APPLICATION OF
PRECISION ENGINEERING PRINCIPLES
IN LINEAR STAGE DESIGN

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Key Points

- Some Basics
- Deterministic mechanical theory
- Temperature
- Flexures
- Kinematics
- Abbe Error
The 6 Degrees of Freedom

Every solid body has 6 degrees of freedom.
A linear stage is meant to provide one degree of freedom only
Stacked Stages

Multiple stages provide additional degrees of freedom
Stiffness Loop

Goal: Fully control the chuck/probe card relationship
Deterministic Mechanical Theory

“An automatic manufacturing process is always operating perfectly. It may not be doing what is required, but if that is so it is because it has not been suitably arranged.”

John Loxham, founder, Cranfield Unit for Precision Engineering

“Automatic machine tools and measuring machines are perfectly repeatable just like the stars and the planets.”

Jim Bryan, Chief Metrologist, Lawrence Livermore National Laboratory (retired)

“Random results are the consequence of random procedures.”

Jeff Portas, Managing Director, Cranfield Precision
Obstacles to Repeatability

- Random processes
- Temperature effects
- Mechanical hysteresis
- Vibration
- Poor resolution
- Dirt
- Friction
- Fluctuations in power, air, vacuum
Temperature

- The rate of change can be more critical than the change itself
- A machine’s response to temperature change is similar to a network of RC circuits

Steel stages attached to aluminum bases can behave like bi-metallic strips

300mm of steel changes 4 μm in length for every degree C change; for aluminum, 7μm
Hysteresis

Linked components exhibit hysteresis
Flexures allow movement without hysteresis
Simple support can often handle off-center loads better than cantilevered
XY Gantry with flexures

Addition of flexural supports prevents racking and allows for some theta positioning
Kinematic mounts

The 6 degrees of freedom are constrained at only 6 points
Overconstraint

If 3 legs don’t rock, why have 4?
Kinematically Mounted Stage

A twist in ‘A’ does not induce twist in ‘B’
The Abbe Principle

If errors in parallax are to be avoided, the measuring system must be placed coaxially with the axis along which displacement is to be measured on the workpiece.

Ernst Abbe
1840-1905
Abbe Error

Measurements at the encoder ‘A’ do not match those at encoder ‘B’
‘B’ is less than that indicated by encoder ‘A’
Roll

Roll contribution from skewed rails
Compounded Error

Abbe error is compounded when stages are stacked
Guided Z Stage

Pitch and roll errors can be minimized when the Z drive is only guided by the X and Y stages.
Laser interferometry

Abbe error is eliminated, but the cost is high
Managing Abbe Error

- Kinematics and flexures
- Tighter tolerancing in components
- Advanced environmental control
- Error mapping at the workpiece
- Laser interferometry
Conclusions

Using precision engineering principles, linear stage design can be optimized to:

- Mitigate temperature effects
- Achieve high resolution
- Minimize Abbe errors