

Structura de Reglare Automata

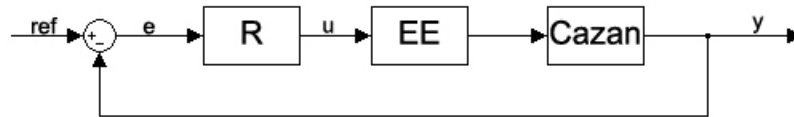
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– 2010 –

Se considera un cazan alimentat cu carbune prin intermediul unei benzi transportoare de lungime 200m si cu $v=20\text{m/s}$. Procesul de ardere al combustibilului macinat de o moara cu bile asigura o evolutie a temperaturii in incinta cazanului dupa un model $H_c(s) = \frac{K_p}{T_s s + 1} \cdot e^{-\tau s}$, unde K_p , T_s si τ vor fi alese din intervalele $K_p \in [5, 20]$, $T_s \in [20, 80]$ secunde, $\tau \in [10, 30]$ secunde.

Se cere:

a) Analiza de proces si adoptarea structurii de reglare a debitului de combustibil a.i. sa se asigure evolutia dorita a temperaturii in focar.



$$H_p(s) = H_{\text{cazan}}(s) \cdot H_{EE}(s)$$

$$H_{EE}(s) = K_T \cdot e^{-\tau s}, \text{ unde } \tau = \frac{200\text{m}}{20\text{m/s}} = 10\text{s} \text{ si se alege } K_T = 1.$$

$$\Rightarrow H_{EE}(s) = e^{-10s}$$

$$\Rightarrow H_p(s) = \frac{K_p}{T_s s + 1} \cdot e^{-\tau s} \cdot e^{-10s} = \frac{K_p}{T_s s + 1} \cdot e^{-(10+\tau)s}.$$

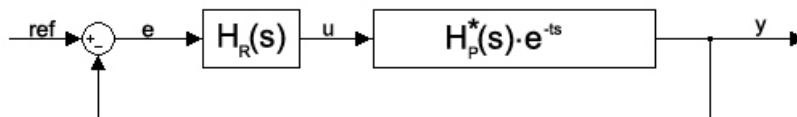
Aleg $K_p = 13$, $T_s = 33$ si $\tau = 13$

$$\Rightarrow H_p(s) = \frac{13}{33s + 1} \cdot e^{-23s}$$

Procesul este :

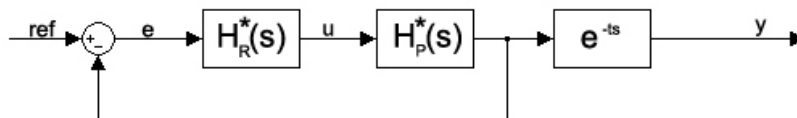
- lent – constante de timp mai mari de 10 secunde ($T_s = 33\text{s}$)
- fara constanta parazita
- cu timp mort, $\tau = 23$

Schema de Reglare cu predictor Smith



$$\Rightarrow H_o$$

$\Leftrightarrow$



$$\Rightarrow H_o^*$$

$$\text{unde } H_p^*(s) = \frac{13}{33s + 1}$$

Echivalenta scheme

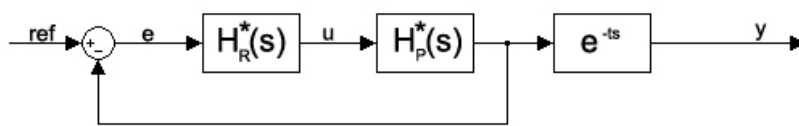
$$H_o = H_o^*$$

$$H_o = \frac{H_R(s) \cdot H_p^*(s) \cdot e^{-\tau s}}{1 + H_R(s) \cdot H_p^*(s) \cdot e^{-\tau s}} \text{ si } H_o^* = \frac{H_o^*(s) \cdot H_p^*(s)}{1 + H_o^*(s) \cdot H_p^*(s)} \cdot e^{-\tau s}$$

$$\Rightarrow H_R(s) = \frac{H_p^*(s)}{1 + H_R^*(s) \cdot H_p^*(s) \cdot (1 - e^{-\tau s})}$$

b) Sa se sintetizeze structura de regulator a.i. raspunsul indicial al sistemului de reglare sa fie un raspuns aperiodic cu timpul tranzitoriu >50 sec si timpul tranzitoriu <100 secunde.

$$\text{Regulator cu predictor Smith} \Rightarrow H_R(s) = \frac{H_R^*(s)}{1 + H_R^*(s) \cdot H_p^*(s) \cdot (1 - e^{-Ts})}$$



$$\Rightarrow H_o^*$$

$$H_o^* = \frac{H_R^*(s) \cdot H_p^*(s)}{1 + H_R^*(s) \cdot H_p^*(s)} \cdot e^{-Ts}$$

Unde se cer criteriile de performanta : $\varepsilon_{st} = 0$, $\sigma = 0$, $50\text{sec} < t_t^* < 100\text{sec}$, unde $t_t^* = t_t + 23\text{sec}$

Se noteaza $H_{o1}^* = \frac{H_R^*(s) \cdot H_p^*(s)}{1 + H_R^*(s) \cdot H_p^*(s)}$, functie de transfer ce trebuie sa indeplineasca

criteriile de performanta : $\varepsilon_{st} = 0$, $\sigma = 0$, $27\text{sec} < t_t < 77\text{sec}$

Se va proiecta regulatorul cu metoda poli-zero-uri.

$$H_R^*(s) = H_d(s) \cdot \frac{1}{H_p^*(s)}$$

$$H_d(s) = \frac{H_{o1}^*(s)}{1 - H_{o1}^*(s)}$$

$$e_{H01} \geq e_{Hp} = 1 \Rightarrow \text{se alege } H_{o1}^* \text{ de forma } H_{o1}^*(s) = \frac{K_R}{T_i s + 1}$$

$$\text{din } \varepsilon_{st} = 0 \text{ si conform teoremei valorii finale} \Rightarrow H_{o1}^*(0) = \frac{K_R}{T_i \cdot 0 + 1} = 1 \Rightarrow K_R = 1$$

$$\text{din } 27s < t_t < 77s \quad t_t = 3T \Rightarrow T_i = \frac{t_t}{3} \Rightarrow 9 < T_i < 25,66. \text{ Se alege } T_i = 13\text{sec}.$$

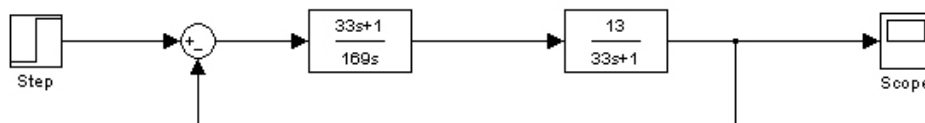
$$\Rightarrow H_{o1}^*(s) = \frac{1}{13s + 1}$$

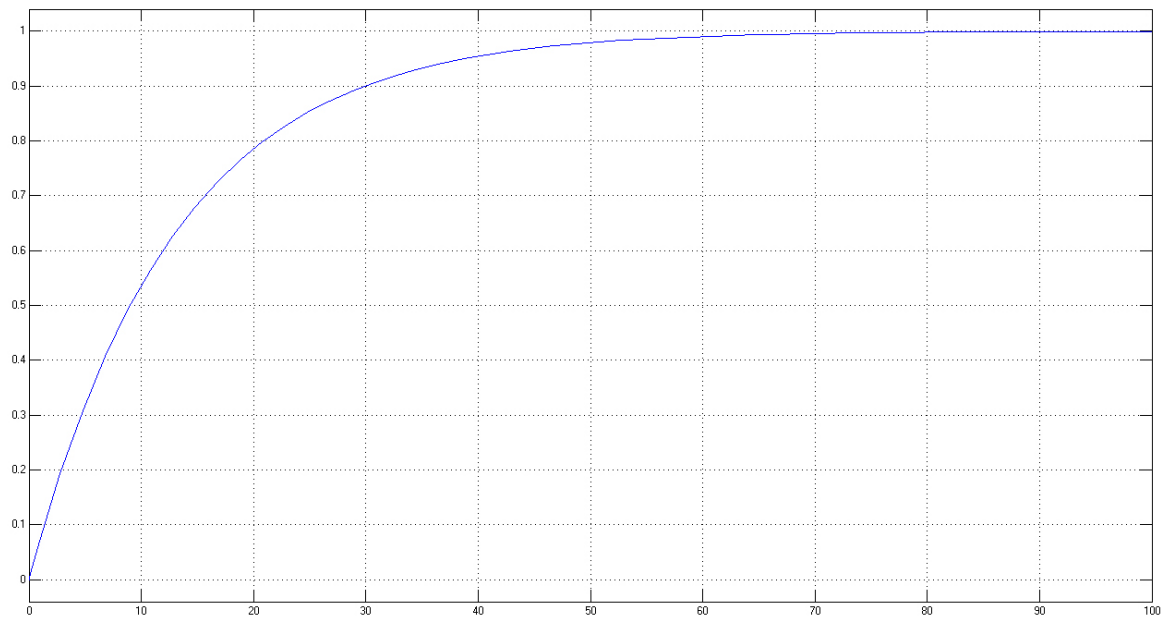
$$\Rightarrow H_d(s) = \frac{\frac{1}{13s + 1}}{1 - \frac{1}{13s + 1}} = \frac{1}{13s}$$

$$\Rightarrow H_R^*(s) = \frac{1}{13s} \cdot \frac{33s + 1}{13} = \frac{33s + 1}{169s} = \frac{33}{169} \left(1 + \frac{1}{33s} \right)$$

$$\Rightarrow K_R^* = 0.195 \text{ si } T_i^* = 33\text{sec}$$

Se evalueaza cerintele de performanta utilizand schema Simulink





Raspuns indicial al SRA cu H_R^* ($\varepsilon_{st} = 0$, $\sigma = 0$, $27\text{sec} < t_t \approx 39\text{s} < 77\text{sec}$)

Din $H_o = H_o^*$

$$\Rightarrow H_R(s) = \frac{H_R^*(s)}{1 + H_R^*(s) \cdot H_p^*(s) \cdot (1 - e^{-\tau s})} = \frac{\frac{33s+1}{169s}}{1 + \frac{33s+1}{169s} \cdot \frac{13}{33s+1} \cdot (1 - e^{-23s})}$$

$$\Rightarrow H_R(s) = \frac{\frac{33s+1}{169s}}{1 + \frac{13}{169s} \cdot (1 - e^{-23s})} = \frac{33s+1}{169s + 13(1 - e^{-23s})} = \frac{\frac{1}{13} + \frac{33s}{13}}{1 + 13s - e^{-23s}} = \frac{0.07 + 2.53s}{1 + 13s - e^{-23s}}$$

c) Discretizati algoritmul si calculati valoarea comenzii initiale in functie de perioada de discretizare selectata.

Pentru discretizare se foloseste metoda lui Euler, unde $\frac{1}{s} \rightarrow \frac{1-z^{-1}}{T}$ si $e^{-Ts} \rightarrow z^{-d}$, unde

$$d = \frac{\tau}{T} \in \mathbb{N}.$$

Aleg $T = 5.75\text{sec} \Rightarrow d = \frac{23}{5.75} = 4$, unde $T \in \left(\frac{1}{6} \div \frac{1}{15}\right) t_t^*, t_t^* = 77 \Rightarrow T \in (5,13 \div 12)\text{sec}$

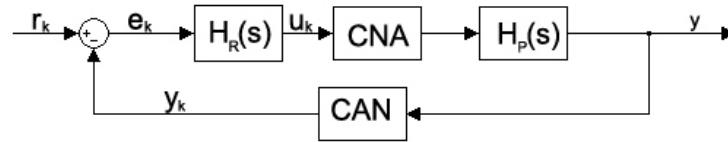
$$H_R(z^{-1}) = \frac{0.07 + 2.53 \cdot \frac{1-z^{-1}}{T}}{1 + 13 \cdot \frac{1-z^{-1}}{T} - z^{-d}} = \frac{0.07 + 2.53 \cdot \frac{1-z^{-1}}{5.75}}{1 + 13 \cdot \frac{1-z^{-1}}{5.75} - z^{-4}}$$

$$H_R(z^{-1}) = \frac{0.07 + 0.44 \cdot (1-z^{-1})}{1 + 2.26 \cdot (1-z^{-1}) - z^{-4}} = \frac{0.51 - 0.44 \cdot z^{-1}}{3.26 - 2.26 \cdot z^{-1} - z^{-4}} = \frac{0.15 - 0.13 \cdot z^{-1}}{1 - 0.69 \cdot z^{-1} - 0.3 \cdot z^{-4}}$$

$$H_R(z^{-1}) = \frac{R(z^{-1})}{S(z^{-1})} = \frac{r_0 + r_1 z^{-1} + r_2 z^{-2} + \dots + r_n z^{-n}}{1 + s_1 z^{-1} + s_2 z^{-2} + \dots + s_m z^{-m}}$$

Rezulta o comanda initiala $u_0 = 0.15$

d) Determinati modelul discret echivalent al procesului alegand perioada de estantionare(T) si tinand seama de timpul mort(τ).



$$H_c(s) = H_{CNA}(s) \cdot H_p(s) = H_{EOZ}(s) \cdot H_p(s) = \frac{1 - e^{-Ts}}{s} \cdot \frac{13}{33s + 1} \cdot e^{-23s}$$

$$\text{Aleg } T = 5.75 \text{ sec} \Rightarrow d = \frac{23}{5.75} = 4$$

$$e^{-23s} \rightarrow z^{-4}$$

$$H_c(z^{-1}) = \mathcal{Z} \left\{ \frac{1 - e^{-Ts}}{s} \cdot \frac{13}{33s + 1} \cdot e^{-23s} \right\} = (1 - z^{-1}) \cdot z^{-4} \cdot \mathcal{Z} \left\{ \frac{1}{s} \cdot \frac{13}{33s + 1} \right\}$$

$$\frac{1}{s} \cdot \frac{13}{33s + 1} = \frac{A}{s} + \frac{B}{33s + 1} \Rightarrow 33As + A + Bs = 13 \Rightarrow A = 13$$

$$\Rightarrow s(33A + B) = 0 \Rightarrow B = -33A = -429$$

Cu formula :

$$\mathcal{Z} \left\{ \frac{1}{s + a} \right\} = \frac{1}{1 - z^{-1} \cdot e^{-aT}} \text{ se calculeaza transformata } \mathcal{Z} \left\{ \frac{13}{s} - \frac{429}{33s + 1} \right\}$$

$$H_c(z^{-1}) = (1 - z^{-1}) \cdot z^{-4} \cdot \mathcal{Z} \left\{ \frac{13}{s} - \frac{429}{33s + 1} \right\} = (1 - z^{-1}) \cdot z^{-4} \cdot \left(\frac{13}{1 - z^{-1}} - \mathcal{Z} \left\{ \frac{13}{s + 0.03} \right\} \right)$$

$$\Rightarrow H_c(z^{-1}) = (1 - z^{-1}) \cdot z^{-4} \cdot \left(\frac{13}{1 - z^{-1}} - \frac{13}{1 - z^{-1} \cdot e^{-\frac{5.75}{33}}} \right) = (1 - z^{-1}) \cdot z^{-4} \cdot \left(\frac{13}{1 - z^{-1}} - \frac{13}{1 - 0.84 \cdot z^{-1}} \right)$$

$$\Rightarrow H_c(z^{-1}) = (1 - z^{-1}) \cdot z^{-4} \cdot \frac{13 - 0.84z^{-1} - 13 + 13z^{-1}}{(1 - z^{-1})(1 - 0.84z^{-1})} = z^{-4} \frac{12.16z^{-1}}{1 - 0.84z^{-1}}$$

e) Sa se proiecteze algoritmul numeric care asigura un raspuns indical :
 $Y(T)=Y(2T)=Y(3T)=Y(4T)=0, Y(5T)=0.7, Y(6T)=1=Y(7T)=Y(8T)=\dots$

$$\text{Aleg } T = 5.75\text{sec} \Rightarrow d = \frac{\tau}{T} = \frac{23}{5.75} = 4$$

$$H_0^d(z^{-1}) = \frac{Y(z^{-1})}{R(z^{-1})} = \frac{Y(z^{-1})}{1} = (1 - z^{-1}) \cdot Y(z^{-1}) = (1 - z^{-1})(y_0 + y_1 z^{-1} + y_2 z^{-2} + \dots)$$

$$\Rightarrow H_0^d(z^{-1}) = y_0 + y_1 z^{-1} + y_2 z^{-2} + \dots - (y_0 z^{-1} + y_1 z^{-2} + y_2 z^{-3} + \dots)$$

$$\Rightarrow H_0^d(z^{-1}) = y_0 + (y_1 - y_0)z^{-1} + (y_2 - y_1)z^{-2} + \dots = 0.7z^{-5} + 0.3z^{-6}$$

$$H_d^{dorit}(z^{-1}) = \frac{H_0^d(z^{-1})}{1 - H_0^d(z^{-1})} = \frac{0.7z^{-5} + 0.3z^{-6}}{1 - 0.7z^{-5} - 0.3z^{-6}}$$

$$H_R^{dorit}(z^{-1}) = H_d^d(z^{-1}) \cdot \frac{1}{H_c(z^{-1})}$$

$$\Rightarrow H_R^{dorit}(z^{-1}) = \frac{0.7z^{-5} + 0.3z^{-6}}{1 - 0.7z^{-5} - 0.3z^{-6}} \cdot \frac{1 - 0.84z^{-1}}{12.16z^{-1} \cdot z^{-4}} = \frac{0.7 + 0.3z^{-2}}{1 - 0.7z^{-5} - 0.3z^{-6}} \cdot \frac{1 - 0.84z^{-1}}{12.16}$$

$$\Rightarrow H_R^{dorit}(z^{-1}) = \frac{0.7 + 0.3z^{-1} - 0.58z^{-1} - 0.25z^{-2}}{1 - 0.7z^{-5} - 0.3z^{-6}} \cdot \frac{1}{12.16} = \frac{0.05 - 0.02z^{-1} - 0.02z^{-2}}{1 - 0.7z^{-5} - 0.3z^{-6}}$$

Comanda initiala este : $u_0 = 0.05$

iar formula recursiva a comenzii este : $u_k = 0.05\varepsilon_k - 0.02\varepsilon_{k-1} - 0.02\varepsilon_{k-2} + 0.7u_{k-5} + 0.3u_{k-6}$