Modele złożone

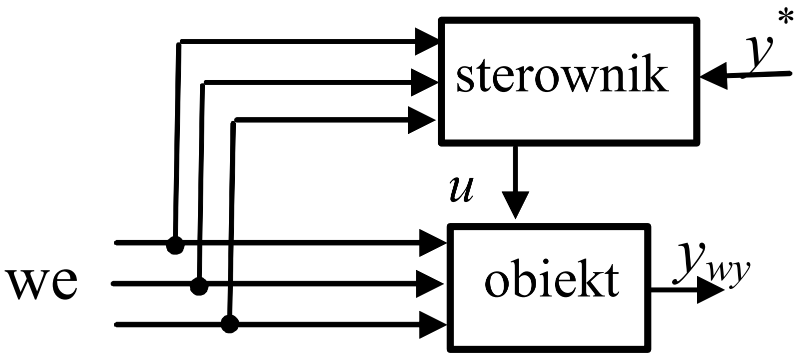
Rozbudowa modelu

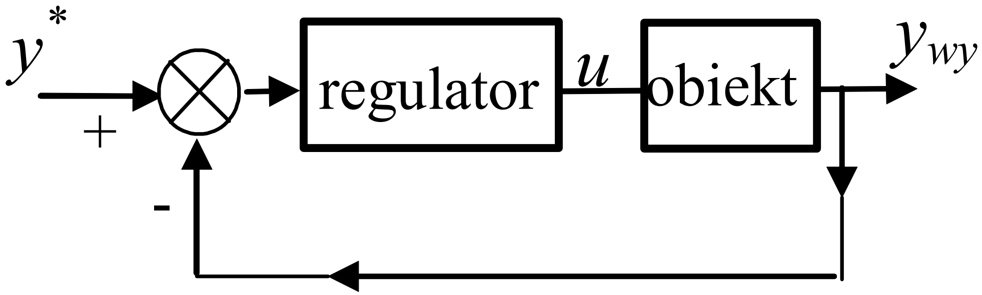
- układy sterowania (regulacji)

- modele obiektów (procesów) technologicznych

Sterowanie w

układzie otwartym	układzie zamkniętym (regulacja)

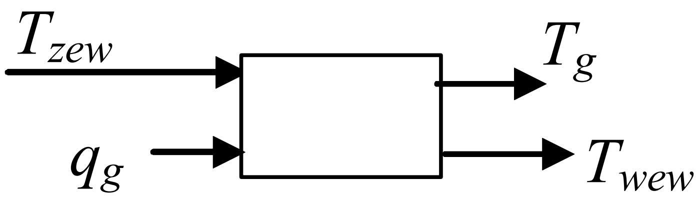


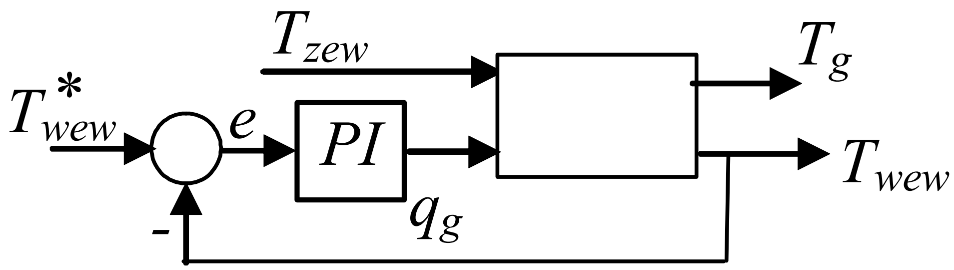


- *znany „przepis” na sterowanie*
- *stabilne*
- *niedokładne*

- *sterowanie jest wypracowywane*
- *stabilne/niestabilne*
- *dokładne*

Regulator ciągły PI





$$\begin{cases} 0 = K_{cg}\left(T_g - T_{wew}\right) - K_{cw}\left(T_{wew} - T_{zew}\right) \\ 0 = q_g - K_{cg}\left(T_g - T_{wew}\right) \end{cases}$$

$$\begin{cases} 0 = K_{cg}\left(T_g - T_{wew}\right) - K_{cw}\left(T_{wew} - T_{zew}\right) \\ 0 = q_g - K_{cg}\left(T_g - T_{wew}\right) \\ T_{wew} = T^*_{wew} \end{cases}$$

wejścia: T_{zew0}, q_{g0}

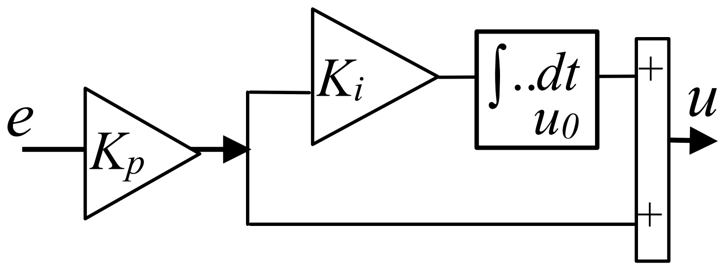
$T_{wew0} = \ldots$

$T_{g0} = \ldots$

wejścia: $T_{zew0}, T^*_{wew0}, e = 0$

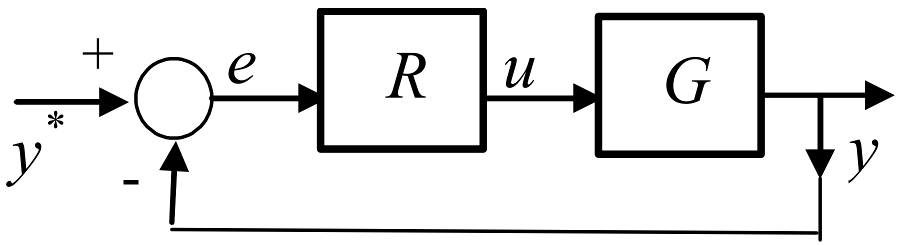
$q_{g0} = \ldots$ $\qquad T_{wew0} = T^*_{wew0}$

$T_{g0} = \ldots$



$$\text{PI}: R = K_p\left(1 + \frac{1}{T_i s}\right)$$

Transmitancje układu regulacji ciągłej



$$\begin{cases} Y(s) = G(s)U(s) \\ U(s) = R(s)E(s) \\ E(s) = Y^*(s) - Y(s) \end{cases}$$

$$\frac{Y}{Y^*} = G_z = \frac{RG}{1+RG}$$ t.układu zamkniętego

$$Y(s) = \frac{R(s)G(s)}{1+R(s)G(s)} Y^*(s)$$

$$\frac{E}{Y^*} = G_e = \frac{1}{1+RG}$$ t.uchybowa

$$E(s) = \frac{1}{1+R(s)G(s)} Y^*(s)$$

$$G(s) = \frac{L_o(s)}{M_o(s)}$$

$$G_z = \frac{L_o(s)L_R(s)}{M_o(s)M_R(s) + L_o(s)L_R(s)}$$

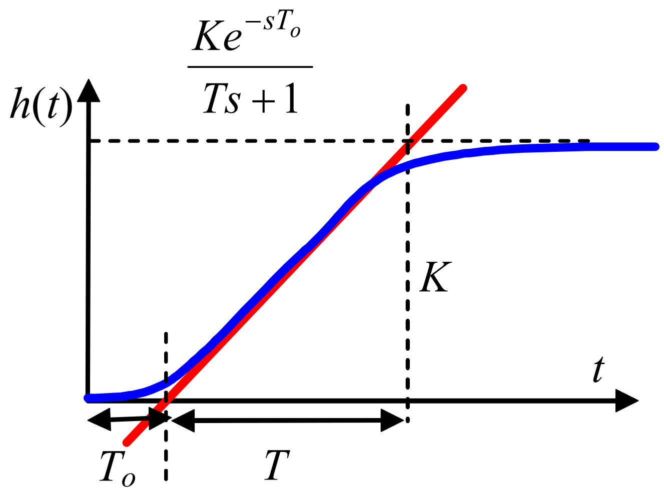
$$R(s) = \frac{L_R(s)}{M_R(s)}$$

$$G_e = \frac{M_o(s)M_R(s)}{M_o(s)M_R(s) + L_o(s)L_R(s)}$$

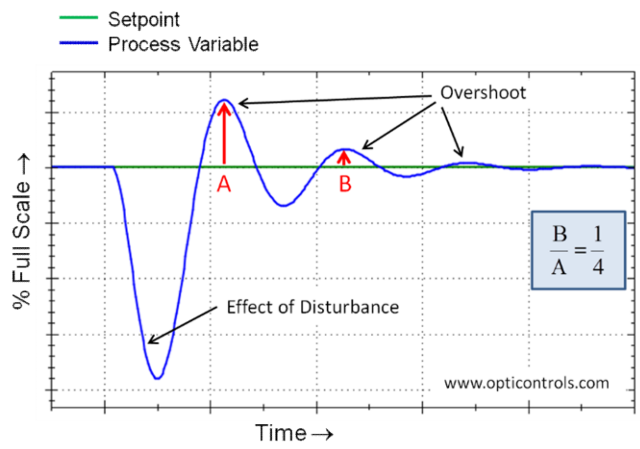
Dobór nastaw PID (auto-tuning, samonastrajanie)

▶ Metoda Zieglera-Nicholsa (odpowiedzi skokowej)
- identyfikacja modelu (przy otwartej pętli)
- nastawy wg tabel dla różnych klas obiektów

Regulator	K_p	T_i	T_d
PI	$\frac{0{,}9T}{KT_o}$	$3{,}33T_o$	
PID	$\frac{1{,}2T}{KT_o}$	$2T_o$	$0{,}5T_o$



Metoda **QDR** (Quarter-Decay Ratio)
- każde następne przeregulowane ma amplitudę 4 razy mniejszą od poprzedniej



Uwagi:
- Esperyment Zieglera-Nicholsa (1942) zautomatyzowany w latach '70

(+) prosty eksperyment

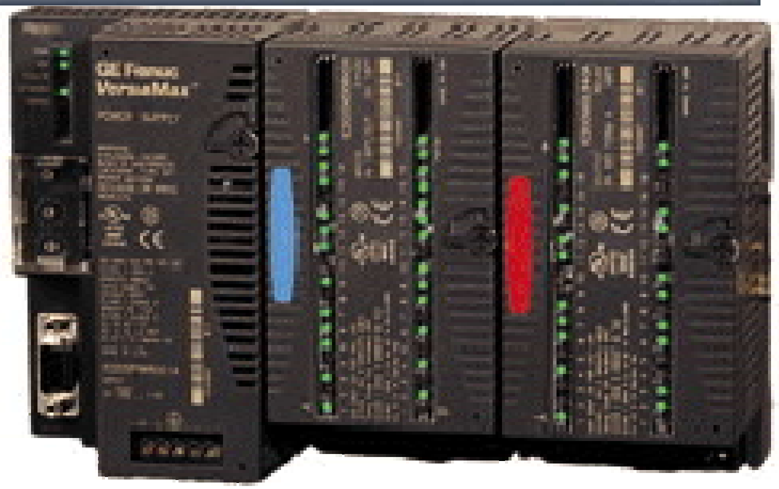
(-) identyfikacja modelu obiektu przy rozwartej pętli regulacji
- PID-kaskadowy (interacting)
- A jeśli $T_o \approx 0$?

np.: https://engineering.purdue.edu/~zak/ECE680/Ziegler-Nichls_1942.pdf

Praktyka inżynierska – korzystamy z tego co mamy

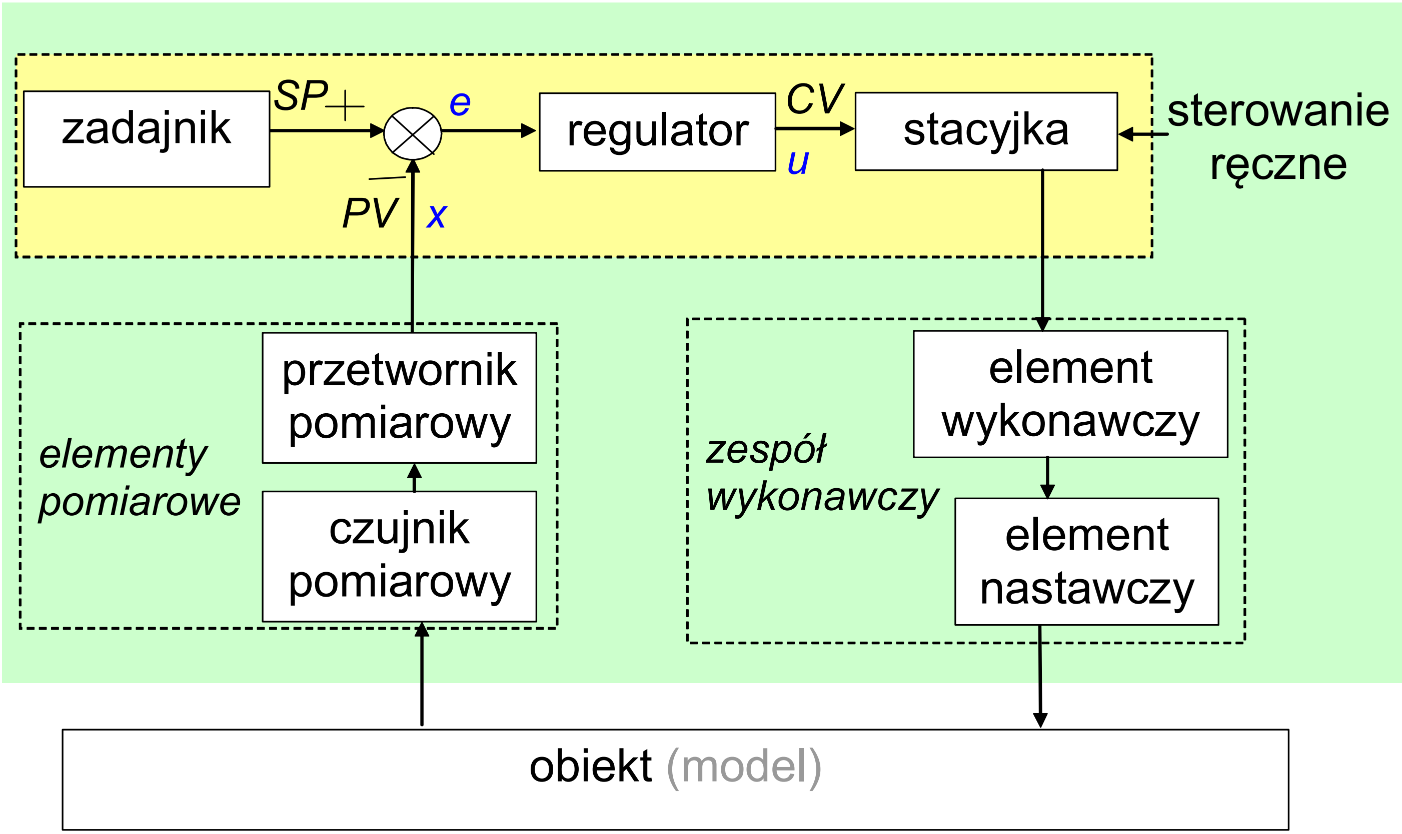
Urządzenia realizujące regulację:

- blok funkcyjny PID w sterowniku PLC
- moduł PID w sterowniku PLC
- regulator wielofunkcyjny
- prosty regulator cyfrowy

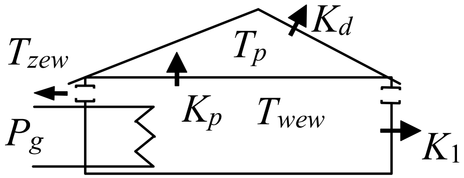


Urządzenia automatyki:

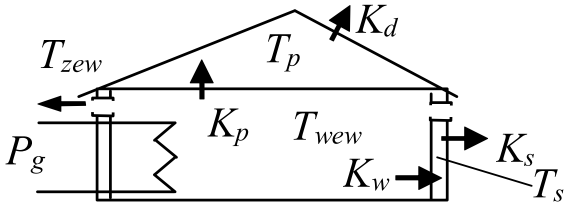
- elementy pomiarowe
- elementy wykonawcze
- sterowniki, regulator



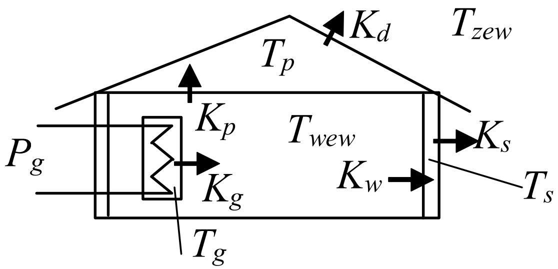
Rozbudowa modelu



$$\begin{cases} C_{vw}\dot{T}_{wew}(t) = P_g(t) - K_1\left(T_{wew}(t) - T_{zew}(t)\right) - K_p\left(T_{wew}(t) - T_p(t)\right) - c_p\rho_p f_p(t)\left(T_{wew}(t) - T_{zew}(t)\right) \\ C_{vp}\dot{T}_p(t) = K_p\left(T_{wew}(t) - T_p(t)\right) - K_d\left(T_p(t) - T_{zew}(t)\right) \end{cases}$$

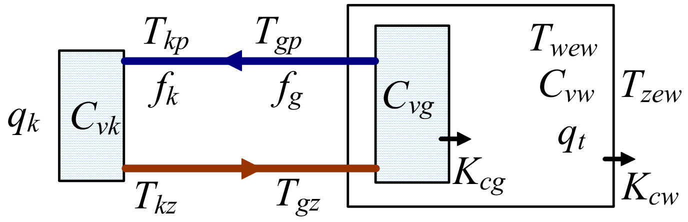


$$\begin{cases} C_{vw}\dot{T}_{wew}(t) = P_g(t) - K_w\left(T_{wew}(t) - T_s(t)\right) - K_p\left(T_{wew}(t) - T_p(t)\right) - c_p\rho_p f_p(t)\left(T_{wew}(t) - T_{zew}(t)\right) \\ C_{vs}\dot{T}_s(t) = K_w\left(T_{wew}(t) - T_s(t)\right) - K_s\left(T_s(t) - T_{zew}(t)\right) \\ C_{vp}\dot{T}_p(t) = K_p\left(T_{wew}(t) - T_p(t)\right) - K_d\left(T_p(t) - T_{zew}(t)\right) \end{cases}$$

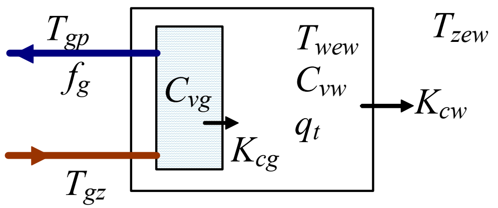


$$\begin{cases} C_{vg}\dot{T}_g(t) = P_g(t) - K_g\left(T_g(t) - T_{wew}(t)\right) \\ C_{vw}\dot{T}_{wew}(t) = K_g\left(T_g(t) - T_{wew}(t)\right) - K_w\left(T_{wew}(t) - T_s(t)\right) - K_p\left(T_{wew}(t) - T_p(t)\right) \\ C_{vs}\dot{T}_s(t) = K_w\left(T_{wew}(t) - T_s(t)\right) - K_s\left(T_s(t) - T_{zew}(t)\right) \\ C_{vp}\dot{T}_p(t) = K_p\left(T_{wew}(t) - T_p(t)\right) - K_d\left(T_p(t) - T_{zew}(t)\right) \end{cases}$$

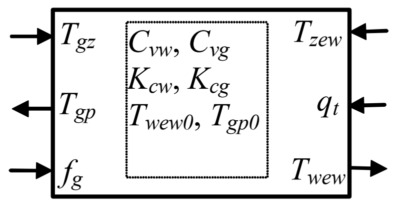
Własna biblioteka modeli

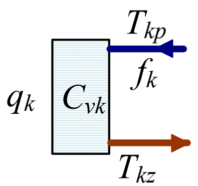


Blok (subsystem)

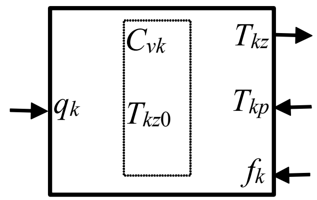


$$\begin{cases} C_{vw}\dot{T}_{wew} = K_{cg}\left(T_{gp} - T_{wew}\right) - K_{cw}\left(T_{wew} - T_{zew}\right) + q_t \\ C_{vg}\dot{T}_{gp} = c_{pw} f_{mg}\left(T_{gz} - T_{gp}\right) - K_{cg}\left(T_{gp} - T_{wew}\right) \end{cases}$$

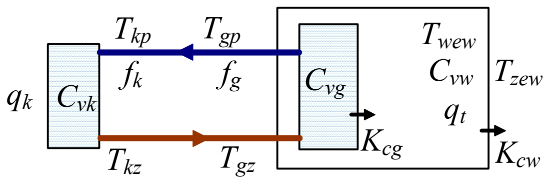


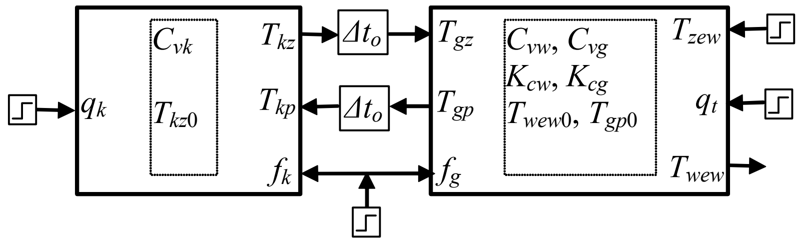


$$C_{vk}\dot{T}_{kz} = q_k - c_{pw} f_{mk}\left(T_{kz} - T_{kp}\right)$$

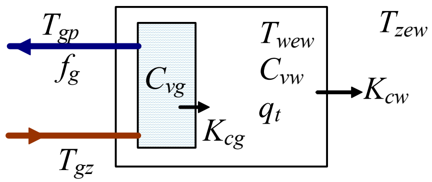


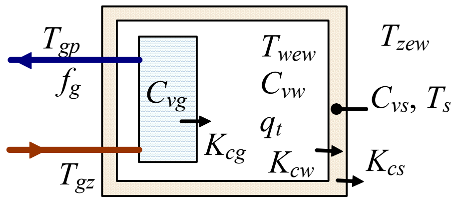
Schemat oparty na blokach





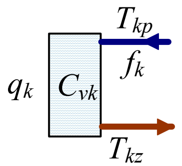
Modele złożone



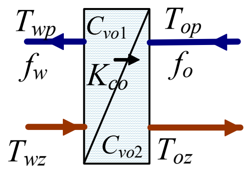


$$\begin{cases} C_{vw}\dot{T}_{wew} = K_{cg}\left(T_{gp} - T_{wew}\right) - K_{cw}\left(T_{wew} - T_{zew}\right) + q_t \\ C_{vg}\dot{T}_{gp} = c_{pw} f_{mg}\left(T_{gz} - T_{gp}\right) - K_{cg}\left(T_{gp} - T_{wew}\right) \end{cases}$$

$$\begin{cases} C_{vw}\dot{T}_{wew} = K_{cg}\left(T_{gp} - T_{wew}\right) - K_{cw}\left(T_{wew} - T_s\right) + q_t \\ C_{vg}\dot{T}_{gp} = c_{pw} f_{mg}\left(T_{gz} - T_{gp}\right) - K_{cg}\left(T_{gp} - T_{wew}\right) \\ C_{vs}\dot{T}_s = K_{cw}\left(T_{wew} - T_s\right) - K_{cs}\left(T_s - T_{zew}\right) \end{cases}$$



$$C_{vk}\dot{T}_{kz} = q_k - c_{pw} f_{mk}\left(T_{kz} - T_{kp}\right)$$



$$\begin{cases} C_{vo2}\dot{T}_{oz} = K_{co}\left(T_{wp} - T_{oz}\right) - c_{pw} f_{mo}\left(T_{oz} - T_{op}\right) \\ C_{vo1}\dot{T}_{wp} = c_{pw} f_{mw}\left(T_{wz} - T_{wp}\right) - K_{co}\left(T_{wp} - T_{oz}\right) \end{cases}$$