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Benodigdhede vir hierdie vraestel:				Oopboek-eksamen:	
Multikeusekaarte:		Nie-programmeerbare sakrekenaar:	X		
Grafiekpapier:		Draagbare rekenaar:			

SEMESTERTOETS / SEMESTER TEST:	2	KWALIFIKASIE/ QUALIFICATION:	**B ING**
MODULEKODE/ MODULE CODE:	**EERI418**	DUUR/ DURATION:	1.5 UUR / 1.5 HOUR
MODULE BESKRYWING/ SUBJECT:	BEHEERTEORIE II CONTROL THEORY II	MAKS / MAX:	38
EKSAMINATOR(E)/ EXAMINER(S):	PROF. K.R. UREN	DATUM / DATE:	**14-04-2016**
MODERATOR:	PROF. G. VAN SCHOOR	TYD / TIME	**14:00**

VRAAG 1 / QUESTION 1

Die digtale filter in Figuur 1 los die volgende verskilvergelyking op: /

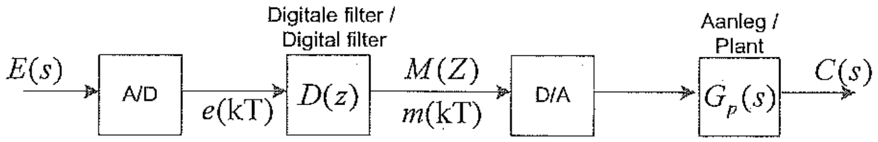
The digital filter in Figure 1 solves the following difference equation:

$$m(k) = 0.7m(k-1) + 0.5e(k)$$

Die monstertempo is 20 Hz. / *The sampling rate is 20 Hz*

Die aanlegoordragsfunksie word gegee deur: / *The plant transfer function is given by:*

$$G_p(s) = \frac{1}{s+5}$$



Figuur / *Figure* 1

Bepaal die stelseloordragsfunksie $C(z)/E(z)$ indien die verwerkingstyd van die digitale filter van 185 ms ook gemodelleer moet word. /

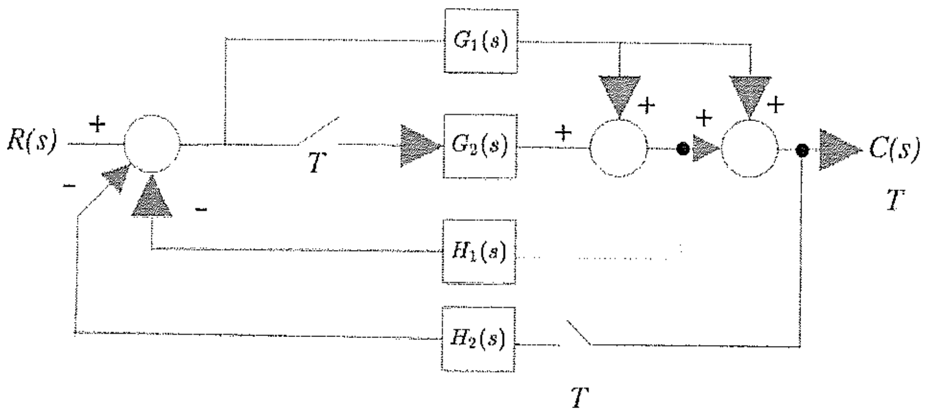
Determine the system transfer function $C(z)/E(z)$ when the computational delay of the digital filter of 185 ms also needs to be modelled.

[8]

VRAAG 2 / QUESTION 2

Druk in Figuur 2 $C(z)$ uit as 'n funksie van $R(z)$ en die gegewe oordragsfunksies. /

Express $C(z)$ in Figure 2 in terms of $R(z)$ and the given transfer functions.

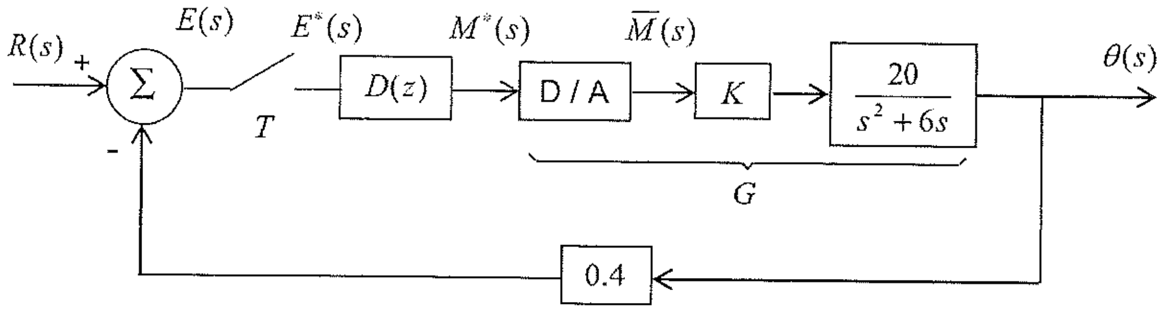


Figuur / *Figure* 2

[10]

VRAAG 3 / QUESTION 3

Beskou die antenna-beheerstelsel in Figuur 3. Die eenheid vir die antennahoek $\theta(t)$ is grade. / *Consider the antenna control system shown in figure 3. The unit for the antenna angle $\theta(t)$ is degrees*



Figuur / *Figure* 3

3.1 Bepaal die waardes van $r(t)$ wat hoeke van ±30° vir $\theta(t)$ sal gee. / *Determine the values of $r(t)$ that will give the angles of ±30° for $\theta(t)$.* (1)

3.2 Bepaal die stelseloordragsfunksie $\theta(z)/R(z)$ in terme van $G(z)$ en $D(z)$. / Determine the system transfer function $\theta(z)/R(z)$ in terms of $G(z)$ and $D(z)$. (1)

3.3 Bepaal die oordragsfunksie vir $D(z) = 1$, $K = 20$ en $T = 0.05$ s. Wat is die tipe van die stelsel? /

Determine the transfer function for $D(z) = 1$, $K = 20$ and $T = 0.05$ s. Find the system type. (4)

3.4 Bepaal die bestendige toestand fout van die stelsel vir 'n eenheidshellingsinset. /

Determine the steady state error of the system for a unit ramp input. (4)

3.5 Bepaal die demping asook die natuurlike frekwensie van die diskrete stelsel. /

Determine the damping as well as the natural frequency of the discrete system. (5)

3.6 Die filter *D(z)* realiseer nou die volgende verskilvergelyking: /

The filter D(z) now realises the following difference equation:

$$m(k) = e(k) - 0.9e(k-1) + m(k-1)$$

Wat is die tipe van die stelsel nou? /

What is the now the system type? (3)

3.7 Met *D(z)* soos in 3.6, bepaal weer die bestendige toestand fout van die stelsel vir 'n eenheidshellingsinset. /

For D(z) as in 3.6, again determine the steady state error of the system for a unit ramp input. (2)

[20]

Addisionele inligting / *additional information:*

$$\zeta = \frac{-\ln r}{\sqrt{\ln^2 r + \theta^2}}$$

$$\omega_n = \frac{1}{T}\sqrt{\ln^2 r + \theta^2}$$

$$\tau = \frac{1}{\zeta\omega_n}$$

TOTAAL/*TOTAL* [38]

TABLE 2-3 z-TRANSFORMS

Sequence	z-Transform
$\delta(k-n)$	z^{-n}
1	$\frac{z}{z-1}$
k	$\frac{z}{(z-1)^2}$
k^2	$\frac{z(z+1)}{(z-1)^3}$
a^k	$\frac{z}{z-a}$
ka^k	$\frac{az}{(z-a)^2}$
$\sin ak$	$\frac{z \sin a}{z^2 - 2z \cos a + 1}$
$\cos ak$	$\frac{z(z - \cos a)}{z^2 - 2z \cos a + 1}$
$a^k \sin bk$	$\frac{az \sin b}{z^2 - 2az \cos b + a^2}$
$a^k \cos bk$	$\frac{z^2 - az \cos b}{z^2 - 2az \cos b + a^2}$

TABLE 2-2 PROPERTIES OF THE z-TRANSFORM

Sequence	Transform
$e(k)$	$E(z) = \sum_{k=0}^{\infty} e(k)z^{-k}$
$a_1 e_1(k) + a_2 e_2(k)$	$a_1 E_1(z) + a_2 E_2(z)$
$e(k-n)u(k-n);\quad n \geq 0$	$z^{-n} E(z)$
$e(k+n)u(k);\quad n \geq 1$	$z^n\left[E(z) - \sum_{k=0}^{n-1} e(k)z^{-k}\right]$
$\epsilon^{ak} e(k)$	$E(z\epsilon^{-a})$
$ke(k)$	$-z\frac{dE(z)}{dz}$
$e_1(k) * e_2(k)$	$E_1(z)E_2(z)$
$e_1(k) = \sum_{n=0}^{k} e(n)$	$E_1(z) = \frac{z}{z-1}E(z)$

Initial value: $e(0) = \lim_{z\to\infty} E(z)$

Final value: $e(\infty) = \lim_{z\to 1} (z-1)E(z)$, if $e(\infty)$ exists

Table 3. z-transforms

Laplace transform $E(s)$	Time function $e(t)$	z-Transform $E(z)$	Modified z-transform $E(z,m)$
$\frac{1}{s}$	$u(t)$	$\frac{z}{z-1}$	$\frac{1}{z-1}$
$\frac{1}{s^2}$	t	$\frac{Tz}{(z-1)^2}$	$\frac{mT}{z-1}+\frac{T}{(z-1)^2}$
$\frac{1}{s^3}$	$\frac{t^2}{2}$	$\frac{T^2 z(z+1)}{2(z-1)^3}$	$\frac{T^2}{2}\left[\frac{m^2}{z-1}+\frac{2m+1}{(z-1)^2}+\frac{2}{(z-1)^3}\right]$
$\frac{(k-1)!}{s^k}$	t^{k-1}	$\lim_{a\to 0}(-1)^{k-1}\frac{\partial^{k-1}}{\partial a^{k-1}}\left[\frac{z}{z-\epsilon^{-aT}}\right]$	$\lim_{a\to 0}(-1)^{k-1}\frac{\partial^{k-1}}{\partial a^{k-1}}\left[\frac{\epsilon^{-amT}}{z-\epsilon^{-aT}}\right]$
$\frac{1}{s+a}$	ϵ^{-at}	$\frac{z}{z-\epsilon^{-aT}}$	$\frac{\epsilon^{-amT}}{z-\epsilon^{-aT}}$
$\frac{1}{(s+a)^2}$	$t\epsilon^{-at}$	$\frac{Tz\epsilon^{-aT}}{(z-\epsilon^{-aT})^2}$	$\frac{T\epsilon^{-amT}[\epsilon^{-aT}+m(z-\epsilon^{-aT})]}{(z-\epsilon^{-aT})^2}$
$\frac{(k-1)!}{(s+a)^k}$	$t^k\epsilon^{-at}$	$(-1)^k\frac{\partial^k}{\partial a^k}\left[\frac{z}{z-\epsilon^{-aT}}\right]$	$(-1)^k\frac{\partial^k}{\partial a^k}\left[\frac{\epsilon^{-amT}}{z-\epsilon^{-aT}}\right]$
$\frac{a}{s(s+a)}$	$1-\epsilon^{-at}$	$\frac{z(1-\epsilon^{-aT})}{(z-1)(z-\epsilon^{-aT})}$	$\frac{1}{z-1}-\frac{\epsilon^{-amT}}{z-\epsilon^{-aT}}$
$\frac{a}{s^2(s+a)}$	$t-\frac{1-\epsilon^{-at}}{a}$	$\frac{z[(aT-1+\epsilon^{-aT})z+(1-\epsilon^{-aT}-aT\epsilon^{-aT})]}{a(z-1)^2(z-\epsilon^{-aT})}$	$\frac{T}{(z-1)^2}+\frac{amT-1}{a(z-1)}+\frac{\epsilon^{-amT}}{a(z-\epsilon^{-aT})}$
$\frac{a^2}{s(s+a)^2}$	$1-(1+at)\epsilon^{-at}$	$\frac{z}{z-1}-\frac{z}{z-\epsilon^{-aT}}-\frac{aT\epsilon^{-aT}z}{(z-\epsilon^{-aT})^2}$	$\frac{1}{z-1}-\left[\frac{1+amT}{z-\epsilon^{-aT}}+\frac{aT\epsilon^{-aT}}{(z-\epsilon^{-aT})^2}\right]\epsilon^{-amT}$
$\frac{b-a}{(s+a)(s+b)}$	$\epsilon^{-at}-\epsilon^{-bt}$	$\frac{(e^{-aT}-\epsilon^{-bT})z}{(z-\epsilon^{-aT})(z-\epsilon^{-bT})}$	$\frac{\epsilon^{-amT}}{z-\epsilon^{-aT}}-\frac{\epsilon^{-bmT}}{z-\epsilon^{-bT}}$
$\frac{a}{s^2+a^2}$	$\sin(at)$	$\frac{z\sin(aT)}{z^2-2z\cos(aT)+1}$	$\frac{z\sin(amT)+\sin(1-m)aT}{z^2-2z\cos(aT)+1}$
$\frac{s}{s^2+a^2}$	$\cos(at)$	$\frac{z(z-\cos(aT))}{z^2-2z\cos aT+1}$	$\frac{z\cos(amT)-\cos(1-m)aT}{z^2-2z\cos(aT)+1}$
$\frac{1}{(s+a)^2+b^2}$	$\frac{1}{b}\epsilon^{-at}\sin bt$	$\frac{1}{b}\left[\frac{z\epsilon^{-aT}\sin bT}{z^2-2z\epsilon^{-aT}\cos(bT)+\epsilon^{-2aT}}\right]$	$\frac{1}{b}\left[\frac{\epsilon^{-amT}[z\sin bmT+\epsilon^{-aT}\sin(1-m)bT]}{z^2-2z\epsilon^{-aT}\cos bT+\epsilon^{-2aT}}\right]$
$\frac{s+a}{(s+a)^2+b^2}$	$\epsilon^{-at}\cos bt$	$\frac{z^2-z\epsilon^{-aT}\cos bT}{z^2-2z\epsilon^{-aT}\cos bT+\epsilon^{-2aT}}$	$\frac{\epsilon^{-amT}[z\cos bmT+\epsilon^{-aT}\sin(1-m)bT]}{z^2-2z\epsilon^{-aT}\cos bT+\epsilon^{-2aT}}$
$\frac{a^2+b^2}{s[(s+a)^2+b^2]}$	$1-\epsilon^{-at}\left(\cos bt+\frac{a}{b}\sin bt\right)$	$\frac{z(Az+B)}{(z-1)(z^2-2z\epsilon^{-aT}\cos bT+\epsilon^{-2aT})}$	$\frac{1}{z-1}$
		$A=1-\epsilon^{-aT}\left(\cos bT+\frac{a}{b}\sin bT\right)$	$-\frac{\epsilon^{-amT}[z\cos bmT+\epsilon^{-aT}\sin(1-m)bT]}{z^2-2z\epsilon^{-aT}\cos bT+\epsilon^{-2aT}}$
		$B=\epsilon^{-2aT}+\epsilon^{-aT}\left(\frac{a}{b}\sin bT-\cos bT\right)$	$\frac{+\frac{a}{b}\{\epsilon^{-amT}[z\sin bmT-\epsilon^{-aT}\sin(1-m)bT]\}}{z^2-2z\epsilon^{-aT}\cos bT+\epsilon^{-2aT}}$
$\frac{1}{s(s+a)(s+b)}$	$\frac{1}{ab}+\frac{\epsilon^{-at}}{a(a-b)}$	$\frac{(Az+B)z}{(z-\epsilon^{-aT})(z-\epsilon^{-bT})(z-1)}$	$A=\frac{b(1-\epsilon^{-aT})-a(1-\epsilon^{-bT})}{ab(b-a)}$
	$+\frac{\epsilon^{-bt}}{b(b-a)}$		$B=\frac{a\epsilon^{-aT}(1-\epsilon^{-bT})-b\epsilon^{-bT}(1-\epsilon^{-aT})}{ab(b-a)}$

EERI418

Semestertoets 2 - (memo) 14-04-2016

VRAAG 1 (8)

Determine $D(z)$

$$\therefore \quad m(k) = 0{,}7\,m(k-1) + 0{,}5\,e(k)$$

$$M(z) = 0{,}7\,M(z)\,z^{-1} + 0{,}5\,E(z)$$

$$M(z)\left[1 - 0{,}7\,z^{-1}\right] = 0{,}5\,E(z)$$

$$\frac{M(z)}{E(z)} = \frac{0{,}5\,z}{z - 0{,}7} \quad ✓✓$$

Time delay: $t_0 = 185$ ms $\qquad T = \frac{1}{20\,\text{Hz}} = 50$ ms

$$\frac{t_0}{T} = k \text{ res } \Delta \implies \frac{185}{50} = 3{,}7 = 3 \text{ res } 0{,}7 \quad ✓$$

$$\therefore k = 3 \qquad \Delta = 0{,}7$$

$$m = 1 - \Delta = 0{,}3 \quad ✓$$

$$G(z,m) = \mathcal{Z}_m\left[\frac{1 - e^{-sT}}{s(s+5)}\right]\Bigg|_{m=0{,}3} \quad ✓$$

$$= (1 - z^{-1})\frac{1}{5}\,\mathcal{Z}_m\left(\frac{5}{s(s+5)}\right)\Bigg|_{m=0{,}3}$$

$$= \frac{z-1}{z}\cdot\frac{1}{5}\cdot\left[\frac{1}{z-1} - \frac{e^{-5\times 0{,}3/20}}{z - e^{-5/20}}\right] \quad ✓$$

$$= \frac{z-1}{z}\cdot\frac{1}{5}\left[\frac{1}{z-1} - \frac{0{,}93}{z - 0{,}78}\right]$$

$$= \frac{z-1}{z}\cdot\frac{1}{5}\left[\frac{z - 0{,}78 - 0{,}93(z-1)}{(z-1)(z-0{,}78)}\right]$$

$$= \frac{1}{5z} \cdot \left[\frac{0{,}07z + 0{,}15}{z - 0{,}78} \right]$$

$$\therefore \frac{C(z)}{E(z)} = z^{-3} \cdot 0{,}2 \cdot z^{-1} \left[\frac{0{,}07z + 0{,}15}{z - 0{,}78} \right] \frac{0{,}5z}{(z-0{,}7)}$$

$$= z^{-3} \cdot 0{,}2 \cdot z^{-1} \frac{0{,}035z^2 + 0{,}075z}{(z-0{,}78)(z-0{,}7)}$$

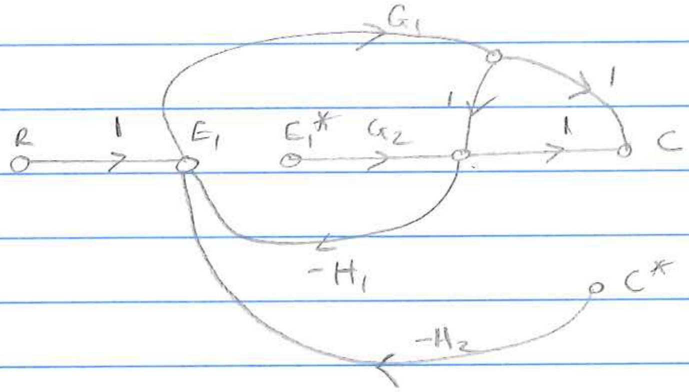
$$= z^{-3} \cdot 0{,}2\,(0{,}035)\,z^{-1} \cdot z \frac{(z + 2{,}143)}{(z-0{,}78)(z-0{,}7)}$$

$$= \frac{z^{-3} \cdot 0{,}007\,(z + 2{,}143)}{(z-0{,}78)(z-0{,}7)}$$

✓✓

VRAAG 2 (10)

DRAW SIGNAL-FLOW DIAGRAM



List of inputs and outputs:

Inputs: R, E_1^*, C^*

Outputs: E_1, C

① $E_1 = R - H_1(G_2E_1^* + G_1E_1) - H_2C^*$

② $C = G_2E_1^* + G_1E_1 + G_1E_1$

① can be rewritten:

$$\boxed{E_1 = \frac{R}{(1+H_1G_1)} - \frac{H_1G_2E_1^*}{(1+H_1G_1)} - \frac{H_2C^*}{(1+H_1G_1)}}$$

$C = G_2E_1^* + 2G_1E_1$, Then by substituting ① in this eq one get

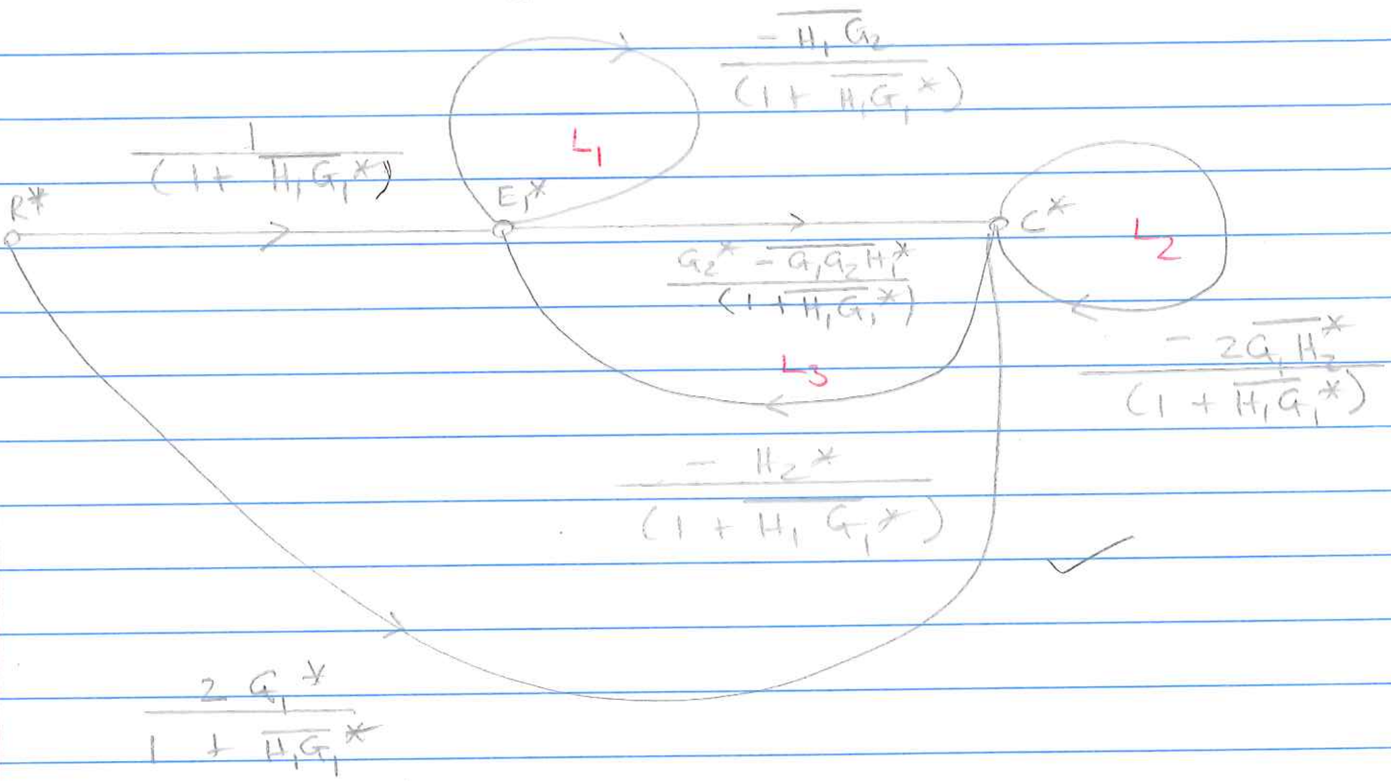
$$\boxed{C = \left[\frac{G_2 - G_1G_2H_1}{(1+H_1G_1)}\right]E_1^* + \left[\frac{2G_1}{(1+H_1G_1)}\right]R - \left[\frac{2G_1H_2}{(1+H_1G_1)}\right]C^*}$$

next, take the starred transform

$$E_1^* = \left[\frac{1}{(1+\overline{H_1G_1}^*)}\right]R^* - \left[\frac{\overline{H_1G_2}^*}{(1+\overline{H_1G_1}^*)}\right]E_1^* - \left[\frac{H_2^*}{(1+\overline{H_1G_1}^*)}\right]C^*$$

$$C^* = \left[\frac{G_2^* - \overline{G_1G_2H_1}^*}{(1+\overline{H_1G_1}^*)}\right]E_1^* + \left[\frac{2G_1^*}{1+\overline{H_1G_1}^*}\right]R^* - \left[\frac{2\overline{G_1H_2}^*}{(1+\overline{H_1G_1}^*)}\right]C^*$$

Draw the starred signal-flow diagram



Use Mason's rule to derive the transfer function

Forward paths : $P_1 = \frac{G_2^* - \overline{G_1 G_2 H_1}^*}{(1 + \overline{H_1 G_1}^*)^2}$

$P_2 = \frac{2 G_1^*}{(1 + \overline{H_1 G_1}^*)}$

Loops: $L_1 = \frac{-\overline{H_1 G_2}^*}{(1 + \overline{H_1 G_1}^*)}$

$L_2 = \frac{-2\overline{G_1 H_2}^*}{(1 + \overline{H_1 G_1}^*)}$

$L_3 = \frac{G_2^* - \overline{G_1 G_2 H_1}^*}{(1 + \overline{H_1 G_1}^*)}$

2 non-touching loop $= L_1 L_2$

$\Delta = 1 - (L_1 + L_2 + L_3) + (L_1 L_3)$

$\Delta_1 = 1$

$\Delta_2 = 1 - (L_1)$ since P_2 does not touch L_1

$$\frac{C^*}{R^*} = \frac{\sum P_k \Delta_k}{\Delta}$$

$$= \frac{P_1(1) + P_2(1-L_1)}{1-(L_1+L_2+L_3)+(L_1L_3)}$$

$$= \frac{\dfrac{G_2 - \overline{G_1G_2H_1}^*}{(1+\overline{H_1G_1}^*)^2} + \dfrac{2G_1^*}{(1+\overline{H_1G_1}^*)}\left[1 - \dfrac{-\overline{H_1G_2}^*}{(1+\overline{H_1G_1}^*)}\right]}{1 - \left[\dfrac{-\overline{H_1G_2}^*}{(1+\overline{H_1G_1}^*)} + \dfrac{-2\overline{G_1H_1}^*}{(1+\overline{H_1G_1}^*)} + \dfrac{G_2^* - \overline{G_1G_2H_1}^*}{(1+\overline{H_1G_1}^*)}\right] + \left[\dfrac{-\overline{H_1G_2}^*}{1+\overline{H_1G_1}^*}\right]\left[\dfrac{G_2^* - \overline{G_1G_2H_1}^*}{(1+\overline{H_1G_1}^*)}\right]}$$

✓

VRAAG 3 [20]

3.1 If the system error is 0, then

$$r(t) - 0{,}4\,\theta(t) = 0$$

So for $\theta(t) = 30^\circ$

$$\therefore\ r(t) = 0{,}4\,\theta(t) = 0{,}4\,(30)$$
$$= 12$$

For $\theta(t) = -30^\circ$

$$\Rightarrow\ r(t) = -12$$ ✓ (1)

3.2 Outputs : θ, E
Inputs : E^*, R

$$\therefore\ E = R - 0{,}4\,\theta$$
$$\theta = G D^* E^*.$$

① $E = R - 0{,}4\,G D^* E^*$
② $\theta = G D^* E^*$

$\Big\}$ outputs in terms of system inputs.

Star $\therefore$ (a) $E^* = R^* - 0{,}4\,G^* D^* E^*$
(b) $\theta^* = G^* D^* E^*$

$\therefore$ FROM (a) : $E^*(1 + 0{,}4\,G^* D^*) = R^*$

$$E^* = \frac{R^*}{1 + 0{,}4\,G^* D^*}$$

subs in (b)

$$\theta^* = \frac{G^* D^* R^*}{(1 + 0{,}4\,G^* D^*)}$$ ✓ (1)

$$\therefore\ \frac{\theta(z)}{R(z)} = \frac{G(z)\,D(z)}{1 + 0{,}4\,G(z)\,D(z)}$$

3.3 $$\frac{\Theta(z)}{R(z)} = \frac{G(z)\,D(z)}{1 + 0{,}4\,G(z)\,D(z)}$$

$$G(z) = \mathcal{Z}\left[\frac{1 - e^{-sT}}{s} \cdot k \cdot \frac{20}{s(s+6)}\right] \checkmark$$

$$= \frac{z-1}{z} \; k \; \mathcal{Z}\left[\frac{20}{s^2(s+6)}\right]$$

$$= \frac{z-1}{z} \; \frac{20k}{6} \; \mathcal{Z}\left[\frac{6}{s^2(s+6)}\right] \checkmark$$

with $K = 20$, $T = 0{,}05\,s$ ✓

and $$\mathcal{Z}\left[\frac{a}{s^2(s+a)}\right] = \frac{z\left[(aT - 1 + e^{-aT})z + (1 - e^{-aT} - aTe^{-aT})\right]}{a(z-1)^2(z - e^{-aT})}$$

Then $$G(z) = 0{,}4536\,\frac{z + 0{,}905}{(z-1)(z-0{,}7408)} \checkmark$$ (4)

Tipe 1

3.4) $$e_{ss}(kT) = \lim_{z\to 1}(z-1)\,E(z)$$

$$E(z) = \frac{R(z)}{1 + 0{,}4\,G(z)\,D(z)}$$

$$R(z) = \frac{Tz}{(z-1)^2} = \frac{0{,}05\,z}{(z-1)^2}$$

$$E(z) = \frac{0{,}05z}{(z-1)^2}\left[\frac{1}{1 + 0{,}4\cdot 0{,}54\,\frac{z+0{,}905}{(z-1)(z-0{,}7408)}}\right]$$

$$= \frac{0{,}05z}{(z-1)^2}\left[\frac{(z-1)(z-0{,}7408)}{(z-1)(z-0{,}7408) + 0{,}1814\,(z+0{,}905)}\right]$$

$$= \frac{0{,}05z}{(z-1)}\;\frac{z-0{,}7408}{(z^2 - z - 0{,}7408z + 0{,}7408 + 0{,}1814z + 0{,}164)}$$

$$= \frac{0{,}05z}{(z-1)}\;\frac{z-0{,}7408}{(z^2 - 1{,}559z + 0{,}905)}$$

$$e_{ss}(kT) = \lim_{z\to 1} \frac{0{,}05\,z\,(z-0{,}7408)}{(z^2 - 1{,}559z + 0{,}905)}$$

$$= \frac{0{,}01296}{0{,}346}$$

$$= 0{,}037^{\circ}$$

(4)

3.5) complex poles at $z = 0{,}78 \pm j\,0{,}545$

$= 0{,}95 \angle \pm 0{,}61$ rad

$$\zeta = \frac{-\ln r}{\sqrt{\ln^2 r + \theta^2}} = \frac{-\ln 0{,}95}{\sqrt{\ln^2 0{,}95 + 0{,}61^2}} = 0{,}084$$

$$\omega_n = \frac{1}{T}\sqrt{\ln^2 r + \theta^2}$$

$$= \frac{1}{0{,}05}\sqrt{\ln^2 0{,}95 + 0{,}61^2}$$

$$= 12{,}24 \text{ rad/s}$$

(5)

3.6 $m(k) = e(k) - 0{,}9\, e(k-1) + m(k-1)$

$$M(z) = E(z) - 0{,}9\, E(z)\, z^{-1} + M(z)\, z^{-1}$$

$$M(z)(1 - z^{-1}) = E(z)[1 - 0{,}9 z^{-1}]$$ ✓

$$M(z)/E(z) = \frac{1 - 0{,}9 z^{-1}}{1 - z^{-1}} = \frac{z - 0{,}9}{z - 1}$$ ✓

$$\therefore \quad D(z)\,G(z) = \frac{(z-0{,}9)}{(z-1)} \cdot \frac{(0{,}4536\, z + 0{,}4105)}{(z-1)(z-0{,}7408)}$$

$\therefore$ system typ = 2 ✓

(3)

3.7 $$E(z) = \frac{R(z)}{1 + 0{,}4\, G(z) D(z)} \qquad R(z) = \frac{T\, z}{(z-1)^2} = \frac{(0{,}05)z}{(z-1)^2}$$

$$=$$

$$= \frac{0{,}05}{(z-1)^2}\left[\frac{1}{1 + 0{,}4 \frac{(z-0{,}9)(0{,}4536 z + 0{,}4105)}{(z-1)^2 (z-0{,}7408)}}\right]$$

$$= \frac{0{,}05}{(z-1)^2}\left[\frac{(z-1)^2 (z-0{,}7408)}{(z-1)^2 (z-0{,}7408) + 0{,}4\,(z-0{,}9)(0{,}4536 z + 0{,}4105)}\right]$$

$$e_{ss}(kT) = \left.\frac{(z-1)\quad 0{,}05\,(z-0{,}7408)}{(z-1)^2 (z-0{,}7408) + 0{,}4\,(z-0{,}9)(0{,}4536 z + 0{,}4105)}\right|_{z=1}$$

$$= 0$$ ✓

(2)