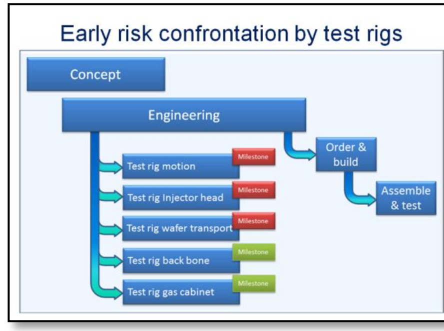
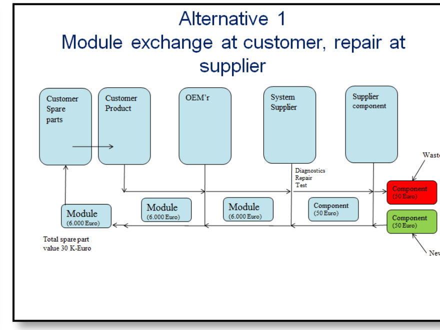
Advanced Mechatronic System Design

Background of the workshop

Idea:

- Provide intensive training in mechatronic system design on a new and uncertain business case based on vague requirements (close to reality!)
- Interactive participation in workshop/masterclass environment.
- Related to the Dutch high-tech industry
- Provided by experienced system designers
- On top of the Mechatronics courses of Mechatronics Academy
- Covering a broad range of subjects
- With adaptable content, when required



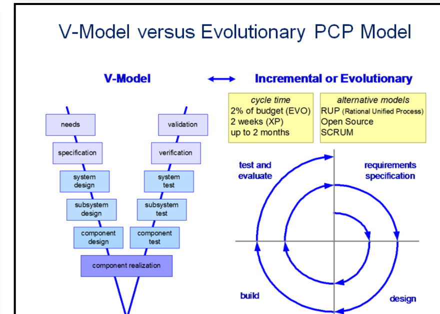


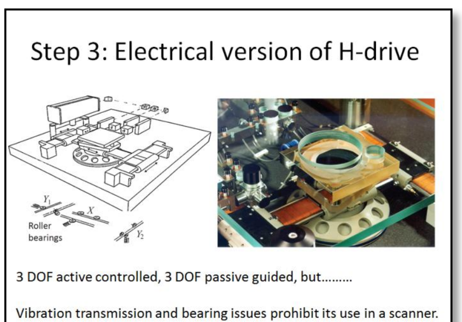
System Decomposition Overview

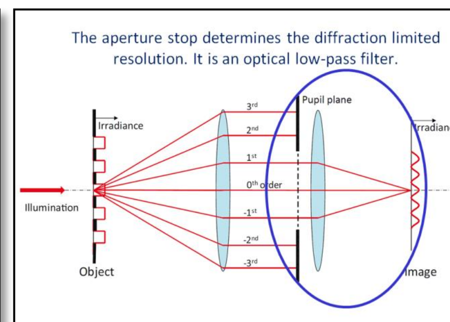
Modules / System Functions	Frame	Optical Column	Stage / Robot	Illumination	Wafer handler	Control hardware	Control Software
Alignment		X	X		X		X
Metrology / Calibration	X	X	X		X		X
Contamination control	X		X	X	X		
Thermal control	X	X	X	X	X	X	
Wafer handling			X		X		X
Production Data Management					?		X
....							

(Sub) Project Leaders

System Designers



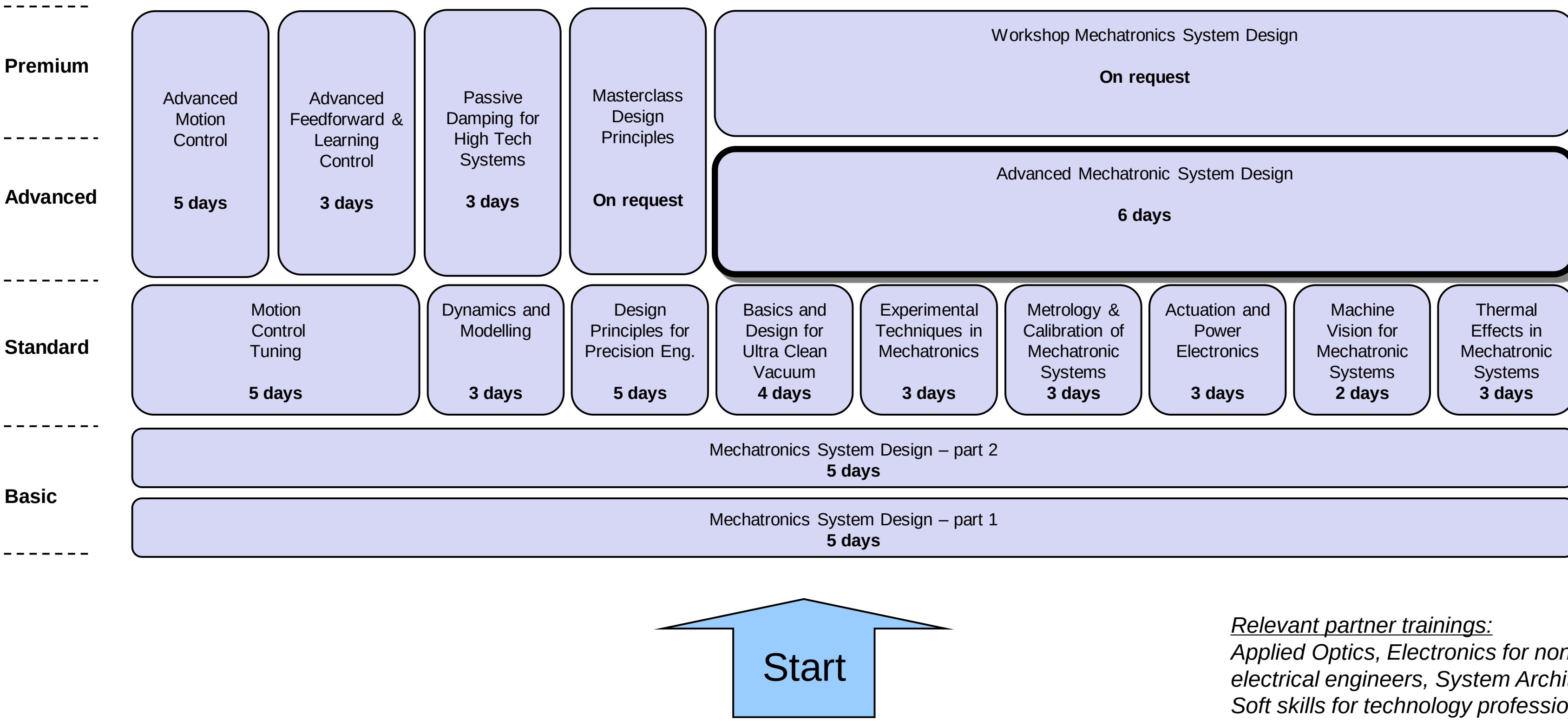




Contents

- Mechatronics Training Curriculum
- Details of Course *Advanced Mechatronic System Design*

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.

Advanced Mechatronic System Design

Course Director(s) / Trainers

Teachers

- Prof.ir. Rob Munnig Schmidt (TUDelft / RMS Acoustics & Mechatronics)
- Ir. Ad Vermeer (AdInsyde)
- Dr.ir. Adrian Rankers (Mechatronics Academy)
- Ir. Hans v.d. Rijdt (van de Rijdt Innovatie)
- Rob Oldenburg (Sales Improvement Group)

Course Director(s)

- Prof.dr.ir. Jan van Eijk (MiceBV)
- Dr.ir A.M. Rankers (Mechatronics Academy)

Program

Day	Session	Time	Topic	Presenter
Day 1	Morning	09.00 09.30 11.30	Introduction (who-is-who, goals, expectations, ...) Introduction Case Team Work (discussion of assignment, understanding, clarifying, ...)	Rob Rob/Ad
	Afternoon	13.30 15.30	Optical Systems for Imaging (focus on case) System Decomposition Overview (SDO) incl. weekend assignment	Rob Ad
Day 2	Morning	09.00 10.30 11.30	Team discussion (understanding/Questions URS, Initial Concept(s) + SDO Plenary discussion Agile Systems Engineering Principles incl. (agile)(V-model , (agile) requirements, decomposition, ...	Ad
	Afternoon	13.30 15.00 16.30	Team Exercise Agile Systems Engineering incl. preparation of initial customer feedback presentation (draft of requirements, deliverables, ...) to “test” whether you are in sync with the customer 3 x (10min presentation+20min discussion on contents & presentation) Is your audience yellow, blue, green or red ?	Ad Rob/Ad + Rob Oldenburg Rob Oldenburg
Day 3	Morning	09.00 10.00	Layout & Motion Concepts Team Work	Rob
	Afternoon	13.30 15.00	Risk Assessment Team Work	Ad
	Evening*	18.00	Dinner (Auberge Nassau)	
Day 4	Morning	09.00 10.30	Design for (Service) Costs Team Work	Hans v.d. Rijdt
	Afternoon	13.30 15.30	Precision Drive & Sensing Principles Team Work	Rob
Day 5	Morning	09.00 12.00	Vibrations & Dyn. Error Budgetting Decision Tables	Adrian Ad
	Afternoon	13.30 15.00	Conceptual Thermal Analysis (30% accuracy calculations) Team Work	Ad
Day 6	Morning	09.00 10.00	Example presentation of a real project Preparation Customer Meeting	Rob
	Afternoon	13.30 16.00	3x Customer Presentation (20min + 20min discussion) Evaluation incl. most important lessons learned & improvement points	Rob/ Ad / Guest

Day 1 (morning): Introduction / Case

Background of the workshop

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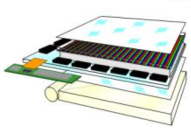
Top down approach

The participant will be confronted with aspects on different levels:

- The product creation process including creativity and innovation-targeted process steps based on vague "customer requirements"
- The fact that the customer is in fact multiple persons with often different views
- Technical trade-offs on system level by teams of which the members have a different technical background.
- Recent insights/developments on module/function level.

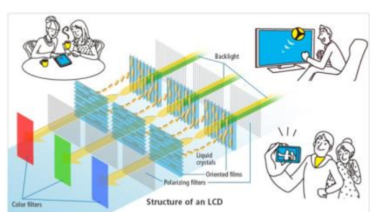

Flexible Small Flat Panel Display manufacturing

a case study



Rob Munnig Schmidt

Basic principle LCD display



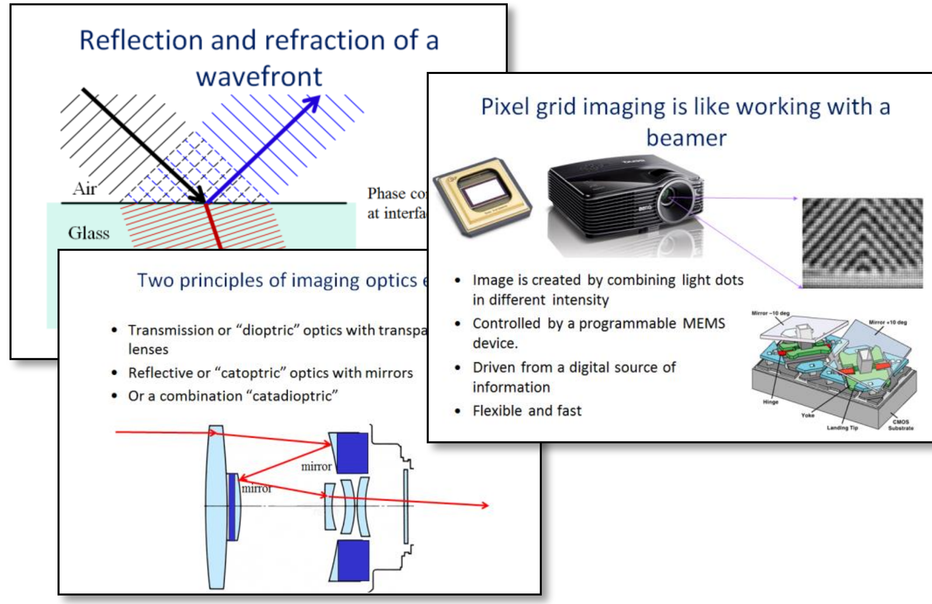
So what will be the task in this workshop?

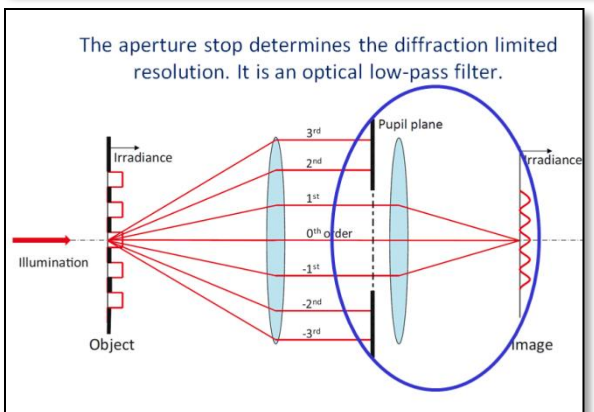
- Concept design of a flexible LCD/OLED pattern definition system, focusing on the huge diversity in <u>small</u>, high resolution displays used in smartphones and related products by breaking with the trend for ever larger substrates, preferably on a single item basis.
- Starting with a thorough investigation of requirements and working according to a systematic design process.

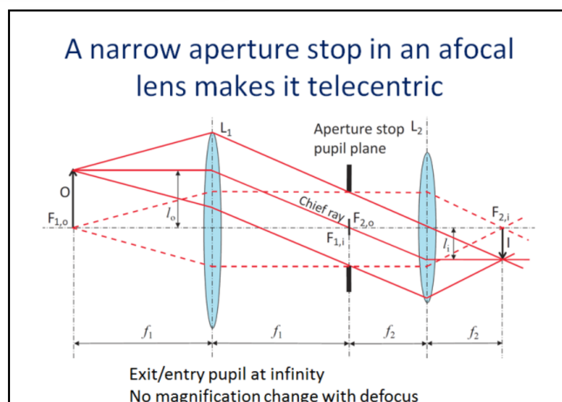
Day 1 (afternoon): Optical Systems …

Main message

1. The wavelength and radiance of a source of light determine the ability of a lithographic exposure system to concentrate light on a small spot.
2. A wavefront is an artificial concept that is used in visualising optical properties.
3. Geometric optics is a straightforward way to construct an image by means of ray-tracing.
4. Telecentricity is applied in technical optics to avoid magnification errors.
5. Pixel-grid imaging differs from normal imaging in the way how a total image is created.







System Decomposition Overview

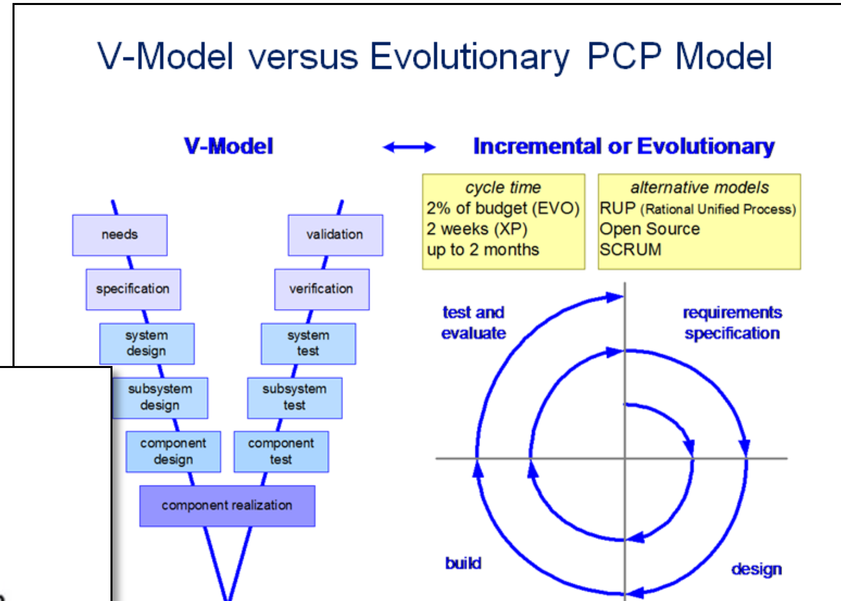
System Functions \ Modules	Frame	Optical Column	Stage / Robot	Illumination	Wafer handler	Control hardware	Control Software
	(Sub) Project Leaders						
Alignment		X	X		X		X
Metrology / Calibration	X	X	X		X		X
Contamination control	X		X	X	X		
Thermal control	X	X	X	X	X	X	
Wafer handling			X		X		X
Production Data Management					?		X
….							

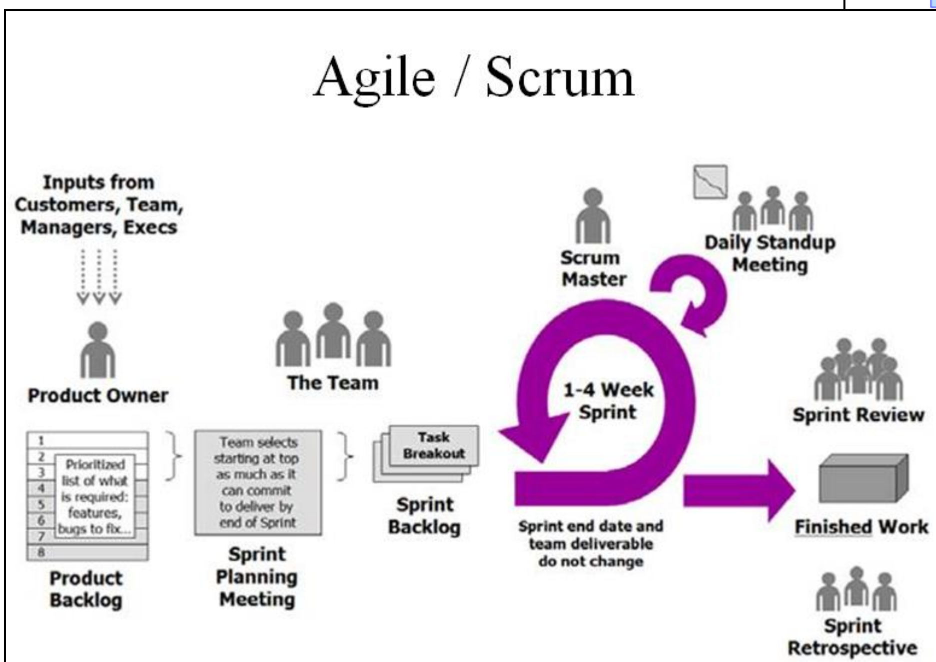
System Designers

Day 2 (morning):

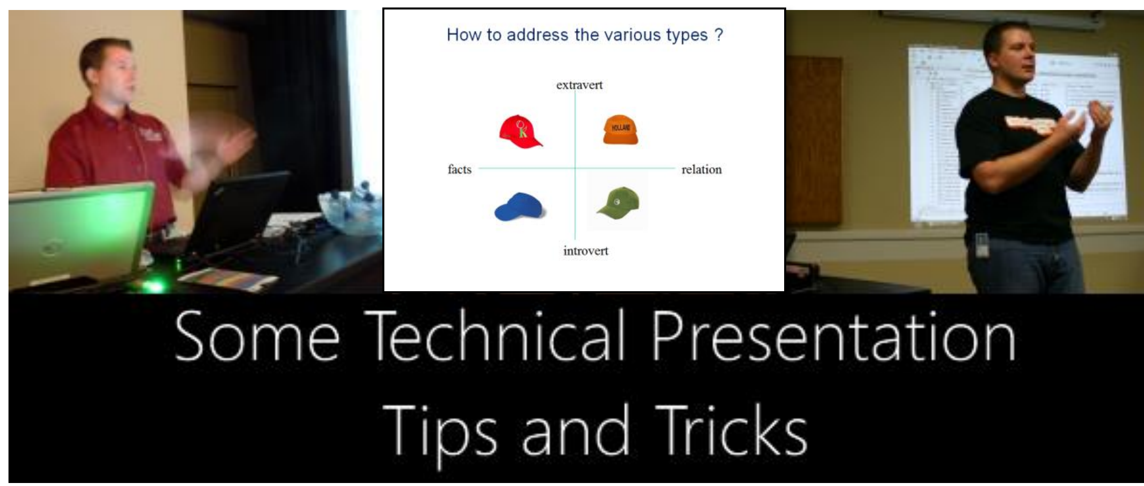
Team Discussion

Agile Systems Engineering





Day 2 (afternoon): Case + Presentation

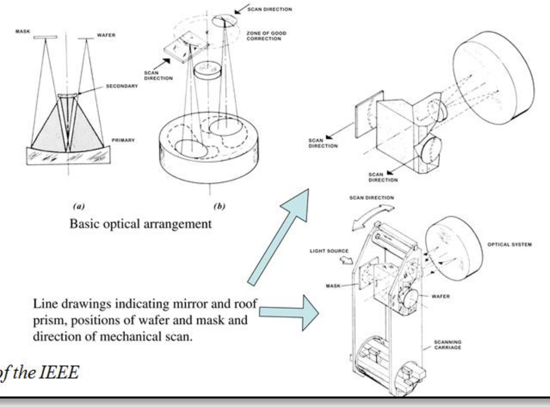


Day 3 (morning): Layout Concepts

Breakdown of motion system requirements and constraints

- Imaging:
  - Guarantee vibration free environment of exposure system
  - 6 DOF Position measurement of wafer relative to lens
- Overlay:
  - Same requirements as with imaging plus:
  - Position calibration of image to wafer (alignment)
- Throughput:
  - Avoid waiting times, keep lens always active imaging
  - Accurate positioning at high speed

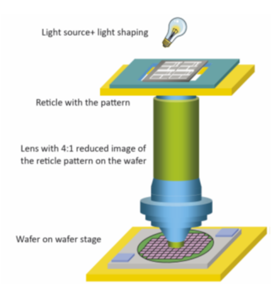
1:1 projection Perkin-Elmer (SVG-ASML) Micralign (1973)



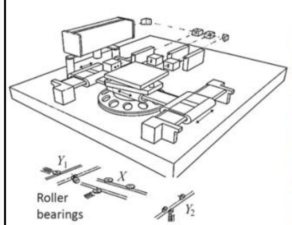
Proceedings of the IEEE

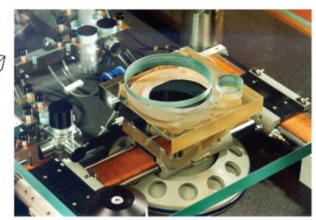
Disruptive, paradigm shifting technology of a waferstepper (Philips 1971)

- Smaller exposure area
- Alignment per die possible
- High NA only at imaging side
- Mask manufacturing less critical
- No contact



Step 3: Electrical version of H-drive

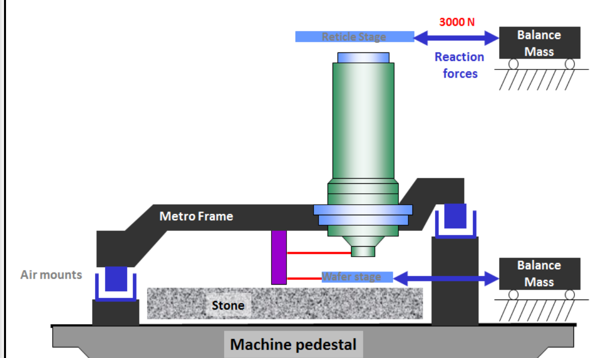




3 DOF active controlled, 3 DOF passive guided, but........

Vibration transmission and bearing issues prohibit its use in a scanner.

Dynamic architecture Twinscan



Day 3 (afternoon): Risk Assessment

Identifying risks early in project

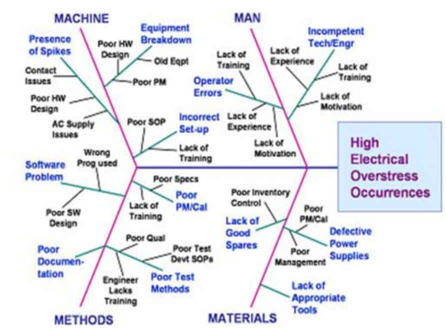
- Finding risks is a creative process
- Structured creativity by Fish Bone diagram
- Follow Ground Rules for Creativity:
  - Quantity above Quality
  - Cross Stimulation
  - Suspended Judgment
  - Writing it down
  - Listening
- Suggestion: Start with "brainwriting"

Practical method: Failure Mode and Effect Analysis

Functie per deelproces	Risico's	Kans	Gevolg	Detectie	RPN	Maatregelen	KBA	Kies
Invoeren van een order	Typefout bij ingeven order	4	6	9	216	Robuust order invoer systeem om verkeerde invoer te voorkomen	+	Doen, baten > kosten
	Klant geeft verkeerde bestelling door	6	6	1	36	Productinformatie verbeteren	-	Niet doen, gevolgen zijn beperkt
Inkoop	Geen leveringen door faillissement key-supplier							
Centrale voorraad	Verlies voorraad door brand in DC							
Transport	Te late levering door congestie							
Automatisch sorteren	Sorteren niet mogelijk door stroomstoring							

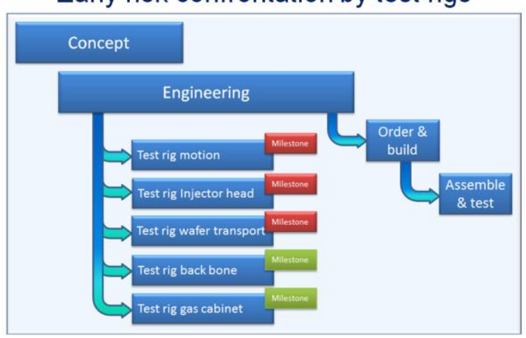
Kans: 1= nihil 10 =vaak
Gevolg: 1= voor de klant nihil, 10 = langdurige wanprestatie,
Detectie vooraf: 1= fout wordt zeker opgemerkt, via een alarm
RPN = Kans X Gevolg X Detectie
KBA = De afweging tussen de kosten om de RPN te verlagen

Ishikawa (Fish Bone Diagram)



Example risk mitigation: HVT SoLayTec

Early risk confrontation by test rigs



Assignment (2): Use FMEA

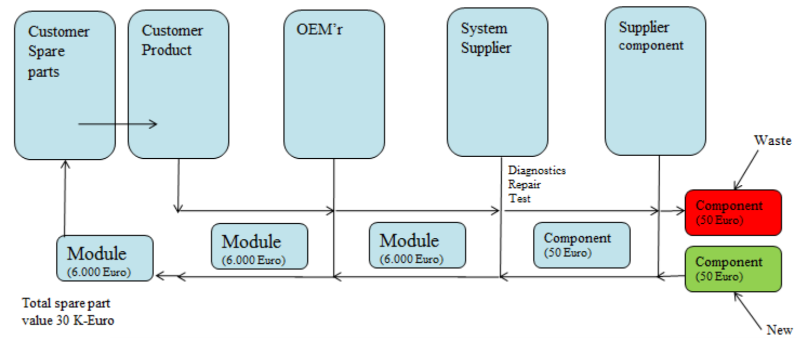
- Start from System Decomposition Overview
- Follow FMEA workflow on concept level
- Use FMEA Template
- Fill in main risks found with fish bone diagram
- Define Mitigation Strategy
  - Analysis of critical performance aspects
  - Plan B for critical elements
  - Test rigs, fast prototyping in project plan

Day 4 (morning): Design for Service

Content

- Philips Digital Pathology
- Some explanation on UFS
- Stage
- Optics
- Glass handling
- Service strategy
  - •Assignment 1
  - •Assignment 2

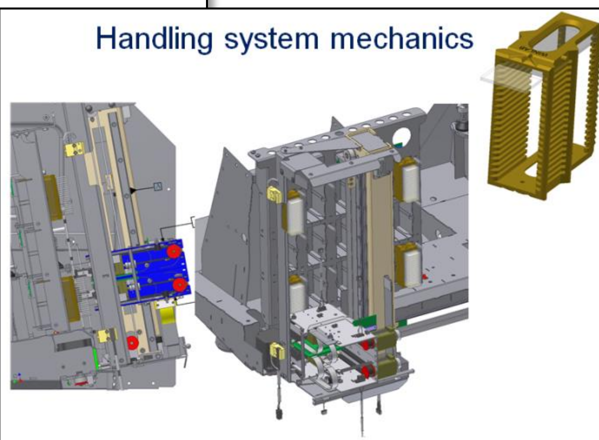
Alternative 1
Module exchange at customer, repair at supplier



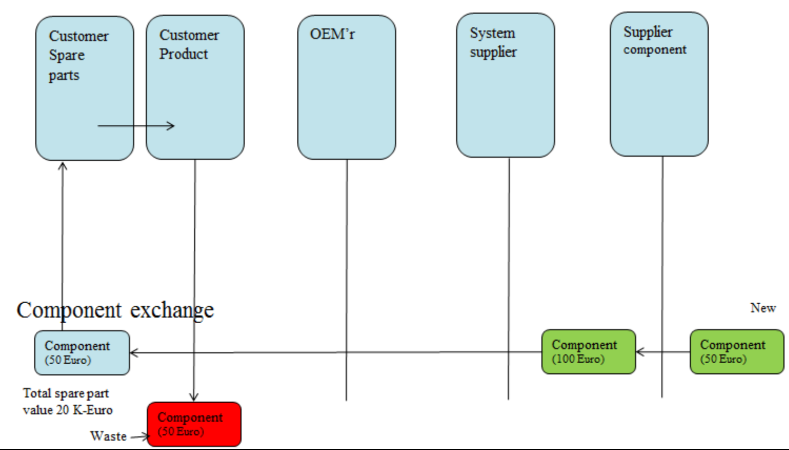
How UFS (Ultra Fast Scanner) wor

- 300 slides in scanner store
- Handler checks slides presence
- Handler moves slides to Snapshot p
- 2 Snapshot images:
  - identification of the label
  - Tissue position detection
- Slide towards stage
- Scan high resolution with continuous
  - •Check on scan quality
- Image to the server
- Slide back to the store

Handling system mechanics



Alternative 2
Module repair / component exchange at customer



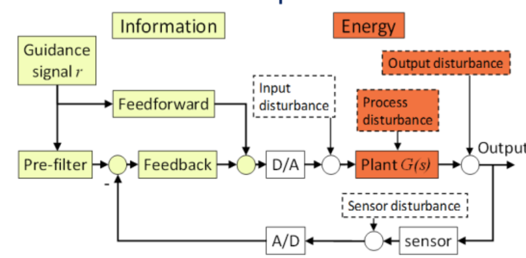
Day 4 (afternoon): Precision Drives …

Main message

1. The choice of the driving actuator depends on the disturbance sources in the application.
2. Actuators convert control action into real action. The amplifier is an inseparable part of the actuator.
3. Sensors convert physical "signals" into electrical signals. Electronics are key in this process.
4. Actuators in an active controlled motion system are characterised by one or more "nested" internal feedback loops with their impact on system dynamics and motion feedback stability.

Air driven wafer positioner

Disturbances in the motion control loop

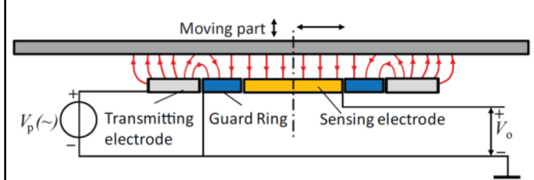


Actuator possibilities

Different drive principles exist :

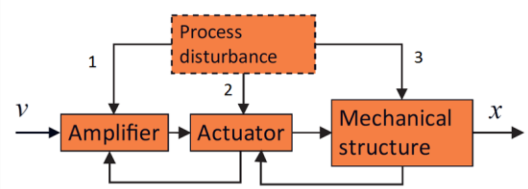
- Piezoelectric
- Electromagnetic
  - Lorentz
  - Variable reluctance
  - Hybrid (biased reluctance)
- Pneumatic
- Electrostatic

Distance to a conductive, parallel moving object



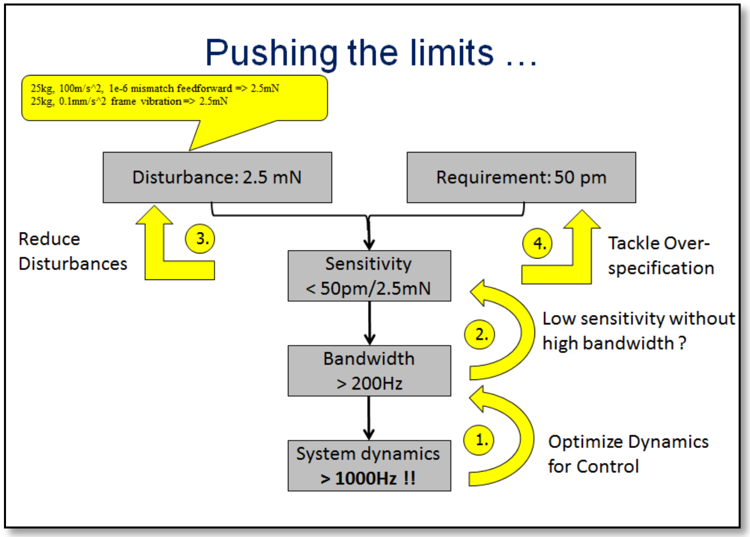
Rotating shaft or flat plate

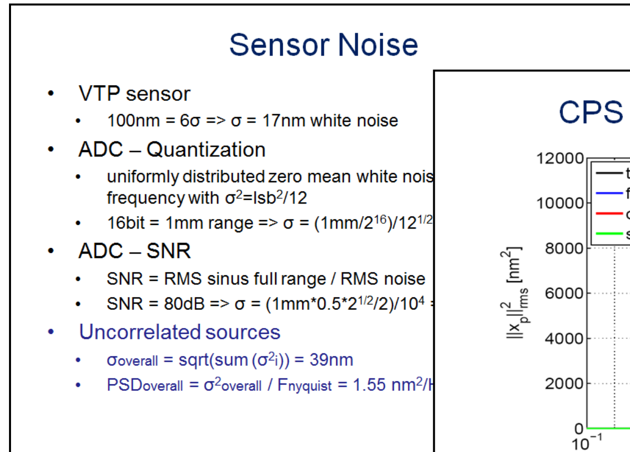
Process disturbances work on different elements in the plant

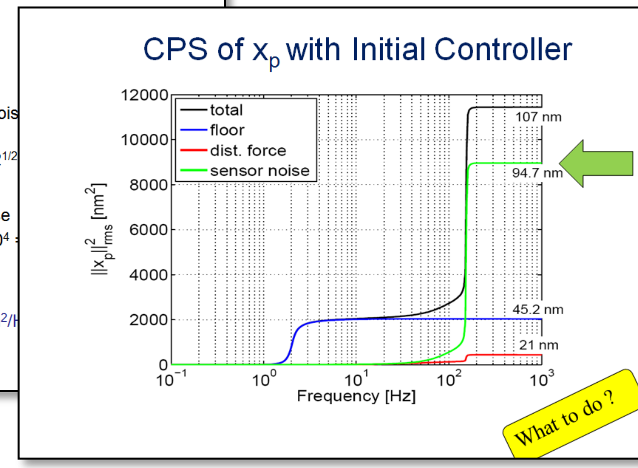


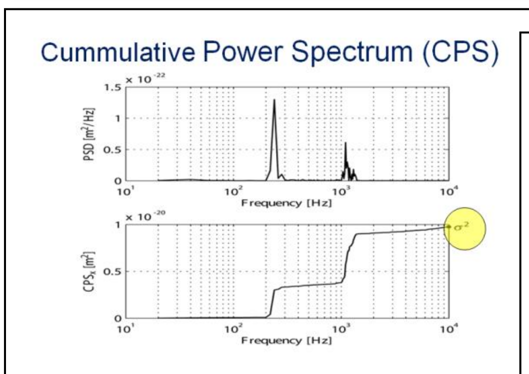
1. Amplifier noise
2. Process forces like from shisel (cutting tool)
3. Vibration transmissibility

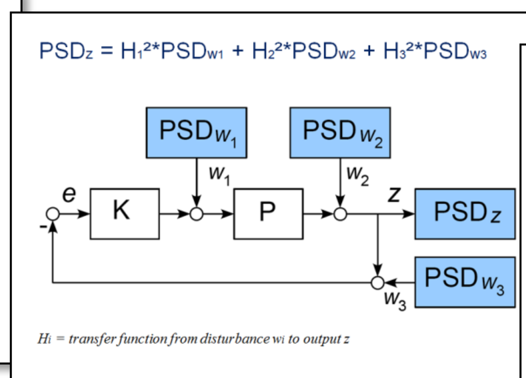
Day 5 (morning): Vibrations & Dyn. Error

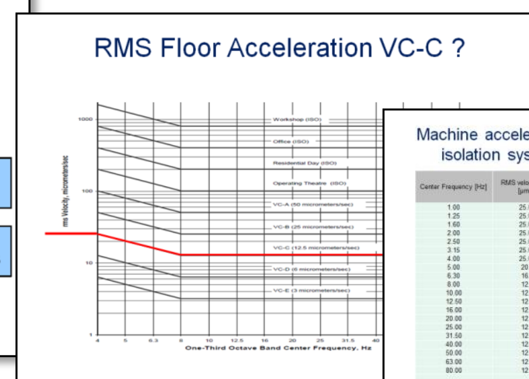












Machine acceleration levels with/without vibration isolation system at VC-C (RMS 12.5 μm/s)

Center Frequency [Hz]	RMS velocity floor [μm/s]	RMS acceleration floor [mm/s^2]	Transmissibility Frame/Floor (3 Hz Isolation, 5% rel. damping)	RMS acceleration frame [mm/s^2]
1.00	25.00	0.16	1.12	0.18
1.25	25.00	0.20	1.21	0.24
1.60	25.00	0.25	1.40	0.35
2.00	25.00	0.31	1.79	0.56
2.50	25.00	0.39	3.17	1.24
3.15	25.00	0.49	6.85	3.39
4.00	25.00	0.63	1.28	0.80
5.00	20.0	0.63	0.57	0.36
6.30	16.0	0.63	0.30	0.19
8.00	12.5	0.63	0.17	0.11
10.00	12.5	0.79	0.10	0.08
12.50	12.5	0.98	0.07	0.06
16.00	12.5	1.26	0.04	0.05
20.00	12.5	1.57	0.03	0.04
25.00	12.5	1.96	0.02	0.04
31.50	12.5	2.47	0.01	0.03
40.00	12.5	3.14	0.01	0.03
50.00	12.5	3.93	0.01	0.03
63.00	12.5	4.95	0.01	0.03
80.00	12.5	6.28	0.00	0.03
		RMS acceleration (mm/s^2)		RMS acceleration (mm/s^2)
		10.3		3.80

Day 5 (afternoon): Thermal Analysis

DSPE Website on Thermomechanics

Chapter 1: Basics of Thermomechanics
1.1 Temperature, heat and heat capacity
1.2 Heat transfer
1.3 Principles of thermal deformations
1.4 Thermo-mechanical beam equations ("vergeet-mij-nietjes")

Chapter 2: In Depth
2.1 Conduction in solids
2.2 Conduction in gasses
2.3 Thermal convection
2.4 Thermal radiation

Chapter 3: Thermomechanical design
3.1 Material selection
3.2 Geometry
3.3 Design principles
3.4 Passive thermal conditioning
3.5 Active thermal conditioning
3.6 Compensation
3.7 Summary

Chapter 4: Thermomechanical Modeling
4.1 Important variables
4.2 Lumped capacitance modeling
4.3 Advanced hand calculations
4.4 Numerical modeling

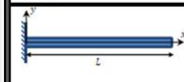
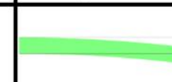
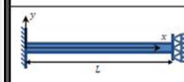
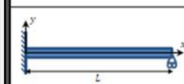
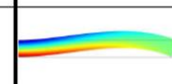
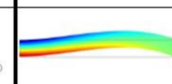
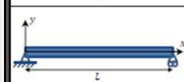
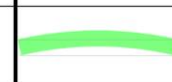
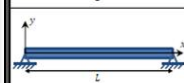
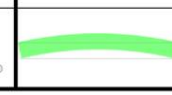
Chapter 5: Sensors
5.1 Contactless temperature sensors
5.2 Contact temperature sensors
5.3 Heat flux sensors

Chapter 6: Measurement
6.1 Calibration
6.2 Practical information

Chapter 7: Examples

Chapter 8: Miscellaneous

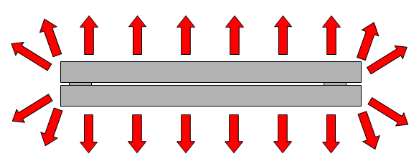
Thermal "vergeet-me-nietjes", DSPE website

Beam equations under thermal load	Thermal load case A: $\Delta T(x,y,z) = \Delta\hat{T}$	Thermal load case B: $\Delta T(x,y,z) = \Delta\hat{T}\frac{x}{L}$	Thermal load case C: $\Delta T(x,y,z) = \Delta\hat{T}\frac{y}{H}$		
Beam type ①	Equations ($w(x) = 0$)	Equations ($w(x) = 0$)	Deformed shape and stress field ②	Equations ($u(x) = 0$)	
	$u(x) = \alpha\Delta\hat{T}x$ $\sigma_{xx}(x,y,z) = 0$	$u(x) = \frac{\alpha\Delta\hat{T}}{2}\frac{x^2}{L}$ $\sigma_{xx}(x,y,z) = 0$		$w(x) = -\frac{\alpha}{2H}\Delta\hat{T}x^2$ $\sigma_{xx}(x,y,z) = 0$	$w_{max} = \frac{\alpha L^2}{2H}\Delta\hat{T}$ $\sigma_{xx,max} = 0$
	$u(x) = 0$ $\sigma_{xx}(x,y,z) = -\alpha E\,\Delta\hat{T}$ ③	$u(x) = \frac{\alpha\Delta\hat{T}}{2}\left(\frac{x^2}{L} - x\right)$ $\sigma_{xx}(x,y,z) = -\frac{\alpha E\,\Delta\hat{T}}{2}$ ③		$w(x) = 0$ $\sigma_{xx}(x,y,z) = -\frac{\alpha E\Delta\hat{T}}{H}y$	$w_{max} = 0$ $\sigma_{xx,max} = \frac{\alpha E\Delta\hat{T}}{2}$
	$u(x) = \alpha\Delta\hat{T}x$ $\sigma_{xx}(x,y,z) = 0$	$u(x) = \frac{\alpha\Delta\hat{T}}{2}\frac{x^2}{L}$ $\sigma_{xx}(x,y,z) = 0$		$w(x) = -\frac{\alpha}{2H}\Delta\hat{T}\left(\frac{x^3}{2L} - \frac{x^2}{2}\right)$ $\sigma_{xx}(x,y,z) = \frac{\alpha E\Delta\hat{T}}{2}\frac{y}{H}\left(3\frac{x}{L} - 3\right)$	$w_{max} = \frac{\alpha L^2}{27H}\Delta\hat{T}$ $\sigma_{xx,max} = \frac{3\alpha E\Delta\hat{T}}{4}$
	$u(x) = 0$ $\sigma_{xx}(x,y,z) = -\alpha E\,\Delta\hat{T}$ ③	$u(x) = \frac{\alpha\Delta\hat{T}}{2}\left(\frac{x^2}{L} - x\right)$ $\sigma_{xx}(x,y,z) = -\frac{\alpha E\,\Delta\hat{T}}{2}$ ③		$w(x) = -\frac{\alpha}{2H}\Delta\hat{T}\left(\frac{x^3}{2L} - \frac{x^2}{2}\right)$ $\sigma_{xx}(x,y,z) = \frac{\alpha E\Delta\hat{T}}{2}\frac{y}{H}\left(3\frac{x}{L} - 3\right)$	$w_{max} = \frac{\alpha L^2}{27H}\Delta\hat{T}$ $\sigma_{xx,max} = \frac{3\alpha E\Delta\hat{T}}{4}$
	$u(x) = \alpha\Delta\hat{T}x$ $\sigma_{xx}(x,y,z) = 0$	$u(x) = \frac{\alpha\Delta\hat{T}}{2}\frac{x^2}{L}$ $\sigma_{xx}(x,y,z) = 0$		$w(x) = -\frac{\alpha}{2H}\Delta\hat{T}(x^2 - Lx)$ $\sigma_{xx}(x,y,z) = 0$	$w_{max} = \frac{\alpha L^2}{8H}\Delta\hat{T}$ $\sigma_{xx,max} = 0$
	$u(x) = 0$ $\sigma_{xx}(x,y,z) = -\alpha E\,\Delta\hat{T}$ ③	$u(x) = \frac{\alpha\Delta\hat{T}}{2}\left(\frac{x^2}{L} - x\right)$ $\sigma_{xx}(x,y,z) = -\frac{\alpha E\,\Delta\hat{T}}{2}$ ③		$w(x) = -\frac{\alpha}{2H}\Delta\hat{T}(x^2 - Lx)$ $\sigma_{xx}(x,y,z) = 0$	$w_{max} = \frac{\alpha L^2}{8H}\Delta\hat{T}$ $\sigma_{xx,max} = 0$

Summary heat transfer (DSPE website)

Heat transfer method	Thermal conductance [W/K]	Heat transfer coefficient [W/(m2K)]	Condition
Conduction	TC = (k A) / L	h = k / L	unidirectional conduction (over length L, cross-section A)
Convection	TC = A h_c	h = h_{conv}	Typical value for laminar water flow: hconv= 1000[W/(m2K)]
Radiation	$TC = \frac{\varepsilon_1 A_1 F_{12}\varepsilon_2}{1 - F_{12}{}^2\frac{A_1}{A_2}(1-\varepsilon_1)(1-\varepsilon_2)} 4\sigma T_{nom}{}^3$	h1 = TC / A_1 h2 = TC / A_2	Linearized: Valid for small deviations from nominal temperature T_{nom}
Contacting surfaces	▪ "dry" contact: TC = A $h_{contact}$ ▪ gap material: TX = A k_{fill} / d (gap height d, filler conductivity k_{fill})	h = $h_{contact}$	Typical value for dry contact at moderate pressure: $h_{contact}$= 100 - 1000[W/(m2K)]

Heat transfer through blocks due to convection outside



Aluminium: λ = 210 [W/m*K]

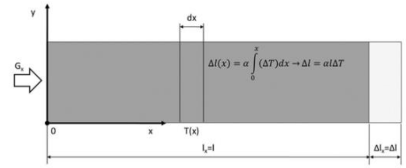
Thickness each (top and bottom) plate d = 0,04 [m]
Area top /bottom side A = 0,2 * 0,2 = 0,04 [m²]
Heat flux natural convection Φ = 5 [W/m²K] * delta T * A = 5*200*0,04 = 40 [W]

Temperature difference between top and bottom of both plates in steady state:

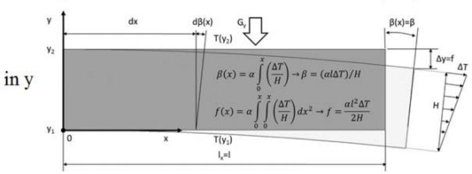
ΔT = (Φ*d) / (A* λ) = (40 * 0,04) / (0,04 * 210) = 0,19 [K]

Uniform and non-uniform expansion

Uniform



T gradient in y



Day 6 (morning): Real Life Example

Day 6 (afternoon): Customer Presentation

Customer Presentation of each team

- Technical concept(s)
- Plan how to proceed
- Convincing the customer

Evaluations / Lessons Learned

Sign-up for this training

Via the website of our partner

High Tech Institute