Løsningsslag 26. feb 2010
BIE240 Reguleringsteknikk

1) a)
$$\frac{dm_1(t)}{dt} = w_{inn}(t) - w_{ut}(t)$$
$$= w_{PA001}(t) - w_{LV001}(t)$$

1) b)
$$\boxed{\frac{dm_2(t)}{dt} = w_{inn}(t) - w_{ut}(t) = w_{LV001}(t) - w_{LV002}(t)}$$

1 a') har at $m_1(t) = V_1(t) \cdot \rho(t) = A_1 \cdot h_1(t) \cdot \rho(t)$

antar A_1 og ρ konstant

slik at $m_1(t) = A \cdot \rho \cdot h_1(t)$

$$w_{LV001}(t) = \rho \cdot q_{LV001}(t)$$
$$= \rho \cdot Kv_{LV001} \cdot u_{LV001}(t) \cdot \sqrt{\Delta p(t)}$$

hvor $\Delta p(t) = p_{atm} + \rho \cdot g \cdot h_1(t) - p_{atm}$

②

Dette fordi røret etter LV001 er åpent.

$$w_{LV001}(t) = \rho \cdot K_{v_{LV001}} u_{LV001}(t) \cdot \sqrt{\rho g h_1(t)}$$

$$w_{PA001}(t) = \rho \cdot q_{PA001}(t)$$

$$= \rho \cdot u_{PA001}(t) \cdot 0.005$$

På samme måte som for $w_{LV001}(t)$ finner vi

$$w_{LV002}(t) = \rho \cdot K_{v_{LV002}} u_{LV002}(t) \cdot \sqrt{\rho g h_2(t)}.$$

Får da:

$$\cancel{\rho} \cdot A_1 \cdot \frac{dh_1(t)}{dt} = \cancel{\rho}\, 0.005 u_{PA001}(t) - \cancel{\rho} K_{v_{LV001}} u_{LV001}(t) \cdot \sqrt{\rho g h_1(t)}$$

$$\frac{dh_1(t)}{dt} = \frac{1}{A_1}\left(0{,}005 u_{PA001}(t) - K_{v_{LV001}} \cdot u_{LV001}(t) \cdot \sqrt{\rho g h_1(t)}\right)$$

Tank 2:

$$m_2(t) = V_2(t)\cdot\rho = V_2(h_2(t))\cdot\rho$$

da blir

$$\frac{dm_2(t)}{dt} = \frac{\partial V_2}{\partial h_2(t)}\cdot\frac{\partial h_2(t)}{\partial t}\cdot\rho$$

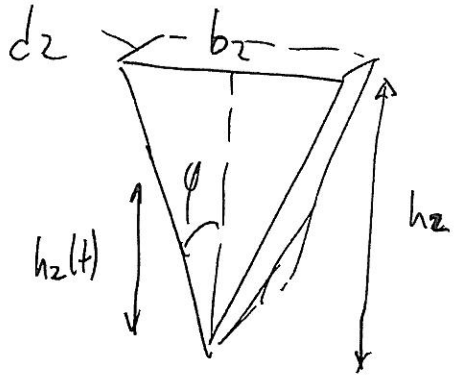
hvor $\frac{dV_2}{dh_2} = A_2(h_2(t))$

Får da:

$$\cancel{\rho}\cdot A_2(h_2(t))\cdot\frac{dh_2(t)}{dt} = \cancel{\rho}\, K_{V_{LV001}}\cdot u_{LV001}(t)\cdot\sqrt{\rho g h_1(t)}$$
$$-\cancel{\rho}\, K_{V_{LV002}}\cdot u_{LV002}(t)\cdot\sqrt{\rho g h_2(t)}$$

$$\frac{dh_2(t)}{dt} = \frac{1}{A_2(h_2(t))}\cdot\Big(K_{V_{LV001}}\cdot u_{LV001}(t)\cdot\sqrt{\rho g h_1(t)}$$
$$-K_{V_{LV002}}\cdot u_{LV002}(t)\cdot\sqrt{\rho g h_2(t)}\Big)$$

c) Dette er en 1.ordens lineær modell



$$\tan\varphi = \frac{b_2/2}{h_2}$$

Volumet opp til $h_2(t)$ er:

$$V(h_2(t)) = \tan\varphi \cdot 2 \cdot d_2 \cdot h_2(t)$$

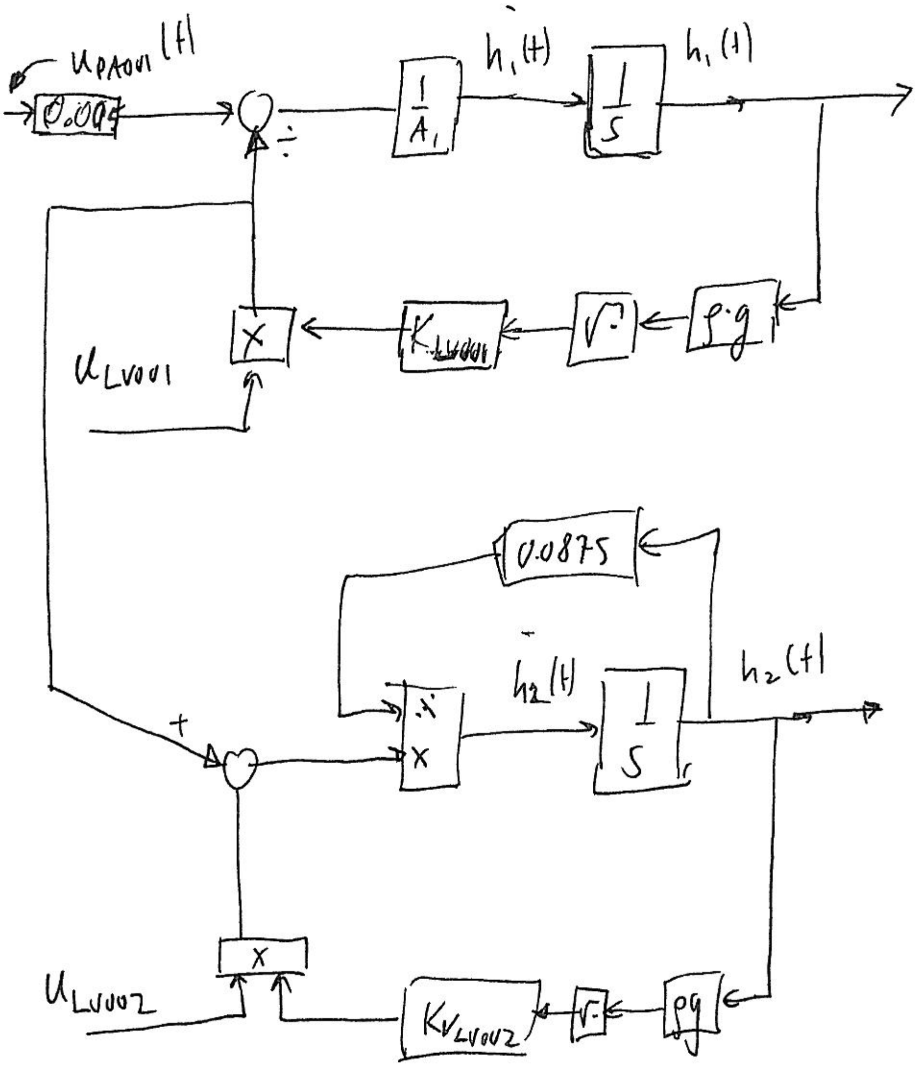
$$= \frac{b_2/2}{h_2} \cdot 2 \cdot d_2 \cdot h_2(t)$$

$$= \frac{b_2 \cdot d_2}{h_2} \cdot h_2(t)$$

$$= \frac{0.35 \cdot 0.1}{0.4} \cdot h_2(t)$$

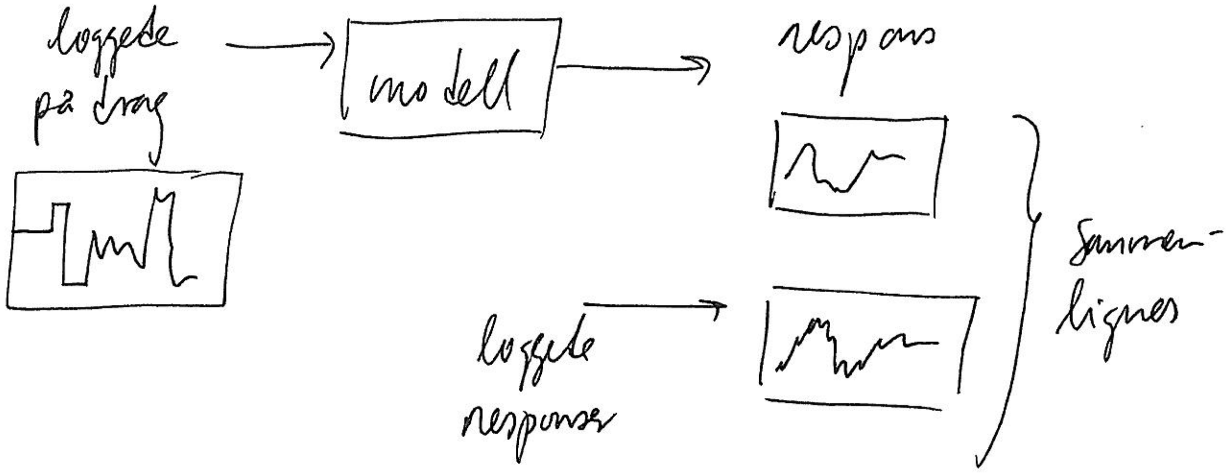
$$= 0.0875\, h_2(t)$$

d)



$u_{PA001}(t)$
0.004
$\dot{h}_1(t)$
$h_1(t)$
$\frac{1}{A_1}$
$\frac{1}{s}$
$\rho \cdot g$
$\sqrt{\cdot}$
K_{LV001}
x
u_{LV001}
0.0875
$\dot{h}_2(t)$
$h_2(t)$
÷
x
$\frac{1}{s}$
+
x
u_{LV002}
Kv_{LV002}
$\sqrt{\cdot}$
ρg

e) Offline verifisering: Da samles pådragsdata og responsdata i en fil som du kan kjøre på PC-offline. Pådragsdata går inn til modellen, og modellens respons sammenlignes med loggede responsdata.



e) Online verifisering: Da kjøres modellen
i parallell med prosessen
i samme tid.

Dette tar selvfølgelig lenger tid.

f) Setter ligning 3) og 4) = 0 (8)

$$0 = \frac{1}{A_1}\left(\cdots\cdots \right)$$

$$0 = \frac{1}{A_2(h_2(t))}\left(\cdots \right)$$

Dette gir:

$$u_{LV001,A} = \frac{u_{PA001,A} \cdot 0.005}{K_{V_{LV001}} \cdot \sqrt{\rho g\, h_{1,A}}}$$

$$= \frac{0.004}{0.00025\sqrt{10 \cdot 1000 \cdot 0.5}}$$

$$= 0.2262$$

Videre får vi

$$u_{LV002,A} = \frac{K_{V_{LV001}} \cdot u_{LV001,A} \cdot \sqrt{\cancel{\rho g}\, h_{1,A}}}{K_{V_{LV002}} \cdot \sqrt{\cancel{\rho g}\, h_{2,A}}}$$

$$= \frac{0.00025 \cdot 0.2262\sqrt{0.5}}{0.00035 \cdot \sqrt{0.20}} = 0.2554$$

9) Har at

$$\frac{dh_1(t)}{dt} = f_1\left(u_{PA001}(t),\ u_{LV001}(t),\ h_1(t)\right)$$

Har da $\left.\frac{\partial f_1}{\partial u_{PA001}}\right|_A = \frac{1}{A_1}$

$$\left.\frac{\partial f_1}{\partial u_{LV001}}\right|_A = -\frac{K_{v_{LV001}}}{A_1} \cdot \sqrt{\rho g h_{1,A}}$$

$$\left.\frac{\partial f_1}{\partial h_1}\right|_A = -\frac{K_{v_{LV001}}}{A_1} \cdot u_{LV001,A} \cdot \sqrt{\rho g} \cdot \frac{1}{2\sqrt{h_{1,A}}}$$

som gir:

$$\Delta \dot{h}_1(t) = \left.\frac{\partial f_1}{\partial u_{PA001}}\right|_A \cdot \Delta u_{PA001}(t) + \left.\frac{\partial f_1}{\partial u_{LV001}}\right|_A \Delta u_{LV001}(t)$$

$$+ \left.\frac{\partial f_1}{\partial h_1}\right|_A \cdot \Delta h_1(t)$$

h)

$$\Delta \dot{h}_1(t) = 33.3\,\Delta u_{PA001}(t) - 0.5892\,\Delta u_{LV001}(t)$$

$$- 0.1332\,\Delta h_1(t)$$

Laplace gir

$$s \cdot \Delta h_1(s) + 0.1332\,\Delta h_1(s) = 33.3\,\Delta u_{PA001}(s)$$

$$- 0.5892\,\Delta u_{LV001}(s)$$

Setter $\Delta u_{PA001}(s) = 0$, dividerer på 0.1332

$$\Delta h_1(s) = -\frac{4.42}{7.5s+1} \cdot \Delta u_{LV001}(s)$$

$$H_{p,1}(s) = \frac{\Delta h_1(s)}{\Delta u_{LV001}(s)} = \frac{-4.42}{7.5s+1}$$

i) $\Delta u_{LV002} = 0.01 \cdot 0.2554$

$= 0.002554$

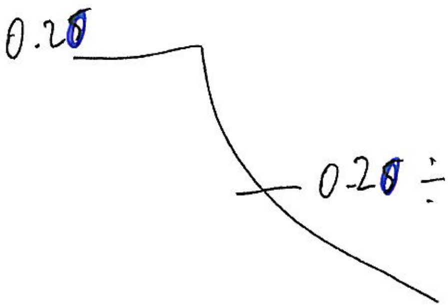
endring i høyden $h_2(t)$ er avlest

$\Delta h_2 = 0.1964 - 0.2 = -0.0036$

$$K = \frac{\Delta h_2}{\Delta u_{LV002}} = \frac{÷ 0.0036}{0.002554} = -1.41$$

<u>Tidskonstanten</u> : 63% av Δh_2 er

$0.63 \cdot 0.0036 = 0.002268$



$0.20 ÷ 0.002268 = \underline{0.1977}$

Avleser 0.1977 ved tidspunkt ved ca 3.6 sek.

Spranget gikk ved $t=2$, slik at $\underline{T = 1.6 \text{ sek.}}$

$$H_{p2}(s) = \frac{÷1.41}{1.6s+1}$$

2 Regulering

a) Har at

$$u(t) = K_p \cdot e(t) + \frac{K_p}{T_i}\int_0^t e(\tau)\,d\tau$$

Laplace gir

$$u(s) = K_p\, e(s) + \frac{K_p}{T_i} \cdot \frac{1}{s} \cdot e(s)$$

rydde:

$$\frac{u(s)}{e(s)} = K_p + \frac{K_p}{T_i s} = \frac{K_p T_i s + K_p}{T_i s}$$

$$H_r(s) = \frac{K_p(T_i s + 1)}{T_i s}$$

$$\boxed{H_m(s) = \frac{1}{0.25 + 1}}$$ for begge

b) Har at $H_{p,1}(s) = \dfrac{-4.42}{7.5s+1}$ 13

Benytt pol-nullpkt kansellering med

$T_M = \dfrac{7.5}{2} \approx 3.75$. Det er naturlig

å velge halvparten tidskonstant, dobbel båndbredde, på reg. system i forhold til prosess.

Dette gir: $K_p = \dfrac{T}{T_M \cdot K} = \dfrac{7.5}{3.75(-4.42)} = -0.45$

$T_i = T = 7.5.$

c) $H_0(s) = H_r(s) \cdot H_{p,2}(s) \cdot H_m(s)$ (14)

$$= \frac{K_p (T_i s + 1)}{T_i s} \cdot \frac{(\div 1.41)}{1.6s+1} \cdot \frac{1}{0.2s+1}$$

Forsterkningsmarginen $\Delta K = \infty$, men

fasemarginen er ca $\varphi = 80^\circ$ ved $w = 1.5$

d) For å få $\varphi = 30^\circ$, må vi inn på

$w = 9$ rad/s

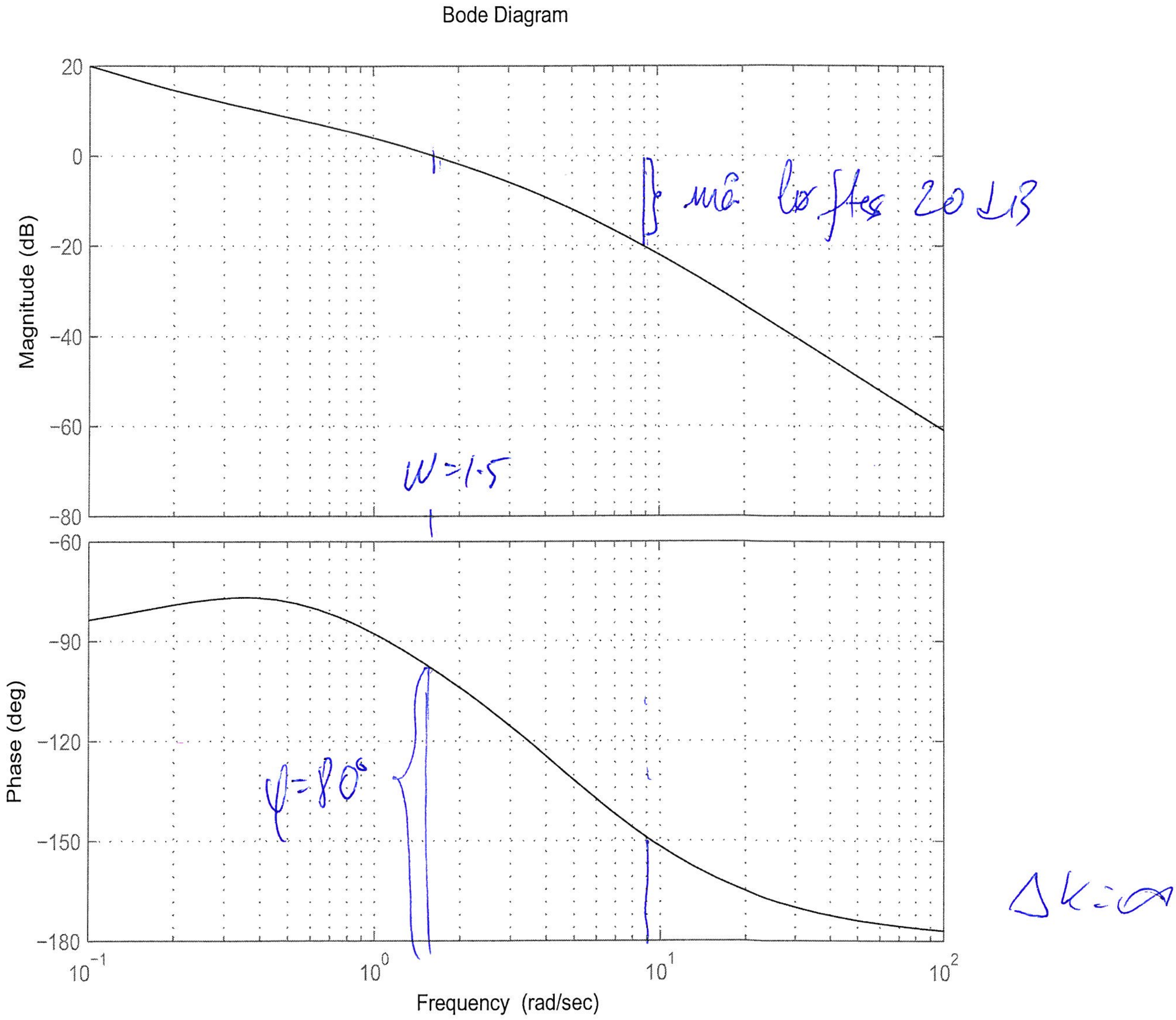
Ved denne frekvensen må $|H_0(j\omega)|$

løftes med ca 20 dB.

Det betyr at K_p må 10dobles,

dvs $\underline{\underline{K_{p,ny} = \div 20}}$

Fag: BIE240, Reguleringsteknikk
Dato: 26. februar 2010
Kandidatnr:
Sidenr:



Figur 5: Bodeplot av sløyfetransferfunksjonen $H_0(j\omega)$ til tank 2.