UNIVERSITÄT DUISBURG-ESSEN

Fakultät für Ingenieurwissenschaften,

Abt. Maschinenbau und Verfahrenstechnik, Lehrstuhl Steuerung, Regelung und Systemdynamik

120 minutes

LAST NAME	
FIRST NAME	
MATRIKEL-NO.	

Attention:

- Give your answers to tasks 1 and 2 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.).
- For tasks 3 to 5 use the additional paper. You may use front and back page of a sheet. Start every task on a new sheet.
- This exam 'Control Technique' is taken by me as a

☐ mandatory (Pflichtfach)
☐ elective (Wahlfach)
☐ prerequsite (Auflage)

subject.
(Cross ONE option according to your own situation.)

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.

Duisburg, den __________ ______________________________
(Unterschrift der/des Studierenden)

Falls Klausurunterlagen vorzeitig abgegeben: __________Uhr

Bewertungstabelle

	a.	b.	c.	d.	e.	f.	g.	h.	Summe
Aufgabe 1									
Aufgabe 2									
Aufgabe 3									
Aufgabe 4									
Aufgabe 5									
Aufgabe 6									
	i.	j.	k.	l.	m.	n.	o.		
Aufgabe 6									
Gesamtpunktzahl									
Anhebungsfaktor									
angehobene Punktzahl									
Bewertung gem. PO in Ziffern									

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

(Datum und Unterschrift 2. Prüfer, PD Dr.-Ing. Wend)

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

Bewertung in Ziffern: __________

Fachnote gemäß Prüfungsordnung in Worten: ____________________

Bemerkung: ____

Problem 1

(each 2 points)

a) Define the terms 'system' and 'input variable'.

☐

b) Visualize the function $y(t) = 3(t-1) + 2(t-2) - 1(t-3)$.

☐

c) Give the physical meaning of the terms 'pole' and 'zero'. What does a double pole look like in time domain? (use a case distinction if necessary).

☐

$\sum$ ☐

d) Define the I/O-behaviour of a PDT_t-system by its differential equation and transfer function.

☐

e) Define the state-space representation for a linear $SISO$-system, and make a statement about the dimensions of the matrices and vectors.

☐

$\sum$ ☐

Problem 2

(each 2 points)

a) A stable transfer element has a PIT_2-transfer behaviour. Derive the Laplace transformation of the step response and define the inital value mathematically.

☐

b) A system has the eigenvalues $-2 \pm j4$ as well as $-4 \pm j1$. Which eigenvalue has the smallest damping coefficient? Answer the question mathematically and explain the geometric representation of damping ratio in the s-plane.

☐

$\sum$ ☐

c) Has the system

$$3\dddot{y} + 2\ddot{y} - \dot{y}y = 4u(t-T)$$

a linear behaviour? State reasons.

☐

d) Given is the Laplace transformation of a function $F(s)$ with $T > 0$

$$F(s) = \frac{1}{Ts},$$

assume that the function $F(s)$ is the input function of a system with a PT_2-transfer behaviour

$$G(s) = \frac{K}{T_1T_2s^2 + (T_1+T_2)s + 1}$$

(with $K = 1$, $T1$, $T2 > 0$), derive the output $f_a(t)$ of the system.

☐

$\sum$ ☐

e) A transfer element with PDT_1-behavior is controlled by a transfer element with P-behavior (positive feedback). Define the disturbance transfer function and the reference transfer function. Is the closed-loop stable? (Calculation is necessary).

□

$\sum$ □

Problem 3

(15 points)

The position control system of a spacecraft platform consists of three elements: a motor, a platform, and an amplifier. The differential equation of each element is given as follows

$$\begin{aligned} \frac{\mathrm{d}\,q(t)}{\mathrm{d}\,t} &= 0.6\,v_2\,, \\ \frac{\mathrm{d}^2\,p(t)}{\mathrm{d}\,t^2} + 3\,\frac{\mathrm{d}\,p(t)}{\mathrm{d}\,t} + 2p(t) &= q(t)\,, \text{ and} \\ K_1\,(T_d\,\frac{\mathrm{d}\,v_1(t)}{\mathrm{d}\,t} + v_1(t)) &= 10\frac{\mathrm{d}\,v_2(t)}{\mathrm{d}\,t} + v_2(t), \end{aligned} \tag{3.1}$$

where $v_1(t)$ denotes the amplifier input voltage, $v_2(t)$ the amplifier output voltage, $q(t)$ the motor shaft position, and $p(t)$ the actual platform position.

a) (3 Points)

Determine the transfer function $G_0(s) = \frac{P(s)}{V_1(s)}$, poles and zeros of the open-loop system $G_0(s)$ for $K_1 = \frac{1}{3}$ and $T_d = 0.1$.

b) (4 Points)

For $K_1 = \frac{1}{3}$ and $T_d = 0.1$ draw the approximated Bode-diagram of the open-loop system given in a). Please note the important frequencies and the approximated gradients of the curve in the diagrams.

Now the relation between $v_1(t)$ and $v_2(t)$ defined above in Eq. (3.1) is replaced by the following equation

$$K_2\,v_1 = 3\frac{\mathrm{d}\,v_2(t)}{\mathrm{d}\,t} + v_2(t)\,. \tag{3.2}$$

The closed-loop is described by the following equation

$$v_1(t) = r(t) - p(t)\,, \tag{3.3}$$

where $r(t)$ represents the desired platform position.

c) (3 Points)

Determine the open-loop transfer function $G_0(s) = \frac{P(s)}{V_1(s)}$. Sketch a block-diagram of the closed-loop system, identifying the three component parts and their own transfer functions.

d) (1 Point)

Draw the polar plot of the open-loop system for $K_2 = \frac{5}{3}$ qualitatively.

e) (4 Points)

For $K_2 = \frac{5}{3}$, use the special Nyquist criterion to determine whether the closed-loop system is stable or not.

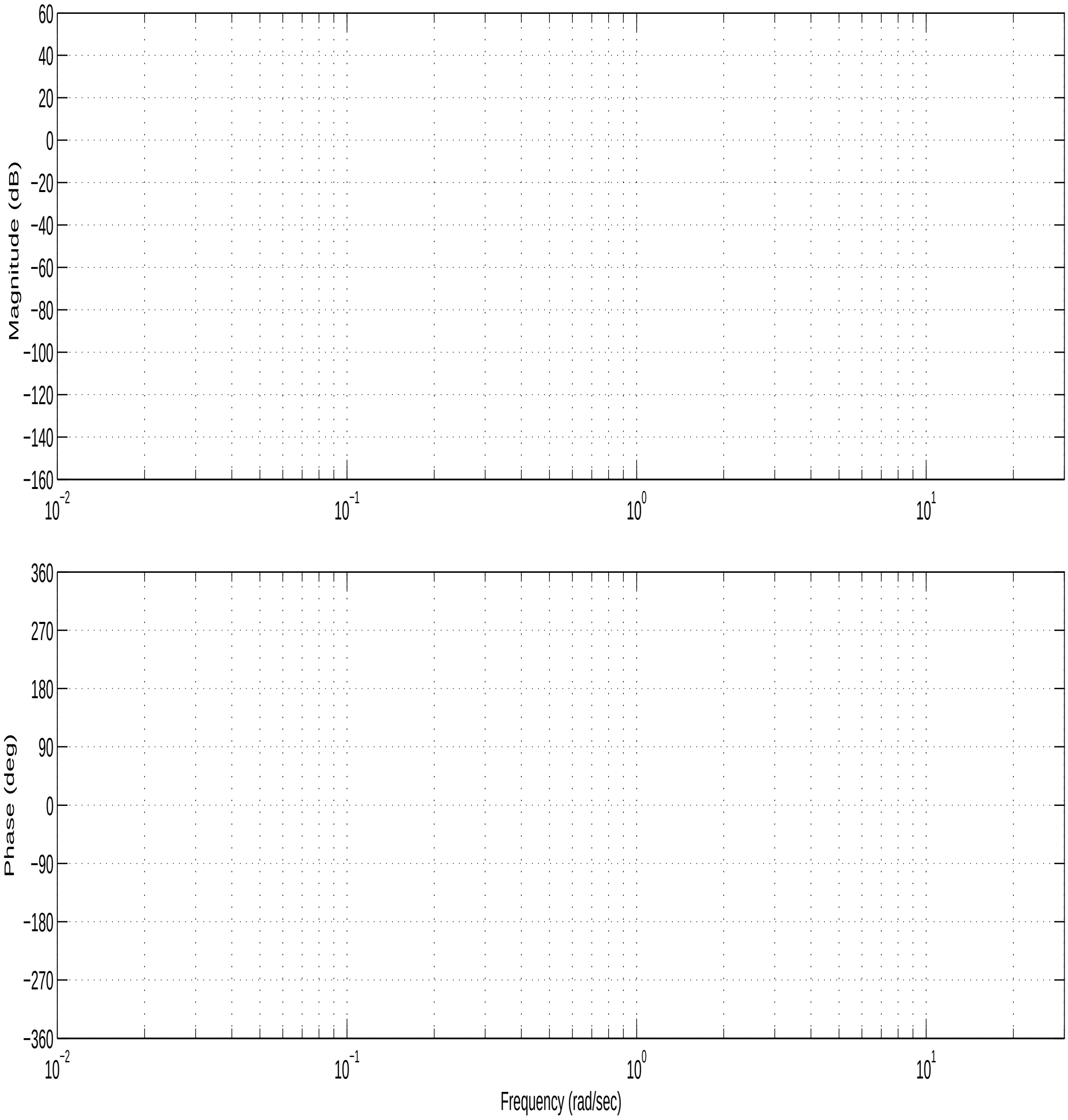

Figure 3.1: Bode Diagram

Problem 4

(15 points)

The following block diagram is given

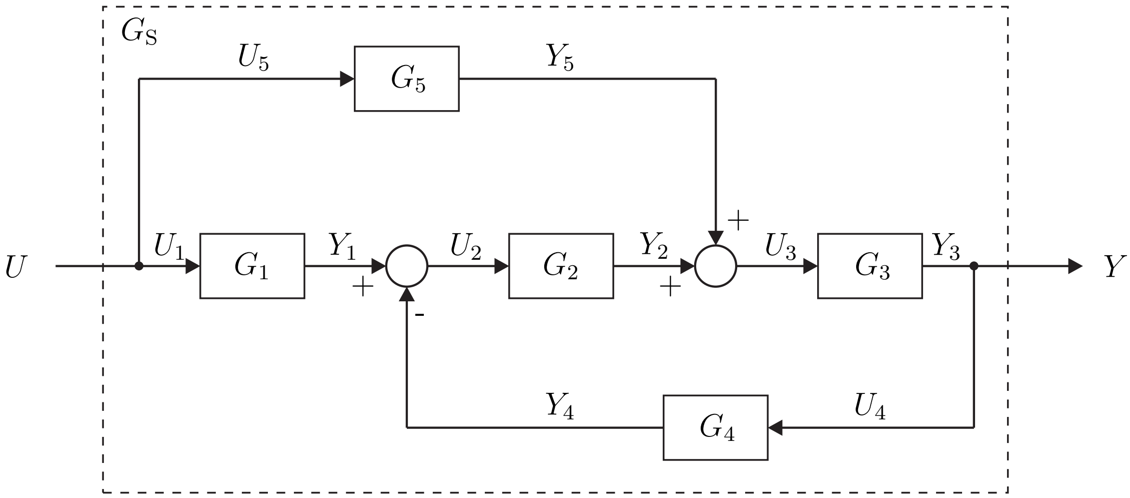

Figure 4.1: Block diagram of the system

a) (3 points)
Calculate the transfer function $G_S = \frac{Y}{U}$ as a function of the blocks G_i.

b) (5 points)
Now the blocks are given with

$$G_1(s) = \frac{1}{s+2}, \quad G_2(s) = K \quad (K > 0), \quad G_3(s) = (s+1)(s+2), \quad G_4 = s+3,$$
$$\text{and} \quad G_5(s) = 0.$$

Set up the transfer function $G_S(s)$.

For which K is the system asymptotic stable? Is the system also I/O stable? State reasons.

c) (7 points)
A new system $G_S(s)$ is defined by the transfer function

$$G_S(s) = \frac{s-3}{s^3 + 9s^2 + 23s + 5}$$

A PDT_1 element is taken as controller with $K = 1$, $T_1 = 1$ and $T_D = 3$. Determine the transfer function of the closed loop system with negative feedback according to a reference value.

If the reference value is a step function $w(t) = 1(t)$, determine the steady-state error of the control loop.

Problem 5

(16 points)
The transfer functions of a plant

$$G_\mathrm{P}(s) = \frac{1}{(s-2)(s-1)(s^2+8s+116)}$$

and a controller

$$G_\mathrm{C}(s) = K_\mathrm{C}(s+2)$$

are given.

a) (2 points)
Classify plant and controller.

b) (4 points)
Determine the poles and zeros, calculate their eigenfrequencies, and give the damping of the complex poles.

c) (1 point)
Give a statement about the stability of the controller and state reasons.

Plant and controller are combined to **two** closed-loop systems, one with positive and another with negative feedback. In the following tasks, the root locus method has to be applied to analyze the dynamics of both closed-loop systems.

d) (2 points)
Calculate the number of separate branches and the number of branches going to infinity in both root loci.

e) (2 points)
Calculate the angles of the asymptotes and the center of the root loci.

f) (4 points)
Sketch the root loci of both systems with their asymptotes and mark the center of the root loci σ_w as well as the critical gains K_crit.

g) (1 point)
Which feedback would you choose? State reasons.

Maximum achievable points:	**66**
Minimum points for the grade 1,0:	**95 %**
Minimum points for the grade 4,0:	**50 %**