TWENTY-SEVENTH ANNUAL

TestConX™

Archive

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Mesa, Arizona
March 1-4, 2026

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

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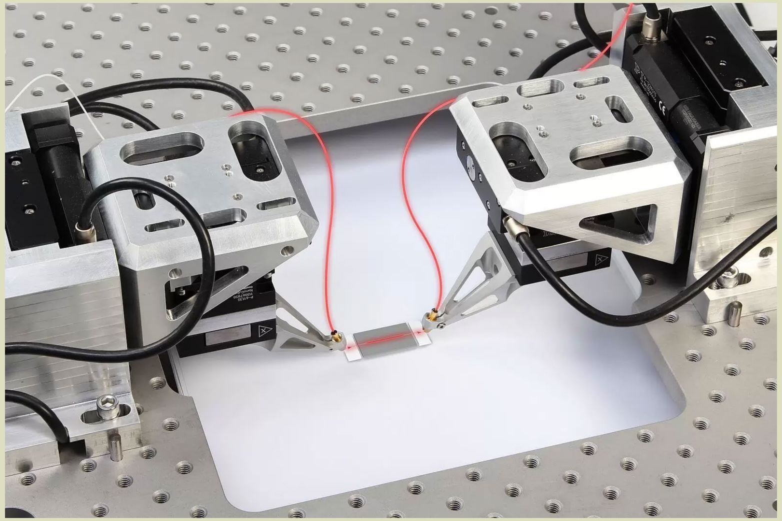
Why Passive Alignment Matters in Test?

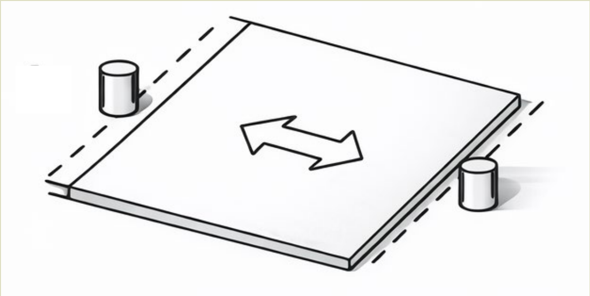
Active alignment works — but it does not scale for test

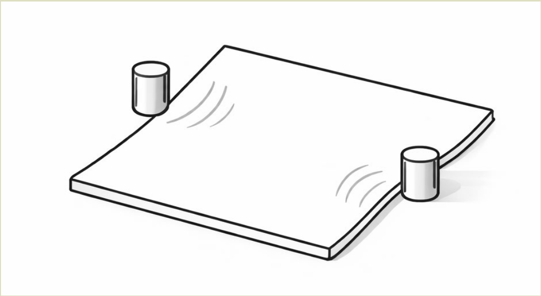


Source: https://www.pi-usa.us/

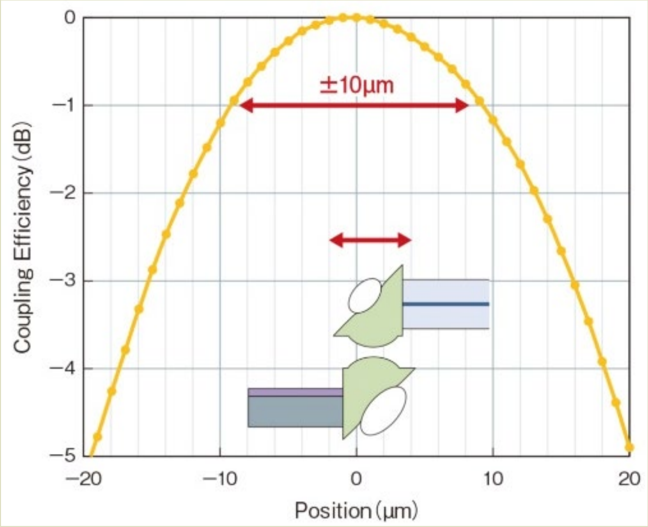
Existing Alignment Methods Fall Short for HVM Test

- 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

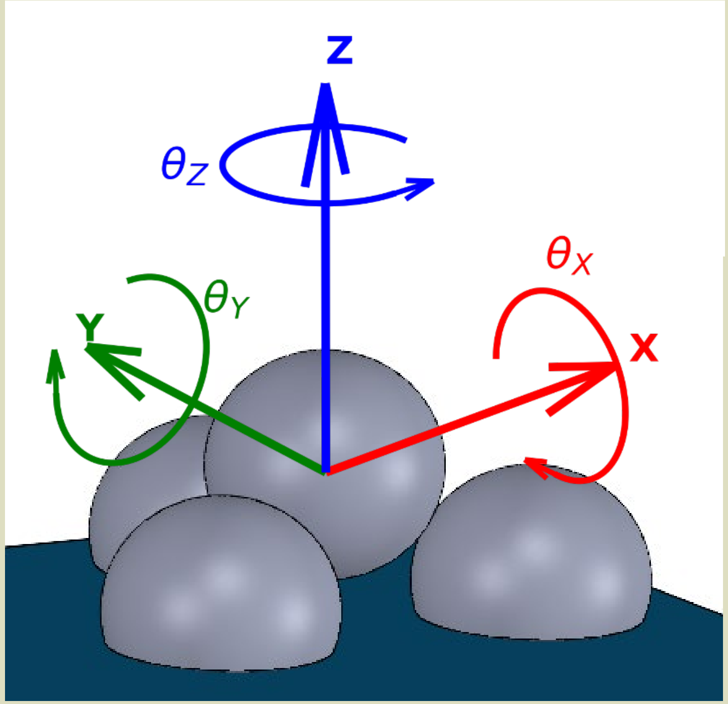
Precision & Accuracy

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

~~Precise~~ / ~~Accurate~~ +Precision +Accuracy

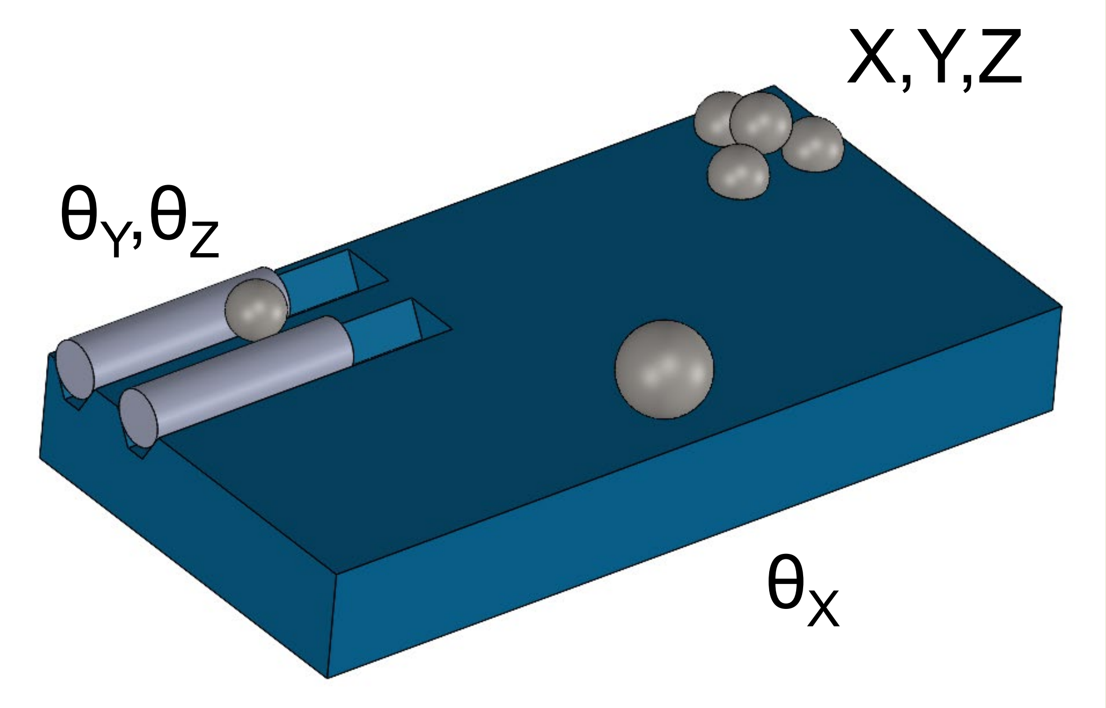
What the Kinematic Connector Gives You

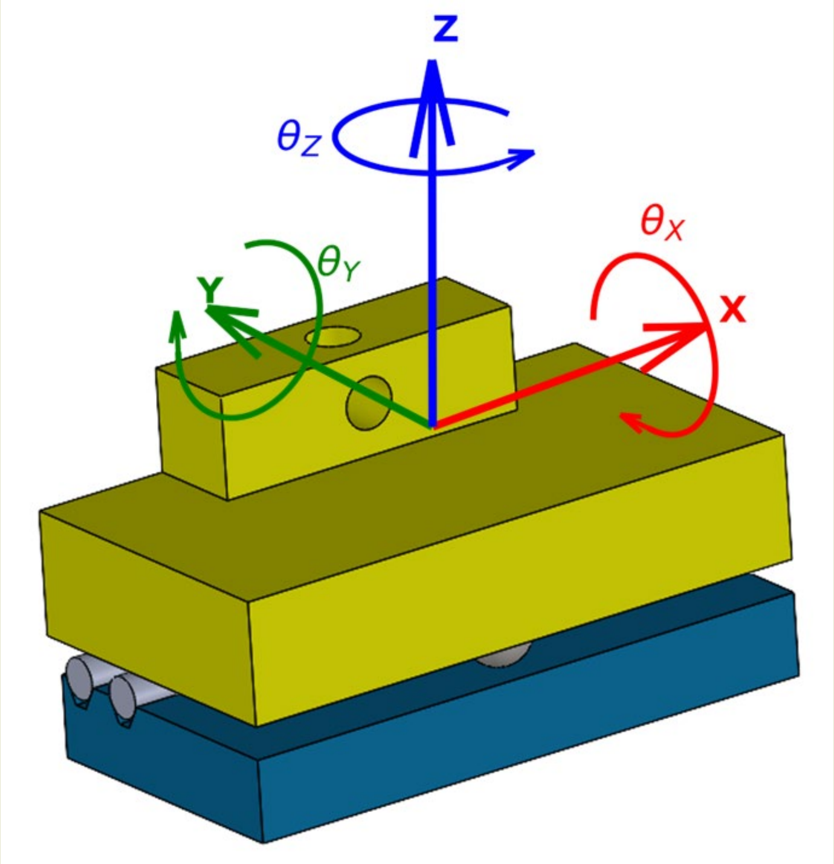
- Exactly constrained system (6-DOF, isostatic constraint)
- Single, repeatable equilibrium position
- Alignment defined by geometry, not contact force



Kinematic Principles Applied to the Connector

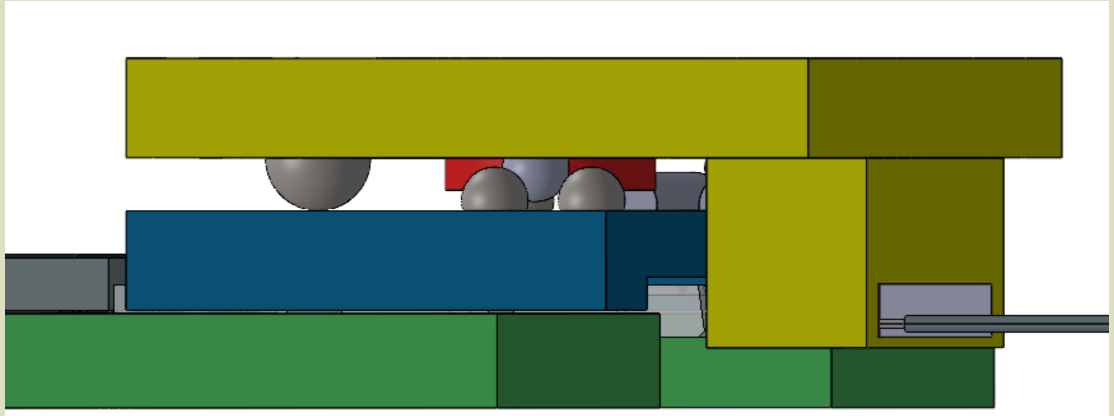
- Three constraint sets fully define all 6-DOF
- Passive self-alignment into a single equilibrium position





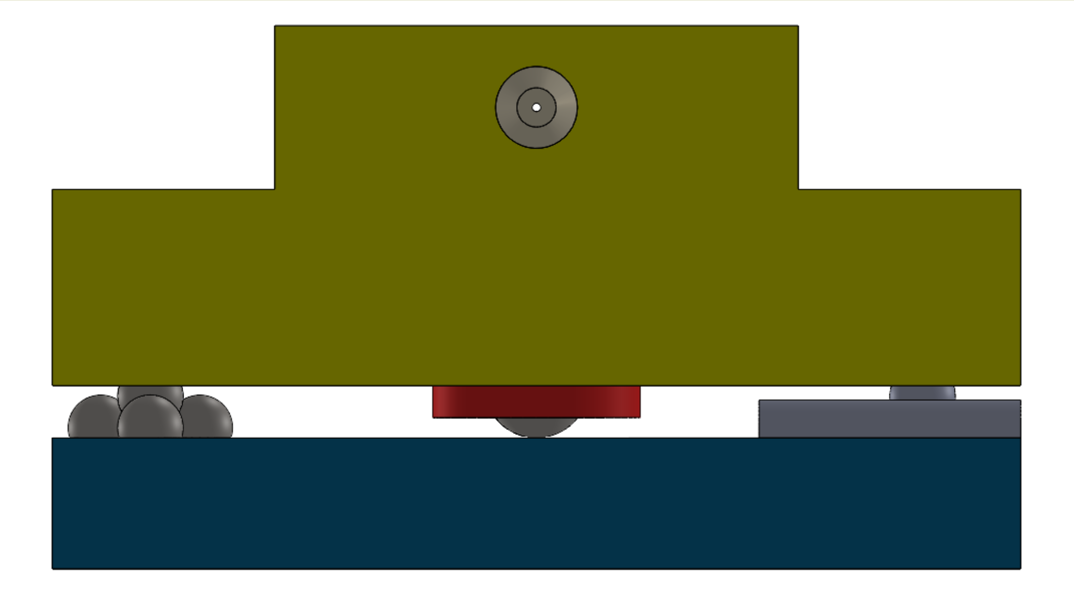
How Accuracy Is Established

- 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



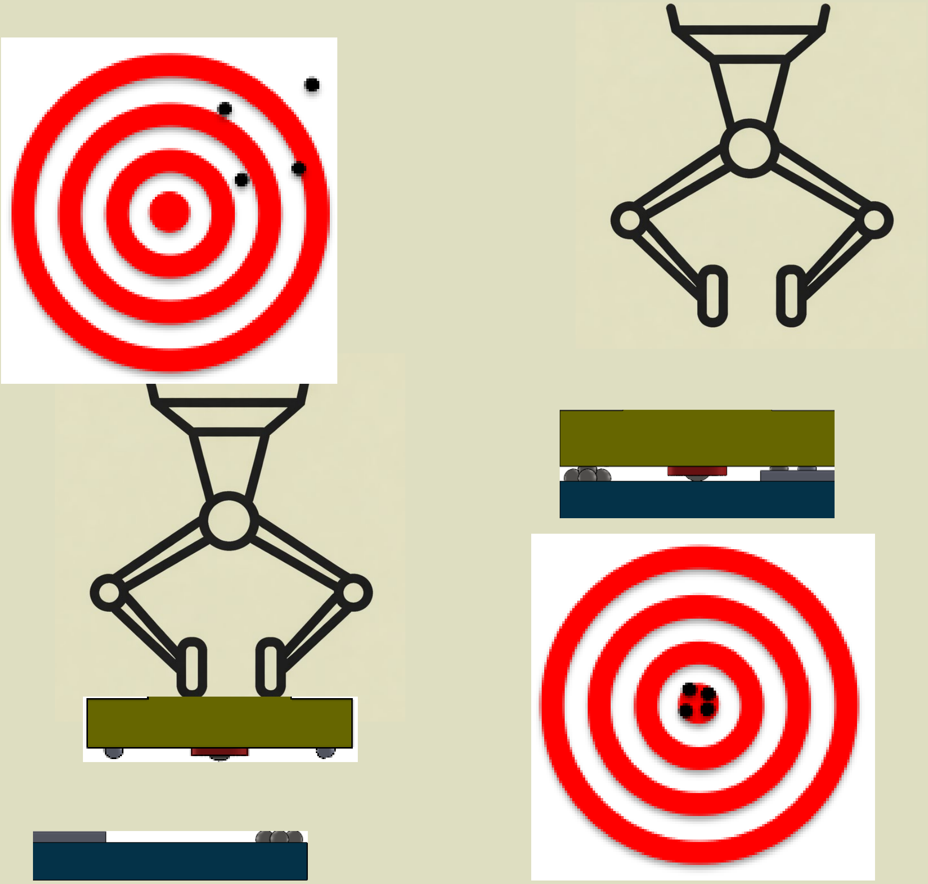
Magnetic Preload & Self-alignment

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



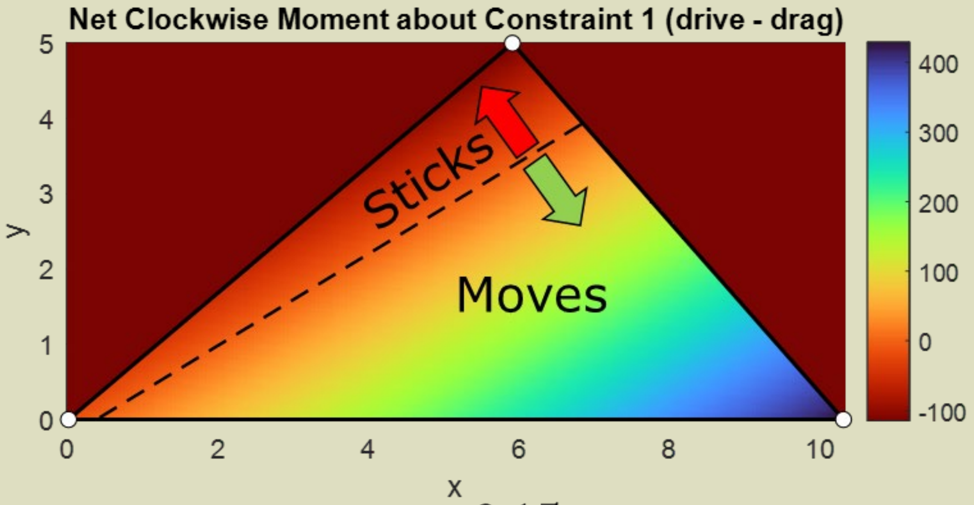
What Changes in Test?

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

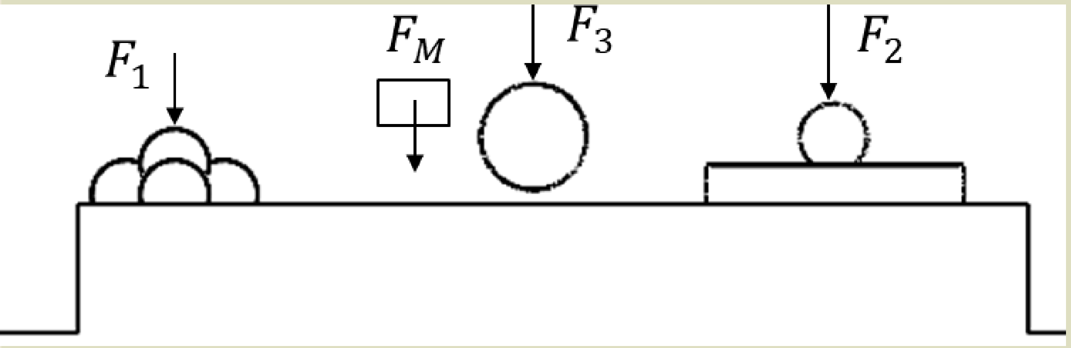


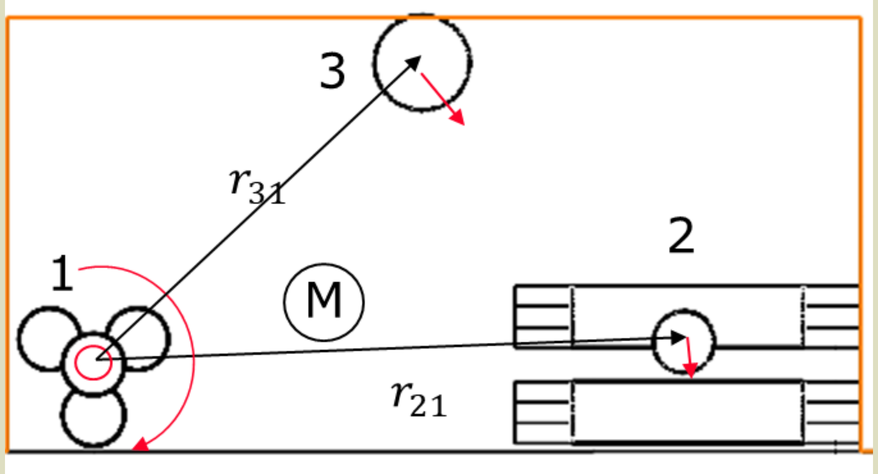
Nesting & Locking Concept

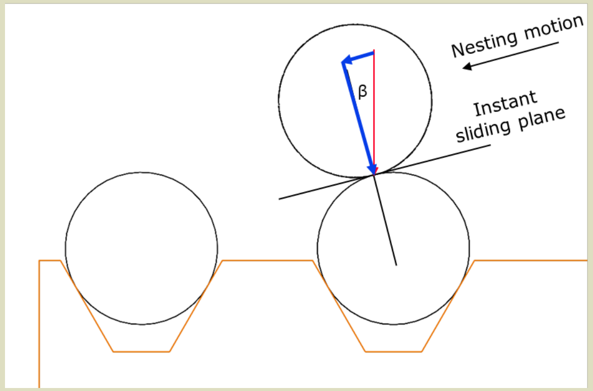
- Motion vs stick regions
- Nesting window exists
- Window size depends on friction



$\mu = 0.15$

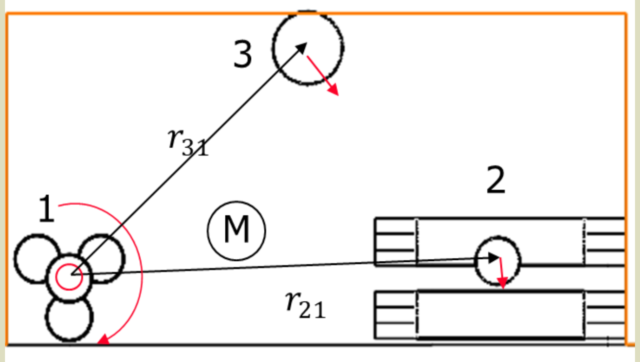


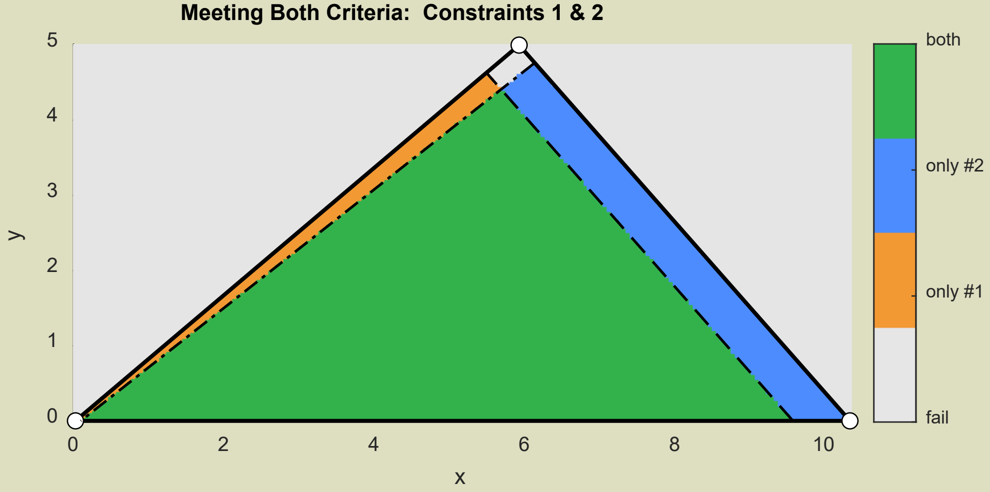




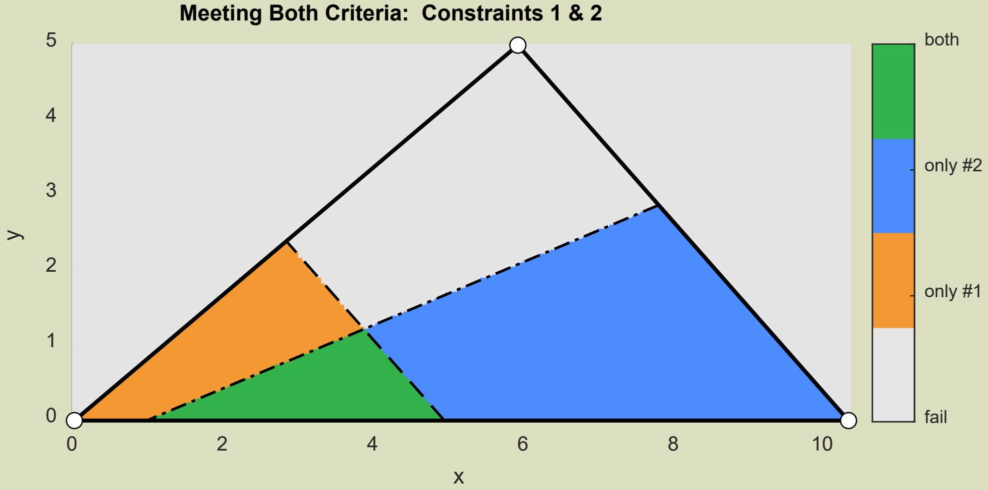
Friction Coefficient Defines the Working Window

- Lower COF → larger motion window
- Materials & coatings are tunable
- Many valid implementations





$\mu = 0.03$



$\mu = 0.35$

External Factors Affecting Precision & Accuracy

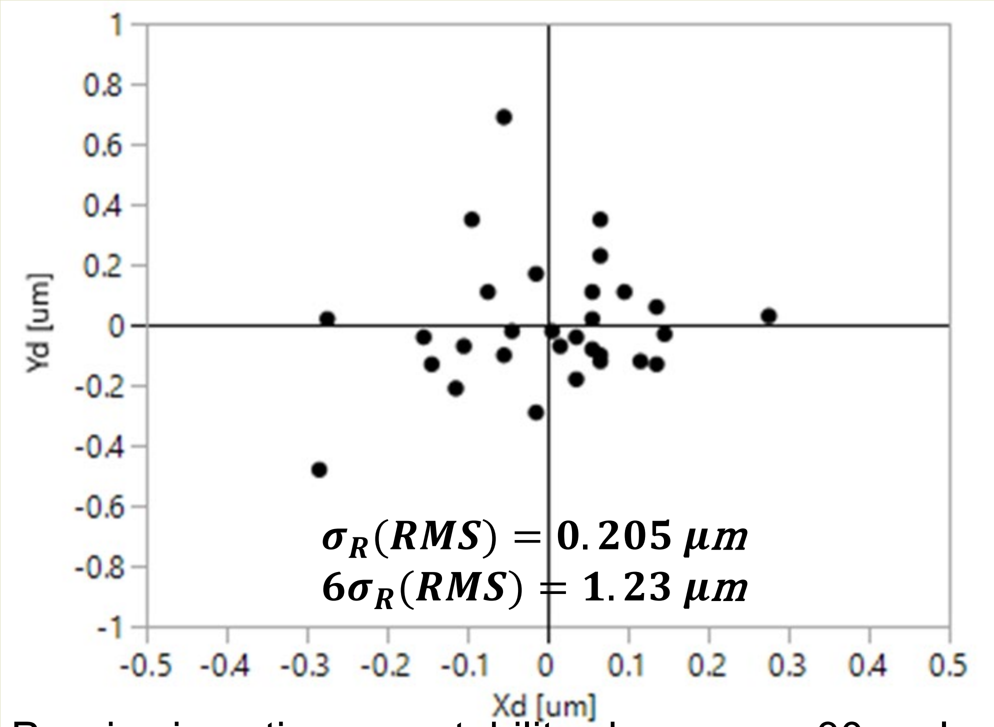
- Fiber pull: Design consideration for directional load and bias mitigation

- Vibration: Low friction ≠ poor retention
  - Low mass / inertia
  - Magnetic preload

- Thermal expansion: Differential expansion is calculable
  - Drift is small and directional
  - Managed via materials & geometry

Dimensional Repeatability Results

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



Passive insertion repeatability shown over 30 cycles

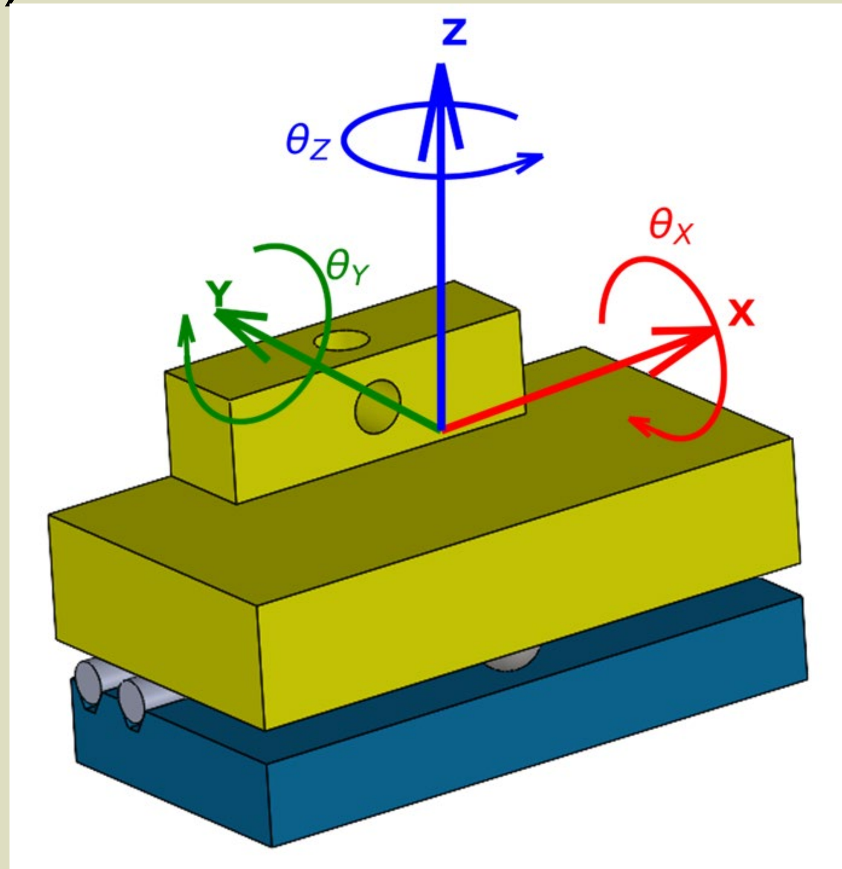
N=30	Static σ [μm]	Dynamic σ [μm]
X	0.059	0.122
Y	0.122	0.215

$$VAR_X = VAR_{Xd} - VAR_{Ys}$$
$$VAR_Y = VAR_{Yd} - VAR_{Ys}$$
$$VAR_R = VAR_X + VAR_Y$$
$$\sigma_R(RMS) = \sqrt{VAR_R}$$

Angular Repeatability Results

- Dynamic repeatability (passive insertion)

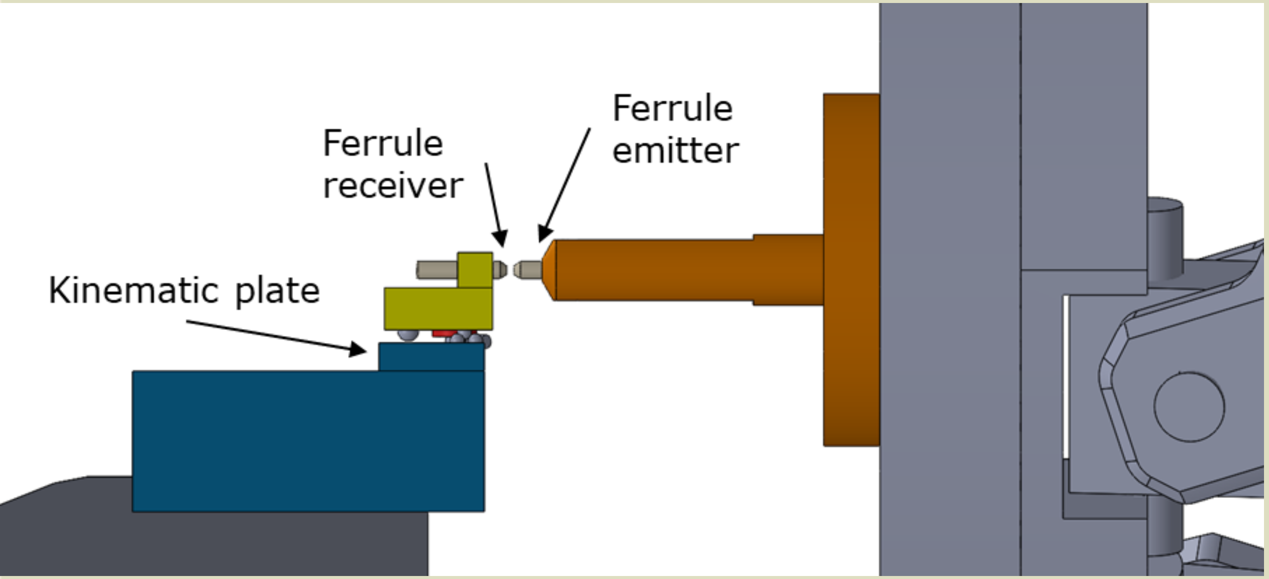
Axis	σ (mdeg)	6σ (mdeg)
θ_X	0.95	5.7
θ_Y	1.96	11.7
θ_Z	1.74	10.5

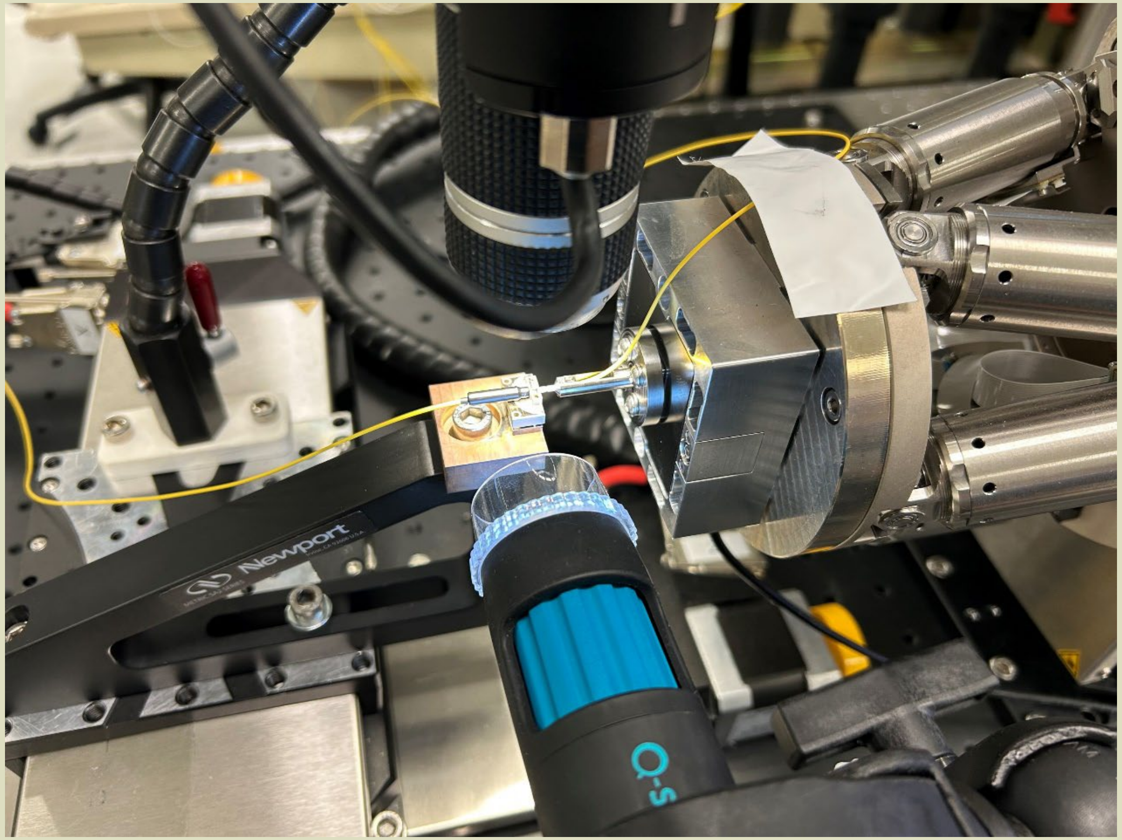


Angular Repeatability (Dynamic / Passive Insertion, N = 30)

Reported as measured (no variance subtraction)

Optical Insertion Loss Repeatability Setup



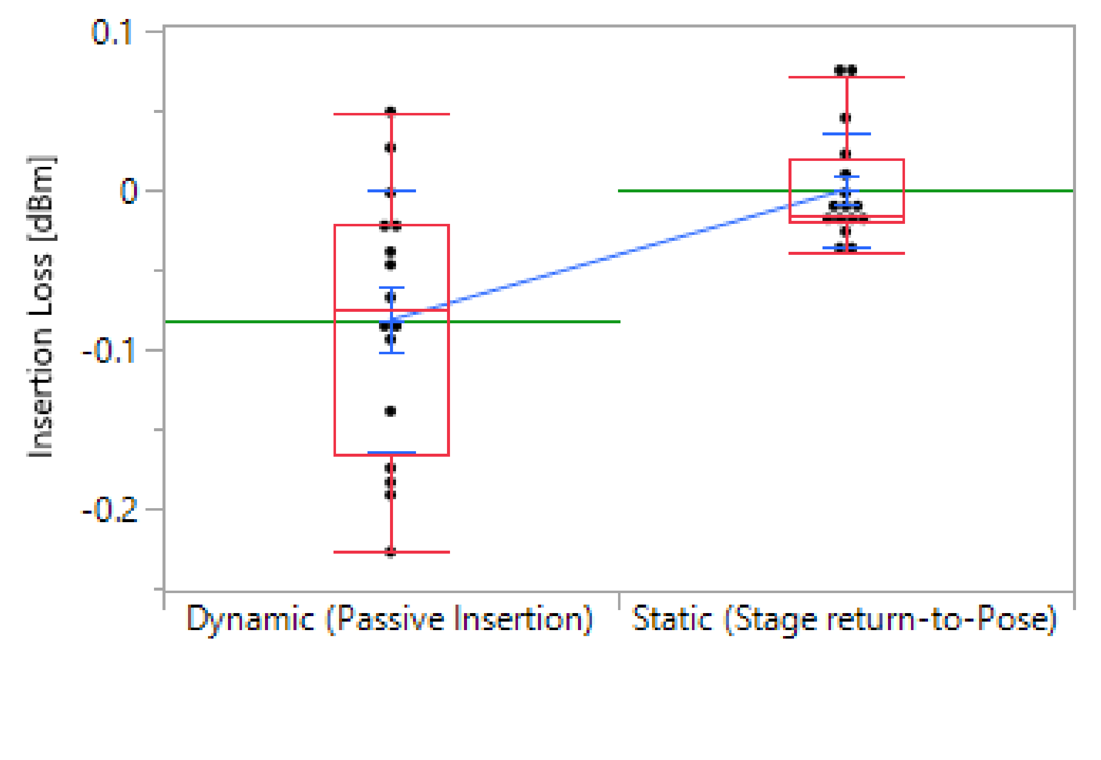


Static repeatability: Move emitter

Dynamic repeatability: Static + hand placement of receiver ferrule

Optical Insertion Loss Repeatability

- Static and dynamic repeatability



Passive Insertion IL Repeatability

$\sigma_{IL} \approx 0.08$ dB

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

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

ΔMean≈ −0.08 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

Path Toward Standardization

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

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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