1st Report

Due: **May 20th(Mon) 17:00**

Place: **S5-204A** (A box will be prepared)

Note :
- A4 paper, both side printing
- the following 6 items should be written on the cover

Subject Name, Report Number, **Department & Course**, Name, Student ID and Submission Date

Computer Access:

Install Guide http://www.t3.gsic.titech.ac.jp/matlab

Office Hour (Technical Support):

Place: S5-204A e-mail: tateam_at_hfg.sc.e.titech.ac.jp
Time: Friday 16:30-17:30

Lecture Information:

http://www.hfg.sc.e.titech.ac.jp/course/ROC/index.html

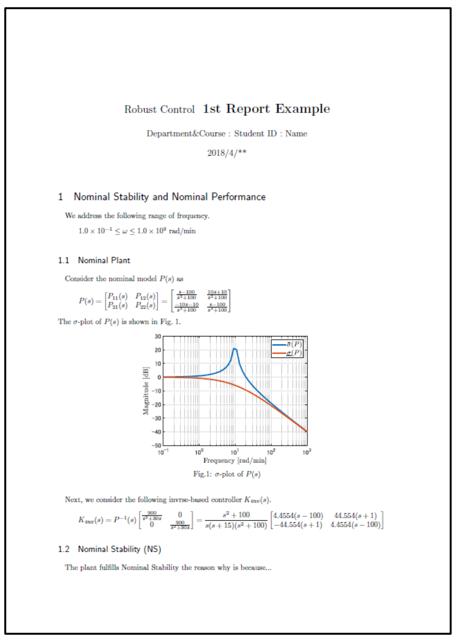
1st Report

Please write your report in accordance with the following format.

Reports should be simple and clear.

The report example (format) can be downloaded by
http://www.hfg.sc.e.titech.ac.jp/course/ROC/handouts/ex/19Report1_ex.pdf

Please follow it.



Robust Control **1st Report Example**

Department&Course : Student ID : Name

2018/4/**

1 Nominal Stability and Nominal Performance

We address the following range of frequency.

$$1.0 \times 10^{-1} \leq \omega \leq 1.0 \times 10^{3} \text{ rad/min}$$

1.1 Nominal Plant

Consider the nominal model $P(s)$ as

$$P(s) = \begin{bmatrix} P_{11}(s) & P_{12}(s) \\ P_{21}(s) & P_{22}(s) \end{bmatrix} = \begin{bmatrix} \frac{s-100}{s^2+100} & \frac{10s+10}{s^2+100} \\ \frac{-10s-10}{s^2+100} & \frac{s-100}{s^2+100} \end{bmatrix}$$

The σ-plot of $P(s)$ is shown in Fig. 1.

Fig.1: σ-plot of $P(s)$

Next, we consider the following invrse-based controller $K_{inv}(s)$.

$$K_{inv}(s) = P^{-1}(s) \begin{bmatrix} \frac{900}{s^2+30s} & 0 \\ 0 & \frac{900}{s^2+30s} \end{bmatrix} = \frac{s^2+100}{s(s+15)(s^2+100)} \begin{bmatrix} 4.4554(s-100) & 44.554(s+1) \\ -44.554(s+1) & 4.4554(s-100) \end{bmatrix}$$

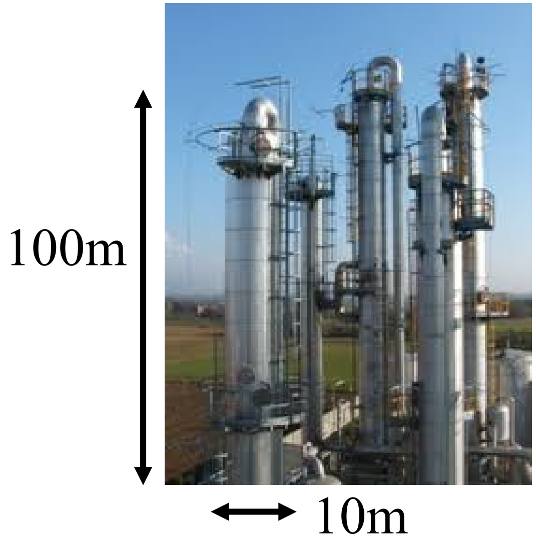
1.2 Nominal Stability (NS)

The plant fulfills Nominal Stability the reason why is because...

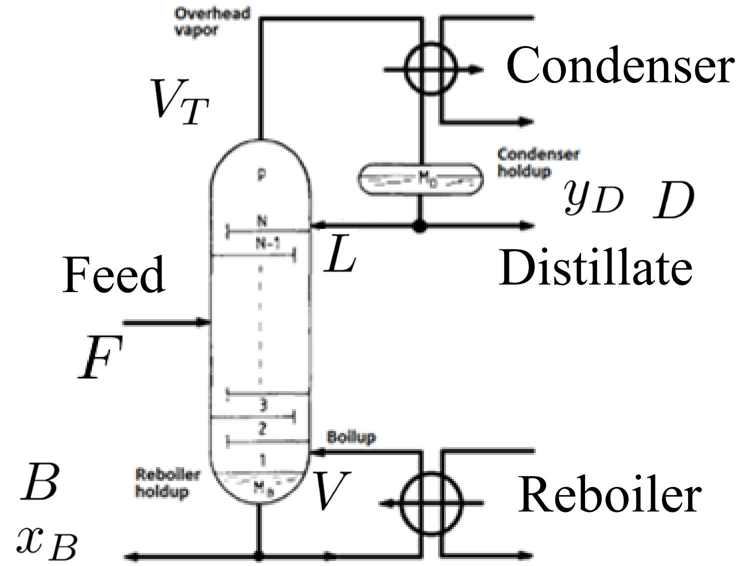
- Write your answer clearly…
- When you display figure, note that…
- etc…

Report*: Distillation Process [SP05, pp. 100, 509-514]

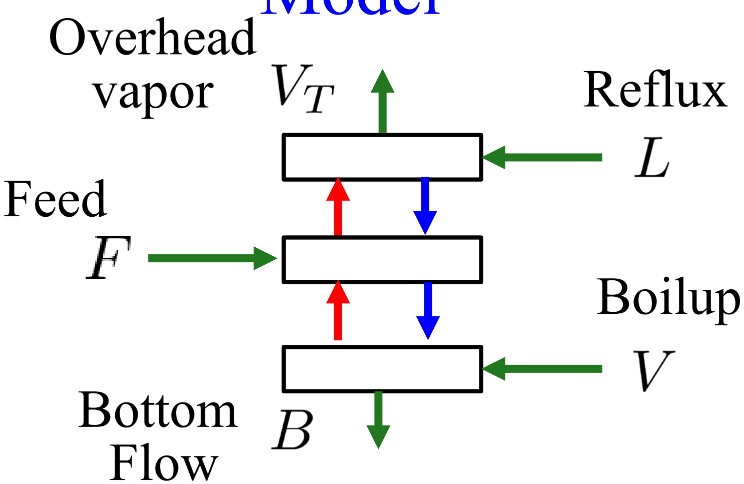
STEP 1. Real Physical System



STEP 2. Ideal Physical Model



STEP 3. Ideal Mathematical Model



STEP 4. Reduced Mathematical Model

2-Input 2-Output System

$[dL \ dV]^T \quad [dy_D \ dx_B]^T$

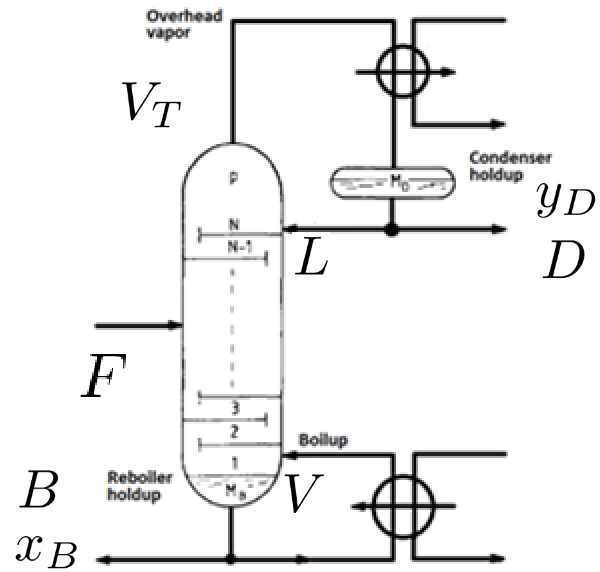
$$P(s) = \begin{bmatrix} \frac{87.8}{75s+1} & \frac{-86.4}{75s+1} \\ \frac{108.2}{75s+1} & \frac{-109.6}{75s+1} \end{bmatrix}$$

Distillation Process (Time Delay System) [SP05, pp. 100, 509-514]

Inputs and Outputs

$$\begin{bmatrix} u_1 \\ u_2 \end{bmatrix} = \begin{bmatrix} dL \\ dV \end{bmatrix}$$

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} dy_D \\ dx_B \end{bmatrix}$$



Controlled Variables

- y_D : top composition
- x_B : bottom composition

Manipulated Inputs

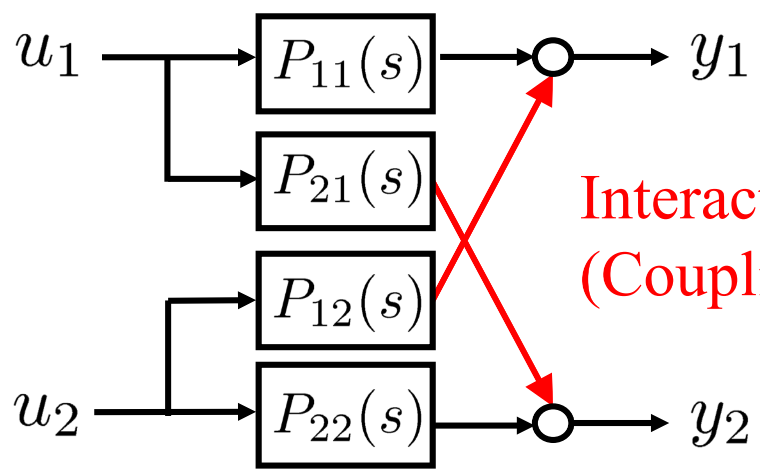
- L : reflux D : distillate
- V : boilup
- B : bottom flow
- V_T : overhead vapor

Nominal Model

$$\begin{bmatrix} dy_D \\ dx_B \end{bmatrix} = P(s) \begin{bmatrix} dL \\ dV \end{bmatrix}$$

$$P(s) = \begin{bmatrix} P_{11}(s) & P_{12}(s) \\ P_{21}(s) & P_{22}(s) \end{bmatrix}$$

$$= \begin{bmatrix} \frac{87.8}{75s+1} & \frac{-86.4}{75s+1} \\ \frac{108.2}{75s+1} & \frac{-109.6}{75s+1} \end{bmatrix}$$



Interaction (Coupling)

Time constant 75 [min]

[1] Nominal Stability and Nominal Performance (15 pts.)

Throughout all 3 reports, consider the following frequency range.

$$1.0 \times 10^{-3} \leq \omega \leq 1.0 \times 10^{2} \quad \text{rad/min}$$

1.1 Nominal Plant

Show σ -plot of the nominal plant $P(s)$.

MATLAB Command

```
sv = sigma(Pnom, w);
figure;
semilogx(w, mag2db(sv));
xlabel(' Frequency [rad/min] ')
```

Consider the following inverse-based controller:

$$K_{\text{inv}}(s) = P^{-1}(s)\begin{bmatrix} \frac{0.7}{s} & 0 \\ 0 & \frac{0.7}{s} \end{bmatrix} = 0.7\frac{75s+1}{s}\begin{bmatrix} 0.3994 & -0.3149 \\ 0.3943 & -0.3200 \end{bmatrix}$$

1.2 Nominal Stability (NS)

Confirm that the closed-loop system is internally stable by checking the Gang of Four.

MATLAB Command

```
F = loopsens(Pnom, KI);
S = F.So;
Si = F.Si;
PS = F.PSi;
KS = F.CSo;
```

1.3 Step Response

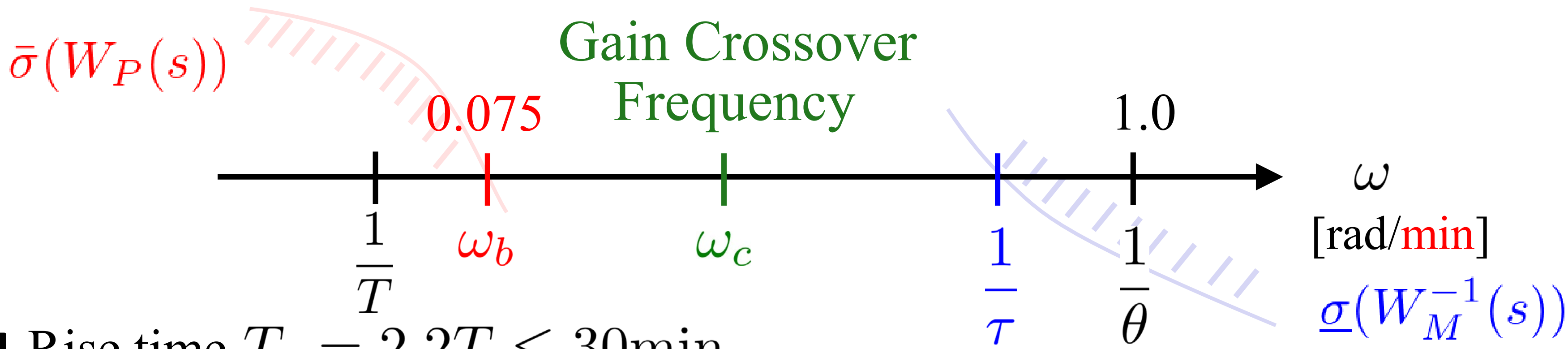
Consider the closed-loop system with $K_{\text{inv}}(s)$.

Show the step response of output y from reference signal $r = [1.0 \quad 0]^T$.

MATLAB Command

```
time = 0:0.1:15;  step_ref = ones(1,length(time));  ref = [step_ref', zeros(1,length(time))'];
figure; hold on; grid on;  FI = loopsens(Pnom,Kinv);  [yhi,t] = lsim(FI.To,ref,time);
plot(t,yhi,'r-','LineWidth',2);  plot(time,ref,'b-.','LineWidth',1.5);
```

Distillation Process: Performance Specifications



- Rise time $T_r = 2.2T \leq 30\text{min}$ (First-order System)

$$\Rightarrow \frac{2.2}{30} \leq \frac{1}{T} \leq \omega_b = 0.075\,\text{rad/min}$$

- Steady state error < 0.01 $A = 0.01$

- Performance Weight

$$\omega_c > \omega_b = 0.075\text{rad}/\text{min}$$

$$A = 0.01 \quad M_s = 2$$

$$W_P(s) = w_P(s) I_2$$

$$w_P(s) = \frac{0.5s + 0.075}{s + 0.00075}$$

- Delay Margin: $\theta \leq 1$ min

$$\Rightarrow \omega_c < 1/\theta = 1 \text{ rad/min}$$

- Gain Margin: $\pm 20\%,\ 2\text{dB}$

- Uncertainty Weight

$$\omega_c < 1/\tau \leq 1/\theta = 1 \text{ rad/min}$$

$$W_M(s) = w_M(s) I_2$$

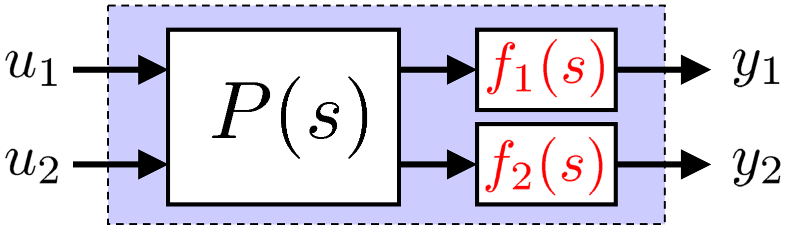
$$w_M(s) = \frac{\tau s + r_0}{\frac{\tau}{r_\infty} s + 1}$$

$\Rightarrow$ 2.1

[2] Uncertainty Weight for Real Plant

Perturbed Plant Model

$$\tilde{P}(s) = \begin{bmatrix} f_1(s) & 0 \\ 0 & f_2(s) \end{bmatrix} P(s)$$



$$f_i(s) = k_i \frac{-\frac{\theta_i}{2}s + 1}{\frac{\theta_i}{2}s + 1}, \quad i = 1, 2$$

Gain Margin: $0.8 \leq k_i \leq 1.2$
($\pm 20\%$, 2dB)

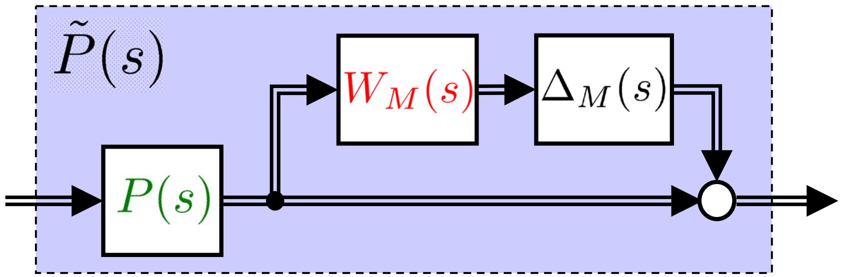
Delay Margin: $0 \leq \theta_i \leq 1$ [min]

Multiplicative (Output) Uncertainty

$$\Pi_0 = \{\tilde{P}(s) |\ \tilde{P}(s) = (I + \Delta_M(s) W_M(s)) P(s),\ \|\Delta_M\|_\infty \leq 1\}$$

$$W_M(s) = w_M(s) I_2$$

$$w_M(s) = \frac{\tau s + r_0}{\frac{\tau}{r_\infty} s + 1}$$



[2] Nominal Performance and Robust Stability (30 pts.)

see the programs in 3rd lecture & Use controller $K_{\rm inv}$ given in [1]

2.1 Nominal Performance (NP)

Show the NP Test graph of the closed-loop system and answer if NP is satisfied.

2.2 Uncertainty Weight

Design an uncertainty weight W_M with order 1 using the MATLAB command "ucover" and write W_M and the parameters $1/\tau$, r_∞ and r_0.

After this, use the uncertainty weight W_M in 2.2.

2.3 Robust Stability (RS)

Show the RS Test graph of the closed-loop system and answer if RS is satisfied.

2.4 Set of time responses

Show the step responses of the closed-loop system with the perturbed plant model $\tilde{P}(s)$ and $K_{\rm inv}(s)$ from the reference signal $u = [1.0\ 0]^T$ to the outputs.