PHILIPS CTT Hogeschool van Utrecht

Systeem en Regeltechniek

FMT / Mechatronica

Deel 4: Stabiliteit van regelsystemen

Blok 9: De PID regelaar in het frequentie domein

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Cursus Systeem en Regeltechniek

Overzicht

Deel 1 *Wo. 14-04*	Blok 1. Blok 2. Blok 3.	Inleiding Basisprincipes modelvorming massa-veersystemen De regelaar als veer-demper combinatie
Deel 2 *Wo. 21-04*	Blok 4. Blok 5.	Frequentie-domein beschrijving Basisconcepten in de regeltheorie
Deel 3 *Wo. 28-04*	Blok 6. Blok 7.	Verdere inleiding in de regeltheorie De PD regelaar als veer-demper combinatie
Deel 4 *Wo. 12-05*	Blok 8. Blok 9.	Stabiliteit van regelsystemen De PID regelaar in het frequentie domein
Deel 5 *Wo. 19-05*	**Toepassing: PID regelaarontwerp**	
Deel 6 *Wo. 26-05*	**Extra regeltechniek**	

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The PID controller in the frequency domain

What are the limitations of PD control?

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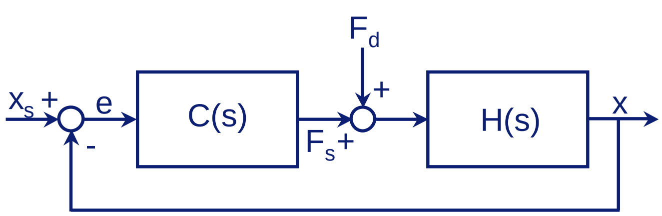
The PID controller in the frequency domain

Limitations of PD controller



Recall k_p/k_v or PD controller: $C_{PD}(s) = (k_p+k_v s)$

Limitations PD controller:

- Suppression of constant disturbance forces F_d
- Pure differentiating action can not be realised
- Suppression of high-frequent noise in the control loop
- Suppression of resonances in the open loop response

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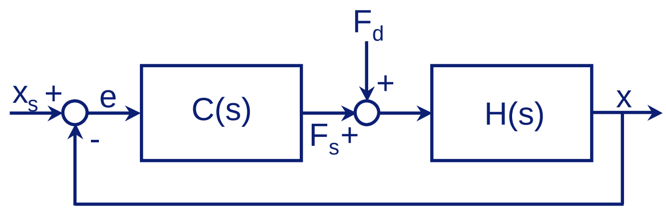
The PID controller in the frequency domain

Limitations of PD controller



Solutions - extend PD controller with filters:

- Integral action (PID)
- Lead-lag filter
- Second order Low Pass filter
- Notch filter(s)

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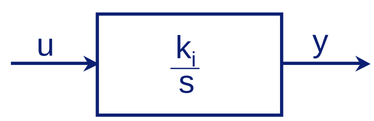
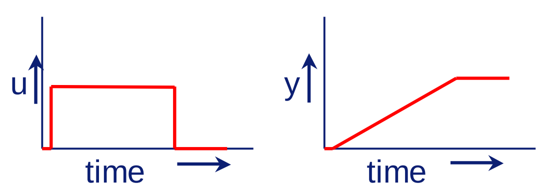
The PID controller in the frequency domain

Integral Control

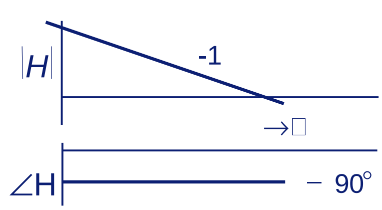
Pure integrator:



Time domain response:



Frequency domain response:



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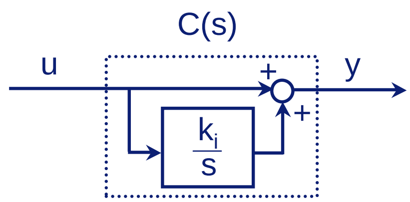
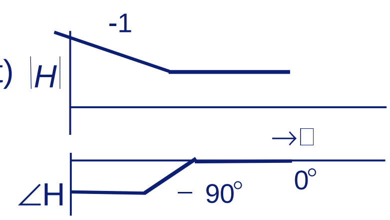
Proportional controller with I-action (PI control)

PI controller:



Transfer function: $C_I(s) = 1 + \frac{k_i}{s}$

Frequency domain response:
(see also Bode plot next sheet)



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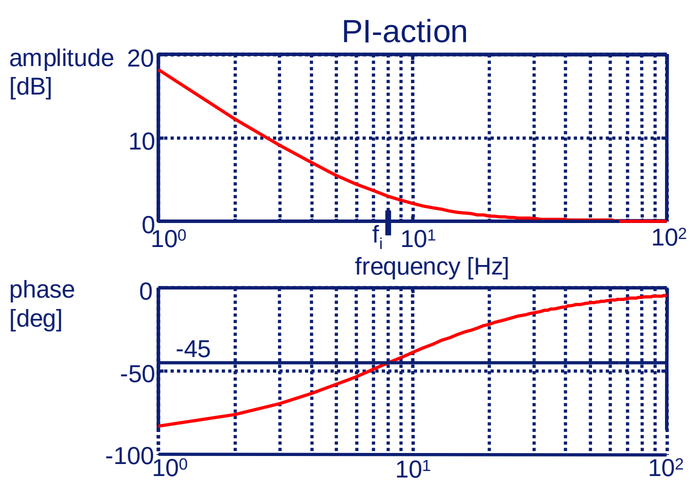
The PID controller in the frequency domain

Proportional controller with I-action (PI control)



$k_i = 2 \cdot \pi \cdot f_i$

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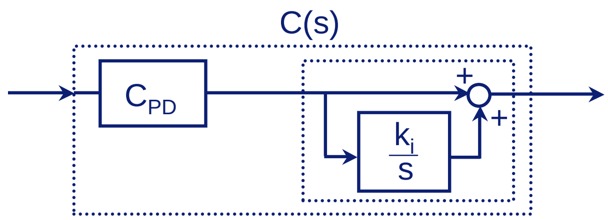
The PID controller in the frequency domain

PD controller with I-action (PID control)

PI controller:



Transfer function:

$$C(s) = (k_p + k_v s) \cdot (1 + \frac{k_i}{s})$$

Frequency domain response: ? => Exercise!!!

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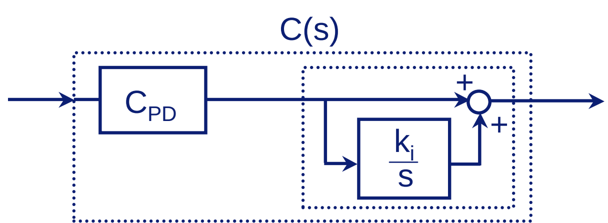
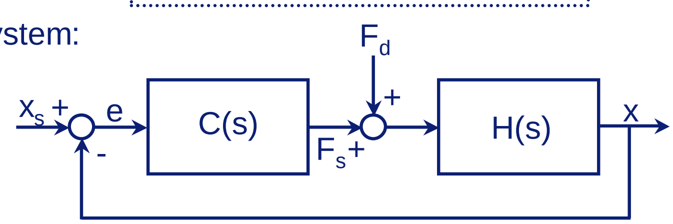
PD controller with I-action (PID control)

PI controller:



Closed loop system:



I-action:
Eliminates the steady state error due to constant F_d !!!

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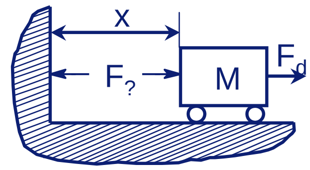
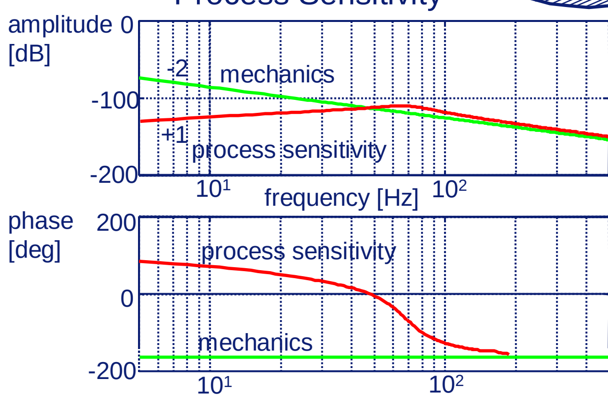
PD controller with I-action (PID control)

m = 5 kg; k_i = 62 rad;
k_p = 1e6 N/m; k_v = 3e3 Ns/m



Process Sensitivity



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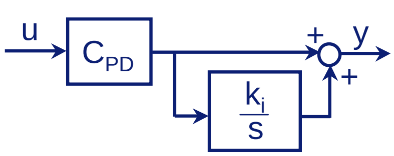
The PID controller in the frequency domain

PID controller - alternative configuration

Standard configuration



$$C(s) = (k_p + k_v s) \cdot \left(1 + \frac{k_i}{s}\right)$$

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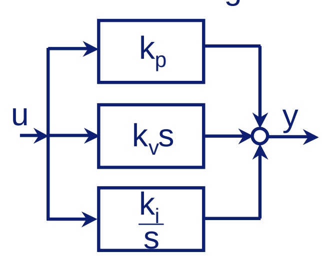
complex zeros not possible

Alternative configuration



$$C(s) = \frac{y(s)}{u(s)} = k_p + k_v s + \frac{k_i}{s}$$

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complex zeros possible

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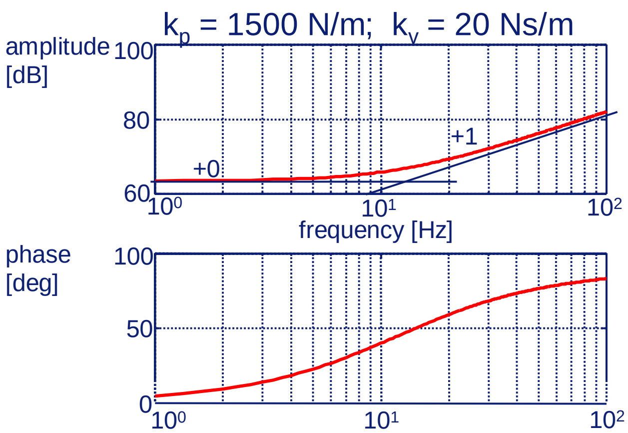
The PID controller in the frequency domain

Differentiating action in pure PD controller

$C_{PD}(s) = (k_p + k_v s)$ or $C_{PD}(s) = k(1 + \frac{1}{2\pi f_1} s)$



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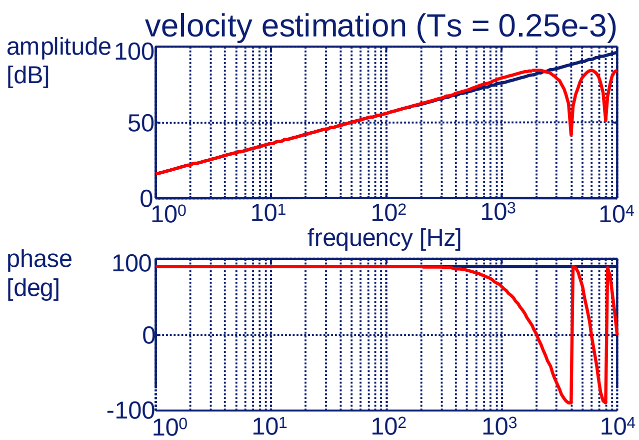
The PID controller in the frequency domain

Differentiating action in pure PD controller

Realisation in motion controller:



Drawback:

High frequent noise is amplified

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Limit gain for high frequencies

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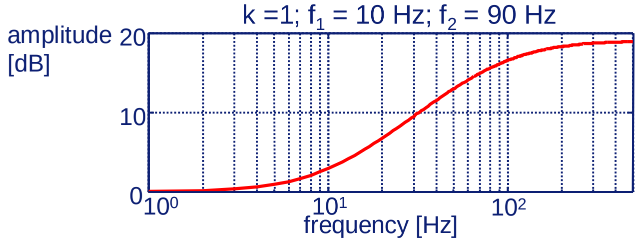
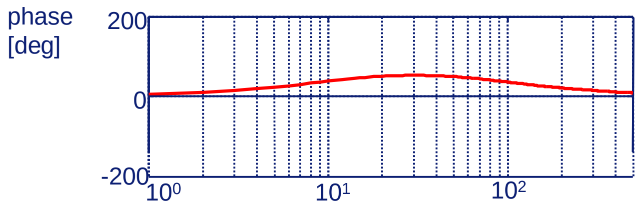
Cut-off differentiating action: lead-lag filter

$$C_{ll}(s) = k\frac{(\tau_1 s + 1)}{(\tau_2 s + 1)}$$

Break points: $f_1 = 1/2\pi\tau_1$
$f_2 = 1/2\pi\tau_2$

k =1; f_1 = 10 Hz; f_2 = 90 Hz





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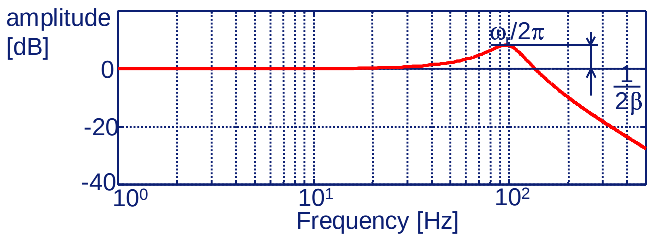
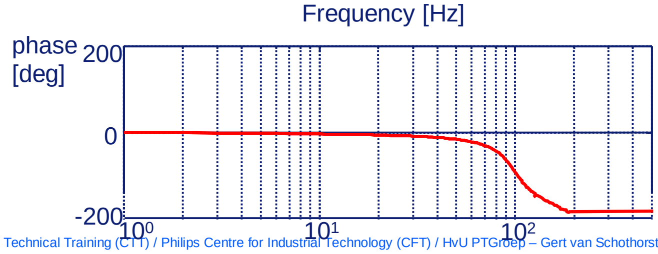
Other filters: second order low pass

$$C_{lp}(s) = \frac{\omega_r^2}{s^2 + 2\beta\omega_r s + \omega_r^2}$$

$\omega_r = 2\pi 100$; $\beta = 0.2$





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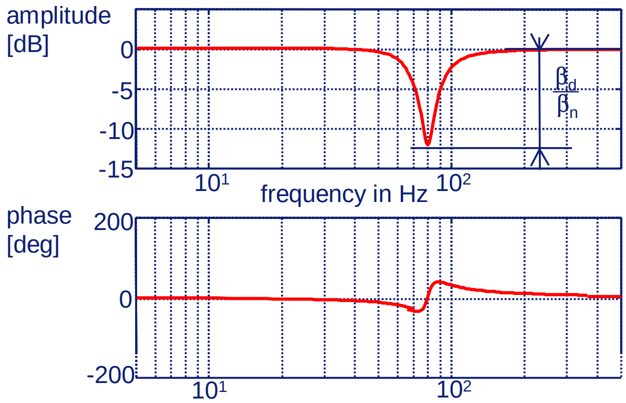
Other filters: notch filter

$$C_{notch}(s) = \frac{s^2 + 2\beta_n \omega_n s + \omega_n^2}{s^2 + 2\beta_d \omega_d s + \omega_d^2} \cdot \left(\frac{\omega_d^2}{\omega_n^2} \right)$$

$\omega_n = 2\pi 80;\ \beta_n = 0.05$
$\omega_d = 2\pi 80;\ \beta_d = 0.2$



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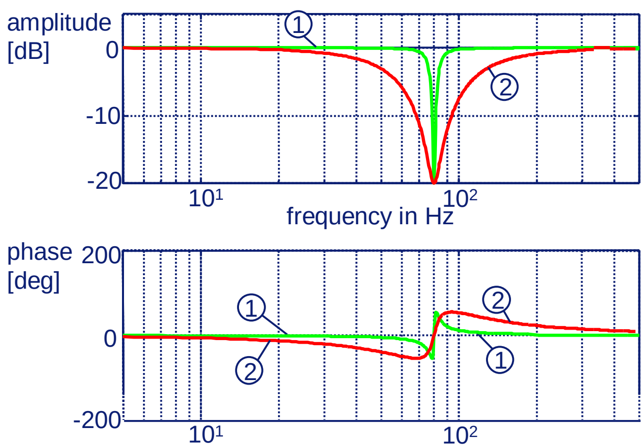
The PID controller in the frequency domain

Other filters: notch filter



$\omega_n = 2\pi 80;\ \beta_n = 0.005;\ \omega_d = 2\pi 80;\ \beta_d = 0.05$
$\omega_n = 2\pi 80;\ \beta_n = 0.05;\quad \omega_d = 2\pi 80;\ \beta_d = 0.5$

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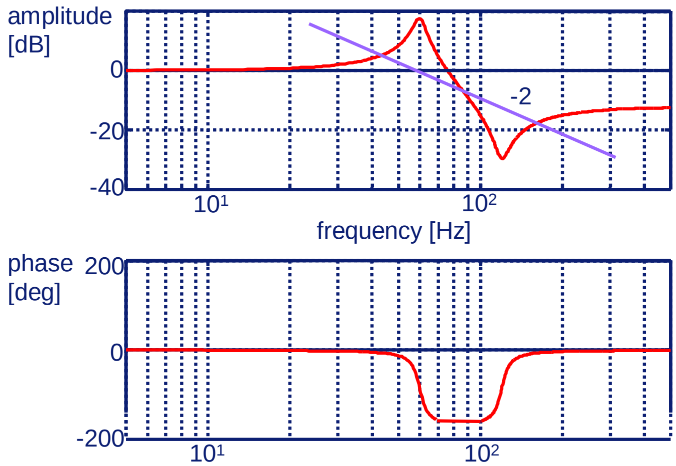
Other filters: skewed notch filter



$\omega_n = 2\pi 120;\ \beta_n = 0.05;\ \omega_d = 2\pi 60;\ \beta_d = 0.05$

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Overview Filters

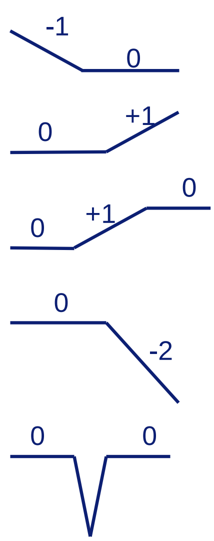
I-action

PD

Lead-lag

2nd order low pass

Notch



Controller tuning - a preview

- Start with PD, PI, or PID controller
- Lead-lag filter often included in PD & PID
- Add filters by series connection
- Look at Nyquist curve of open loop to check stability!!!

Summary

- Limitations of PD controller => extensions:
  - Integral action: suppress steady state error
  - Lead lag filter: avoid differentiation noise
  - Low pass: filter high-frequent noise
  - Notch: suppress resonance peaks
- Assemble controller by series connection