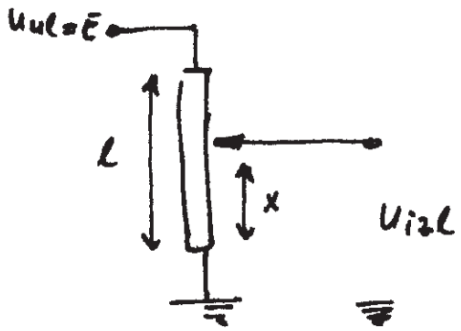
6. Principske šeme SAU

6.1. Napisati funkcije prenosa:

a) Linearnog i obrtnog potenciometra
b) Tahogeneratora
c) Pojačavača snage

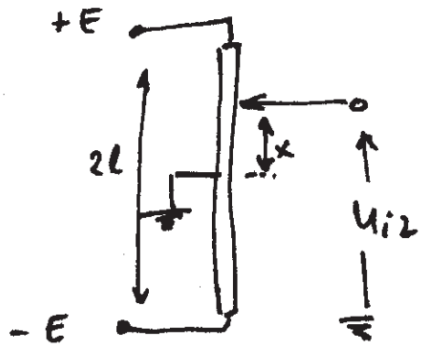
Rešenje:

a) Linearni potenciometar



$$x \in [0,l] \quad U_{izl} = \frac{x}{l} U_{ul} = \frac{x}{l} E$$

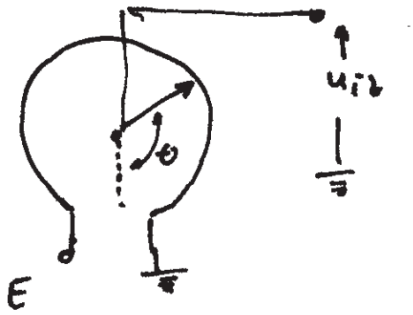
$$G(s) = \frac{U_{izl}(s)}{X(s)} = \frac{E}{l} = k_p$$



$$x \in [-l,l] \quad U_{izl} = \frac{x}{l} U_{ul} = \frac{x}{l} E$$

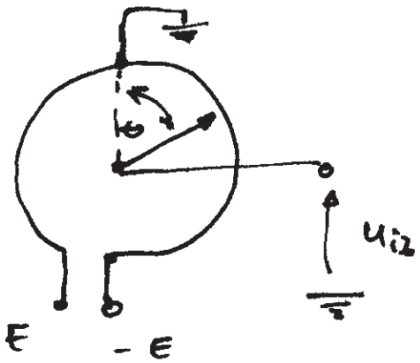
$$G(s) = \frac{U_{izl}(s)}{X(s)} = \frac{E}{l} = k_p$$

Obrtni potenciometar



$$\theta \in [0,2\pi] \quad U_{izl} = \frac{\theta}{2\pi} E$$

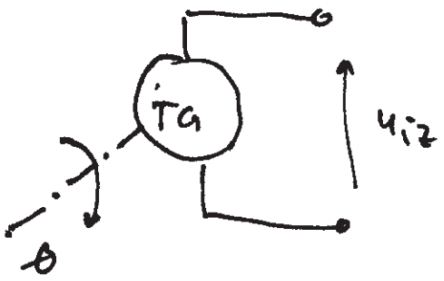
$$G(s) = \frac{U_{izl}(s)}{\theta(s)} = \frac{E}{2\pi} = k_p$$



$$\theta \in [-\pi,\pi] \quad U_{izl} = \frac{\theta}{\pi} E$$

$$G(s) = \frac{U_{izl}(s)}{\theta(s)} = \frac{E}{\pi} = k_p$$

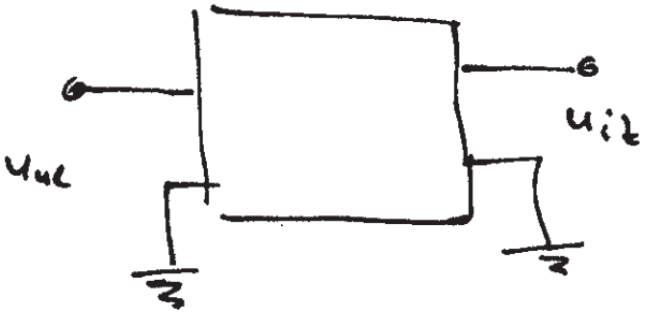
b) Tahogenerator



$$U_{izl} = k_{tg}\omega \quad G_{\omega}(s) = \frac{U_{izl}(s)}{\omega(s)} = k_{tg}$$

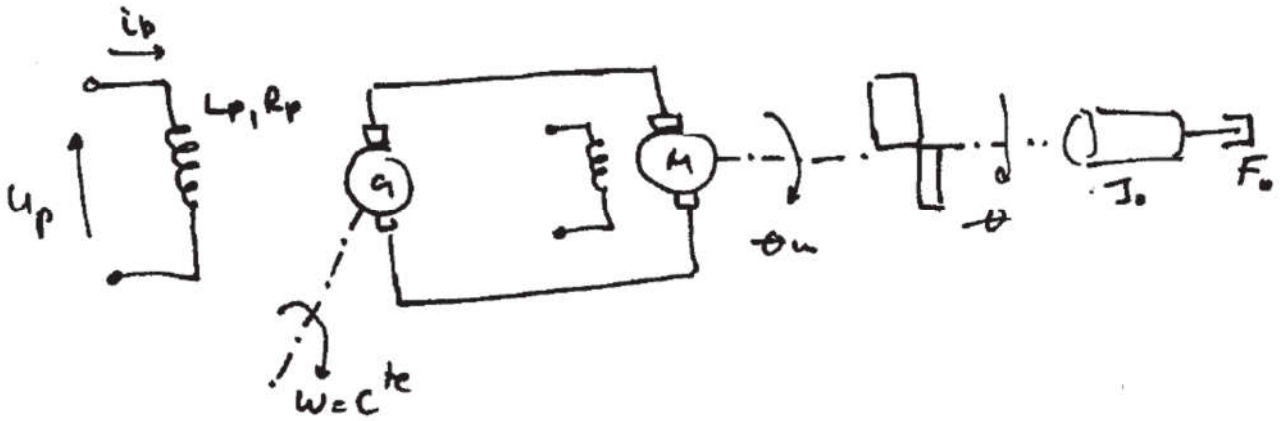
$$U_{izl} = k_{tg}\dot{\theta} = k_{tg}s\theta(s) \quad G_{\theta}(s) = \frac{U_{izl}(s)}{\theta(s)} = sk_{tg}$$

c) Pojačavač snage



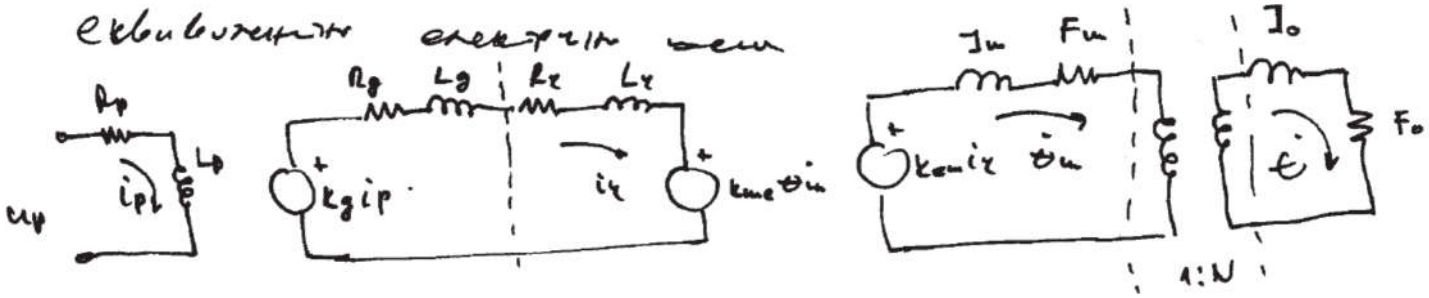
$$G(s) = \frac{U_{izl}(s)}{U_{ul}(s)} = K_{PS}$$

6.2. Odrediti funkciju prenosa $W(s) = \frac{\theta_m(s)}{U_p(s)}$ sistema sa slike (Vard-Leonardova grupa):



Rešenje:

Ekvivalentna električna šema:



$$\dot{\theta}_m = N\dot{\theta} \quad J = J_m + \frac{J_o}{N^2} \quad F = F_m + \frac{F_o}{N^2}$$

$$\begin{aligned}
&\left(R_p + sL_p\right)I_p(s) && && = U_p(s)\\
&-k_g I_p(s) && +\left[\left(L_r + L_g\right)s + R_r + R_g\right]I_r(s) && +k_{me}\dot{\theta}_m(s) && = 0\\
& && -k_{em}I_r(s) && +\left(Js + F\right)\dot{\theta}_m(s) && = 0
\end{aligned}$$

$$L_g, L_r \approx 0$$

$$G(s) = \frac{\theta_m(s)}{U_p(s)} = \frac{\dot{\theta}_m(s)}{sU_p(s)} = \frac{\Delta_{13}(s)}{s\Delta(s)}$$

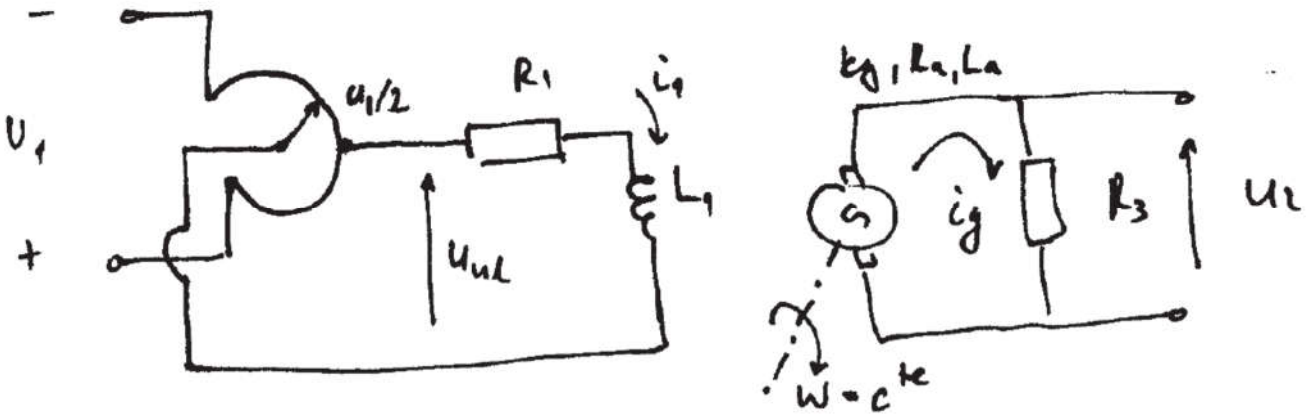
$$\Delta(s) = \begin{vmatrix} R_p + sL_p & 0 & 0 \\ -k_g & R_r + R_g & k_{me} \\ 0 & -k_{em} & Js + F \end{vmatrix}$$

$$G(s) = \frac{k_g k_{em}}{s\left(R_p + sL_p\right)\left[\left(R_r + R_g\right)\left(Js + F\right) + k_{em}k_{me}\right]} = \frac{k}{s\left(1 + sT_1\right)\left(1 + sT_2\right)}$$

$$k = \frac{k_g k_{em}}{R_p\left[\left(R_r + R_g\right)F + k_{em}k_{me}\right]} \quad T_1 = \frac{L_p}{R_p} \quad T_2 = \frac{\left(R_r + R_g\right)J}{\left[\left(R_r + R_g\right)F + k_{em}k_{me}\right]}$$

6.3. Nacrtati strukturni blok dijagram i naći funkciju prenosa generatora prikazanog na slici. Ulazni signal je ugao obrtanja potenciometra θ_1, a izlaz je napon u_2 na opterećenju. Parametri sistema su:

$$k_g = 1000\frac{V}{A}; R_1 = 1k\Omega; L_1 = 10H; L_a = 0.1H; R_a = 1\Omega; U_1 = 50V; \theta_{\max} = 2.285rad; R_3 = 9\Omega$$



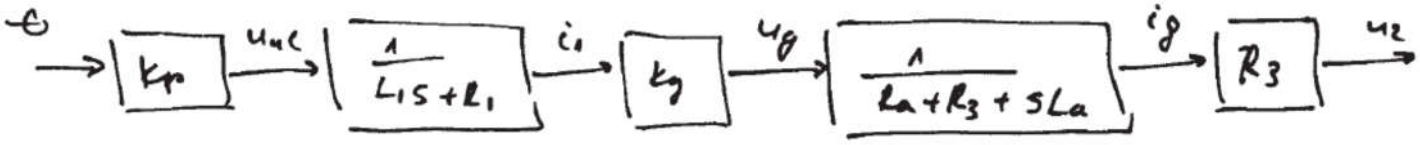
Rešenje:

Potenciometar: $U_{ul} = k_p\theta \quad k_p = ? \quad \frac{U_1}{2} = k_p\theta_{\max} \Rightarrow k_p = \frac{U_1}{2\theta_{\max}}$

Pobudno kolo: $U_{ul} = L_1\frac{di_1}{dt} + R_1 i_1 \quad \Rightarrow I_1(s) = \frac{U_{ul}(s)}{R_1 + sL_1}$

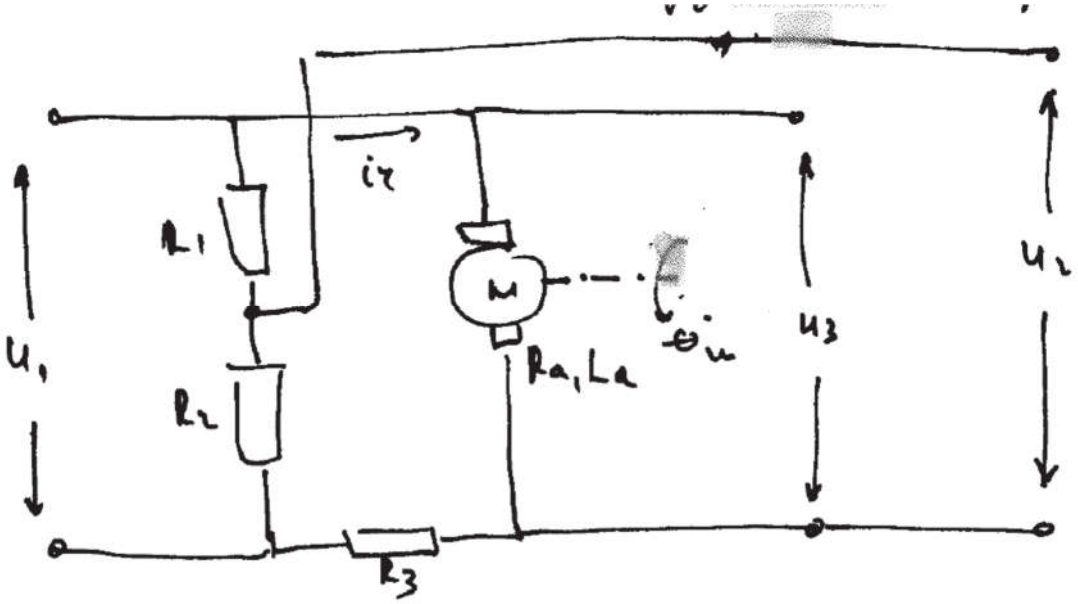
Generator: $u_g = k_g i_1 \Rightarrow U_g(s) = k_g I_1(s); \quad u_g = L_a\frac{di_a}{dt} + \left(R_a + R_3\right)i_g \Rightarrow I_g(s) = \frac{U_g(s)}{R_a + R_3 + sL_a}$

Izlaz: $u_2 = R_3 i_g \Rightarrow U_2(s) = R_3 I_g(s)$



$$\frac{U_2(s)}{\theta(s)} = \frac{k_p k_g R_3}{(L_1 s + R_1)(L_a s + R_a + R_3)} = \frac{\frac{k_p k_g R_3}{R_1(R_a + R_3)}}{\left(1 + \frac{L_1}{R_1} s\right)\left(1 + \frac{L_a}{R_a + R_3} s\right)} = \frac{k}{(1 + sT_1)(1 + sT_2)}$$

6.4. Na slici je prikazan sistem za merenje brzine obrtanja motora jednosmerne struje. Odrediti funkciju prenosa $W(s) = \frac{U_2(s)}{\dot{\theta}_m(s)}$. Parametri sistema su: $k_{me} = 0.105 \frac{V}{ob/\min}; R_1 = R_2 = 100\Omega; R_a = 2\Omega;$ Odrediti otpornost R_3 iz uslova ravnoteže $u_2 = 0$, kada je motor zakočen. Zanemariti induktivnost rotora motora L_a.



$$\dot{\theta}_m = \omega$$

$$u_1 = L_a \frac{di_r}{dt} + R_a i_r + k_{me}\omega + R_3 i_r$$

$$u_2 = \frac{R_2}{R_1 + R_2} u_1 - R_3 i_r$$

$$u_2 = \frac{R_2}{R_1 + R_2} L_a \frac{di_r}{dt} + \frac{R_2(R_a + R_3)}{R_1 + R_2} i_r + \frac{R_2}{R_1 + R_2} k_{me}\omega - R_3 i_r$$

$$u_2 = \frac{R_2}{R_1 + R_2} L_a \frac{di_r}{dt} + \frac{R_a R_2 - R_1 R_3}{R_1 + R_2} i_r + \frac{R_2}{R_1 + R_2} k_{me}\omega$$

$$L_a = 0 \Rightarrow u_2 = \frac{R_a R_2 - R_1 R_3}{R_1 + R_2} i_r + \frac{R_2}{R_1 + R_2} k_{me}\omega$$

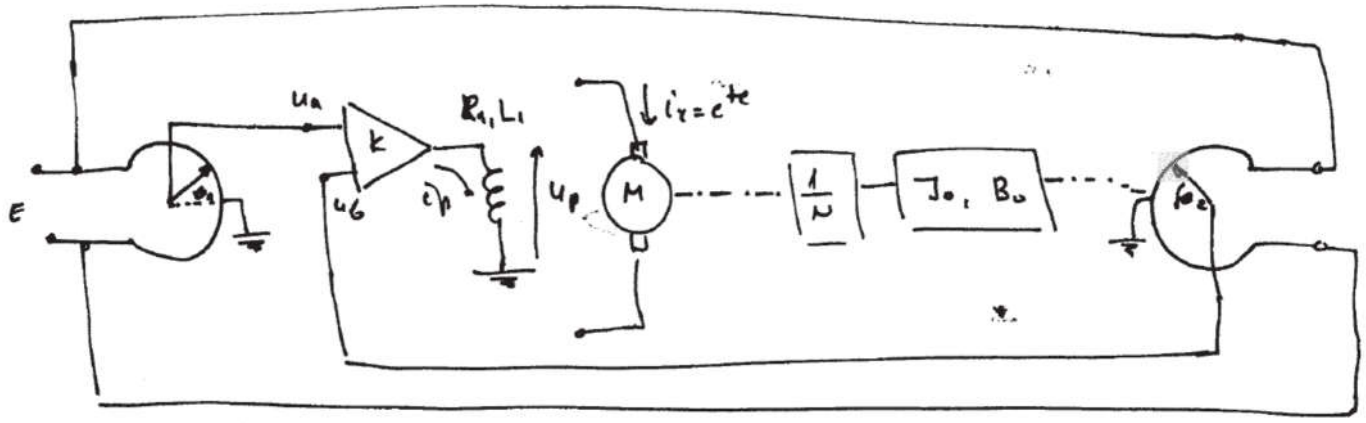
$$\omega = 0 \Rightarrow u_2 = 0 \Rightarrow R_a R_2 = R_1 R_3 \Rightarrow R_3 = \frac{R_a R_2}{R_1} = R_a = 2\Omega$$

$$u_2 = \frac{R_2}{R_1 + R_2} k_{me}\omega = \frac{1}{2} k_{me}\omega = 0.05025\omega$$

$$W(s) = \frac{U_2(s)}{\omega(s)} = 0.05025$$

6.5. Na slici je prikazan pozicioni servosistem. Formirati strukturnu blok šemu. Parametri sistema su:

$$J_m = 0.26\cdot 10^{-3} k_g m^2; B_m = 65.5\cdot 10^{-5} Nms; k_{em} = 74.5\cdot 10^{-3}\frac{Nm}{A}; N = 22.5; k_p = 1\frac{V}{rad}; R_1 = 1k\Omega; L_1 = 5H; K = 2;$$



Rešenje:

Potenciometar: $u_a = k_p\theta_1 \quad u_b = k_p\theta_2$

Pojačavač: $U_p = K\left(u_a - u_b\right)$

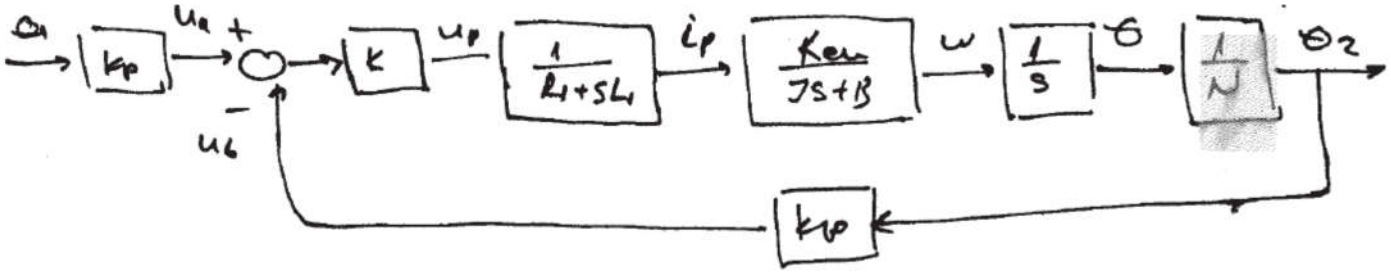
MJS upravljan strujom u pobudnom kolu:

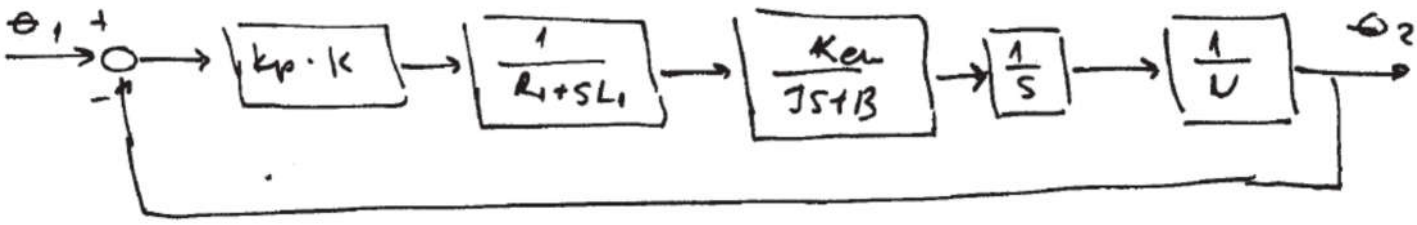
$$u_p = R_1 i_p + L_1\frac{di_p}{dt}\ ;\quad u_r = R_r i_r + L_r\frac{di_r}{dt} + k_{me}\omega\ ;\quad i_r = const.$$

$$J = J_m + \frac{J_o}{N^2};\quad B = B_m + \frac{B_o}{N^2}$$

$$k_{em} i_p = J\frac{d\omega}{dt} + B\omega\ ;\quad U_p(s) = \left(R_1 + sL_1\right) I_p(s) \Rightarrow \frac{I_p(s)}{U_p(s)} = \frac{1}{\left(R_1 + sL_1\right)}$$

$$\left(Js + B\right)\omega(s) = \frac{k_{em}}{\left(R_1 + sL_1\right)} U_p(s) \Rightarrow \frac{\omega(s)}{U_p(s)} = G_m(s) = \frac{k_{em}}{\left(R_1 + sL_1\right)\left(Js + B\right)}$$

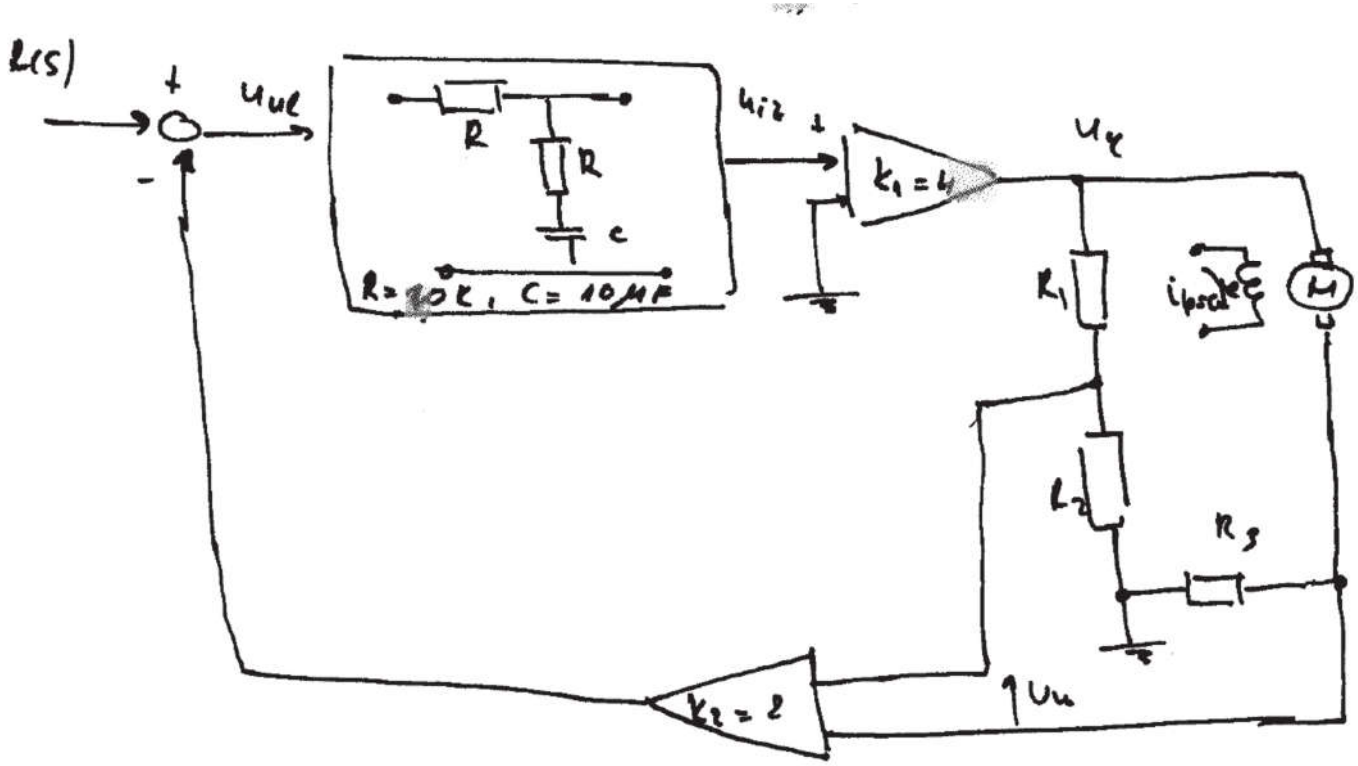




6.6. Formirati strukturnu blok šemu brzinskog servosistema prikazanog na slici. Parametri sistema su:

$$k_{me}=0.105\frac{V}{ob/\min};k_{em}=0.001\frac{Nm}{A};J_m=10^{-5}k_gm^2;J_o=222\cdot10^{-3}k_gm^2;$$
$$F_m=F_o=0;R_1=R_2=100\Omega;R_r=2\Omega;L_r=0;R=10k\Omega;C=10\mu F.$$

Odrediti otpornost R_3 iz uslova da je napon $U_m = 0$ kada je $\omega = 0$.



Rešenje:

Integralni kompenzator:

$$U_{iz}=\frac{R+\frac{1}{sC}}{2R+\frac{1}{sC}}U_{ul}=\frac{1+sRC}{1+s2RC}U_{ul}$$

$$\frac{U_{iz}}{U_{ul}}=\frac{1+sRC}{1+s2RC}=\frac{1+s0.1}{1+s0.2}=\frac{1}{2}\frac{s+10}{s+5}$$

Motor jednosmerne struje:

$$u_r=k_1u_{iz}=4u_{iz}\quad u_r=L_r\frac{di_r}{dt}+R_ri_r+R_3i_r+k_{me}\omega\Rightarrow i_r=\frac{u_r-k_{me}\omega}{R_r+R_3}$$

$$k_{em}i_r=J\frac{d\omega}{dt}+B\omega\ ;\quad J=J_m+\frac{J_o}{N^2};\quad B=B_m+\frac{B_o}{N^2}$$

$$0=J\frac{d\omega}{dt}+B\omega+\frac{k_{em}k_{me}\omega}{R_r+R_3}-\frac{k_{em}}{R_r+R_3}u_r$$

$$\frac{k_{em}}{R_r+R_3}U_r(s)=\left[(Js+B)+\frac{k_{em}k_{me}}{R_r+R_3}\right]\omega(s)$$

$$k_{em}U_r(s)=\left[(Js+B)(R_r+R_3)+k_{em}k_{me}\right]\omega(s)$$

$$\frac{\omega(s)}{U_r(s)}=\frac{k_{em}}{(Js+B)(R_r+R_3)+k_{em}k_{me}}=\frac{k_m}{1+sT_m}$$

Tahometarski merni most:

$$u_m = \frac{R_2}{R_1+R_2}u_r - R_3 i_r \;;\quad u_r = \left(R_r + R_3\right)i_r + k_{me}\omega$$

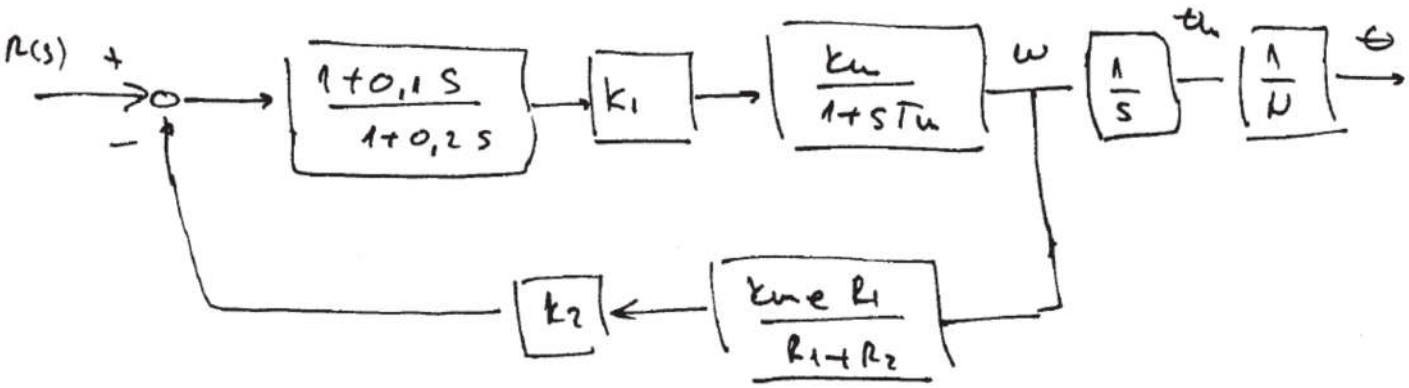
$$u_m = \frac{R_2}{R_1+R_2}\left[\left(R_r + R_3\right)i_r + k_{me}\omega\right] - R_3 i_r$$

$$u_m = \frac{R_r R_2 - R_1 R_3}{R_1+R_2}i_r + \frac{R_2}{R_1+R_2}k_{me}\omega$$

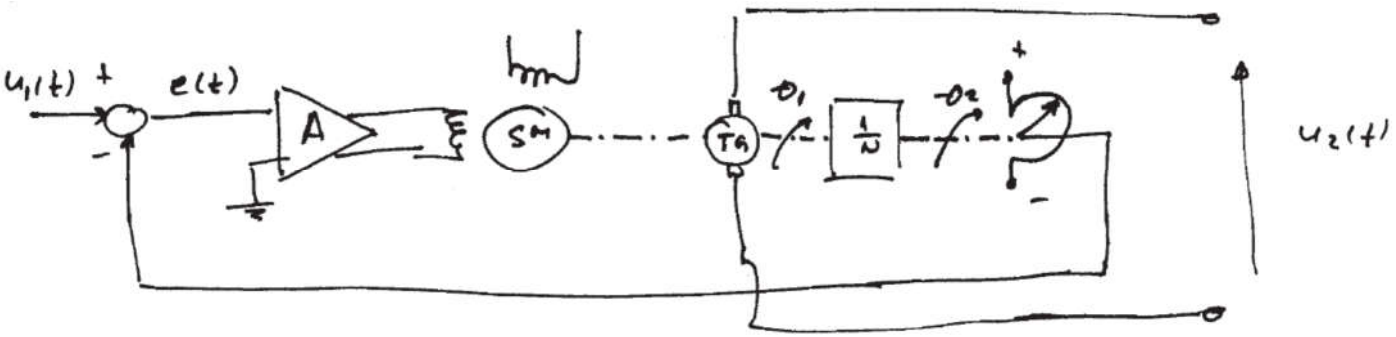
$$\omega = 0 \Rightarrow u_m = 0 \Rightarrow R_r R_2 = R_1 R_3 \Rightarrow R_3 = \frac{R_r R_2}{R_1} = R_r = 2\Omega$$

$$u_m = \frac{R_2}{R_1+R_2}k_{me}\omega = \frac{1}{2}k_{me}\omega = 0.05025\omega$$

$$\frac{U_m(s)}{\omega(s)} = 0.05025$$



6.7. Za servomehanizam sa slike ulaz je u_1, a izlaz u_2. Nacrtati strukturnu blok šemu i odrediti pojedinačno f-je prenosa elemenata sistema.



Rešenje:

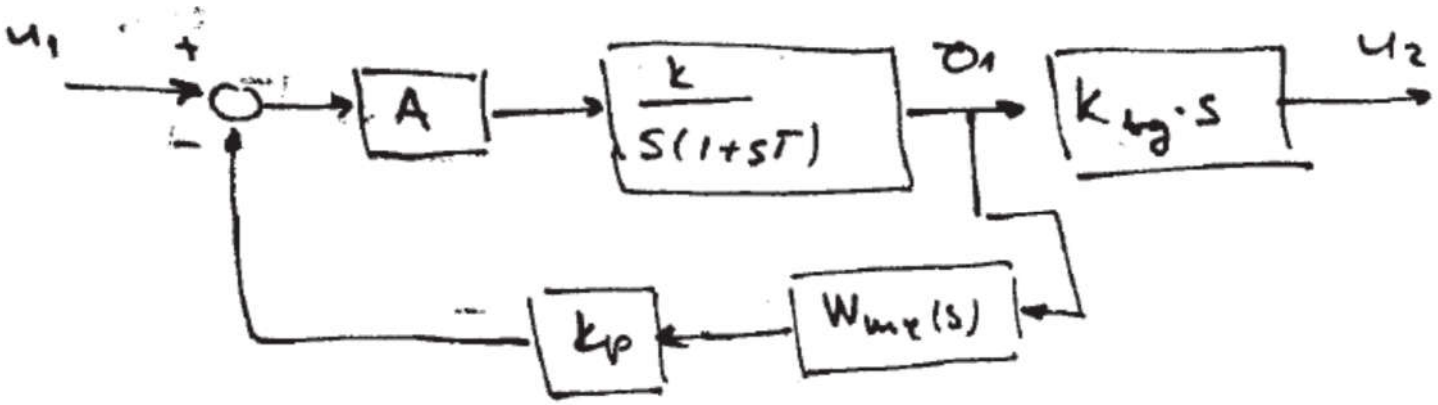
Servo pojačavač: $W_{sp}(s) = A$

Mehanički reduktor: $W_{mr}(s) = \dfrac{\theta_2(s)}{\theta_1(s)} = \dfrac{1}{N}$

Servo motor: $W_{sm}(s) = \dfrac{\theta_1(s)}{U_m(s)} = \dfrac{k}{s(1+sT)}$

Potenciometar: $W_{pot}(s) = k_p$

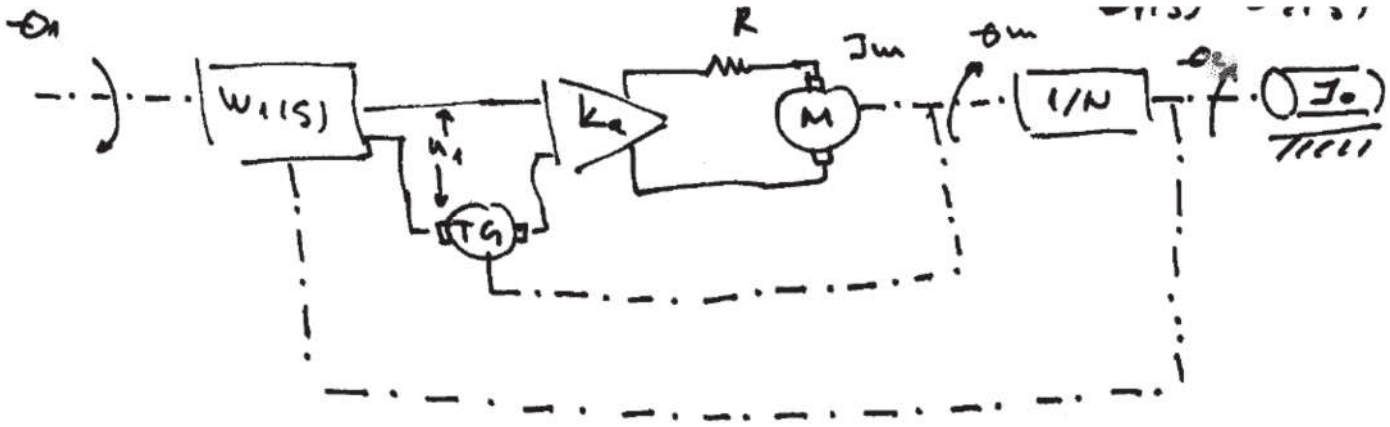
Tahogenerator: $W_{tg}(s) = \dfrac{U_2(s)}{\theta_1(s)} = sK_{tg}$



6.8. Na slici je prikazana principska šema pratećeg sistema. Formirati strukturnu blok šema ako je poznato sledeće:

$R = 1\Omega; K_a = 60; k_{me} = 0.75\frac{V}{rad/s}; k_{em} = 0.5\frac{Nm}{A}; J_m = 0.007 k_g m^2; J_o = 2880 k_g m^2; N = 100;$

$F_m = F_o = 0; L_r = 0; K_{tg} = 0.04\frac{V}{rad/s}$. Dok je $W_1(s) = \frac{U_1(s)}{\theta_1(s) - \theta_2(s)} = \frac{5}{1 + 0.025 \cdot s}$.



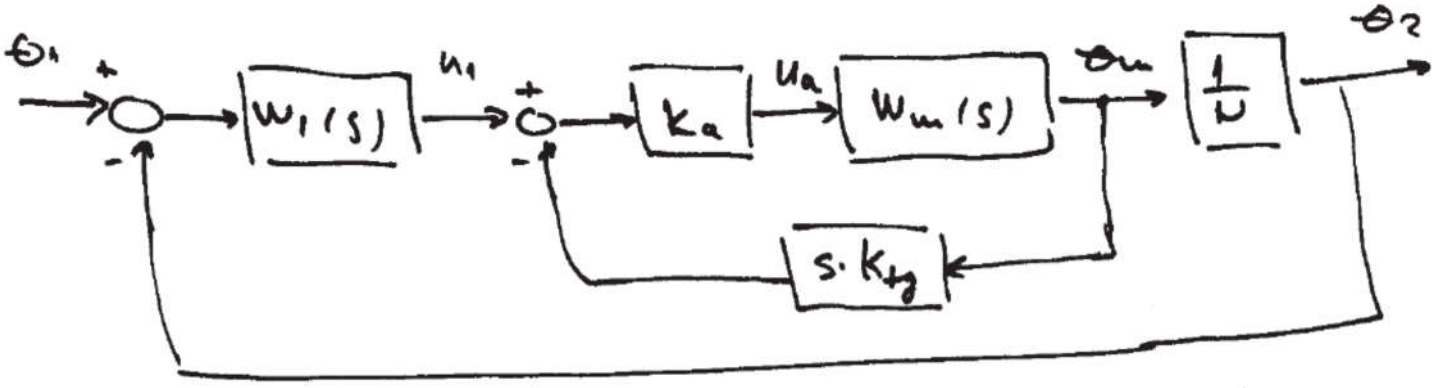
Rešenje:

$W_1(s)$ – transformatorska veza selsina.

$$RI_r(s) + k_{me} s\theta_m(s) = U_a(s)$$

MJS upravljan strujom u rotorskom kolu: $-k_{em} I_r(s) + \left(J_m + \frac{J_o}{N^2}\right) s\theta_m(s) = 0$

$$W_m(s) = \frac{\theta_m(s)}{U_a(s)} = \frac{k_{em}}{s\left[R\left(J_m + \frac{J_o}{N^2}\right)s + k_{em}k_{me}\right]}$$

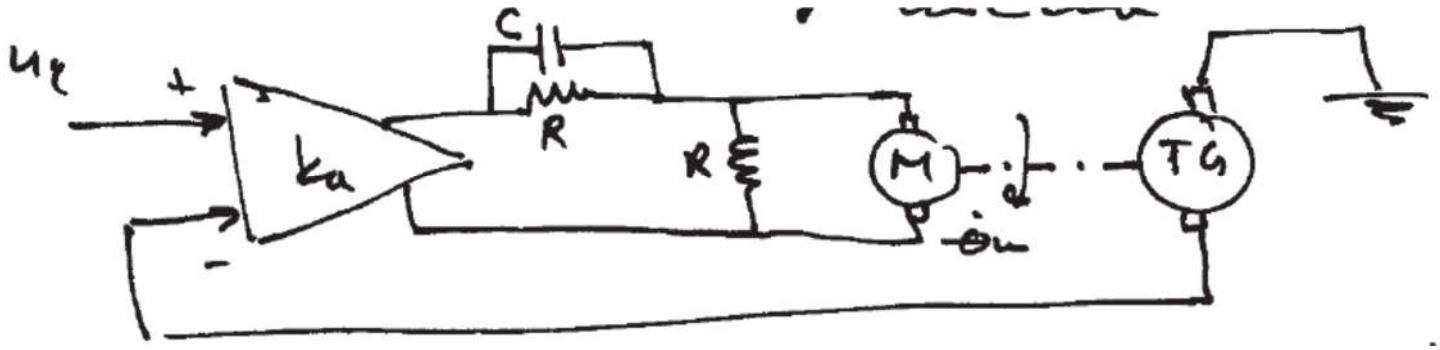


6.9. Na slici je prikazan sistem za regulaciju brzine obrtanja jednosmernog motora. Parametri sistema su:

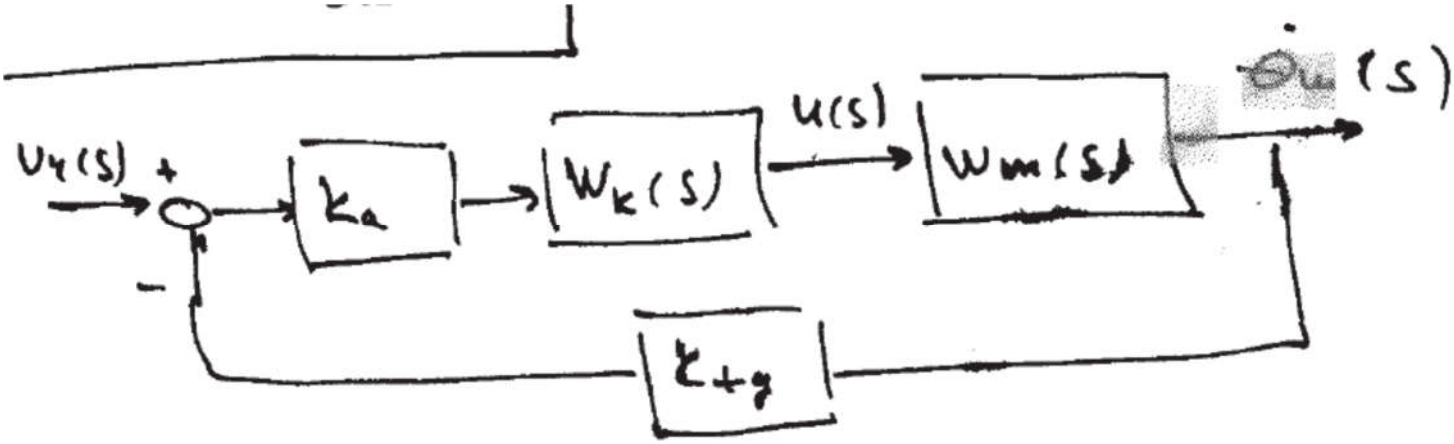
pojačanje motora $k_m = 0.5\frac{rad}{V \cdot s}$; vremenska konstanta motora $T_m = 0.04s$;

$K_a = 20; K_{tg} = 1\frac{V}{rad \cdot s^{-1}}; R = 100k\Omega; C = 1\mu F;$

Nacrtati strukturnu blok šemu sistema.



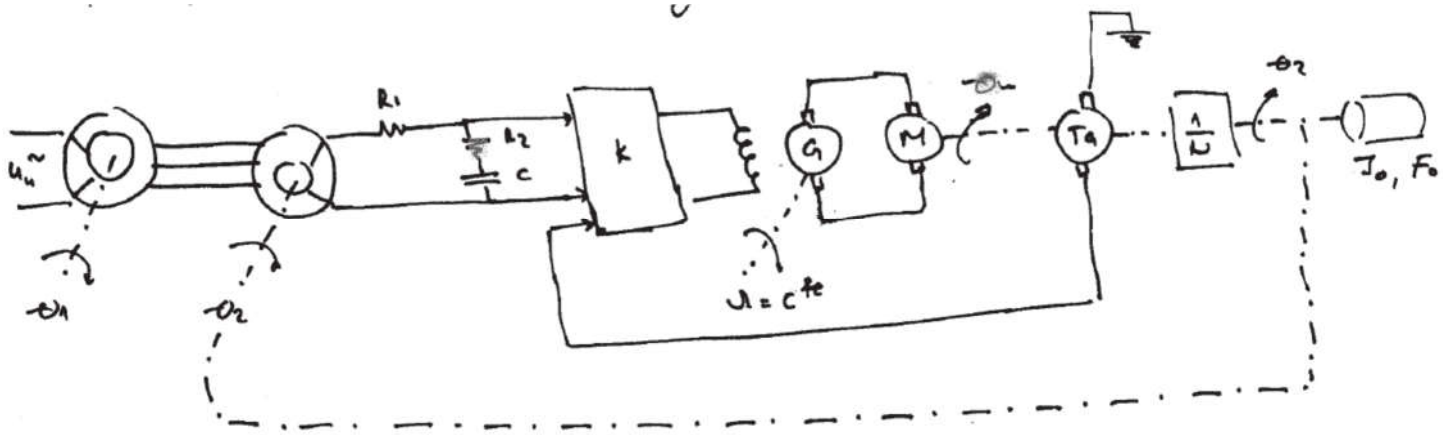
Rešenje:



Diferencijalni kompenzator: $W_k(s) = \frac{R}{\frac{R}{1+sCR} + R} = \frac{1+sCR}{2+sCR} = \frac{0.1s+1}{2(0.05s+1)} = \frac{s+10}{s+20}$

Motor jednosmerne struje: $W_m(s) = \frac{\dot{\theta}_m(s)}{U(s)} = \frac{k_m}{1+sT_m} = \frac{0.5}{1+s0.04}$

6.10. Na slici je prikazana principska šema selsinskog pozicionog servosistema sa tahometarskom stabilizacionom povratnom spregom. Nacrtati strukturnu blok šemu i odrediti f-je prenosa elemenata u njoj.



Rešenje:

Transformatorska veza selsina:

$$u_s = K_s \sin\left(\theta_1 - \theta_2\right)$$

$$\text{za } \theta_1 - \theta_2 \text{ malo } \Rightarrow \; u_s = K_s\left(\theta_1 - \theta_2\right) \quad \text{jer je } \sin\left(\theta_1 - \theta_2\right) \approx \theta_1 - \theta_2$$

$$W_s = \frac{U_s\left(s\right)}{\theta_1\left(s\right) - \theta_2\left(s\right)} = K_s$$

Integralni kompenzator: $W_k\left(s\right) = \dfrac{U_k\left(s\right)}{U_s\left(s\right)} = \dfrac{1 + sT_1}{1 + sT_2};\; T_1 = R_2C;\; T_2 = \left(R_1 + R_2\right)C;$

Pojačavač: $W_p\left(s\right) = \dfrac{U_p\left(s\right)}{U_e\left(s\right)} = K;\; U_e\left(s\right) = U_k\left(s\right) - U_{tg}\left(s\right)$

Vard-Leonardova grupa:

$$W_{WLG}\left(s\right) = \frac{k}{s\left(1 + sT_1\right)\left(1 + sT_2\right)}$$

$$k = \frac{k_g k_{em}}{R_p\left[\left(R_r + R_g\right)F + k_{em}k_{me}\right]} \qquad T_1 = \frac{L_p}{R_p} \qquad T_2 = \frac{\left(R_r + R_g\right)J}{\left[\left(R_r + R_g\right)F + k_{em}k_{me}\right]}$$

$$F = F_m + \frac{F_o}{N^2};\; J = J_m + \frac{J_o}{N^2}$$

Reduktor: $W_R\left(s\right) = \dfrac{\theta_2\left(s\right)}{\theta_m\left(s\right)} = \dfrac{1}{N}$

Tahogenerator: $W_{tg}\left(s\right) = \dfrac{U_{tg}\left(s\right)}{\theta_m\left(s\right)} = sK_{tg}$