SMPM

150 kW

400 V

50 Hz

4 pola

$R_s = 0.03$

$X_{\sigma s} = 0.05$

$X_{md} = 0.2$

$X_{mq} = 0.5$

$U_s = 1$

a) ako je $\gamma = 0$

$I_s = 1, f = 1$

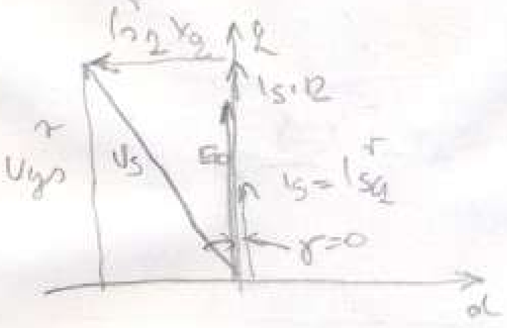
$M, \cos\varphi, E_0$

b) ako je $I_s = 1$

$E_0 = E_0(\alpha)$

γ i U_s za max M

$M = ?$



a) $X_d = X_{md} + X_{\sigma s} = 0.25$

$X_q = X_{mq} + X_{\sigma s} = 0.55$

$$E_0 = \sqrt{U_s^2 - (I^r_{sq} X_q)^2} - I^r_{sq} R_s$$

$= 0.805$

$$M_{em} = \frac{1}{\omega} E_0 I^r_{sq} = \frac{1}{1} 0.805 \cdot 1$$

$= 0.805$

$$\cos\varphi = \frac{E_0 + I_s R_s}{U_s} = 0.835$$

6-1 $M_{em} = \frac{1}{\omega}\left[E_{d0}\cos\gamma + \frac{1}{2}(X_d - X_q) I_s^2 \sin 2\gamma\right] \quad / \quad \frac{dM}{d\gamma}$

⋮

$0.6 \sin^2\gamma - 0.805 \sin\gamma - 0.3 = 0$

$\sin\gamma = -0.3039 \rightarrow \gamma = -17.69'$

$V_S = \sqrt{(E_0 + I_{q0}^r R_s + I_{d0}^r X_d)^2 + (-I_{d0}^r R_s + I_{q0}^r X_q)^2}$

$\underline{V_S = 0.9264 \text{ p.u.}}$

27. AM

50 kW

400 V

50 Hz

2 pola

$R_S = 0.018\ \Omega$

$X_{\sigma s} = 0.09$

$R_r' = 0.022$

$X_{\sigma r}' = 0.05$

$\underline{X_m = 3.6}$

$s_n = 0.02575$

a) $i_{s\psi}$ i i_{sM} ?

za koji pogon za $M = 0.5\,M_n$

uz ψ_n

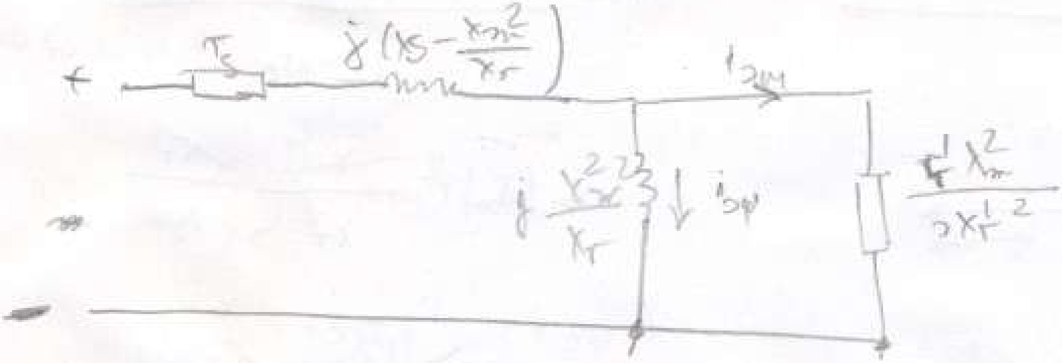
za navedeno opt. faktor odrediti i_S, s_r i U_S. Izracunajte napon statora ako je $f = 15\,Hz$

bf $i_{s\psi}$ i i_{sM}

M_{max}

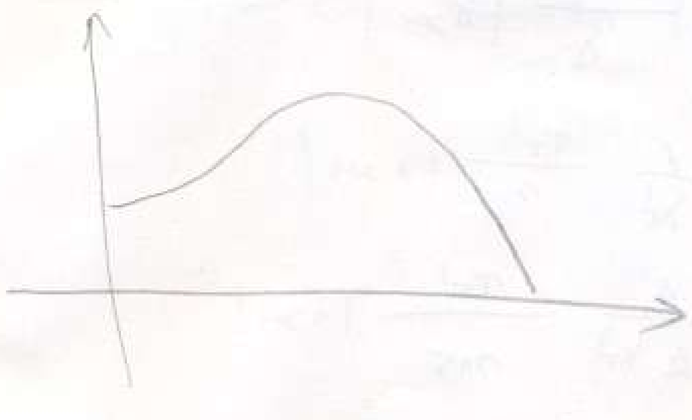
$i_s \leq i_{s(a)}$

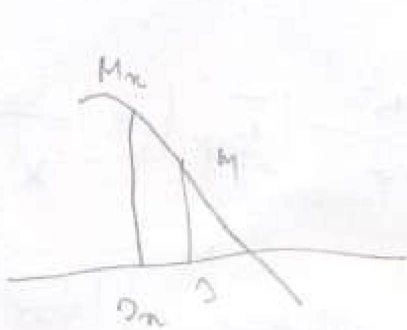
<u>a</u>



$$M_n = \frac{1}{1 - s_n} = 1.0264$$

$$M = 0.5\,M_n = 0.5132$$





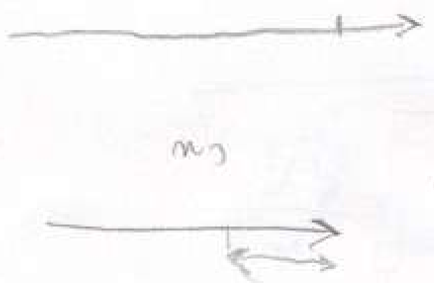
$s = 0.012875$

$$k = \frac{f}{f_n} = \frac{15}{50} = 0.3$$

$s_{new} = s_{15Hz} \cdot k$

50 Hz:

$s = s_{15Hz} \cdot k$



$$M = \frac{|\bar{i}_{sM}|^2 \frac{x_m^2}{x_r^2} \frac{\cancel{k}}{k^{\cancel{2}}} \cdot \frac{r_r'}{s_{15Hz}}}{k \cdot \omega_s}$$

$$= |\bar{i}_{sM}|^2 \frac{x_m^2}{x_r'^2} \frac{r_r'}{s}$$

$$\Rightarrow |\bar{i}_{sM}| = 0.5261$$

$x_r' = x_{\sigma r}' + x_m = 3.59$

$x_s = x_{\sigma s} + x_m = 3.59$

$$\frac{x_m^2}{x_r'} |\bar{i}_{s\psi}| = \frac{x_m^2}{x_r'^2} \frac{r_r'}{s} |\bar{i}_{sM}|$$

50Hz $$|\bar{i}_{s\psi}| = \frac{1}{x_r'} \frac{r_r'}{s} |i_{sM}|$$

15 Hz $$|\bar{i}_{s\psi}| = \frac{1}{k\, x_r'} \frac{r_r'}{s_{15}} |i_{sM}|$$

$$|i_{sy}| = \frac{1}{x_r'} \frac{r_2'}{s} |\bar{i}_{sm}|$$

$$= \cancel{0.2675}$$

$$i_s = \sqrt{|i_{sm}|^2 + |i_{sy}|^2} = 0.6225$$

$$Z = 0.4808 \angle 30.27^\circ$$

$$u_s = |i_s| \cdot |Z| = 0.2993$$

$$U = 4.44 N \phi f$$

$$M = \frac{x_m^2}{x_r'} |\bar{i}_{sm}| |\bar{i}_{sy}|$$

$$|i_s|^2 = |i_{sm}|^2 + |i_{sy}|^2$$

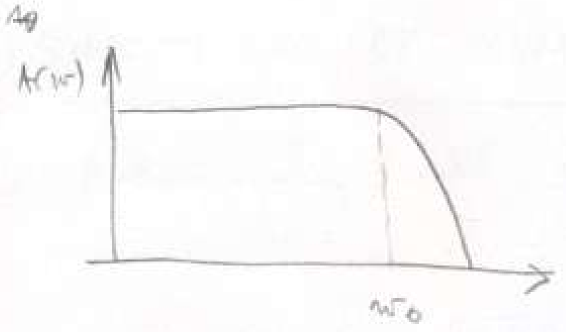
$$M = \frac{x_m^2}{x_r} |\bar{i}_{sm}| \sqrt{|i_s|^2 - |\bar{i}_{sm}|^2}$$

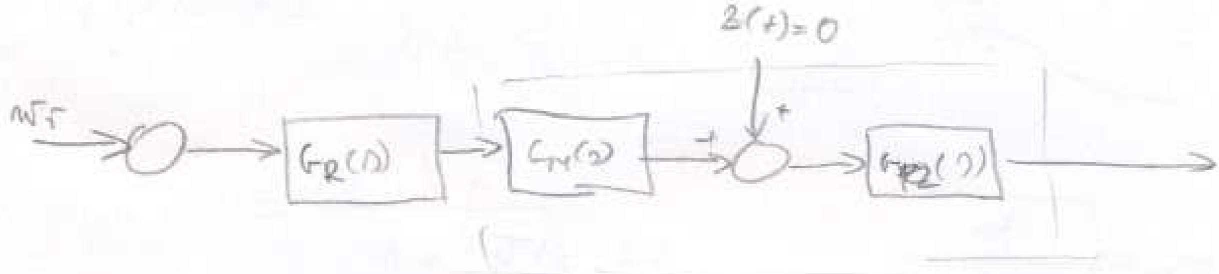
0.625

$$\frac{dM}{d|i_{sm}|} \Rightarrow 0 \quad \Rightarrow |i_{sm}| = \frac{|\bar{i}_s|}{\sqrt{2}} = 0.4402$$

(1) TEHNIČKI OPTIMUM

- prošireni optimum na dolazi





$$G_{p1}(s) = \frac{K_p}{1+T_1 s}$$

$K_p = 2$

$T_1 = 0.05 s$

$T_\Sigma = 0.01 s$

$$G_{p2}(s) = \frac{1}{1+T_\Sigma s}$$

$$G_{PT2}(s) = \frac{K}{\frac{1}{\omega_n^2} s^2 + \frac{2\xi}{\omega_n} s + 1}$$

$$G_R(s) = K_R \frac{1+T_I s}{T_I s} \quad , \quad T_I = T_1 = 0.05 s$$

$$G_0(s) = G_R(s)\, G_p(s) = K_R \frac{1+T_I s}{T_I s} \frac{K_p}{(1+T_1 s)(1+T_\Sigma s)} =$$

$$K_0 \frac{1}{T_I \cdot s(1+T_\Sigma s)}$$

$$G_{cl}(s) = \frac{G_d(s)}{1+G_d(s)}$$

$$= \frac{K_0}{T_1 T_\Sigma s^2 + T_1 s + K_0}$$

$$= \frac{1}{\frac{T_1 T_\Sigma}{K_0} s^2 + \frac{T_1}{K_0} s + 1}$$

$$\omega_n = \sqrt{\frac{K_0}{T_1 T_\Sigma}} \qquad \frac{2\xi}{\omega_n} = \frac{T_1}{K_0}$$

$$\xi = \frac{1}{2}\sqrt{\frac{K_0}{T_1 T_\Sigma}}\ \frac{T_1}{K_0}$$

$$\xi = \frac{1}{2}\sqrt{\frac{T_1}{K_0 T_\Sigma}}\ \Big|^2$$

$$\rightarrow 4\xi^2 = \frac{1}{K_R K_p}\ \frac{T_1}{T_\Sigma}$$

$$K_R = \frac{1}{4\xi^2}\ \frac{1}{K_p}\ \frac{T_1}{T_\Sigma} = 1.25$$

Uvjet za tehnički optimum = nema oscilacija ⇒ [illegible]

② SIMETRIČNI OPTIMUM

- frekvencijska karakt. simetrična u odnosu na neku točku

$$G_R(s) = K_R \frac{1+T_I s}{T_I s}$$

$$G_{p1}(s) = \frac{K_p}{1+T_\Sigma s}$$

$$G_{p2}(s) = \frac{1}{T_1 s}$$

$$G_o(s) = G_R(s) \cdot G_p(s) = K_o \frac{1}{T_I T_1 s^2} \quad \frac{1+T_I s}{1+T_\Sigma s}$$

$$\varphi_o(\omega) =$$

HURWITZ

$$\Delta_a(s) = \underbrace{T_I T_1 T_\Sigma s^3}_{a_3} + \underbrace{T_I T_1 s^2}_{a_2} + \underbrace{K_o T_I s}_{a_1} + \underbrace{K_o}_{a_0}$$

$$K_o > 0 \rightarrow K_R > 0, \; T_I > 0$$

$$\begin{array}{cccccc} a_1 & a_0 & 0 & 0 & 0 & 0 \\ a_3 & a_2 & a_1 & 0 & 0 & 0 \\ a_5 & a_4 & a_3 & a_2 & \cdots & \\ a_7 & & & & & \end{array}$$

$$D_2 = a_1 a_2 - a_0 a_3 = K_R T_1 T_i T_1 - K_0 T_2 T_1 T_\Sigma > 0$$

$$T_1 - T_\Sigma > 0 \rightarrow T_1 > T_\Sigma$$

$$\varphi_0(\omega) = -180^\circ + \operatorname{arc\,tg}(T_1 \omega) - \operatorname{arc\,tg}(T_\Sigma \omega)$$

$$\frac{d}{dx} \operatorname{arc\,tg} x = \frac{1}{x^2+1}$$

$$\frac{d\varphi_0}{d\omega} = \frac{T_1}{1+(T_1\omega)^2} - \frac{T_\Sigma}{1+(T_\Sigma \omega)^2} = 0$$

$$\Rightarrow T_1 + T_1 T_\Sigma^2 \omega^2 - T_\Sigma - T_1^2 T_\Sigma \omega^2 = 0$$

$$T_1 T_\Sigma \omega^2 (T_\Sigma - T_1) - (T_\Sigma - T_1) = 0$$

$$\omega_m = \frac{1}{\sqrt{T_1 T_\Sigma}}$$

$$\omega_c = \omega_m = \frac{1}{\sqrt{T_1 T_\Sigma}}$$

$$|G_0(j\omega_c)| = 1$$

$$\boxed{T_1 = a^2 T_\Sigma}$$ a biramo sami

$$\to a > 1$$

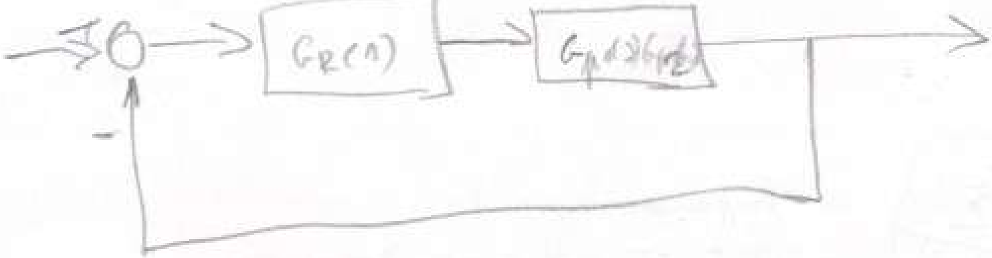
$$\omega_c = \frac{1}{a T_\Sigma}$$

$$\frac{K_0}{T_i a^2 T_\Sigma \frac{1}{a^2 T_\Sigma^2}} \frac{\sqrt{1 + (a^2 T_\Sigma \frac{1}{a T_\Sigma})^2}}{\sqrt{1 + (T_\Sigma \frac{1}{a T_\Sigma})^2}} = 1$$

$$K_R \frac{T_\Sigma}{T_1} K_p \frac{\sqrt{a^2+1}}{\sqrt{\frac{a^2+1}{a^2}}} = 1$$

$$\boxed{K_R = \frac{1}{a} \frac{1}{K_p} \frac{T_i}{T_\Sigma}}$$

3. OPTIMUM DVOSTRUKOG ODNOSA



$$G_R(s) = K_R \frac{1+T_1 s}{T_1 s}$$

$$G_p(s) = \frac{1}{(1+0.5s)(1+0.08s+0.002s^2)}$$

$$G_o(s) = \frac{2K_R(1+T_1 s)}{(1+0.5s)(1+0.08s+0.002s^2)\,T_1 s}$$

$$G_d(s) = \frac{2K_R(1+T_1 s)}{(1+0.5s)(1+0.08s+0.002s^2)\,T_1 s + 2K_R(1+T_1 s)}$$

$$G_d(s) = \frac{2K_R(1+T_1 s)}{(1+0.08s+0.002s^2+0.5s+0.04s^2+0.001s^3)\,T_1 s + 2K_R(1+T_1 s)}$$

$$G_d(s) = \frac{2K_R(1+T_1 s)}{0.001T_1 s^4 + 0.042T_1 s^3 + 0.58T_1 s^2 + T_1(1+2K_R)s + 2K_R}$$

$$G_{opt2} = \frac{1}{D_4 D_3^2 D_2^3 T_e^4 s^4 + D_3 D_2^2 T_e^3 s^3 + D_2 T_e^2 s^2 + T_e s + 1}$$

$$D_2 = D_3 = D_4 = 0.5$$

$$T_e \to G_d(s) \simeq \frac{1}{1+T_e s}$$

$$G_d = \frac{1+T_1 s}{0.0005 \frac{T_1}{K_R} s^4 + 0.021 \frac{T_1}{K_R} s^3 + 0.29 \frac{T_1}{K_R} s^2 + \frac{T_1}{K_R}(0.5+K_R) s + 1}$$

(1) $\frac{T_1}{K_R}(K_R + 0.5) = T_e$

(2) $0.29 \frac{T_1}{K_R} = D_2 T_e^2$

(3) $0.021 \frac{T_1}{K_R} = D_3 D_2^2 T_e^3$

$$\frac{(3)}{(2)} \to \frac{0.021 \frac{T_1}{K_R}}{0.29 \frac{T_1}{K_R}} = \frac{D_3 D_2^2 T_e^3}{D_2 T_e^2}$$

$$\to T_e = \frac{1}{D_2 D_3} \frac{0.021}{0.29}$$

$$\boxed{T_e = 0.2897\, s}$$

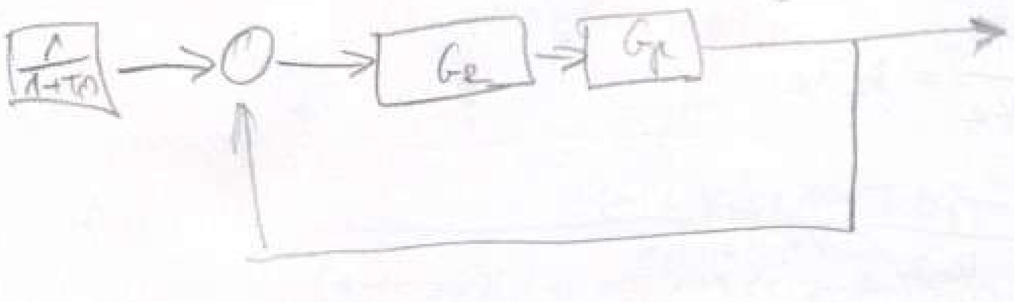
$$\frac{(1)}{(2)} \Rightarrow \frac{(K_R+0.5)\,\frac{T_I}{K_R}}{0.29\,\frac{T_I}{K_R}}$$

$$= \frac{T_e}{b_2 T_e^2}$$

$$K_R = \frac{0.29}{b_2 T_e} - 0.5 \Rightarrow K_R = 1.5$$

$$\Downarrow$$

$$\boxed{T_i = 0{,}21735}$$



(4) MODULNI OPTIMUM

$$G_p(s) = \frac{1}{(1+0.5s)(1+0.08s+0.002s^2)}$$

$$G_d = \frac{1+T_1 s}{0.005\frac{T_1}{K_R}s^4 + 0.021\frac{T_1}{K_R}s^3 + 0.29\frac{T_1}{K_R}s^2 + \frac{T_1}{K_R}(K_R+0.5)s+1}$$

$$G_{mod}(s) = \frac{1}{a_n s^n + a_{n-1}s^{n-1} + \dots + a_1 s + a_0}$$

$$G_{mod}(s) = \frac{1}{a_n s^n + a_{n-1}s^{n-1} + \dots + a_1 s + a_0}$$

(1) $a_1^2 - 2a_0a_2 = 0$

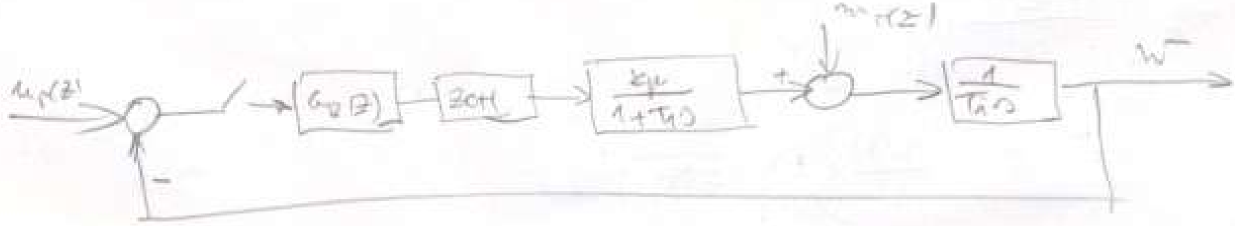
(2) $a_2^2 - 2a_1a_3 + 2a_0a_4 = 0$

(3) $a_3^2 - 2a_2a_4 = 0$

$K_R = 1.701$

$T_1 = 0.2036\,s$

1. SIMETRIČNI OPTIMUM (DIG. DOMENA)



$K_{pr}=2$ $\quad T=10ms$

$T_\Sigma = 0.1s$ $\quad G_R$ - PI regulator

$T_i = 0.5s$

, REGULATOR (DISKRETIZACIJA)

$$G_R(s) = K_R \frac{1+T_1 s}{T_1 s}$$

$$\frac{d}{dt}y(t) \approx \frac{y(k)-y(k-1)}{T}$$

$$sY(s) \approx \frac{Y(z)(1-z^{-1})}{T} \Rightarrow s = \frac{z-1}{zT}$$

$$G_R(z) = K_R\left(1+\frac{T}{T_i}\frac{z}{z-1}\right) = K_R\left(\frac{T_1 z - T_1 + T z}{T_1(z-1)}\right) = K_R \frac{z(T_1+T)-T_1}{T_1(z-1)} =$$

$$K_R \frac{T_1+T}{T_1}\frac{z-\frac{T_1}{T_1+T}}{z-1}$$

$$a^* = \frac{T_1}{T_1+T}$$

$$\boxed{G_R(z) = \frac{K_R}{a^*}\frac{z-a^*}{z-1}}$$

• PROCES (DISKRETIZACIJA)

$$G_p(z) = Z\left\{ \frac{1-e^{-sT}}{s} G_p(s) \right\} =$$

$$(1-z^{-1})\, Z\left\{ \frac{G_p(s)}{s} \right\} \quad \text{ZOH DISKT.}$$

$$G_p(z) = 0.00194 \frac{z+0.9672}{(z-1)(z-0.9042)}$$

BILINEARNA TRANS.: $z = \dfrac{1+\Omega\frac{T}{2}}{1-\Omega\frac{T}{2}}$

• REGULATOR (BT)

$$G_R(\Omega) = \frac{K_R}{a^*} \frac{\dfrac{1+\Omega\frac{T}{2}}{1-\Omega\frac{T}{2}} - a^*}{\dfrac{1+\Omega\frac{T}{2}}{1-\Omega\frac{T}{2}} - 1} = \frac{K_R}{a^*} \frac{1+\Omega\frac{T}{2} - a^* + a^*\frac{T}{2}}{1+\Omega\frac{T}{2} - 1 + \Omega\frac{T}{2}}$$

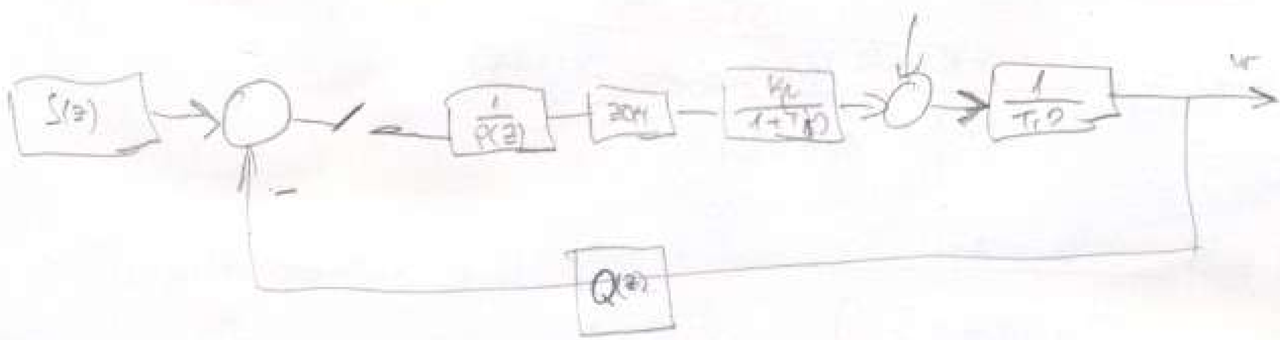
$$= \frac{K_R}{a^*} \frac{(1-a^*) + (1+a^*)\Omega\frac{T}{2}}{\Omega T} =$$

$$\frac{K_R}{a^*}(1-a^*) \frac{1 + \frac{1+a^*}{1-a^*}\frac{T}{2}\Omega}{\Omega T \frac{2}{2} \frac{1+a^*}{1-a^*} \frac{1-a^*}{1+a^*}}$$

$$= \frac{K_R}{2a^*}(1+a^*) \frac{1+T_1\Omega}{T_1\Omega}$$

$$G_p(\Omega) \doteq K_p \frac{1}{T_1\Omega(1+T_\Sigma^*\Omega)}$$ $$T_\Sigma^* = 0.1049 \simeq 0.105$$

K_R' i T_1'



· PROCES

$$G_p(z) = \frac{0.00194z + 0.00187z}{z^2 - 1.905z + 0.9048} = \frac{B(z)}{A(z)}$$

· MODELSKA FJA

$$G_M(s) = \frac{1}{D_2T_e^2s^2 + T_e s + 1}$$

$$T_e = 0,5\,s$$

$$G_M(z) = \frac{0.000942z + 0.000389z}{z^2 - 1.96z + 0.9048}$$

• OBSERVER

$A_o(z)$

→ ako je prijenosna A-je 2. reda → observer je prvog

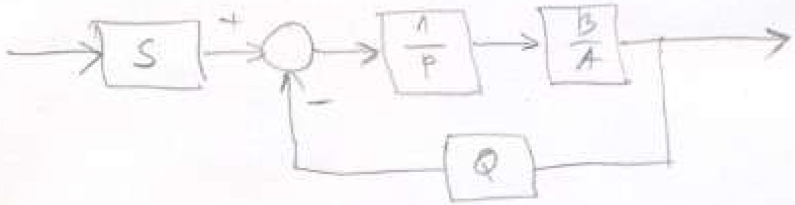
• BEZ INTEGRATORA

$\deg A_o = n-1 = 1$

$A_o(z) = z$

$\deg P = \deg S = \deg Q = n-1$

$S(z) = \frac{A_M(1)}{B(1)} A_o(z) = 0.20986\, z$



$G_d = \frac{BS}{AP+BQ} = \frac{B_M}{A_M} \frac{A_o}{A_o}$

$A(z)P(z) + B(z)Q(z) = A_M(z) A_o(z)$

$P(z) = z + p_0$

$Q(z) = q_1 z + q_0$