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Challenges in Advanced Motion Control

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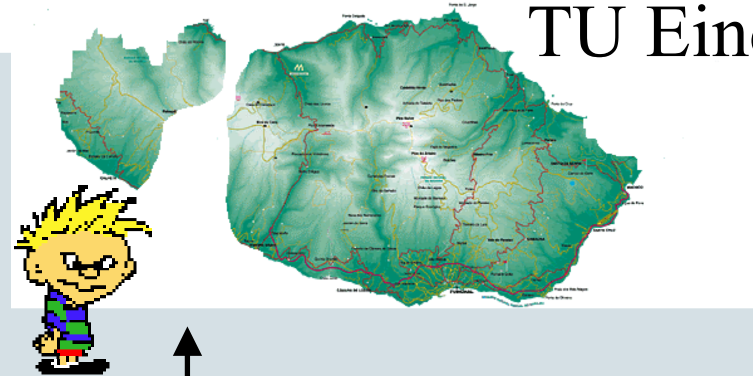
Control Systems Technology Group

DCSC symposium june 2004

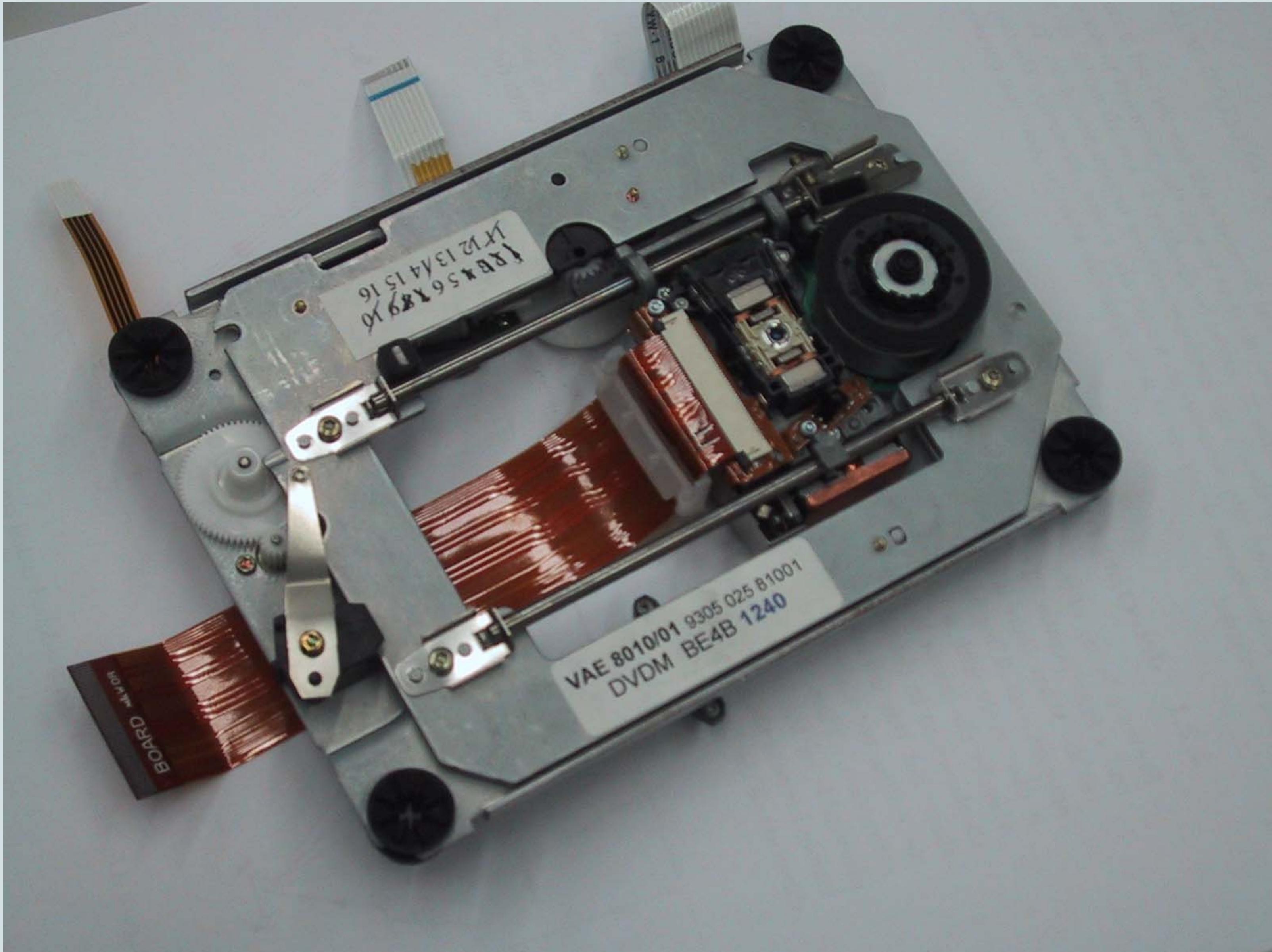
/department of mechanical engineering

TU Eindhoven



TU Delft

Philips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DVDM BE4B 1240
BOARD

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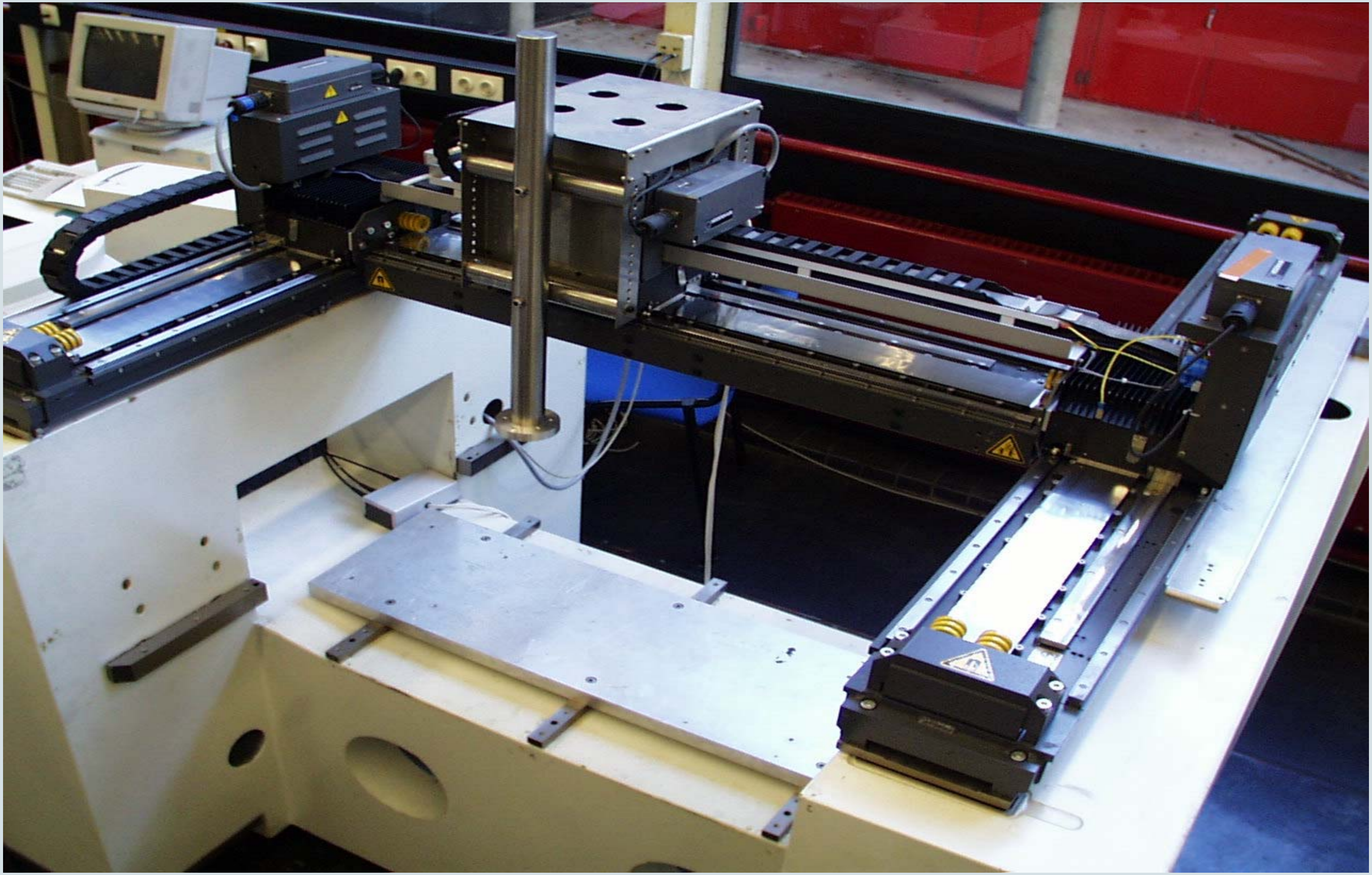

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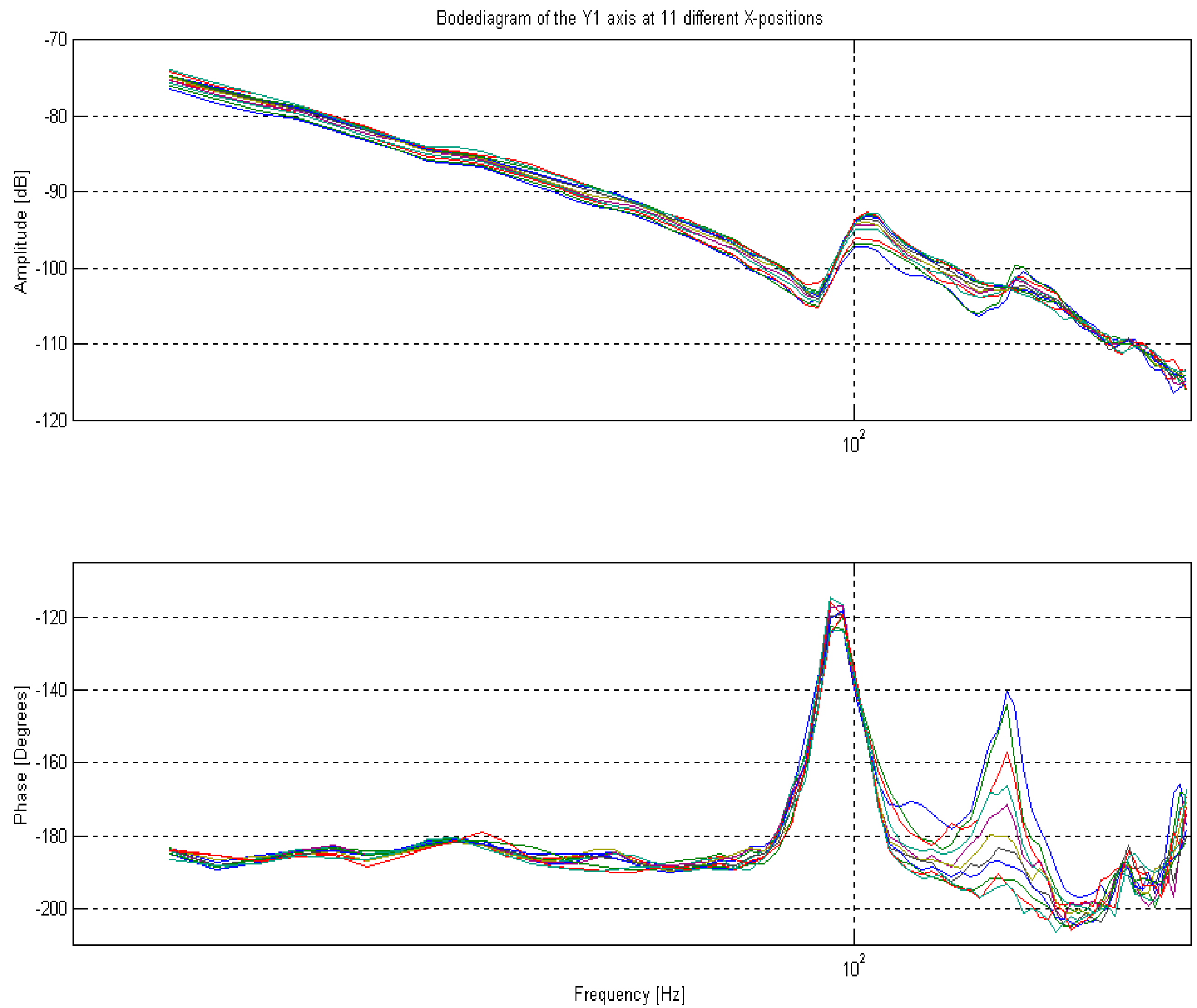

Bodediagram of the Y1 axis at 11 different X-positions
-70
-80
-90
-100
-110
-120
Amplitude [dB]
10^2
-120
-140
-160
-180
-200
Phase [Degrees]
10^2
Frequency [Hz]

Motion Control Properties

- experimentation is ‘cheap’ (design cycle 7 min: FRF measurement, model, loopshape, implementation)
- plant decoupling, i.e. SISO
- feedforward: low-order model-based
- feedback: loopshaping
- key limitation: bode sensitivity integral
- finished?

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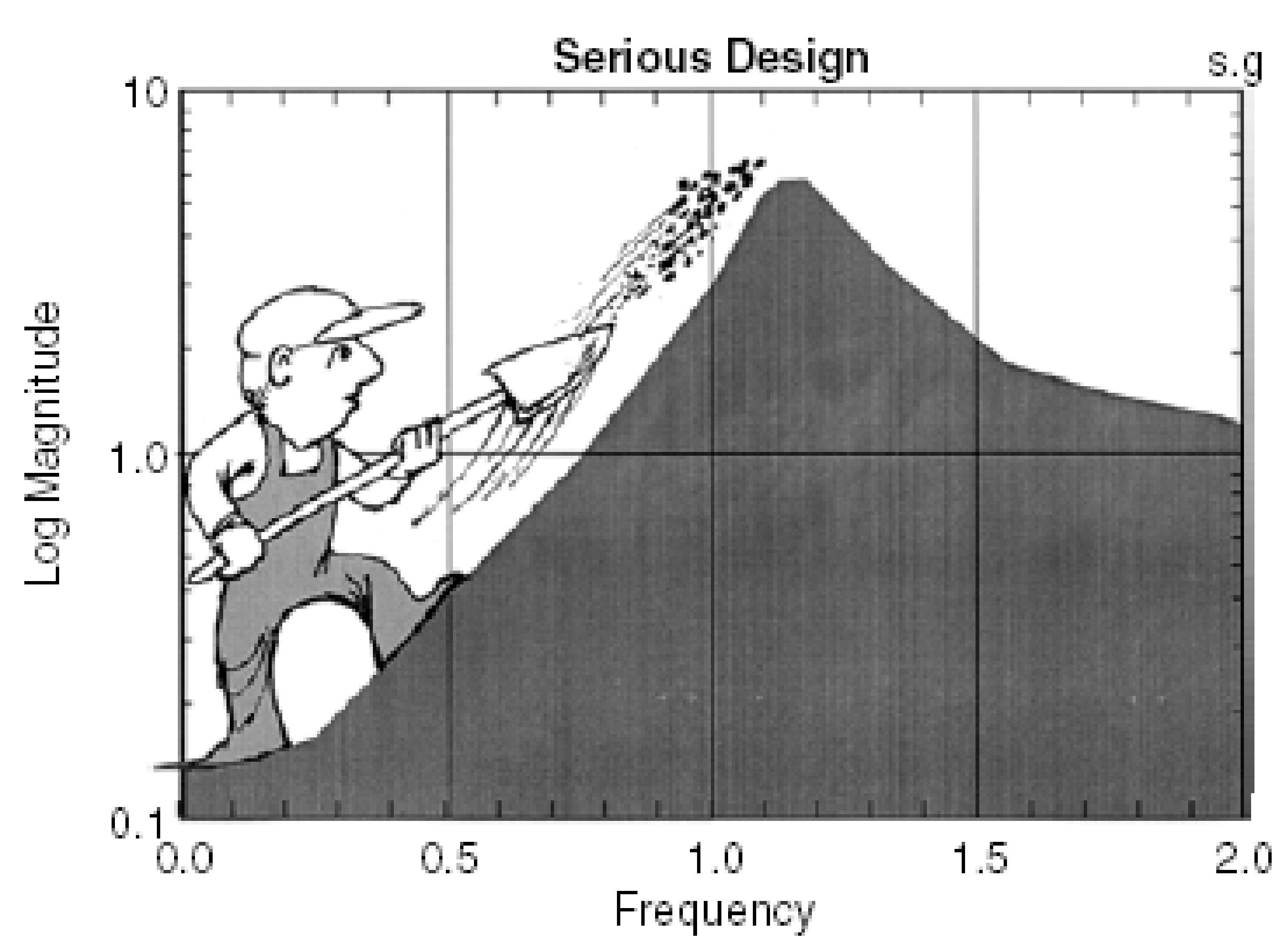
Gunter Stein's Bode Lecture, CDC 1989

IEEE Control Systems Magazine, 23 (2003), pp 12- 25



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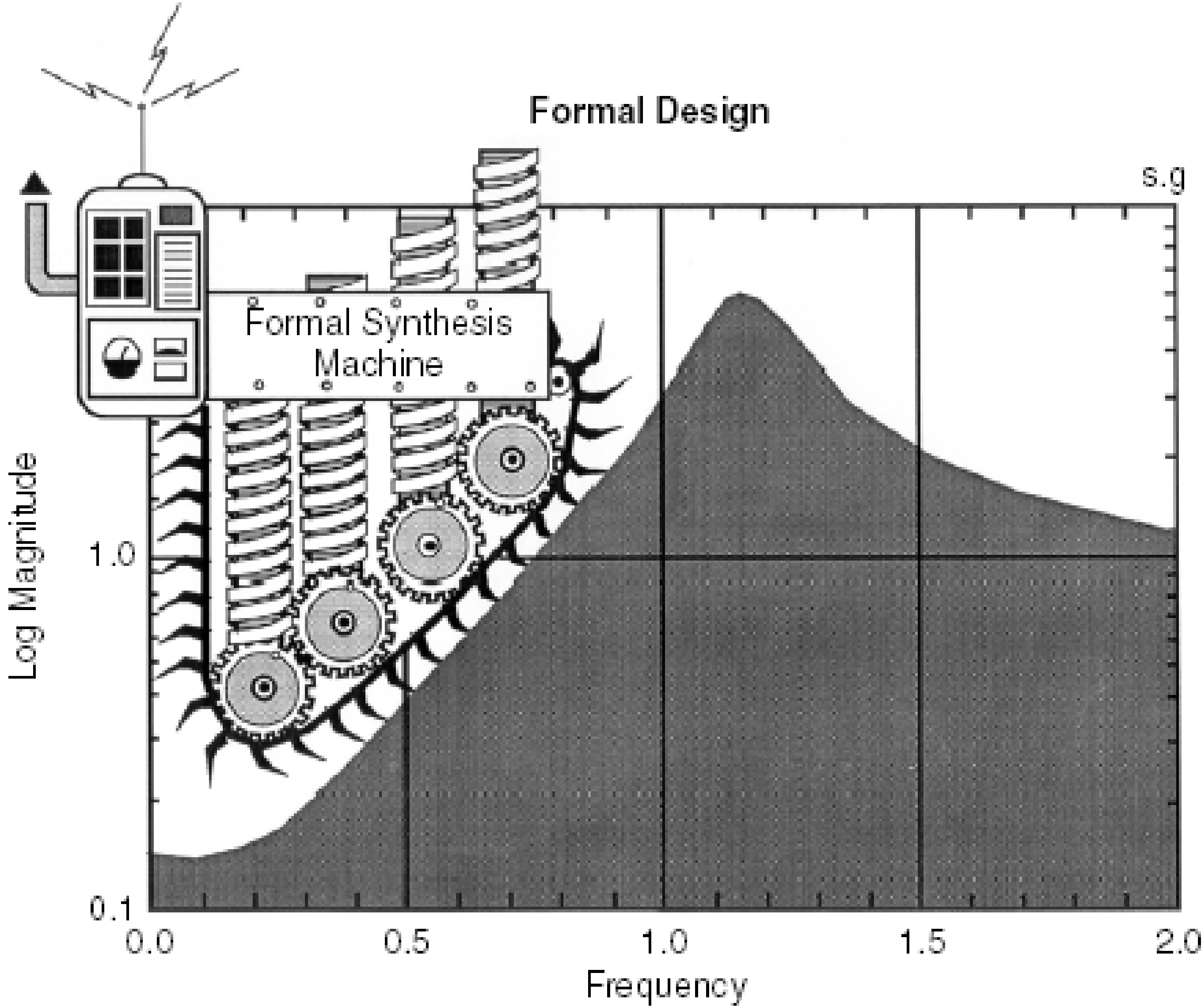

Formal Design
s.g
Formal Synthesis
Machine
Log Magnitude
1.0
0.1
0.0
0.5
1.0
1.5
2.0
Frequency

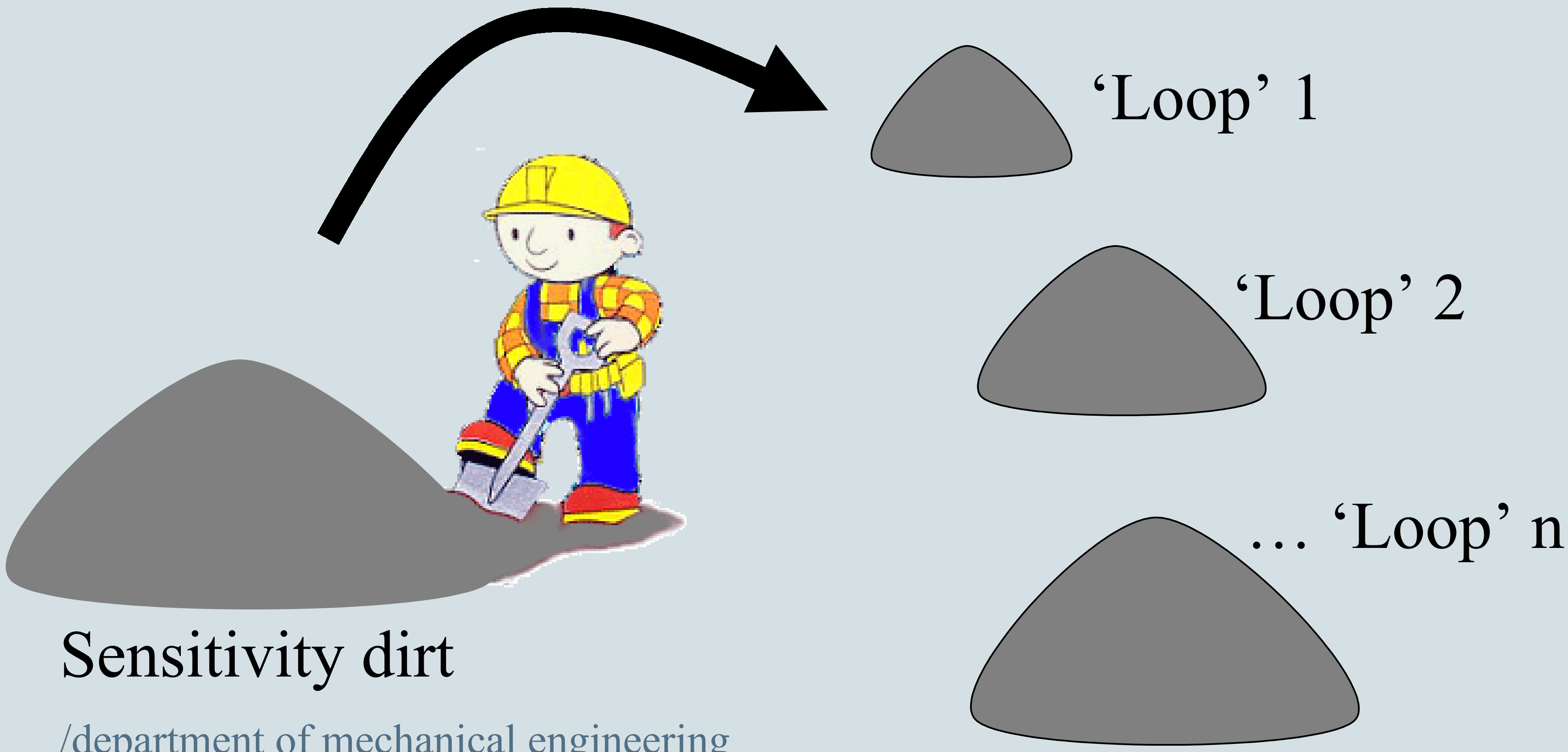
Motion Control Challenge:

how to cope with Bode sensitivity limitation?

directions of motion control research

- nonlinear control of linear systems (reset…)
- MIMO loopshaping
- disturbance-based modelling and control
- data-driven control

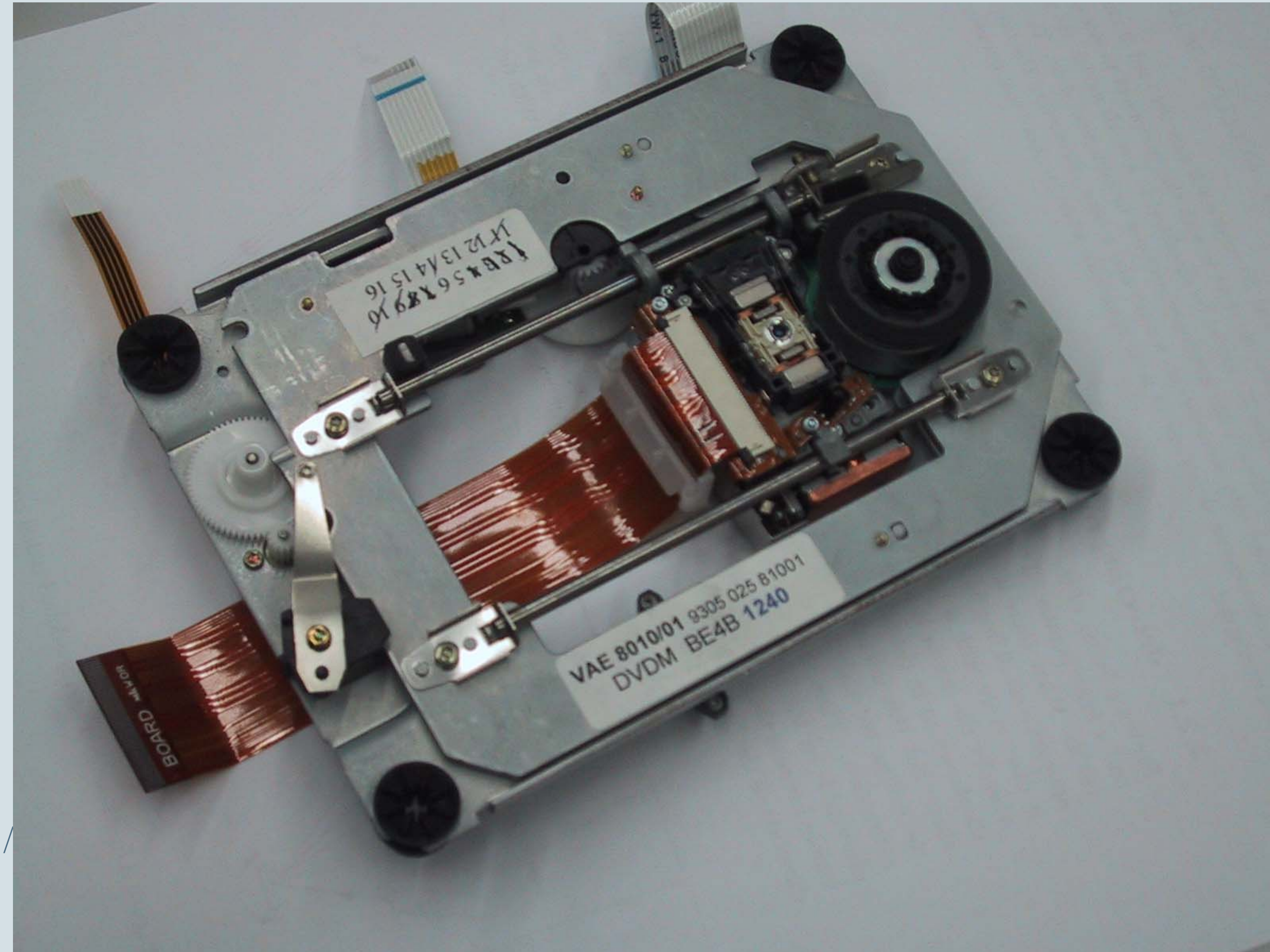
MIMO integral constraints…



disturbance-based modelling and control

- disc errors vs shocks optical storage
- stochastic vs deterministic disturbances
- repetitive vs a-periodic setpoints or disturbances

Internal model principle….


VAE 8010/01 8305 025 81001
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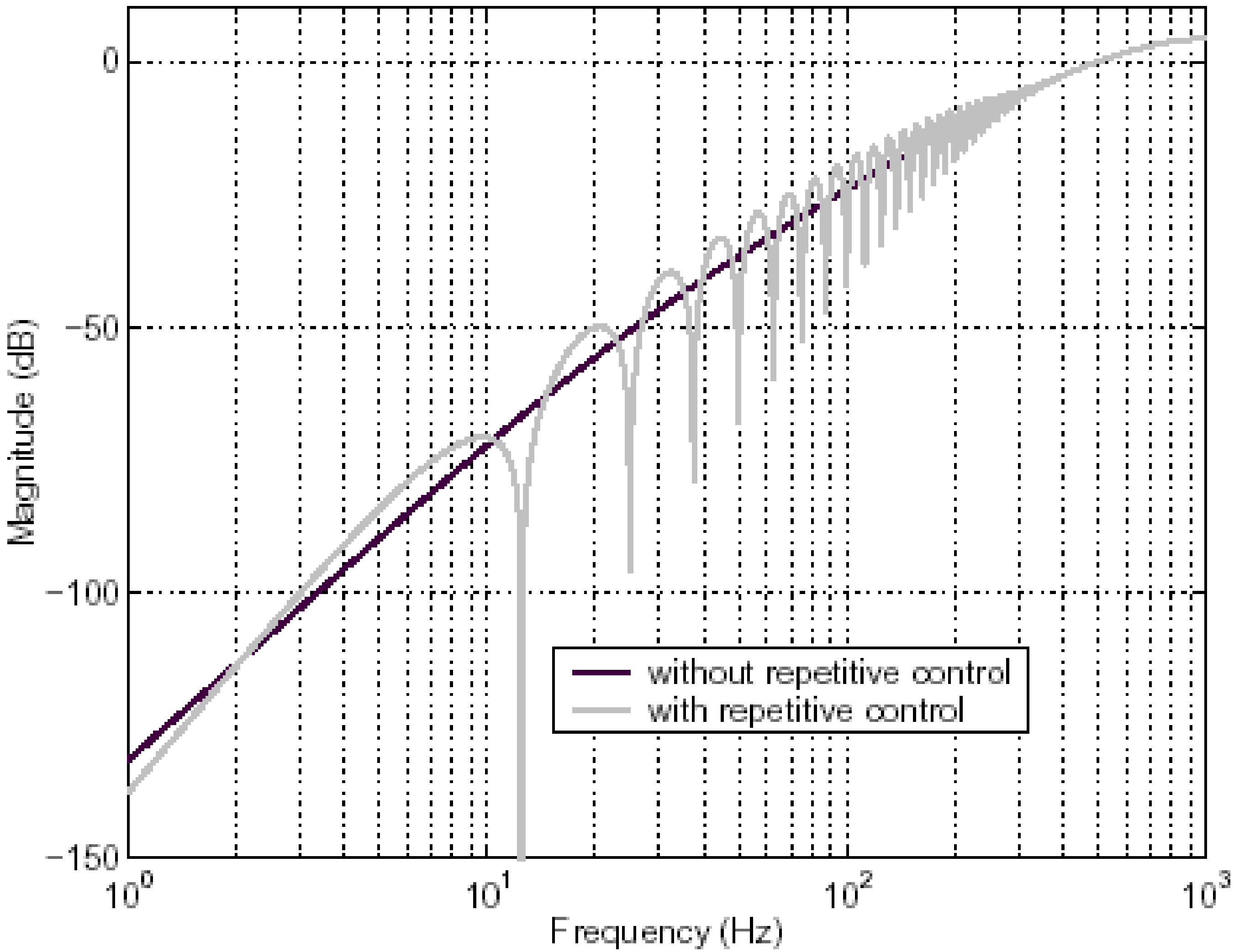
BOARD


0
−50
−100
−150
Magnitude (dB)
10^0
10^1
10^2
10^3
Frequency (Hz)
without repetitive control
with repetitive control

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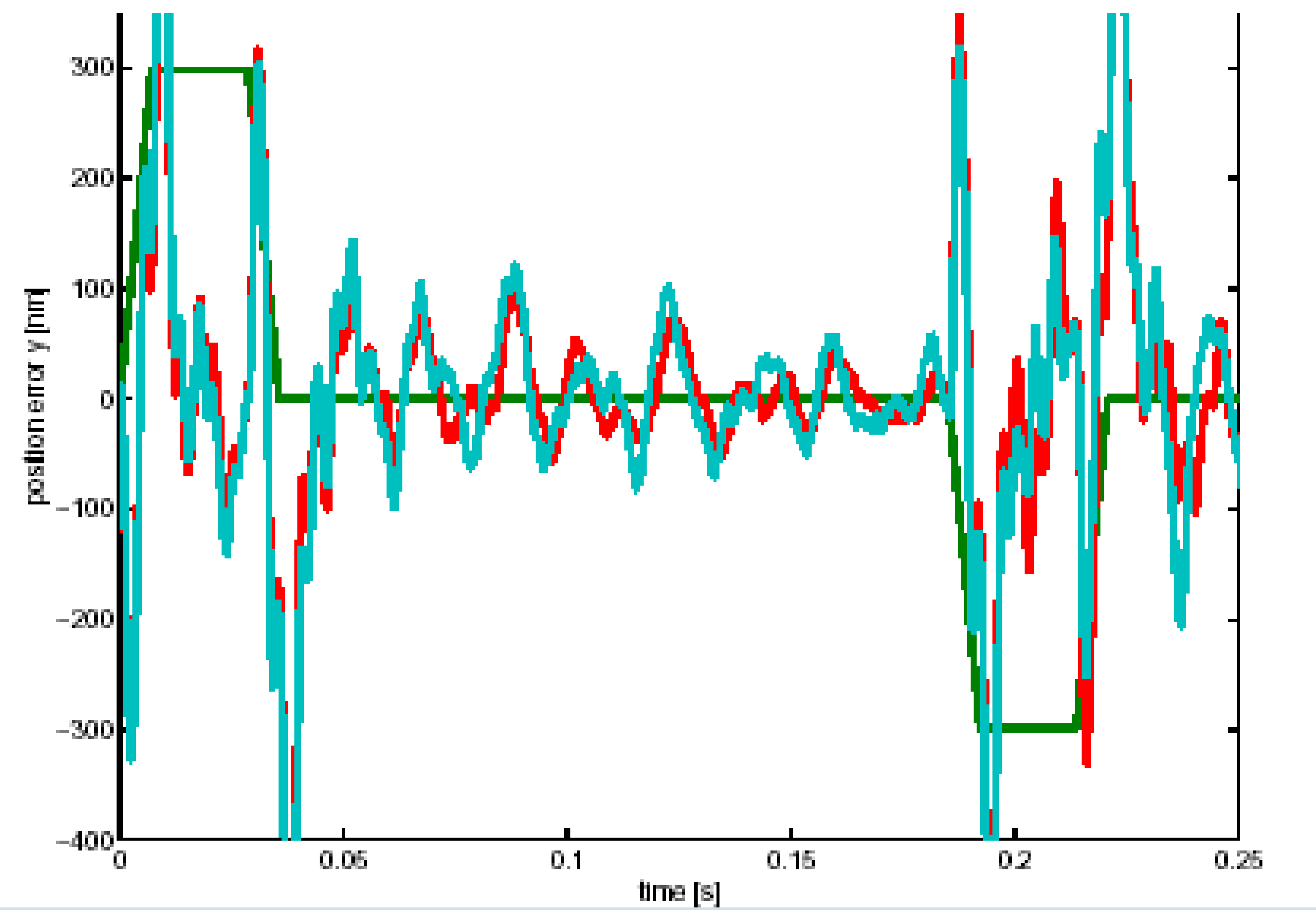
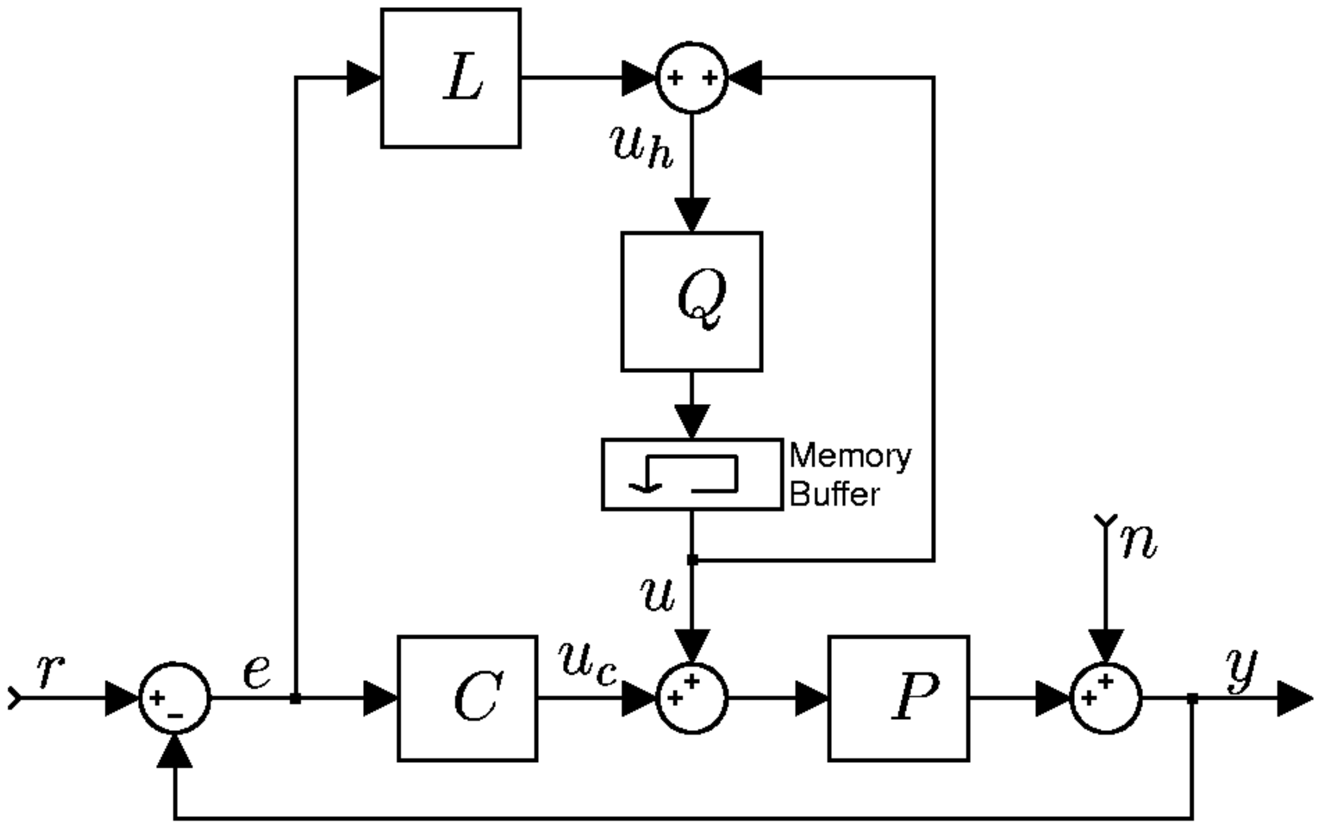
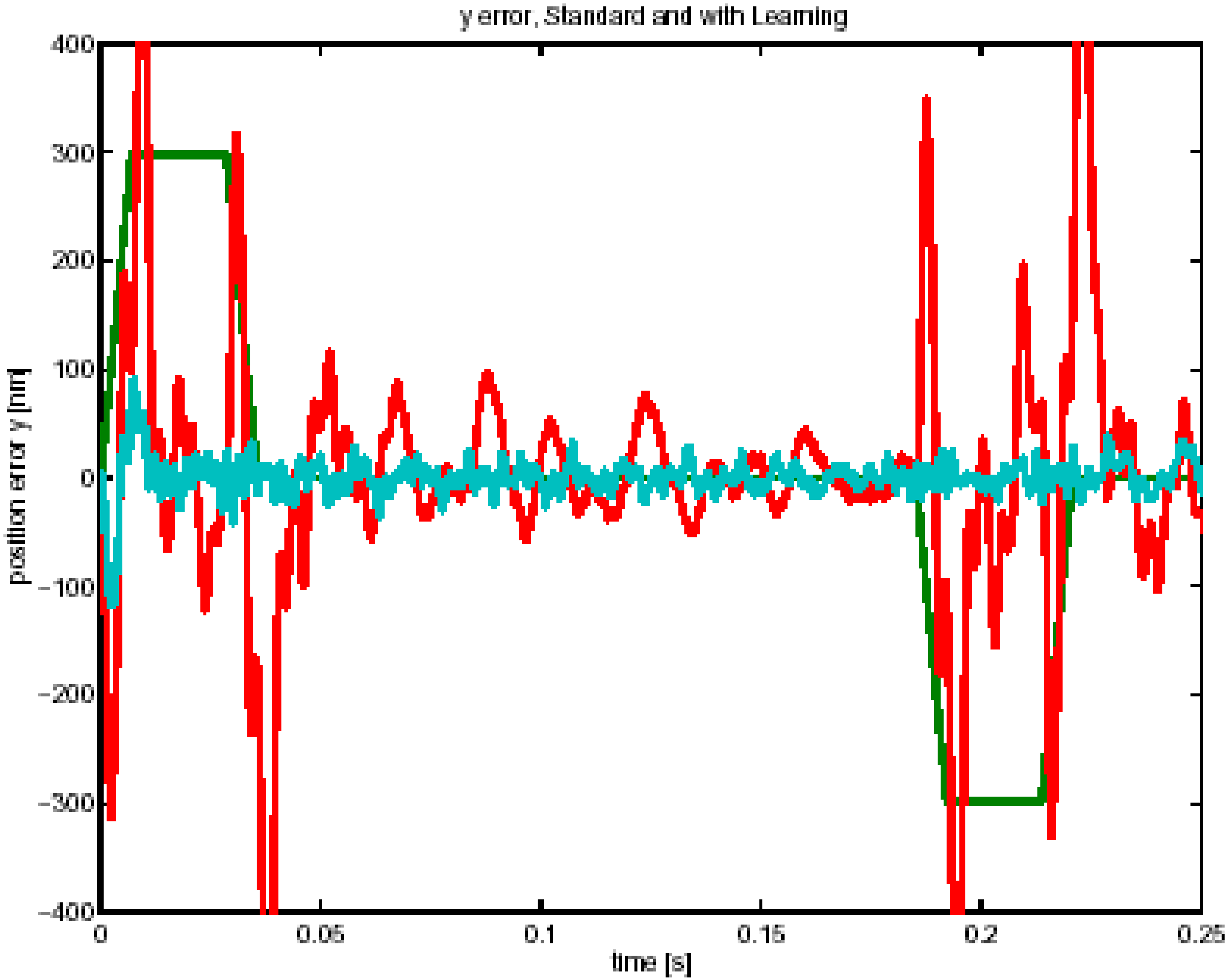


300
200
100
0
−100
−200
−300
−400
position error y [nm]
0
0.05
0.1
0.15
0.2
0.25
time [s]

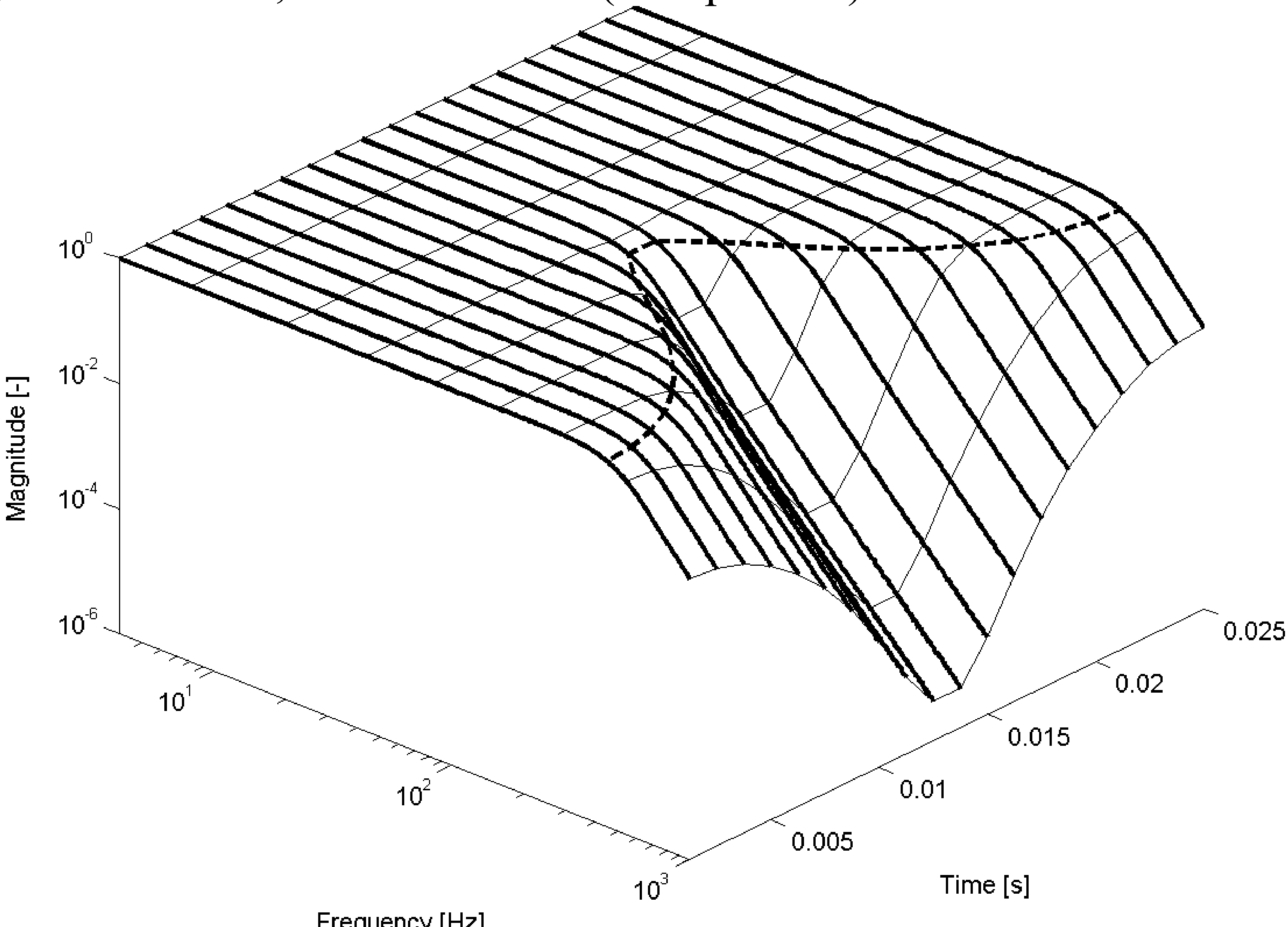
Iterative Learning Control (ILC)



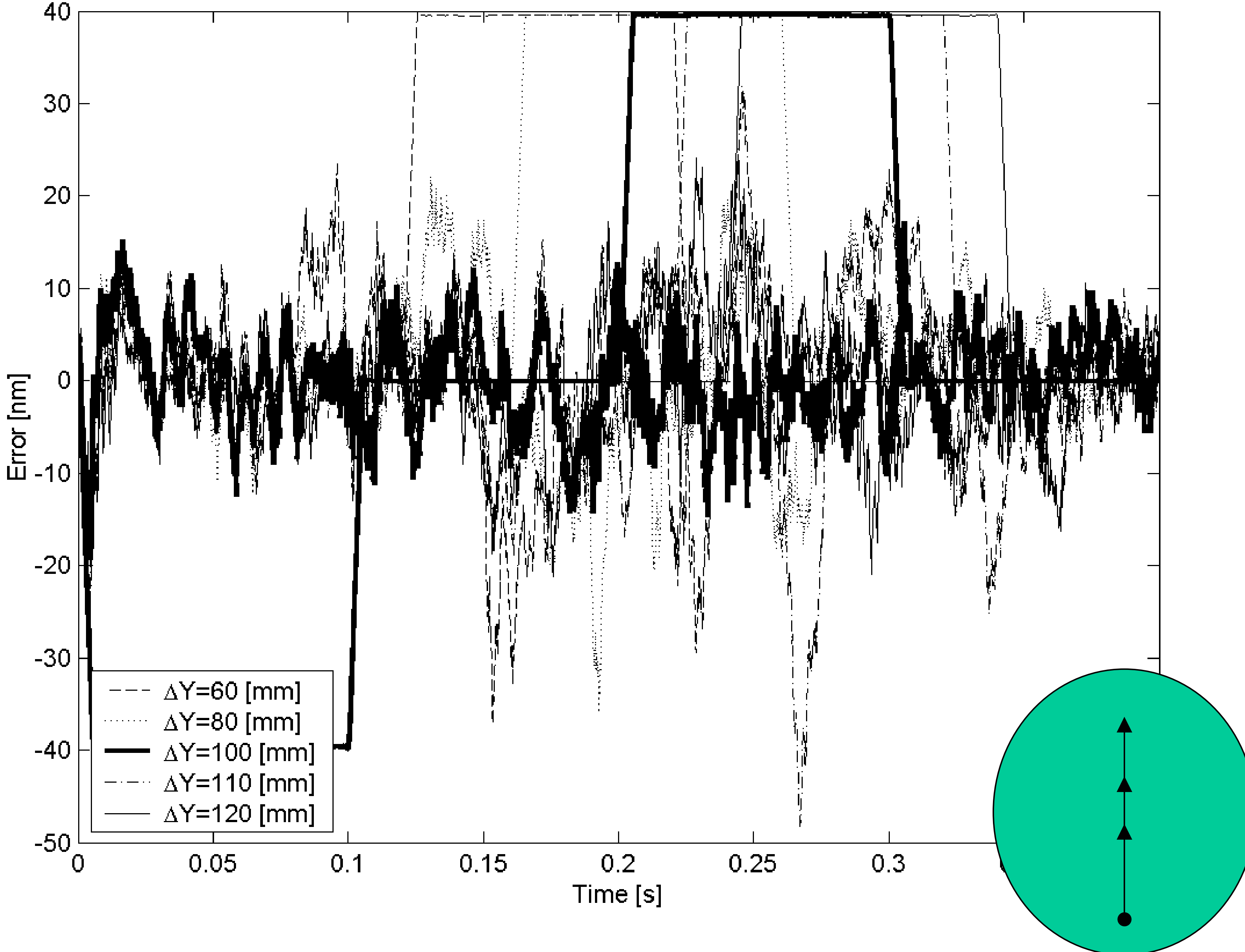
$$e_{k+1} < e_k \longleftarrow \left|Q\left(1 - L\,PS\right)\right| < 1$$


y error, Standard and with Learning
position error y [nm]
400
300
200
100
0
−100
−200
−300
−400
0
0.05
0.1
0.15
0.2
0.25
time [s]

Time-frequency adaptive Iterative Learning Control
Rogier Ellenbroek, Iuliana Rotariu (Philips CFT)



Experimental results



directions of motion control research

- nonlinear control of linear systems (reset…)
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- disturbance-based modelling and control
- data-driven control

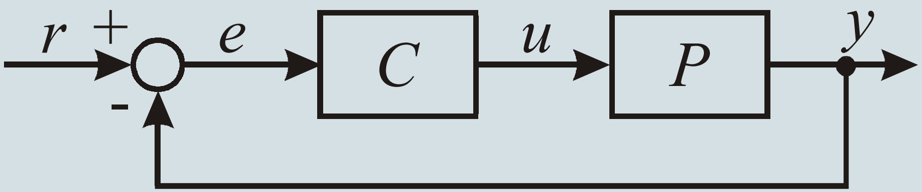
Data-based Design of High-performance Motion Controllers

Dragan Kostić

- Examples:
  - *data-based LQG control*
  - *unfalsified control*
  - *iterative feedback tuning*
  - *virtual reference feedback tuning*

Problem statement

- Design a SISO LTI controller C for LTI plant P



- Control objective: realize the desired S_o and T_o
- Ideal controller C_o:

$$S_o = \frac{1}{1+PC_o}, \quad T_o = \frac{PC_o}{1+PC_o}.$$

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Data-based controller design

- The controller class: $\{C(z,\boldsymbol{\theta})\} = \{C_{\mathrm{p}}(z)\boldsymbol{\beta}^T(z)\boldsymbol{\theta}\}$.
- $C_{\mathrm{p}}(z)$ is directly prescribed by the designer: notches, integrators, etc.
- Basis functions: $\boldsymbol{\beta}(z) = [\beta_0(z)\ \beta_1(z)\ \ldots\ \beta_n(z)]^T$.
- Tuning parameters: $\boldsymbol{\theta} = [\theta_0\ \theta_1\ \ldots\ \theta_n]^T$.

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Data-based controller design

- Constraint on C_o: $T_o(z) = C_o(z) S_o(z) P(z)$

- Model-based cost function:

$$J_{MB}(\boldsymbol{\theta}) = \left\| \left(T_o(z) - C(z,\boldsymbol{\theta}) S_o(z) P(z) \right) W(z) \right\|_2^2$$

- Processing the measurements:

$$T_o(z)u(t) = C(z,\boldsymbol{\theta}) S_o(z) P(z) u(t) \;\Rightarrow\; T_o(z)u(t) = C(z,\boldsymbol{\theta}) S_o(z) y(t)$$

- Data-based cost function:

$$J_{DB}^N(\boldsymbol{\theta}) = \frac{1}{N} \sum_{t=1}^{N} \left[L(z) \left(T_o(z)u(t) - C(z,\boldsymbol{\theta}) S_o(z) y(t) \right) \right]^2$$

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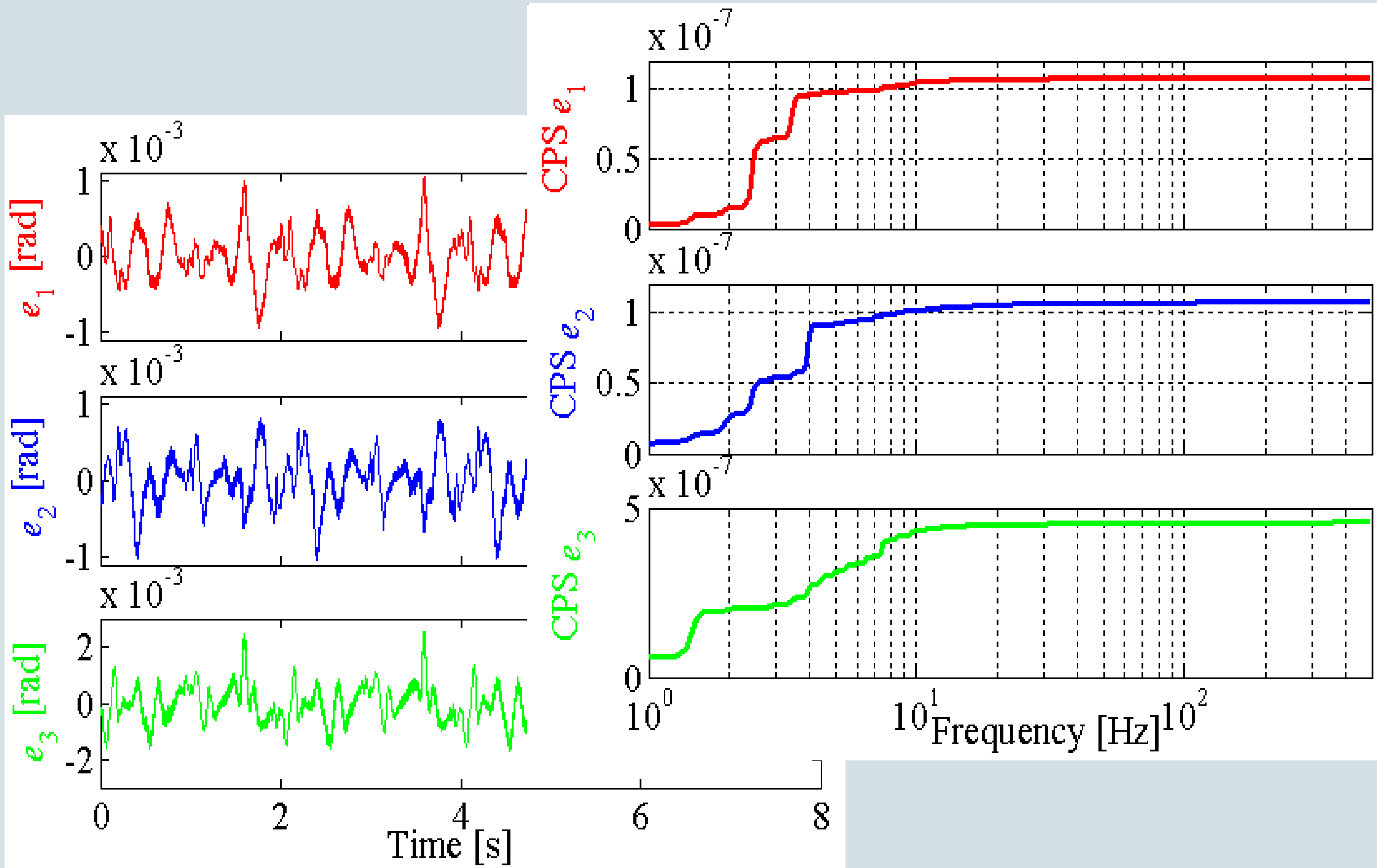
x 10^-3
e_1 [rad]
e_2 [rad]
e_3 [rad]
Time [s]
x 10^-7
CPS e_1
CPS e_2
CPS e_3
Frequency [Hz]

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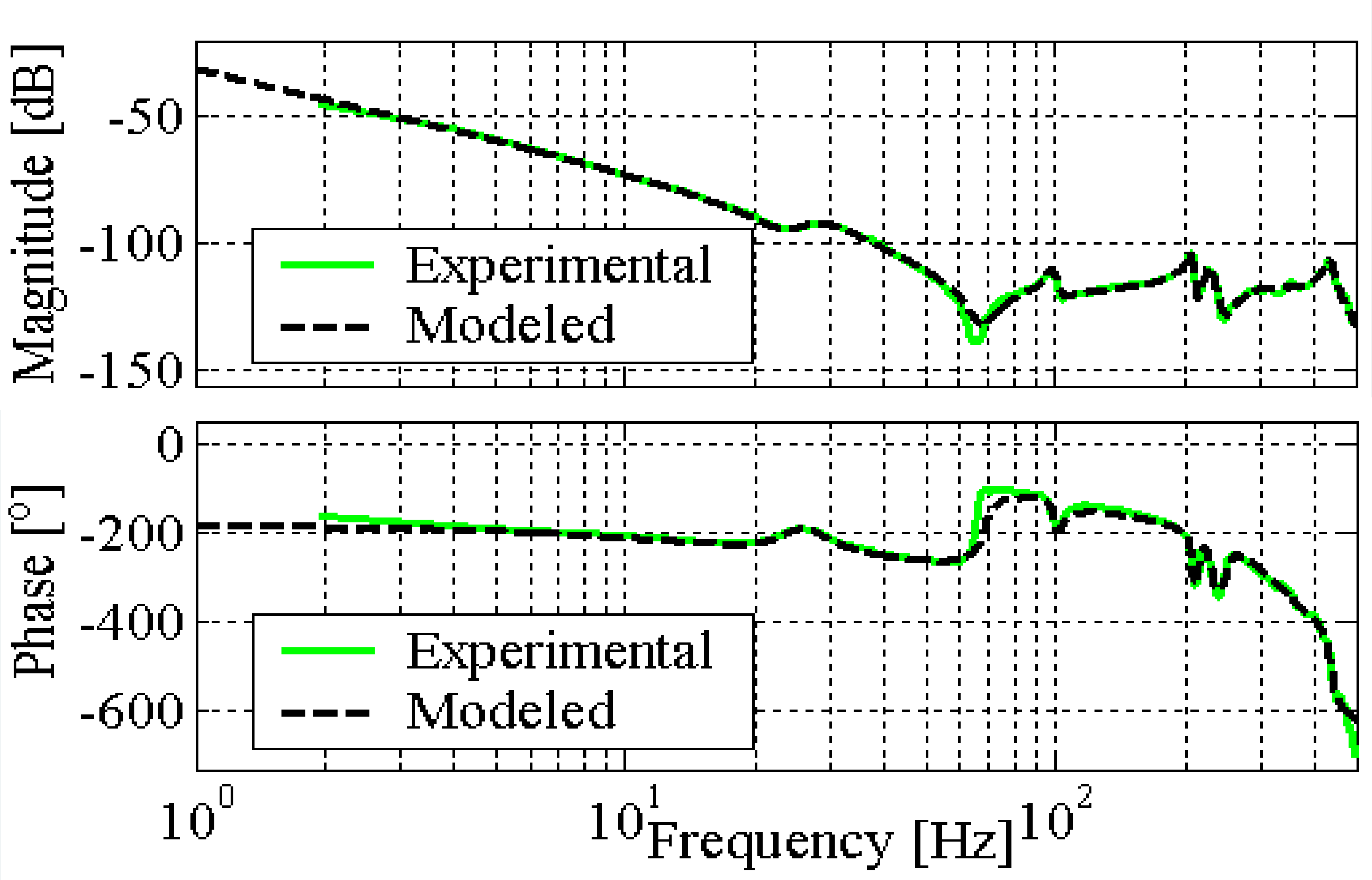

Magnitude [dB]
-50
-100
-150
Experimental
Modeled
Phase [°]
0
-200
-400
-600
Experimental
Modeled
10^0
10^1
Frequency [Hz]
10^2

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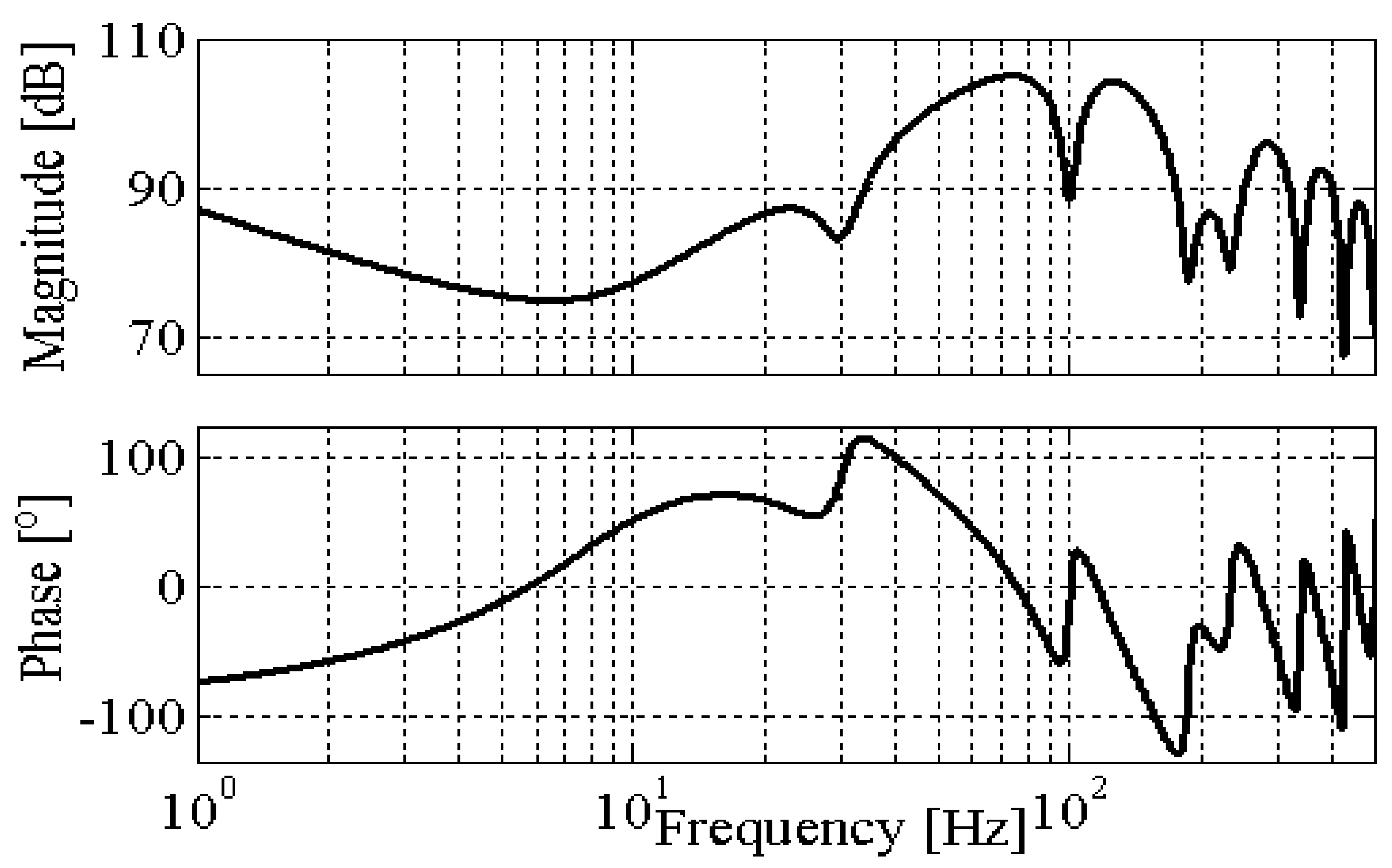

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$$C_1(z, \hat{\boldsymbol{\theta}}_{\mathrm{DB}}^{N})$$

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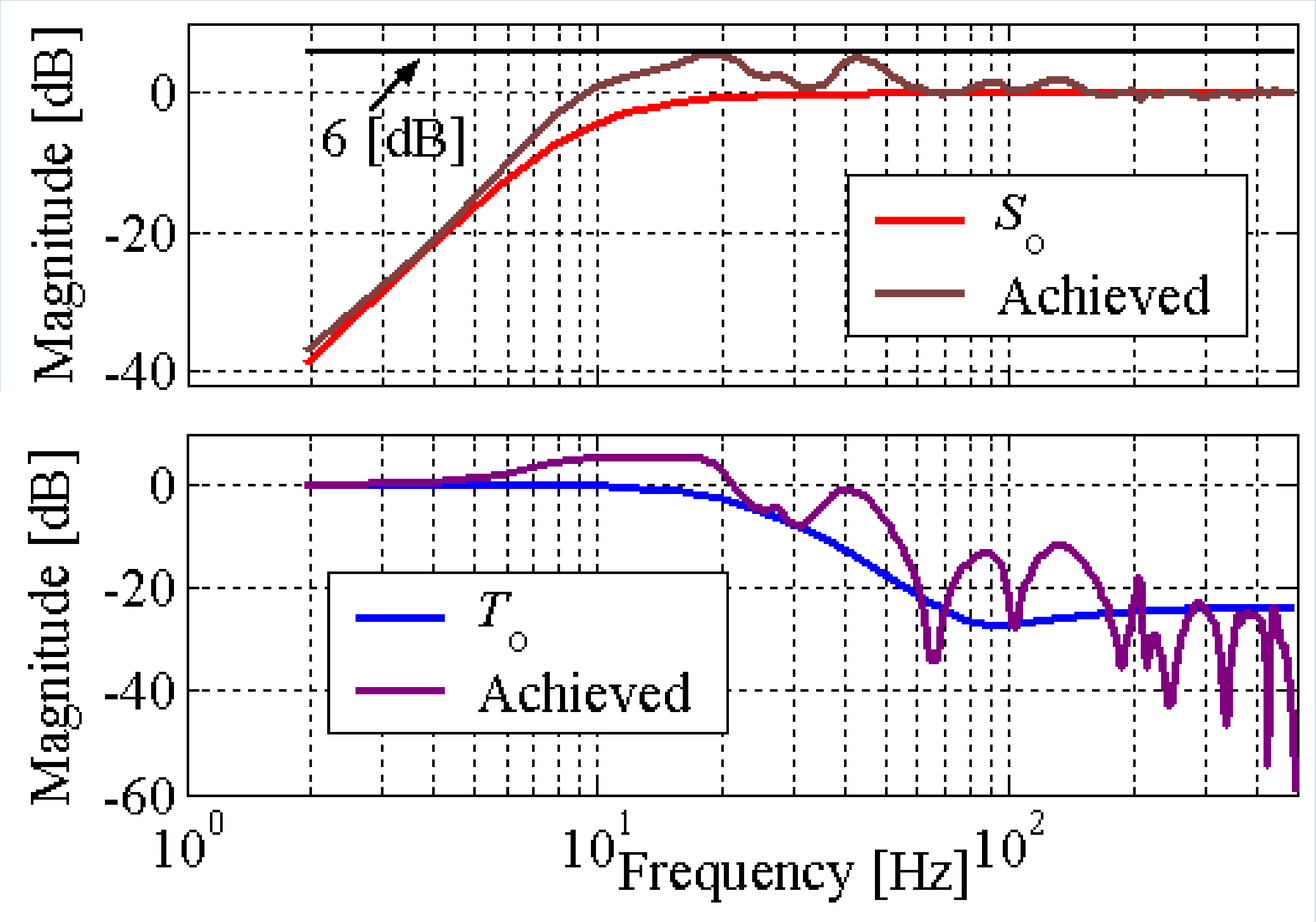
Magnitude [dB]
0
-20
-40
6 [dB]
S o
Achieved
Magnitude [dB]
0
-20
-40
-60
T o
Achieved
10^0
10^1
10^2
Frequency [Hz]

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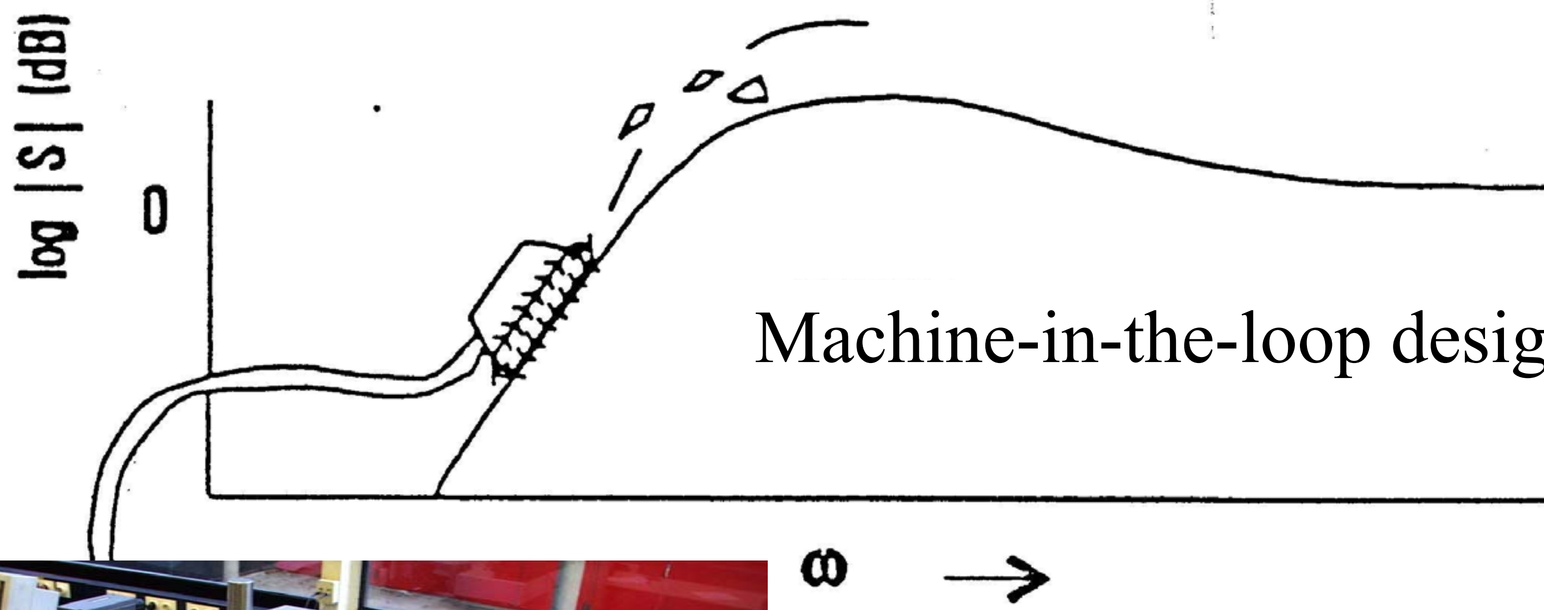
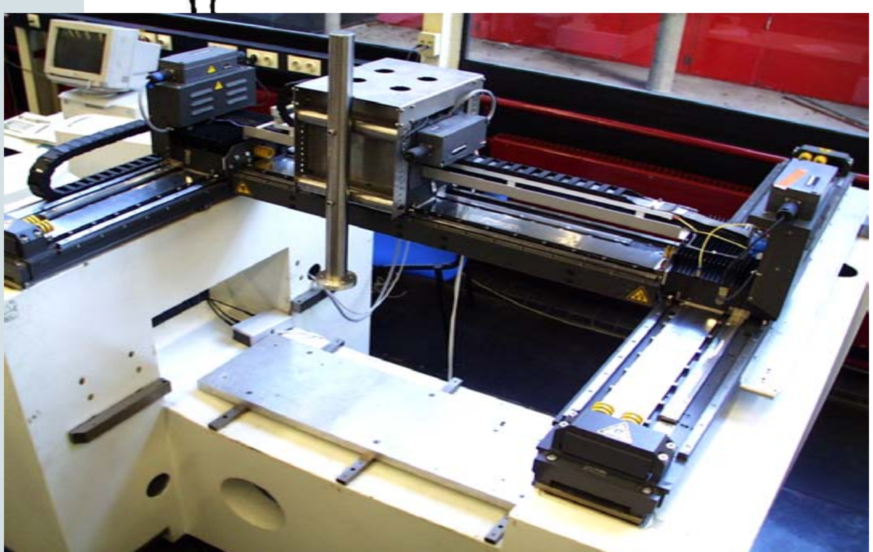


Machine-in-the-loop design



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DCSC: Success!!!!!!

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