higher education & training

Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

CONTROL SYSTEMS N6

(8080016)

20 April 2020 (X-paper)
09:00–12:00

This question paper consists of 7 pages, 2 diagram sheets, a Nichols chart, a formula sheet of 2 pages and a Laplace transform table of 3 pages.

309Q1A2020

DEPARTMENT OF HIGHER EDUCATION AND TRAINING
REPUBLIC OF SOUTH AFRICA

NATIONAL CERTIFICATE
CONTROL SYSTEMS N6
TIME: 3 HOURS
MARKS: 100

INSTRUCTIONS AND INFORMATION

1. Answer all the questions.

2. Read all the questions carefully.

3. Number the answers according to the numbering system used in this question paper.

4. The completed Nichols chart must be inserted into the ANSWER BOOK before handing it in.

5. Write neatly and legibly.

QUESTION 1

Indicate whether the following statements are TRUE or FALSE by writing only 'True' or 'False' next to the question number (1.1–1.10) in the ANSWER BOOK.

1.1 Output is a quantity that must be maintained at a prescribed value.

1.2 A linear variable differential transformer is an electromagnetic device that can detect mechanical rotary motion.

1.3 A steady-state error is a slow variation of the output voltage or current of the amplifier when the input signal is maintained at a constant level.

1.4 A gain margin means the gain corresponds to the point where the phase crosses the 180° line.

1.5 A control system is a mathematical expression describing the transfer of data from the applied input to the output of the system.

1.6 Overshoot is that part of the total response which approaches zero as time approaches infinity.

1.7 In a closed-loop system output has an effect on input in order to maintain the output at a desired value.

1.8 Overdamping is defined as the amount of damping that reduces the overshoot to zero when a system is excited by a change in the control value.

1.9 A second-order control system cannot become unstable because there are feedback elements that adjust and make the output uncontrollable.

1.10 A stable system remains at rest unless excited by an external source and returns to rest once all excitations are removed.

(10 × 1) **[10]**

QUESTION 2

2.1 Determine, with the aid of block diagram algebra, the controlled output (C) for the block diagram in FIGURE 1.

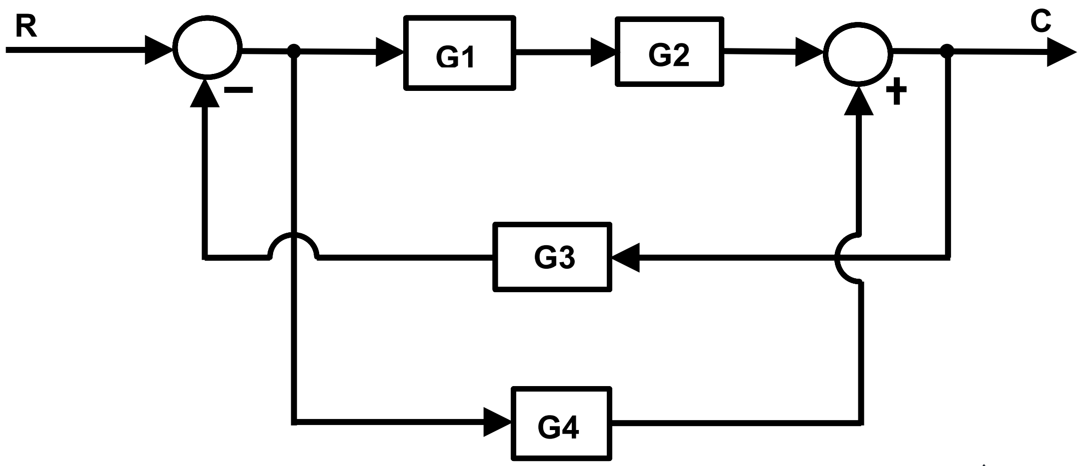


FIGURE 1 (6)

2.2 Convert the Laplace transform function below to a function of time.

$$\frac{40}{(s+4)(s+5)}$$ (2)

2.3 Convert the function of time below to a Laplace transform function.

$$\frac{15}{100}(e^{-10t}+10t-1)$$ (2)

[10]

QUESTION 3

DIAGRAM SHEET 1 (attached) shows a point-by-point Bode diagram of the gain and phase values of a system with the frequency varying from 0.1 to 100 radians per second.

Determine each of the following from the graph:

3.1 Gain crossover frequency (1)

3.2 Phase crossover frequency (1)

3.3 Phase margin (1)

3.4 Gain and phase values at a frequency of 10 rad/s (2)

3.5 Gain corner frequencies (2)

3.6 Gain cut-off rates (3)

[10]

QUESTION 4

4.1 Plot the gain and phase values for an open-loop control system on the attached Nichols chart using the data in the table below.

ω(rad/sec)	Magnitude in dB	Phase in degrees
0.1	27	- 60°
0.6	18	- 95º
1	9	- 130º
12	- 2	- 150º
19	- 13	- 175º
24	- 24	- 195 º

(5)

4.2 Use the Nichols chart to determine each of the following:

4.2.1 Gain margin

4.2.2 Phase margin

4.2.3 Gain crossover frequency

4.2.4 Phase crossover frequency

4.2.5 Undamped natural resonant frequency

(5 × 1) (5)
[10]

QUESTION 5

DIAGRAM SHEET 2 (attached) illustrates the root locus plot of a system as an amplifier gain varies from zero to infinity.

Use the plot to determine each of the following:

5.1 Open-loop poles and zeros (3)

5.2 Smallest value of damping ratio that the system could have (2)

5.3 Damped resonant frequency ω_d at the smallest damping ratio (1)

5.4 Undamped resonant frequency ω_n at the smallest damping ratio (1)

5.5 Gain constant K_o at the smallest damping ratio (2)

5.6 Frequency at which the system becomes unstable (1)
[10]

QUESTION 6

6.1 Name TWO types of resistive transducers. (2)

6.2 Identify the terminals of an operational amplifier shown in the diagram in FIGURE 2. Write only the answer next to the letter (A–C) in the ANSWER BOOK.

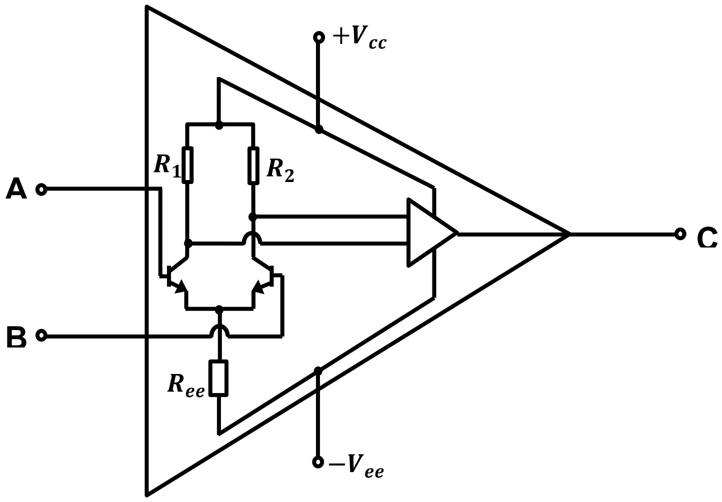


FIGURE 2 (3)

6.3 A summing operational amplifier is subjected to three input voltages of 8 V, 12 V and 24 V respectively. The feedback resistance is 11 KΩ and all input resistance is 50 Ω.

Calculate the value of the output voltage. (2)

6.4 State THREE components of an optical relay. (3)
[10]

QUESTION 7

7.1 Name THREE types of systems in which synchros may be used. (3)

7.2 State FOUR advantages of using AC servo motors. (4)

7.3 Explain *breakaway voltage* with regard to servo motors. (2)

7.4 Name the type of rotary synchro that consists of three stators and three rotor windings connected to two transmitter stators. (1)
[10]

QUESTION 8

8.1 Draw a neat, labelled schematic diagram of a reversible half-wave universal speed-control circuit. (6)

8.2 Define *feedback* with regard to a closed-loop control system. (2)

8.3 Name TWO conditions which can be improved.in the design and performance of a system. (2)
[10]

QUESTION 9

9.1 Name TWO types of spur-gear rotary pumps. (2)

9.2 A certain type of rotary hydraulic pump is shown in the diagram in FIGURE 3.

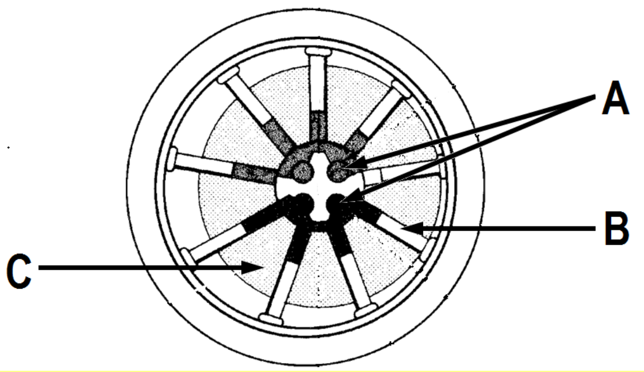


FIGURE 3

9.2.1 Name the pump. (1)

9.2.2 Identify the indicated parts of the pump by writing the answer next to the letter (A–C) in the ANSWER BOOK. (3)

9.2.3 Explain the operation of the pump. (4)
[10]

QUESTION 10

10.1 Name the type of control required on a basic pneumatic control system to counteract each of the following problems:

10.1.1 Sluggishness

10.1.2 Offset and steady-state errors

(2 × 1) (2)

10.2 Define *hunting* with regard to proportional control. (1)

10.3 A proportional pneumatic controller is shown in the diagram in FIGURE 4.

Explain the working principle of this type of controller.

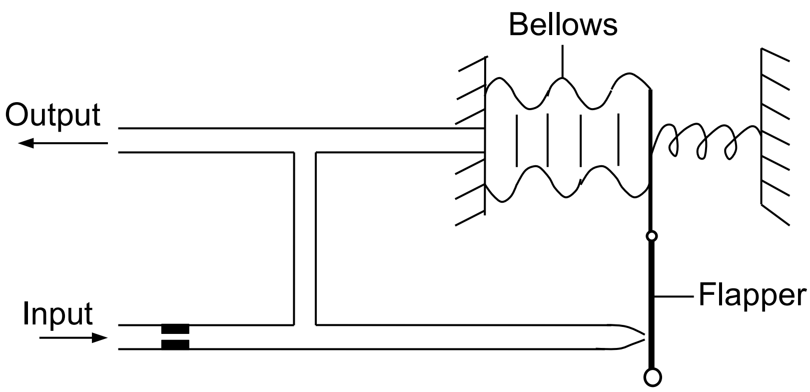


FIGURE 4

(7)

[10]

TOTAL: 100

DIAGRAM SHEET 1

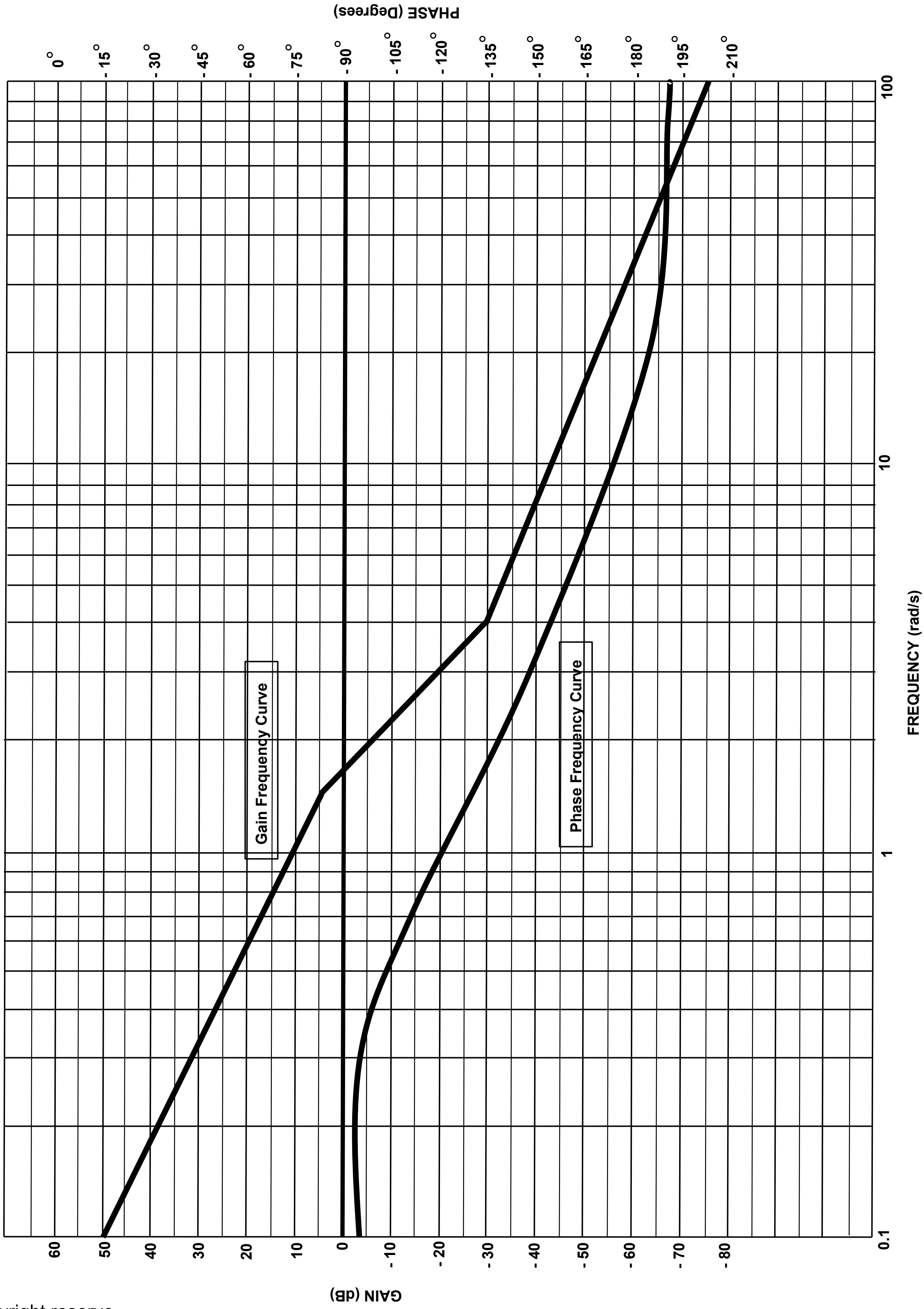
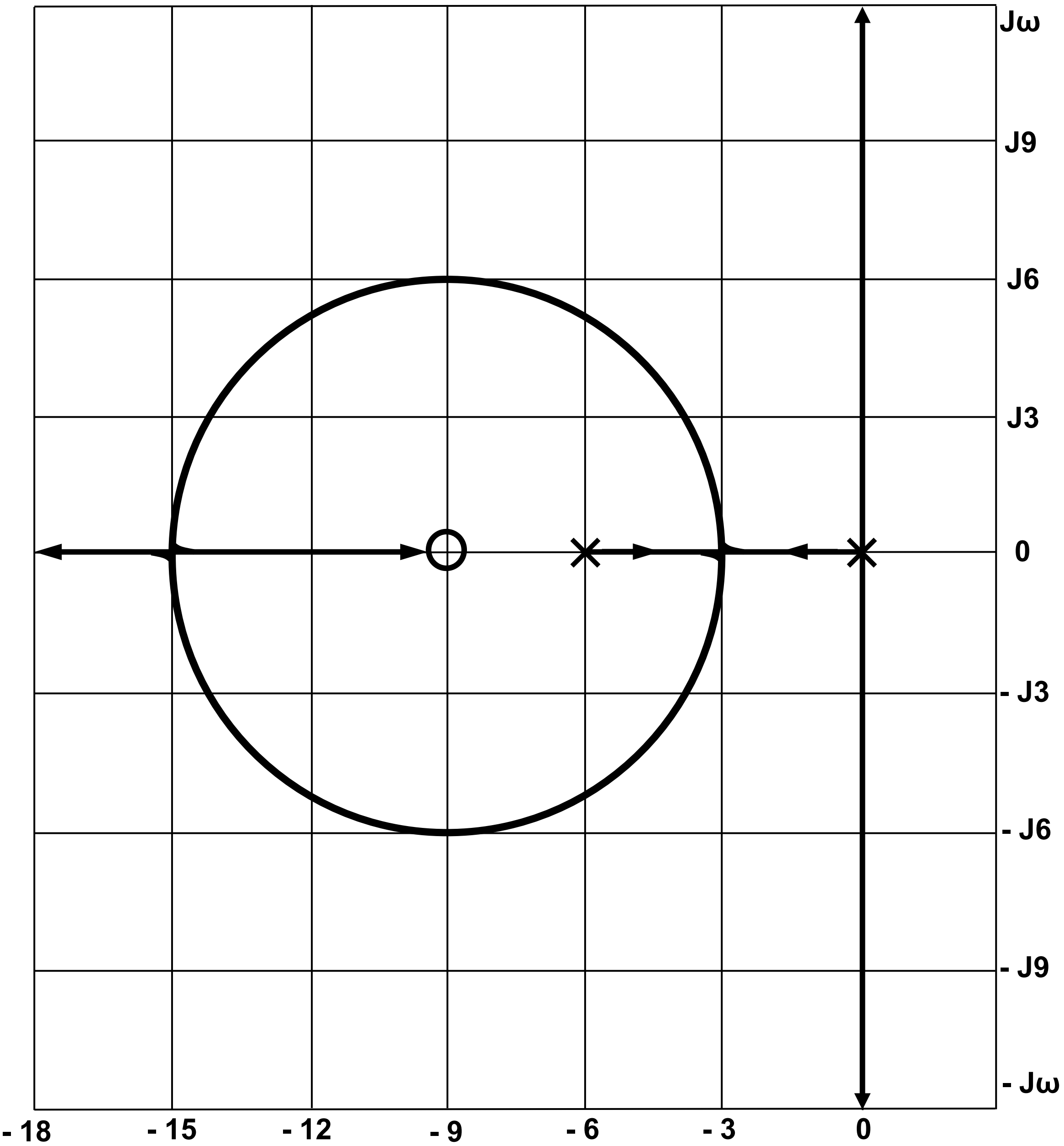


DIAGRAM SHEET 2



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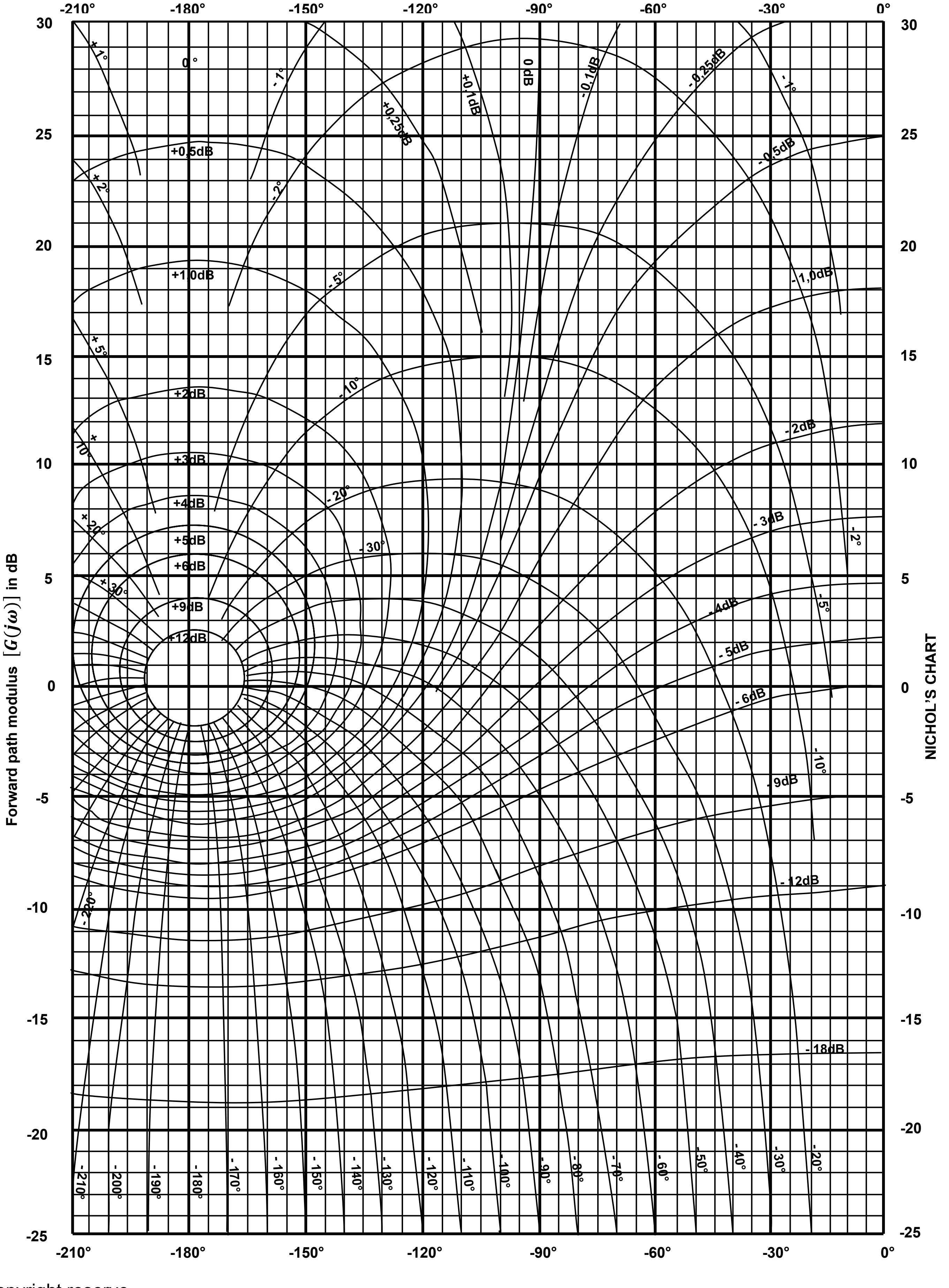
NICHOLLS CHART (DETACH AND HAND IN WITH EXAMINATION BOOK)

EXAMINATION NUMBER:
EKSAMMENOMMER:



CONTROL SYSTEMS N6

FORMULA SHEET

$$\omega_d = \omega_n\sqrt{1-\zeta^2} = 2\pi f \qquad t_p = \frac{1}{f}$$

Number of oscillations / Aantal ossilasies $\dfrac{t_s}{t_p}$ or / of $\dfrac{2\sqrt{1-\zeta^2}}{\pi.\zeta}$

Damping coefficient / Dempingskoëffisiënt $(\alpha) = \zeta\,.\,\omega_n = \dfrac{1}{\pi}\,\tau$

Overshoot / Oorskiet $= e^{\frac{-\zeta\,\pi N}{\sqrt{1-\zeta^2}}}$

$$\Psi = tan^{-1}\left[\frac{\sqrt{1-\zeta^2}}{-\zeta}\right] + \pi\, rad$$

Amplitude $= \varphi\left[1 + e^{\frac{-\zeta\pi N}{\sqrt{1-\zeta^2}}}\right]$

$$\omega_n = \sqrt{\frac{Ko}{\tau}} \qquad \tau + \frac{t_s}{4} = \frac{1}{\zeta\,.\,\omega_n}$$

$$\omega_p = \omega_n\sqrt{1-2\,\zeta^2}$$

$$\omega_b = \omega_n\sqrt{1-2\zeta^2+\sqrt{2-4\zeta^2+4\zeta^4}}$$

$$\frac{C}{R} = \frac{G}{1 \pm GH} \qquad Sc = \frac{\sum P - \sum Z}{NP - NZ}$$

$$\zeta = COS\,\varphi \qquad \Psi = \frac{(2Ko+1)180°}{NP - NZ}$$

$$Ko = \frac{\Delta P_1\,.\,\Delta P_{2....}}{\Delta Z_1\,.\,\Delta Z_{2....}}$$

AMPLIFIERS

$$\text{Vo} = -V_i \frac{\text{R}_f}{\text{R}_1}$$

$$\text{Vo} = V_i \left[1 + \frac{\text{R}_f}{\text{R}_1}\right]$$

$$\text{Vo} = -R_f \left[\frac{\text{V}_1}{\text{R}_1} + \frac{V_2}{R_2} + \cdots \frac{V_N}{R_N}\right]$$

$$\text{Vo} = -\frac{1}{RC} \int V_i\,(t)dt + V_c$$

$$\text{Vo} = \frac{R_f}{R_1}[V_2 - V_1]$$

$$\text{Vo} = -RC\,\frac{dV_i(t)}{dt}$$

$$\text{i}_e = \frac{V_e}{R_e}$$

$$R_c = \frac{V_c}{i_c}$$

$$\text{gm}R_L = \frac{hfe}{hie}.R_L$$

$$\text{t} = \frac{1}{f}$$

BODE AND NICHOLS CHARTS

$$Gain = 20\log\left[\frac{output}{input}\right]\ db$$

$$Wins = 20\log\left[\frac{uitset}{inset}\right]\ db$$

$$Phase = \text{Sin}^{-1}\left[\frac{phase\ shift}{input}\right] - 180°$$

$$Fase = \text{Sin}^{-1}\left[\frac{faseverskuiwing}{inset}\right] - 180°$$

$$\tau = R.C$$

LAPLACE TRANSFORM TABLE

No	F(s)	f(t)
1.	1	$\delta(t)$
2.	$\frac{A}{s}$	$A(t)$ $\{0 \;\; t < 0\}$ $\{A \;\; t \geq 0\}$
3.	$\frac{1}{s}$	$U(t)$ $\{0 \;\; t < 0\}$ $\{1 \;\; t \geq 0\}$
4.	$\frac{A}{s^2}$	At
5.	$\frac{2A}{s^3}$	At^3
6.	$\frac{A_\omega}{s^2 + \omega^2}$	$A \sin \omega t$
7.	$\frac{A_s}{s^2 + \omega^2}$	$A \cos \omega t$
8(a).	$\frac{A}{\tau s + 1}$	$\frac{A}{\tau} e^{\frac{-t}{\tau}}$
8(b).	$\frac{A}{s + a}$	Ae^{-at}
9(a).	$\frac{A}{(\tau_1 s + 1)(\tau_2 s + 1)}$	$\frac{A}{\tau_1 - \tau_2} \left[e^{\frac{-t}{\tau_1} - \frac{-t}{\tau_2}} \right]$
9(b).	$\frac{A}{(s + a)(s + b)}$	$\frac{A}{(b - a)} \left[e^{-at} - e^{-bt} \right]$
10(a).	$\frac{A}{(\tau_s + 1)^2}$	$\frac{At}{\tau^2} \left[e^{\frac{-t}{\tau}} \right]$
10(b).	$\frac{A}{(s + a)^2}$	Ate^{-at}
11.	$\frac{A{\omega_n}^2}{s^2 + 2\,\zeta \omega_n s + {\omega_n}^2}$	$\frac{A\omega_n e^{-\zeta \omega_n t}}{\sqrt{1 - \zeta^2}} \sin\,(\omega_n \sqrt{1 - \zeta^2 t}$
12(a).	$\frac{A}{s(\tau s + 1)}$	$A(1 - e^{\frac{-t}{\tau}})$
12(b).	$\frac{A}{s(s + a)}$	$\frac{A}{a}(1 - e^{-at})$
13(a).	$\frac{A}{s^2(\tau s + 1)}$	$A\tau \left[e^{\frac{-t}{\tau}} + \frac{t}{\tau} - 1 \right]$
13(b).	$\frac{A}{s^2(s + a)}$	$\frac{A}{a^2}(e^{-at} + at - 1)$

14(a).	$\frac{A\omega}{(s^2+\omega^2)(\tau s+1)}$	$\frac{A\omega\tau}{1+\omega^2\tau^2}e^{\frac{-t}{\tau}}+\frac{A}{\sqrt{1+\omega^2\tau^2}}\sin(\omega t-\Psi)$ *where* $\Psi=\tan^{-1}\omega\tau\ (0<\Psi<\pi)$
14(b).	$\frac{A\omega}{(s^2+\omega^2)(s+a)}$	$\frac{A\omega e^{-at}}{(\omega^2+a^2)}+\frac{A}{\sqrt{\omega^2+a^2}}\sin(\omega t-\Psi)$ *where* $\Psi=\tan^{-1}\frac{\omega}{a}\ (0<\Psi<\pi)$
15(a).	$\frac{A}{s(\tau_1 s+a)(\tau_2 s+1)}$	$A\left[1+\frac{\tau_1 e^{\frac{-t}{\tau_1}}-\tau_2 e^{\frac{-t}{\tau_2}}}{\tau_1-\tau_2}\right]$
15(b).	$\frac{A}{s(s+a)(s+b)}$	$\frac{A}{ab}\left[1+\frac{ae^{-bt}-be^{-at}}{b-a}\right]$
16(a).	$\frac{A}{s(\tau+a)^2}$	$A\left[1-\frac{(\tau+t)}{\tau}e^{\frac{-t}{\tau}}\right]$
16(b).	$\frac{A}{s(s+1)^2}$	$\frac{A}{a^2}[1-(1+at)e^{-at}]$
17.	$\frac{A{\omega_n}^2}{s(s^2+2\zeta\omega_n s+{\omega_n}^2)}$	$A\left[1+\frac{e^{-\zeta\omega_n t}}{\sqrt{1-\zeta^2}}\sin(\omega_n t\sqrt{1-\zeta^2}-\Psi\right]$ *where* $\Psi=tan^{-1}\frac{\sqrt{1-\zeta^2}}{-\zeta}$ $(0<\Psi<\pi)$
18(a).	$\frac{A}{s^2(\tau_1 s+1)(\tau_2 s+1)}$	$A\left[t-\tau_1-\tau_2-\frac{{\tau_2}^2 e^{\frac{-t}{\tau_2}}-{\tau_1}^2 e^{\frac{-t}{\tau_1}}}{\tau_1-\tau_2}\right]$
18(b).	$\frac{A}{s^2(s+a)(s+b)}$	$\frac{A}{ab}\left[t-\frac{a+b}{ab}-\frac{\frac{b}{a}e^{-bt}-\frac{a}{b}e^{-at}}{b-a}\right]$
19(a).	$\frac{A}{s^2(\tau s+1)^2}$	$A\left[t-2\tau+(t+2\tau)e^{\frac{-t}{\tau}}\right]$
19(b).	$\frac{A}{s^2(s+a)^2}$	$\frac{A}{a^2}\left[t-\frac{2}{a}+\left(t+\frac{2}{a}\right)e^{-at}\right]$
20.	$\frac{A{\omega_n}^2}{s^2(s^2+2\zeta\omega_n s+{\omega_n}^2)}$	$A\left[\tau-\frac{2\zeta}{\omega_n}+\frac{e^{-\zeta\omega_n t}}{\omega_n\sqrt{1-\zeta^2}}\sin(\omega_n t\sqrt{1-\zeta^2}-\Psi\right]$ *where* $\Psi=2tan^{-1}\frac{\sqrt{1-\zeta^2}}{-\zeta}$ $(0<\Psi<\pi)$

21(a).	$\frac{A\omega}{(s^2+\omega^2)(\tau_1 s+1)(\tau_2 s+1)}$	$A\left[\frac{\tau_1{}^2\omega e^{\frac{-t}{\tau_1}}}{(\tau_1-\tau_2)(1+\omega^2\tau_1{}^2)}+\frac{\tau_2{}^2\omega e^{\frac{-t}{\tau_2}}}{(\tau_1-\tau_2)(1+\omega^2\tau_2{}^2)}+\frac{\sin(\omega t-\Psi)}{(1+\omega^2\tau^2)(1+\omega^2\tau_2{}^2)^{\frac{1}{2}}}\right]$ *where* $\Psi=tan^{-1}\omega\tau_1+tan^{-1}\omega\tau_2$
21(b).	$\frac{A\omega}{(s^2+\omega^2)(s+a)(s+b)}$	$A\left[\frac{\omega e^{-at}}{(b-a)(\omega^2+a^2)}+\frac{\omega e^{-bt}}{(a-b)(\omega^2+b^2)}+\frac{\sin(\omega t-\Psi)}{(\omega^2+a^2)(\omega^2+b^2)^{\frac{1}{2}}}\right]$ *where* $\Psi=tan^{-1}\frac{\omega(a+b)}{ab-\omega^2}$ $(0<\Psi<\pi)$
22(a).	$\frac{A\omega}{(s^2+\omega^2)(\tau s+1)^2}$	$\frac{A}{1+\omega^2\tau^2}\left[\frac{\omega t+2\omega\tau}{1+\omega^2\tau^2}e^{\frac{-t}{\tau}}+\sin(\omega t-\Psi\right]$ *where* $\Psi=2tan^{-1}\omega\tau$
22(b).	$\frac{A\omega}{(s^2+\omega^2)(s+a)^2}$	$\frac{A}{\omega^2+a^2}\left[\frac{a\omega(at+2)e^{-at}}{\omega^2+a^2}+\sin(\omega t-\Psi\right]$
23.	$\frac{A\omega\omega_n{}^2}{(s^2+\omega^2)(s^2+2\zeta\omega_n s+\omega_n{}^2)}$	$\frac{A\omega_n{}^2}{[(\omega_n{}^2-\omega^2)^2+4\zeta^2\omega^2\omega_n{}^2]^{\frac{1}{2}}}$ $\left[\sin(\omega t-\Psi)+\frac{\omega e^{-\zeta\omega_n t}\sin(\omega_n\sqrt{1-\zeta^2}\,t-\Psi_2)}{\omega_n\sqrt{1-\zeta^2}}\right]$ *where* $\Psi_1=tan^{-1}\left[\frac{2\zeta\omega\omega_n}{\omega_n{}^2+\omega^2}\right]$ $(0<\Psi_1<\pi)$ and $\Psi_2=tan^{-1}-\frac{2\zeta\omega_n{}^2\sqrt{1-\zeta^2}}{\omega^2-\omega_n{}^2(1-2\zeta^2)}$ $(0<\Psi_2<\pi)$