Structural Dynamic Testing and Design Evaluation of the Formax Detector Gantry

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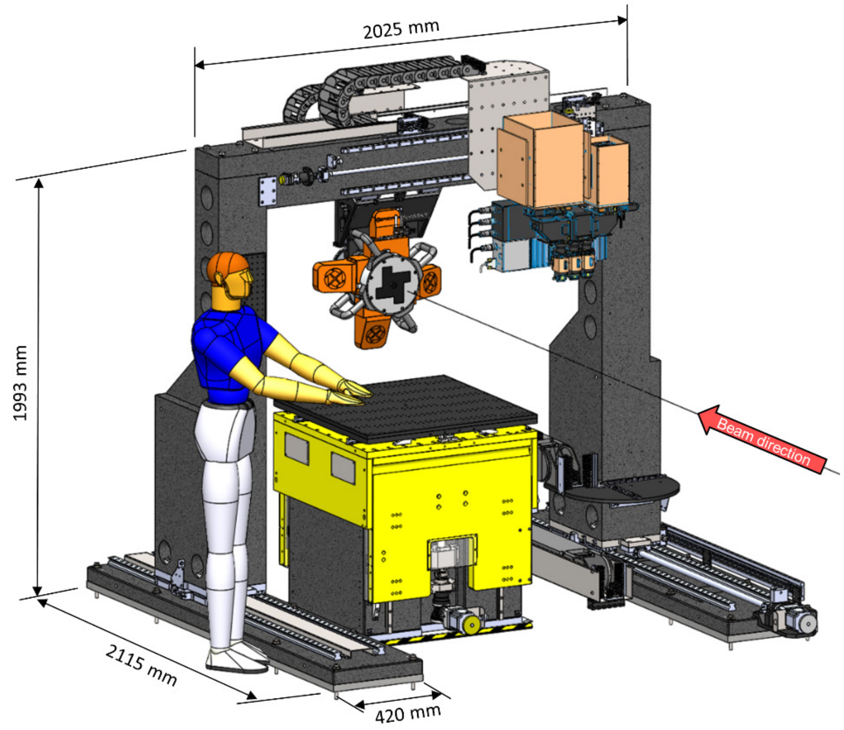
MAX IV

Outline

- Background
- Design, requirements and simulation
- Experimental verification
- Correlation between measurement and calculation
- Result summary and discussion

Background, the ForMAX gantry

- Formax is one of the latest beamlines at MAX IV
- Studies hierarchical materials by combining multiple techniques
- Granit gantry
- Independent in-and-out motion of tomography microscope and WAXS detector
- Longitudinal motion on motorized floor rails (grouted)



Design goals, expectations

- Specifications for the ForMAX Gantry:
  - lowest eigenfrequency >30 Hz (standard “>55Hz“ lowered)
  - <2µm RMS (transversal to the beam, 4-100 Hz, tomography stage)
  - vibration goals instead of strict vibration requirements

Simulation model

FEA model in ANSYS

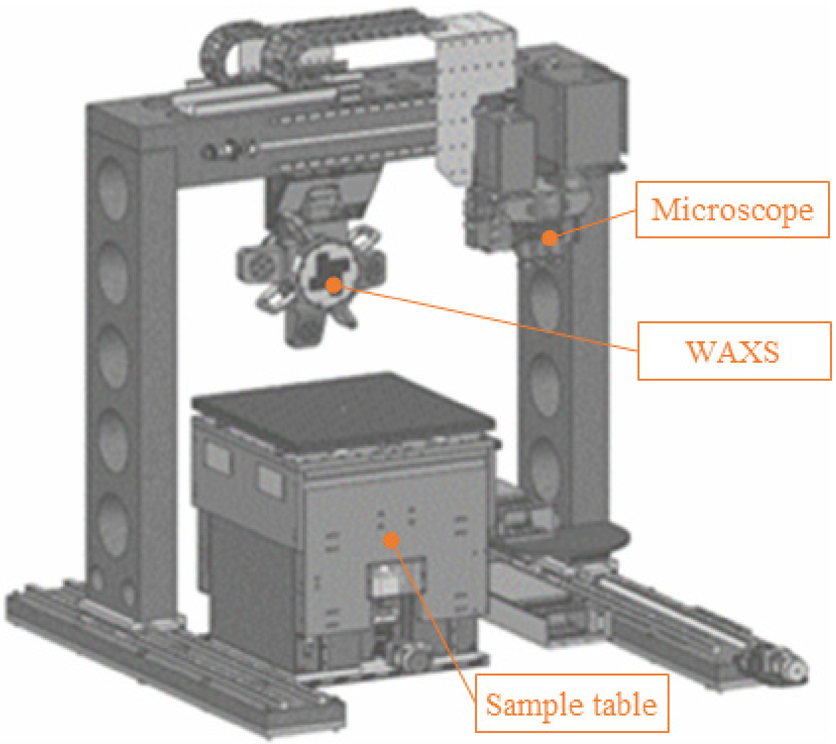
- Gantry: geometry according to CAD
- Detectors: geometry according to CAD, evenly distributed mass[1]
- Base plate of rails grouted to floor (fixed BC)
- Rail carriage along the motion axis: sliding contact with stiffness[1]

[1] based on nominal mass and rigidity values provided by manufacturers

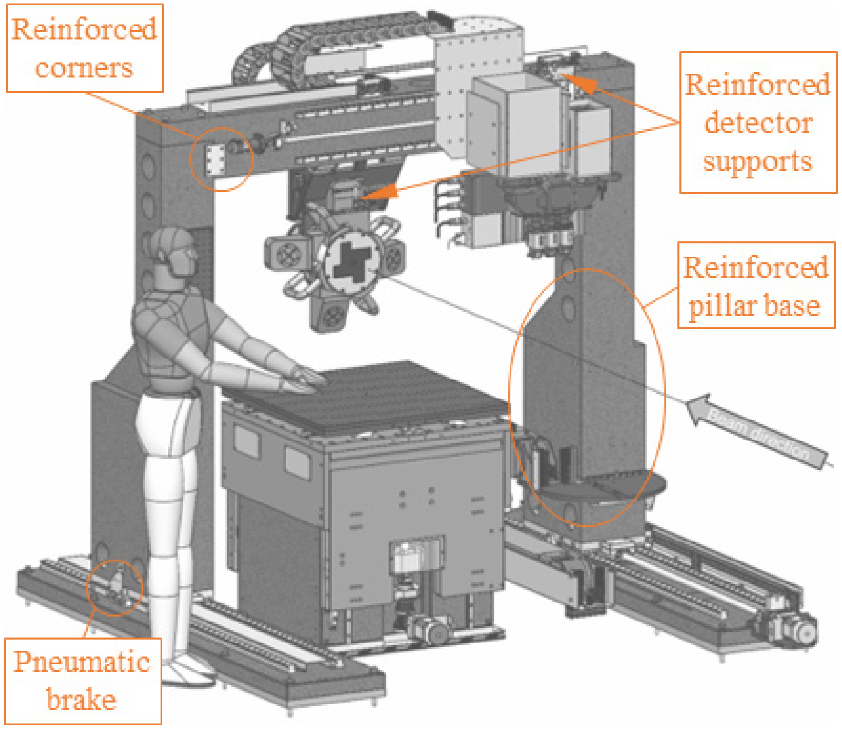
Initial calculation, 9 Hz

Design improvements

Initial design



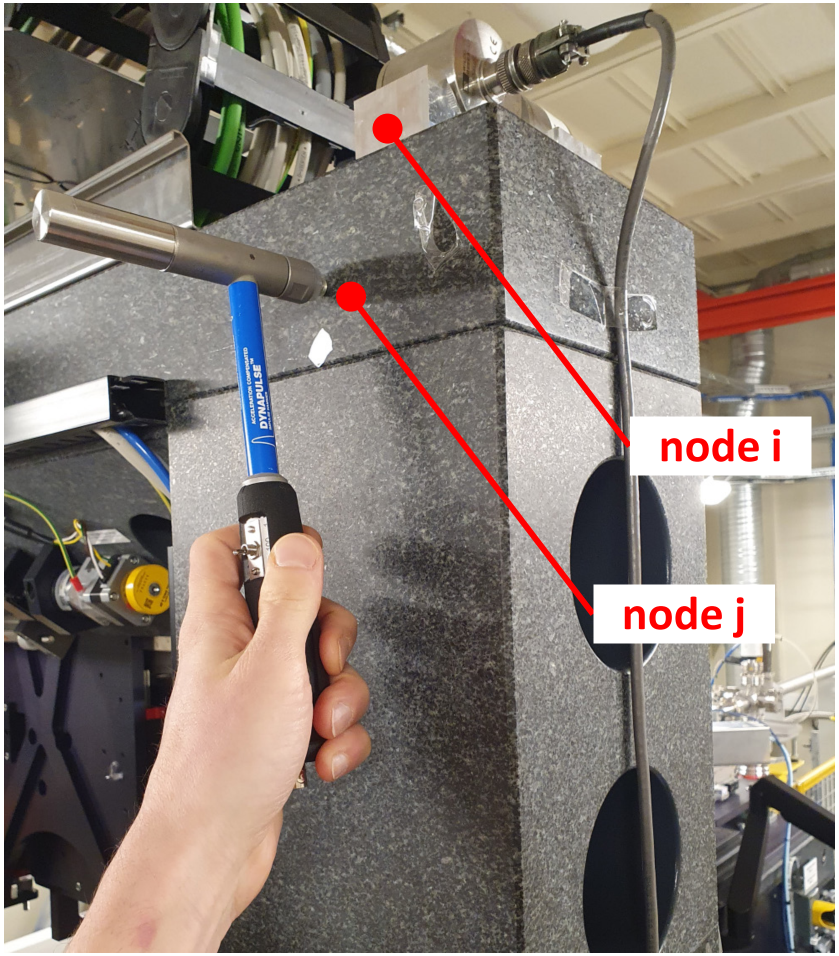
Final design



Frequency response functions (FRF)

- Force-response relationship between two DOFs as a function of frequency:

$$\mathrm{FRF}_{\mathrm{i,j}}(\mathrm{f}) = \frac{response\ at\ node\ i}{excitation\ at\ node\ j}$$



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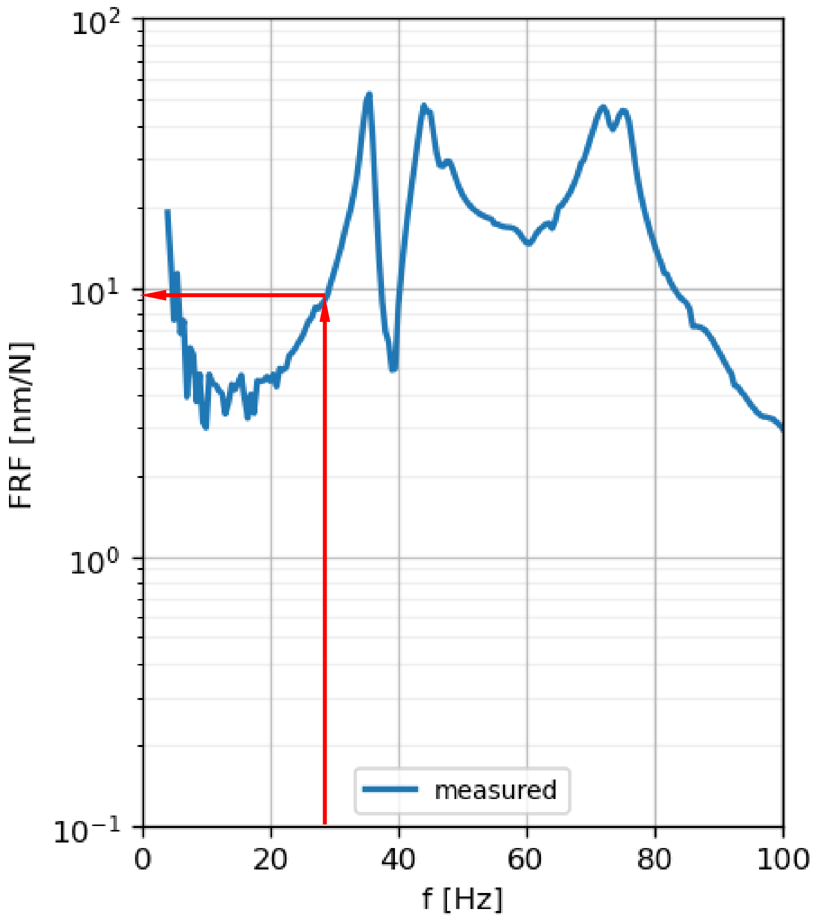
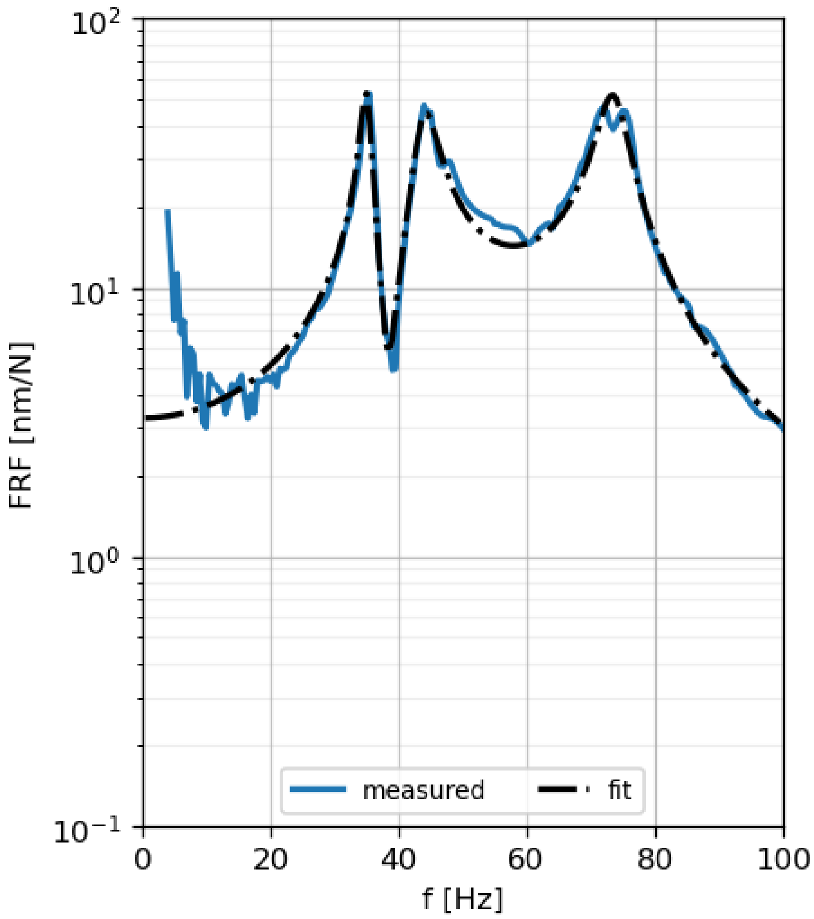
- Peaks → resonances
- f=0Hz → static stiffness



Experimental modal analysis (EMA)

- Experimental technique to extract vibration modes from measurements
- “Fitted curve” has parameters with physical meaning (natural frequency, damping, mode shape participation for SDOF oscillator)
- suited for updating FE model



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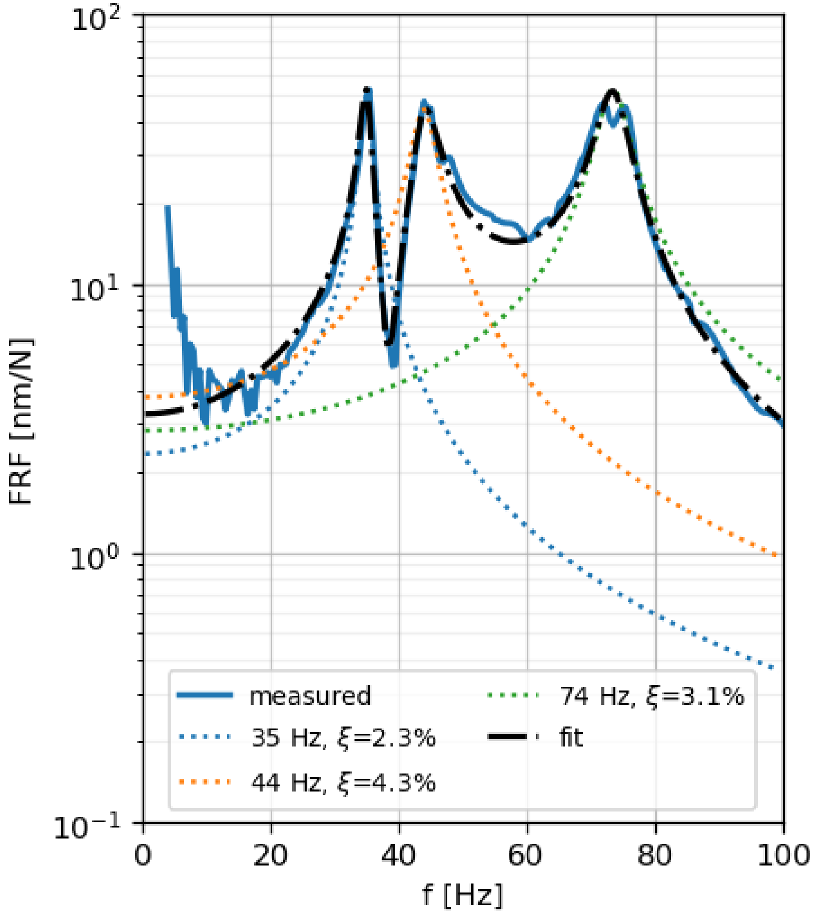
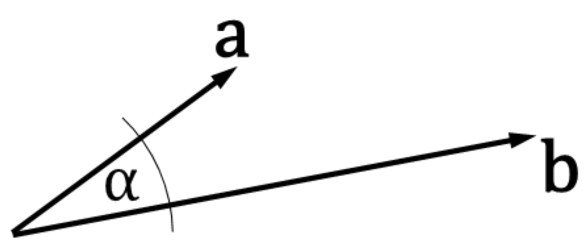


Modal Assurance Criterion (MAC)

- Easier to “guess” mode shapes with FE than eigenfrequencies
- MAC compares two modeshapes (e.g. calculated to measured)
- MAC is between 0-1 (>0,9..0,95 indicates a match)
- The basic idea: mode shapes are unscaled vectors (no magnitude, only direction) → angle can be calculated with dot product

$$\mathbf{a} \cdot \mathbf{b} = \sum a_i b_i$$

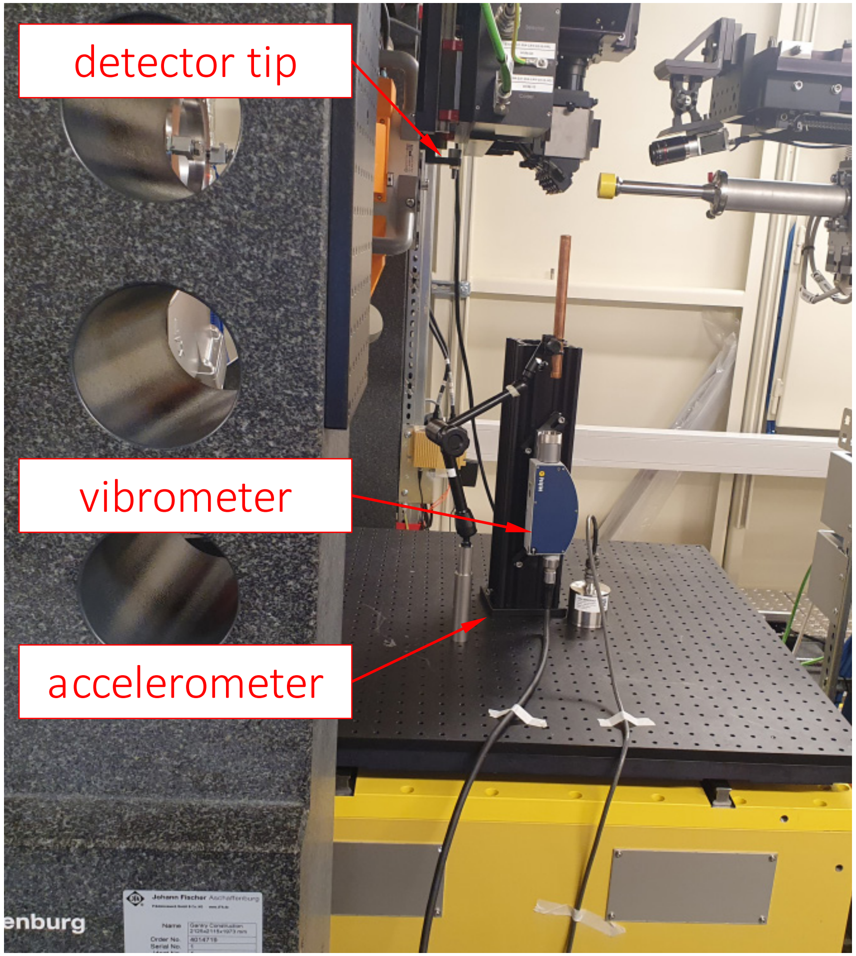
$$\mathbf{a} \cdot \mathbf{b} = |\mathbf{a}| \cdot |\mathbf{b}| \cos\alpha \;\rightarrow \cos\alpha = \frac{\mathbf{a}\cdot\mathbf{b}}{|\mathbf{a}|\cdot|\mathbf{b}|}$$



Displacement vibration rms

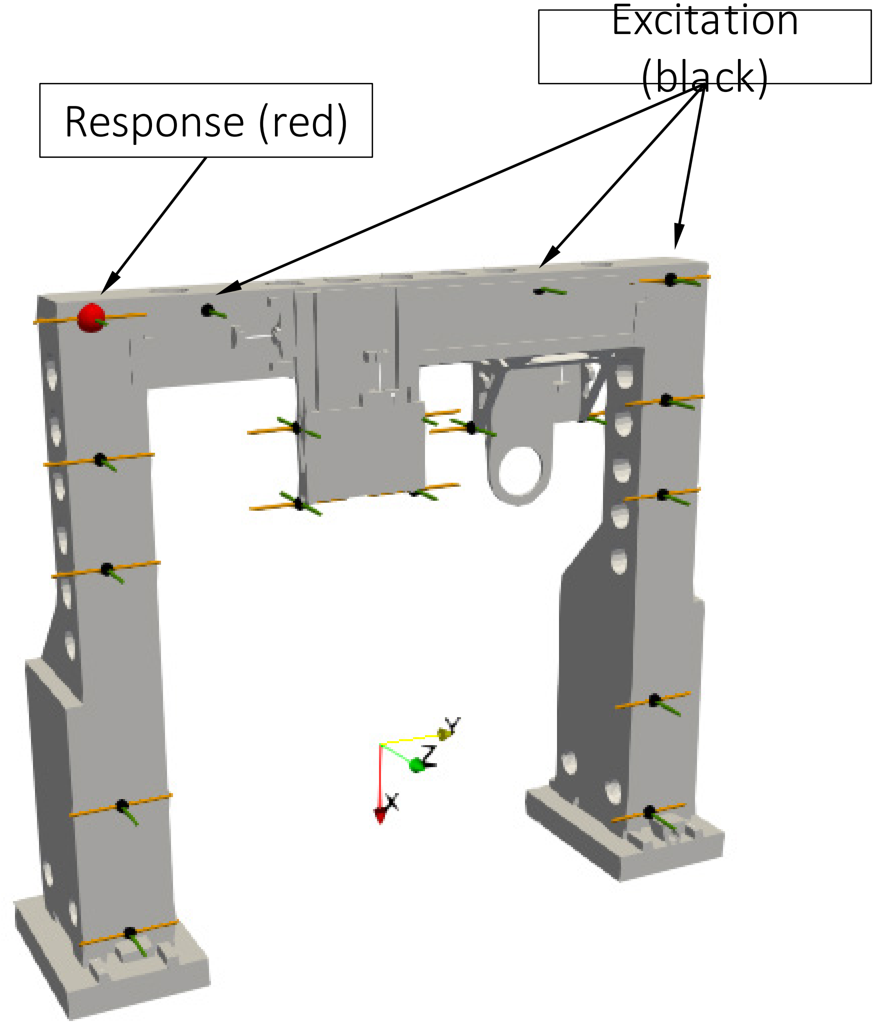
- Measured only in a plane transversal to the beam
- Vibration of sample table added to relative vibration table-to-detectortip
- <20 nm rms (4-100 Hz) → meets the design goal with large margin
- Insignificant influence from pneumatic brake

direction	brake	ambient machinery OFF	ON
transversal	engaged	nan nm	18 nm
	not engaged	12 nm	20 nm
vertical	engaged	14 nm	18 nm
	not engaged	16 nm	19 nm



EMA, test setup

- Roving hammer technique
- Aiming for acceptable signal-to-noise ratio (SNR) while keeping forces low → mild hammer blows + very sensitive accelerometer
- Vertical DOFs excluded (initial measurements indicated high rigidity)
- With pneumatic brake




X
X

EMA results

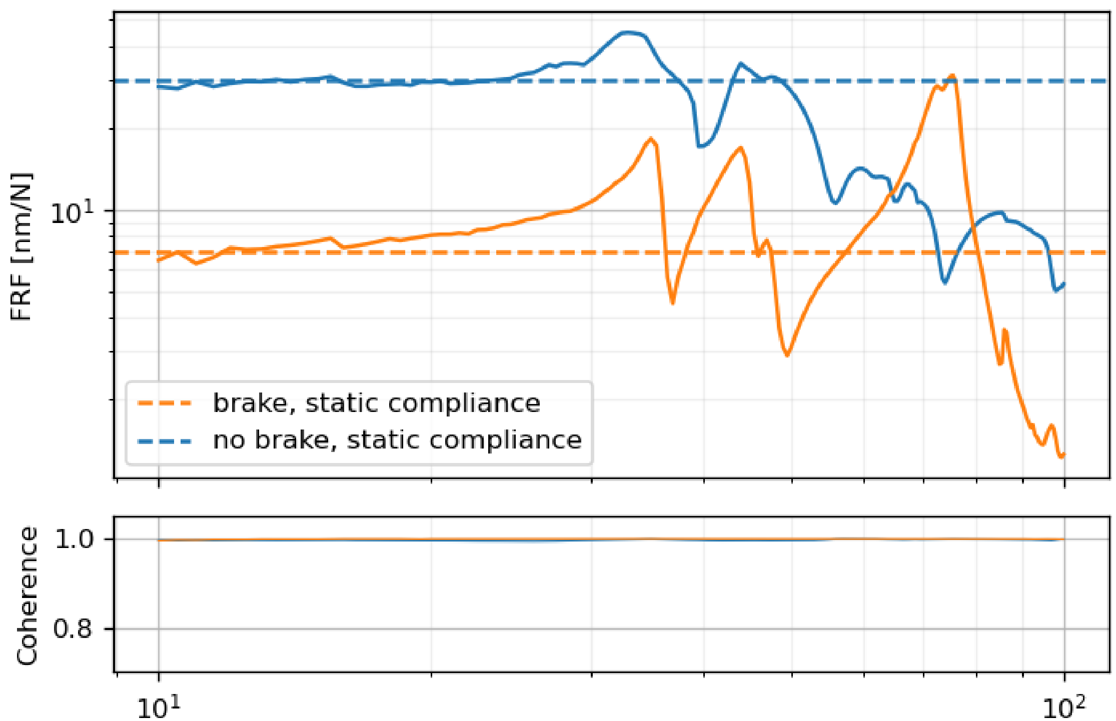
- five modes were identified under 100 Hz with 2-3% damping
- Complex modes due to local damping elements (eg ballscrews)
- In general, poor measurement quality due to difficulty in obtaining good SNR

	Nat. freq.	ξ (% of crit.)	MPC
1	34.7 Hz	1.95%	68.31%
2	37.9 Hz	3.11%	78.95%
3	43.8 Hz	3.43%	77.82%
4	62.9 Hz	2.33%	41.63%
5	73.3 Hz	2.54%	84.94%

simulated / **measured**	**mode #0 20.1 Hz**	**mode #1 28.8 Hz**	**mode #2 29.5 Hz**	**mode #3 41.8 Hz**	**mode #4 57.2 Hz**	**mode #5 62.3 Hz**
34.7 Hz	86.7%	3.5%	0.0%	43.5%	11.6%	7.2%
37.9 Hz	0.0%	0.5%	98.5%	0.3%	0.0%	82.9%
43.8 Hz	86.5%	1.2%	0.0%	49.3%	14.1%	8.1%
62.9 Hz	7.2%	65.1%	10.2%	41.9%	1.2%	14.7%
73.3 Hz	2.1%	79.1%	0.6%	15.0%	0.3%	1.4%

Pneumatic brake

- stiffness of leg support determined from low frequency asymptote:
  - With pneumatic brake : 1,4e8 N/m (opposite leg very similar)
  - Without pneaumatic brake 3,3e7 N/m
  - Original estimate for driven leg (motorized side): 3e7 N/m



Conclusions

- Way of working summarized
- Design goals in terms of mechanical stability are met
- Difficulties in measuring modal parameters on stiff and heavy structure (poor SNR)
- Caveats of using MAC number for measurement-to-calculation correlation
- Pneumatic brake did not have a significant influence on total rms
- Underestimated rail stiffness

THANK YOU FOR LISTENING!

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  - FE calculations: Mohammad Al-Najdawi
  - Testing: Magnus Malmgren

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