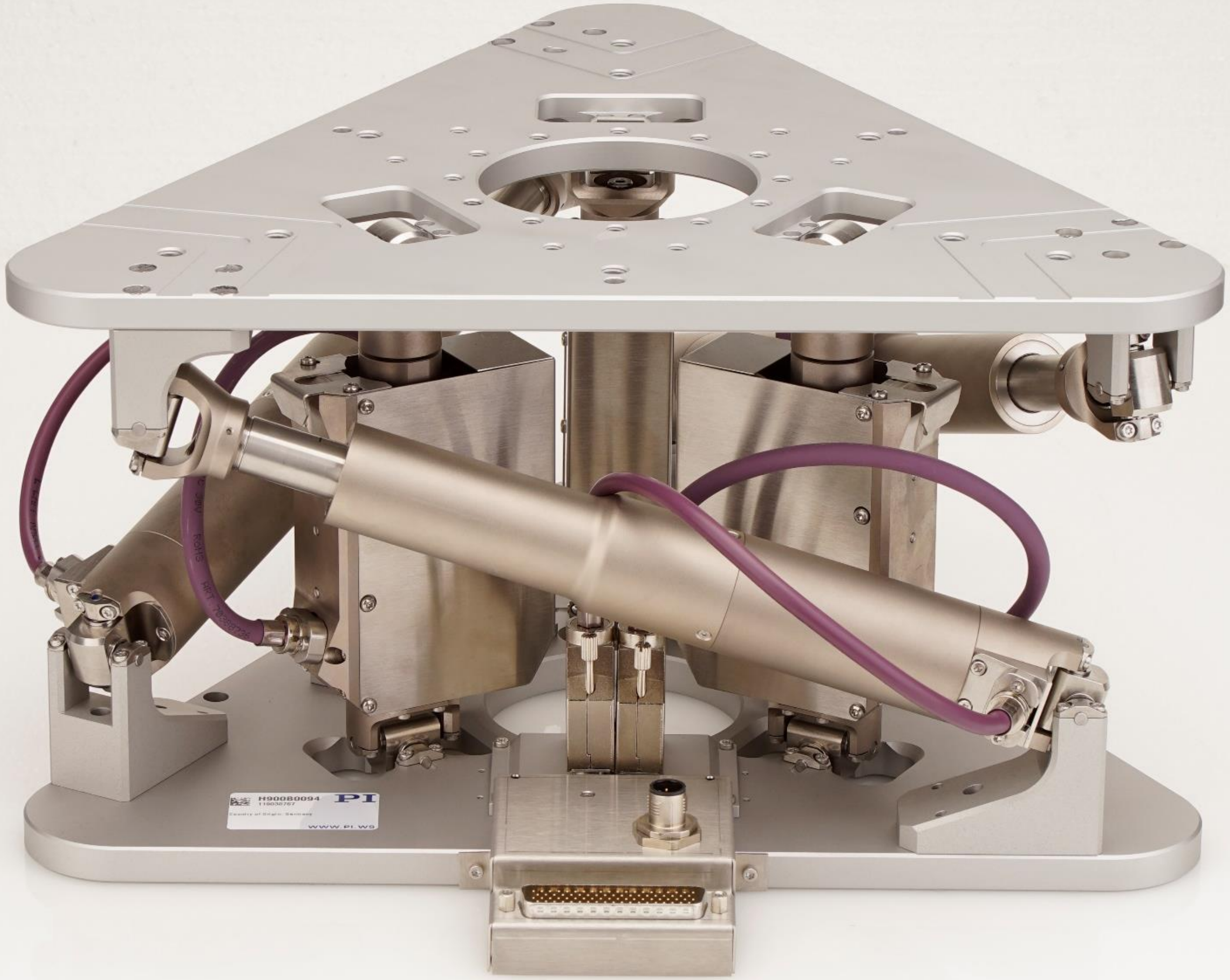
PHYSIK INSTRUMENTE

Ist 2x3 = 3x2?
Oder: Sind das noch Hexapoden?



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Technology Center Parallel Kinematics
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2022-10-13

External

Agenda

- What is a hexapod? Examples
- Hexapod – Micro Cube
- Flat hexapod structure
- Flat, compact high-load hexapod system
- Conclusion & Outlook

What is a hexapod?

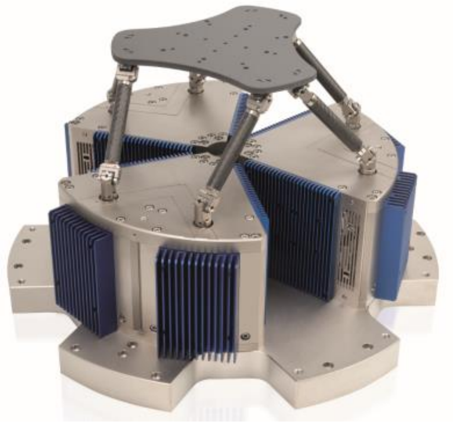
Platform mounted on 6 independent struts

- Used for realizing motion in 6 degrees of freedom
- Three linear axes
- Three rotational axes

- Parallel vs. Serial Set-up

What is a hexapod?

Examples



Properties and Specifications

Standard Hexapod H-811.I2

H-811 Datasheet

Motion	Unit		H-811.I2
Active axes			X, Y, Z, θX, θY, θZ
Travel range in X	mm		± 17
Travel range in Y	mm		± 16
Travel range in Z	mm		± 6.5
Rotation range in θX	°		± 10
Rotation range in θY	°		± 10
Rotation range in θZ	°		± 21

Stiffness in X	N/µm		0.7
Stiffness in Y	N/µm		0.7
Stiffness in Z	N/µm		8

Minimum incremental motion in X	µm	Typ.	0.2
Minimum incremental motion in Y	µm	Typ.	0.2
Minimum incremental motion in Z	µm	Typ.	0.08
Minimum incremental motion in θX	µrad	Typ.	2.5
Minimum incremental motion in θY	µrad	Typ.	2.5
Minimum incremental motion in θZ	µrad	Typ.	5

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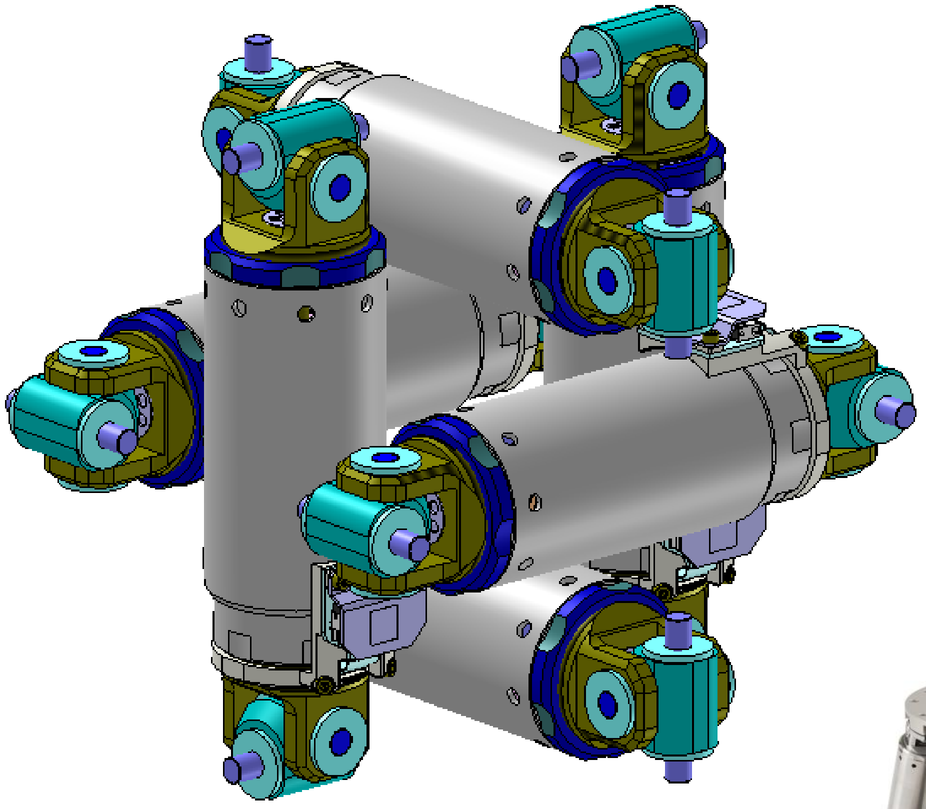
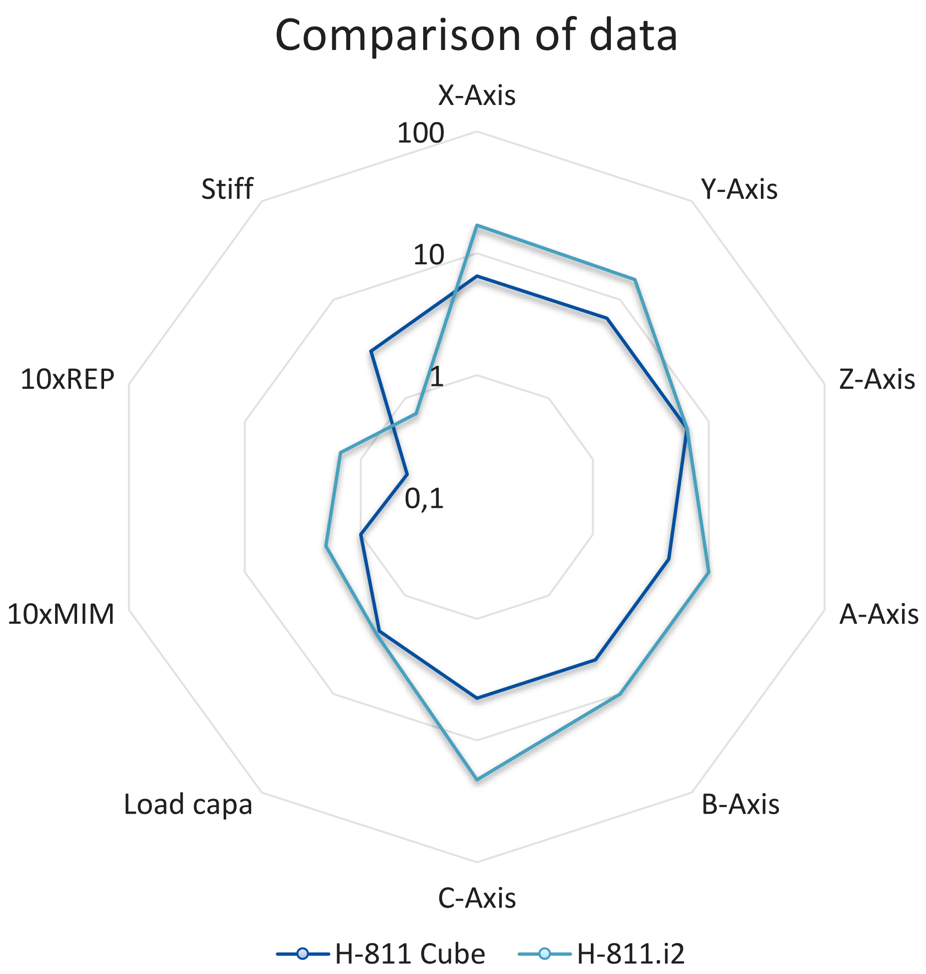
How can we realize a more homogeneous structure?

Cubic structure based on H-811.I2



Comparison of data

	H-811 Cube Structure	H-811.I2
X	**+/- 6,5 mm**	+/- 17 mm
Y	**+/- 6,5 mm**	+/- 16 mm
Z	**+/- 6,5 mm**	+/- 6,5 mm
A (θX)	**+/- 4,5 °**	+/- 10 °
B (θY)	**+/- 4,5 °**	+/- 10 °
C (θZ)	**+/- 4,5 °**	+/- 21 °
Load capacity	**2,3 kg**	5 kg (upright) / 2,5 kg (all orientations)
MIM (X,Y / Z)	**0,1 µm**	0,2 µm / 0,08 µm
Rep. (X,Y / Z)	**0,04 µm**	0,15 µm / 0,06 µm
Stiffness (X,Y / Z)	**3 N/µm**	0,7 N/µm / 8 N/µm



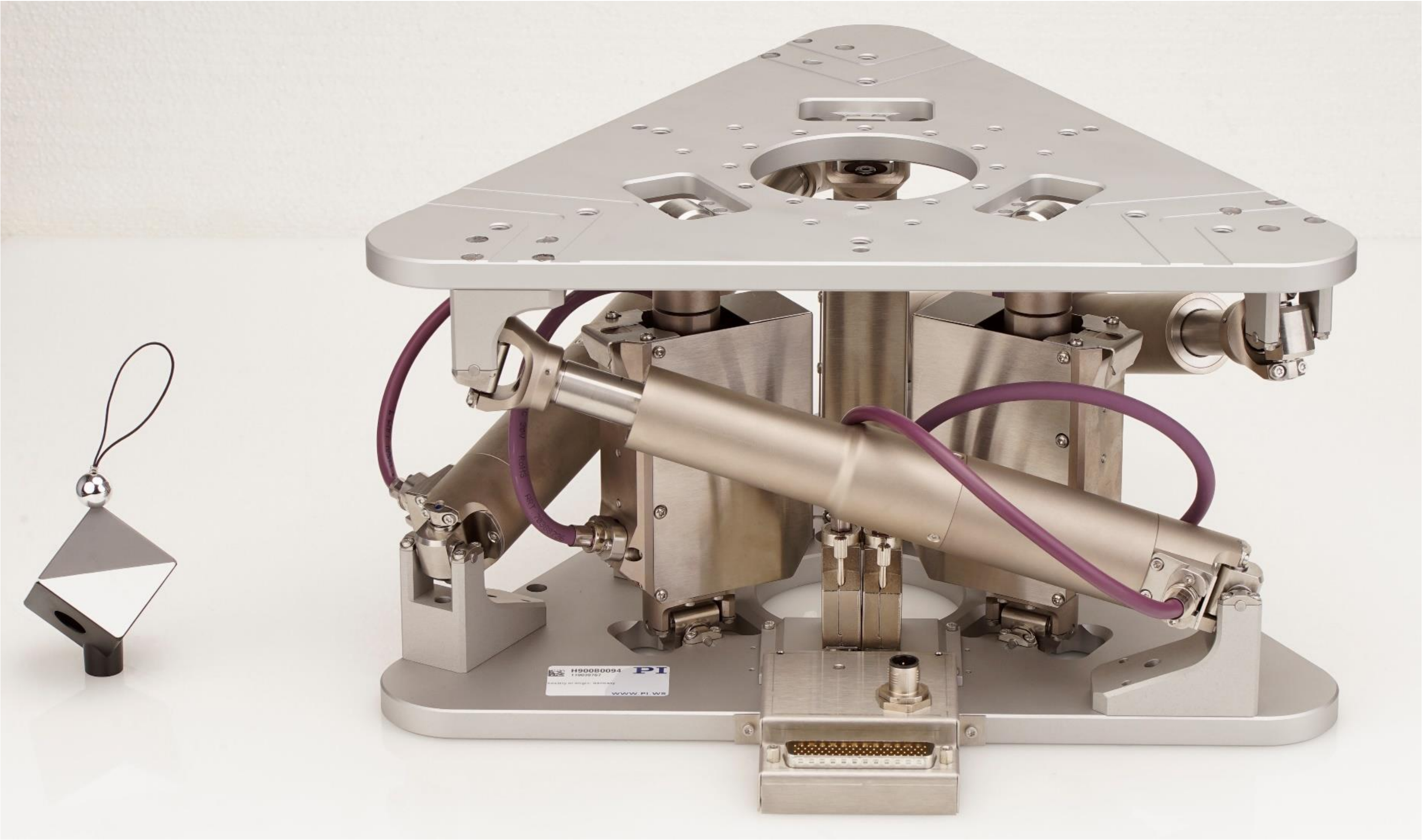
Conclusion – Cube

- Overall size comparable (113,4 mm x 113,4 mm x 133,4 mm vs. d136 mm x 114,3 mm)
- Aperture not possible
- All axes have similar behaviour (stroke, precision performance, stiffness)
- Smaller payload
- All struts are of identical design
- Still 3x bipod structure

- What will happen when all hexapod struts will no longer be of identical design?

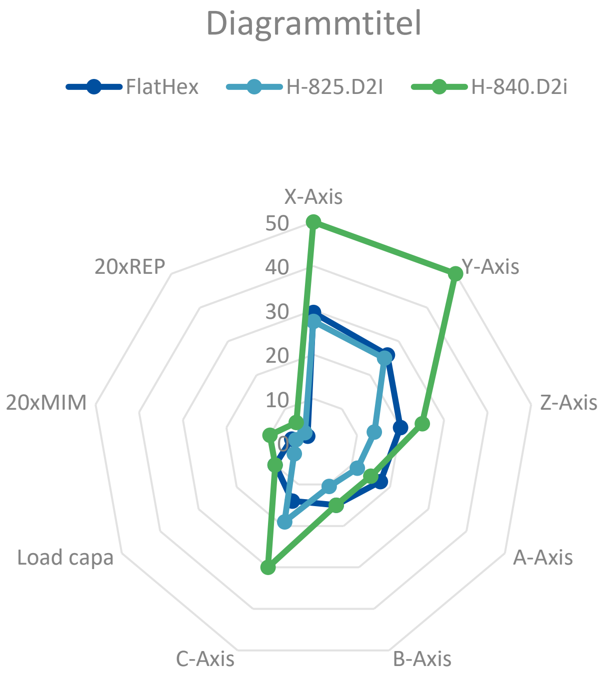
Flat Hexapod Structure

Functional model using standard PI hexapod struts – 3x H-840.D2I and 3x H-825.D2I



Comparison of data

	Flat Hex	H-825.D2I	H-840.D2I
X	**+/- 29,5 mm**	+/- 27,5 mm	+/- 50 mm
Y	**+/- 26 mm**	+/- 25 mm	+/- 50 mm
Z	**+/- 20 mm**	+/- 14 mm	+/- 25 mm
A (θX)	**+/- 17,5 °**	+/- 11,5 °	+/- 15 °
B (θY)	**+/- 15 °**	+/- 10,5 °	+/- 15 °
C (θZ)	**-16,5 / + 14 °**	+/- 19 °	+/- 30 °
Load capacity	**10 kg (upright) 5 kg (all orientations)**	5 kg (upright) 2,5 kg (all orientations)	10 kg (upright) 3 kg (all orientations)
MIM (X,Y / Z)	**0,25 µm**	0,2 µm	0,5 µm / 0,25 µm
Rep. (X,Y / Z)	**0,05 / 0,15 µm**	0,15 µm	0,30 µm / 0,1 µm
Size (dxh)	**400 mm x 187 mm**	320 mm x 195 mm	348 mm x 328 mm



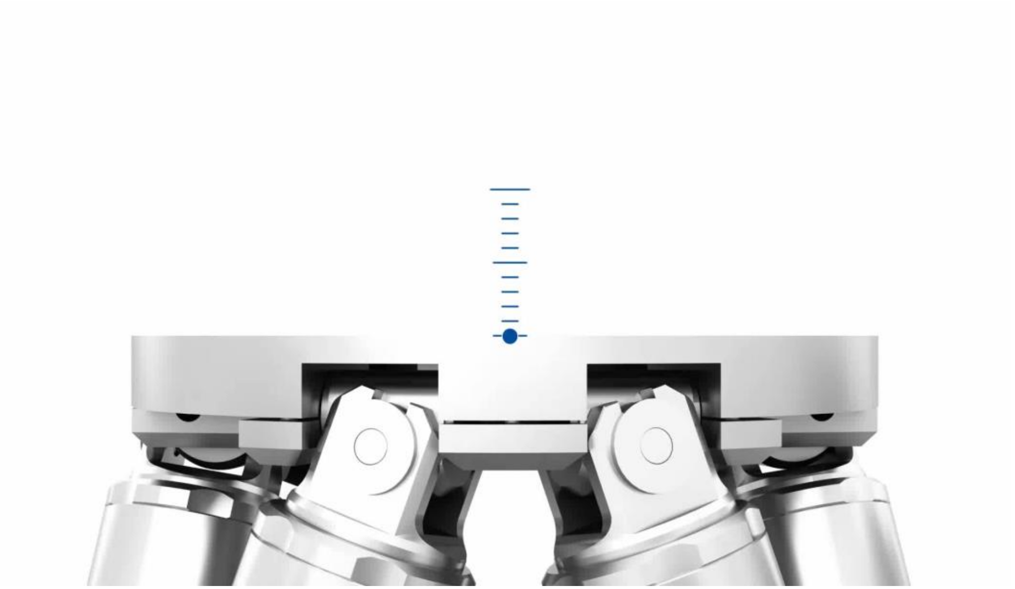
Conclusion – Flat Hex

- Relations of size dimensions change
  - Larger footprint but reduced height
- Potential for higher payload in compact hexapod design
  - Three weight bearing short stroke struts with high load capacity
  - Three stabilizing slender long stroke struts
  - Reduction of internal collision issues despite compact system size
- More components may be more cost intensive

Challenge – External request

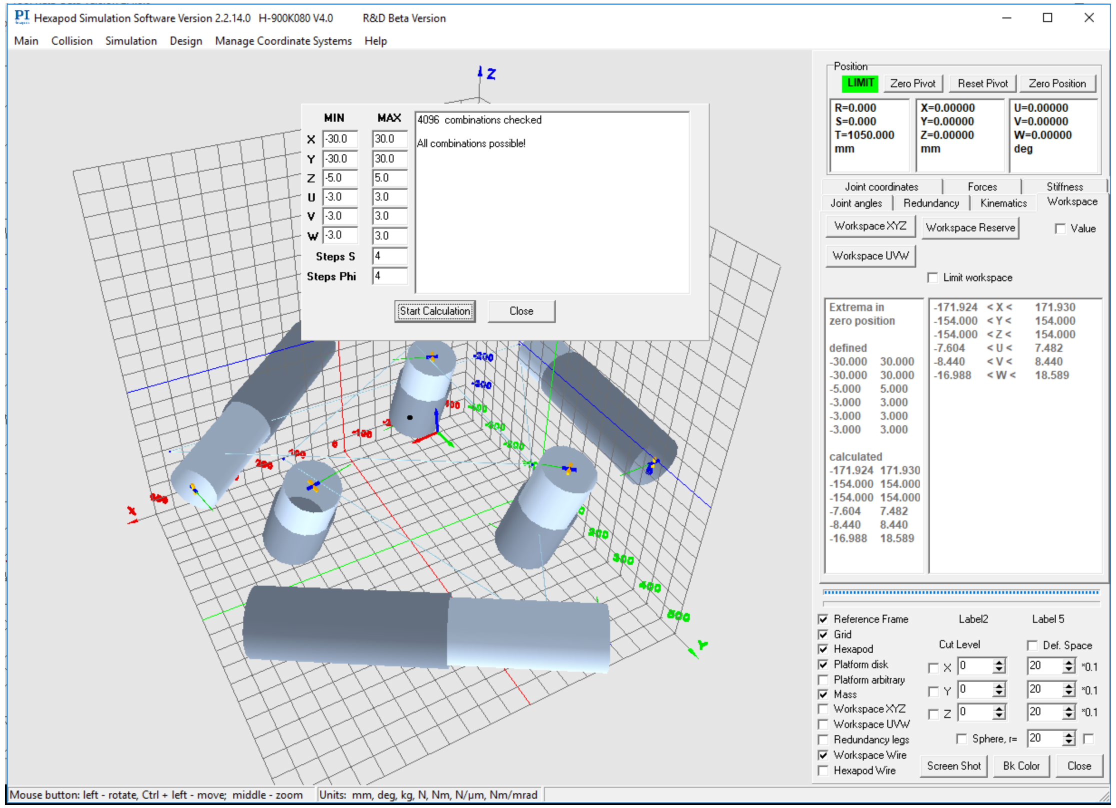
- Payload: 2000 kg @ (x, y, z: 0 mm, 0 mm, 1000 mm)
- Height limitation: <= 300 mm
- Platform shape requirement: diameter (<=) 2000 mm
- System eigen frequency > 20 Hz
- Vacuum atmosphere <= 1e-6 hPa

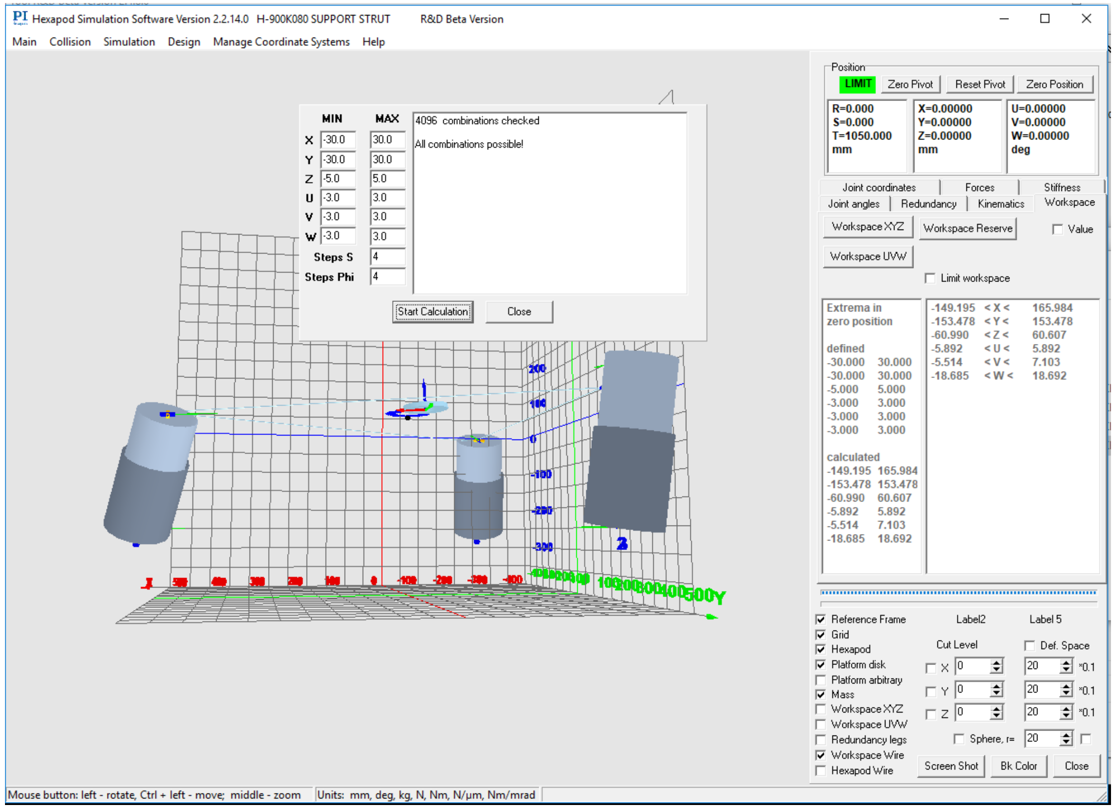
- Center of rotation: x, y, z: 0 mm, 0 mm, 1000 mm
- Travel ranges (combined):
  - x, y: +/- 30mm,
  - z: +/- 5mm,
  - A,B,C: +/- 3 deg



Design concept based on flat hexapod set-up

Simulation of design structure





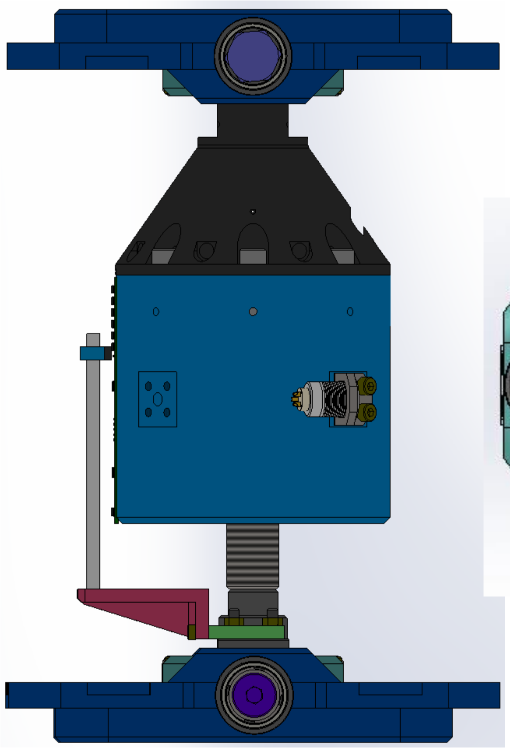
Strut dimension overview

- Short stroke: -20/+ 58 mm
- Long stroke: +/- 152 mm
- Max. strut force 10 kN @ 2t external load

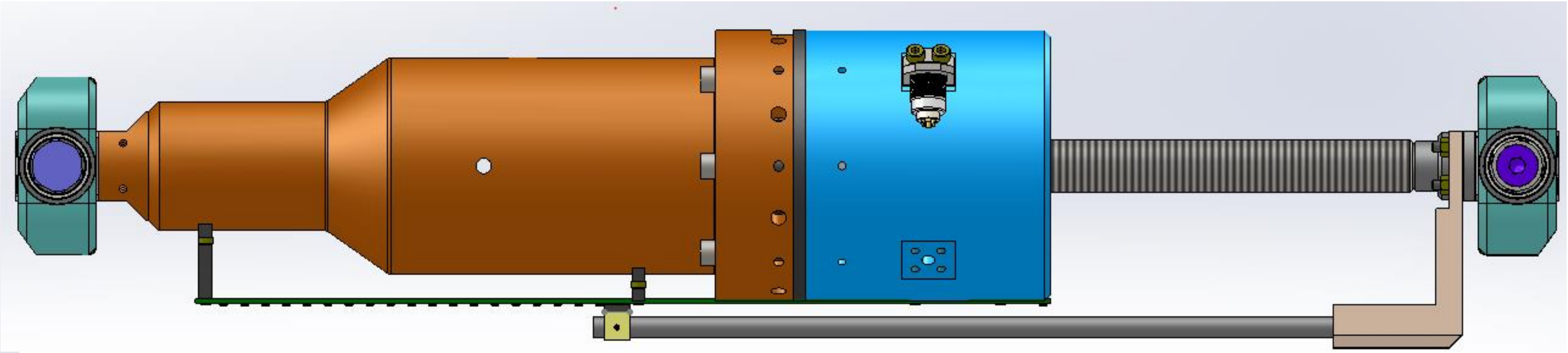
Hexapod struts

Identical drive train design for both lengths

Vertical Struts



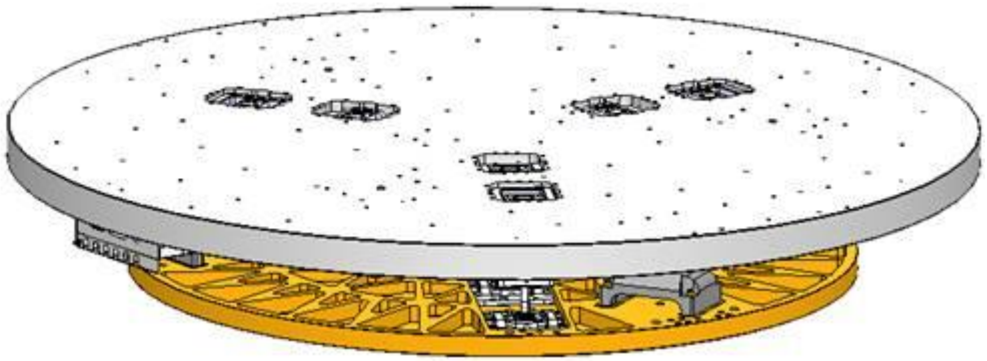
Horizontal Struts

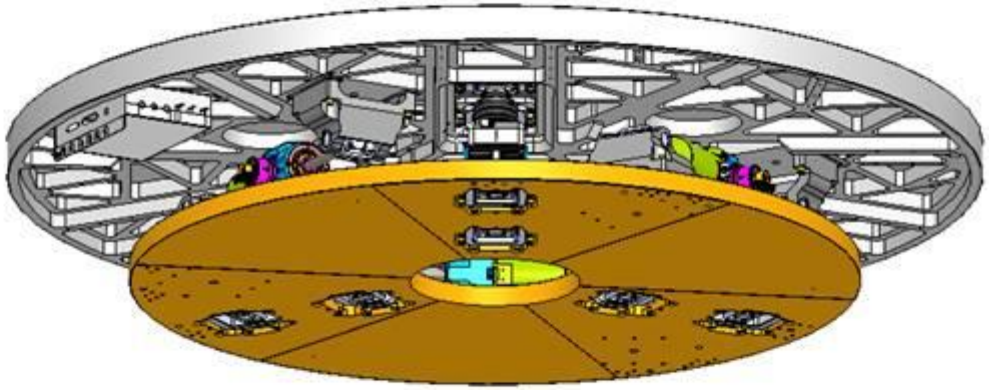


Compact Flat High-Load Hexapod System

- Height 300 mm
- Strut diameter 140 mm
- Tight space
- → Check for internal collision issues

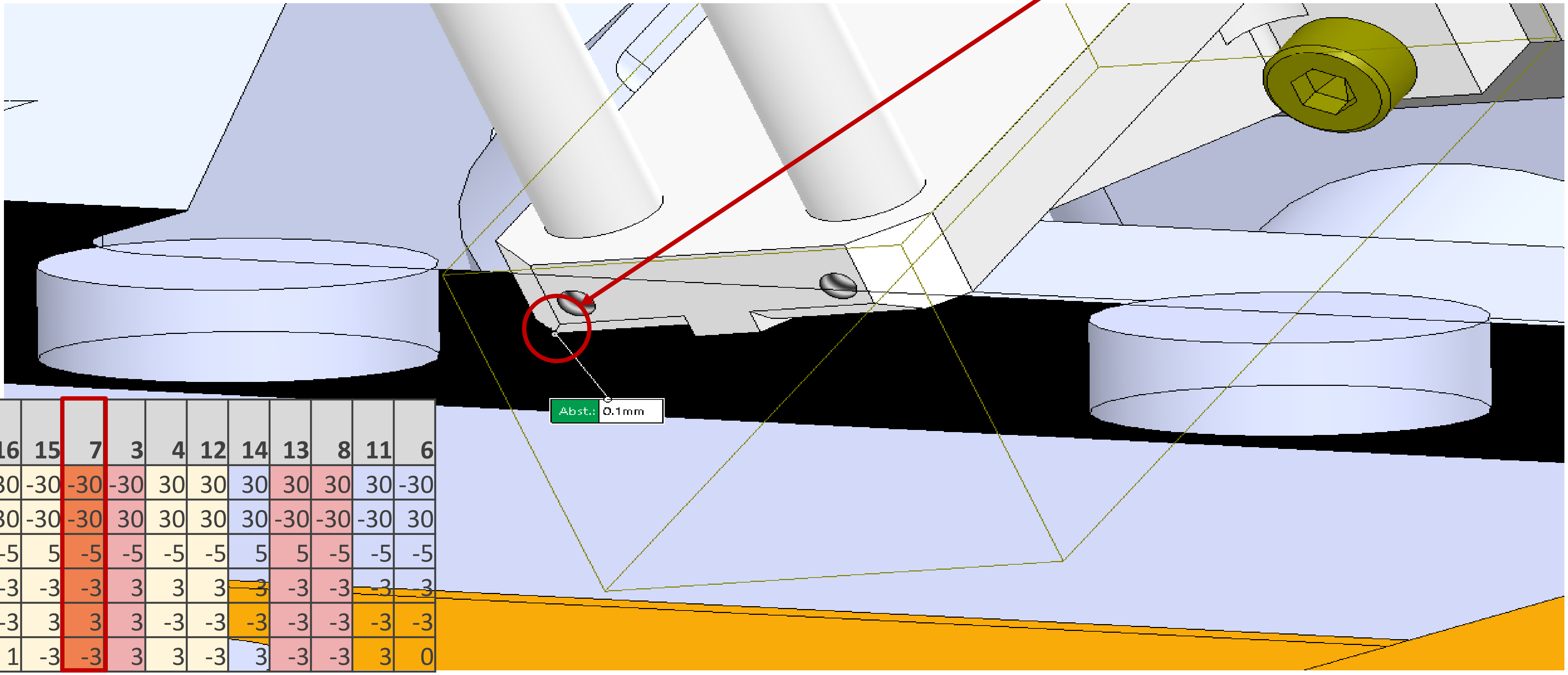
Pos.-Nr	16	15	7	3	4	12	14	13	8	11	6
x	-30	-30	-30	-30	30	30	30	30	30	30	-30
y	30	-30	-30	30	30	30	30	-30	-30	-30	30
z	-5	5	-5	-5	-5	-5	5	5	-5	-5	-5
u	-3	-3	-3	3	3	3	3	-3	-3	-3	-3
v	-3	3	3	3	-3	-3	-3	-3	-3	-3	-3
w	1	-3	-3	3	3	-3	3	-3	-3	3	0





Collision analysis of extreme positions

Distance between lower joint structure and cantilevered sensor mount



Pos.-Nr	16	15	7	3	4	12	14	13	8	11	6
x	-30	-30	-30	-30	30	30	30	30	30	30	-30
y	30	-30	-30	30	30	30	30	-30	-30	-30	30
z	-5	5	-5	-5	-5	-5	5	5	-5	-5	-5
u	-3	-3	-3	3	3	3	3	-3	-3	-3	-3
v	-3	3	3	3	-3	-3	-3	-3	-3	-3	-3
w	1	-3	-3	3	3	-3	3	-3	-3	3	0

-30
-30
-5
-3
3
-3
0

0
0
1050

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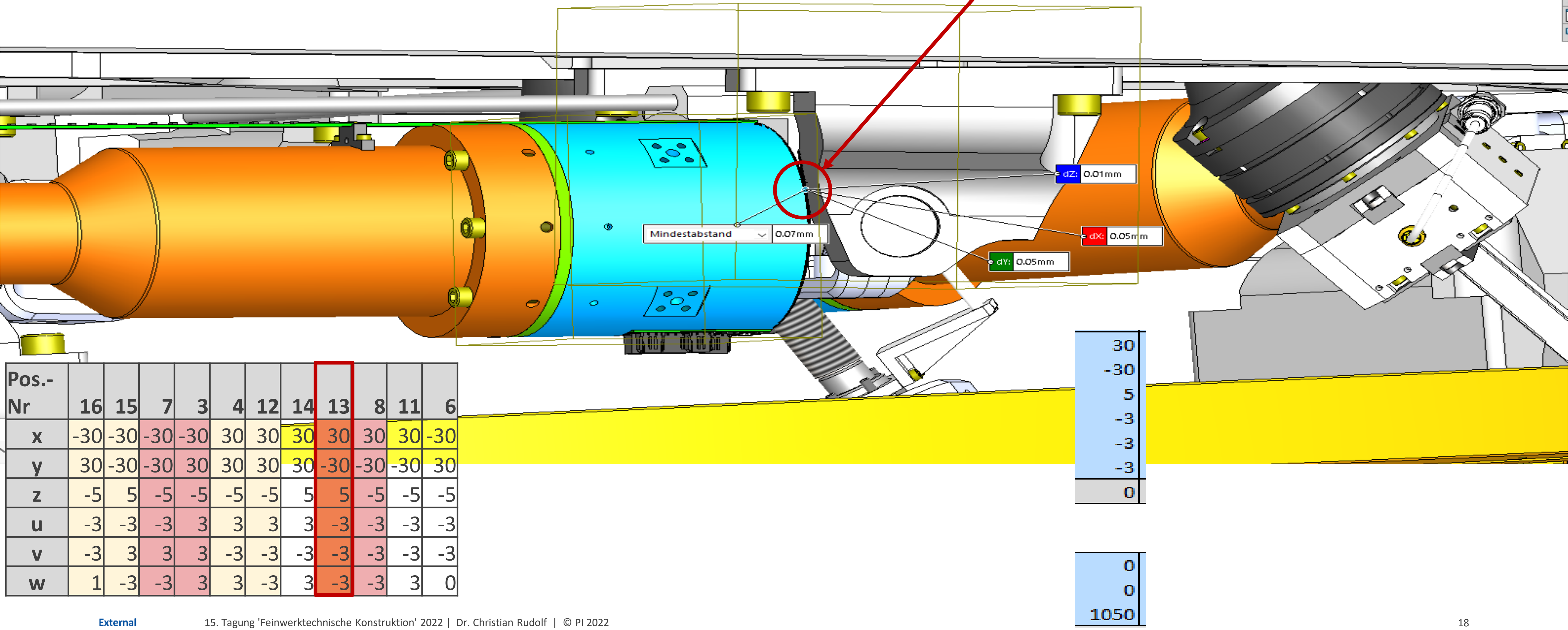
Collision analysis of extreme positions

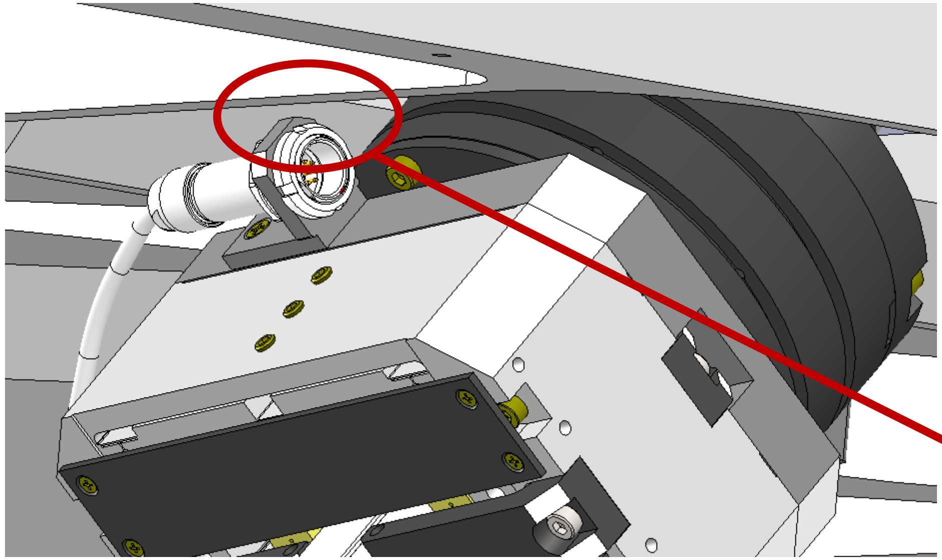
Distance between motor housing and joint structure

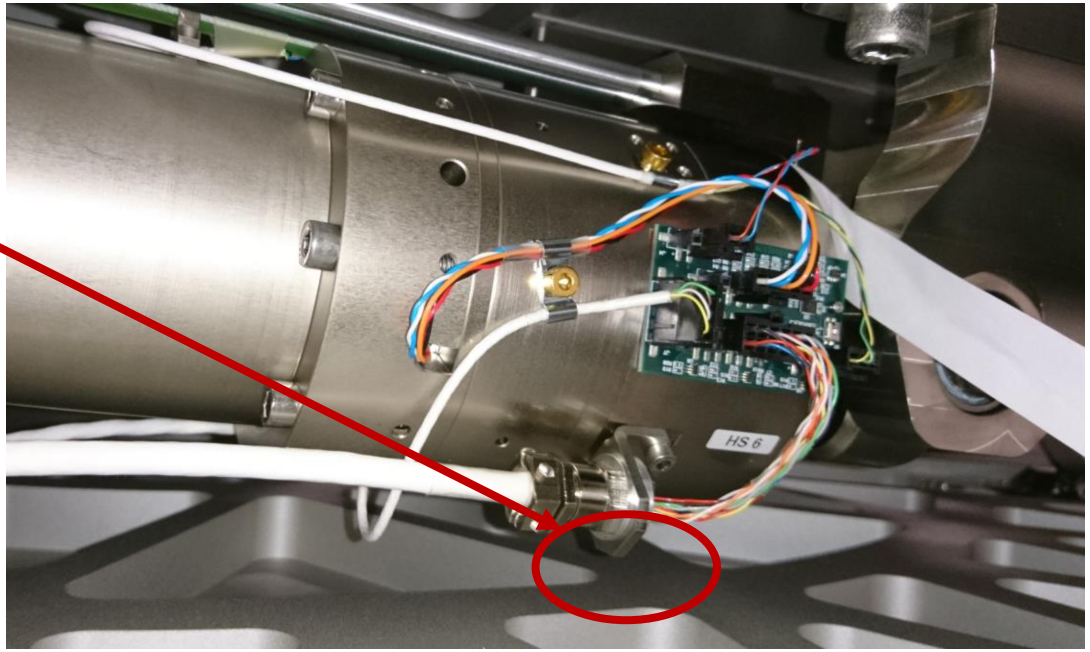


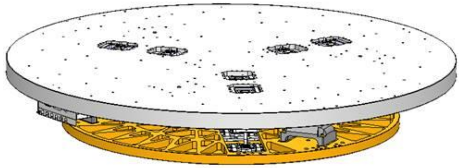
Pos.-Nr	16	15	7	3	4	12	14	13	8	11	6
x	-30	-30	-30	-30	30	30	30	30	30	30	-30
y	30	-30	-30	30	30	30	30	-30	-30	-30	30
z	-5	5	-5	-5	-5	-5	5	5	-5	-5	-5
u	-3	-3	-3	3	3	3	3	-3	-3	-3	-3
v	-3	3	3	3	-3	-3	-3	-3	-3	-3	-3
w	1	-3	-3	3	3	-3	3	-3	-3	3	0

Collision analysis of extreme positions

Distance between connector and platform

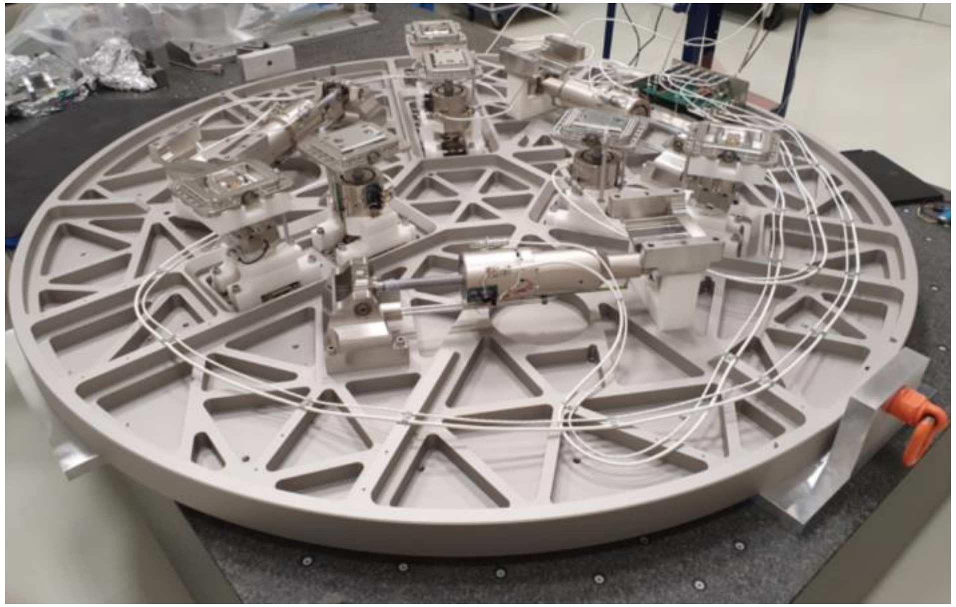


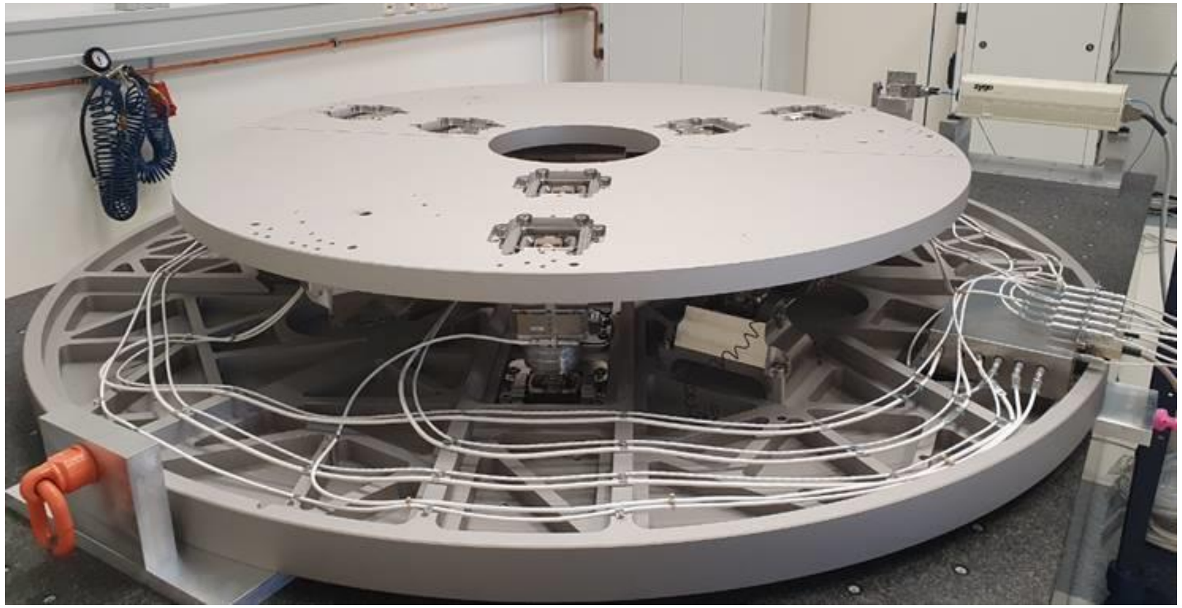




Compact Flat High-Load Hexapod System

Impressions





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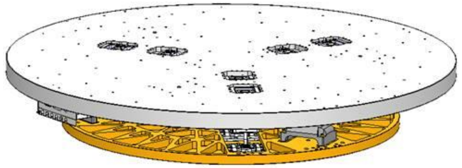
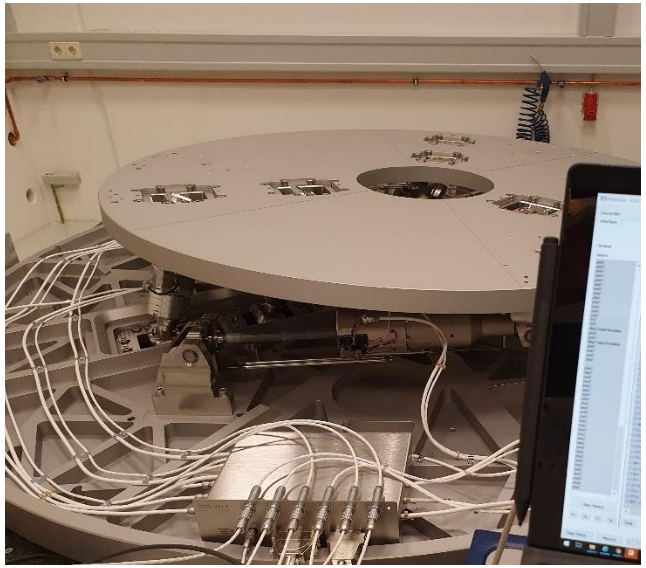
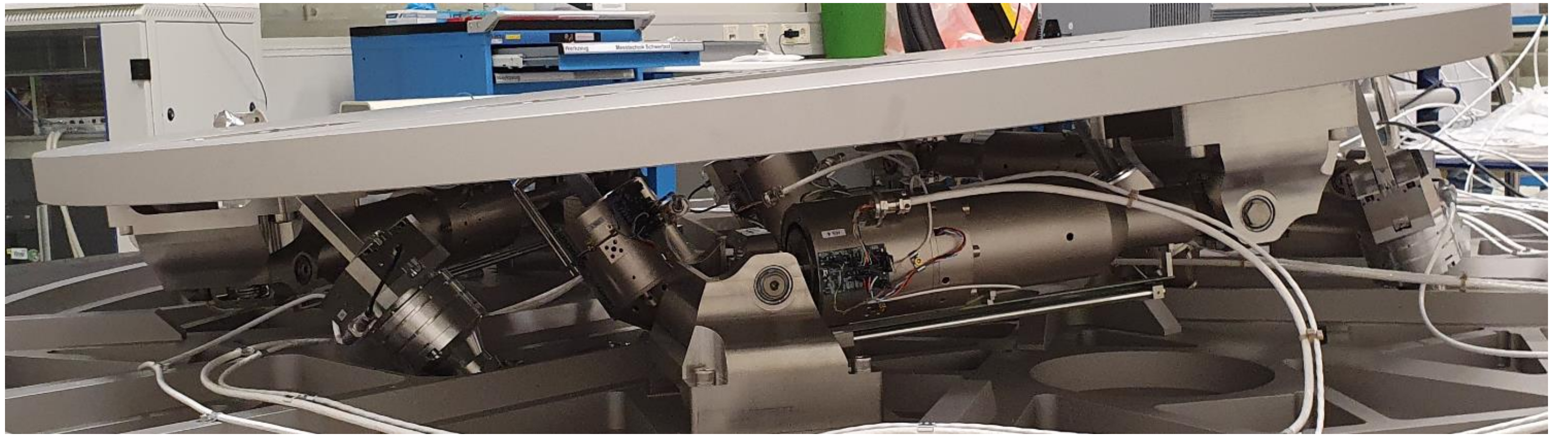
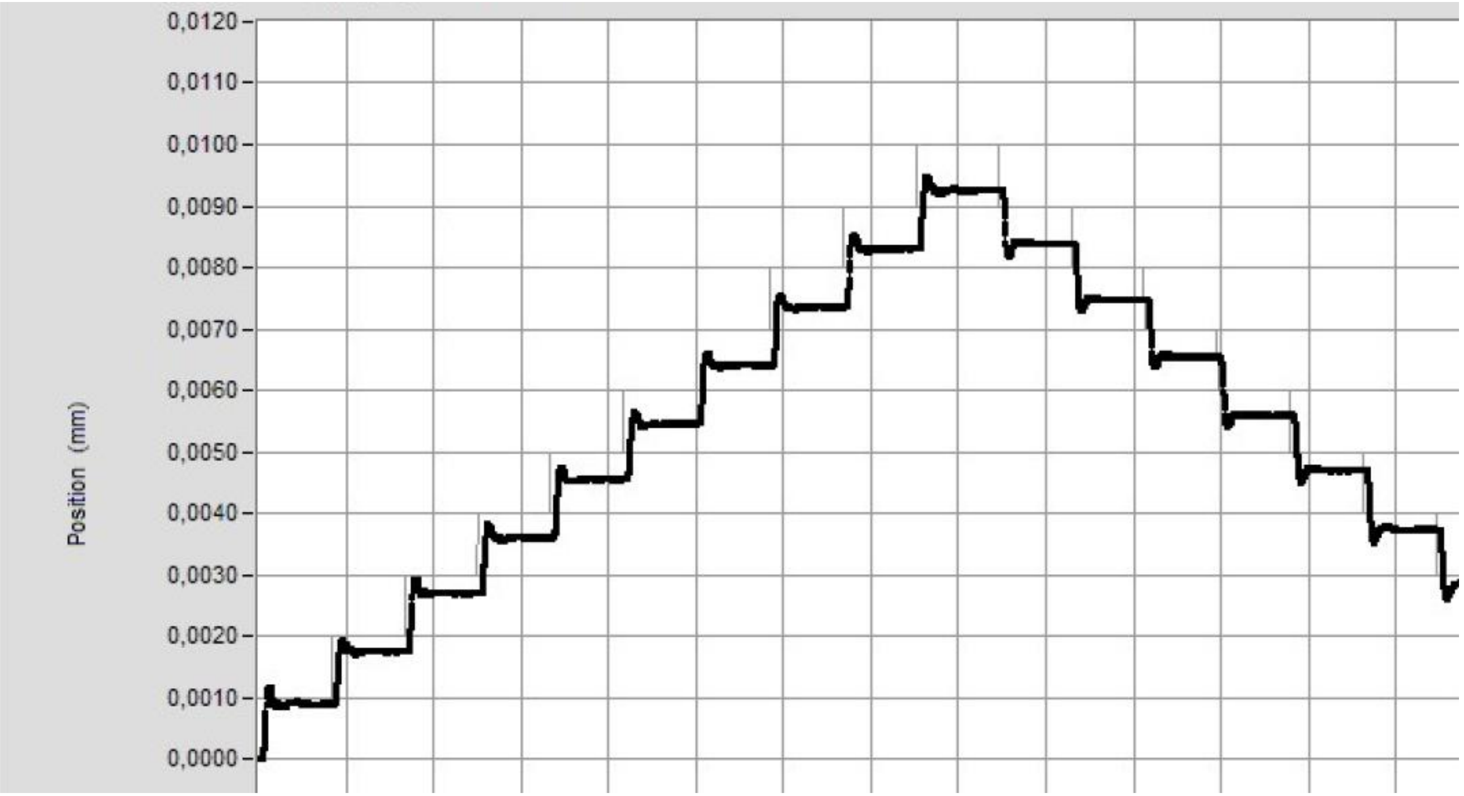






Compact Flat High-Load Hexapod System

Results

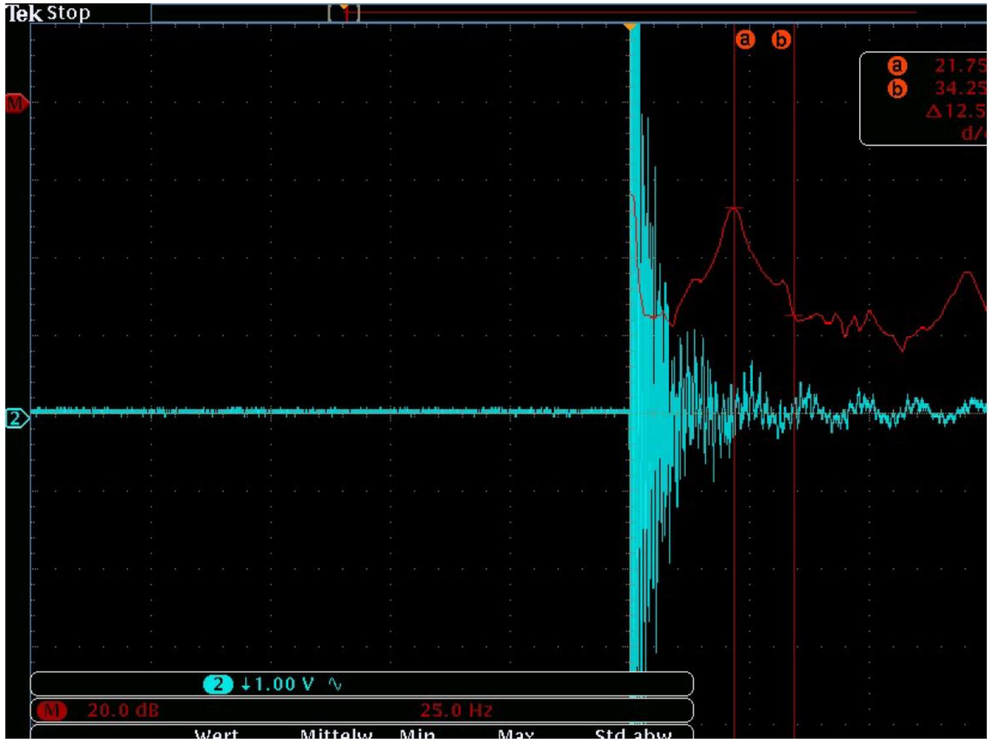


Minimum incremental motion in x-direction

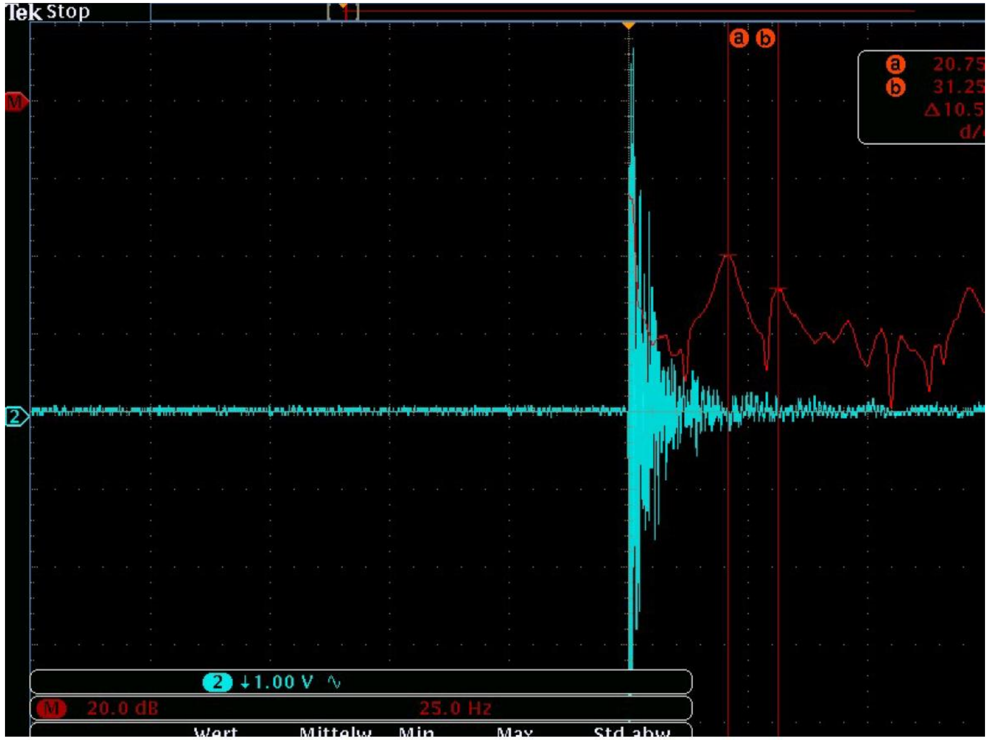
Compact Flat High-Load Hexapod System

Results – Eigen frequencies

Payload: 1500 kg → 21,7 Hz



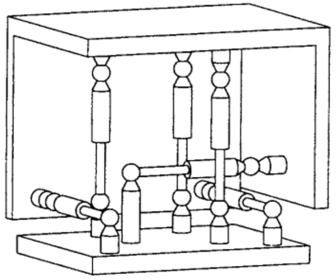
Payload: 2000 kg → 20,7 Hz



Conclusion & Outlook

Is 3x2 = 2x3?

- Yes:
  - These systems are still hexapods, six degrees of freedom motion systems
  - Parallel kinematics set-up with need of transformation calculations
- But – new designs offer options and opportunities such as
  - Homogeneous system behavior and performance, or
  - Ultra-flat and compact systems



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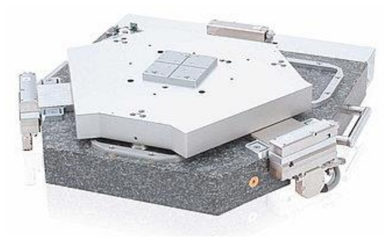
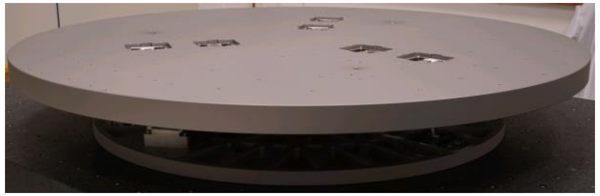
- So, what's next?
  - 3-2-1 manipulator?
    - No(t yet)
  - Variants of presented systems?
    - Yes
  - No (mechanical) legs at all?
    - Yes





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