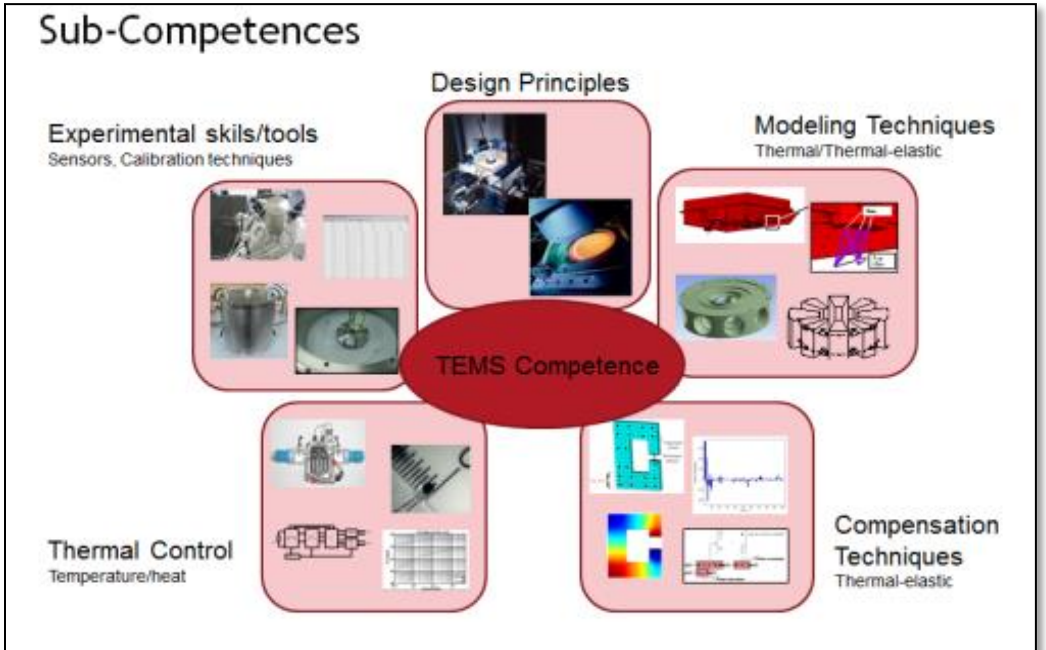
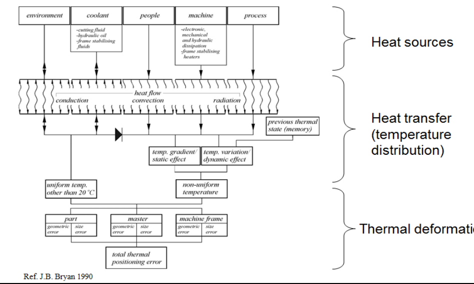
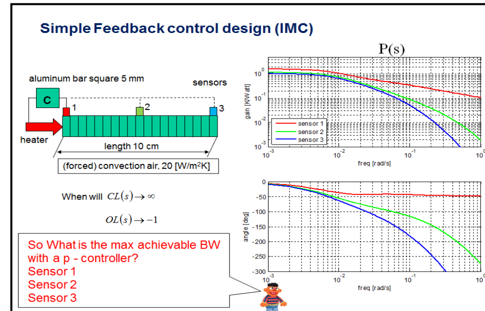
Thermal Effects in Mechatronic Systems



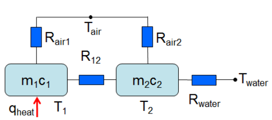
Heat load to position error





Simple Lumped mass model example

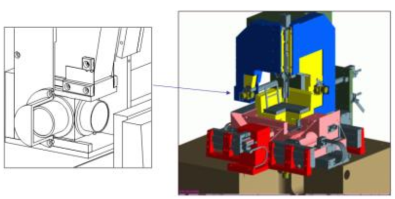
- 2 lumped masses (LM) with temperatures T_1 and T_2
- Heat exchange with surrounding air on both LM's
- Heat exchange with cooling water on LM_2
- Heat exchange between LM_1 and LM_2
- Heat load on LM_1



Metrology Frame

Shielded metrology frame:

- Aluminum shielding acts as a thermal low pass filter;
- and increases the temperature uniformity of the metrology frame.



Sensor Calibration

Philips Apptech developed own calibration setup:
Consist of an isotherm metal block of which the temperature is measured by 3 calibrated NTCs (ref. to absolute temperature scale). In this metal block the sensors under calibration can be installed.

Isothermal block is created inside metal container which is conditioned by water.

- Static gradients negligible: $\Delta T < 0.2$ mK
- Absolute accuracy reference temperature 2.5 mK

Contents

- Mechatronics Training Curriculum
- Details of Course *Thermal Effects in Mechatronic Systems*

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**
Basic	Mechatronics System Design – part 1 **5 days**

Start

<u>Relevant partner trainings:</u>
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.

Thermal Effects in Mechatronic Systems

Course Director(s) / Trainers

<u>Teachers</u>

- Dr.ir. T.A.M. Ruijl (MI-Partners)
- Ing. J. van der Sanden (ASML)
- Ir. Marco Koevoets (ASML)
- Dr.ir. Rob van Gils (Philips Innovation Services)

<u>Course Director(s)</u>

- Dr.ir. T.A.M. Ruijl (MI-Partners)
- Dr.ir. A.M. Rankers (Mechatronics Academy)

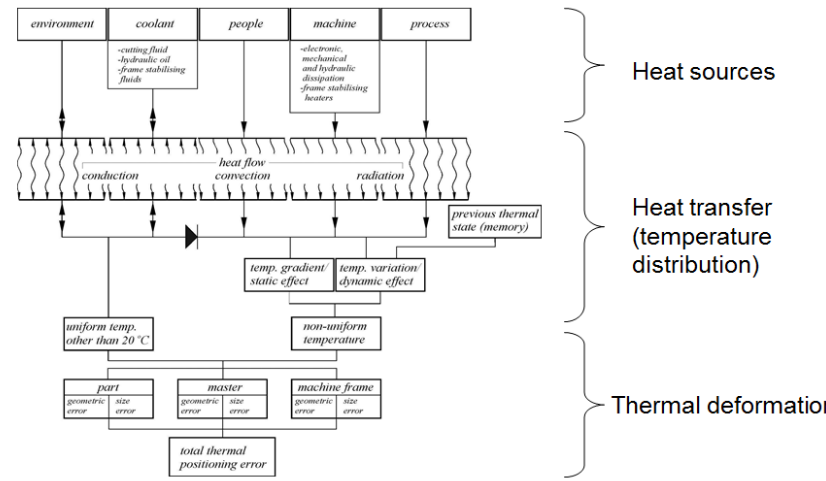
Program

Day	Contents
1	Basic Theory
	Lunch
	Basic Theory - continued
	Introduction to modeling techniques: building lump-mass models part
2	Recap day
	Precise temperature measurements
	Case Cryo
	Lunch
	Case, Cryo - continued
	Design for Thermal Stability + Case Shielding
3	Active Thermal Control
	Lunch
	Advanced Topics - model reduction / thermal modes / compensation & sensor placement

Day 1 (morning): Basic Theory

- Heat loads
- Theory of heat transfer
- Theory fluid flow
- Theory thermal deformations
- Transient effects
- Vacuum aspects

Heat load to position error

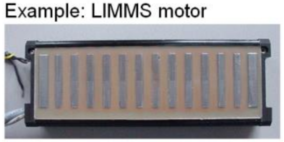


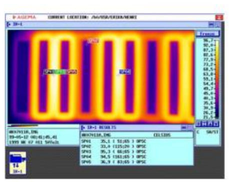
Ref. J.B. Bryan 1990

Common heat loads in Mechatronic Systems

- Motors, actuators, measurements systems, sensors and additional electronics close to the machine

Example: LIMMS motor





2 of 3 windings powered

Thermal issues:
- Internal temperature → lifetime, degradation of insulation
- Heat load to frame → accuracy, heat "loss" to structure

Summary: Heat transfer mechanism

ΔT is driving potential for energy flow. $\Delta T = R_{th} \cdot Q$

1. Conduction $R_{th} = \dfrac{d}{\lambda\, A}$ — λ: thermal conductivity (W/(m.K)) material parameter, see handbooks

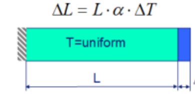
2. Convection (boundary fluid and solid) $R_{th} = \dfrac{1}{h\, A}$ — h: heat transfer coefficient (W/(m^2.K)) =f(type of fluid, geometry, velocity, ...)

3. Radiation $R_{th} = \dfrac{1}{h_{rad}\, A}$ — h_{rad} effective heat transfer coefficient for radiation (W/m^2.K) dependent on absolute temperature of both objects, geometry (view factors), emissivity's

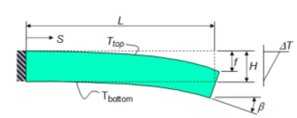
Summary: Deformations

Linear thermal expansion:

$$\Delta L = L \cdot \alpha \cdot \Delta T$$



Thermal bending:

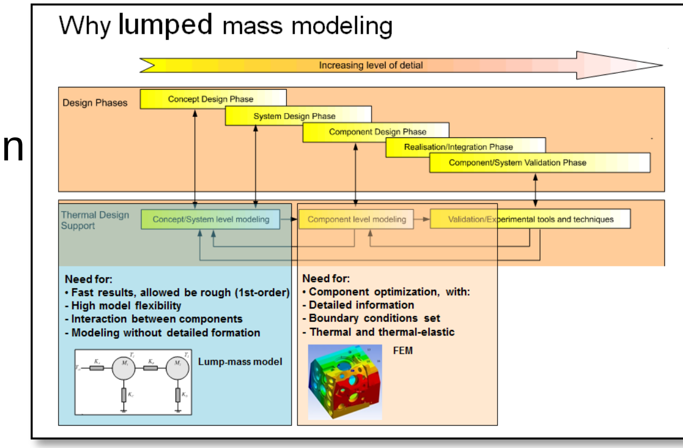


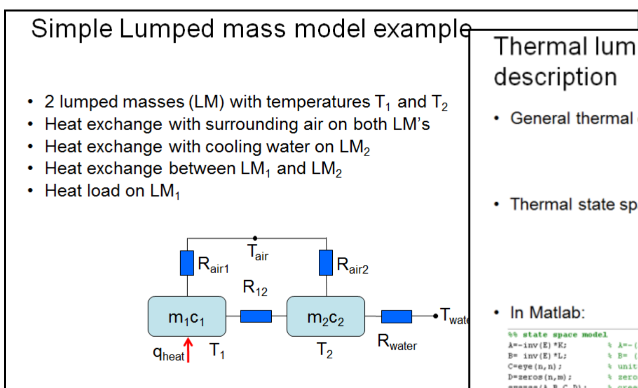
$$\beta = \frac{\alpha \cdot \Delta T \cdot L}{H}$$

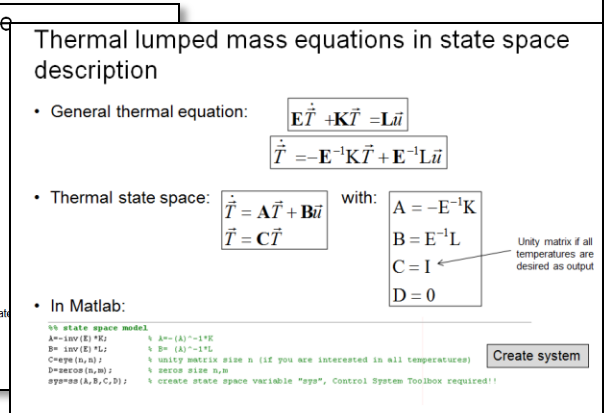
$$f = \frac{\alpha \cdot \Delta T \cdot L^2}{2H}$$

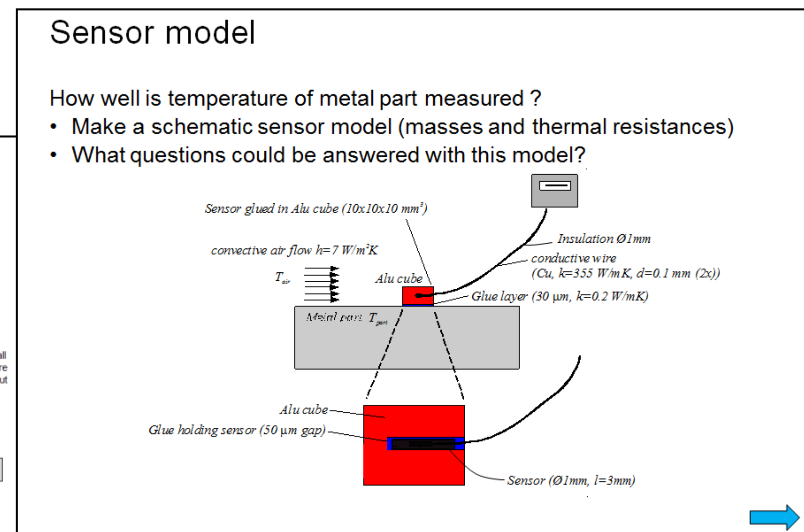
Day 1 (afternoon): Modelling

- Why lumped mass modeling
- Simple Lumped mass model example
- Analysis and simulation using a state space description
  - Stationary solution
  - Transient simulation
  - Frequency domain analysis
- Exercises
  - simple lumped mass model (deriving system matrices)
  - effects of cooling water
  - analyzing a temperature sensor









Day 2 (morning): Temp. Measurement

Spot Sensor types:

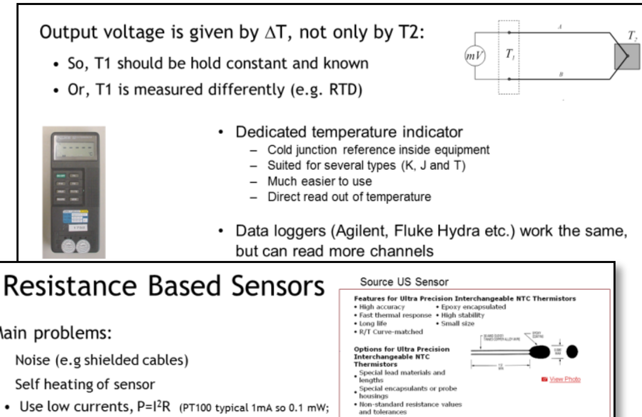
- Thermocouples
- Resistance based sensors
  - RTD (Resistance Temperature Detector)
  - Thermistor: NTC (Negative Temperature Coefficient)

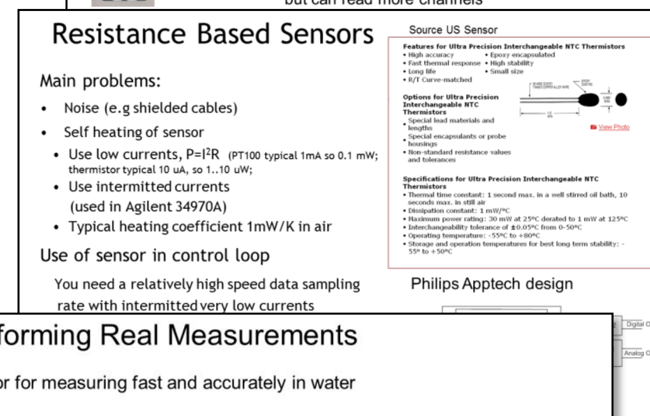
Performing Real Measurements

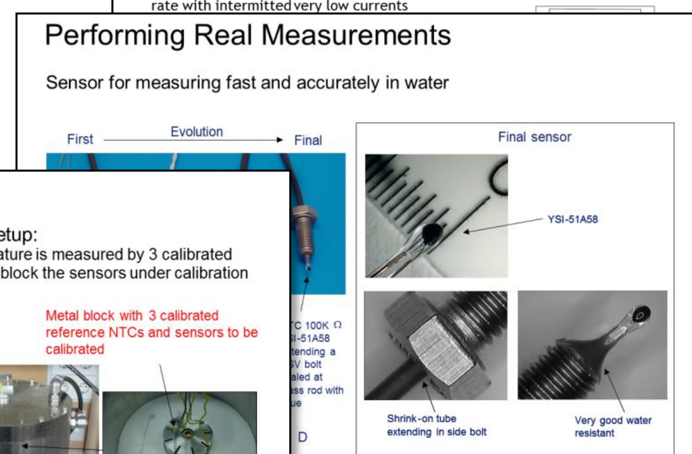
- From True to Observed value
- Real Ideal Sensor Model
- Temperature measurement of Solids/Liquids/Gas
- Dynamic behaviour, general remarks
- Sensor Calibration

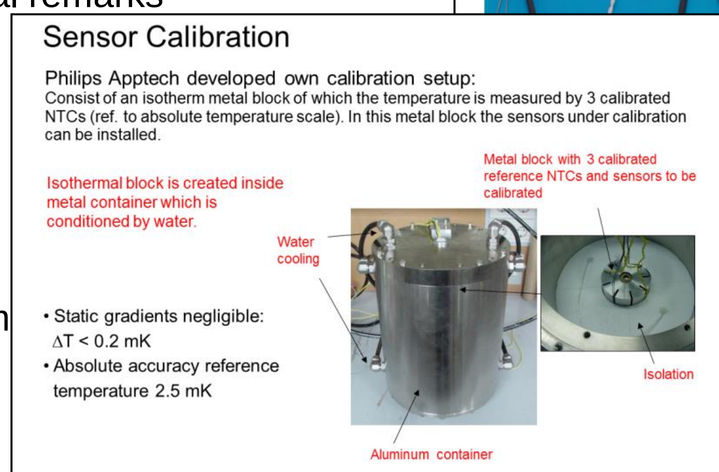
IR Temperature Meters:

- Principle and limitations
- IR spot meters
- IR scanners/imaging system









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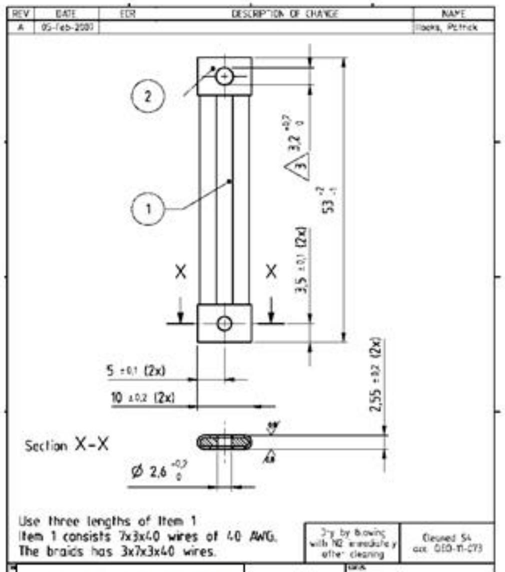
Day 2 (morning/afternoon): Case

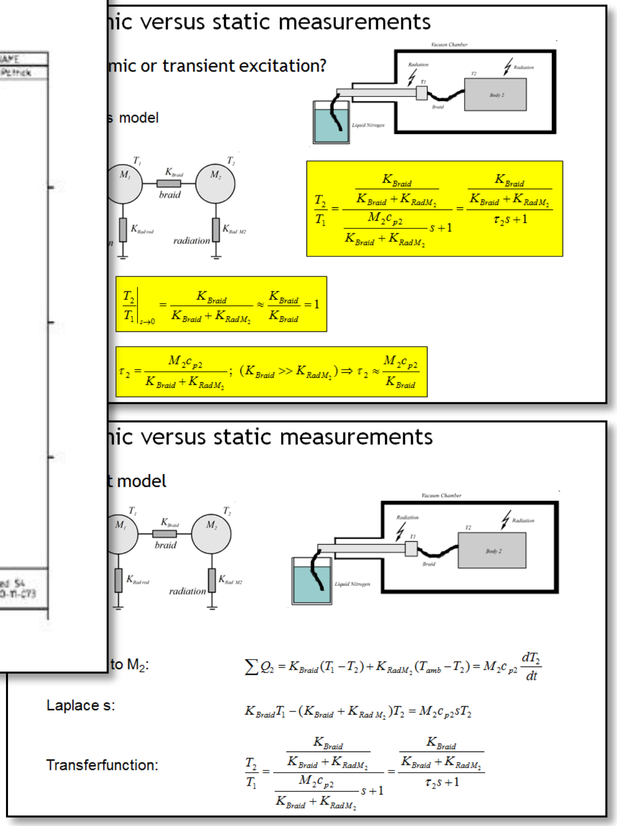
Exercise: Determine thermal resistance of braid

This braid is used in an electron microscope to cool a sample, which is positioned on a TEM stage, down to cryogenic temperatures (e.g. 100 K).

Braid between cooling rods



D_{wire} = 0.0799mm



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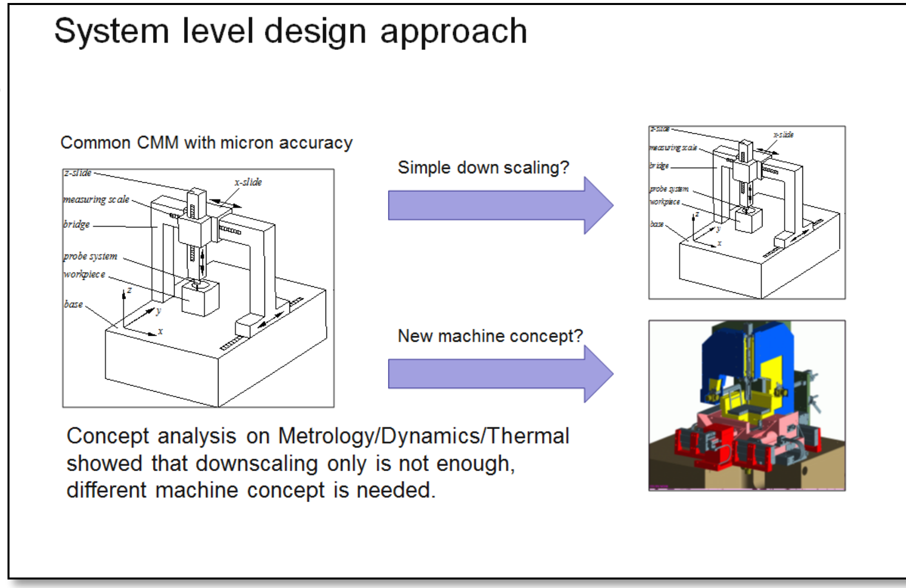
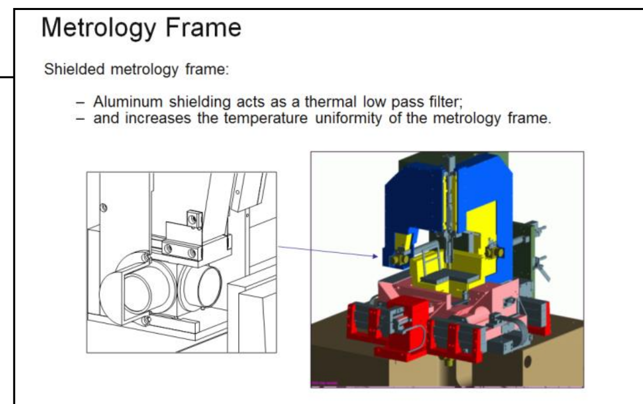
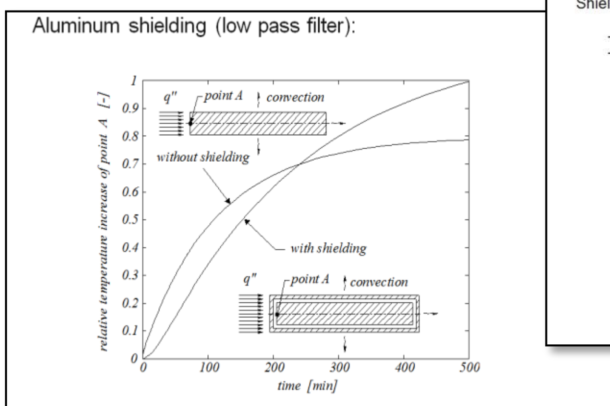
Day 2 (afternoon): Design for TEMS

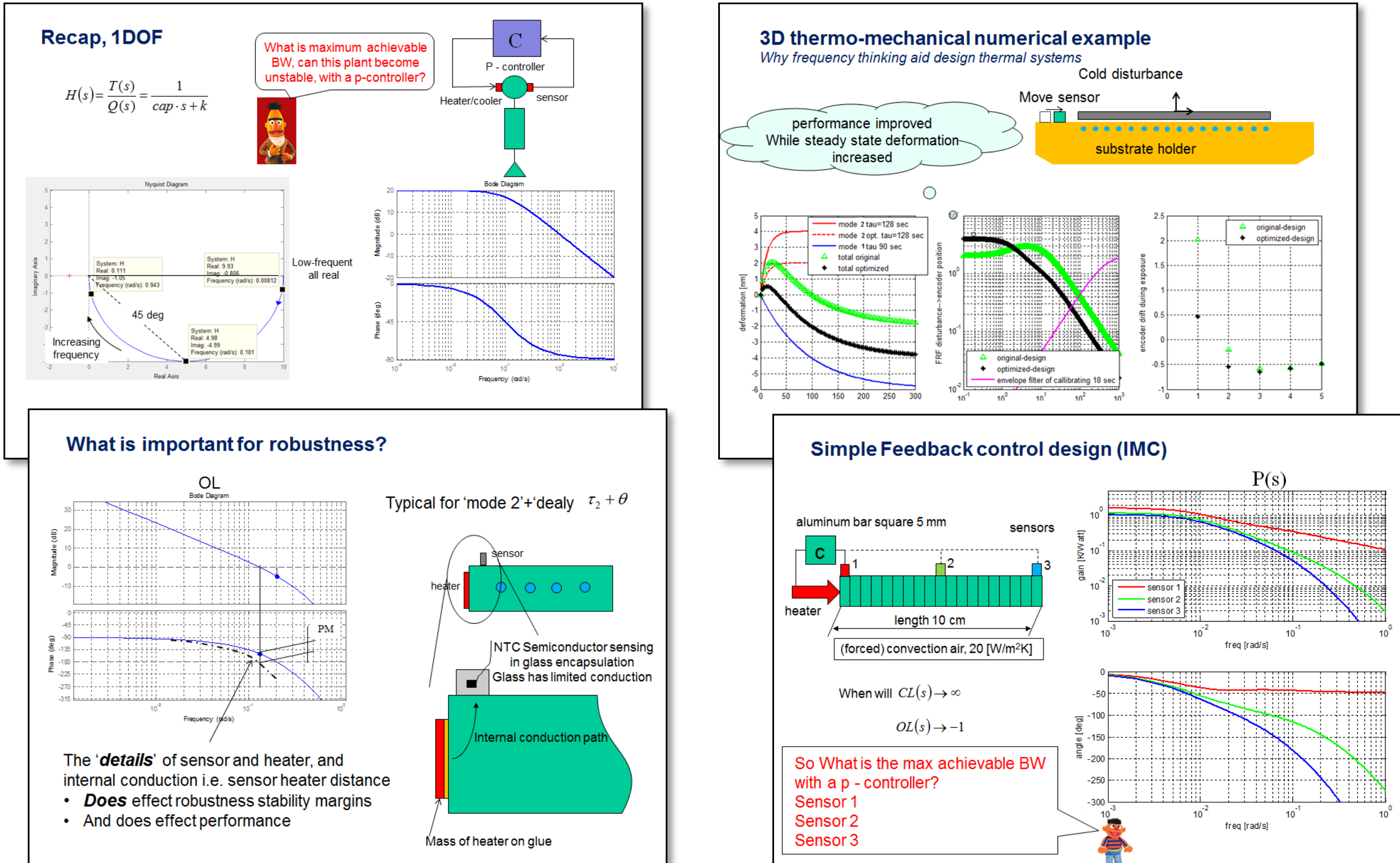
- Basic design rules for precision equipment
- Structural and metrology function
- Thermal design considerations
- Example case: Ultra precision CMM
    - System level design approach
    - Structural and metrology function
    - Thermal shielding
    - Metrology frame support
    - Static versus transient behavior
    - Minimizing heat generation in manipulation system
    - Thermal compensation
    - Shielding and enclosure (case)



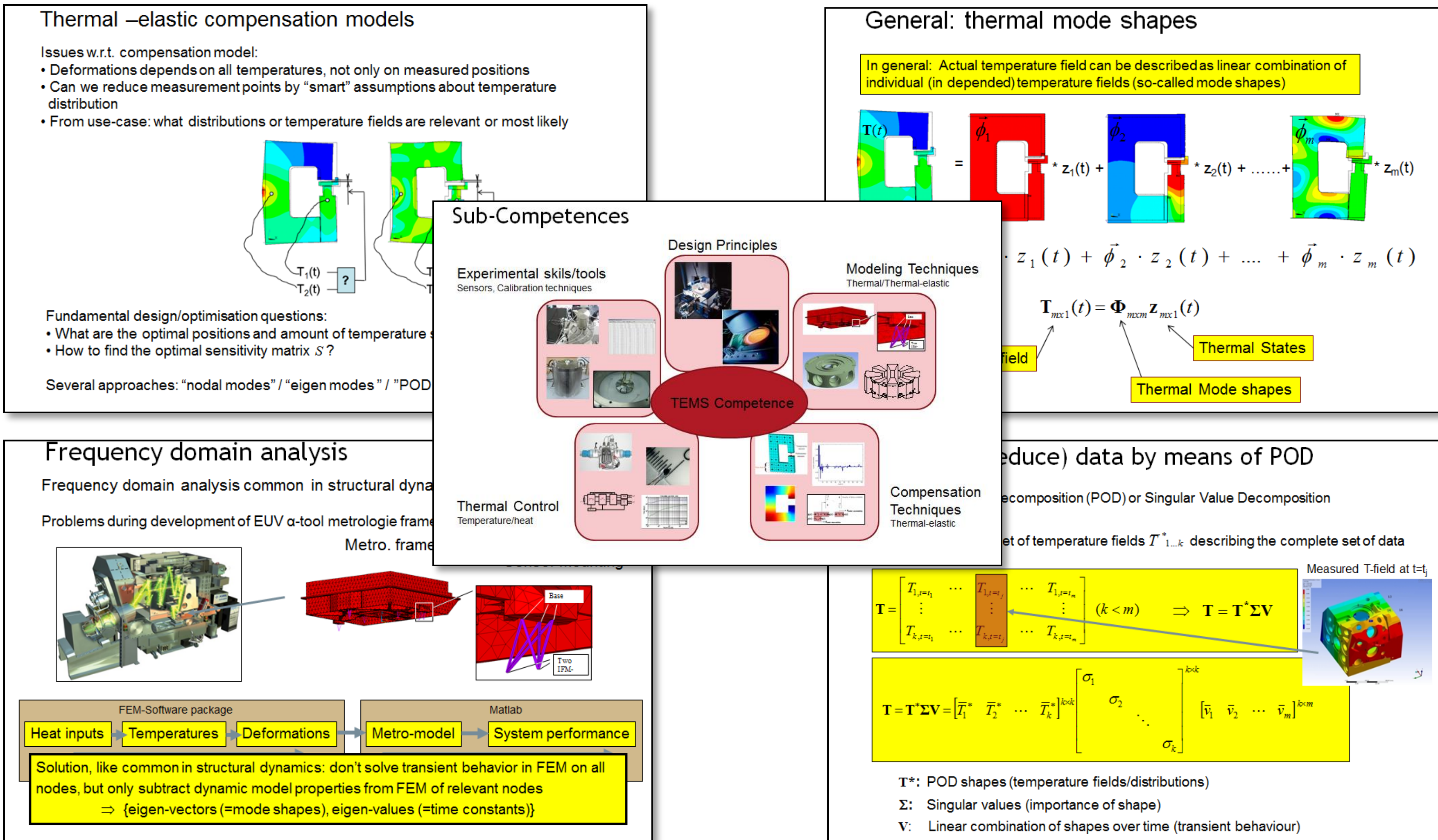




Day 3 (morning): Active Thermal Control



Day 3 (afternoon): Advanced Topics



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Via the website of our partner

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