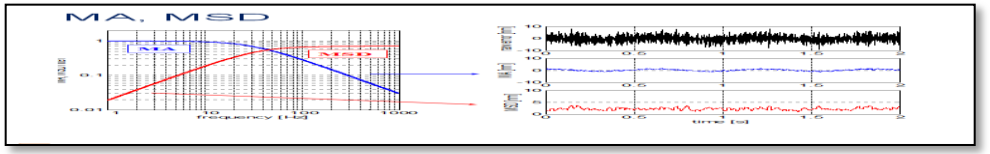
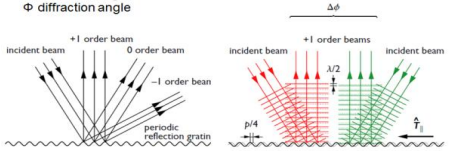
Metrology and Calibration of Mechatronic Systems



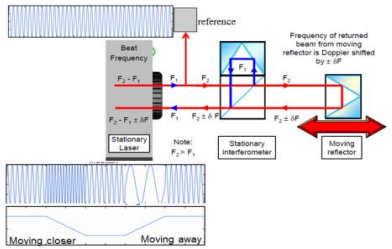
Diffraction grating

sin(φ-i) = m*λ/p - sin(i)
i incidence angle
Φ diffraction angle

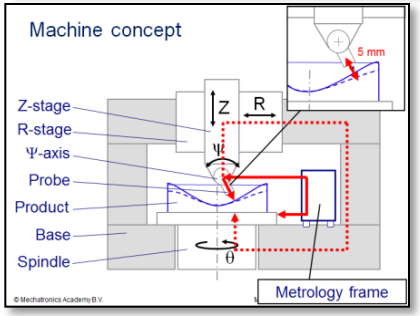


- Grating as beam splitter
- Interference between orders

Basic heterodyne configuration

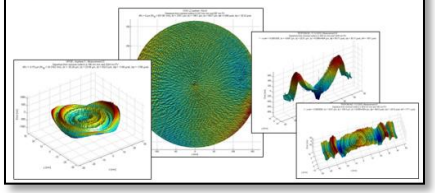


Machine concept

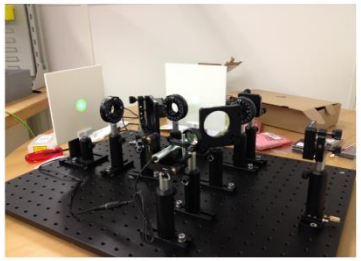


Machine performance

- Repeatability ~ 1 nm rms on form
- Speed: 15 mins for ∅380 mm (4M points)
- Calibrated with known artefacts (chicken-egg issue…)

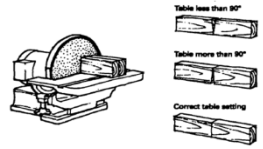


Demonstration Interferometer



Exercise

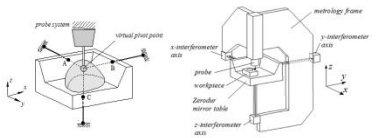
- Exercise 8.4: How to set a disk sander?



- External calibration: carpenters square or level
- Internal calibration: reversal (auto-calibration)

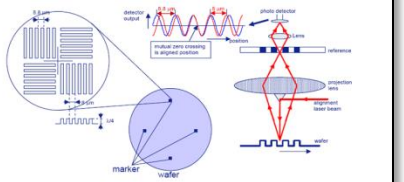
Rules of Abbe and Bryan

- Abbe compliant CMM (Ruijl, 2001)
- Commercialized as IBS PE ISARA



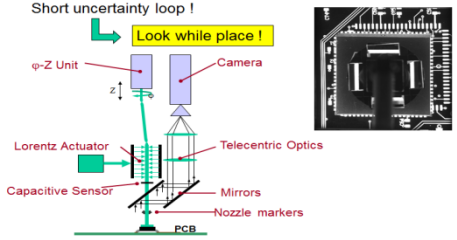
- Others: Vermeulen 1999, Van Seggelen 2007, Xpress TriNano

Alignment System

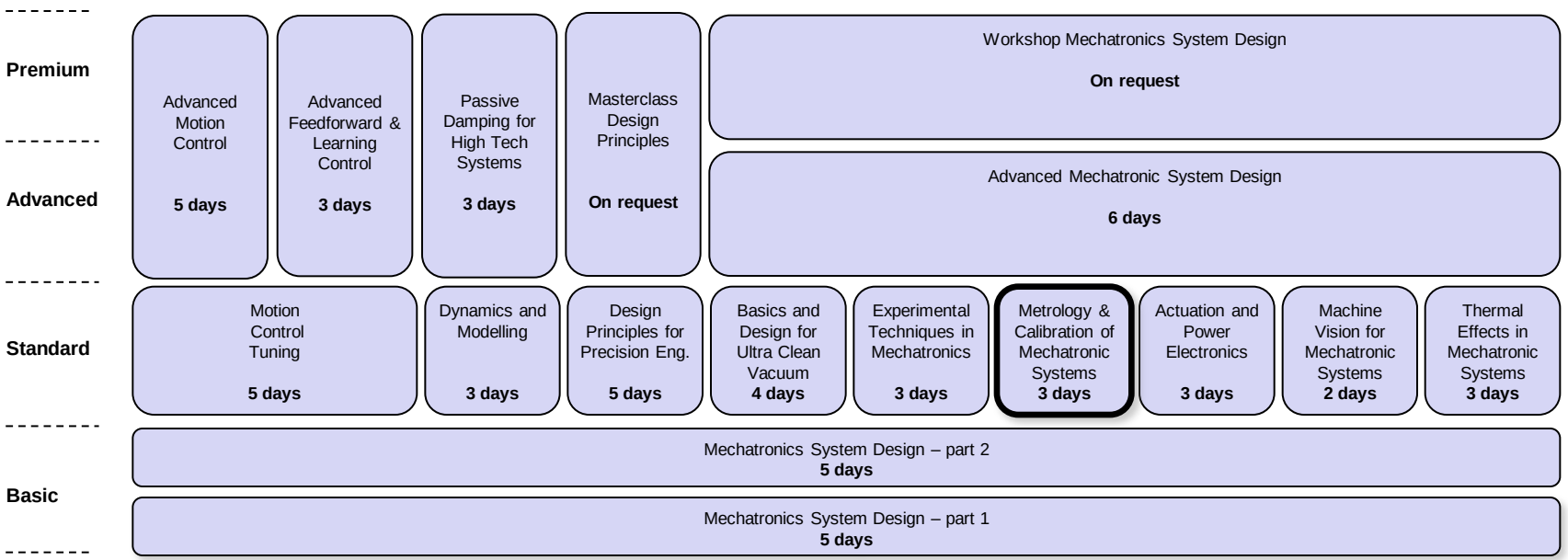


How to eliminate calibration steps ?

Short uncertainty loop !



Mechatronics Training Curriculum



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.

Metrology and Calibration of Mechatronic Systems

Trainers

- Dr.ir. Rens Henselmans (Dutch United Instruments)
- Dr.ir. Stefan Bäumer (TNO)
- Dr.ir. René Klaver (IBS Precision Engineering)
- Ir. Jef Horijon (Kulicke & Soffa)
- Dr.ir. Adrian Rankers (Mechatronics Academy)

Course Director(s)

- Dr.ir. Rens Henselmans (Dutch United Instruments)
- Dr.ir. Adrian Rankers (Mechatronics Academy)

Global Program

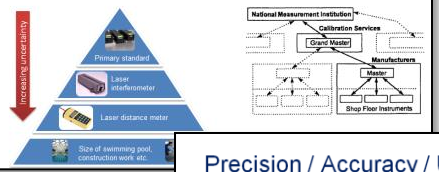
Day	Topic	Presenter
1	Introduction / Definitions Short Range Sensors	Rens Henselmans Rens Henselmans
	Interferometry Systems Encoder Systems	Stefan Bäumer René Klaver
2	Case Introduction Mechatronic Context	Rens Henselmans Adrian Rankers
	Metrology on System Level	Rens Henselmans
3	System Calibration	Rens Henselmans
	SMD component mounter case Wrap-Up & Closure	Jef Horijon Adrian Rankers

Day 1 (morning)

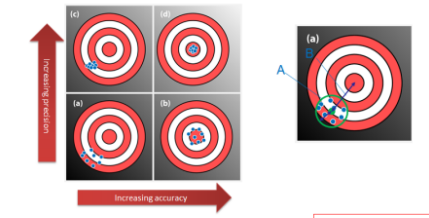
- Introduction & Metrology definitions
- Short Range Sensors
  - Sensor terminology (range, resolution, sensitivity etc.)
  - Sensor types (capacitive, inductive, optical etc.)

Traceability

- A measurement result is linked to the definition of the unit
  - by an unbroken series of comparisons (traceability chain & hierarchy)
  - each with a specified uncertainty
- Traceable measurements are absolute: independent of instrument and method



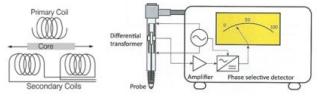
Precision / Accuracy / Uncertainty



Precision: Measure for random errors (A) ⇒ System metrology
Accuracy: Measure for systematic errors (B) ⇒ System calibration
Uncertainty: Includes both (A+B)
Note: Uncertainty has confidence interval (e.g. k = 2 means 95.4%)

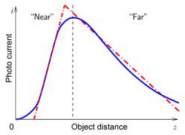
Distance - LVDT

- Linear Variable Differential Transformer
- Differential coupling between coils and movable core
- Analog, resolution down to 0.1 µm
- Contact
- Very easy to setup, direct readout
- Universal and built-in versions available
- Mainly useful in experiments and calibration



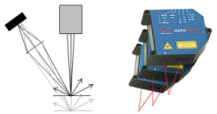
Distance – Optical - Proximity

- Measures intensity of reflected light
- Chip or fibre coupled
- Near and far side
- Resolution down to tens of nm
- Low cost, but highly non-linear
- Reflectivity dependent



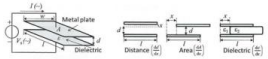
Distance – Optical – Triangulation

- Resolution down to µm
- Mostly available for diffuse surfaces
- Relatively large
- Large standoff
- Some have PSD (fast), some CCD (slow)
- For diffuse surfaces

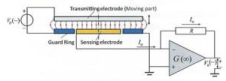


Distance - Capacitive

- Measure capacitance between two electrodes
- $C = \varepsilon_0 \varepsilon_r \frac{A}{d}$ ⇒ 3 ways to vary capacitance

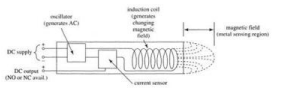


- Guard to linearize output (minimize stray field)



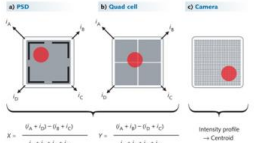
Distance - Inductive

- Also called Eddy current sensor
- Measures influence on generated magnetic fiel
- Analog, resolution down to sub-µm, tens of kH
- Non-contact
- Material dependent, must be calibrated
- Temperature dependent, some have internal sensor
- Quite non-linear

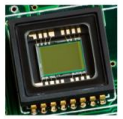


Optical position – CCD

- Measure spot position
- Sensitivity to intensity and distribution depends on algorithm
- Digital (slower, < 5 kHz with dedicated FPGA)
- Dimensions determined by camera market
- Resolution can be sub-pixel by fitting intensity profile

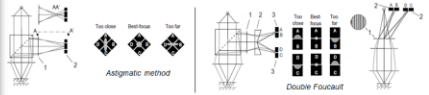


Source: LaserFocusWorld

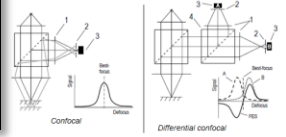


Distance – Optical – Focus detection)

Focus detection derived from cd-players



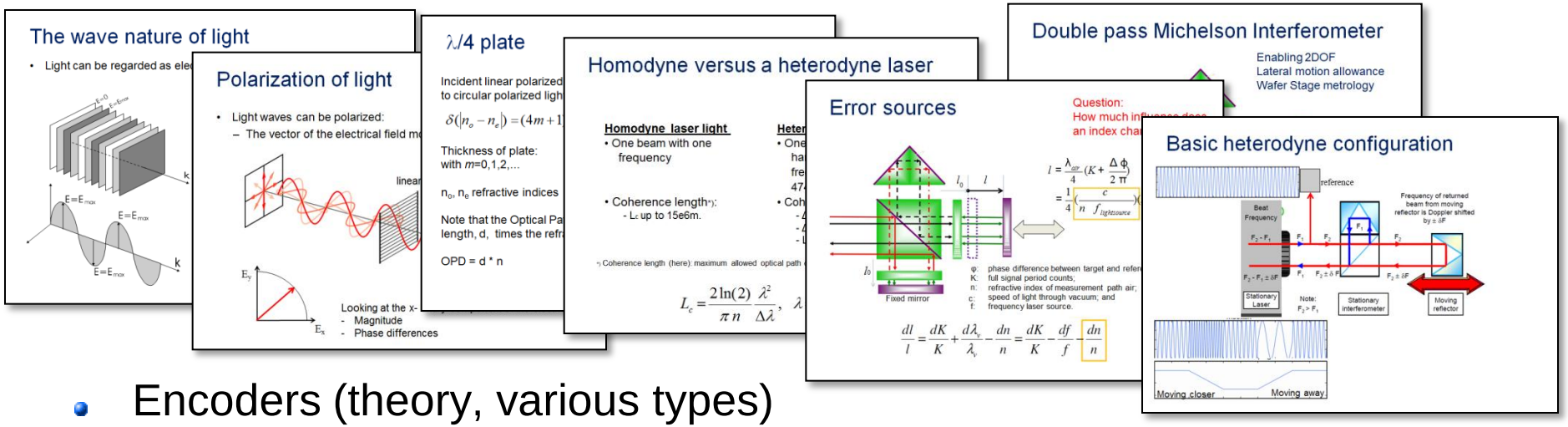
Confocal derived from 3D microscopes



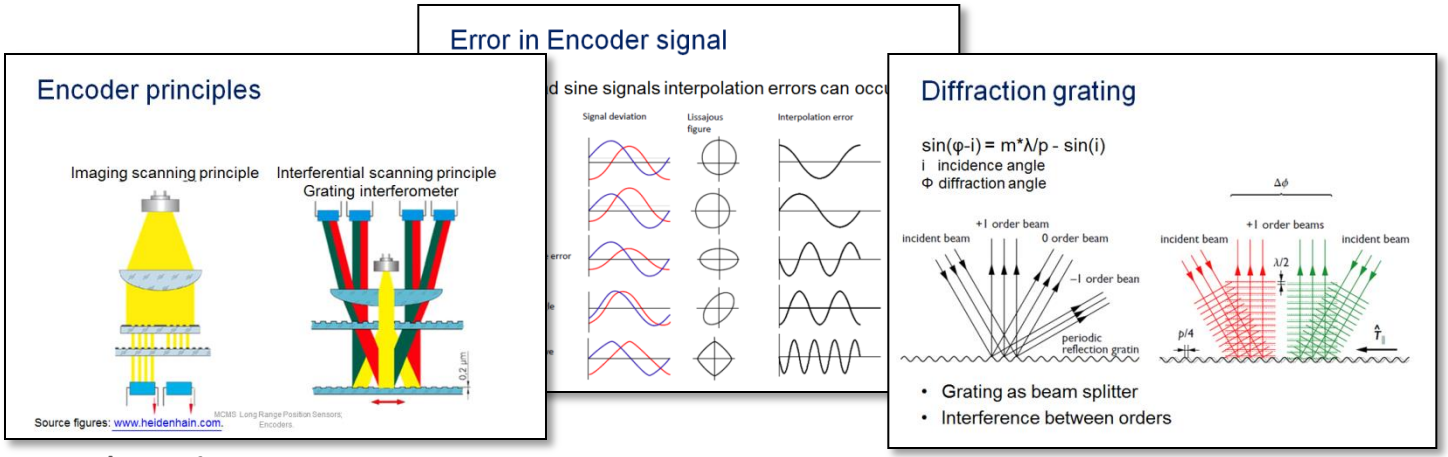
Source: Cacace 2009 – An optical distance sensor

Day 1 (afternoon)

- Displacement interferometry (principle, components, error sources etc.)



- Encoders (theory, various types)



Day 2 (morning)

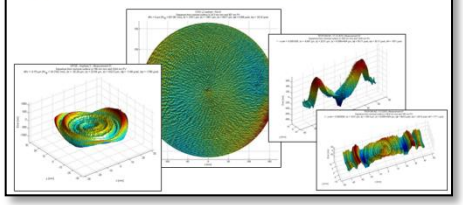
- Case introduction
  - Measurement machine for freeform optics
  - Analysis of existing solutions
  - Performance estimation
- Mechatronic context
  - Control theory summary
  - Influence of sensor properties / placement

NANOMEFOS

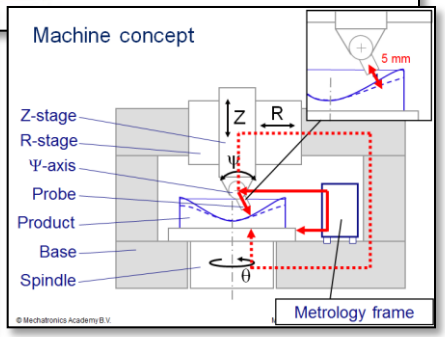
- Nanometer Accuracy NOn-contact MEasurement of Freeform Optical Surfaces
- MSc and PhD project (TU/e, TNO and VSL)
- Design and realization of measurement machine

Machine performance

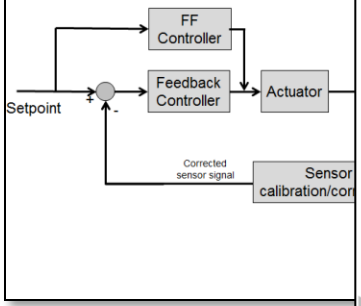
- Repeatability ~ 1 nm rms on form
- Speed: 15 mins for ∅380 mm (4M points)
- Calibrated with known artefacts (chicken-egg issue…)



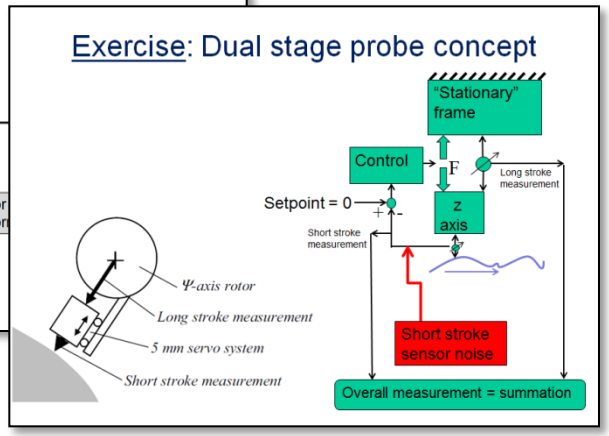
Machine concept



Mechatronic System



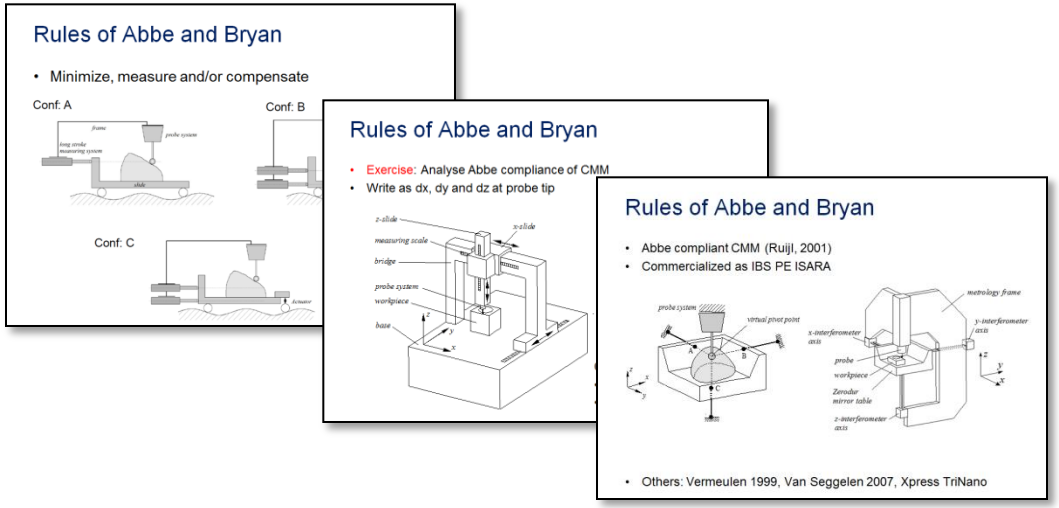
Exercise: Dual stage probe concept

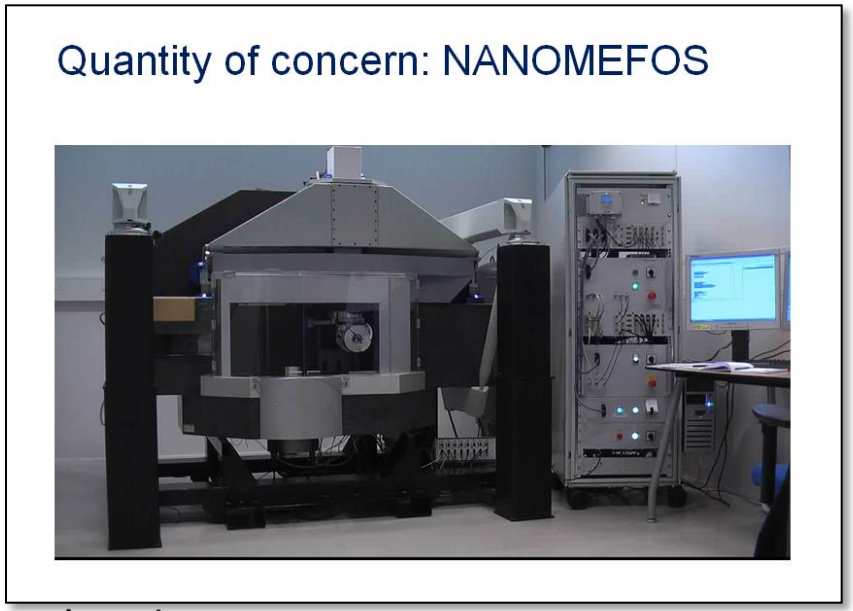


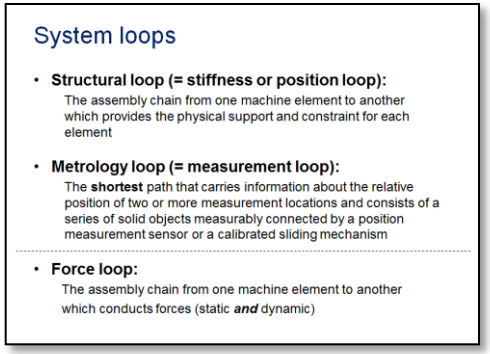
Day 2 (afternoon)

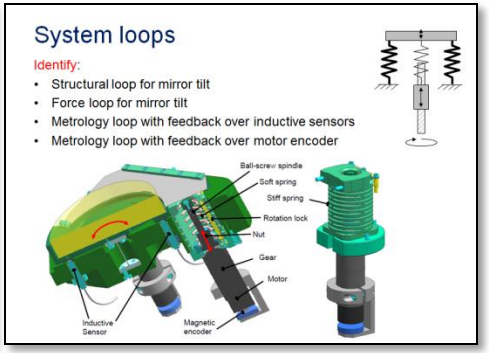
Metrology on System Level

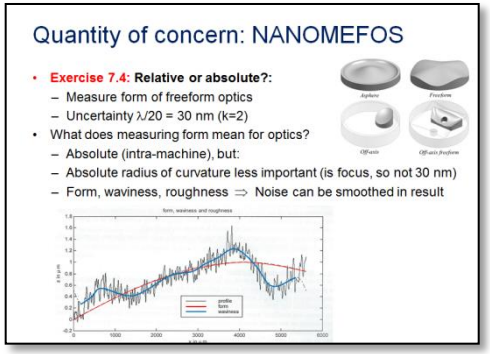
- Design for low uncertainty
- Error types
- Rules of Abbe and Bryan
- System loops
- Quantity of concern

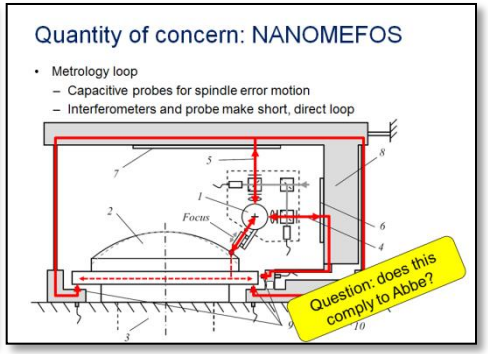










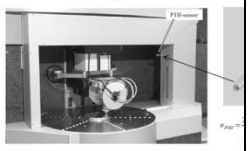


Day 3 (morning)

- System Calibration
  - Basics
  - Calibration instruments & artefacts
  - Self-calibration
  - Calibration application examples
  - Use of calibration data

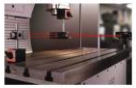
Types of calibration

- Measurement based
  - Direct measurement of the errors
  - e.g. error motion of stage measur
- Model based
  - For instance thermal effects, diffic
  - Measure temperature, compensat



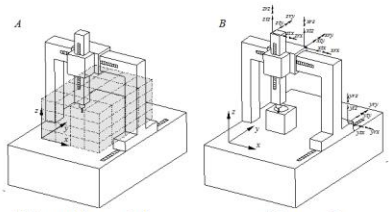
Types of calibration

- Using external reference
  - Periodic /single time calibration w
    - e.g. Send instruments to NMi
    - e.g. CMM calibration with interf



- Using internal reference ('desi
  - Machine calibrates itself 'every cy
    - Measure dedicated artefact (e.
    - Part of measurement routine (e
    - Tool height setting on lathe

Types of calibration

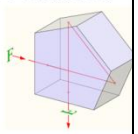


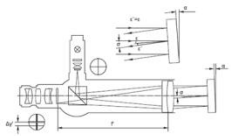
Volumetric model
(Integral / end-to-end / black-box)

Kinematic
(Parametric)

Calibration instruments: Autocollimator

- Measure angle of mirror
- Spot displacement on CCD
- Can measure sub-µrad over meters of motion
- Can be used with pentaprism
- National standard for angular motion



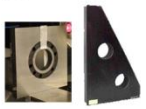


Source: Moller-We

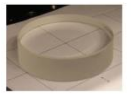
Calibration instruments: Artefacts

- **Straightedge (Dutch: 'Rei')**
  - Metal or granite, down to few µm/m

- **True square**
  - Metal or granite
  - Parallelism < 1 µm / squareness few µm/m

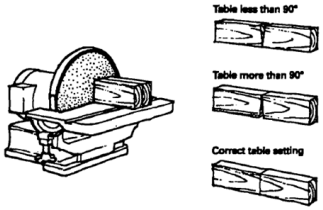


- **Flat**
  - Granite tables: few µm per m²
  - Optical flats: ∅100 mm at few nm (e.g. λ/20). Available up to ∅500 mm (liquid mercury)



Exercise

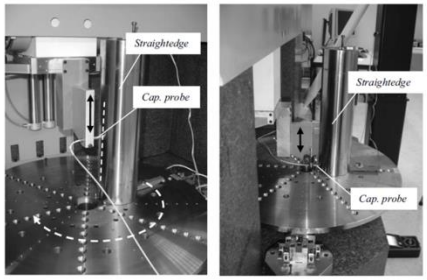
- Exercise 8.4: How to set a disk sander?



- External calibration: carpenters square or level
- Internal calibration: reversal (auto-calibration)

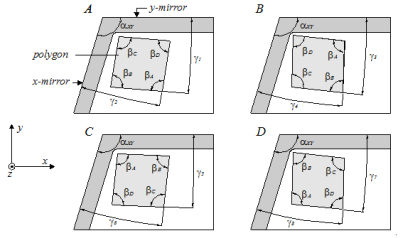
Exercise: NANOMEFOS Z-axis alignmen

- Use straightedge with reversal
- Angle of straightedge known: measure other angle



Closure

- CMM mirror squareness calibration, using CMM itself
- Procedure:
  - Using single artifact: polygon with four faces.
  - Polygon is measured in four positions



From combinations A..D

$$\beta_A + \gamma_1 + \gamma_2 = \alpha_{xy}$$
$$\beta_B + \gamma_3 + \gamma_4 = \alpha_{xy}$$
$$\beta_C + \gamma_5 + \gamma_6 = \alpha_{xy}$$
$$\beta_D + \gamma_7 + \gamma_8 = \alpha_{xy}$$

Polygon with four faces:

$$\beta_A + \beta_B + \beta_C + \beta_D = 2\pi$$

So, angle of mirror table:

$$\alpha_{xy} = \frac{2\pi + \sum_{k=1}^{8} \gamma_k}{4}$$

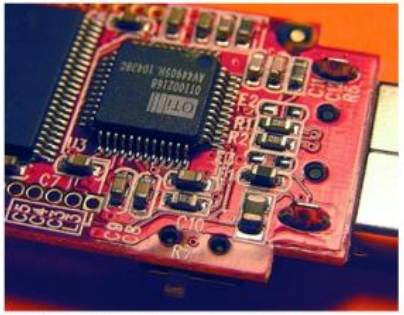
Day 3 (afternoon)

- SMD Component Mounter Case
  - Vision Metrology
  - Calibration of Series Products

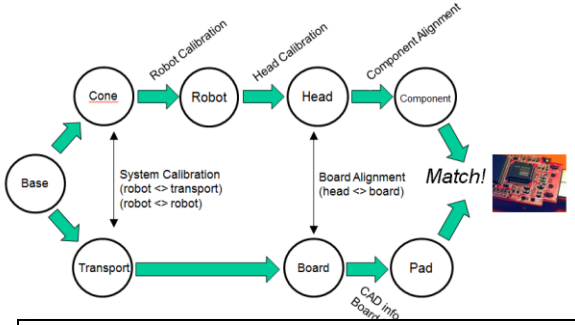
Surface Mount Technology

Surface-mount technology (**SMT**) is a method for producing electronic circuits in which the components are mounted directly onto the surface of a **printed circuit board** (**PCB**). An electronic device so made is called a **surface-mount device** (**SMD**)

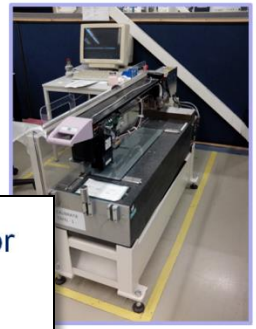
SMD capacitor

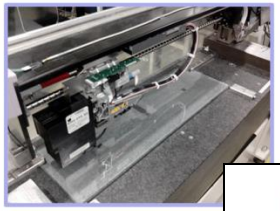

The capacitors and resistors pictured are a combination of 0805 (2012 metric) and 0603 (1608 metric) package sizes.

Calibrations



XY Robot calibration set up

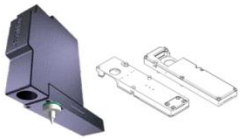


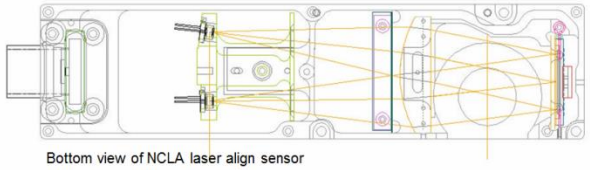


- Calibration is performe
  robot interface
- Covers full work area
- Applies two BA camera

Component alignment with laser sensor

- Two beams by 2 lasers
- Single line sensor
- Measurement at one height
- Shadow images are evaluated during rotation

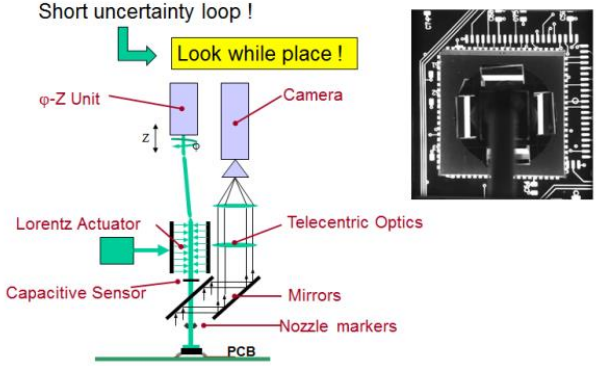



Bottom view of NCLA laser align sensor

How to eliminate calibration steps ?

Short uncertainty loop !

Look while place !



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Via the website of our partner

High Tech Institute