

TWENTY-SEVENTH ANNUAL



TestConX™

Archive

DoubleTree by Hilton
Mesa, Arizona
March 1-4, 2026

Passive Kinematic Photonic Connector with High-Volume Test-Compatible Micron-Level Alignment Repeatability

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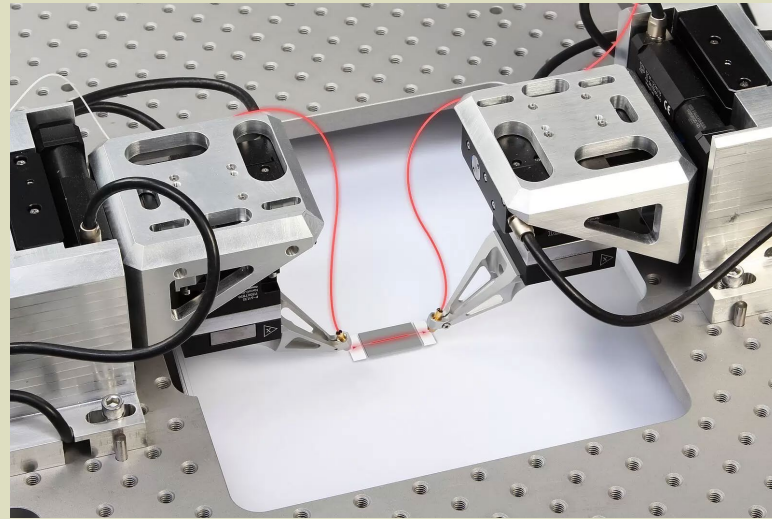


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Why Passive Alignment Matters in Test?

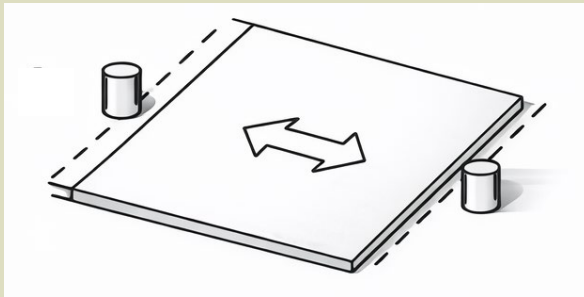
Active alignment works — but it does not scale for test



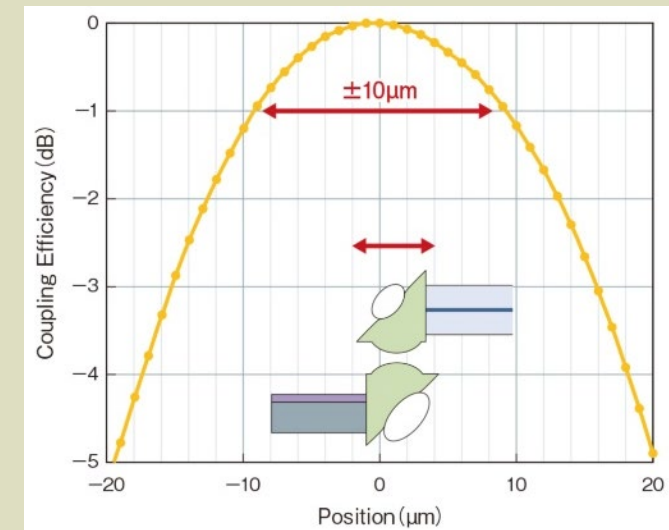
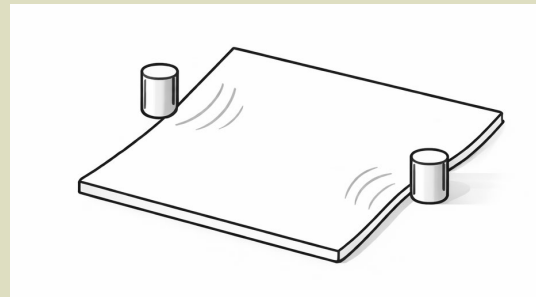
Source: <https://www.pi-usa.us/>

Existing Alignment Methods Fall Short for HVM Test

- Pins and picture-frame schemes are over-constrained
- Contact forces and tolerance stack dominate final position
- Expanded-beam optics shift complexity to the optics



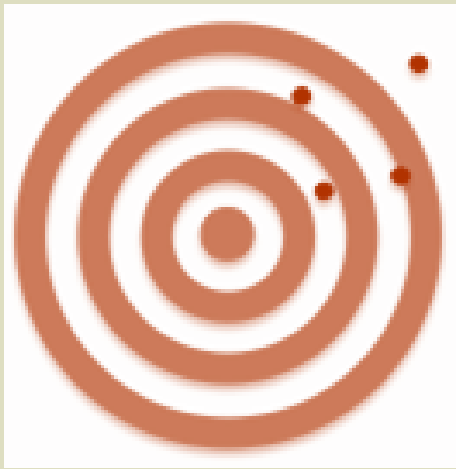
Adapted from Slocum, *Precision Machine Design*



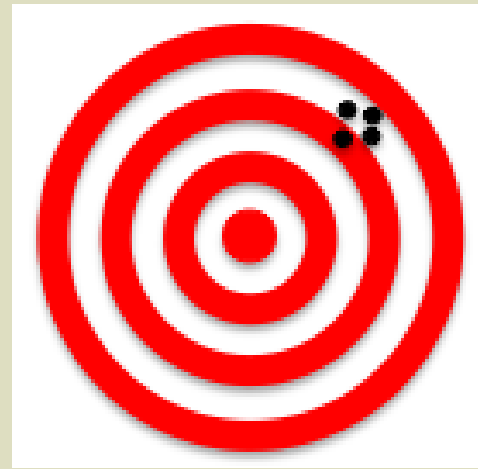
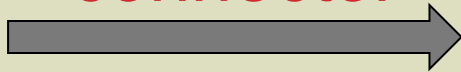
Source: Sumitomo Electric Industries

Precision & Accuracy

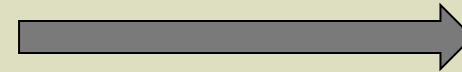
- Test needs precision (return to same position)
- Accuracy is set at assembly
- Kinematic systems excel at precision



Kinematic
connector



Assembly



Precise / Accurate

+Precision

+Accuracy

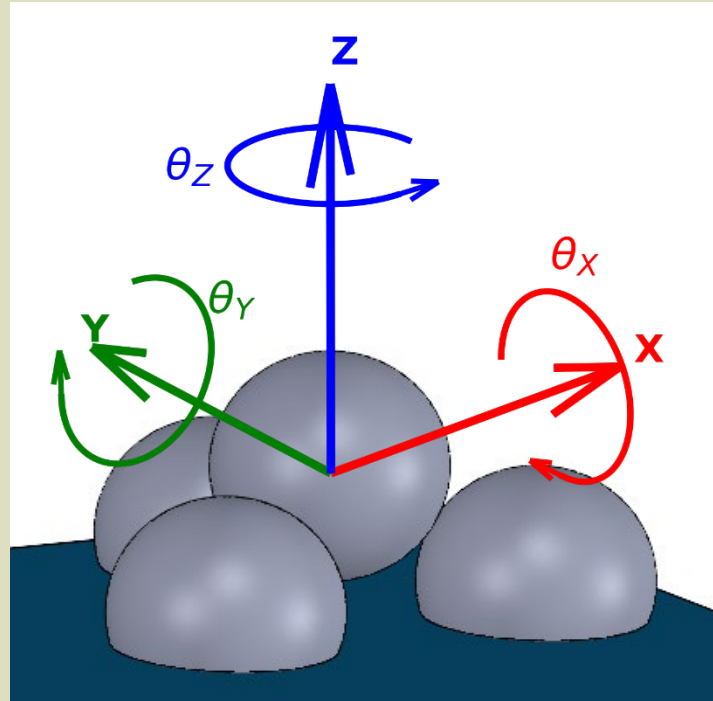


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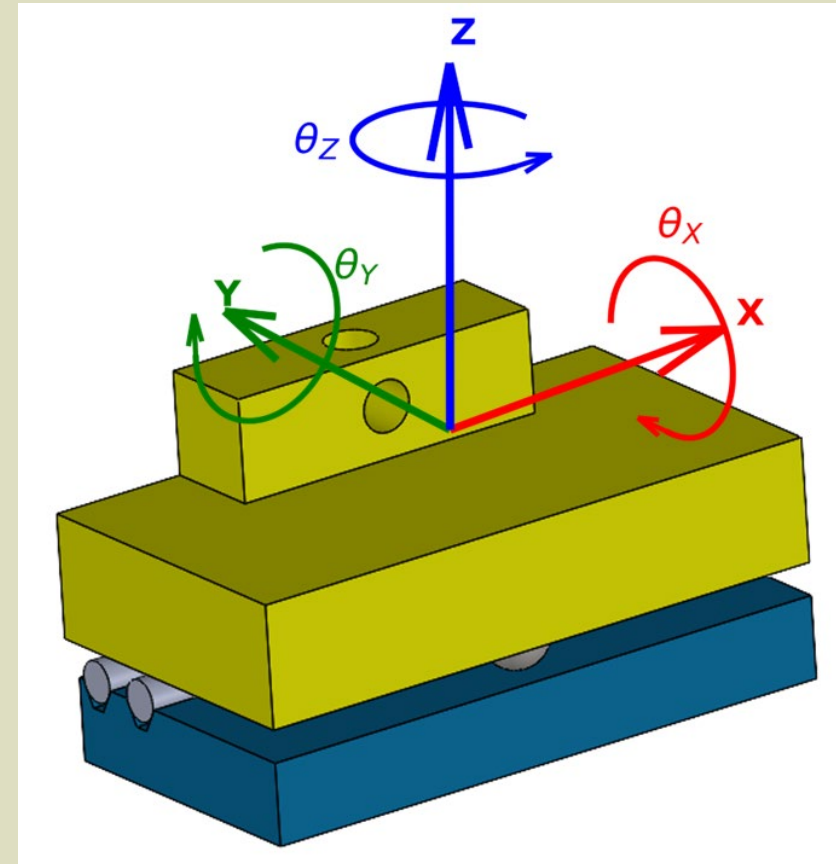
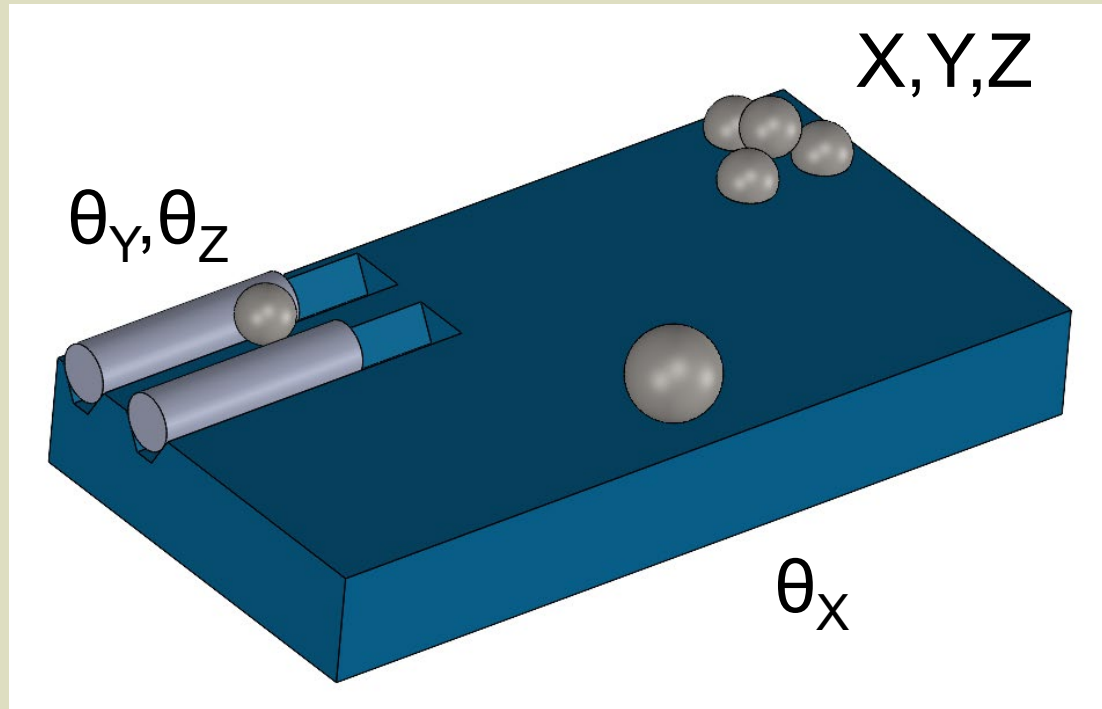
What the Kinematic Connector Gives You

- Exactly constrained system (6-DOF, isostatic constraint)
- Single, repeatable equilibrium position
- Alignment defined by geometry, not contact force



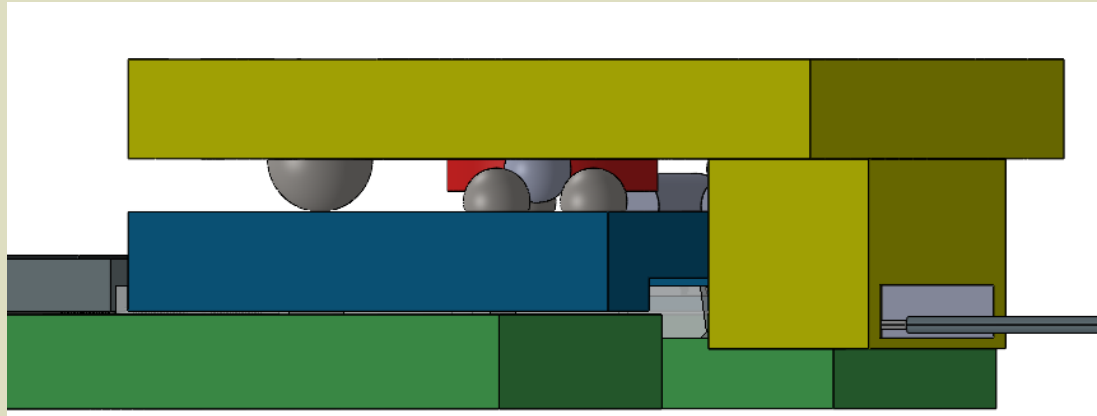
Kinematic Principles Applied to the Connector

- Three constraint sets fully define all 6-DOF
- Passive self-alignment into a single equilibrium position



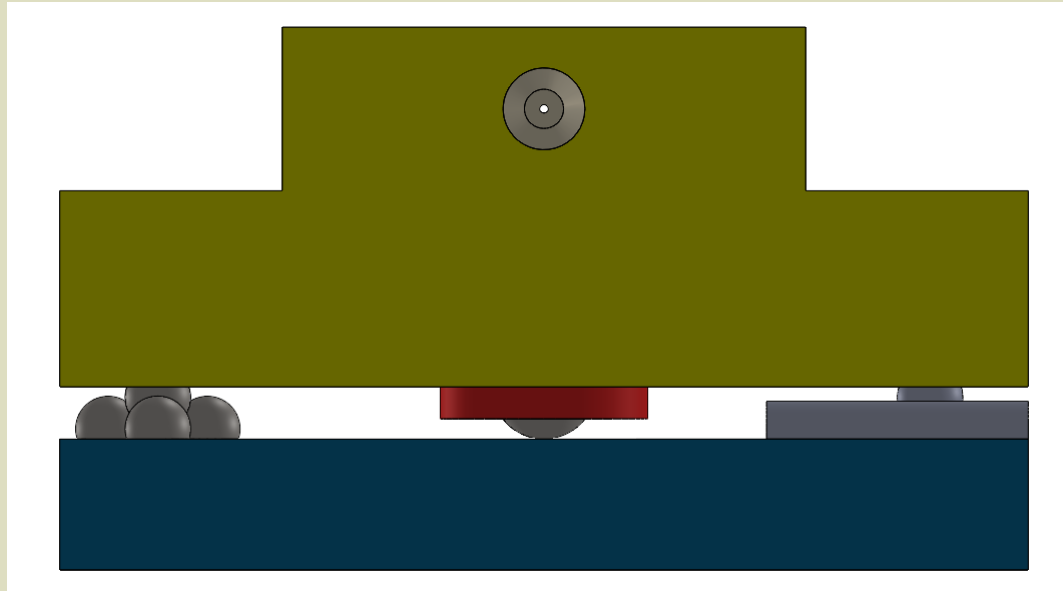
How Accuracy Is Established

- Accuracy is established once during component alignment
- Active alignment is confined to the assembly flow
- Ceramic spheres + flat glass = precision datum
- Test insertion relies on passive repeatability, not re-optimization



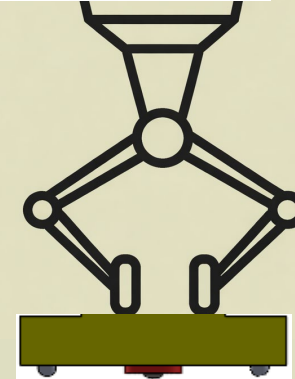
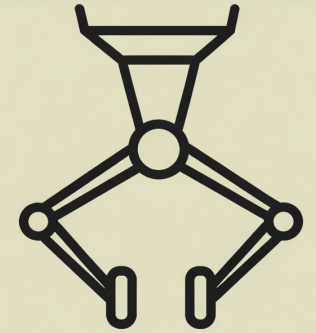
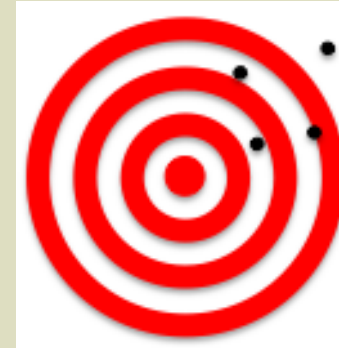
Magnetic Preload & Self-alignment

- Magnetic force is the only preload
- Known direction & magnitude
- No clamp-induced distortion
- No added friction



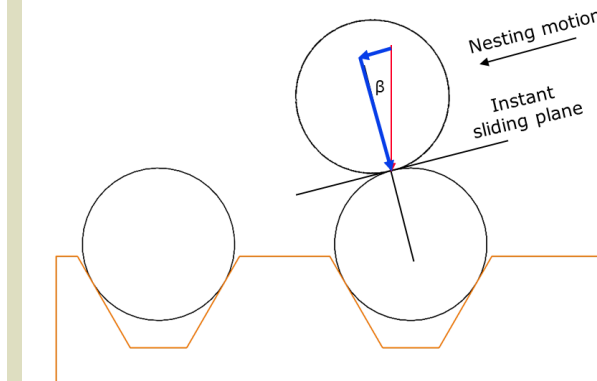
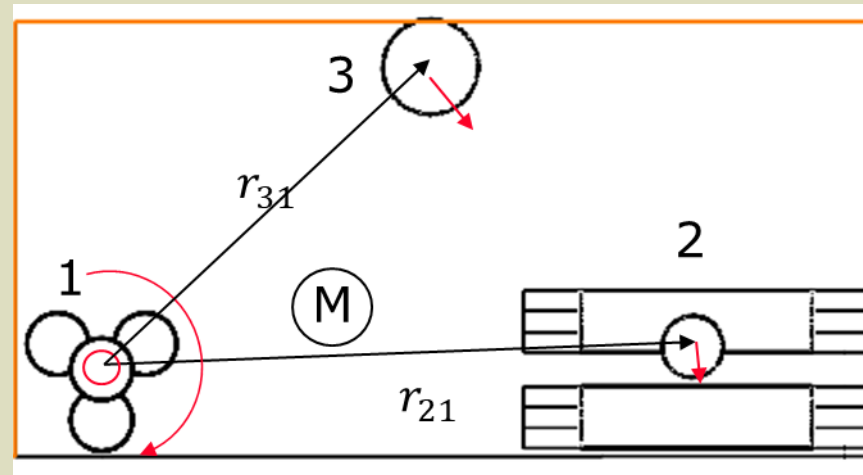
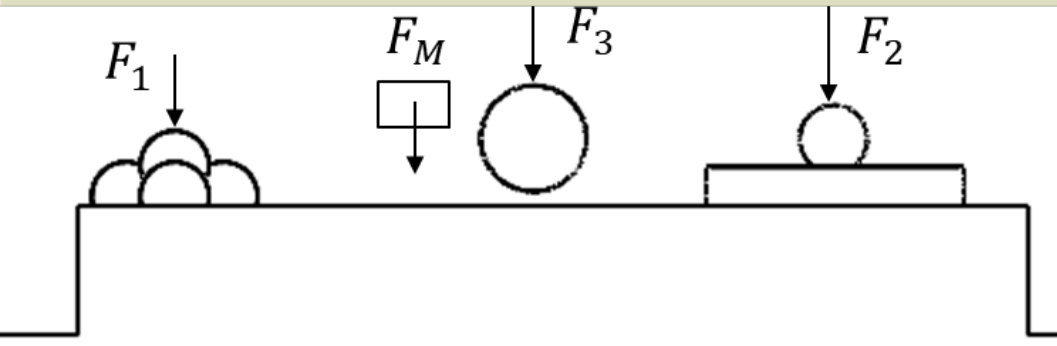
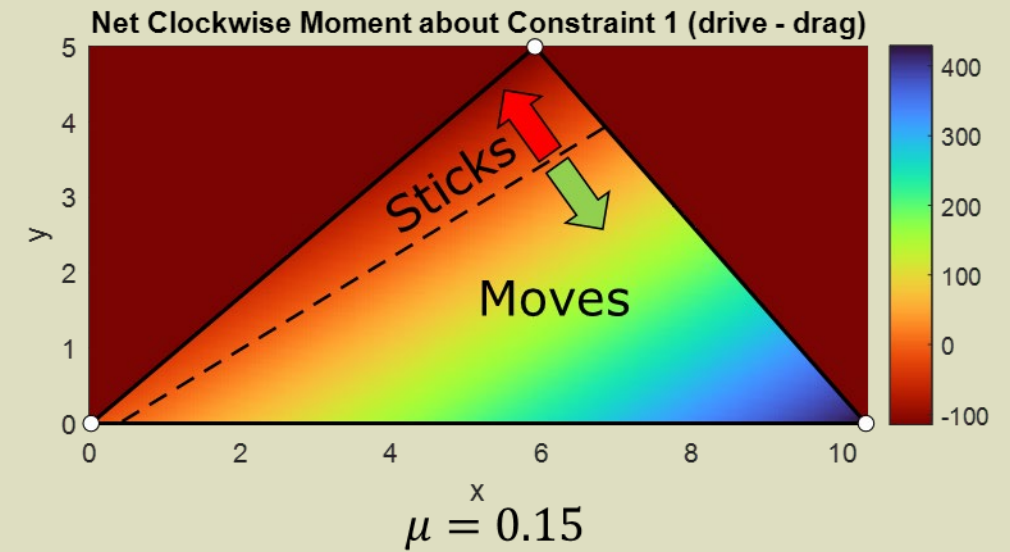
What Changes in Test?

- No active alignment during test
- No holding actuator required
- Pick-and-place + magnetic preload
- Self-aligned, self-loaded interface



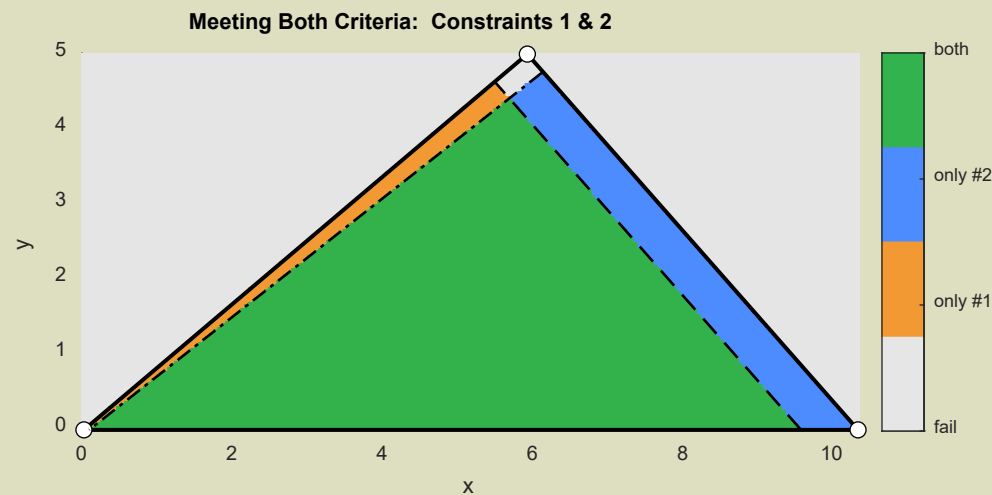
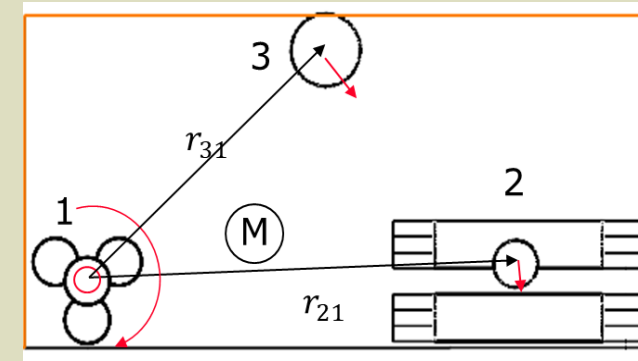
Nesting & Locking Concept

- Motion vs stick regions
- Nesting window exists
- Window size depends on friction

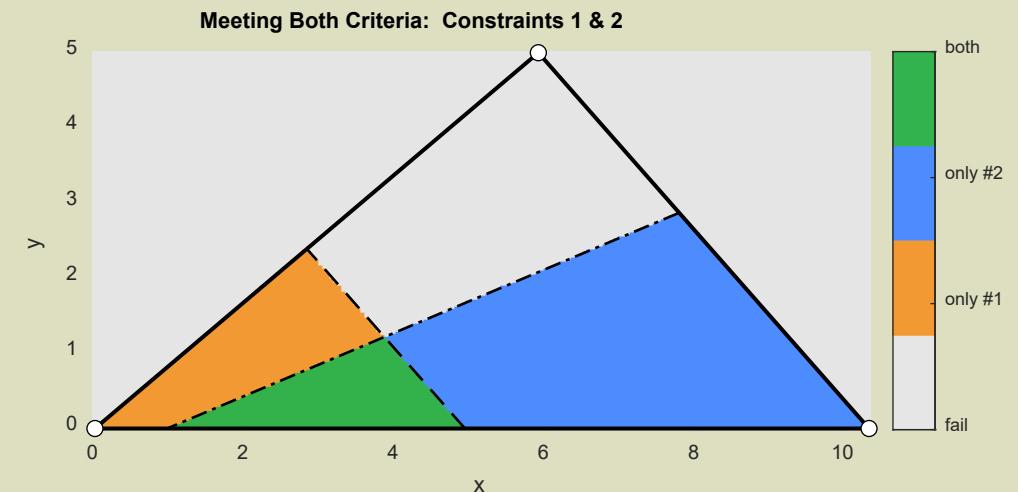


Friction Coefficient Defines the Working Window

- Lower COF $\rightarrow$ larger motion window
- Materials & coatings are tunable
- Many valid implementations



$$\mu = 0.03$$



$$\mu = 0.35$$

External Factors Affecting Precision & Accuracy

- Fiber pull: Design consideration for directional load and bias mitigation
- Vibration: Low friction $\neq$ poor retention
 - Low mass / inertia
 - Magnetic preload
- Thermal expansion: Differential expansion is calculable
 - Drift is small and directional
 - Managed via materials & geometry

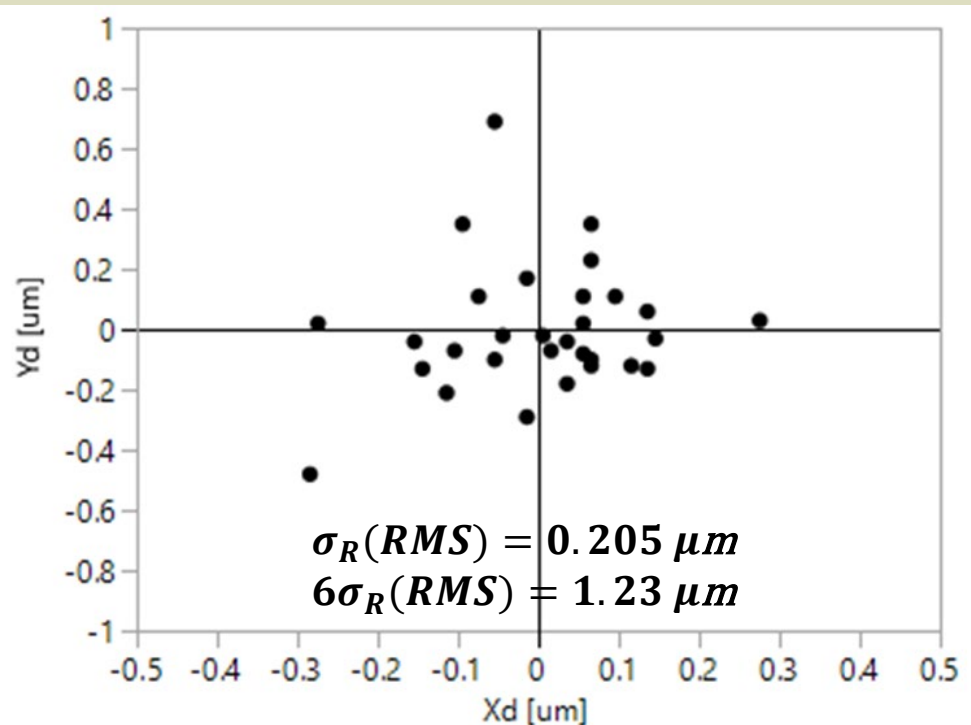


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Dimensional Repeatability Results

- Baseline static and dynamic data collected
- Radial repeatability computed from Cartesian variances



N=30	Static σ [μm]	Dynamic σ [μm]
X	0.059	0.122
Y	0.122	0.215

$$VAR_X = VAR_{Xd} - VAR_{Ys}$$

$$VAR_Y = VAR_{Yd} - VAR_{Xs}$$

$$VAR_R = VAR_X + VAR_Y$$

$$\sigma_R(RMS) = \sqrt{VAR_R}$$

Passive insertion repeatability shown over 30 cycles



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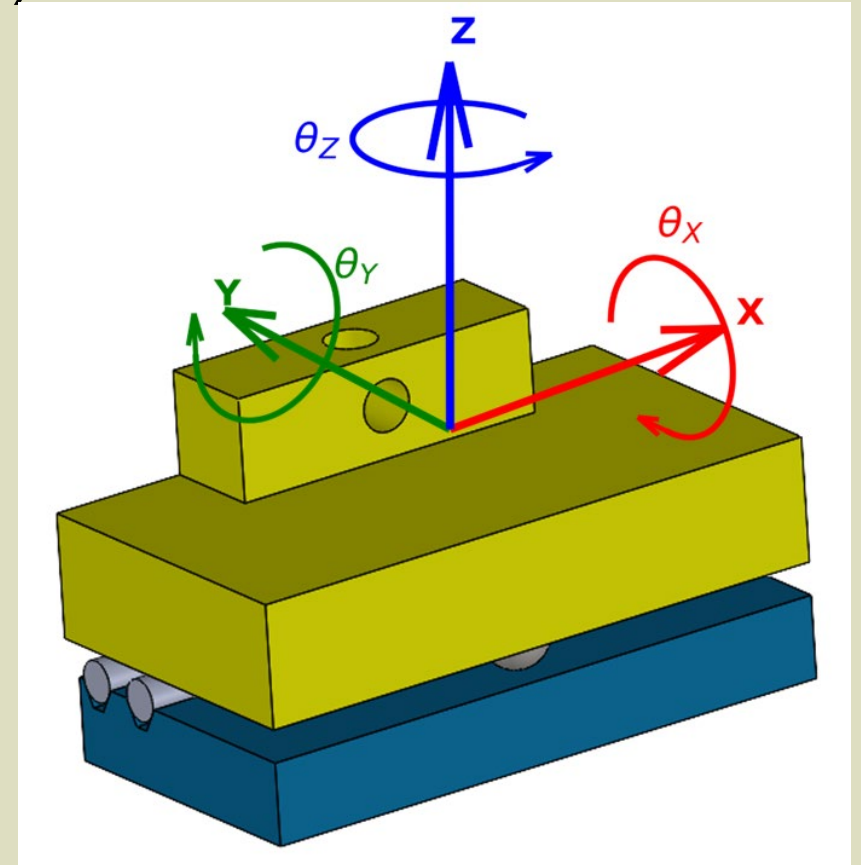
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Angular Repeatability Results

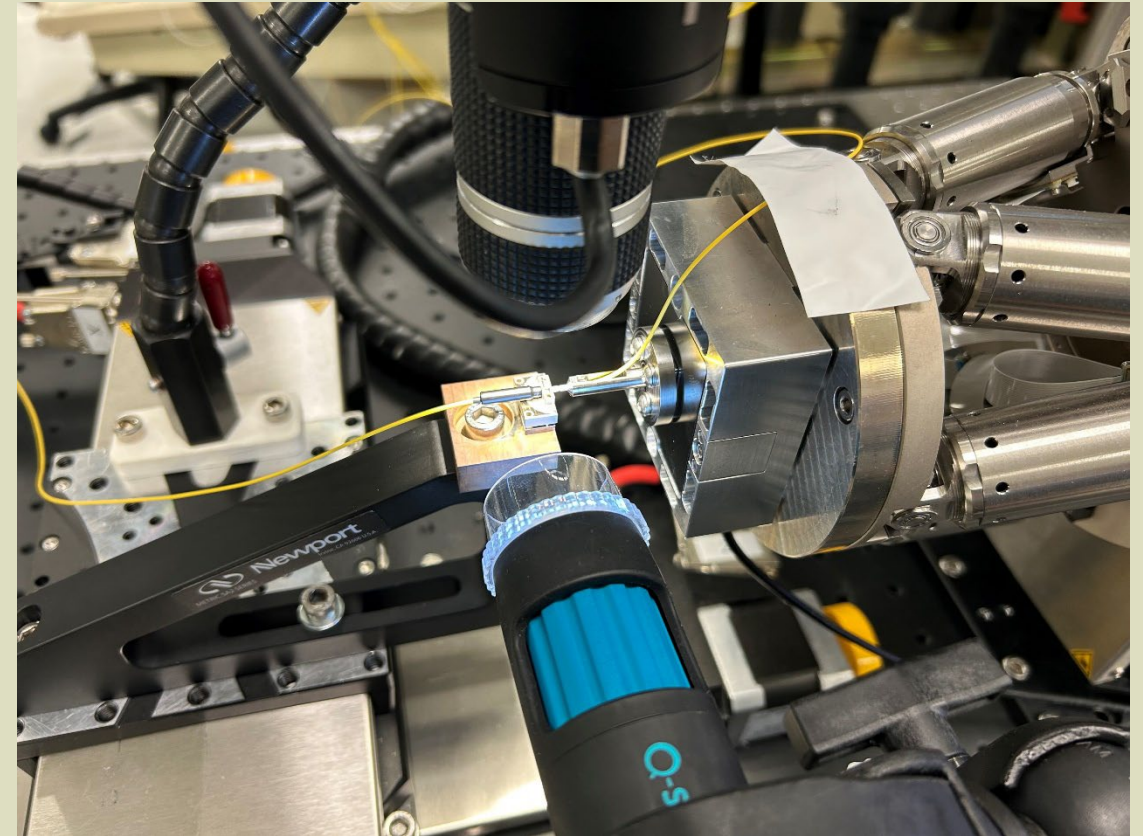
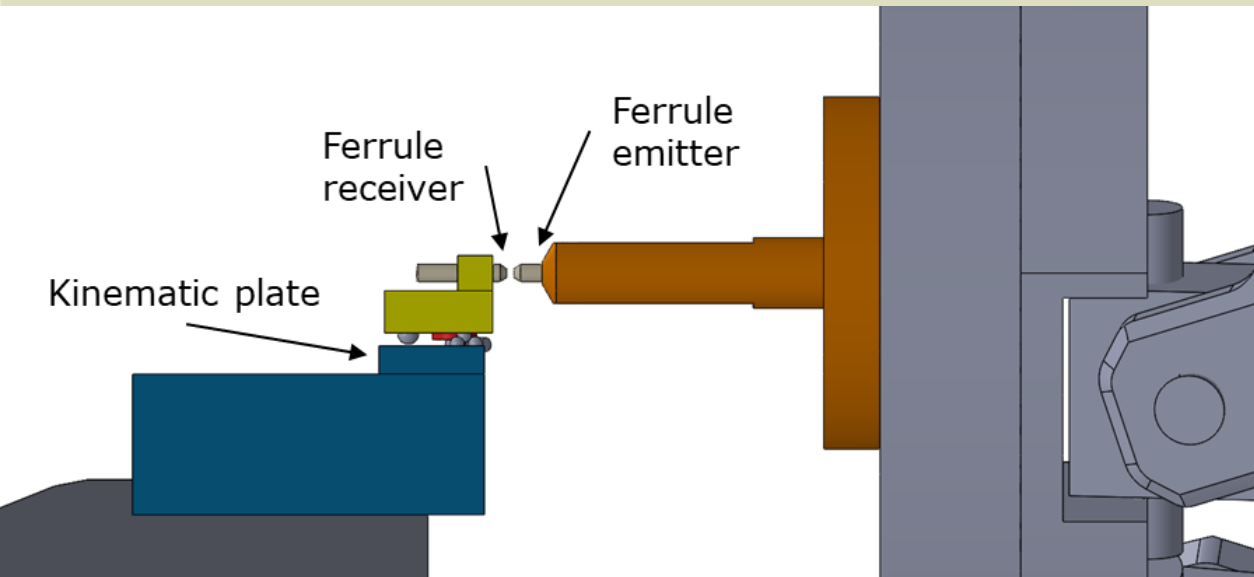
- Dynamic repeatability (passive insertion)

Axis	σ (mdeg)	6σ (mdeg)
θ_X	0.95	5.7
θ_Y	1.96	11.7
θ_Z	1.74	10.5

Angular Repeatability (Dynamic / Passive Insertion, N = 30)
Reported as measured (no variance subtraction)



Optical Insertion Loss Repeatability Setup

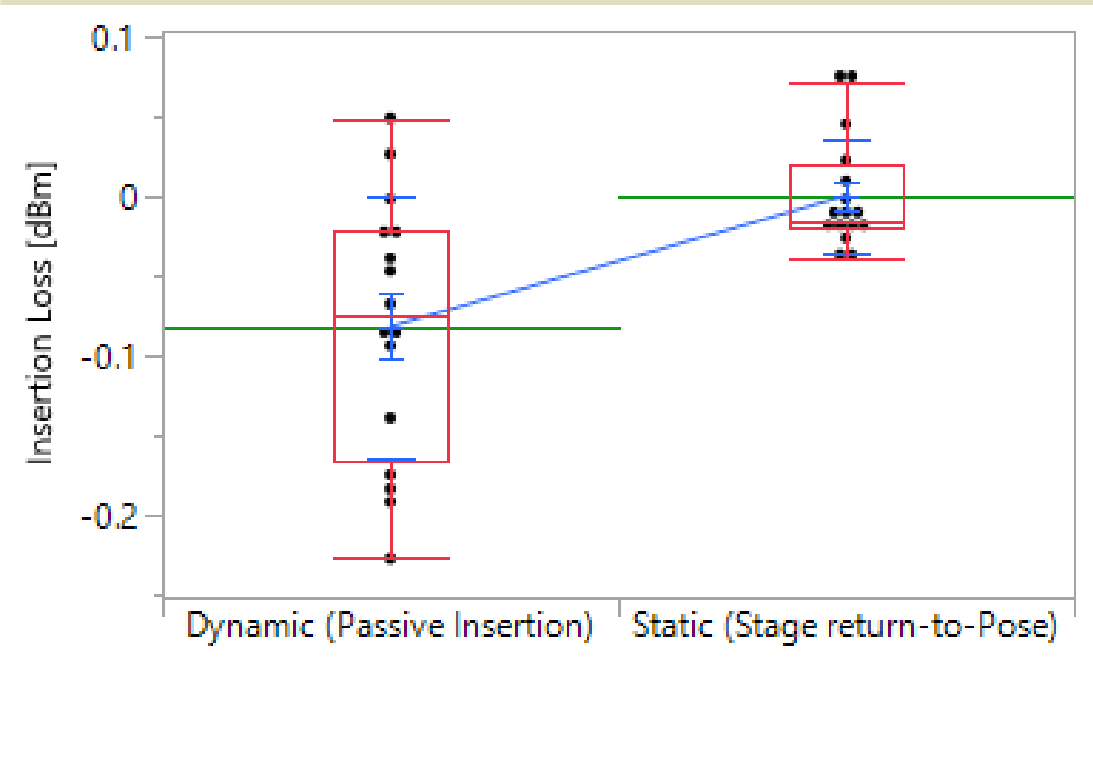


Static repeatability: Move emitter

Dynamic repeatability: Static + hand placement of receiver ferrule

Optical Insertion Loss Repeatability

- Static and dynamic repeatability



Passive Insertion IL Repeatability

$$\sigma_{IL} \approx 0.08 \text{ dB}$$

$$6\sigma_{IL} \approx 0.5 \text{ dB}$$

Mean IL Offset (relative to Static Return-to-Pose)

$$\Delta\text{Mean} \approx -0.08 \text{ dB (expected)}$$



Not One Design, a Design Class

- Geometric variants: planar, pocketed, and hybrid kinematic interfaces
- Material variants: metals, ceramics, coated interfaces (friction tuned)
- Invariant principle: deterministic constraint + preload defines alignment



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Path Toward Standardization

- Deterministic datums improve test repeatability
- Non-kinematic optical connectors are already standardized
- Opportunity: standardize passive kinematic test couplers



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Summary

- Passive kinematic interface achieves micron-level repeatability
- Eliminates active alignment and holding actuators during test
- Enables faster, simpler, and more scalable optical test flows



Next Steps

- Robustness tuning across preload and vibration
- Multi-channel scaling for parallel optical test
- Industry engagement towards kinematic test standards



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