APPLICATION OF
PRECISION ENGINEERING PRINCIPLES
IN LINEAR STAGE DESIGN

Gary Gunderson

Applied Precision, LLC

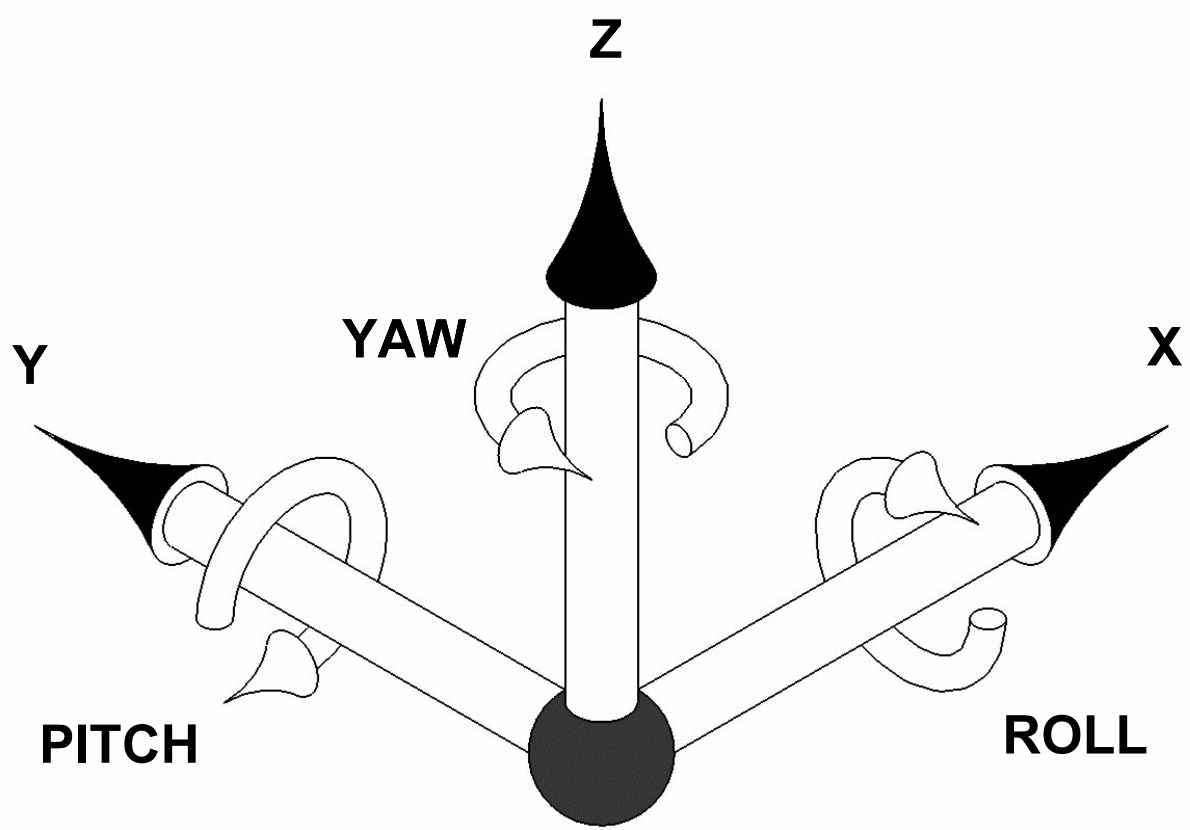
South West Test Workshop
10 June 2002
Long Beach, CA USA

AppliedPrecision
Enabling the world's core technologies

Key Points

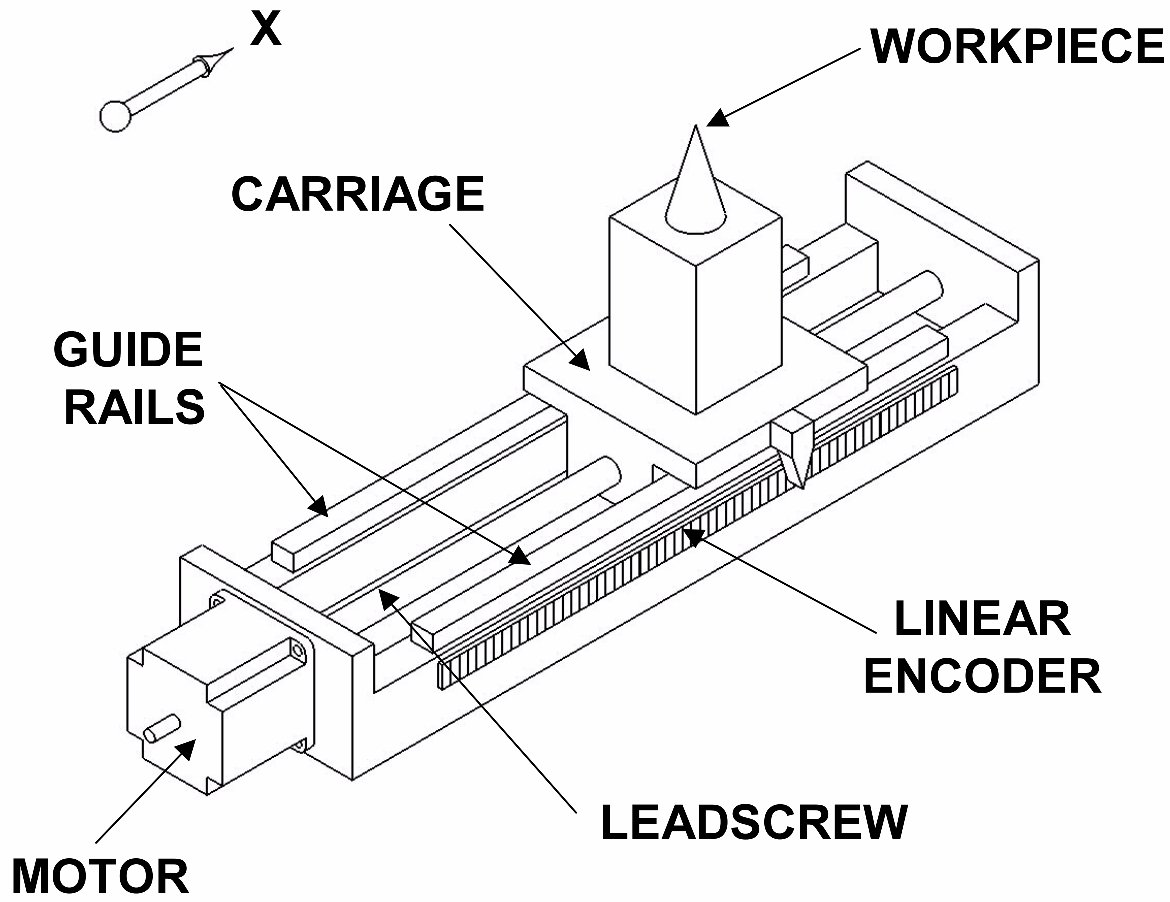
- **Some Basics**
- **Deterministic mechanical theory**
- **Temperature**
- **Flexures**
- **Kinematics**
- **Abbe Error**

The 6 Degrees of Freedom



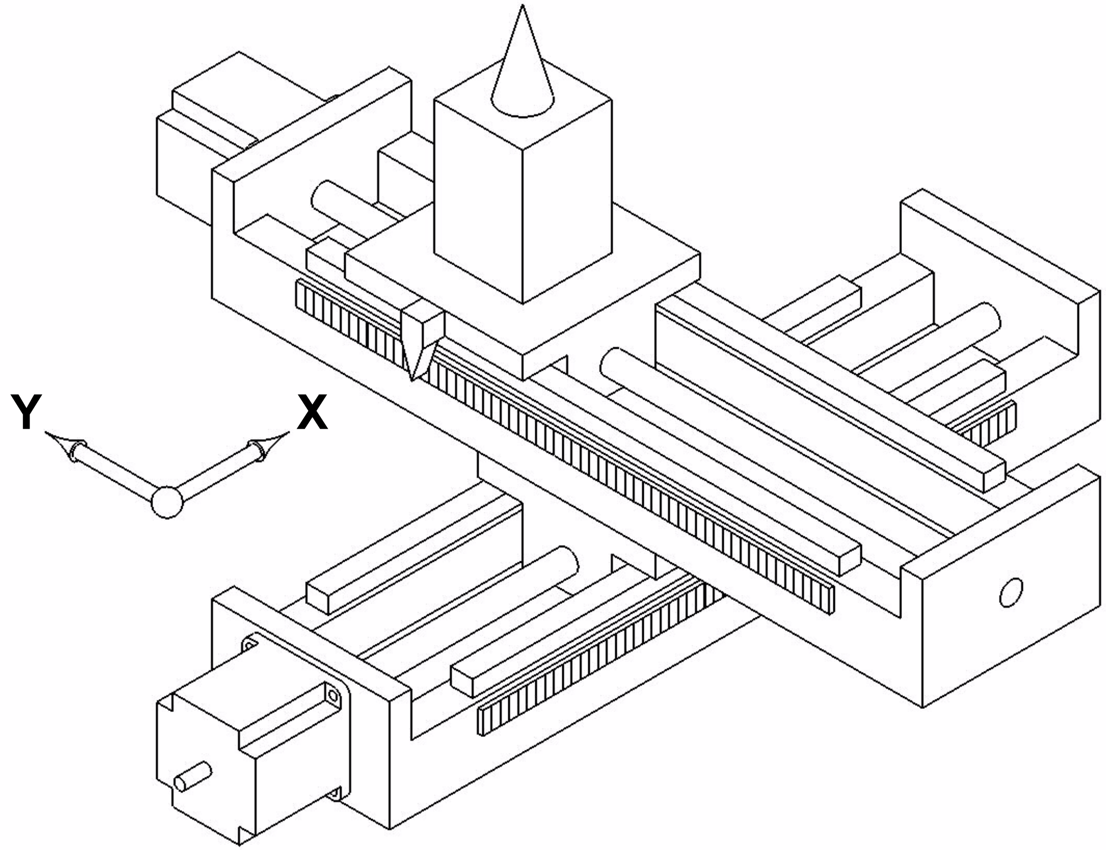
Every solid body has 6 degrees of freedom

Basic Linear Stage



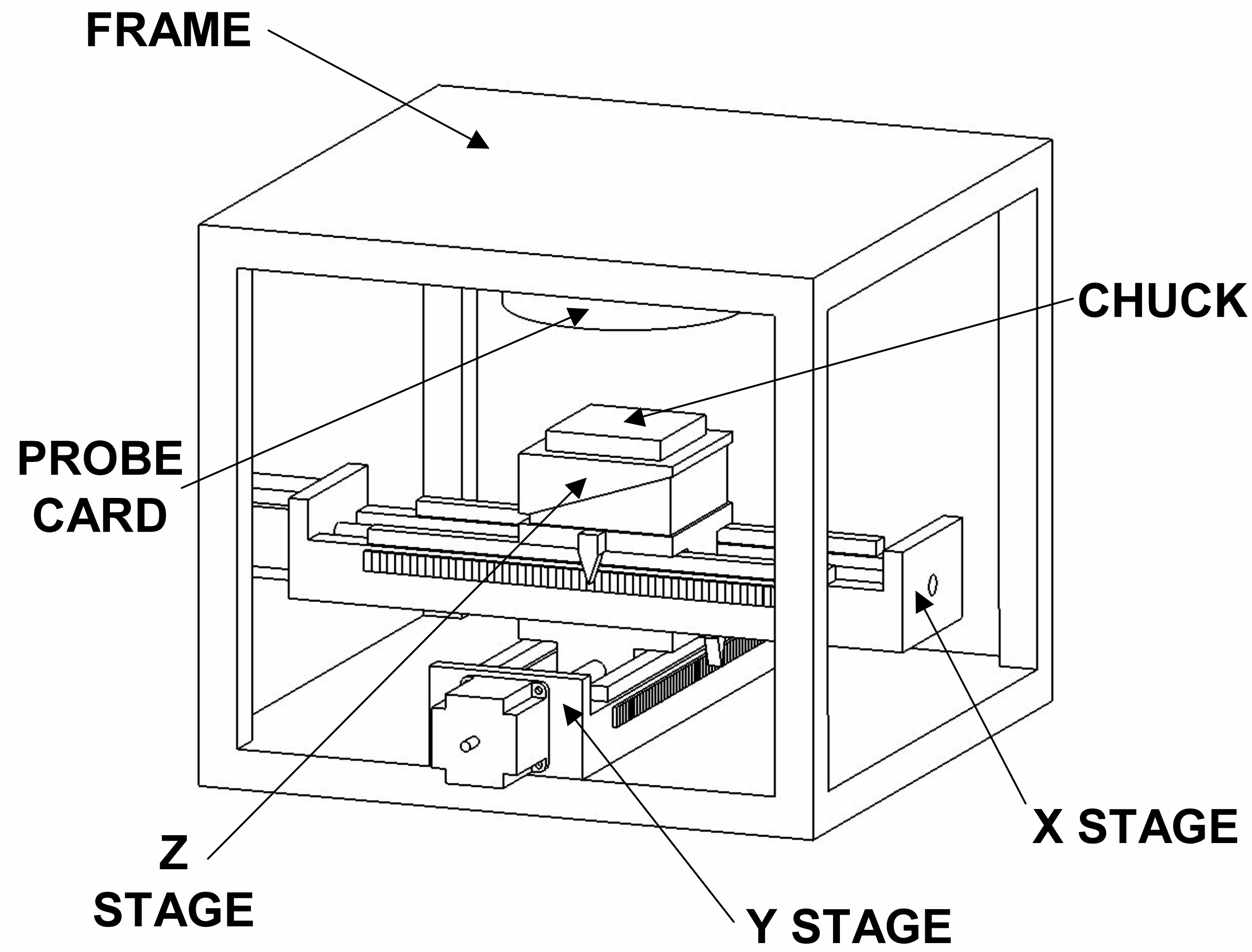
A linear stage is meant to provide one degree of freedom only

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**

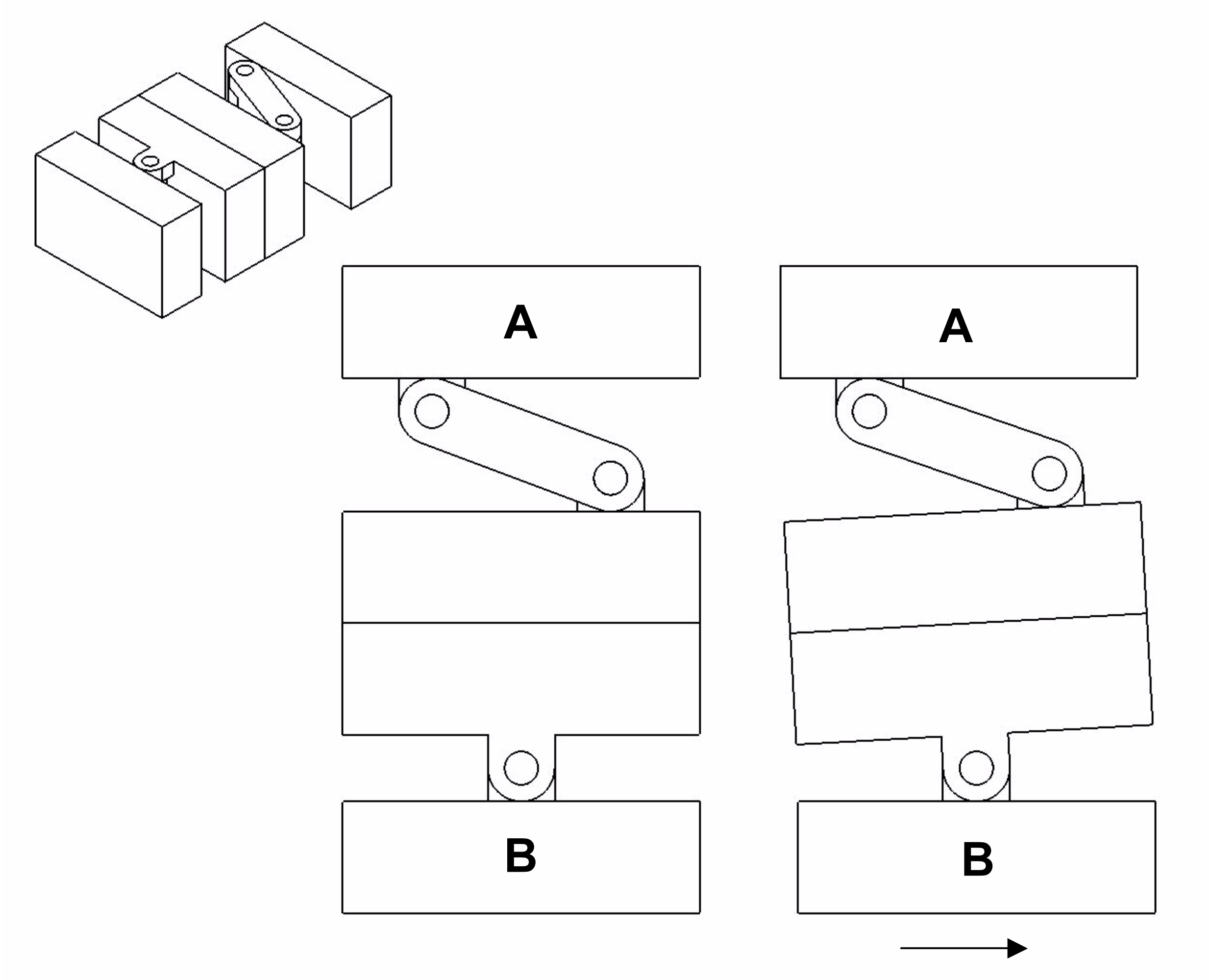
Temperature

- **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**

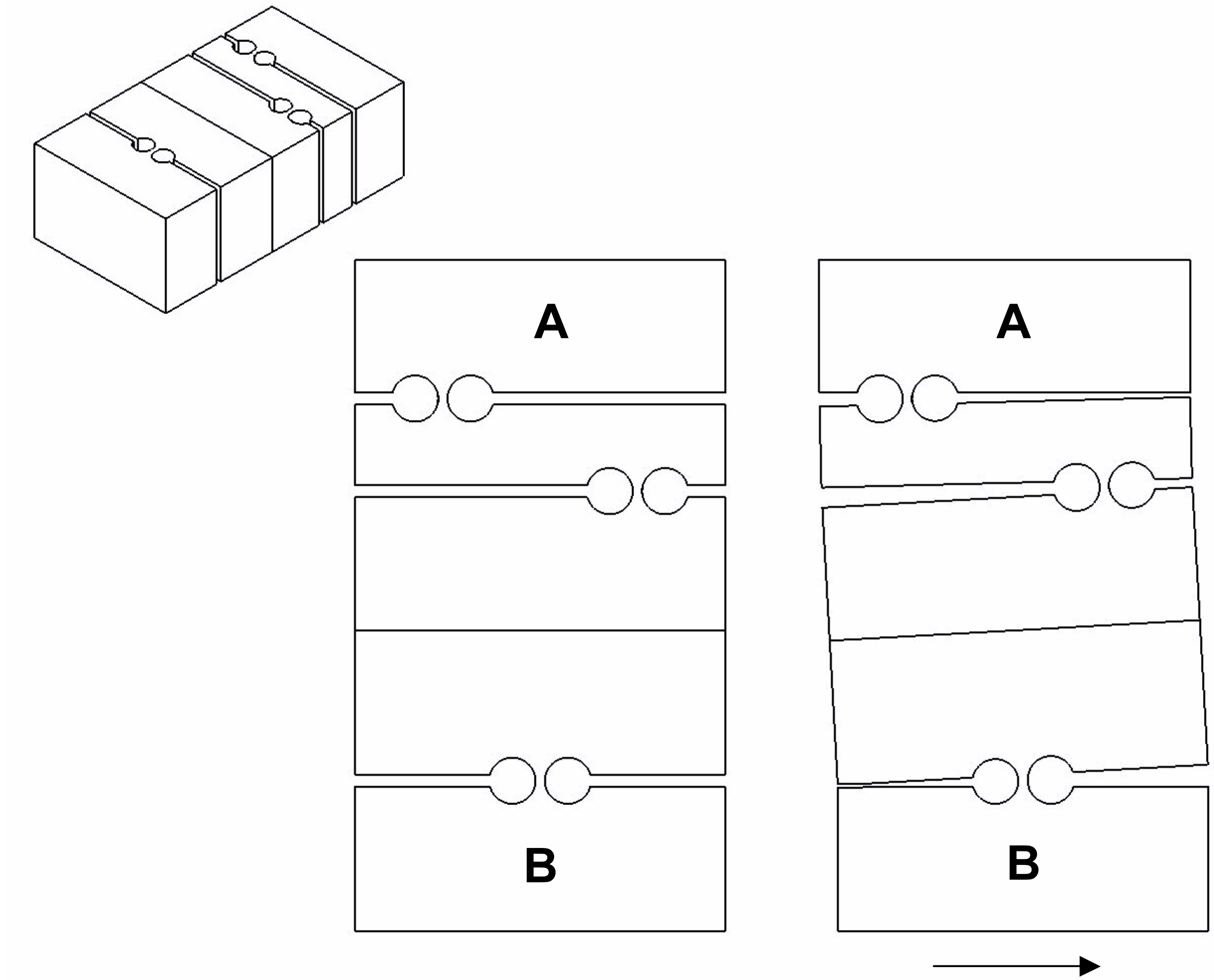
Steel stages attached to aluminum bases can behave like bi-metallic strips	**300mm of steel changes 4 μm in length for every degree C change; for aluminum, 7μm**

Hysteresis



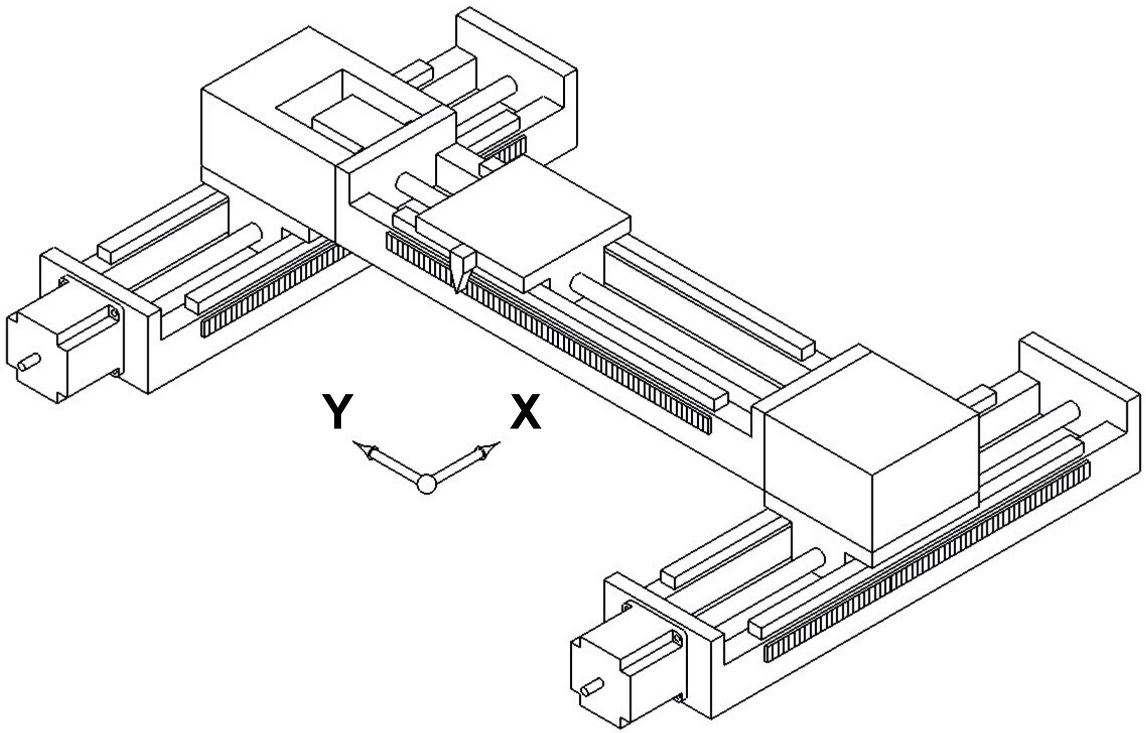
Linked components exhibit hysteresis

Flexures



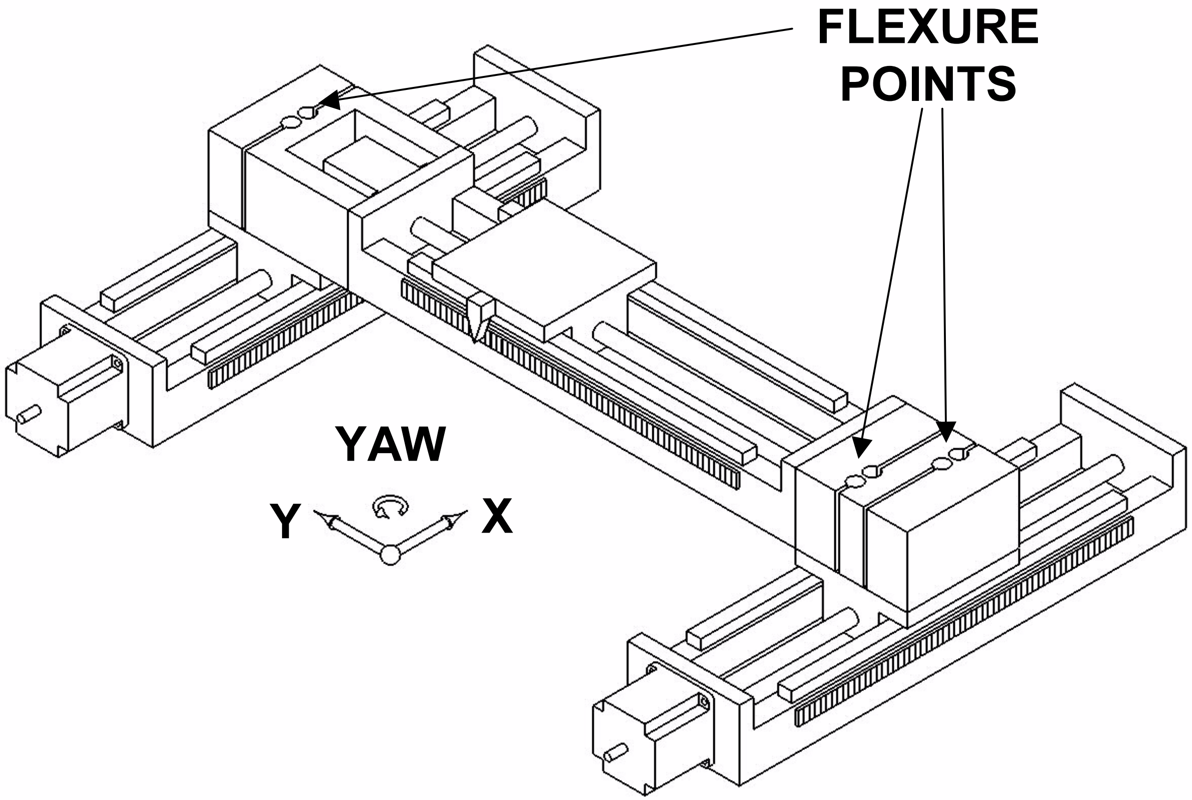
Flexures allow movement without hysteresis

XY Gantry



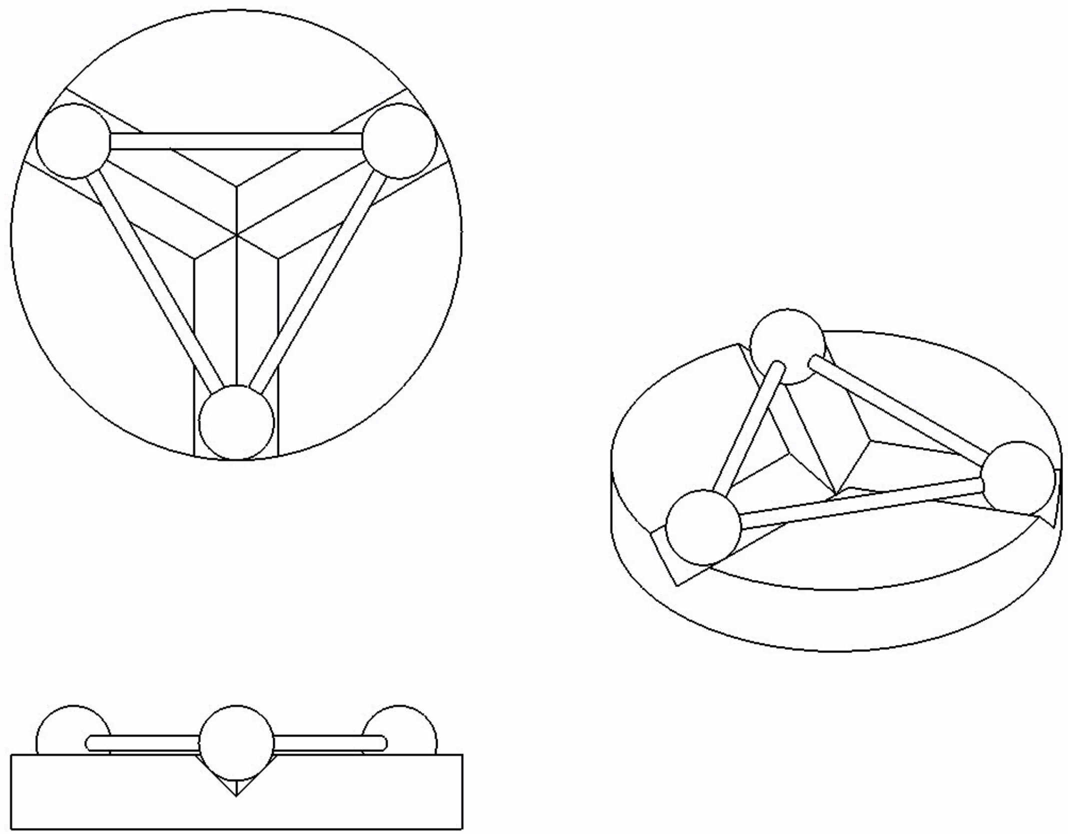
Simple support can often handle off-center loads better than cantilevered

XY Gantry with flexures



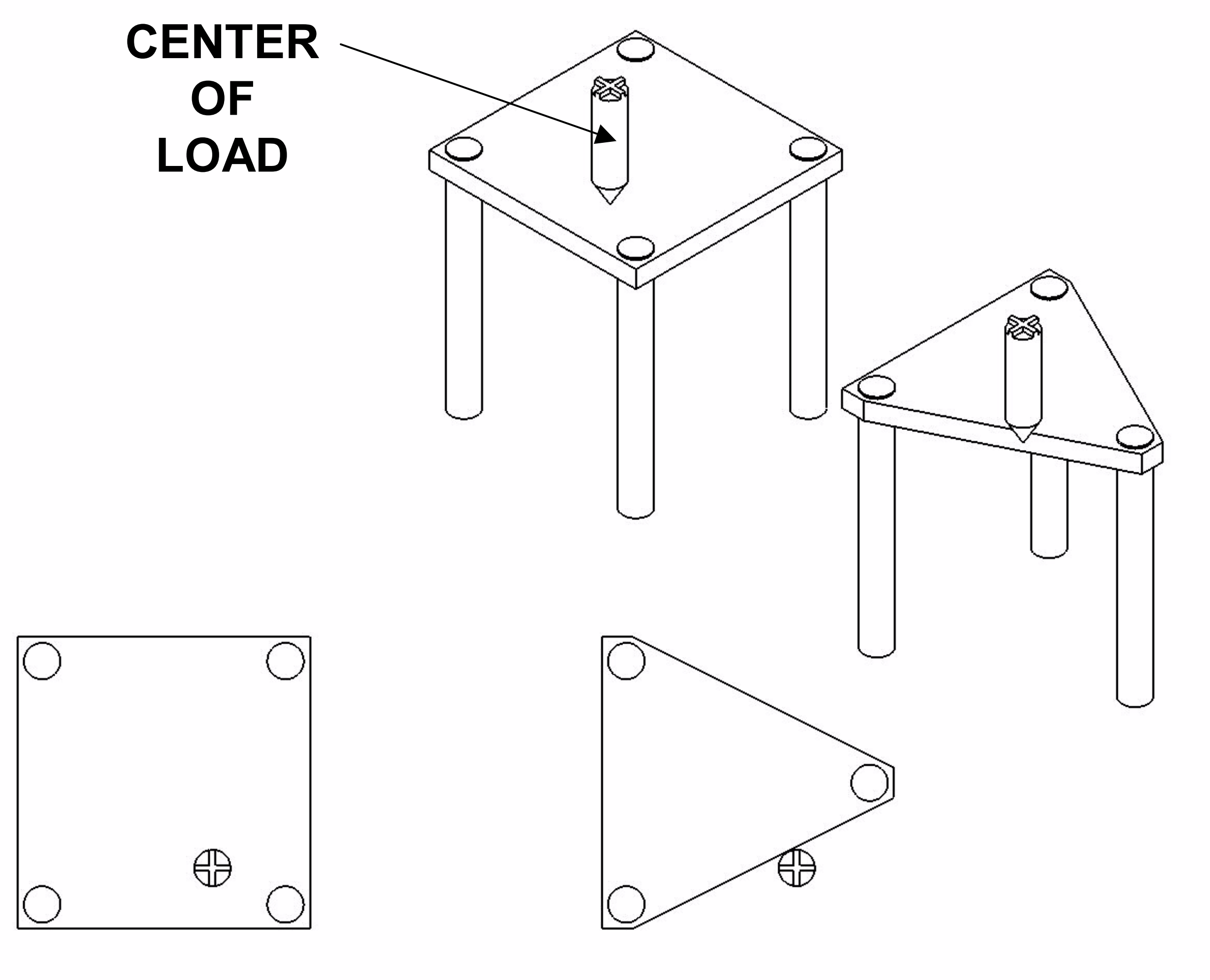
Addition of flexural supports prevents racking and allows for some theta positioning

Kinematic mounts



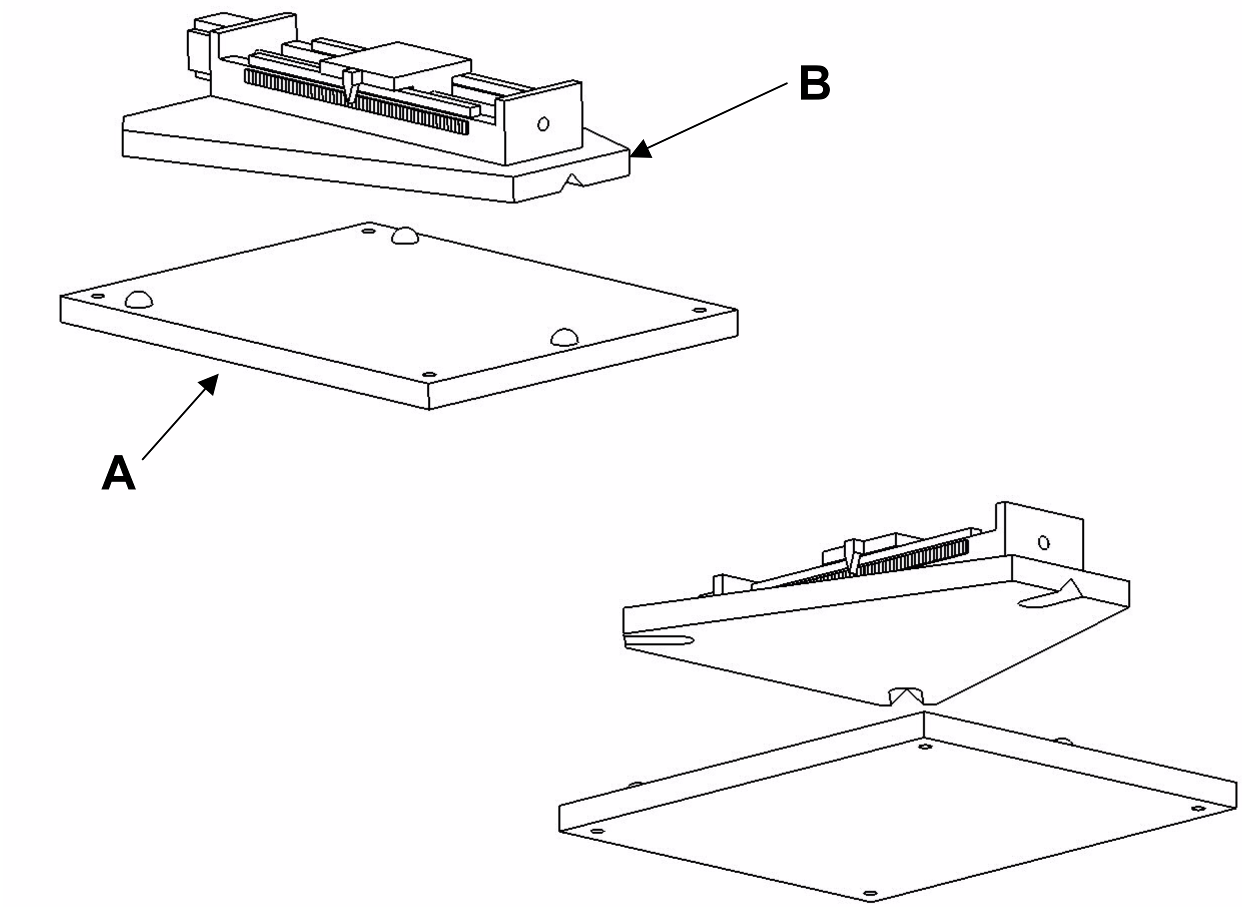
The 6 degrees of freedom are constrained at only 6 points

Overconstraint



If 3 legs don't rock, why have 4?

Kinematically Mounted Stage



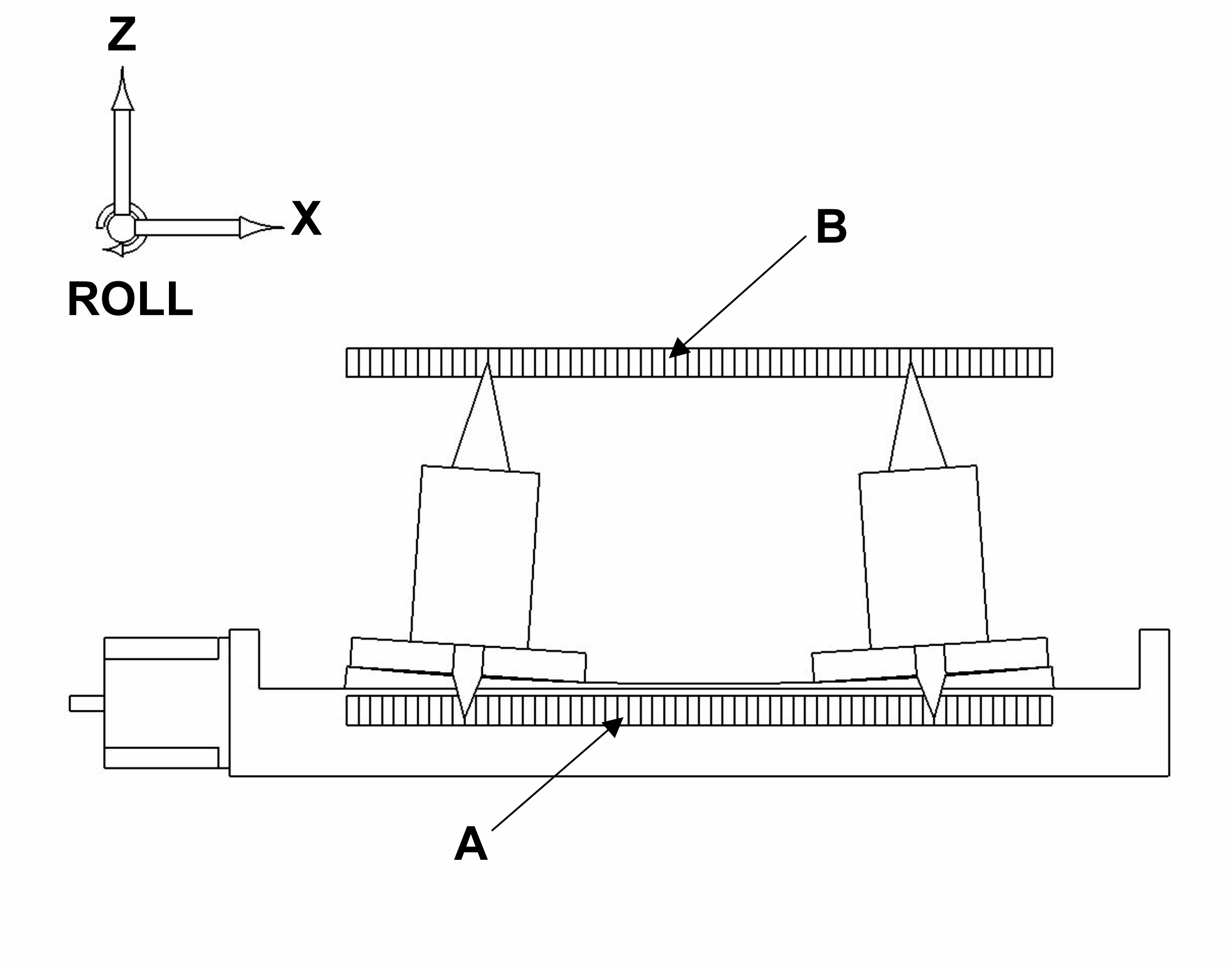
A twist in ‘A’ does not induce twist in ‘B’

The Abbe Principle

Ernst Abbe
1840-1905

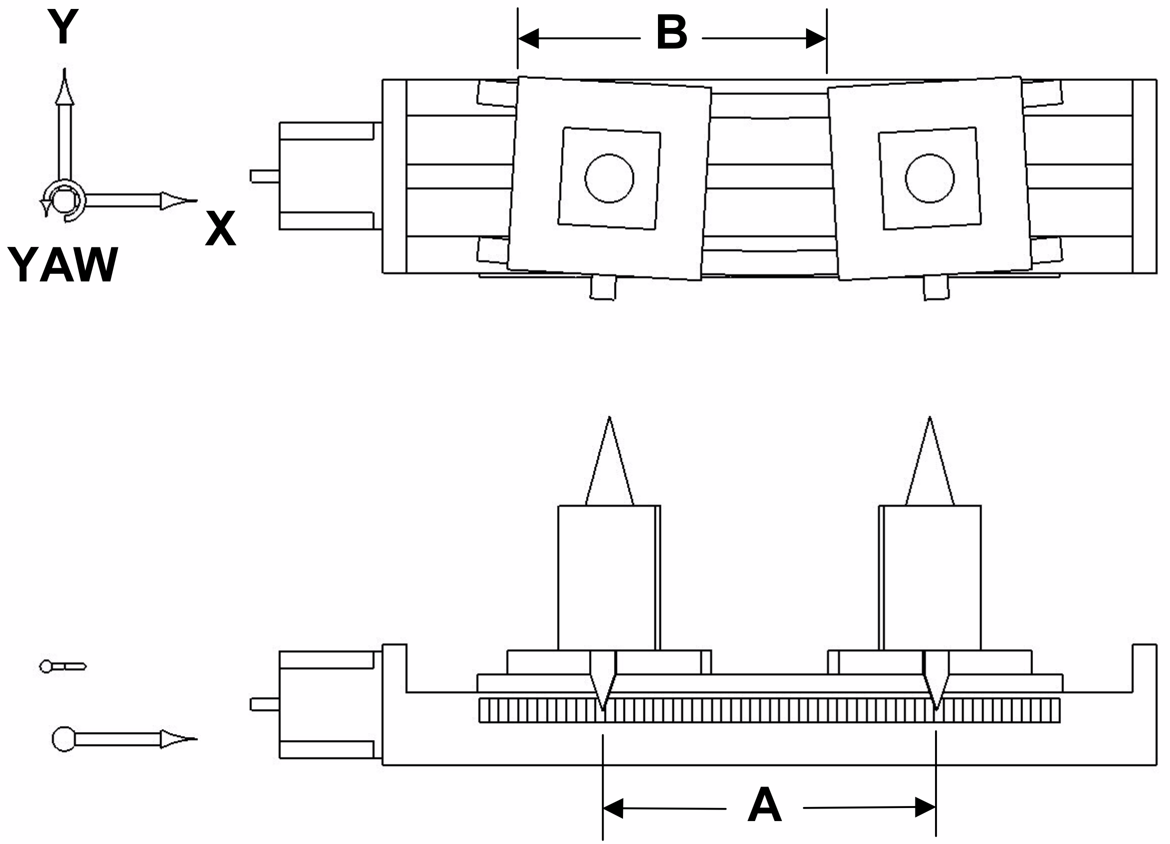
If errors in parallax are to be avoided, the measuring system must be placed coaxially with the axis along which displacement is to be measured on the workpiece.

Abbe Error



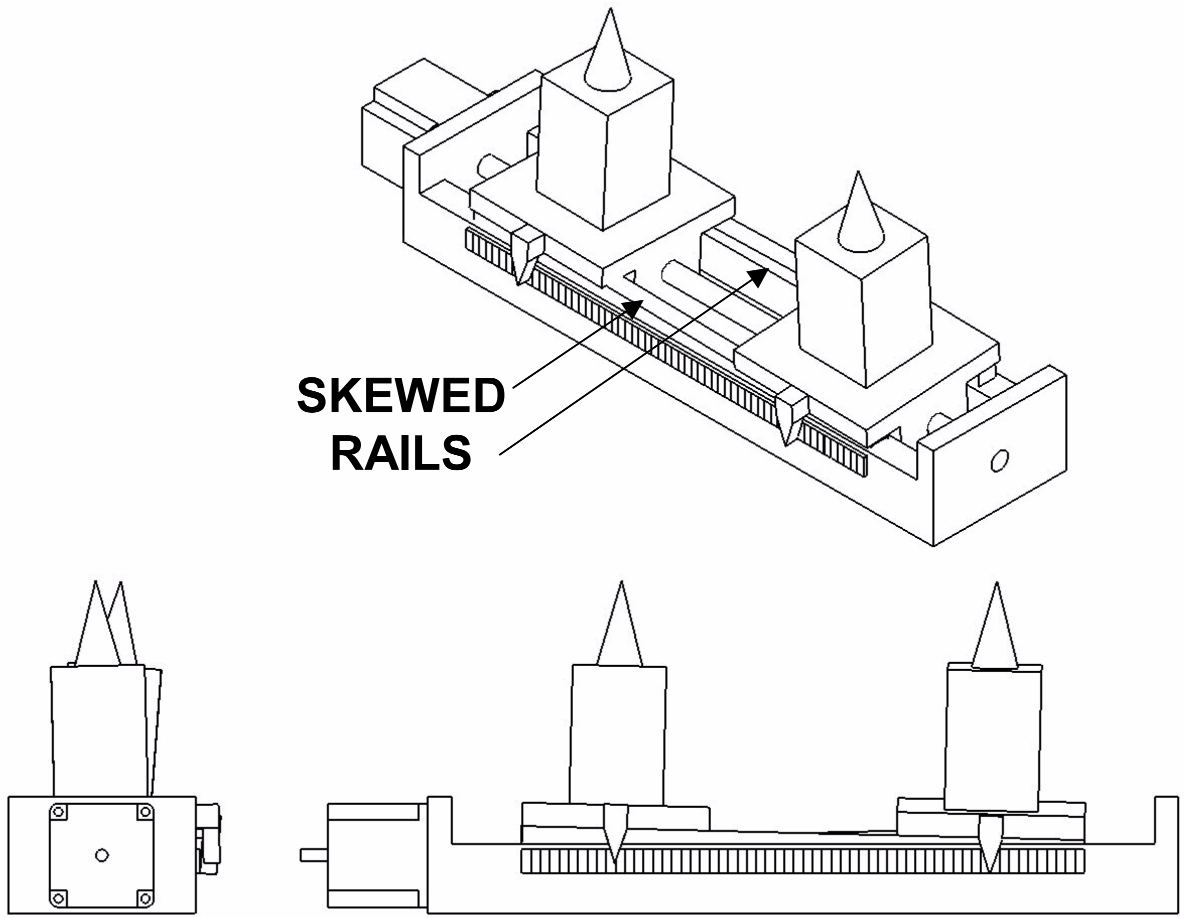
Measurements at the encoder 'A' do not match those at encoder 'B'

Yaw



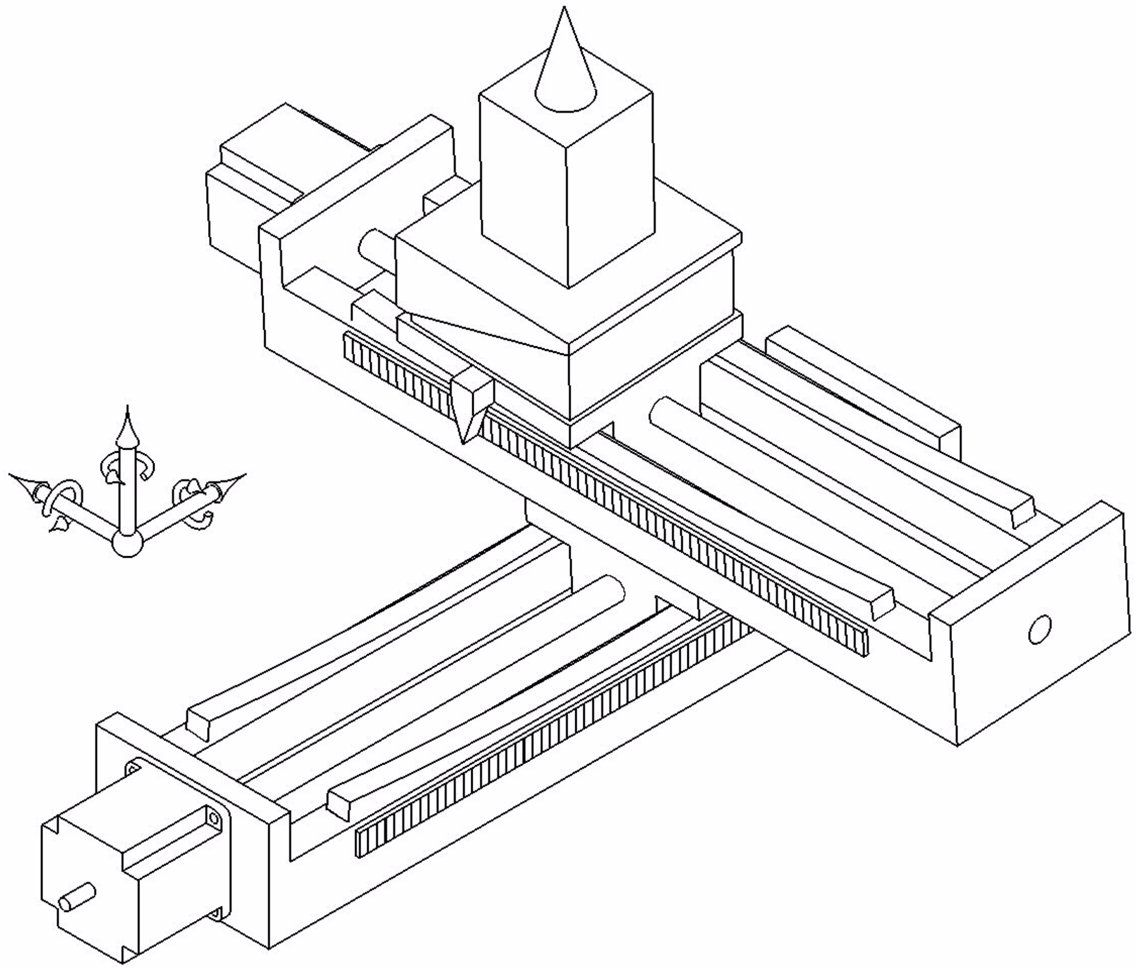
‘B’ is less than that indicated by encoder ‘A’

Roll



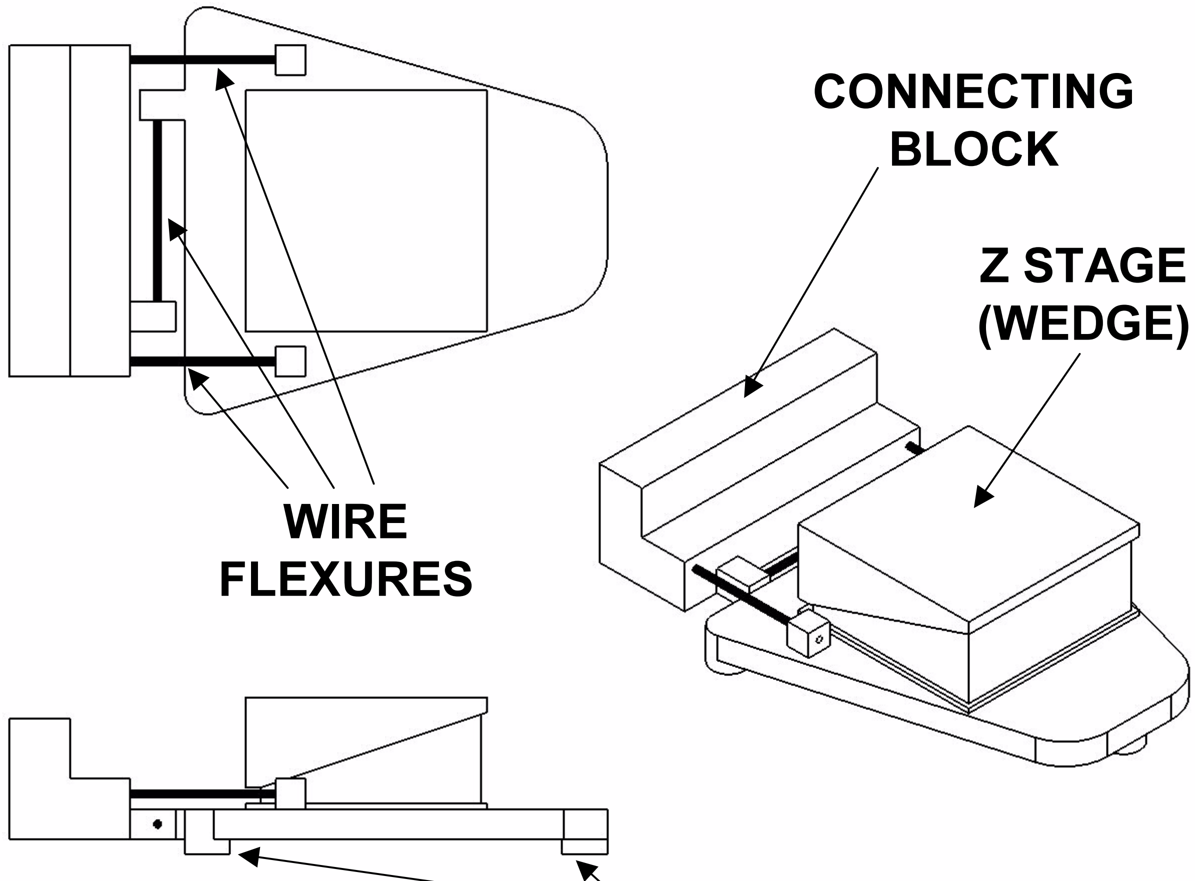
Roll contribution from skewed rails

Compounded Error



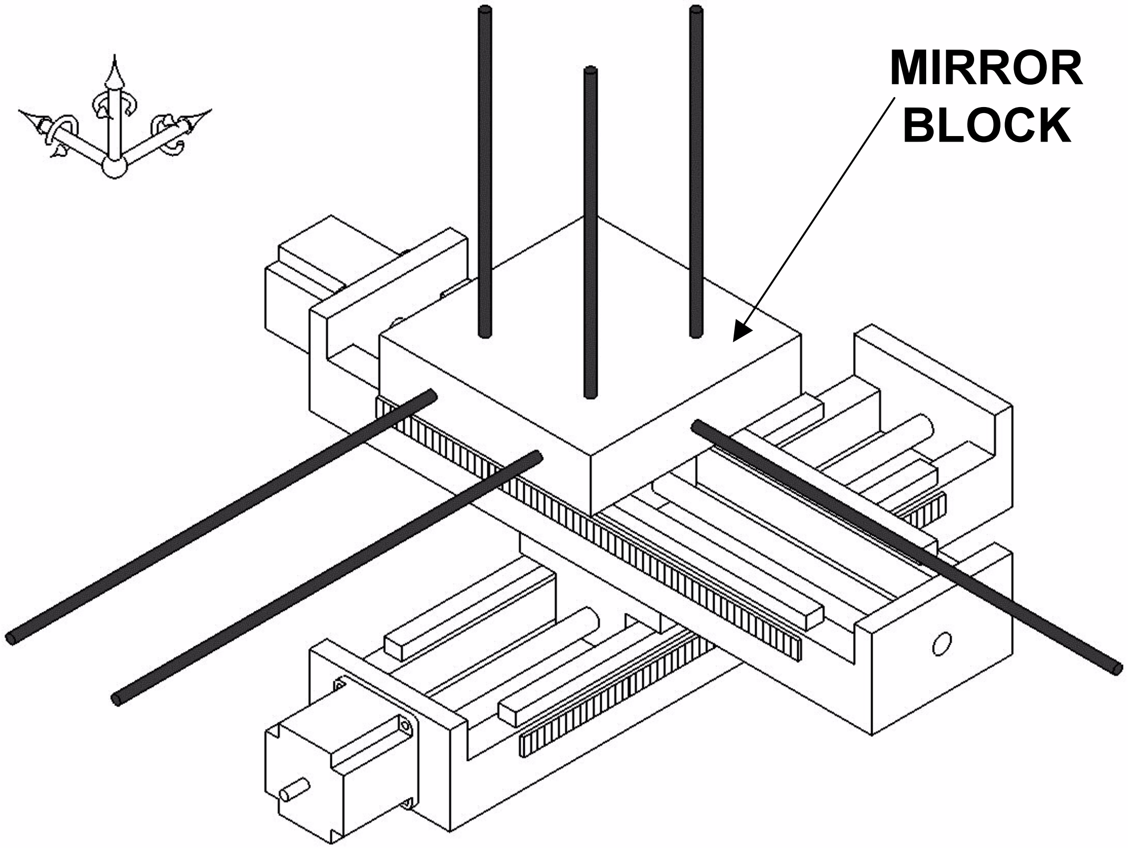
Abbe error is compounded when stages are stacked

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**