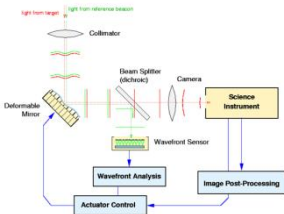


Summerschool Opto-Mechatronics

an initiative of the Dutch Society for Precision Engineering (DSPE)

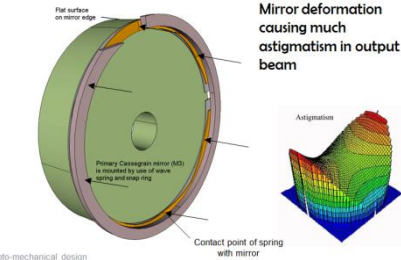
System layout of AO

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Opto-Mechanics



Design error 4

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Breaking of glass due to thermal mismatch

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Hooke's law: $\sigma = \epsilon \cdot E$

Thermal expansion difference

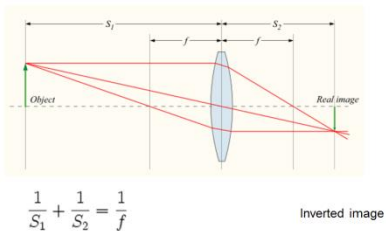
$$\Delta L = \Delta T \cdot \Delta \alpha \cdot L \quad \text{or} \quad \frac{\Delta L}{L} = \epsilon = \Delta T \cdot \Delta \alpha$$

Combination: $\sigma = \Delta \alpha \cdot \Delta T \cdot E$

Example: $\sigma = 10 \times 10^{-6} \cdot 50.70000 = 35 \text{ MPa}$

Imaging – real image

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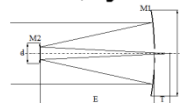


Inverted image

Optical Design of the Cat's Eye

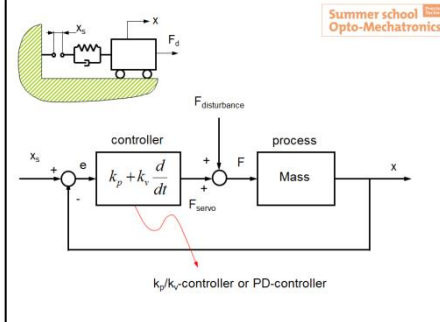
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Ritchey-Chretien type



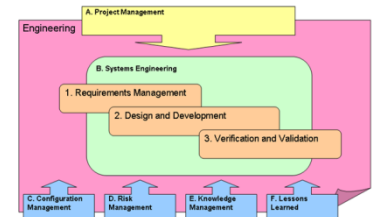
Cat's Eye design physical characteristics

- a. Focal Length: $F = 3600.0 \text{ mm}$
- b. F/N (Full Aperture): $F/6.55$
- c. Full Aperture: $D = 550.0 \text{ mm}$
- d. Distance M1 - M2 vertices: $d = 130.0 \text{ mm}$
- e. Back Focal Distance: $E = 700.0 \text{ mm}$
- f. Field of View: 0.25°



Systems Engineering in project context

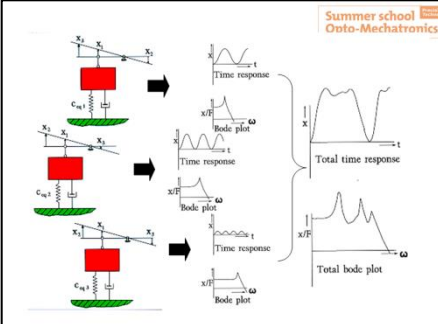
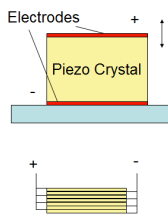
Summer school
Opto-Mechanics



Piezoelectric actuators

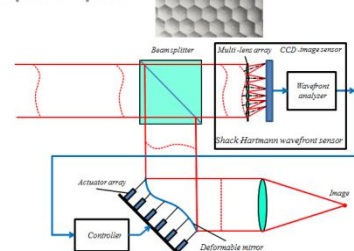
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Opto-Mechanics

- Voltage \Rightarrow charge \Rightarrow stress \Rightarrow strain.
- Capacitive impedance.
- High stiffness.
- Limited range $\sim 1000 \mu\text{m/m}$ @ $\sim 1 \text{ kV}$ voltage (ceramic). Higher levels with polymers or composites.
- Zero static energy consumption.
- Very high force.
- Range can be increased for low voltage by stacking.



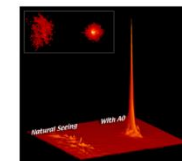
Basic principle of Adaptive Optics

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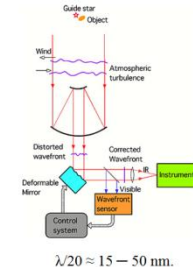


Feedback control in astronomy

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Opto-Mechanics



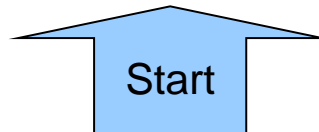
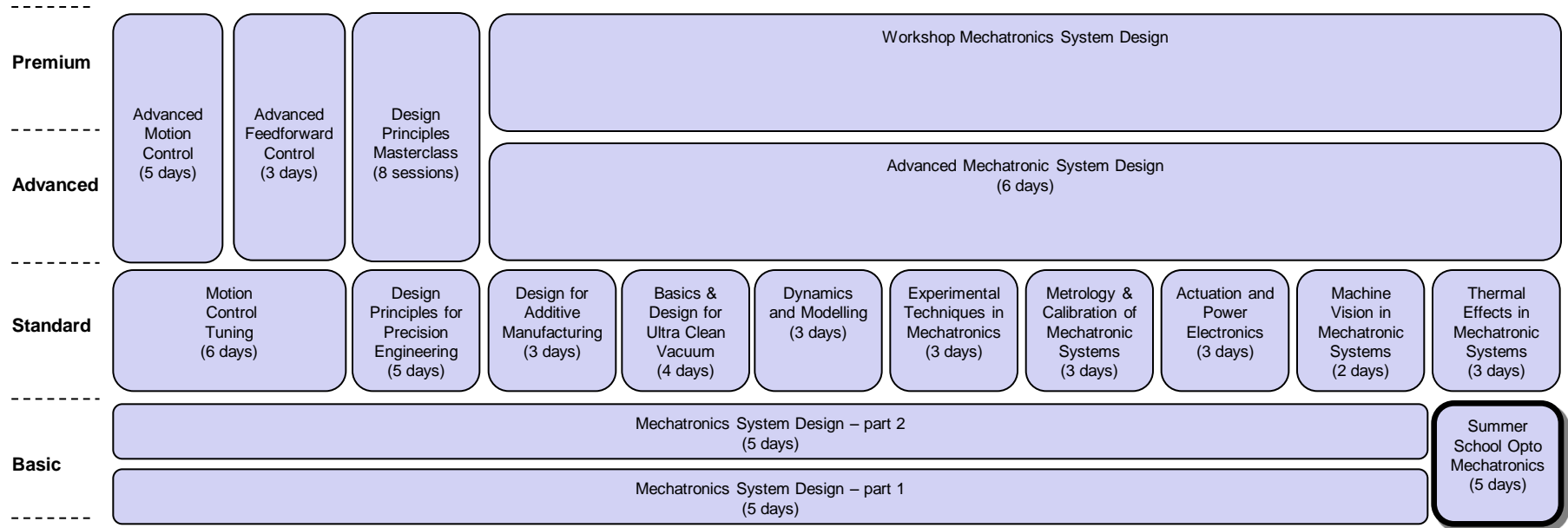
Source: Lick Observatory



Contents

- Mechatronics Training Curriculum
- Details of Course *Summerschool Opto-Mechatronics*

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.

Summerschool Opto-Mechatronics

Course Directors / Trainers / Guests

Course Director(s)

- Prof. ir. Rob Munnig Schmidt
- Dr.ir. Adrian M. Rankers

Teachers

- Prof. ir. Rob Munnig Schmidt (RMS Acoustics & Mechatronics)
- Dr.ir. Adrian M. Rankers (Mechatronics Academy)
- Dr.ir. Stefan Bäumer (TNO)
- ir. Eddy van Brug (TNO)
- Dr.ir. Pieter Nuij (NTS-Group)
- ir. Jan Nijenhuis (Nijenhuis Precision Engineering)
- Ing. Fred Kamphues (Millhouse Consultancy)

Guest Speakers

- ir. Frank de Lange (ASML)
- Dr. Frederic Derie (ESO)

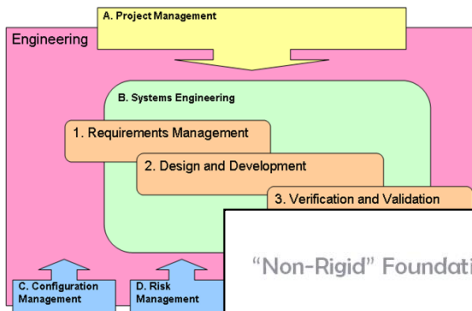
Program

Day	Topic	Trainers
Monday	<p>Systems Engineering Basic Modelling</p> <p><i>Dinner</i></p> <p><u>Evening Presentation</u>: Systems Engineering at ASML</p>	<p>Rob Munnig Schmidt Adrian Rankers</p> <p><i>Frank de Lange</i></p>
Tuesday	<p>Optical Design</p> <p><i>Dinner</i></p> <p><u>Evening Presentation</u>: E-ELT, the World's Biggest Eye on the Sky</p>	<p>Stefan Bäumer Eddy van Brug</p> <p><i>Frederic Derie</i></p>
Wednesday	<p>Control Design I</p> <p><u>Evening</u>: Summerschool Construction Challenge (incl. Pizza's)</p>	<p>Pieter Nuij Adrian Rankers</p>
Thursday	<p>Optomechanical Design</p>	<p>Jan Nijenhuis Fred Kamphues</p>
Friday	<p>Actuation, Sensing & Dynamics</p>	<p>Rob Munnig Schmidt Adrian Rankers</p>

Day 1: Systems Engineering & Modelling

Introduction Case Systems Engineering Basic Modelling

Systems Engineering in project context



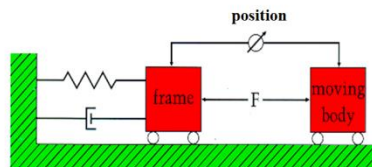
Summer school
Opto-Mechatronics

Performance requirements summary (1)

3.2.1.1.1	Operational lifetime	25 yr
3.2.1.1.2	Storage time	
	System	2 yr
	Spare parts	10 yr
3.2.1.1.3	Duty cycle	50 %
3.2.1.3.1	Mechanical stroke length	66 m
3.2.1.3.2	Observation stroke length	>3.0 m
3.2.1.3.2	Feed forward bandwidth	>7.8 Hz
3.2.1.3.2	Feed forward amplitude	>6.75 μ m
3.2.1.3.3	Absolute mechanical position repeatability	
	Total stroke	<50 μ m
	Observation stroke	<1 μ m
		± 0.5 m/s
		<1.0 μ m/s
		± 0.5 mm/s
		± 0.5 μ m/s
		<0.5 μ m/s
		>600.0 s
		<180.0 s
		<10.0 s
		<32.0 ms
		<0.25 ms

Summer school
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"Non-Rigid" Foundation (basic)



position

F

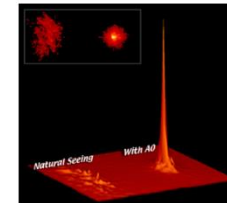
moving body

Scope: ESO (European Southern Observatory)



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Feedback control in astronomy



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Opto-Mechatronics

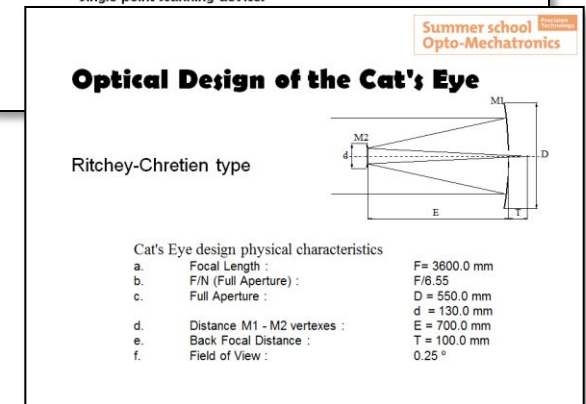
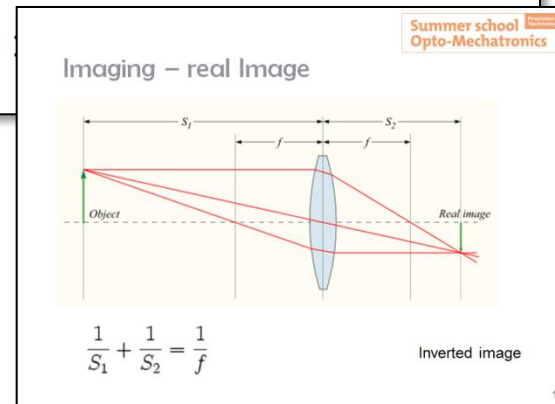
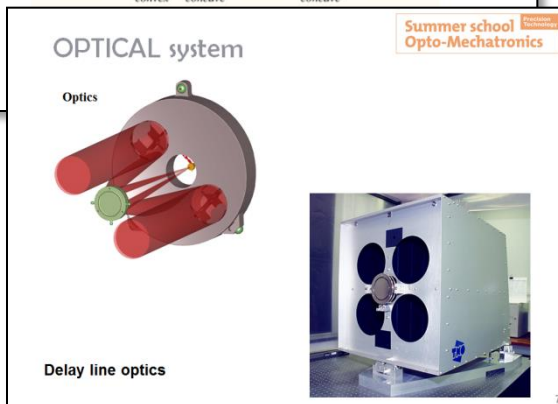
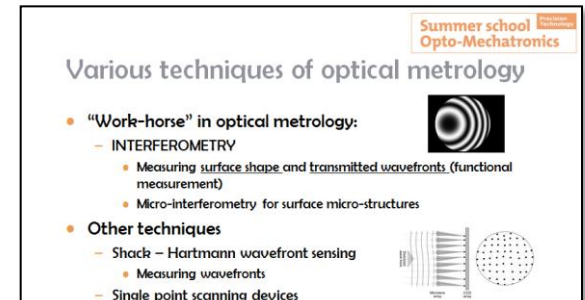
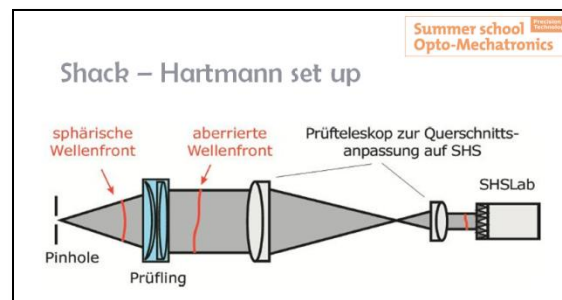
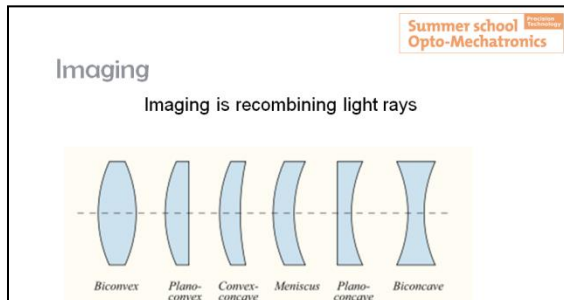
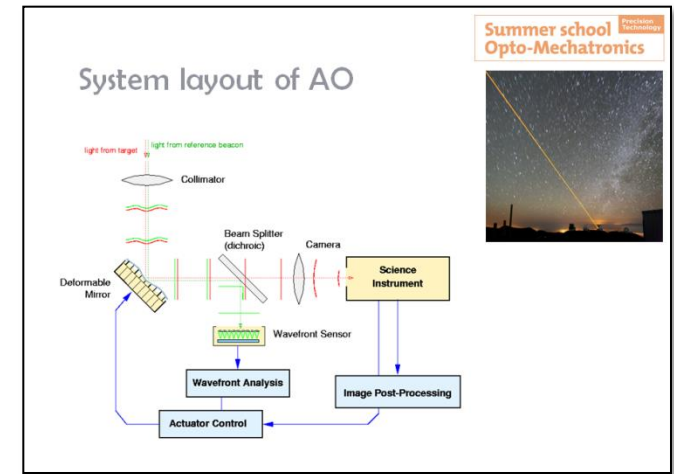
$\lambda/20 \approx 15 - 50$ nm.

Source: Lick Observatory

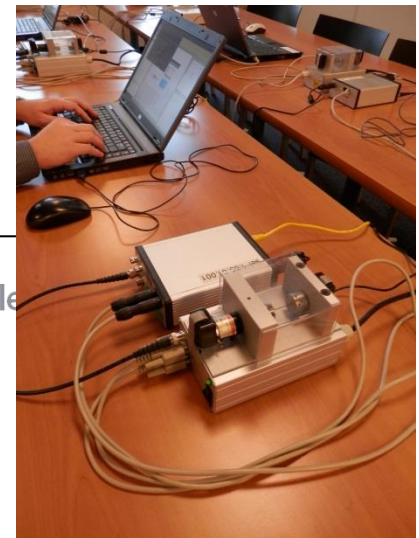


Day 2: Optical Design

- Basic Optics
- VLT Delay Line
- Optical Metrology / Optical Design



Day 3: Control Design



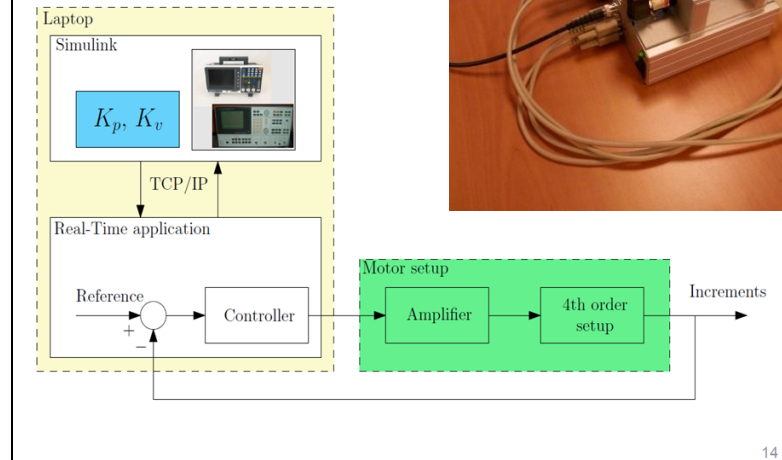
Program Control Design

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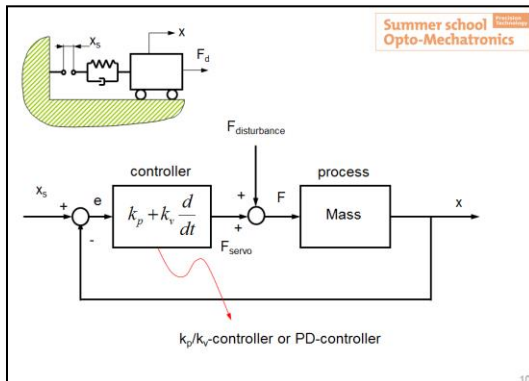
- 9:00 Time domain tuning: theory and hands-on
- 10:30 Coffee break
- 10:45 From time domain to frequency domain
- 12:30 Lunch
- 13:15 Identification and stability: theory and hands-on
- 15:00 Coffee break
- 15:15 Filters and performance
- 16:00 Feed forward: theory and hands-on
- 17:15 Evaluation
- 17:30 Drinks
- 18:00 Activity program & Diner
- 21:30 End

2

Overview of the complete



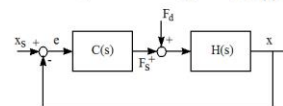
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Four important transfer functions

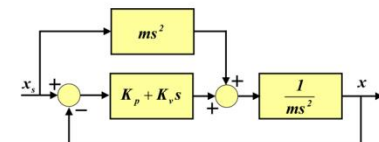
- Open loop: $H_o(s) = H(s)C(s)$
- Closed loop: $H_c(s) = \frac{x}{x_s}(s) = \frac{H(s)C(s)}{1 + H(s)C(s)}$
- Sensitivity: $S(s) = \frac{e}{x_s}(s) = \frac{1}{1 + H(s)C(s)}$
- Process sensitivity: $H_p(s) = \frac{x}{F_d}(s) = \frac{H(s)}{1 + H(s)C(s)}$



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Feedforward in the loop

Note that x_s is known and $L\{m\ddot{x}_s\} = ms^2L\{x_s\}$



Forward feed / prescribe in advance ...

... the force necessary to accelerate the rigid mass.

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Day 4: Optomechanical Design

1: Targets of today:

- Understanding about criticality of optical mounts.
- Basic principles of lightweight structures.
- Basic principles of elastic mechanisms.
- Impact of alignment on the opto-mechanical design.
- Understanding about α-thermal design.

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Precision
Technology

Breaking of glass due to thermal mismatch

Hooke's law: $\sigma = \varepsilon E$

Thermal expansion difference
 $\Delta L = \Delta T \cdot \Delta \alpha \cdot L$ or $\frac{\Delta L}{L} = \varepsilon = \Delta T \cdot \Delta \alpha$

Combination $\sigma = \Delta \alpha \cdot \Delta T \cdot E$

Example: $\sigma = 10 \times 10^{-6} \cdot 50 \cdot 70000 = 35 \text{ MPa}$

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Design error 1.



Design error 2.



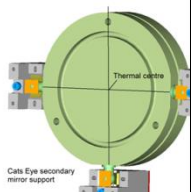
Glass broken due to big thermal mismatch with bracket

Opto-

Opto-

Thermal centre

- Thermal centre does not
axis should preferably

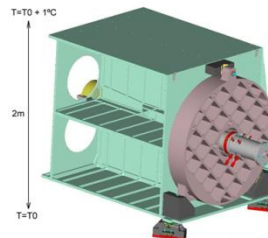


Opto-mechanical design

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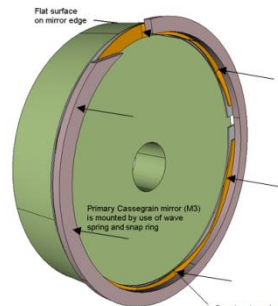
Thermal gradients



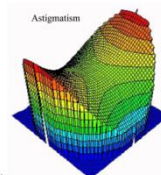
- Compare thermal conductivity
air and aluminium

Opto-mechanical design

Design error 4



Mirror deformation
causing much
astigmatism in output
beam



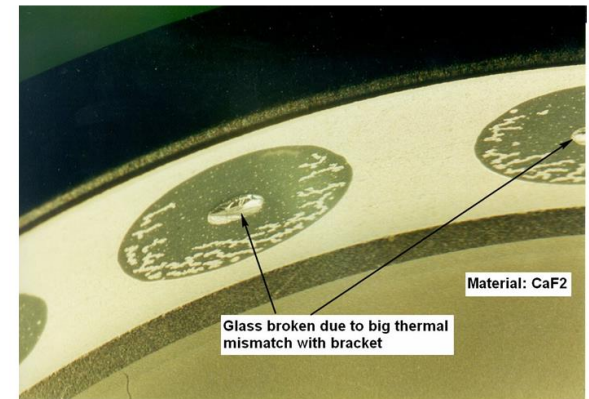
Opto-mechanical design

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Summer school
Opto-Mechatronics

Precision
Technology

Design error 3.



Glass broken due to big thermal mismatch with bracket

Material: CaF2

Opto-mechanical design

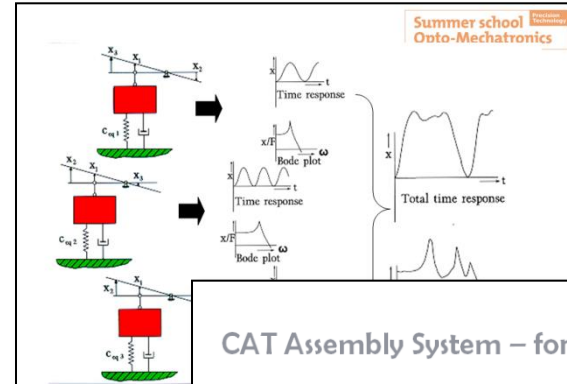
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Day 5: Actuation, Sensing & Dynamics

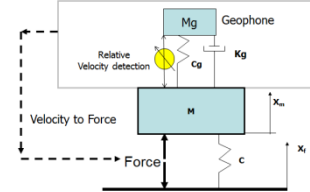
Contents of the course of today

- Problem statement
- Precision positioning of optics
 - Active positioning versus passive stability.
- Adaptive Optics
- System dynamics (Adrian Rankers)
- lunch
- Actuator requirements and possibilities
- Position Metrology
- Exercise
- Things to remember

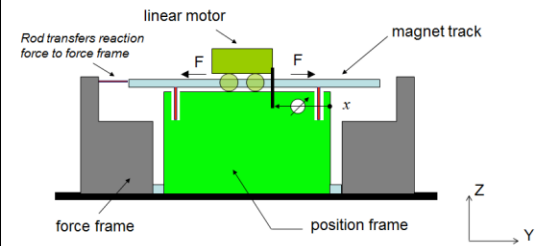
Summer school Opto-Mechatronics



The skyhook vibration isolation.

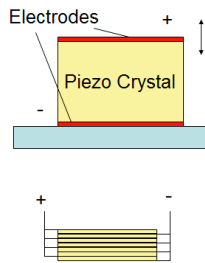


CAT Assembly System – force frame

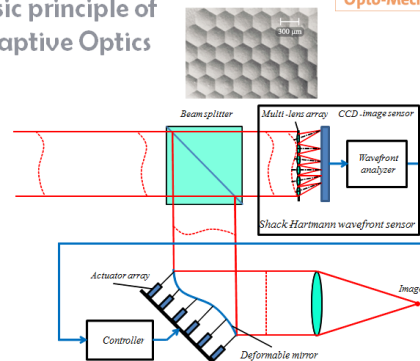


Piezoelectric actuators

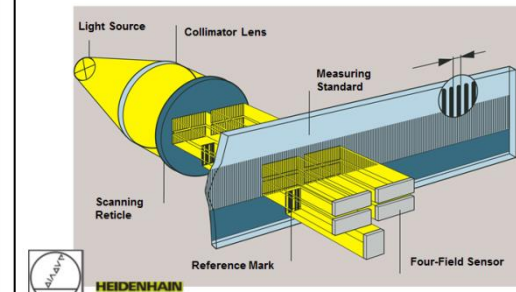
- Voltage \Rightarrow charge \Rightarrow stress \Rightarrow strain.
- Capacitive impedance.
- High stiffness.
- Limited range $\sim 1000 \mu\text{m/m}$ @ ~ 1 kV voltage (ceramic). Higher levels with polymers or composites.
- Zero static energy consumption.
- Very high force.
- Range can be increased for low voltage by stacking.



Basic principle of Adaptive Optics



Encoders, transmission principle



Sign-up for this training

Via the website of our partner
High Tech Institute