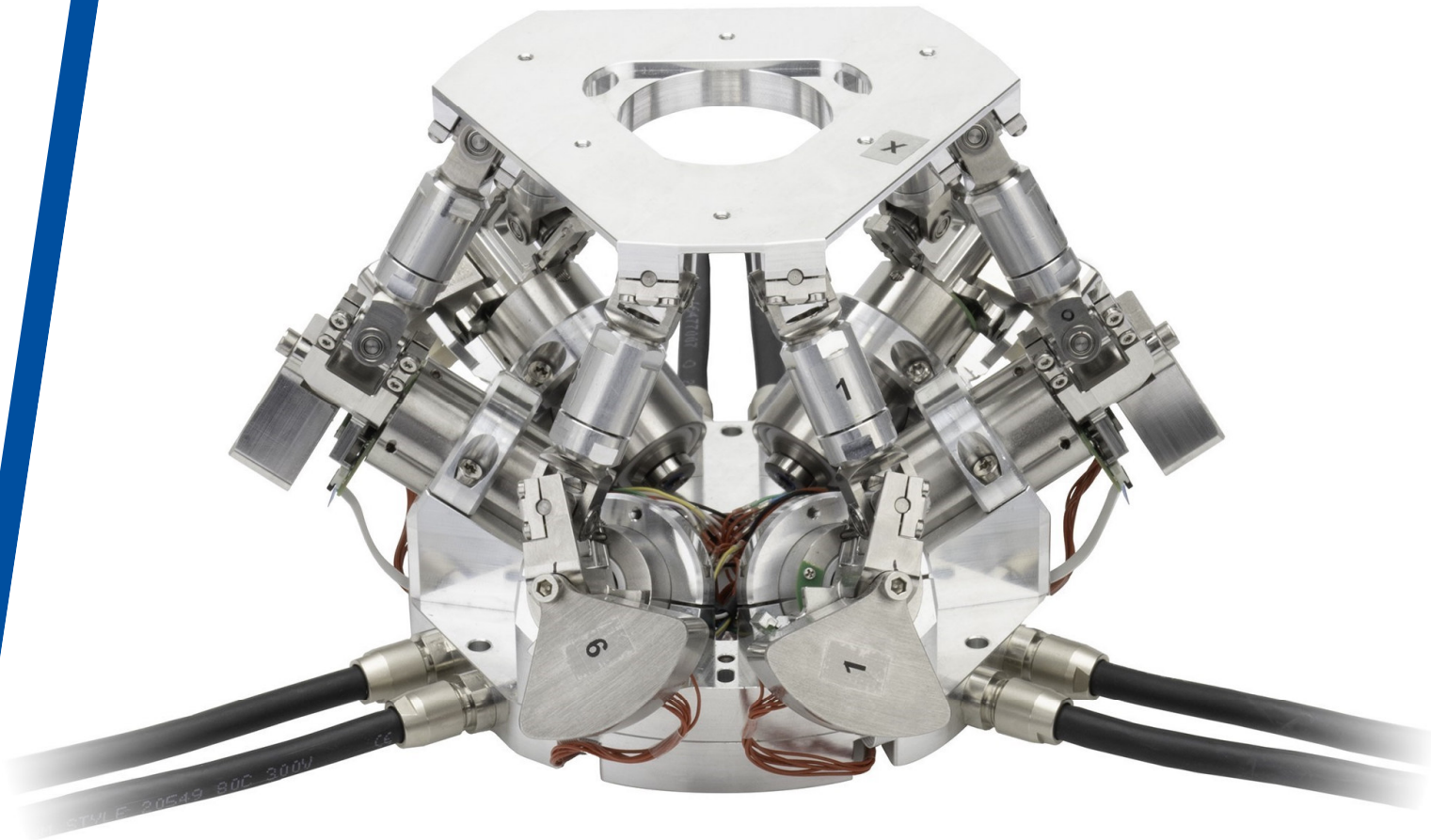
17. TAGUNG FÜR
„FEINWERKTECHNISCHE KONSTRUKTION“
27. SEPTEMBER 2024, DRESDEN

Direktgetriebener Miniatur-Hexapod für dynamische 6-DoF-Positionierung im Submikrometerbereich



Physik Instrumente (PI) GmbH & Co. KG

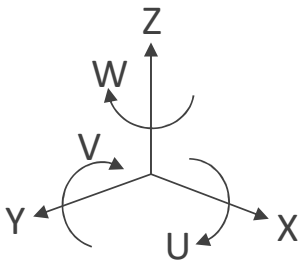
Outline

DGFT Tagung für Feinwerktechnische Konstruktion 2024 - Dresden

- Background and Motivation
- Mechanical Design
- Qualification
- Conclusion and Outlook

Background

Parallel Kinematic Machines (PKM) with Six Degrees of Freedom



- Used for realizing motion in 6 degrees of freedom (three linear axes plus three rotational axes)
- Actuators (struts) arranged in parallel between top platform and base platform
- High stiffness
- Sub-micrometer resolution
- Arbitrary choice of center of rotation (pivot point)
- Payload between 1 kg and few tons

Applications

Hexapods for a variety of tasks

Positioning of subreflectors in large telecopes

Photo: www.physikinstrumente.com

Industrial automation

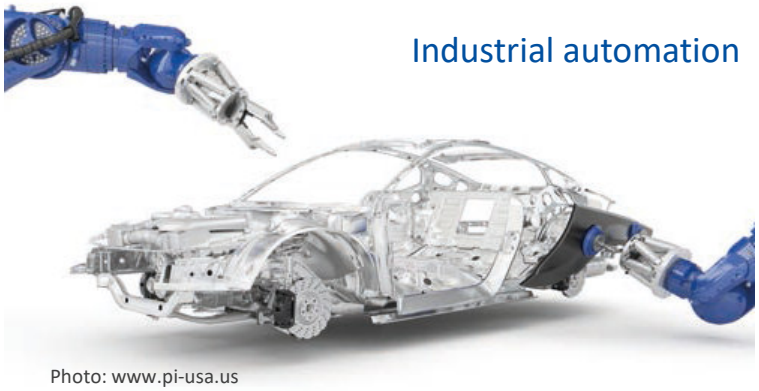


Photo: www.pi-usa.us

Alignment

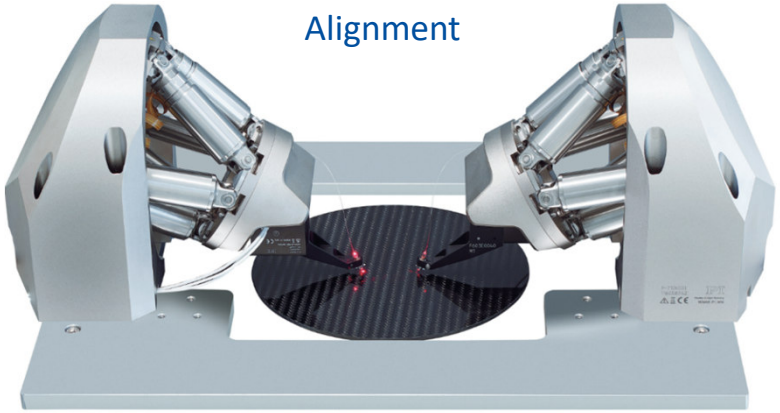


Photo: www.physikinstrumente.com

Research

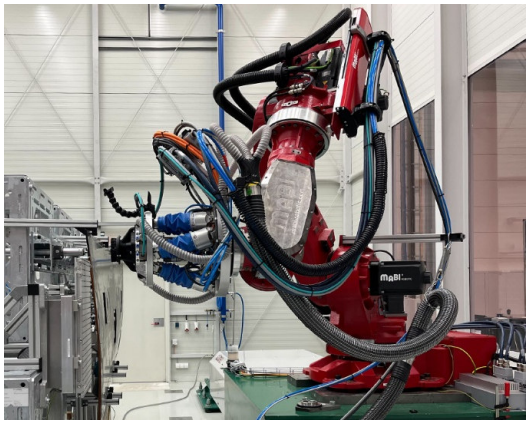


Photo: IFAM

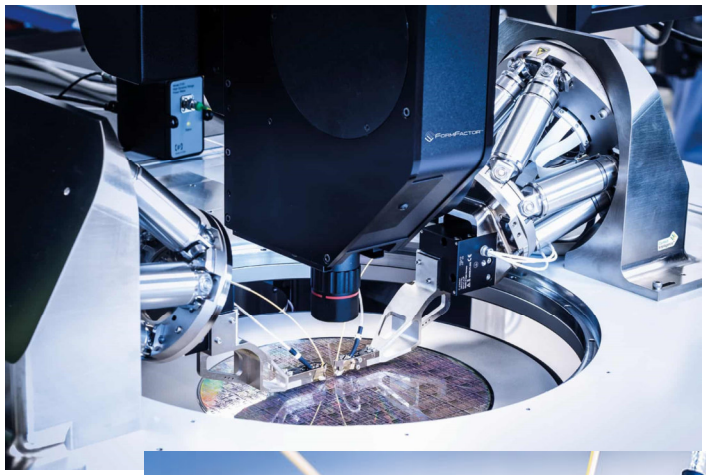
Motion simulation and image stabilization

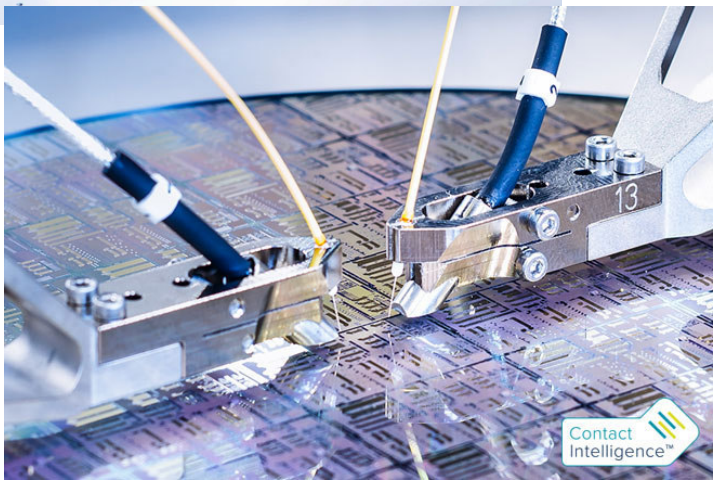
Photo: www.physikinstrumente.com

Motivation

Compact Parallel Kinematic Machines with Basepoint Motion

- Growing demand on compact 6-DoF positioning systems for applications in the photonics and semiconductor industry
  - Wafer probing to identify faulty chips
  - Packaging
  - Optical Assembly → LIDAR sensors





Photos: https://www.formfactor.com/product/probe-systems/autonomous-assistants/autonomous-silicon-photonics/

Need for a compact, robust and cost-effective system for high operating frequencies

Direct driven lever actuated PKM

Outline

DGFT Tagung für Feinwerktechnische Konstruktion 2024 - Dresden

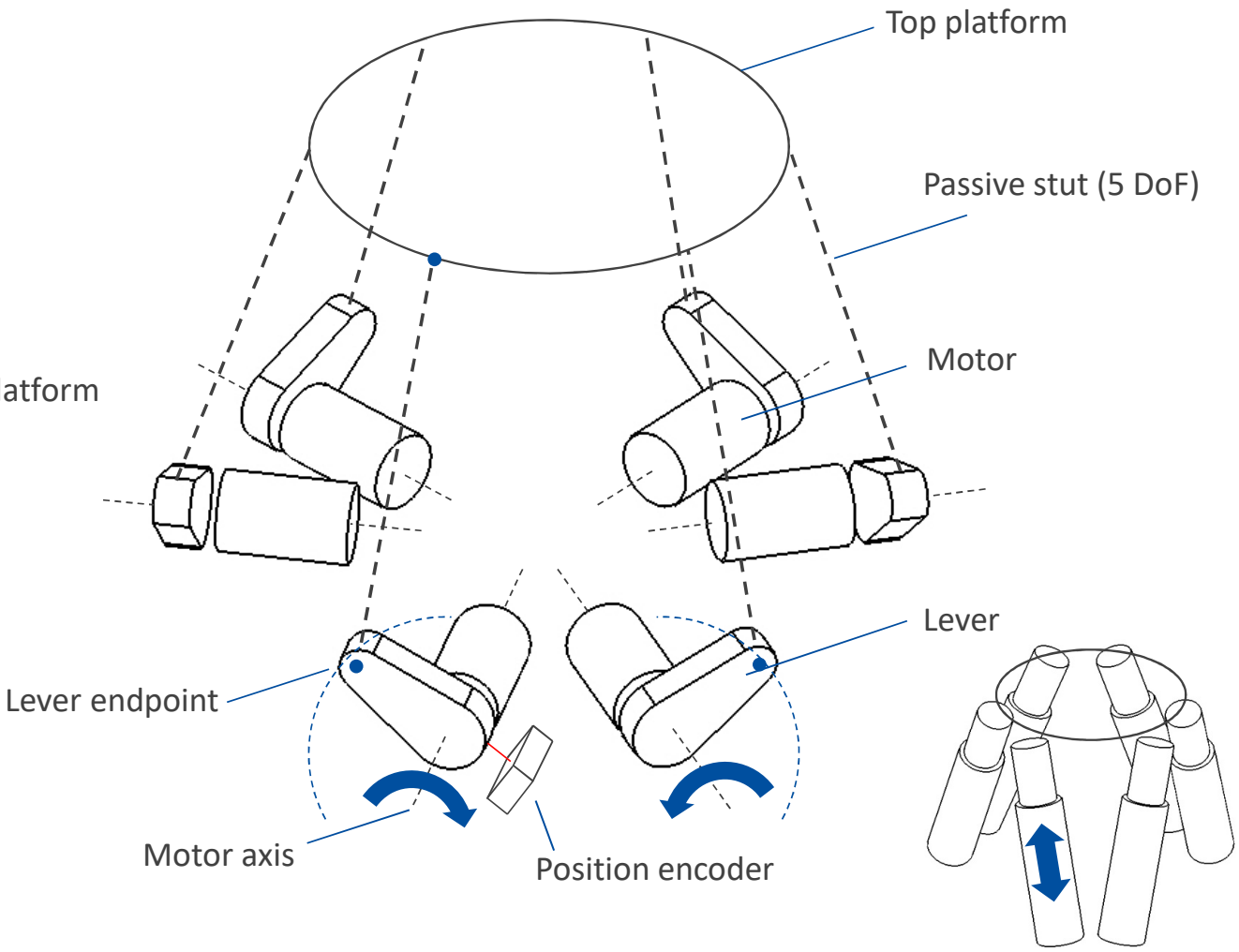
- Background and Motivation
- **Mechanical Design**
- Qualification
- Conclusion and Outlook

Mechanical Design

Lever Actuated Direct Driven 6-DoF PKM

Compared to spindle driven PKM:

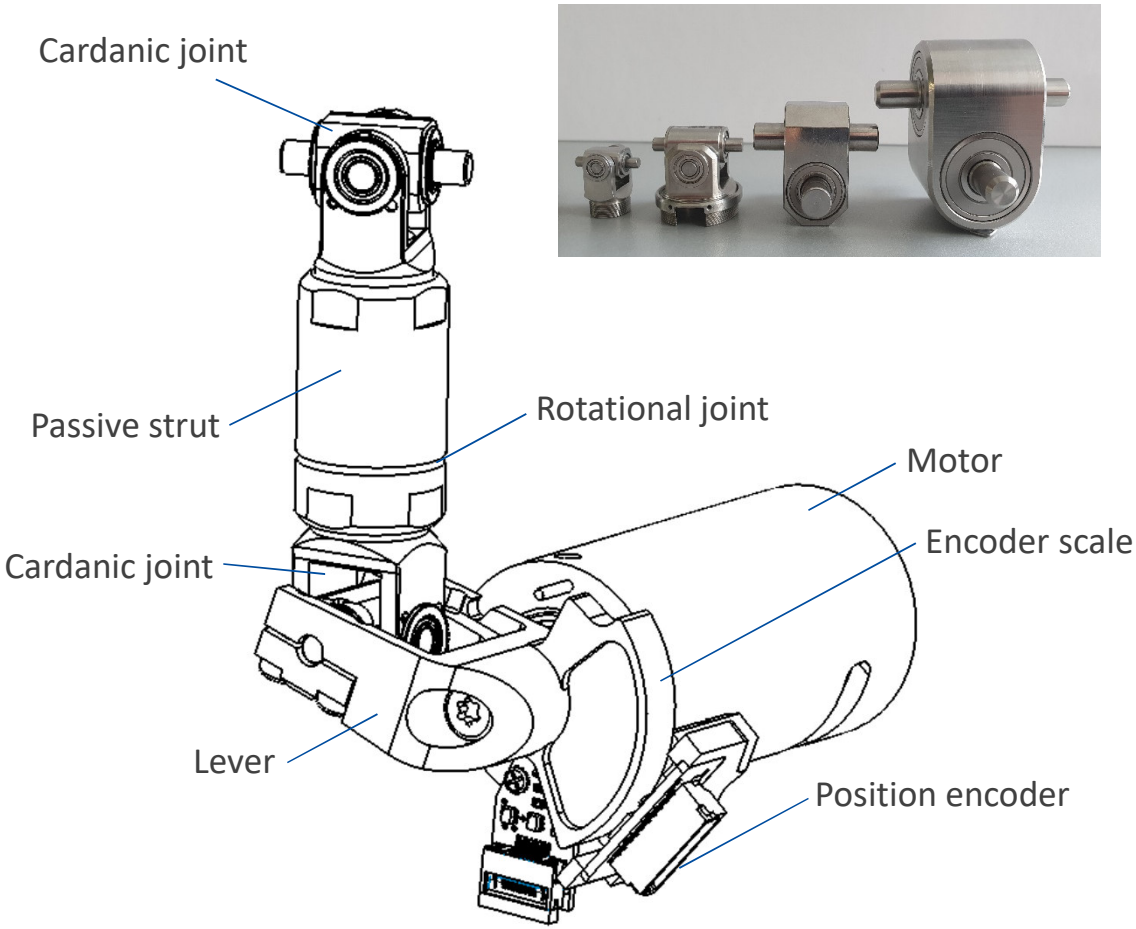
- Direct translation of lever position to top platform
- Higher velocity and acceleration
- Less wear and tear
- Lower payload
- No self locking



Mechanical design

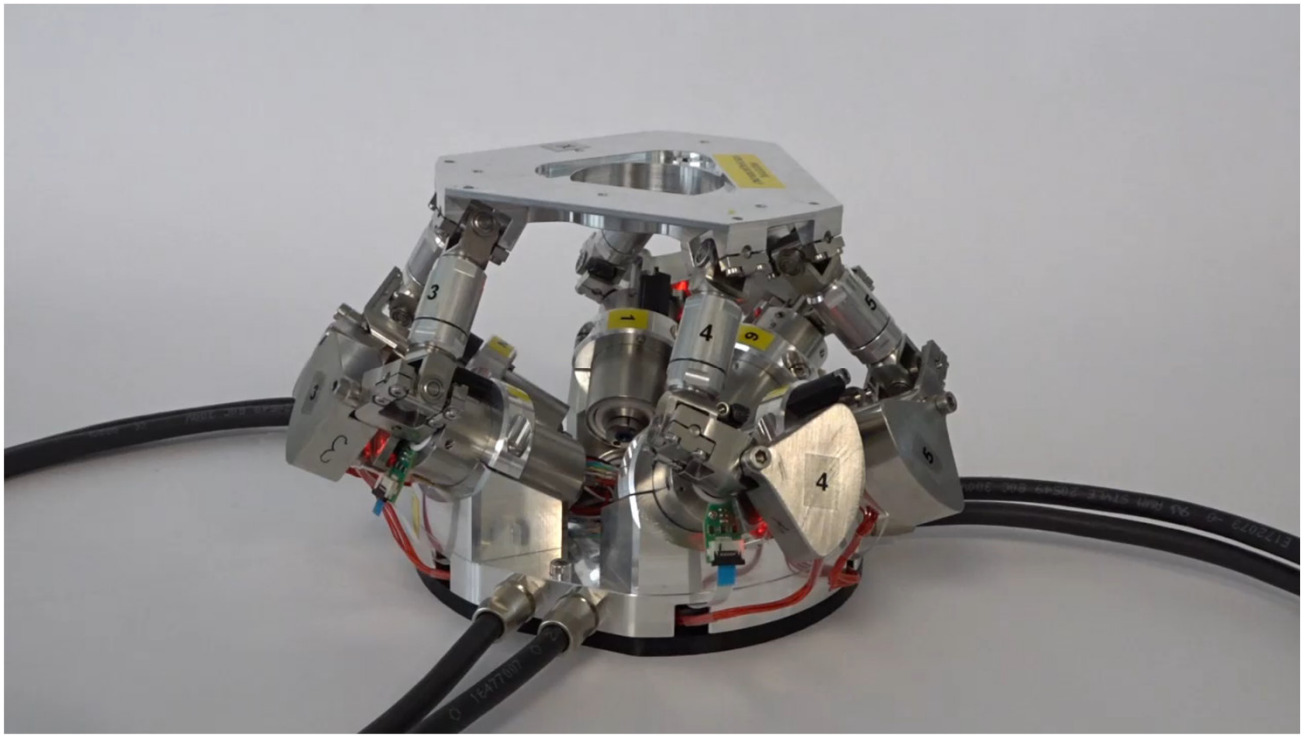
Lever Actuated Direct Driven 6-DoF PKM

- Motor with ceramic ball bearings
- Encoder scale part of the lever
- Measuring of lever position
- Sub-compact universal joints with ball bearings
- Rotational joint in the passive strut
- No parasitic forces due to cables



Mechanical Design

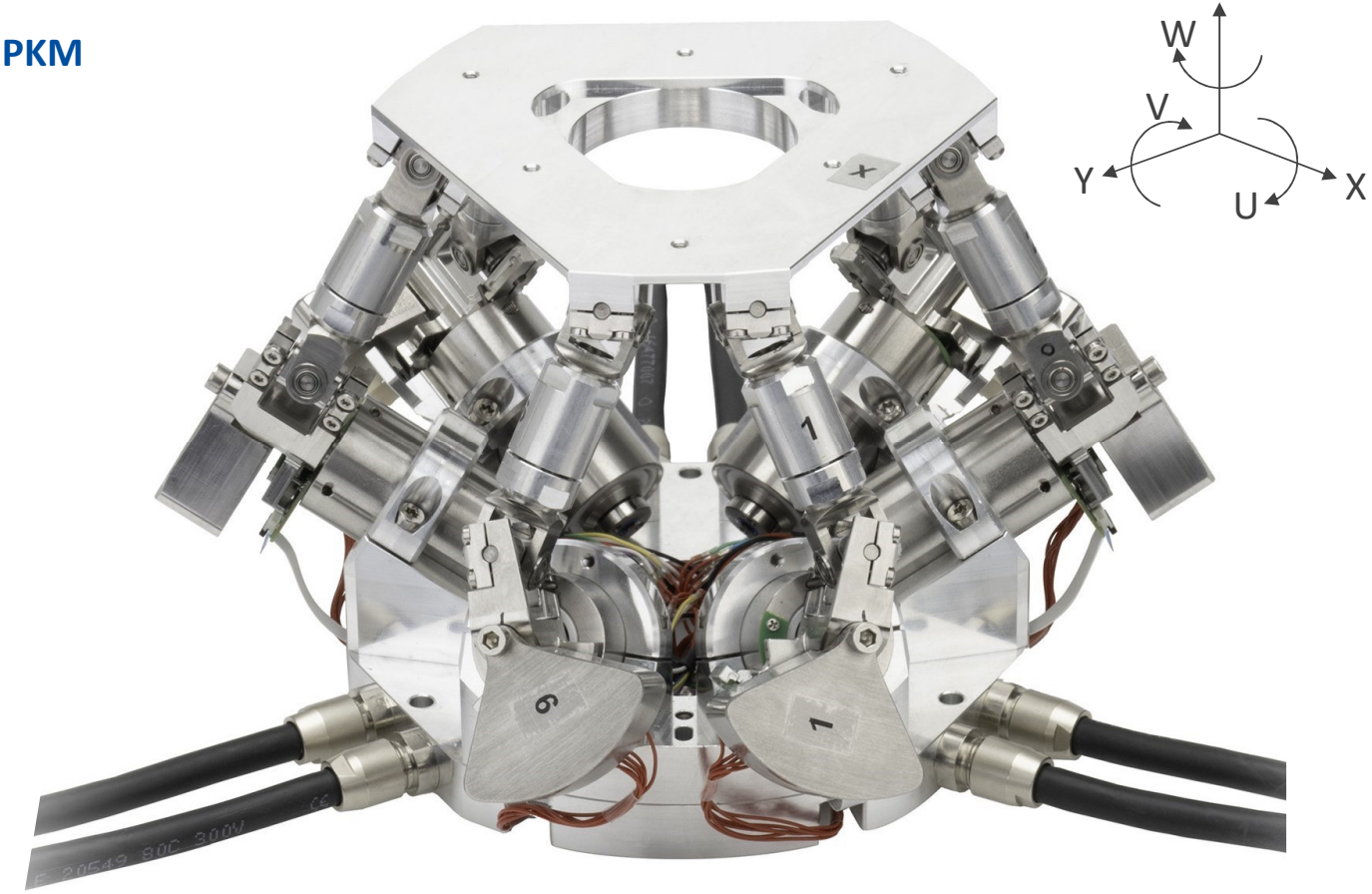
Compact Parallel Kinematic Machines with Basepoint Motion



Mechanical design

Lever Actuated Direct Driven 6-DoF PKM

- Height: 104 mm
- Diameter: 180 mm
- Travel range in X, Y, Z: ± 9.5 mm
- Travel range in U, V, Z: ± 8 °
- Maximal velocity: > 100 mm/s



Outline

DGFT Tagung für Feinwerktechnische Konstruktion 2024 - Dresden

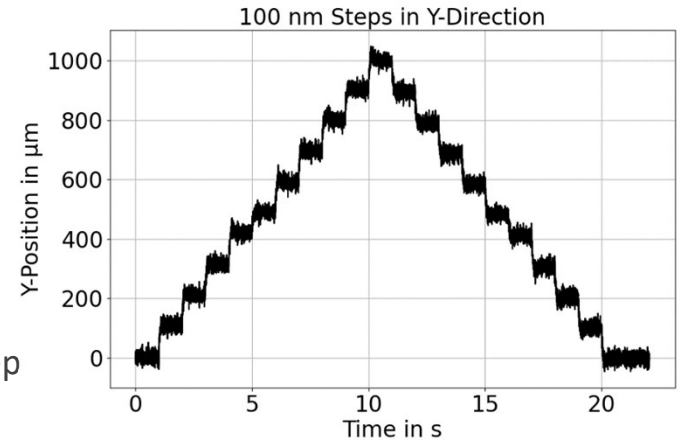
- Background and Motivation
- Mechanical Design
- **Qualification**
- Conclusion and Outlook

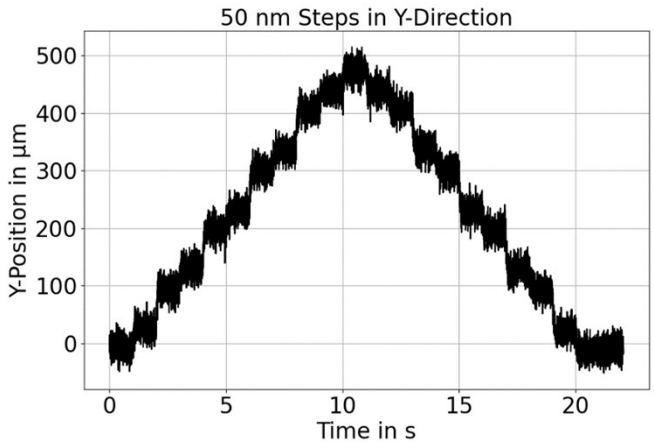
Resolution

Minimal Incremental Motion (MIM)

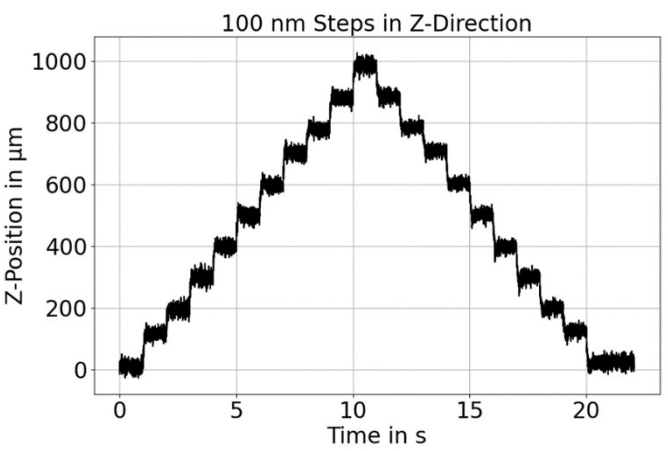
- Interferometer measurement of top platform position
- Twenty steps with 100 nm and 50 nm step width in X, Y and Z-direction
- Good 100 nm steps in X, Y and Z-direction
- Decent 50 nm steps in Z-direction
- Noise of approx. 40 nm (peak-to-peak)

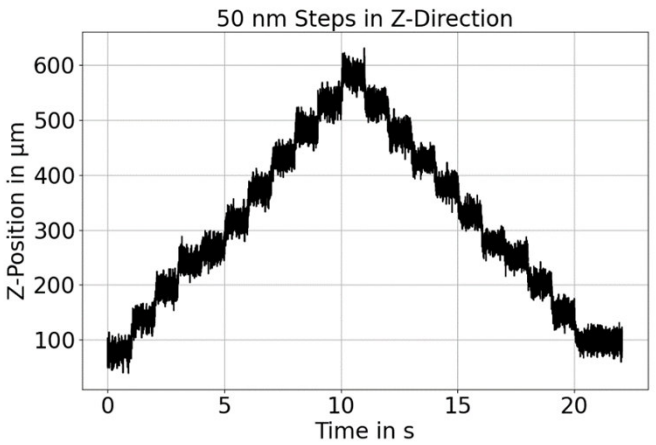
Y-Direction





Z-Direction

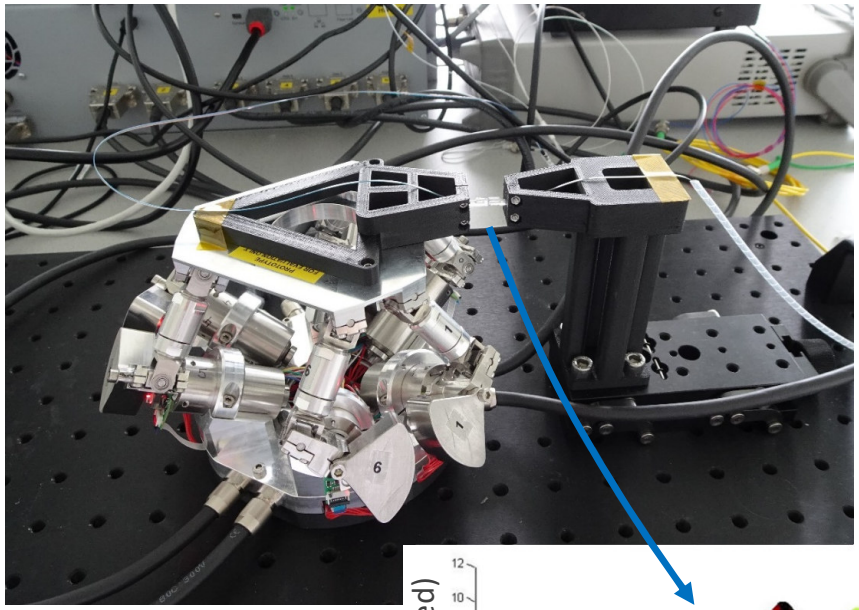


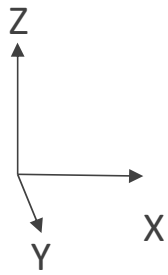


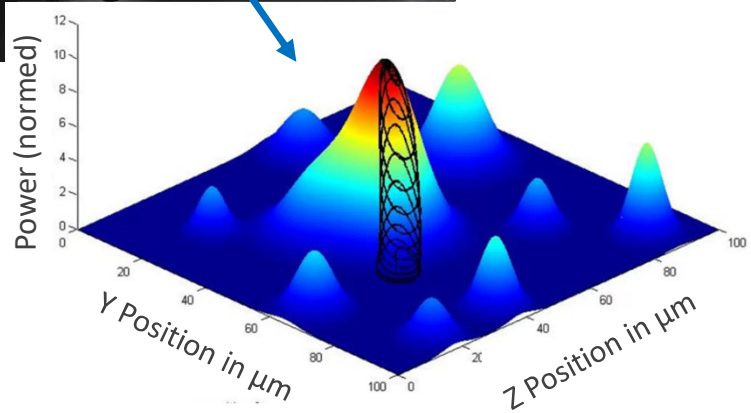
Alignment

Gradient Scan – Constant Frequency

- 3D printed fiber holder on hexapod top platform
- Optical fiber alignment for minimal losses in couplings
- Gradient search routine with constant frequency of 10 Hz
- Circle radii vary between 2 µm and 4 µm
- Results were compared to compact spindle driven H-811 hexapod







Alignment

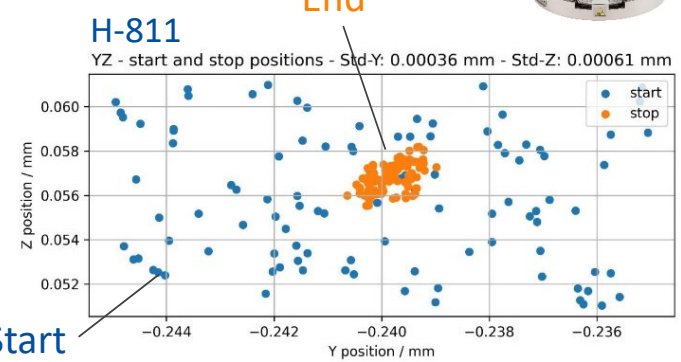
Gradient Scan – Signal Values and Position Deviation

- 100 tests with lever PKM and H-811 hexapod
- Scan area: 10 µm x 10 µm
- Random start positions marked blue
- End positions marked orange
- Good results with both systems
- Similar standard derivations (position and signal value)

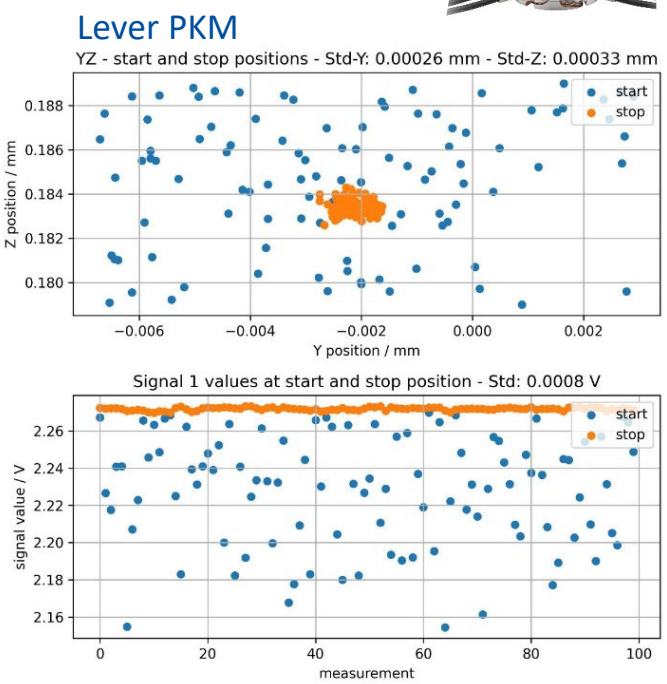
H-811

End

Start



Lever PKM

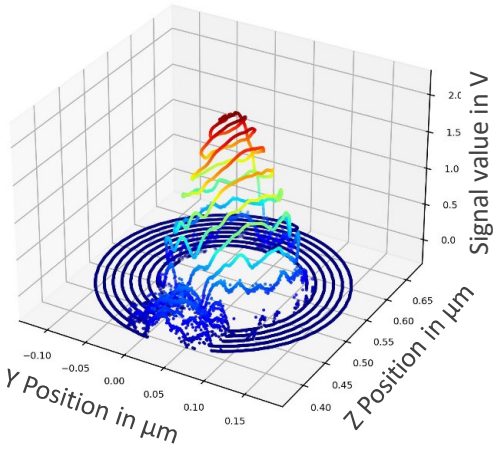


Routine duration in s:
Lever PKM: Mean value: 0.415 s
H-811: Mean value: 0.549 s

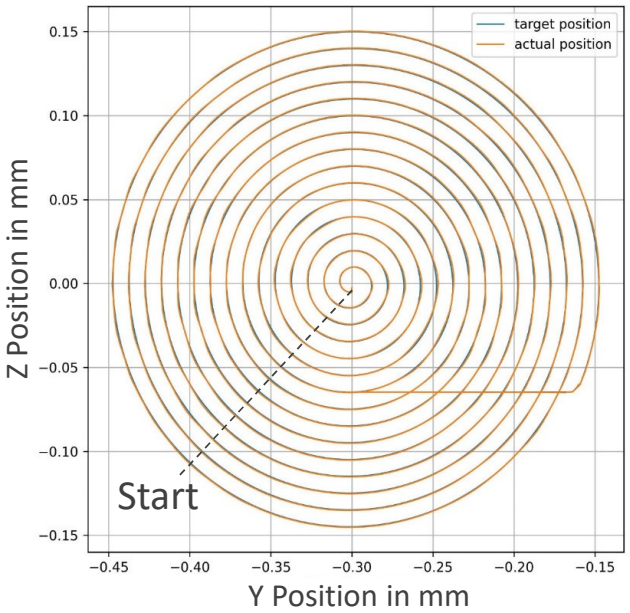
Alignment

Area Scan – constant velocity

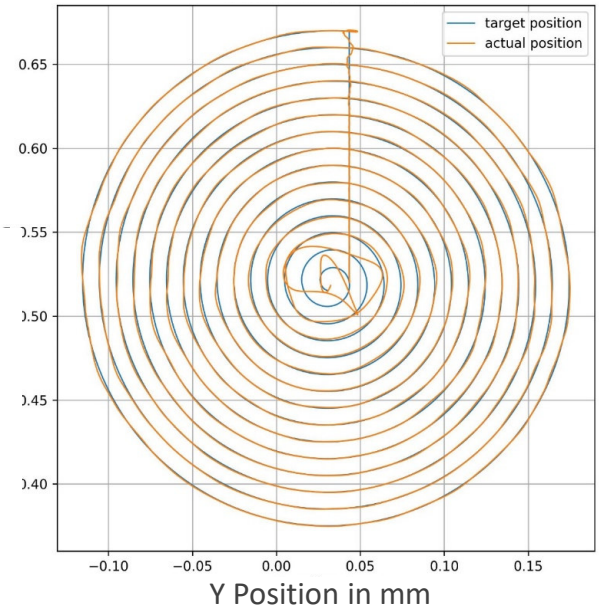
- Spiral scan to find signal maximum
- Scan range of 300 µm
- Line spacing: 10 µm
- Constant velocity: 4 mm / s
- Large position error at the beginning of the scan
- Lever PKM not able to settle at start position → controls reaches limit



H-811



Lever PKM



Outline

DGFT Tagung für Feinwerktechnische Konstruktion 2024 - Dresden

- Background and Motivation
- Mechanical Design
- Qualification
- **Conclusion and Outlook**

Conclusion and Outlook

Conclusion

- Control structure reaching performance limitations with simple PID position control
- Comparable performance with H-811 for standard scan velocities and frequencies

Outlook

- Adaptation of control loop: position, velocity and current control loop
- MIMO control to account for strut coupling?
- Determination of manufacturing costs for higher volumes
- Lifetime tests in scanning and alignment applications

Thank You for Your Attention

Physik Instrumente (PI) GmbH & Co. KG
Auf der Römerstraße 1
76228 Karlsruhe
Germany

Phone +49 721 4846-0
E-mail info@pi.de

Please visit us at: www.physikinstrumente.de

Blog

Alignment

Gradient Scan – Routine Duration