Mechatronics System Design
(part 1 + part 2)

mechatronics academy brainport

Mechatronics Training Curriculum

Premium

- Workshop Mechatronics System Design — **On request**

Premium / Advanced

- Advanced Motion Control — **5 days**
- Advanced Feedforward & Learning Control — **3 days**
- Passive Damping for High Tech Systems — **3 days**
- Masterclass Design Principles — **On request**

Advanced

- Advanced Mechatronic System Design — **6 days**

Standard

- Motion Control Tuning — **5 days**
- Dynamics and Modelling — **3 days**
- Design Principles for Precision Eng. — **5 days**
- Basics and Design for Ultra Clean Vacuum — **4 days**
- Experimental Techniques in Mechatronics — **3 days**
- Metrology & Calibration of Mechatronic Systems — **3 days**
- Actuation and Power Electronics — **3 days**
- Machine Vision for Mechatronic Systems — **2 days**
- Thermal Effects in Mechatronic Systems — **3 days**

Basic

- Mechatronics System Design – part 2 — **5 days**
- Mechatronics System Design – part 1 — **5 days**

Start

Relevant partner trainings:
Applied Optics, Electronics for non-electrical engineers, System Architecture, Soft skills for technology professionals, …

www.mechatronics-academy.nl

Mechatronics Academy

- In the past, many trainings were developed within Philips to train own staff, but the training center CTT stopped.
- **Mechatronics Academy B.V.** has been setup to provide continuity of the existing trainings and develop new trainings in the field of precision mechatronics. It is founded and run by:
  - Prof. Maarten Steinbuch
  - Prof. Jan van Eijk
  - Dr. Adrian Rankers
- We cooperate in the **High Tech Institute** consortium that provides sales, marketing and back office functions.

Mechatronics System Design

Mechatronics System Design

part 1

Day/Module	Topic	Presenter
1a	Introduction	Jan van Eijk
1b	Basic Modelling	Adrian Rankers
2a	Basic Control	Michiel Vervoordeldonk
2b	Design Principles	Raymond Lafarre
3a	Motor Selection	Rik van der Burg
3b	Humanware–1	Jaco Friedrich / Adrian Rankers
4a	Sensors & Metrology	Adrian Rankers
4b	4th Order System	Michiel Vervoordeldonk
5a	(Industrial) Digital Control	Rik van der Burg
5b	Course Project	Jan van Eijk

** sequence of modules might be adapted depending on availability of trainers*

Mechatronics System Design

part 2

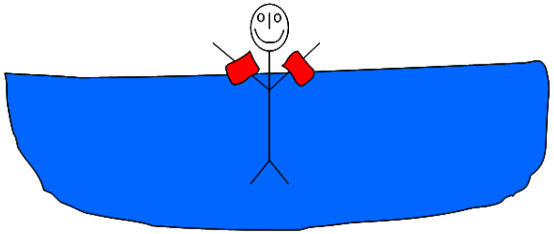
Day/Module	Topic	Presenter
6a	CD-case / Dynamics/ Modes	Jan van Eijk / Adrian Rankers
6b	Exercise Modelling (20sim)	Adrian Rankers / Jan van Eijk
7a	Applied Linear Motor Design	Rob Munnig Schmidt
7b	Electronics & Amplifiers	Rob Munnig Schmidt
8a	Control System Architecture	Rik van der Burg
8b	Humanware–2	Jaco Friedrich / Adrian Rankers
9a	Metrology / Thermal Design	Theo Ruijl
9b	Control Design Experiments	Michiel Vervoordeldonk
10a	Software in Mechatronics	Pieter Jan van Bommel
10b	Case Waferstepper/scanner	Jan van Eijk

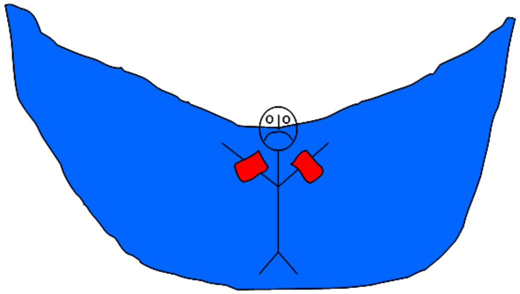
** sequence of modules might be adapted depending on availability of trainers*

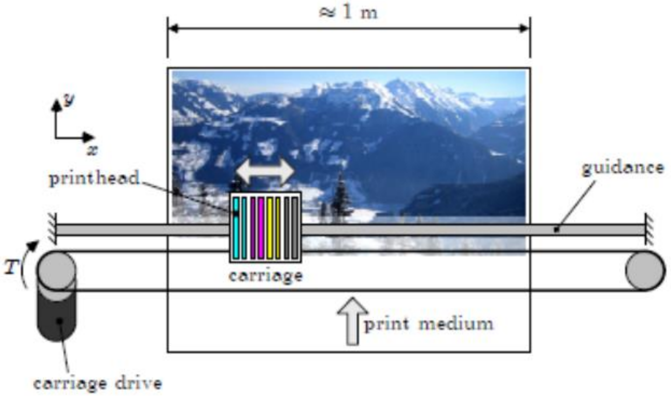
mechatronics academy brainport

Day 1a: Introduction

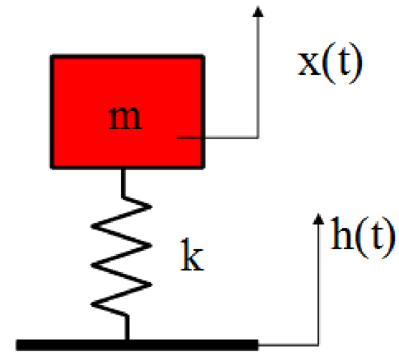
- Introduction
- Historical Background
- Essence of Mechatronics
- Deriving Servo Specifications
- Introduction Wide Format Printer Case



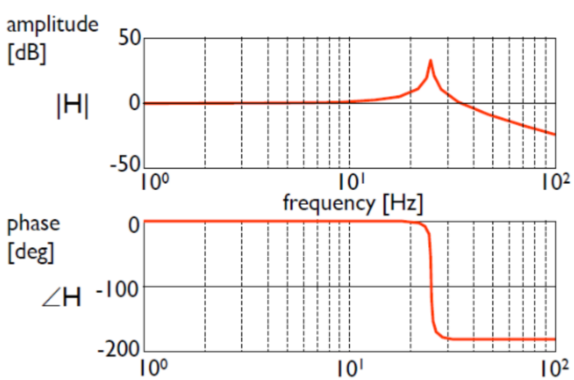


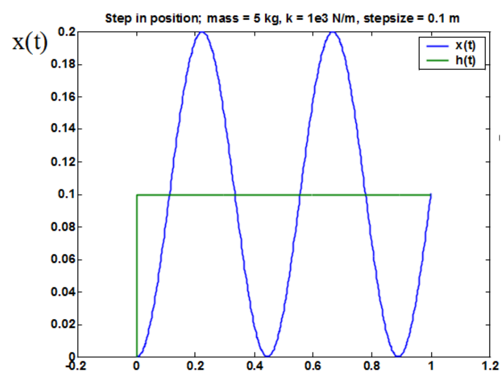


Day 1b: Basic Modelling

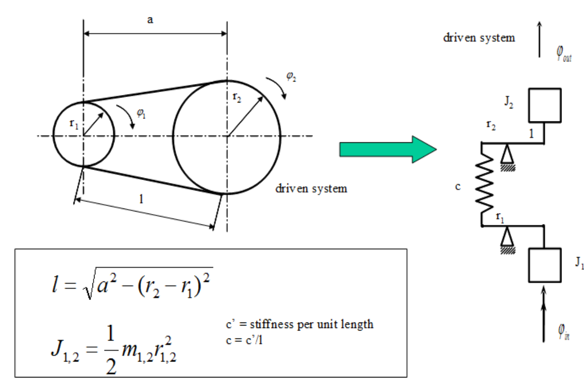


- What, Why, How ?
- Time response single mass-spring system
- Modelling of a complete system
- Building blocks, reduction, equivalent properties
- Frequency domain





Dynamic model of belt drive

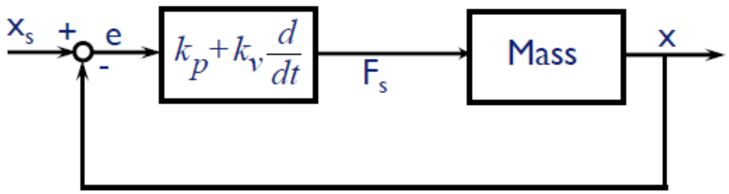


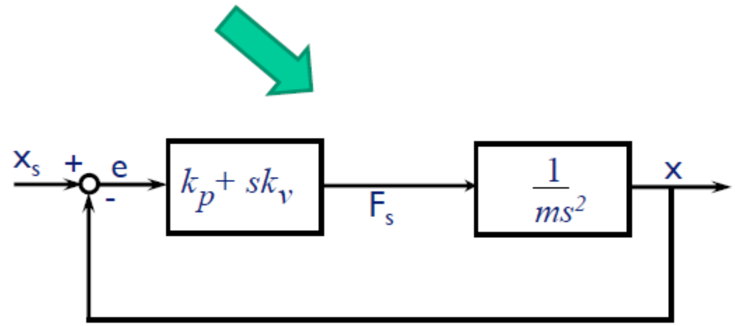
$$l = \sqrt{a^2 - (r_2 - r_1)^2}$$

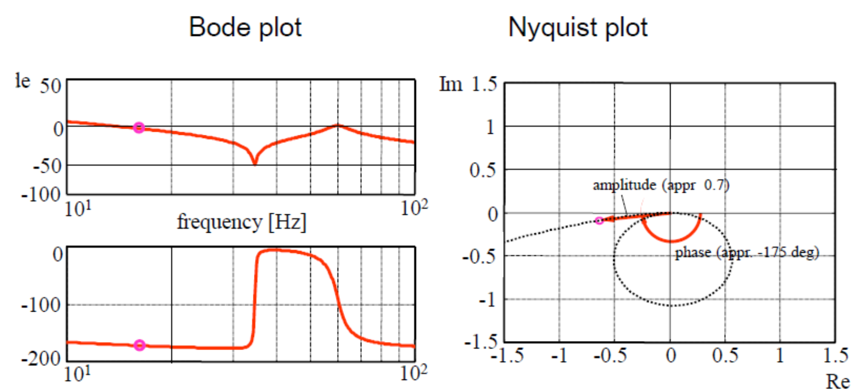
$$J_{1,2} = \frac{1}{2} m_{1,2} r_{1,2}^2$$

Day 2a: Basic Control

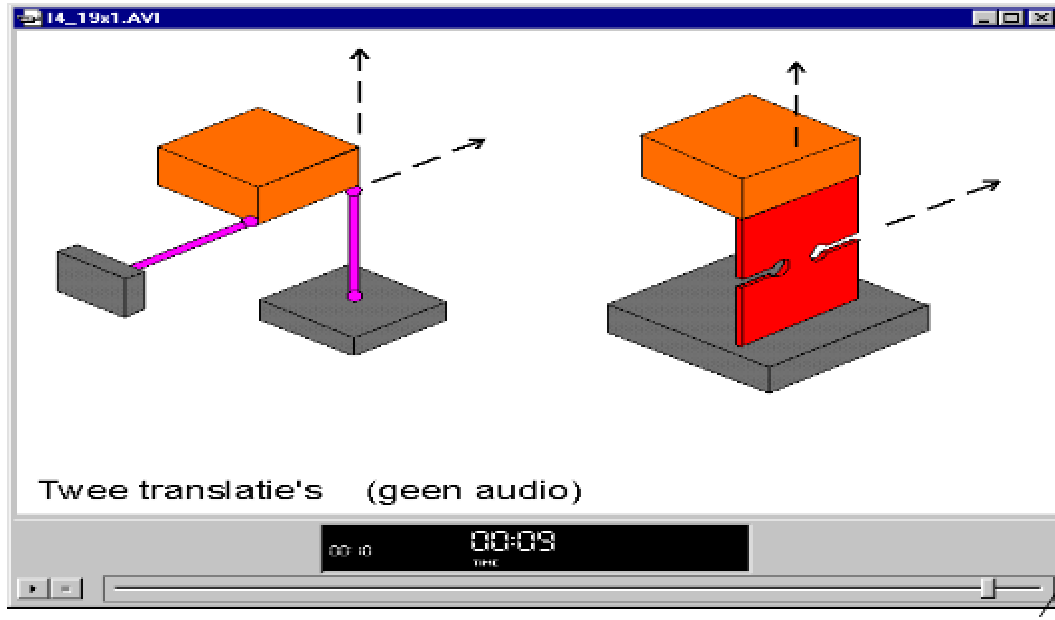
- Introduction
- Kp/Kv controller
- FRF, Bode, Nyquist
- Stability
- (Process) Sensivity
- Open Loop / Closed Loop
- Specs => Bandwidth



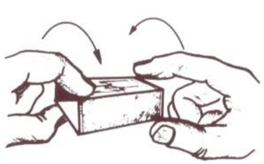




Day 2b: Design Principles



- Degrees of freedom
  - Why ?
  - How ?
  - Manipulators ?
- Supports
- Stiffness
  - Influence on stiffness by gear/transmission ratios
- Virtual play,
  - Hysteresis by friction
  - Influance on accuracies by disturbances

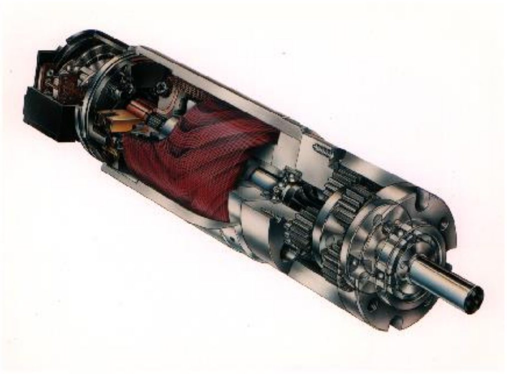


Comparison torsional stiffness of tubes
with different cross sections
and equal perimeter O = 4b and wall thickness t

Cross section	b, b	1.3b	0.5b, 1.5b	0.1b, 1.9b	1.3b
I*	1	0.59	0.56	0.04	1.6

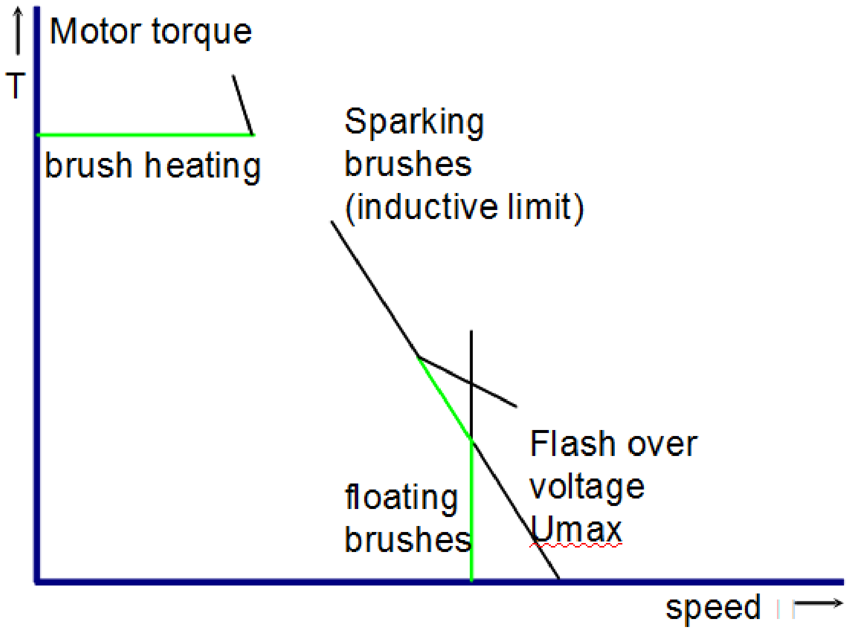
Torsional stiffness $k = \frac{G \cdot I^*}{l}$ Polar moment of inertia: $I^* = \frac{4 A_{om}^2 t}{O}$

Day 3a: Motor Selection



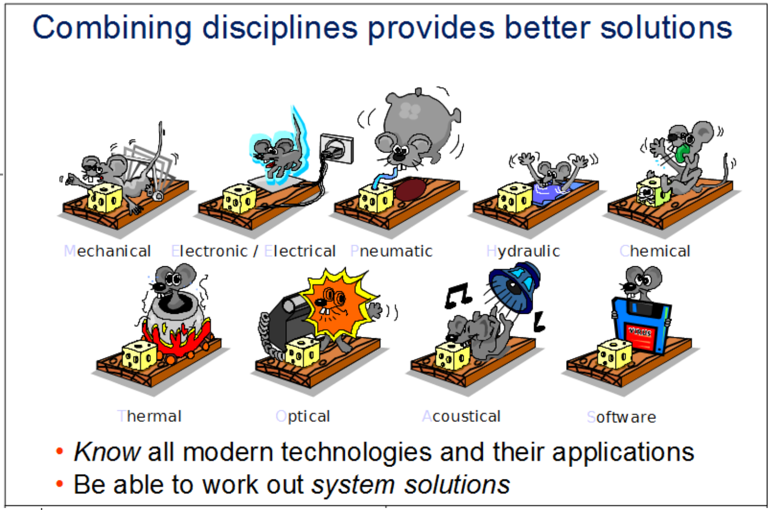
- Servo motors / Basic operation
- Commutation
- Lorentz motor
- Torque speed curve
- Voltage vs. current control
- Thermal behaviour
- Limits
- Motor selection
- Case

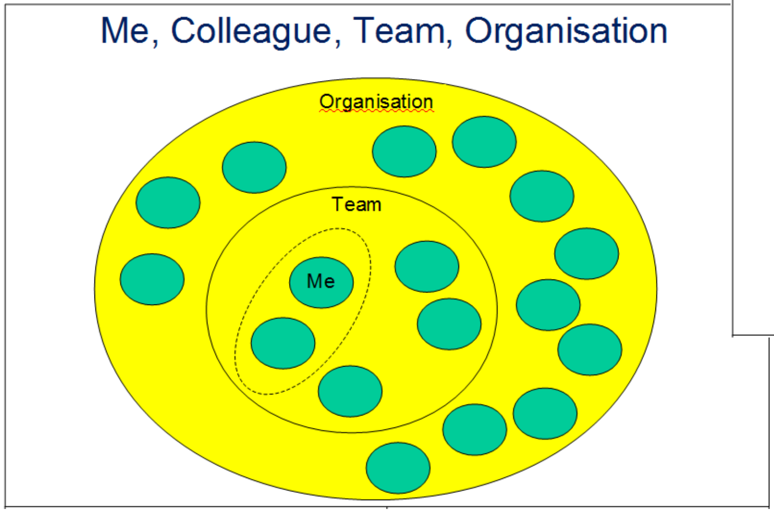
DC Motor limitations



Day 3b: Humanware-1

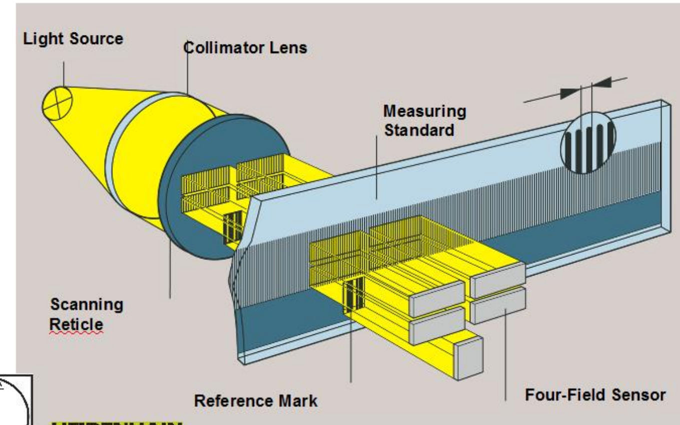
- Introduction / Importance of teamwork
- Good communication starts with listening
- The “art” of giving feedback
- Conclusion





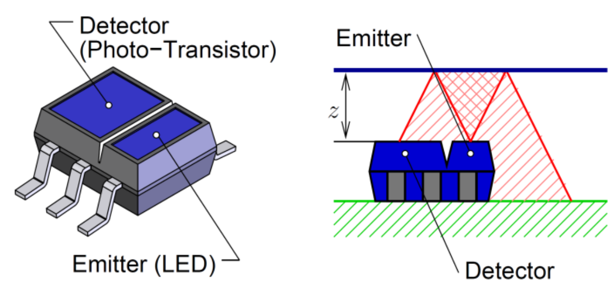
Day 4a: Sensors & Metrology

- What is measuring ?
- Properties of the sensor (system)
- Basic statistics
- Position measurement devices
    - Capacitive sensors
    - Optical proximity sensing
    - Incremental optical sensing
    - ....
- Position measurement on system level



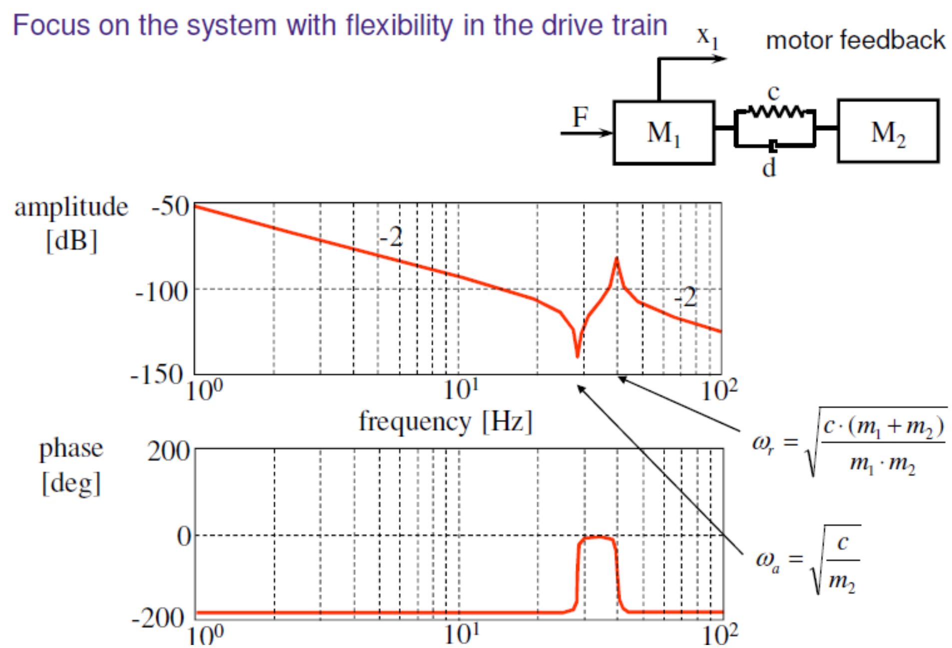
HEIDENHAIN

Amount of reflected light is related to distance of object.



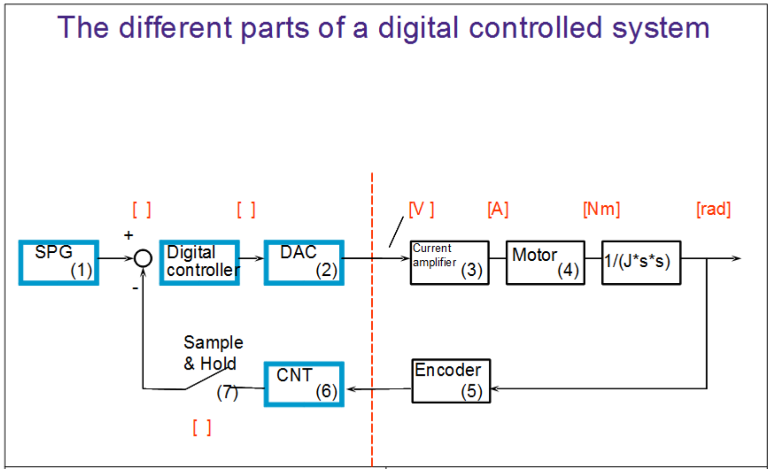
Day 4b: Fourth Order System

- Summary basic control
- Stability criterion
- 4^{th} order system
- Implications for control



Day 5a: Digital Control

- Introduction
- Digital control loop
- Quantization
    - Encoder
    - ADC
- Digital to analog conversion (DAC)
- Sample frequency and calculation delay
- Setpoint generation and feedforward

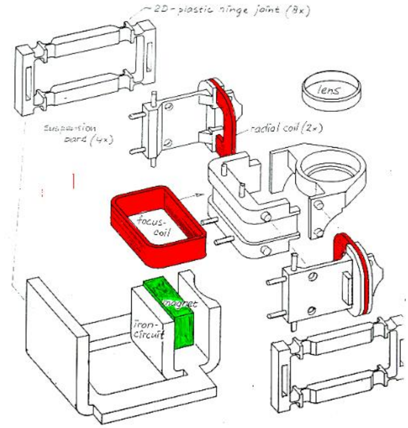


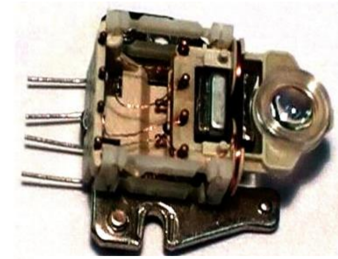
Day 5b: Course Project

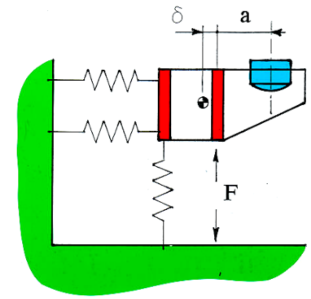
- *Wide Format Printer* case
- Explanation during introduction (day 1a)
- Participants work in 3-4 groups on improvements
- Flip-over presentation of results

Day 6a: CD-case / Dynamics / Modes

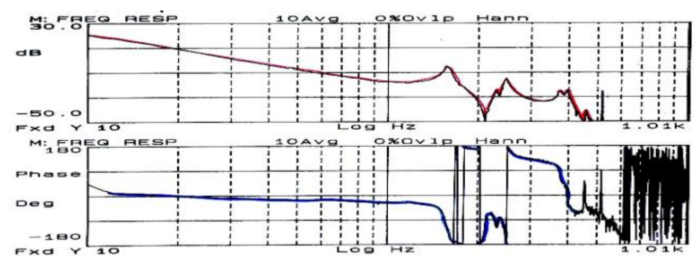
- Compact Disc Player Case
  - Some Historical Background
  - Optical Metrology for Sensing
  - Actuator Principle
- Dynamics made simple
  - Simple mass sprint system
  - Modal description & mode shapes
- Three fundamental dynamics issues incl. Do's & Don'ts
  - Internal actuator flexibility
  - Flexibility of guiding system
  - Non-'Rigid' foundation





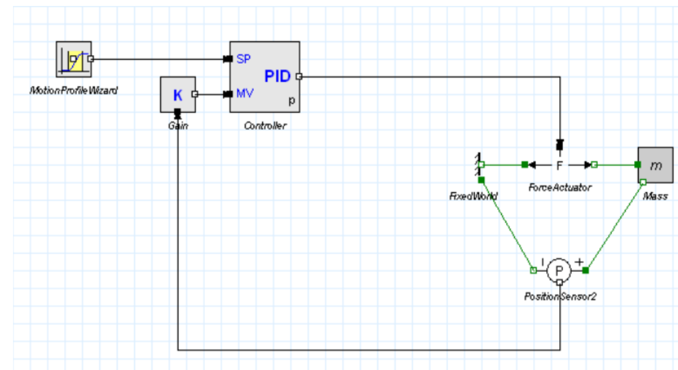


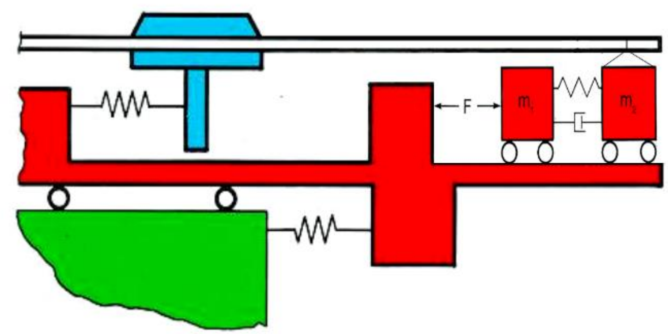
$$err = \frac{m * a * \square}{J}$$

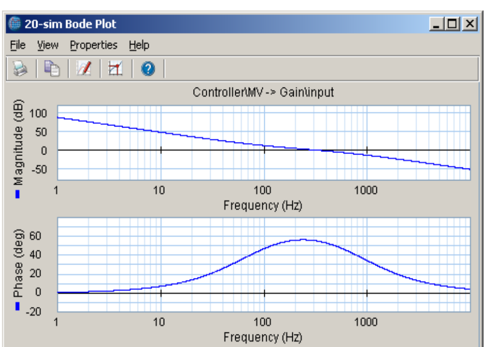


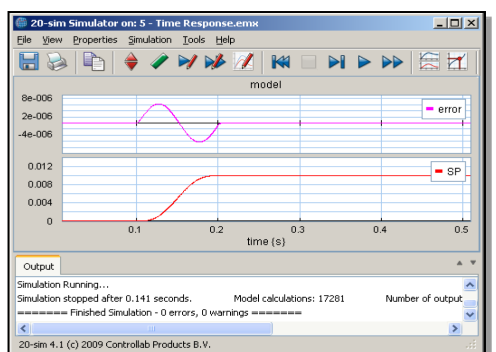
Day 6b: Exercise Modelling (20Sim)

- Basic modelling of PiD controlled motion device
- Basics of 20-Sim as modelling tool
- Tuning of PiD
  - Requirements => bandwidth
  - Stability margins
- Effect of dynamics



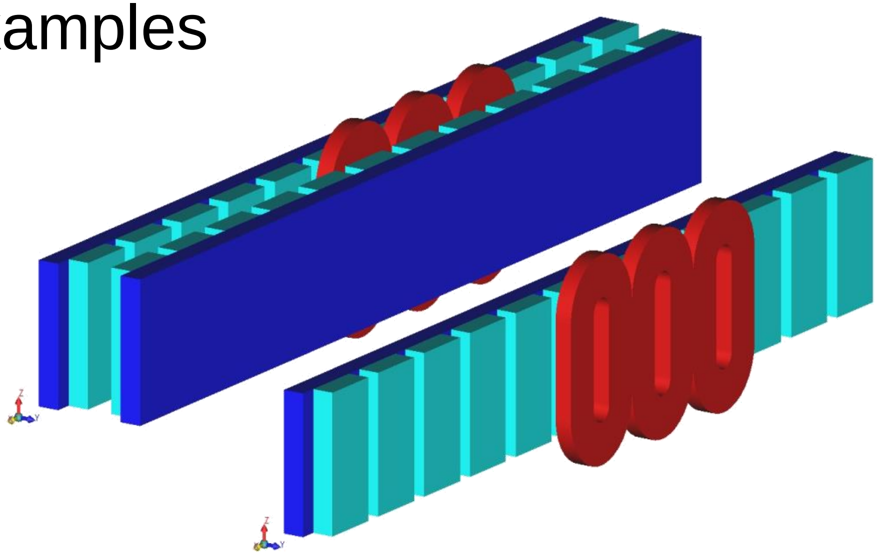


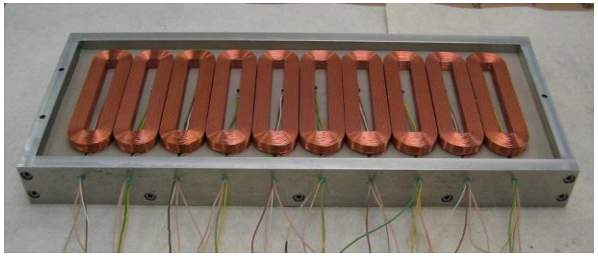




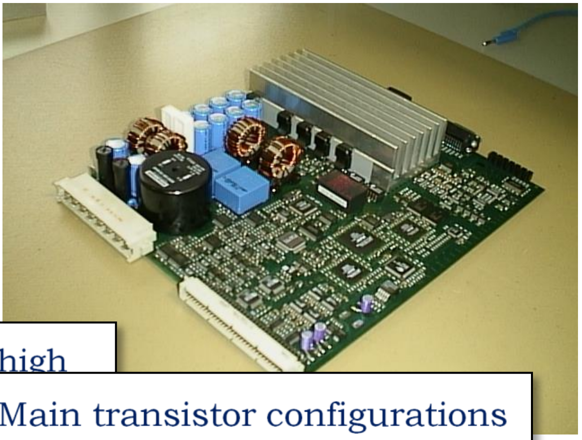
Day 7a: Applied Linear Motor Design

- Introduction & Application Examples
- Classification of Motors
- Design Criteria
- Basic Properties
- Short-Range Systems
- Long-Range Systems
- Case Study

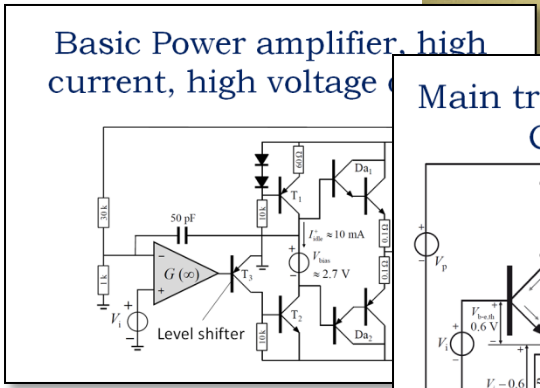


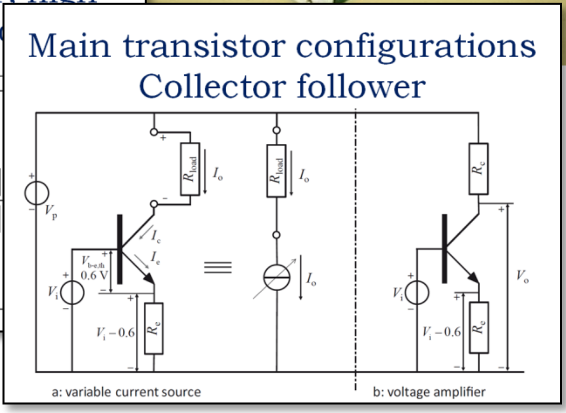


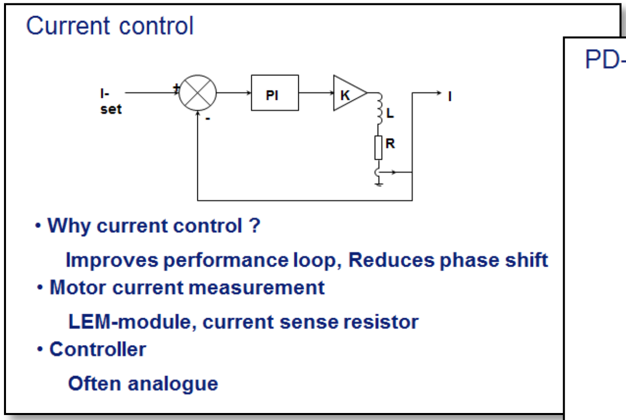
Day 7b: Analog Electronics

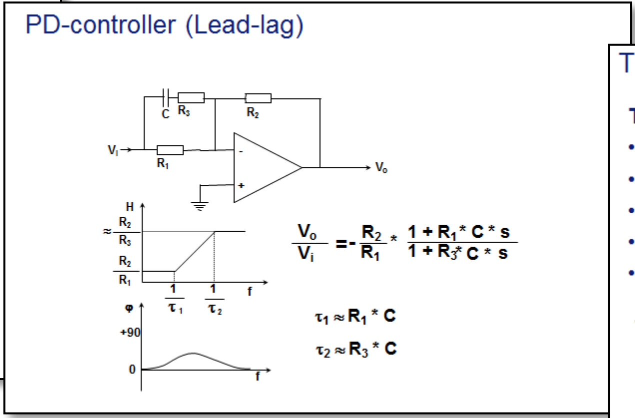


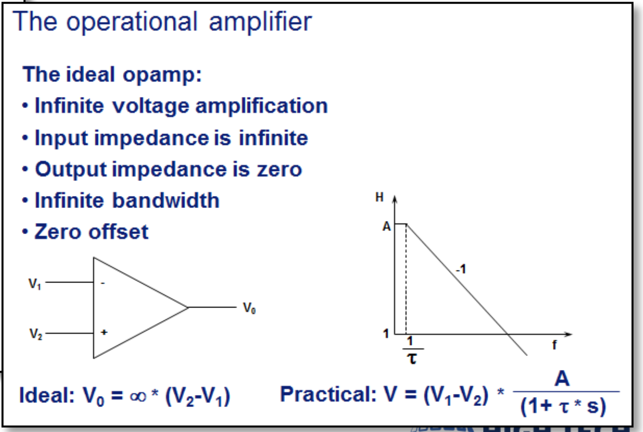
- Transistors
- Operational Amplifiers
- Analog Control
- Intro Power Electronics
- Limitations / Imperfections





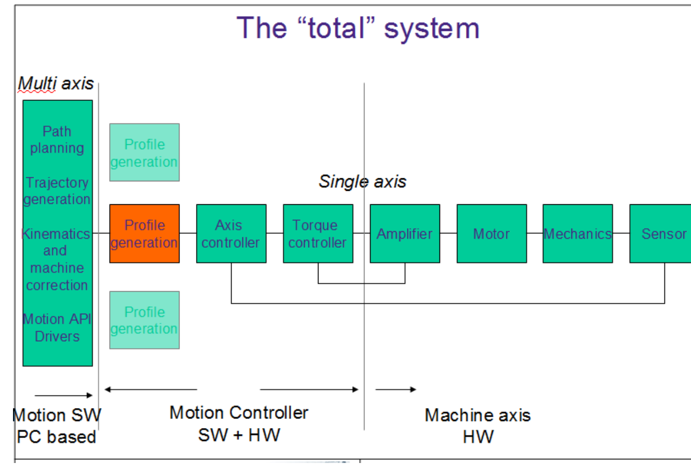


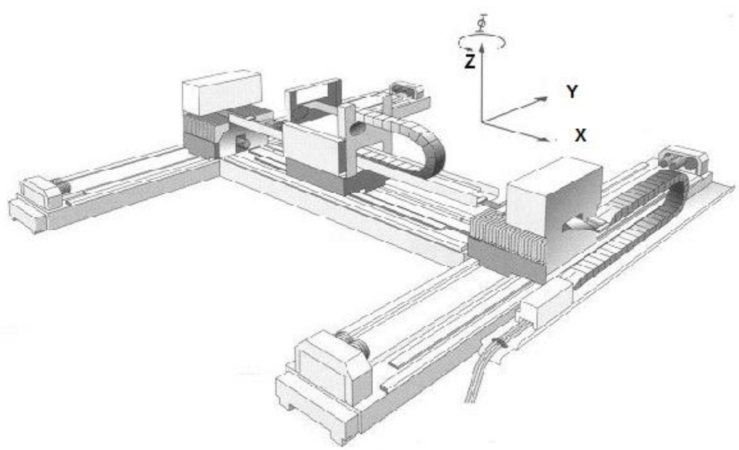


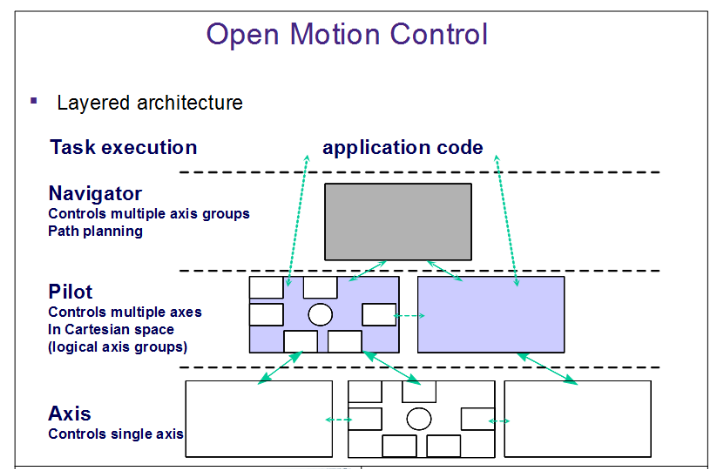


Day 8a: Control System Architecture

- Recap digital control
- Open Motion Control platform
- Technology and standards
- Case: H-drive control

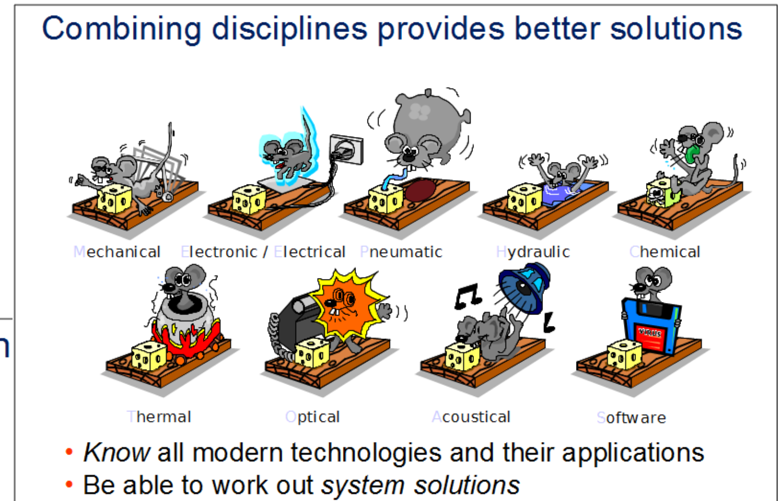


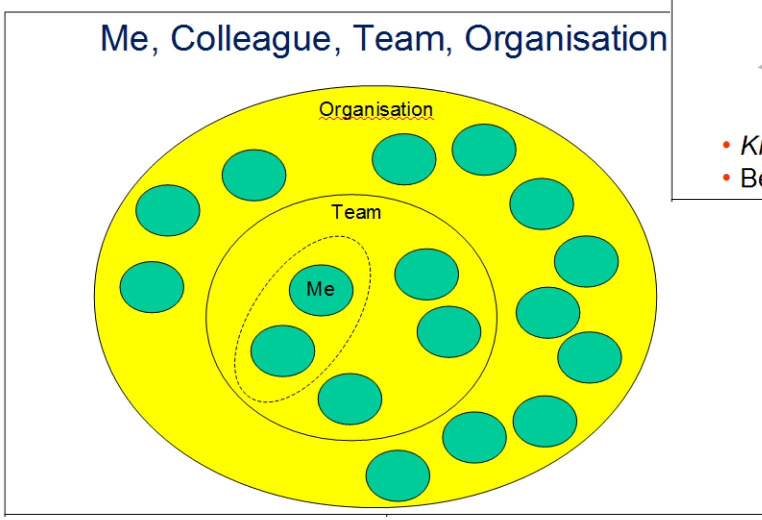




Day 8b: Humanware-2

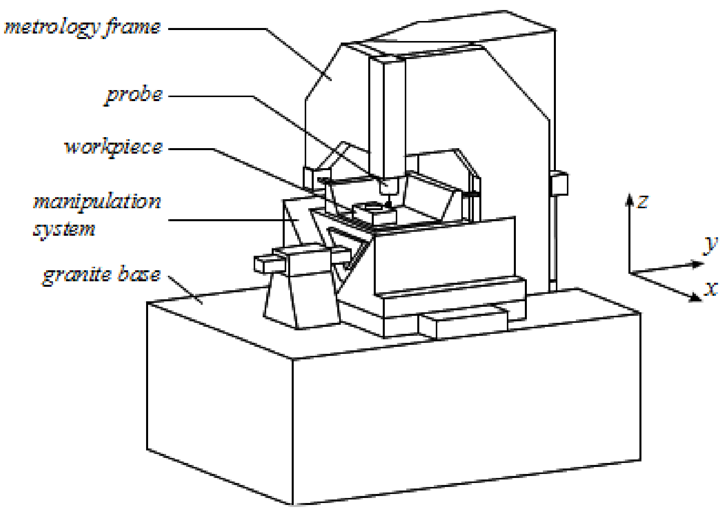
- Introduction
- You as a person (DISC model)
- Teams & team roles



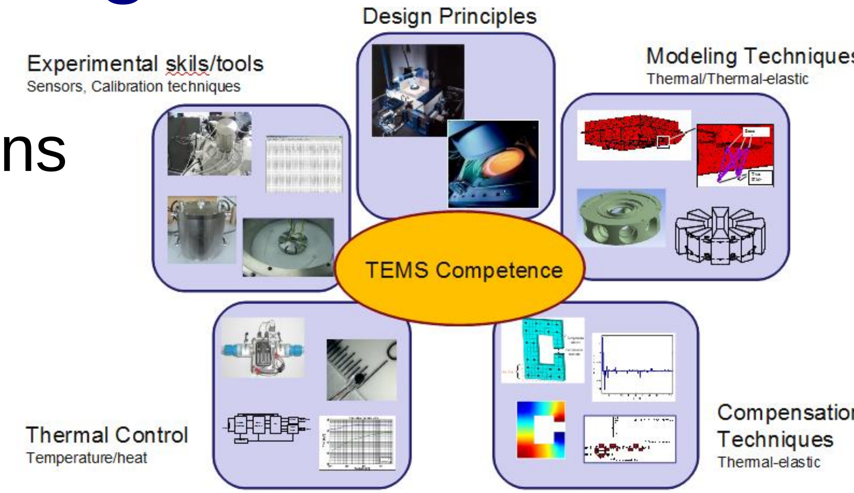


Day 9a/1: Metrology Concepts

- From sensor to system metrology
  - Performing real measurements
- Basic design roles for precision equipment
- Main design considerations
  - Alignment of metrology systems
  - Metrology frame and structural fra
  - Thermal and dynamic consideratio
  - Calibration
- Example: Ultra precision CMM



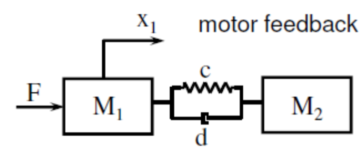
Day 9a/2: Thermal Design



- Need for thermal considerations
- (Sub)competences needed
- Thermal system analysis
  - Different tools
- Thermal system theory
  - Common heat source in mechatronic systems
  - Heat transfer mechanisms
  - Thermally induced deformations
  - Transient effects
- Example Ultra Precision CMM

Day 9b: Exercise Control Design

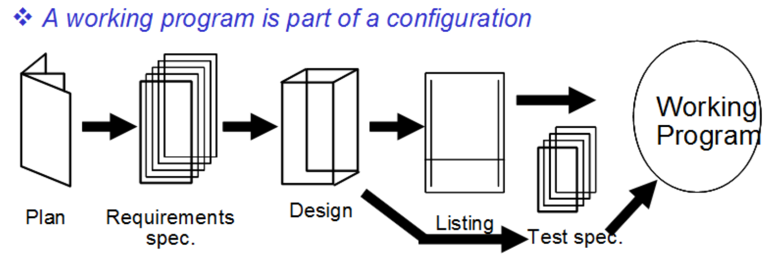
- Introduction
- Tuning in time domain
  - Feeling the effect of Kp, Kv
  - Setpoint response
- FRF measurement
- Competition to achieve highest bandwidth
- Bonus: 4.order system with encoder on payload
- Bonus: discussion of Ki
- Bonus: discussion of feedforward



mechatronics academy brainport

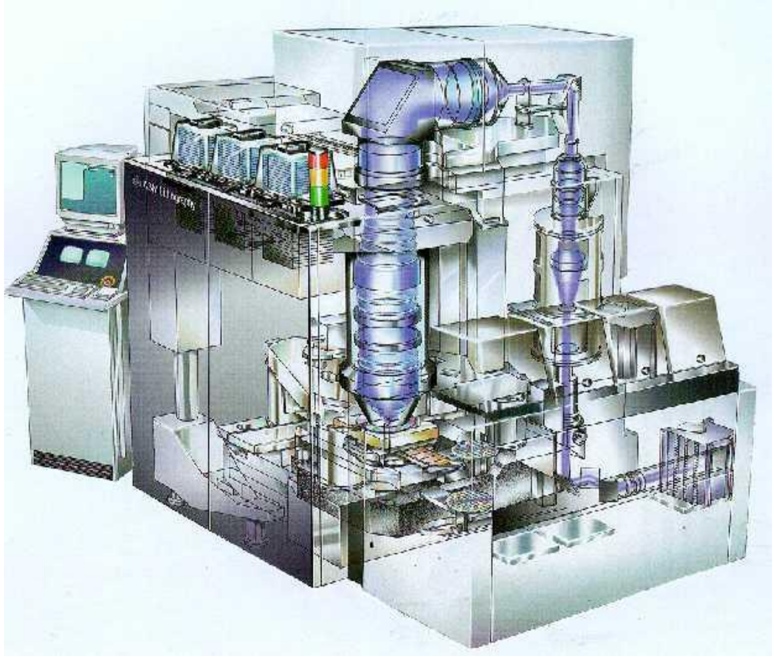
Day 10a: Software in Mechatronics

- Software in Mechatronics context
  - Industrial automation
  - Equipment control
  - User interfacing
- Hardware Software Architecture
  - Computer architecture, DSP, PLC
  - Communication
- PC vs PLC – a programming case
  - PLC / PC programming flavors
- Software engineering process
  - Why designing SW is difficult



Day 10b: Waferstepper/scanner case

- Lithography proces steps & role of waferstepper
- System aspects of a waferstepper
- Historical background
- Alignment system
- Dynamic/Control Challenges
- Long stroke / short stroke
- From stepper to scanner
- Challenges of EUV



mechatronics academy brainport

[Sign-up for part 1]

[Sign-up for part 2]

Via the website of our partner

High Tech Institute