PHILIPS CTT Hogeschool van Utrecht

Systeem en Regeltechniek

FMT / Mechatronica

Deel 6: Extra regeltechniek

Blok 12: Set-points en feedforward tuning

Gert van Schothorst

Philips Centre for Technical Training (CTT)
Philips Centre for Industrial Technology (CFT)
Hogeschool van Utrecht - PTGroep

PHILIPS

Cursus Systeem en Regeltechniek

Overzicht

Deel 1	Blok 1.	Inleiding
Wo. 14-04	Blok 2.	Basisprincipes modelvorming massa-veersystemen
	Blok 3.	De regelaar als veer-demper combinatie
Deel 2	Blok 4.	Frequentie-domein beschrijving
Wo. 21-04	Blok 5.	Basisconcepten in de regeltheorie
Deel 3	Blok 6.	Verdere inleiding in de regeltheorie
Wo. 28-04	Blok 7.	De PD regelaar als veer-demper combinatie
Deel 4	Blok 8.	Stabiliteit van regelsystemen
Wo. 12-05	Blok 9.	De PID regelaar in het frequentie domein
Deel 5	Blok 10.	Bandbreedte en verstoringsonderdrukking
Wo. 19-05	Blok 11.	Toepassing: Tunen PID regelaar mechatronisch systeem
Deel 6	Blok 12.	Set-points en feedforward tuning
Wo. 26-05	Blok 13.	Digitale implementatie effecten
	Blok 14.	Terugblik / Evaluatie

PHILIPS

Setpoints and feedforward tuning

What is the aim of feedforward?

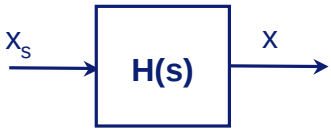
?

PHILIPS

Setpoints and feedforward tuning

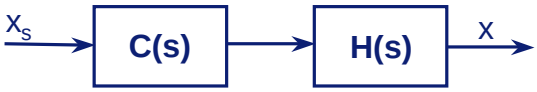
Recap: Why feedback?

Open loop:



$x \neq x_s$

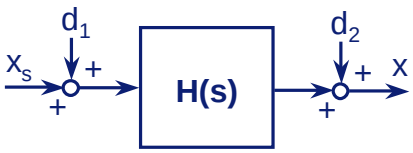
Feedforward:



$x = x_s$ if: $C(s) = H^{-1}(s)$

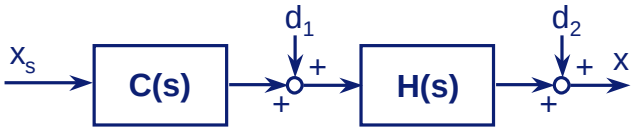
Recap: Why feedback?

Open loop with disturbances:



$x \neq x_s$

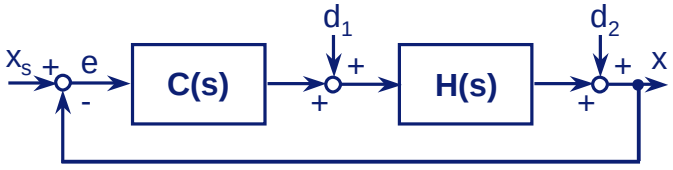
Feedforward with disturbances:



$x \neq x_s$ if: $C(s) = H^{-1}(s)$

Recap: Why feedback?

Feedback with disturbances:



Recall: $H_c(s) = \frac{x(s)}{x_s(s)} = \frac{C(s)\cdot H(s)}{1+C(s)\cdot H(s)}$

So: $x \approx x_s$ if: $C(s)\cdot H(s) >> 1$

PHILIPS

Setpoints and feedforward tuning

What is the effect of feedback without disturbances?

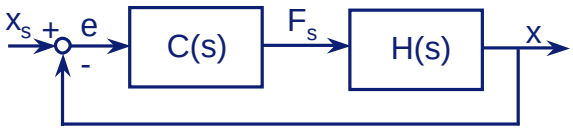
?

PHILIPS

Setpoints and feedforward tuning

Feedback without disturbances

Feedback without disturbances:



Recall: $S(s) = \frac{e(s)}{x_s(s)} = \frac{1}{1+C(s)\cdot H(s)}$

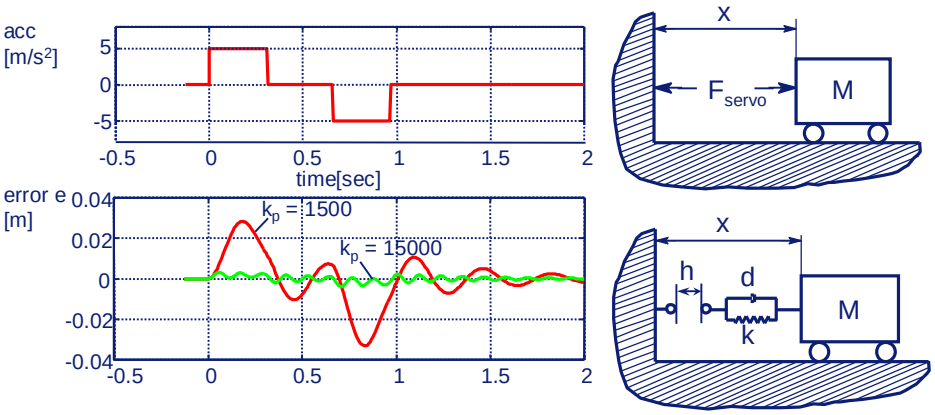
So: $e \approx 0$ if: $C(s)\cdot H(s) >> 1$

PHILIPS

Setpoints and feedforward tuning

Tracking error under feedback

Time response; k_p = 15000 / 1500 N/m; k_v = 20 Ns/m

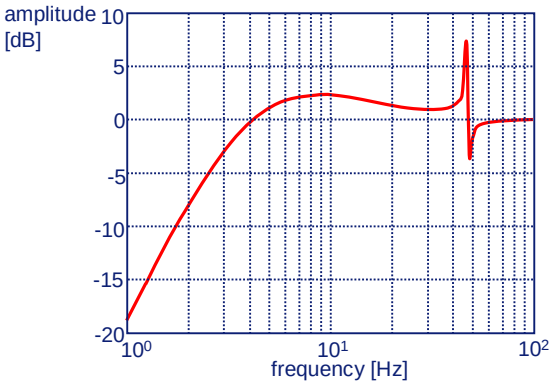


PHILIPS

Setpoints and feedforward tuning

Tracking error under feedback

Frequency domain interpretation: sensitivity function

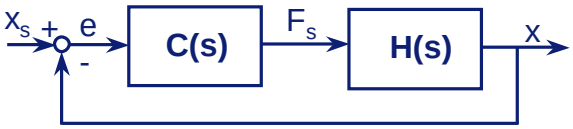


PHILIPS

Setpoints and feedforward tuning

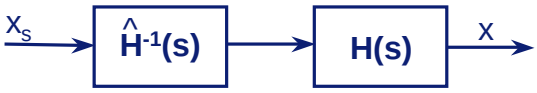
Feedback versus feedforward

Feedback without disturbances:



$e(s) = S(s) \cdot x_s(s)$

Feedforward:



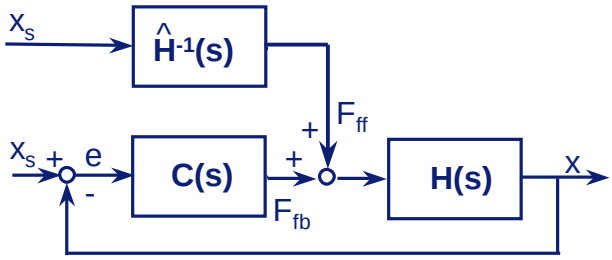
$x(s) = x_s(s)$

if: $C(s) = H^{-1}(s)$

PHILIPS

Setpoints and feedforward tuning

Feedback plus feedforward

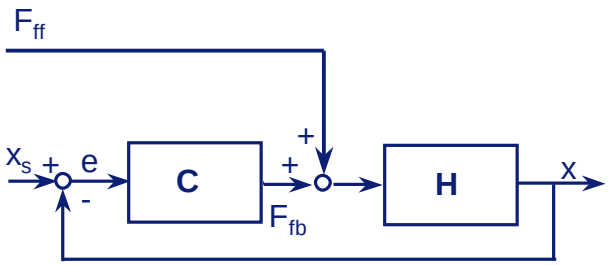


$e(s) = 0$ if: $\hat{H}(s) = H(s)$

PHILIPS

Setpoints and feedforward tuning

Feedback plus feedforward



e = 0 if: F_{ff} is required force for $x = x_s$

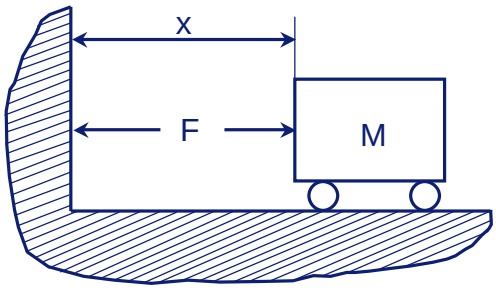
PHILIPS

Setpoints and feedforward tuning

Required feedforward

Equation of motion:

$$F(t) = M\ddot{x}(t)$$

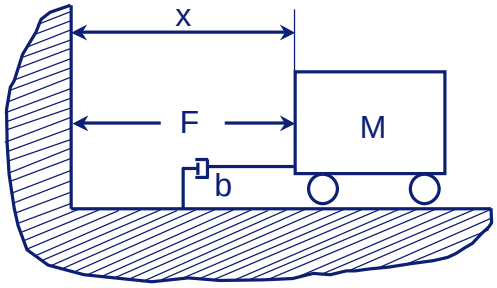


Desired trajectory: $x(t) = x_s(t)$

$$\Downarrow$$

Force feedforward: $F_{ff} = M\ddot{x}_s$

Required feedforward



Equation of motion:

$$F(t) = M\ddot{x}(t) + b\dot{x}(t)$$

Desired trajectory:

$$x(t) = x_s(t)$$

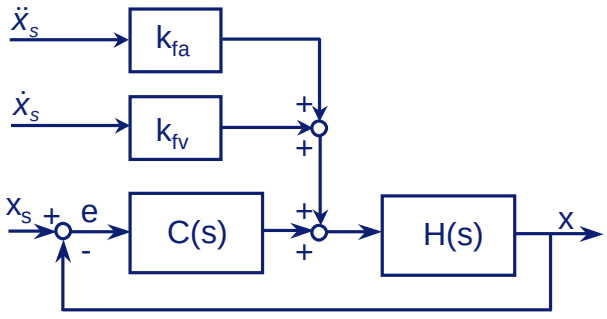
Force feedforward:

$$F_{ff} = M\ddot{x}_s + b\dot{x}_s$$

$M\ddot{x}_s$ acceleration feedforward

$b\dot{x}_s$ velocity feedforward

Feedforward implementation



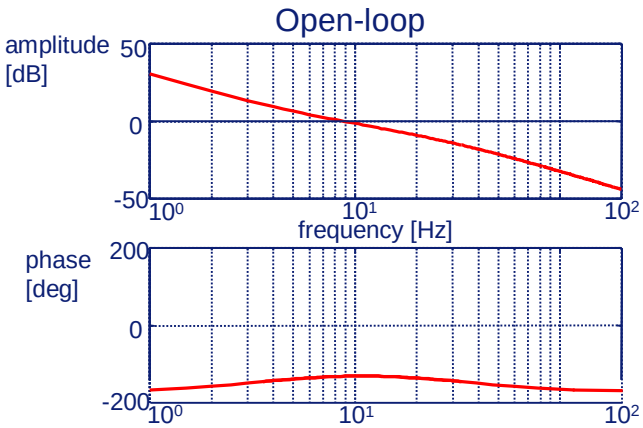
PHILIPS

Setpoints and feedforward tuning

Example of feedforward tuning

2nd order mechanics: M = 5 Kg; b = 1 Ns/m

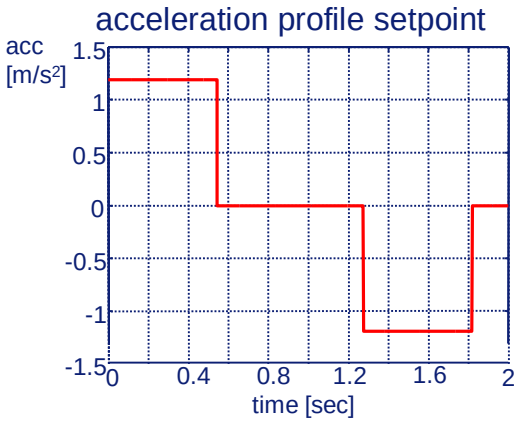
Controller: lead-lag: K = 6.5e^3 N/m: f_1 = 4 Hz; f_2 = 30 Hz



PHILIPS

Setpoints and feedforward tuning

Example of feedforward tuning

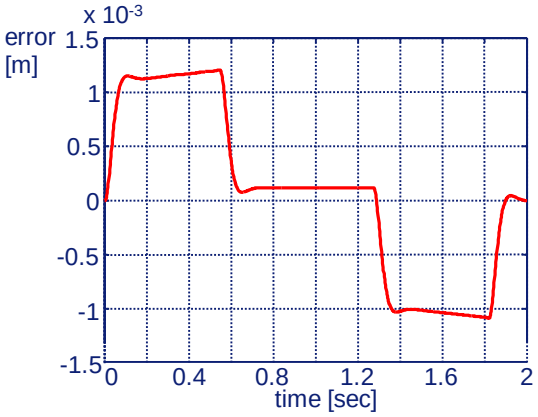


PHILIPS

Setpoints and feedforward tuning

Example of feedforward tuning

Time response; no feedforward

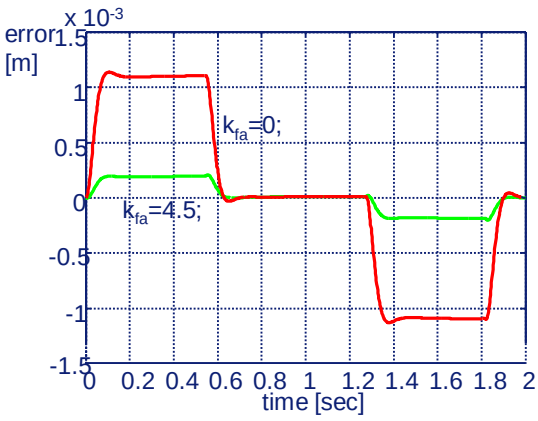


PHILIPS

Setpoints and feedforward tuning

Example of feedforward tuning

Time response; K_{fv} = 0.9 Ns/m; K_{fa} = 0 / 4.5 kg



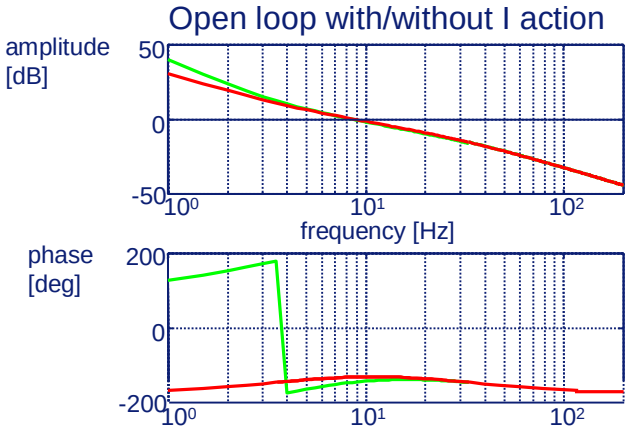
PHILIPS

Setpoints and feedforward tuning

Example of feedforward tuning - Effect I-action

Controller: lead-lag + I-action:

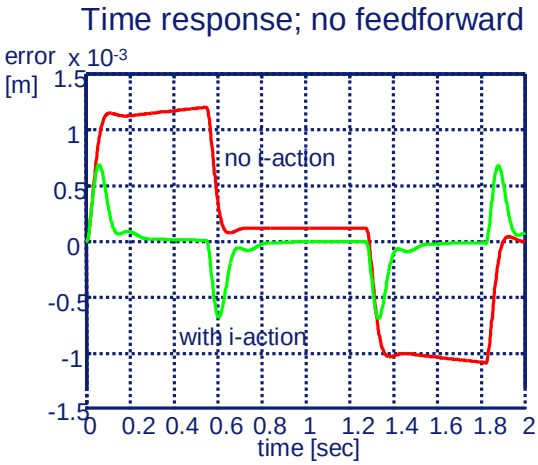
k = 6.5e^3 N/m; f_1 = 4 Hz; f_2 = 30 Hz; f_i = 3 Hz



PHILIPS

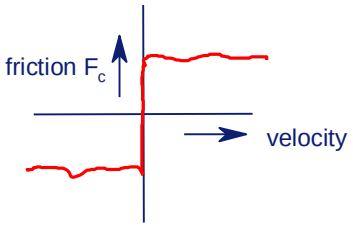
Setpoints and feedforward tuning

Example of feedforward tuning - Effect I-action



Friction feedforward

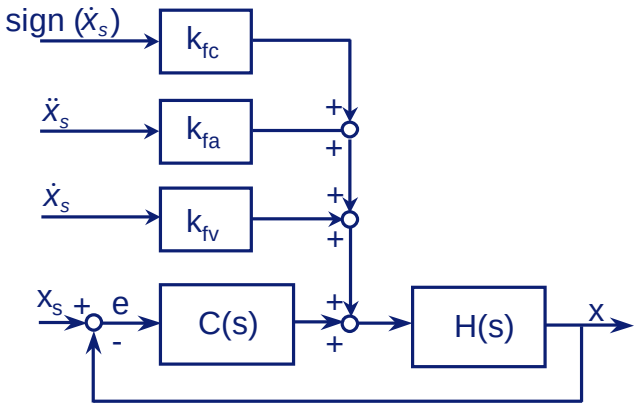
Friction:



Equation of motion:

$$F(t) = M\ddot{x}(t) + b\dot{x}(t) + F_c(\dot{x})$$

Friction feedforward - Implementation



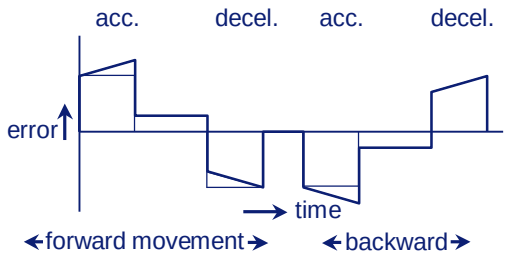
PHILIPS

Setpoints and feedforward tuning

Feedforward tuning

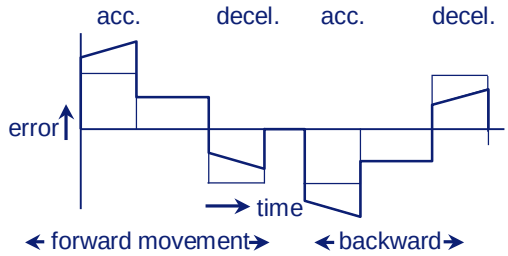
Schematic-approximation of servo error

WITHOUT FRICTION



Schematic-approximation of servo error

WITH FRICTION



PHILIPS

Setpoints and feedforward tuning

Feedforward tuning procedure

1. Set I-action to zero, if applied;
2. Monitor servo error;
3. Define second order setpoint trajectory;
   Trajectory must consist of forward and backward movement, the maximum velocity and acceleration must be set such, that the parts with constant velocity and acceleration are clearly visible; suggestion: in time, 1/3 acceleration, 1/3 constant, 1/3 deceleration;
4. Minimize error during constant velocity traject by adjusting k_{fv};
5. Minimize error during acceleration / deceleration traject by adjusting k_{fa};
6. Set I-action;

Setpoints

Standard setpoints:

- Skew-sine (mechanical cam-design)
- Second order setpoint (software generated; square acceleration profile)

Alternative setpoints - why?

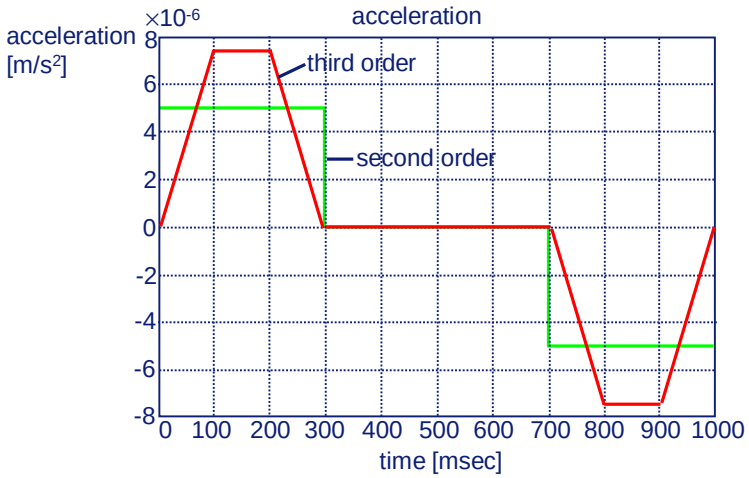
- Limitations current amplifier
- Parasitic dynamics

Which alternatives?

- Third order setpoint (jerk limitation)
- Model-based input shaping

Third order setpoint

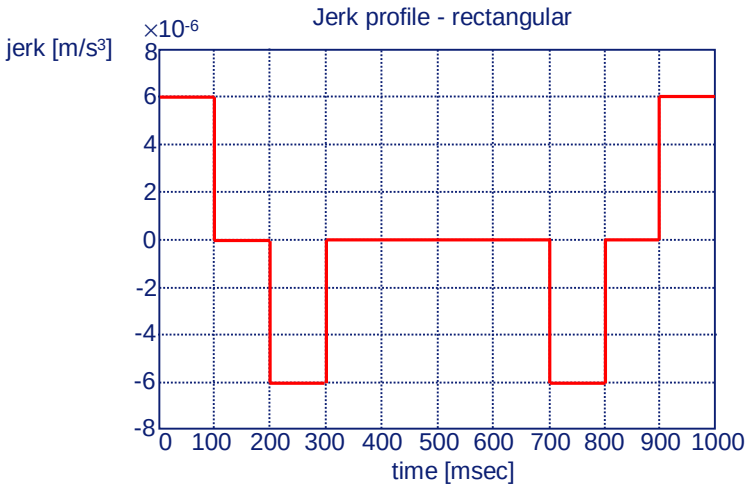
Jerk rectangular instead of acceleration



PHILIPS

Setpoints and feedforward tuning

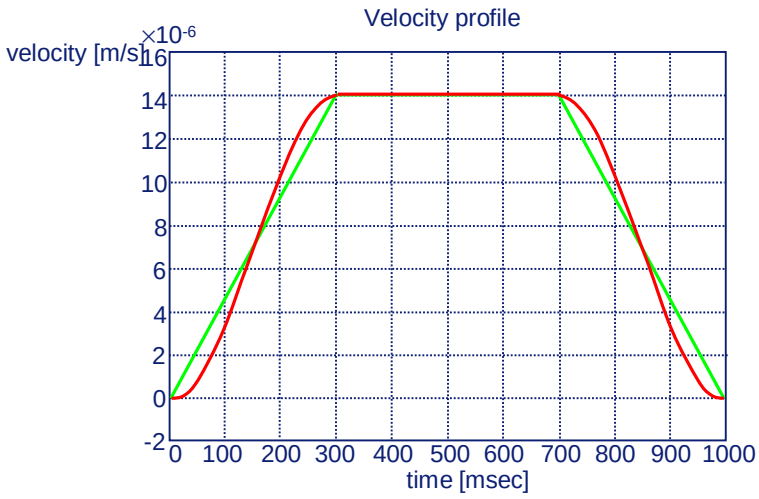
Third order setpoint



PHILIPS

Setpoints and feedforward tuning

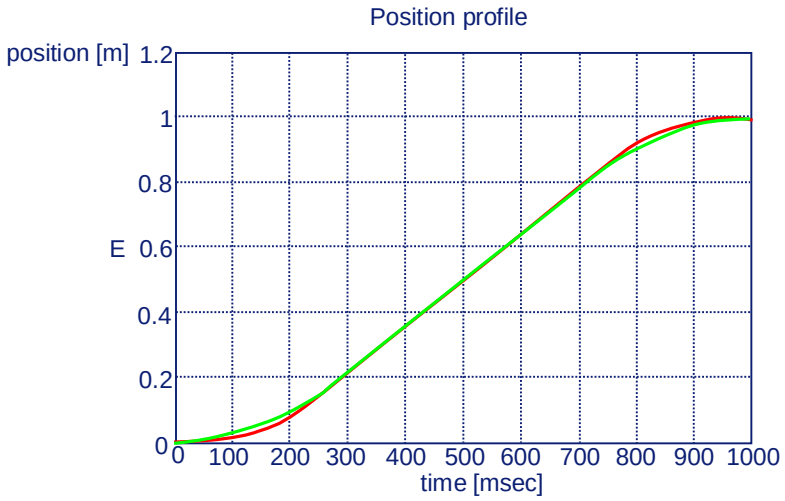
Third order setpoint



PHILIPS

Setpoints and feedforward tuning

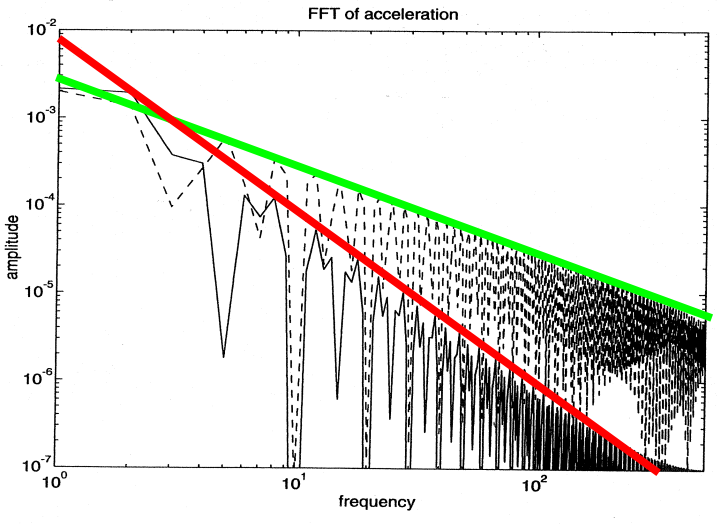
Third order setpoint



PHILIPS

Setpoints and feedforward tuning

Frequency content of setpoints



Summary

- Feedforward versus feedback:
  - Nonzero tracking error due to feedback: S(s)
  - Zero tracking error for ideal feedforward
- Feedforward = needed force for motion:
  - Acceleration / Damping / Friction
- Feedforward tuning: note I-action!
- Third order setpoint: smoother profiles

PHILIPS

CTT