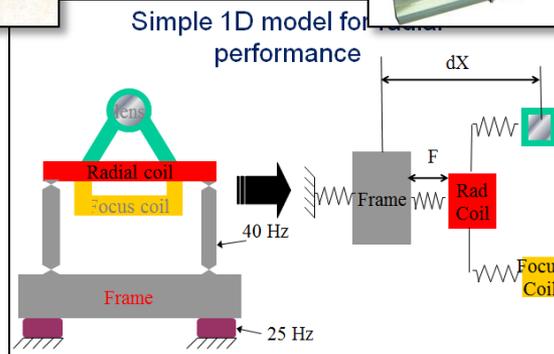
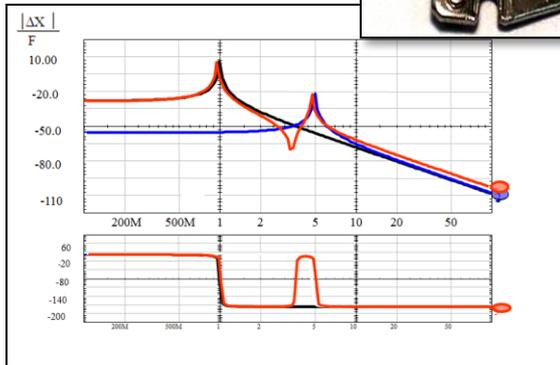
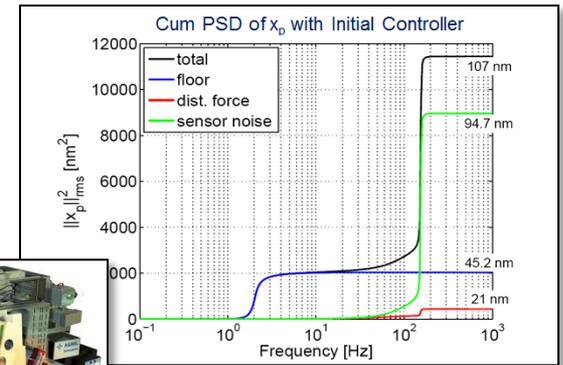
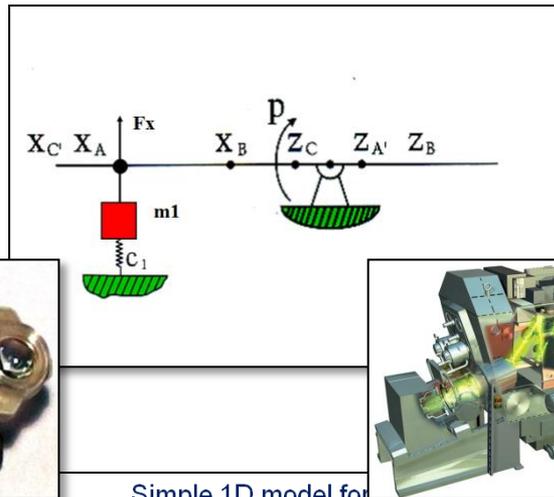
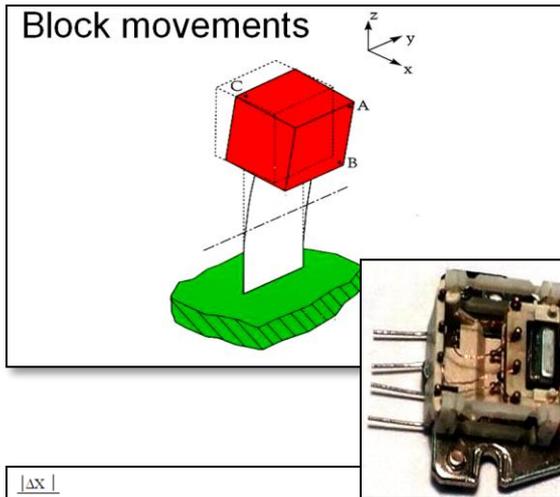


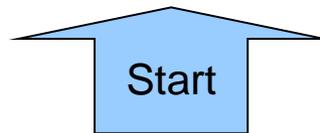
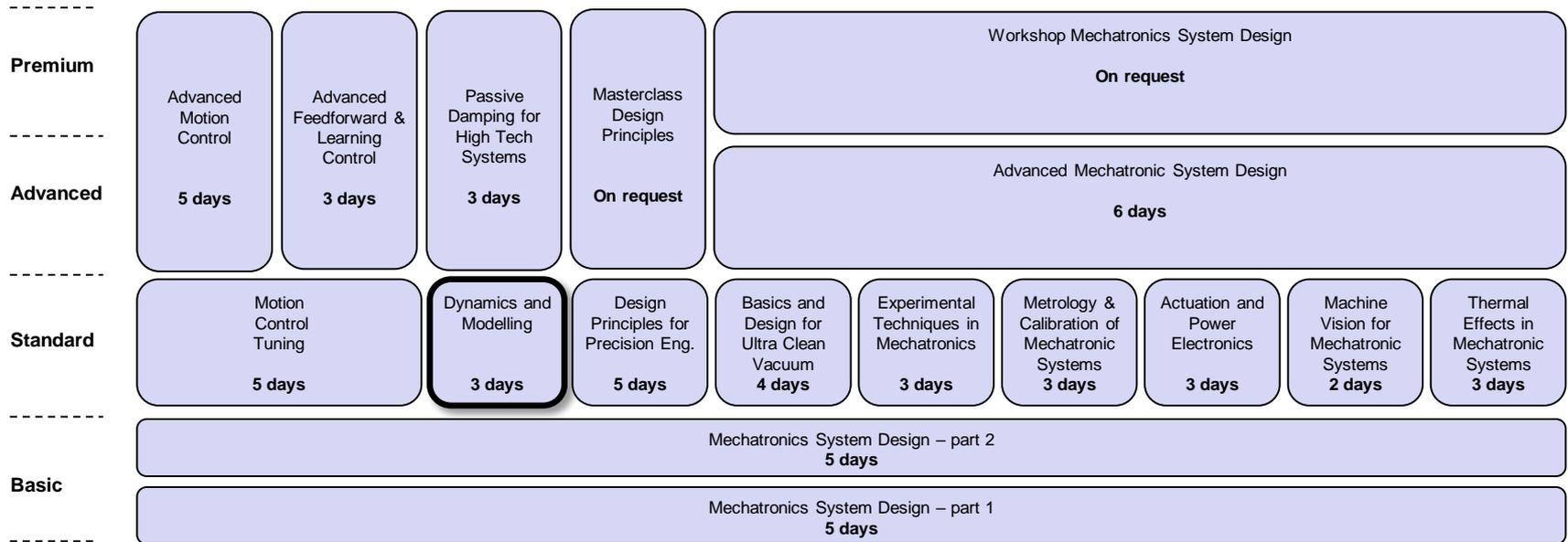
Dynamics and Modelling



Contents

- Mechatronics Training Curriculum
- Details of Course *Dynamics and Modelling*

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.

Dynamics and Modelling

Course Directors / Trainers

Course Director(s) / Trainers

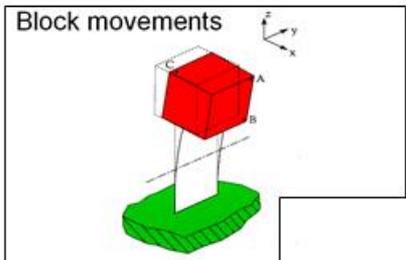
- Prof.dr.ir. Jan van Eijk (MiceBV, Mechatronics Academy)
- Dr.ir. Adrian M. Rankers (Mechatronics Academy)
- Dr.ir. Dick Laro (MI-Partners)

Program

| Day | Topic | Presenters |
|-----|---|----------------------------------|
| 1 | <ul style="list-style-type: none"> • Introduction / Context • Recap control (incl. Exercise 20sim) | Jan van Eijk Adrian Rankers |
| | <ul style="list-style-type: none"> • Modal decomposition • Modelling & optimization radial servo Compact Disc actuator | Jan van Eijk & Adrian Rankers |
| 2 | <ul style="list-style-type: none"> • Allowable vibration levels in precision equipment (external and internal sources) • Reducing negative effects (stability & vibration levels) caused by actuator reaction forces. | Adrian Rankers |
| | <ul style="list-style-type: none"> • Guiding System Flexibility • Dynamic error budgetting | Jan van Eijk |
| 3 | <ul style="list-style-type: none"> • Floor vibration isolation • Overactuation • Friction | Dick Laro |
| | <ul style="list-style-type: none"> • Experimental Modal Analysis • Substructuring / state space / FEM to Matlab • Advanced Feed Forward | Adrian Rankers |

Day 1 (morning)

- Recap Control
- Modal Decomposition
 - Concept
 - Visualization
 - Non-observability
 - Non-controlability

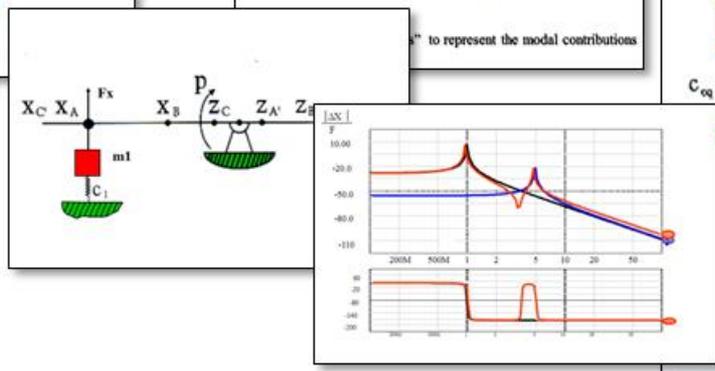


Modal Superposition

- "The response of a mechanism to a load is equal to the sum of the responses of the modal contributions"
- Response: static, time domain or frequency domain
- in mathematical terms:

$$\frac{U_d}{F_m} = \sum_{i=1}^N \frac{\phi_{im} \cdot \phi_{id}}{m_i \cdot s^2 + k_i}$$

" to represent the modal contributions



Summary

- Sensitivity $S(s) = \frac{e}{X_s}(s) = \frac{1}{1+C(s)}$
- Process Sensitivity $H_{ps}(s) = \frac{X}{F_d}(s) = \frac{1}{1+C(s)}$

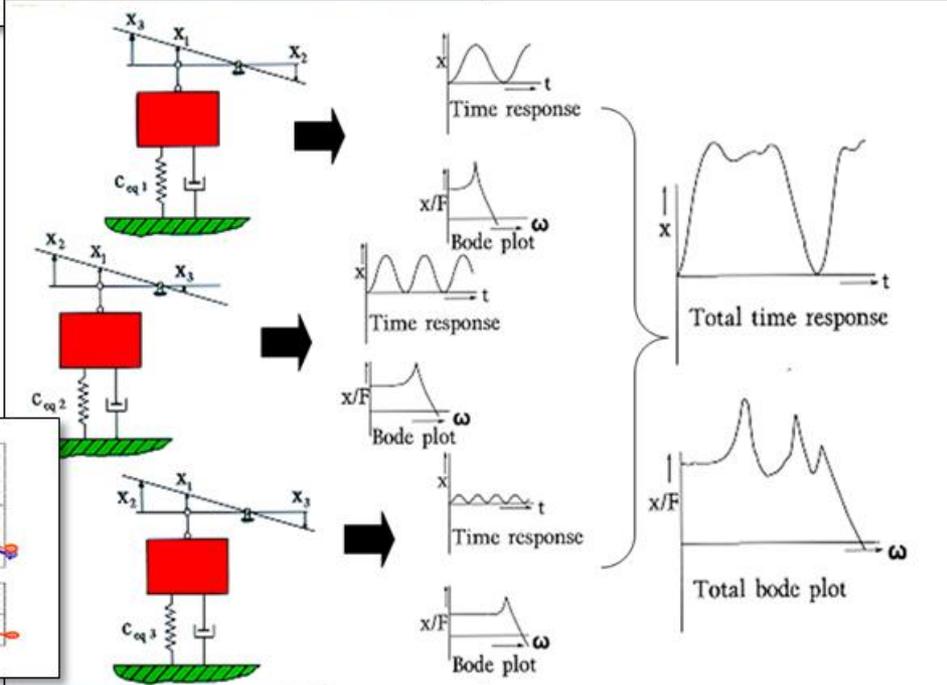
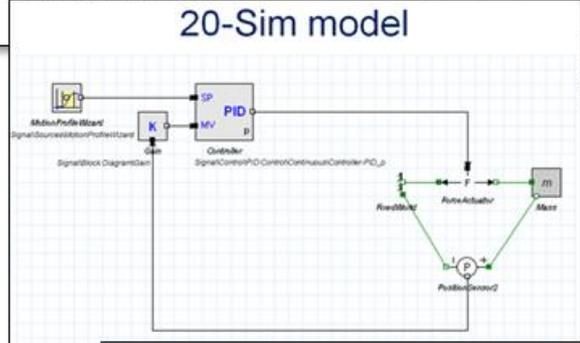
- Specifications + Disturbances => required (process) sensitivity
- Low sensitivity => High Gain => high servo stiffness Kp
- Bandwidth => virtual 0dB crossing => $1/(2 \cdot \pi) \cdot \sqrt{k_p/m}$
- Pure Kp controller is instable => add servo damping Kv
- Dynamics has a de-stabilizing effect

Exercise

Target tracking system based on a camera system mounted on a slide that is driven by a linear motor.

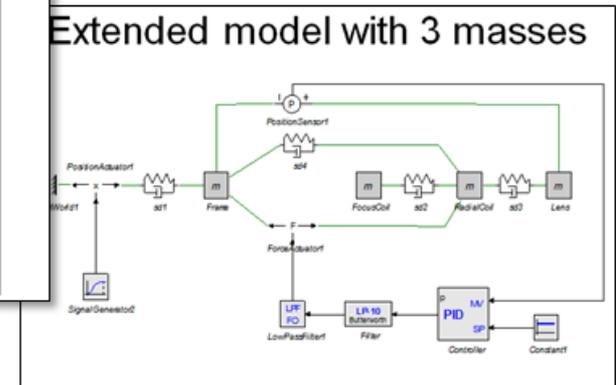
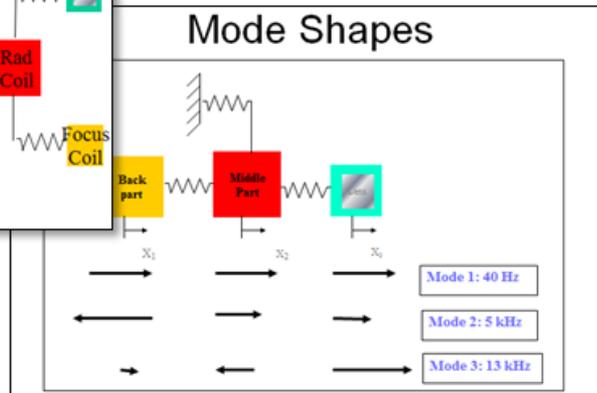
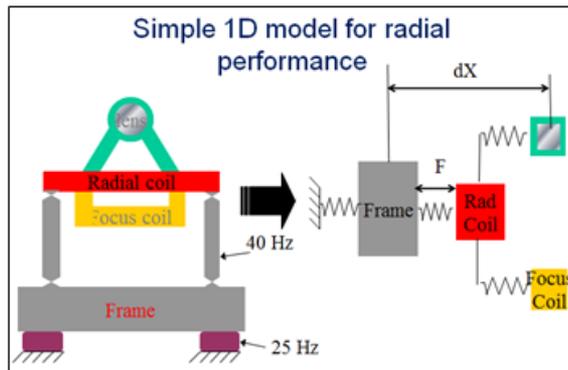
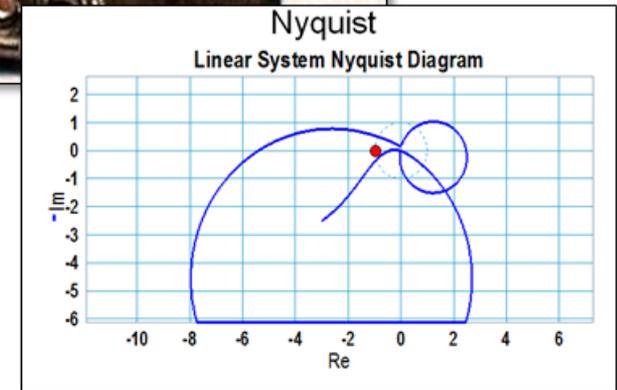
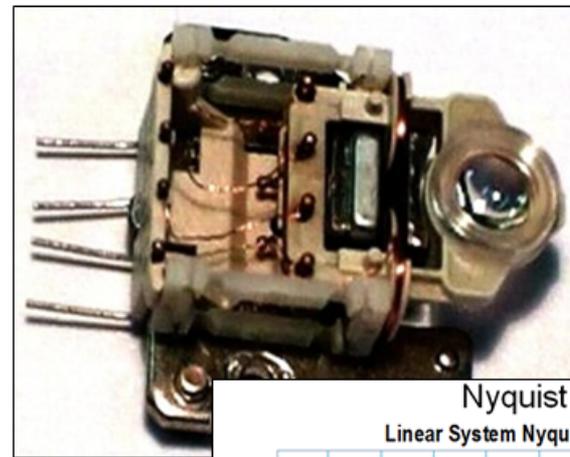
- Moving target: 3mm @3Hz (sinusoidal motion)
- Allowed tracking error: 40µm
- Moving mass slide/camera/linear motor: 5.0 Kg

able PID control loop such that the tracking error of the moving target is small than 40 µm.



Day 1 (afternoon)

- Conceptual Modelling
- Design/Opt. for Dyn. & Control
- Case: Optical Disc Drive

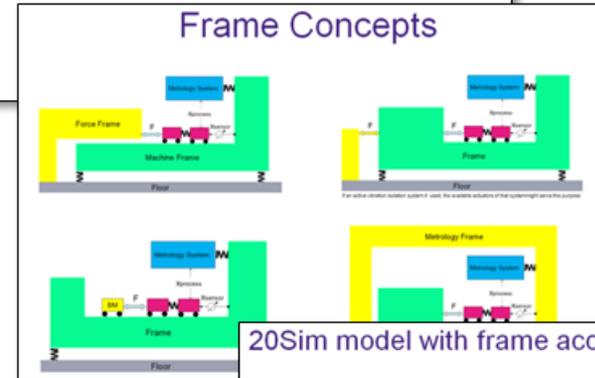


Day 2 (morning)

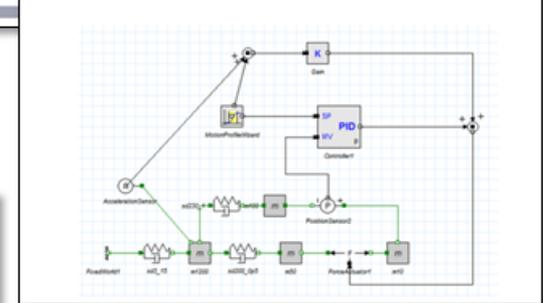
- Allowable vibration levels
- Impact of reactions forces
 - Stability & time response
 - Concepts to reduce effect
 - Simulation Exercises

Concepts to reduce effect

- Mechanical Design
 - Force Frame (reaction force is guided via a force frame to the floor)
 - Frame Force Compensation (counteracting force between frame and floor)
 - Balance Mass (reaction force is "absorbed" by reaction mass)
 - Low Moving Mass
- Control Design
 - Input Shaping, Input Synthesis (minimize excitation of suspension frequency)
 - Iterative Learning Control (smart set-points that are adapted to minimize setting)
 - Frame Acceleration Feed Forward
 - Advanced (MIMO) Feedback to reduce sensitivity to frame vibrations

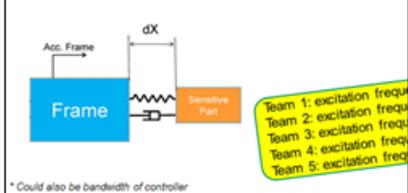


20Sim model with frame acceleration FF



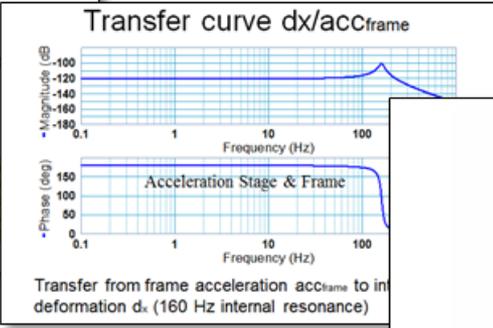
Allowable Vibration Level of Machine Frame ?

- Allowable Error : $dx < 0.1 \mu\text{m RMS}$
- Internal Flexibility : 160 Hz eigen-freq

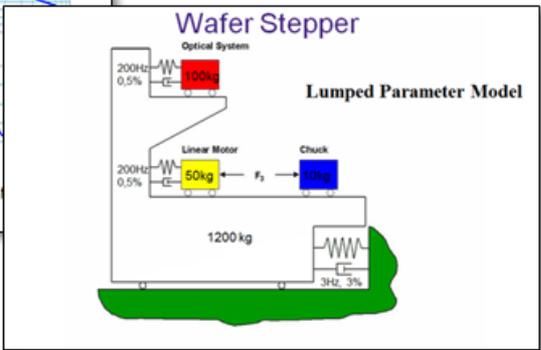


- Team 1: excitation freq
- Team 2: excitation freq
- Team 3: excitation freq
- Team 4: excitation freq
- Team 5: excitation freq

* Could also be bandwidth of controller

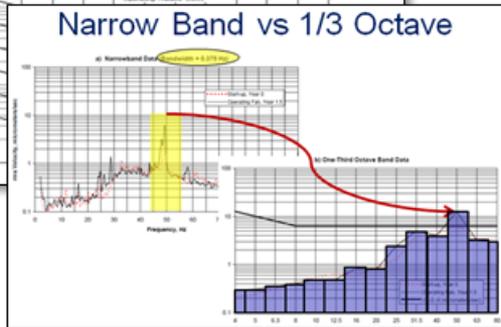
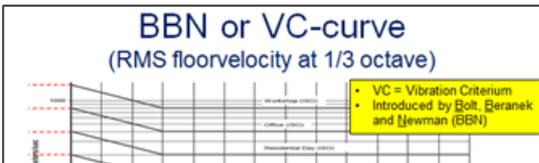
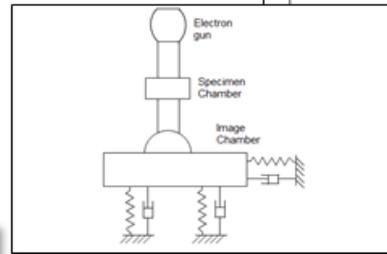
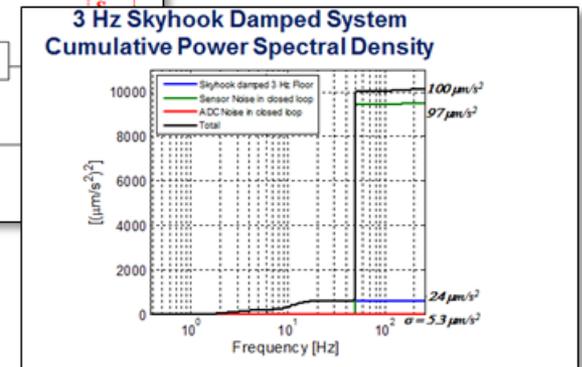
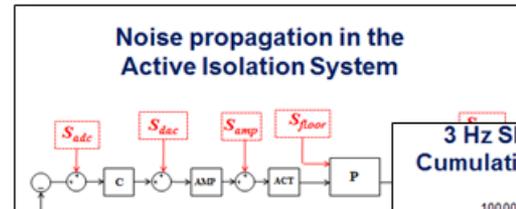
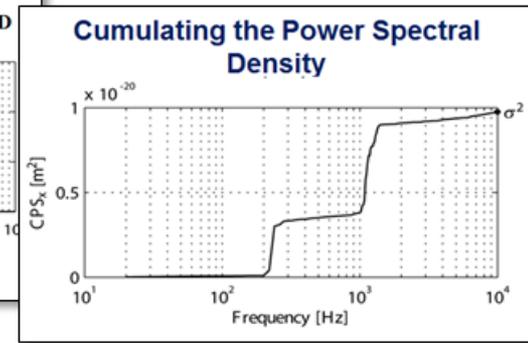
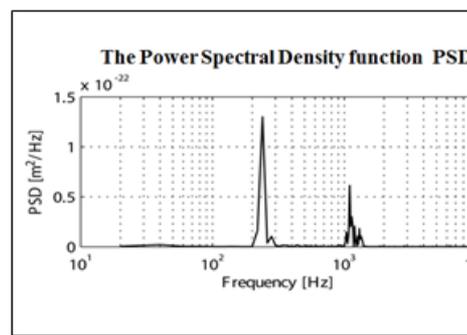


Transfer from frame acceleration acc_{frame} to internal deformation dx (160 Hz internal resonance)

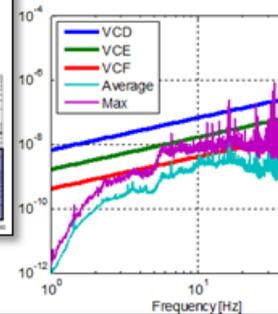


Day 2 (afternoon)

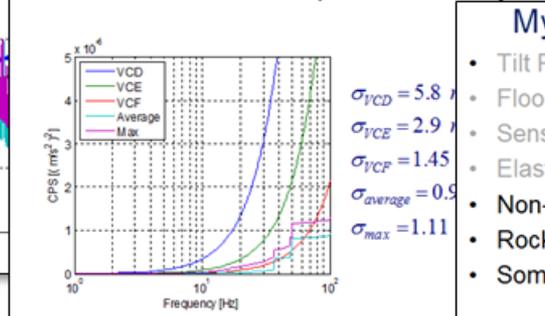
- Dynamic error budgetting
- Floor vibration isolation (layout, spec, modelling)



Comparison in Acceleration Power Spectral Density



Cumulative Power Spectral Density



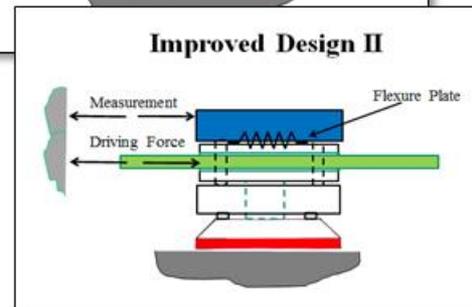
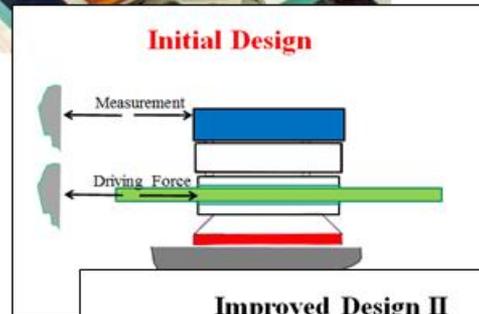
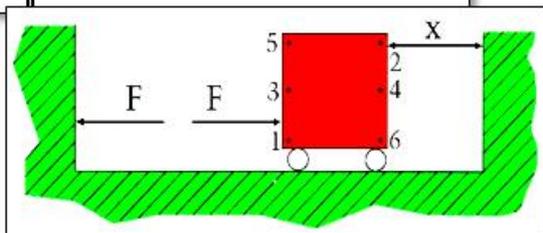
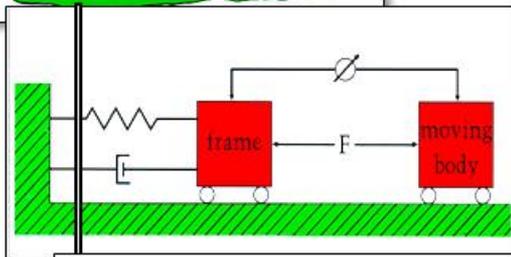
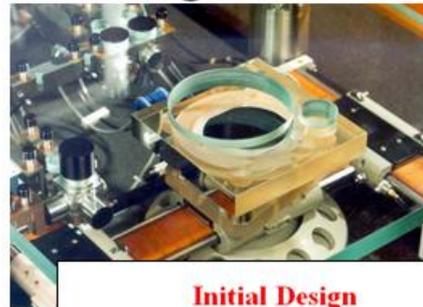
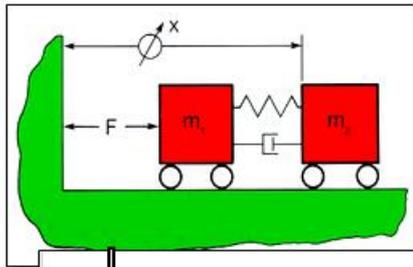
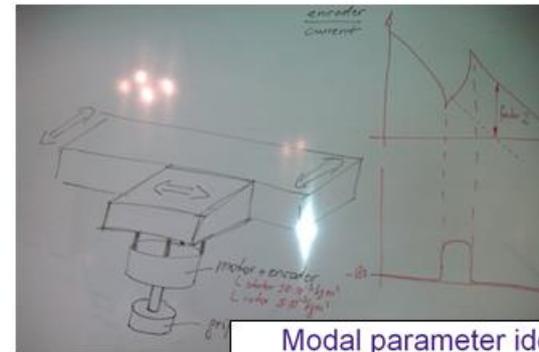
- $\sigma_{VCD} = 5.8$
- $\sigma_{VCE} = 2.9$
- $\sigma_{VCF} = 1.45$
- $\sigma_{average} = 0.9$
- $\sigma_{max} = 1.11$

Myths in Vibration Isolation

- Tilt Problem for Active System
- Floor Specifications
- Sensor Noise
- Elastomer Solutions
- Non-Linearity
- Rock Solid
- Some sound Suggestions

Day 3 (morning)

- Experimental Modal Analysis
- Conceptual design of stage concepts

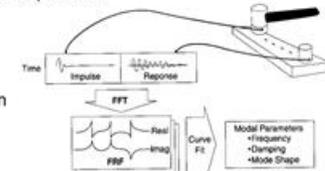


Modal parameter identification

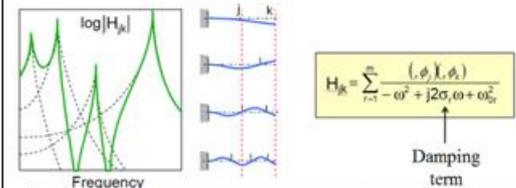
Identify

- Damped natural frequencies
- Damping
- Mode shapes

of predominant modes of vibration of the structure

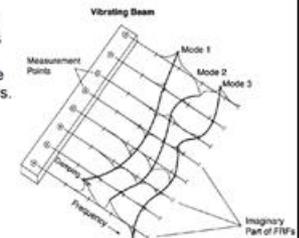


Modal representation of FRF



Quadrature picking

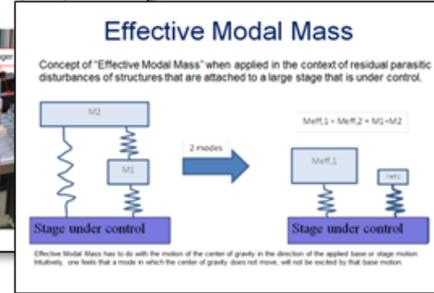
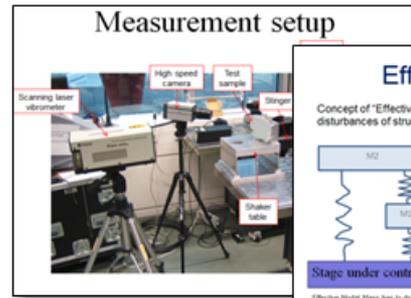
Figure shows imaginary part of each of the FRF measurements between some (arbitrary) excitation point, and each of the response points marked with 'x's.



Damping and frequency – same at each measurement point
Mode shape – obtained at same frequency from all measurement points

Day 3 (afternoon)

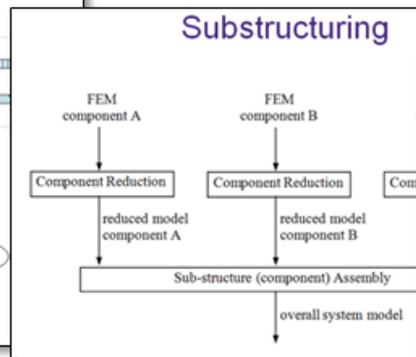
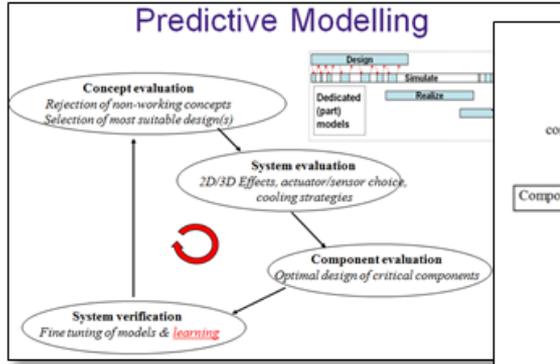
Special Topics



Mathematics

To calculate these effective modal masses, one needs the eigenvectors $\bar{\phi}_i$, the modal masses m_i , the original mass matrix M and the influence matrix $\bar{\Gamma}_i$ which represents the displacement of the masses resulting from a unit base displacement. The formula then is:

$$m_{eff, i} = \frac{\bar{\Gamma}_i^T M \bar{\Gamma}_i}{m_i}$$

$$\bar{L} = \bar{\phi}^T M \bar{\Gamma}$$


- ### Model Reduction Techniques
- Static-Reduction Techniques
 - Static Condensation
 - Guyan reduction
 - Component-Mode Techniques
 - Normal modes
 - Free-interface
 - Fixed-interface
 - Hybrid-interface
 - Loaded-interface
 - Craig-Bampton mode set
 - Combination of constraint modes (= static deflection obtained by successively imposing a unit deflection boundary DOF while keeping the other boundary interface normal modes).

Normal modes in state variable form

Modal DOF q_i and modal velocity \dot{q}_i are the states.

$$\dot{x} = Ax + Bu$$

$$y = Cx + Du$$

$D = 0$

Eigenmodes of a chuck

- Actuators on nodeline?
- Change nodelines?

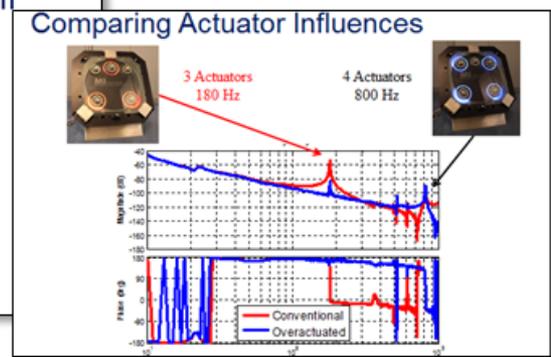
Topology optimization II

Representative measure for mode excitation

- Modal 2-norm for the actuators
- Three load cases (Z, Rx, Ry)

$$\|B_j\|^2 = \sum_{i=1}^5 \|B_{mi,j}\|^2 = \sum_{i=1}^5 \|\phi_i \cdot B_{oj}\|^2$$

- B_{oj} : nodal input matrix for loadcase



Sign-up for this training

Via the website of our partner
High Tech Institute