurate.
- ◯ not bounded.
- ◯ not stationary accurate.

C3) (1 Point)
In frequency domain the I/O-behavior of a PD-controller is described by

- ◯ $G(s) = KT_{\mathrm{D}}s$.
- ◯ $G(s) = K[1 + \frac{1}{T_{\mathrm{I}}s}]$.
- ◯ $G(s) = K[1 + T_{\mathrm{D}}s]$.

C4) (1 Point)

The relation between time and frequency domain is given by

- ◯ $G(s) = \mathcal{L}\{h(t)\}$.
- ◯ $G(s) = \mathcal{L}\{g(t)\}$.
- ◯ $H(s) = \mathcal{L}\{g(t)\}$.

C5) (1 Point)

For initial conditions $\neq 0$ and a bounded input signal $\neq 0$

- ◯ unstable
- ◯ boundary stable
- ◯ asymptotically stable

system behavior exists if an exponential rising of the output behavior appears.

1b) (3.5 Points)
The transfer function of a plant to be controlled is given by

$$G_\mathrm{S}(s) = \frac{12(s+24)}{(s^2-4s+20)(s+3)s}.$$

The plant is controlled with negative feedback using a controller with the transfer function

$$G_\mathrm{R}(s) = \frac{K}{s+T_1}$$

with $T_1 > 0$.

1b) i) (2.5 Points)
Calculate poles and zeros of plant and controller.

1b) ii) (1 Point)
Do plant and controller show asymptotically stable behavior? State reasons for each answer (2 times).

1c) (5 Points)
The reference transfer function is assumed as

$$\tilde{G}_{\mathrm{W}}(s) = \frac{3K(s+1)}{s^4 + s^3 + (T_1 + K)s^2 + (T_1 - 2)s + K}.$$

1c) i) (3 Points)
State the characteristic polynomial of the reference transfer function with $T_1 = 4$ depending on K. Use the Hurwitz criterion to determine for which values of K the closed-loop system is asymptotically stable.

1c) ii) (2 Points)

A step function is applied on the closed-loop system. Can a stationary final value be expected for the control variable? State reasons using a mathematical calculation. Assume positive values of K.

1d) (3.5 Points)

Due to system modification the transfer function of the open loop results in

$$\tilde{G}(s) = \frac{\tilde{K}(s-4)(s-3)(s+1)}{(s-a+j)(s-a-j)(s+5)(s+4)}.$$

1d) i) (1.5 Points)

Is the open loop asymptotically stable for $a = 0$? State reasons.

1d) ii) (2 Points)
Does a K exist for which the closed loop with $a = -5$ shows an unstable behavior? State reasons.

$\sum$

Problem 2 (15 Points)

The human behavior for stimulus-response tasks is assumed as

$$G_{\mathrm{R1}}(s) = \frac{V_{\mathrm{M}}(1 + T_{\mathrm{D}}s)}{(1 + T_{\mathrm{I}}s)} e^{-s(\tau_1 - T_{\mathrm{P}})}.$$

The dynamical behavior of the technical system controlled by the human is described by

$$G_{\mathrm{S}}(s) = \frac{1}{(s+10)(s+4)}.$$

2a) (2 Points)
Give the I/O-behavior in time domain of $G_{\mathrm{R1}}(s) = \frac{u(s)}{e(s)}$ and $G_{\mathrm{S}}(s) = \frac{y(s)}{u(s)}$ for the energy free systems in standard form.

2b) (1 Point)
Determine the phase of the controller $G_{\mathrm{R1}}(j\omega)$ for $\omega = 0$ and $\omega = +\infty$ using $V_{\mathrm{M}} = 1000$, $T_{\mathrm{D}} = 0.5$, $T_{\mathrm{I}} = 10$, $\tau_1 = 1$, and $T_{\mathrm{P}} = 0$.

2c) (6 Points)
Draw the Bode diagram (real and approximated behavior) of the open loop $G_{O1}(s)$ quantitatively into Figure 2.1 using the values of V_M, T_D, T_I, τ_1, and T_P given in task 2b). Mark all gradients (dB/dec.) in the amplitude diagram and all cut-off frequencies. Hint: $20\,\lg(25) \approx 28$ dB.

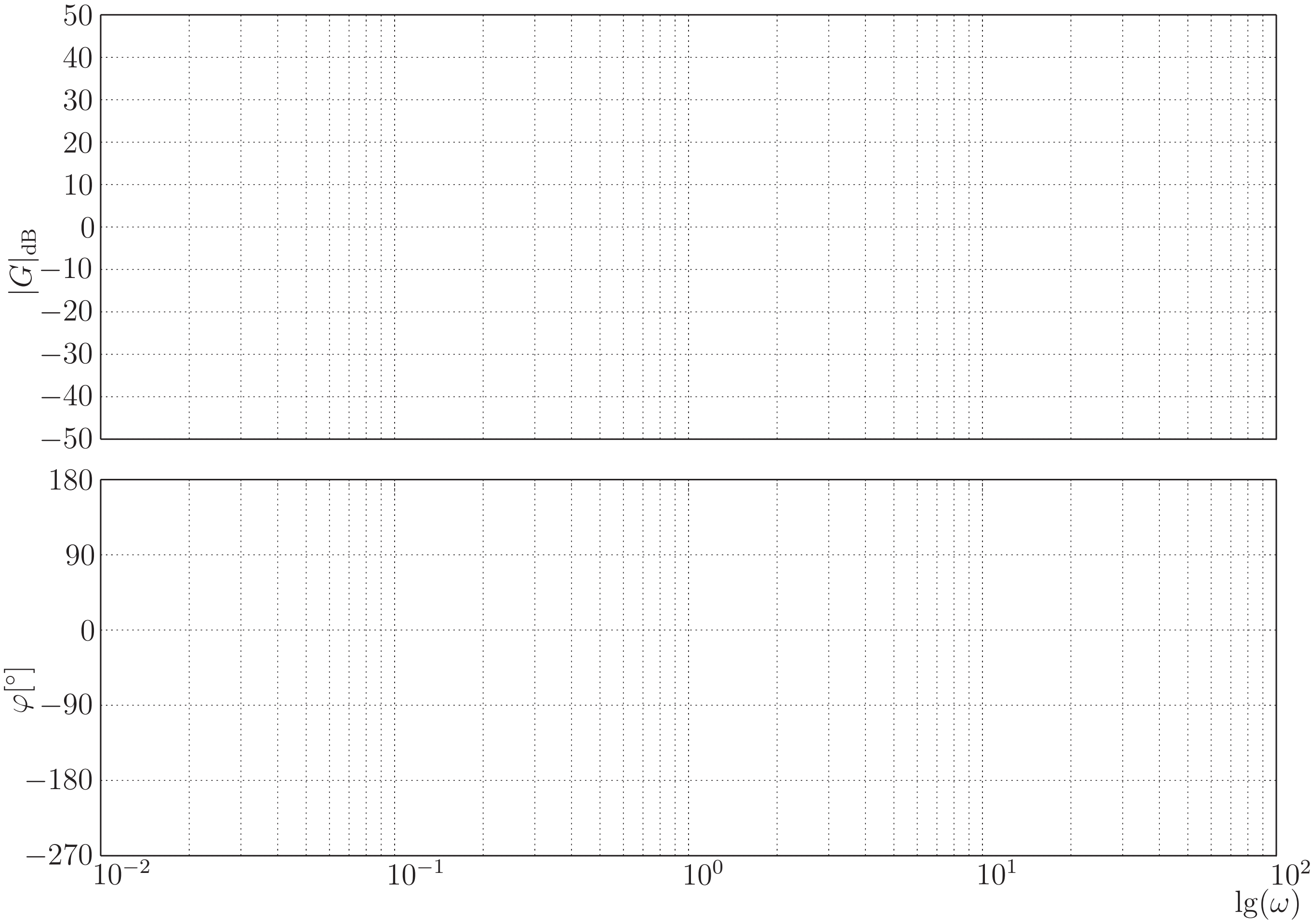


Figure 2.1: Bode diagram of a technical system

2d) (4 Points)
Draw the polar plot of the open loop determined in 2c) once without and once with time delay.

2e) (2 Points)
Mark clearly the variables gain cross-over frequency ω_s and phase cross-over frequency ω_c in Figure 2.2. State the related mathematical equations defining those variables.

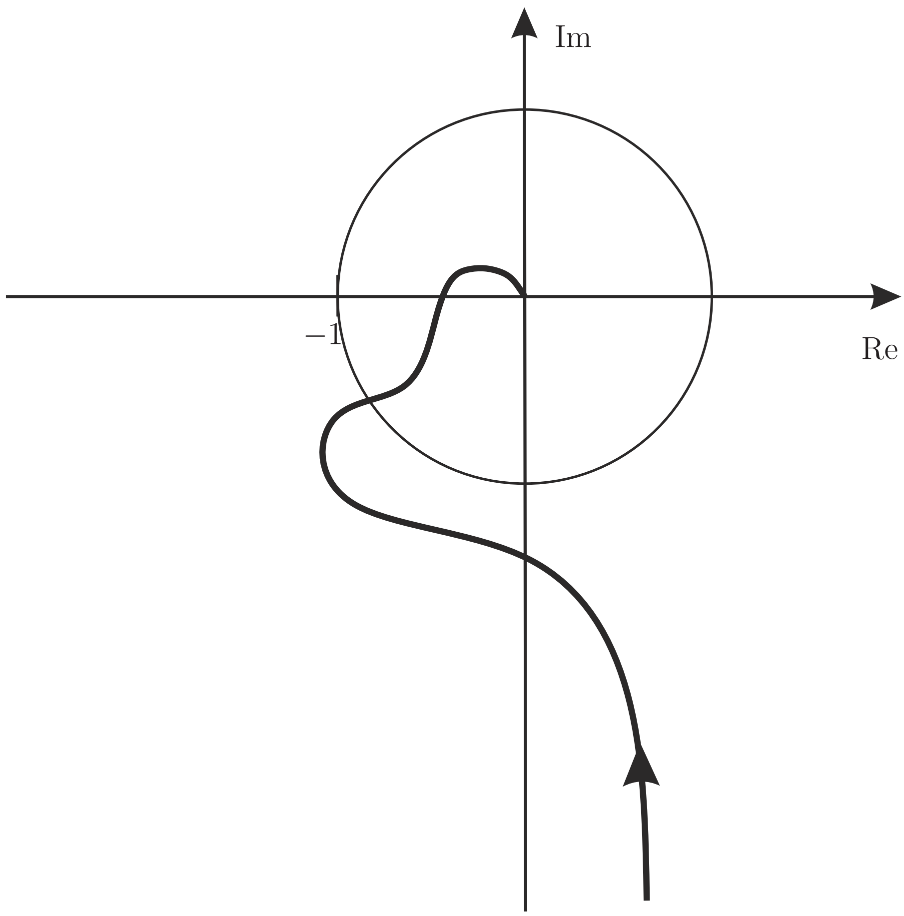


Figure 2.2: Polar plot

$\sum$

Problem 3 (18 Points)

A system with the transfer function

$$G_{\mathrm{S}}(s) = \frac{(s+6)}{(s+3)(s+4)}$$

is controlled with negative feedback by a controller with the transfer function

$$G_{\mathrm{R}}(s) = \frac{K(s+7)(s+1)}{s(s^2+6s+25)}.$$

3a) (2 Points)
The open loop shows the following pole/zero-plot.

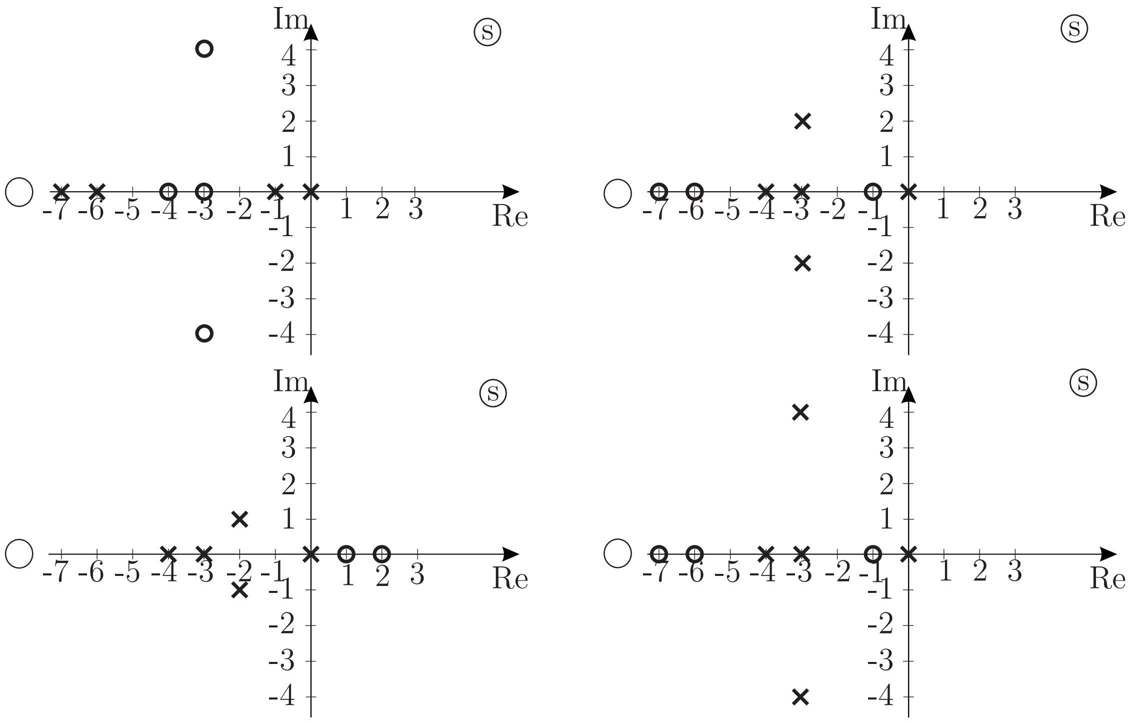


Figure 3.1: Pole/zero-plot

3b) (6 × 1 Point, 6 Points)
Mark the correct solution in the following statements based on the given control loop. (Assume the center of the asymptotes as $\sigma_W = 0.5$.)

A1) (1 Point)
The system always shows damping values

- ◯ $|D| > \frac{\sqrt{2}}{2}$.
- ◯ $|D| < \frac{\sqrt{2}}{2}$.
- ◯ $|D| = \frac{\sqrt{2}}{2}$.

A2) (1 Point)
The open loop is

- ◯ unstable.
- ◯ boundary stable.
- ◯ asymptotically stable.

A3) (1 Point)
For the gain $K \to \infty$ the closed loop is

- ◯ unstable.
- ◯ state stable.
- ◯ I/O-stable.

A4) (1 Point)
By suitable control parameter tuning

- ◯ an asymptotically stable as well as an unstable
- ◯ no unstable
- ◯ no asymptotically stable

behavior can be obtained.

A5) (1 Point)
The controlled system shows

- ◯ more poles than zeros.
- ◯ less poles than zeros.
- ◯ uncertainly more poles than zeros.

A6) (1 Point)
The stability behavior of the closed loop can be described using root locus method. The critical control gains K_{Krit} can

- ◯ be directly read from the root locus.
- ◯ be calculated numerically based on the values read from the root locus.
- ◯ only be determined numerically, graphically only a principle statement about the feasibility can be made.

3c) (2 × 5 × 1 Point, 10 Points)
The root locus is given in Figure 3.2.

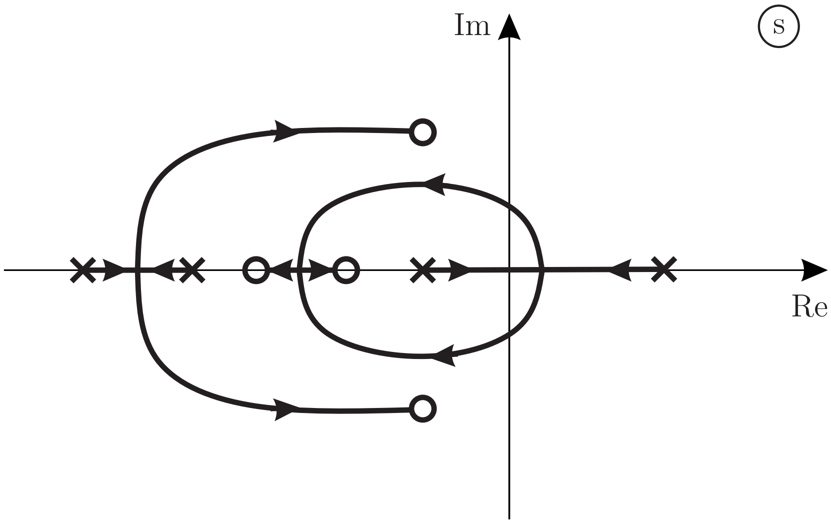


Figure 3.2: Root locus

Mark the correct solution in the following statements.

A1) (1 Point)
The open-loop system is

- ◯ unstable.
- ◯ boundary stable.
- ◯ asymptotically stable.

A2) (1 Point)
The closed-loop system is

- ◯ unstable
- ◯ boundary stable
- ◯ asymptotically stable

for small K.

A3) (1 Point)
The closed-loop system can

- ◯ be stabilized certainly.
- ◯ never be stabilized.
- ◯ only be stabilized under certain circumstances of plant modification.

A4) (1 Point)
It exists

- ◯ a surplus of poles.
- ◯ a surplus of zeros.
- ◯ a surplus of holes.
- ◯ no surplus of poles.

A5) (1 Point)
The sketch is correct if

- ◯ the direction of one branch is plotted in a different direction.
- ◯ it stays like it is.
- ◯ the direction of arrows is interchanged at the zeros.

☐

B1) (1 Point)
The closed-loop system is

- ◯ unstable
- ◯ boundary stable
- ◯ asymptotically stable

for very large gain.

B2) (1 Point)
All branches of the root locus show

- ◯ a value of damping larger than 1
- ◯ an infinite value of damping
- ◯ different values of damping

for large K.

B3) (1 Point)
The graphical determination of critical gains for the closed loop using the amplitude condition for asymptotically stable behavior would result in:

- ◯ $K > K_{\text{krit1}}$.
- ◯ $K < K_{\text{krit1}}$.
- ◯ $K_{\text{krit1}} < K < K_{\text{krit2}}$.

B4) (1 Point)
The open-loop system shows

- ◯ an identical
- ◯ a different
- ◯ a critical

number of poles and zeros.

B5) (1 Point)
The closed-loop system has

- ◯ 4 poles.
- ◯ 8 poles.
- ◯ no poles, all of them disappeared in infinity.

Σ