Motion and Measurement

Definitions

- Error
  - the difference between the actual response of a machine to a command issued according to the accepted protocol of the machine's operation and the response to that command anticipated by the protocol.
- Error motion
  - the change in position relative to the reference coordinate axes, or the surface of a perfect work piece with its center line coincident with the axis of rotation. Error motions are specified as to location and direction and do not include motions due to thermal drift.

Definitions

- Error motion measurement
  - a measurement record of error motion which should includes all pertinent information regarding the machine, instrumentation and test conditions.
- Radial error motion
  - the error motion of rotary axis normal to the Z reference axis and at a specified angular location.
    - ANSI B5.54-1991, Methods for Performance Evaluation of Computer Numerically-Controlled Machining Centers, American Society of Mechanical Engineers, 1991.

Rigid Body Motion

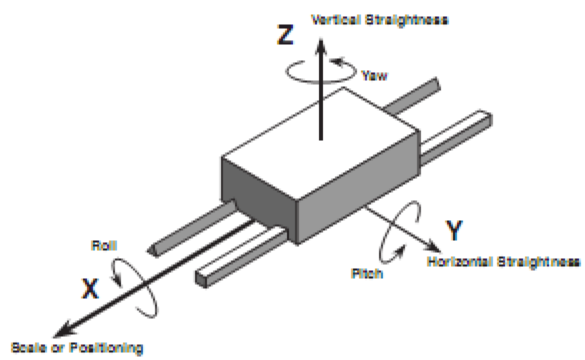
- Six degrees of freedom defined for a rigid body
  - three translational degrees of freedom along the
    - X axis
    - Y axis
    - Z axis
  - three rotational degrees of freedom about the
    - X axis
    - Y axis
    - Z axis

Definitions

- Runout
  - the total displacement measured by an instrument sensing a moving surface or moved with respect to a fixed surface.
- Slide straightness error
  - the deviation from straight line movement that an indicator positioned perpendicular to a slide direction exhibits when it is either stationary and reading against a perfect straightedge supported on the moving slide, or moved by the slide along a perfect straightedge which is stationary

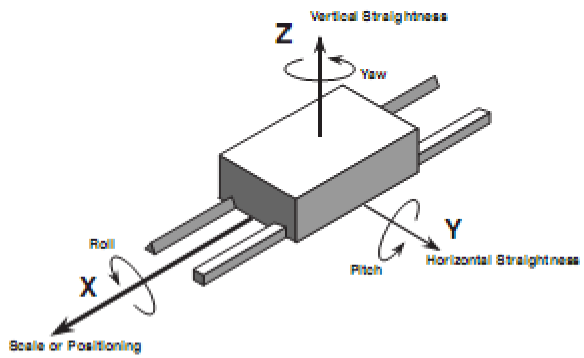
Rigid Body Motion

- Linear slide
  - kinematically designed to have a single translational degree of freedom along the X axis
  - the other 5 degrees of freedom
    - undesired
    - treated as errors often referred to as kinematic errors



Rigid Body Motion

- 2 straightness errors
- 3 angular errors



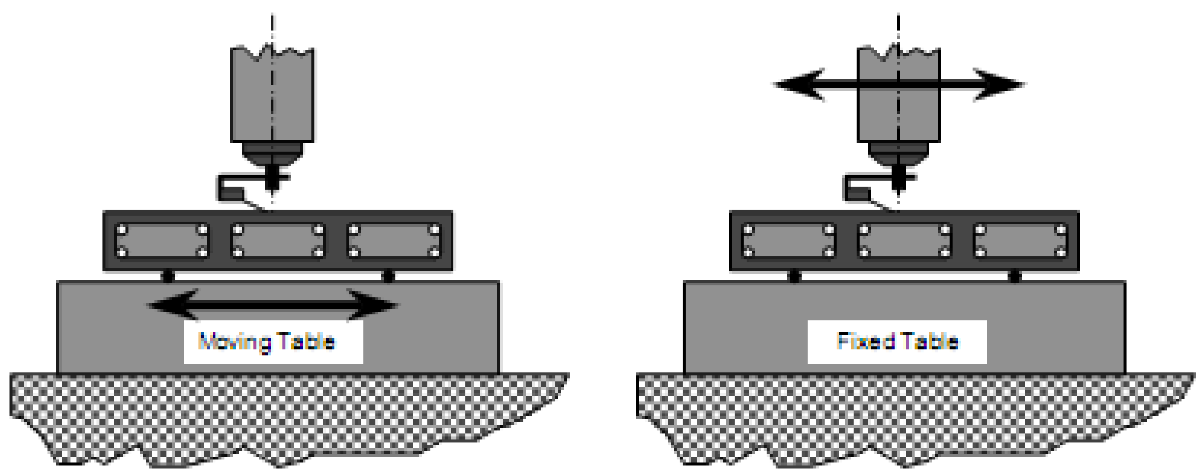
Kinematic Error Definition

- Scale Errors
  - the differences between the position of the read out device (scale) and that of a known reference linear scale (along the X axis).
- Angular Errors
  - small unwanted rotations (about X, Y and Z axes) of a linearly moving carriage about three mutually perpendicular axes.
- Straightness Errors
  - the non-linear movements that an indicator sees when it is either

    i) stationary and reading against a perfect straightedge supported on a moving slide or ii) moved by the slide along a perfect straightedge which is stationary. Basically, this translates to small unwanted motion (along the Y and Z axes) perpendicular to the designed direction of motion.

Straightness Errors

- Stationary and reading against a perfect straightedge supported on a moving slide
- Moved by the slide along a perfect straightedge which is stationary



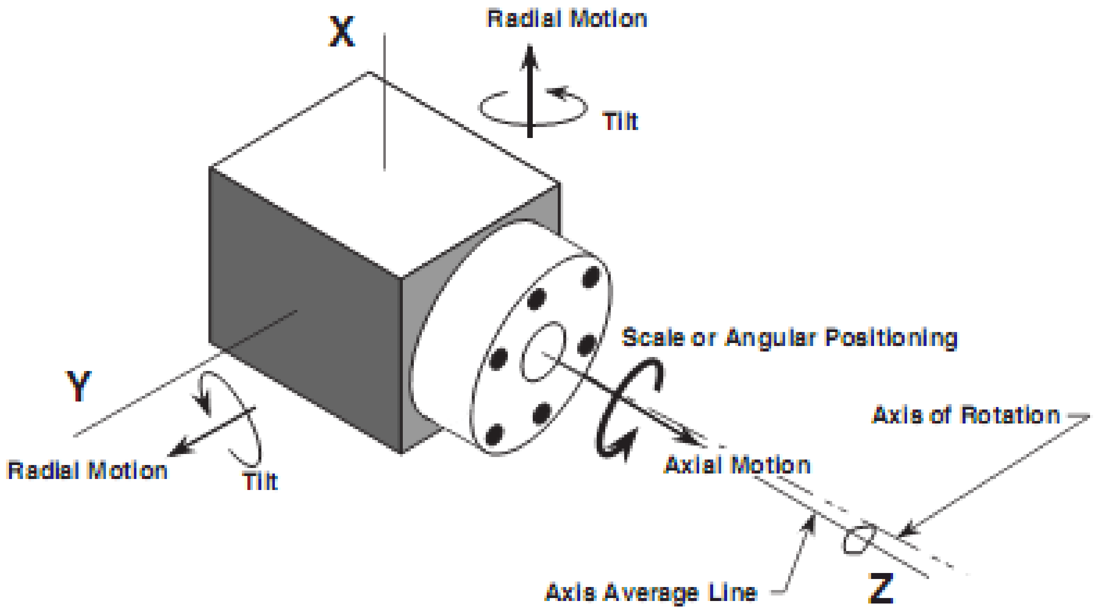
Rotary Axis Errors

- Spindles and rotary tables are designed to have a single rotational degree of freedom
- There are
  - 2 radial motion (translational) errors
  - 1 axial motion error
  - 2 tilt motion (angular) errors
  - a sixth error term for a spindle exists only if it has the ability to index or position angularly.

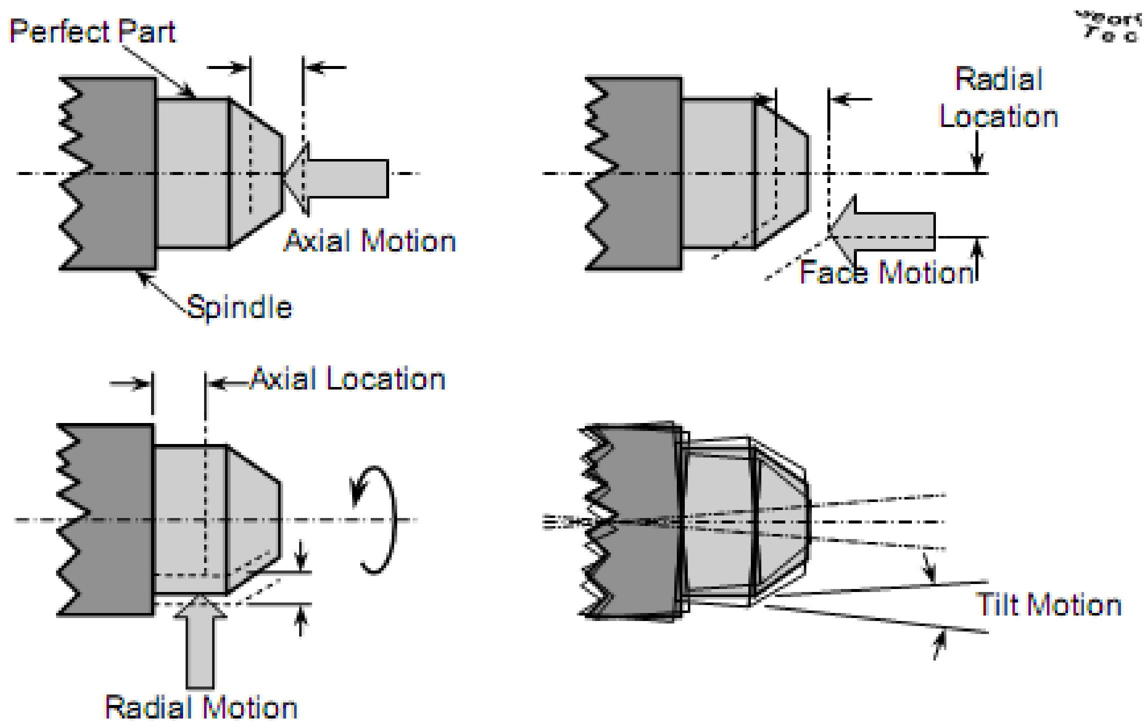
Definitions

- Axial Error Motion
  - the translational error motion collinear with the Z reference axis of an axis of rotation (about the Z axis)
- Face Motion
  - the rotational error motion parallel to the Z reference axis at a specified radial location (along the Z axis)
- Radial Error Motion
  - the translational error motion in a direction normal to the Z reference axis and at a specified axial location (along the X and Y axes)
- Tilt Error Motion
  - the error motion in an angular direction relative to the Z reference axis (about the X and Y axes).

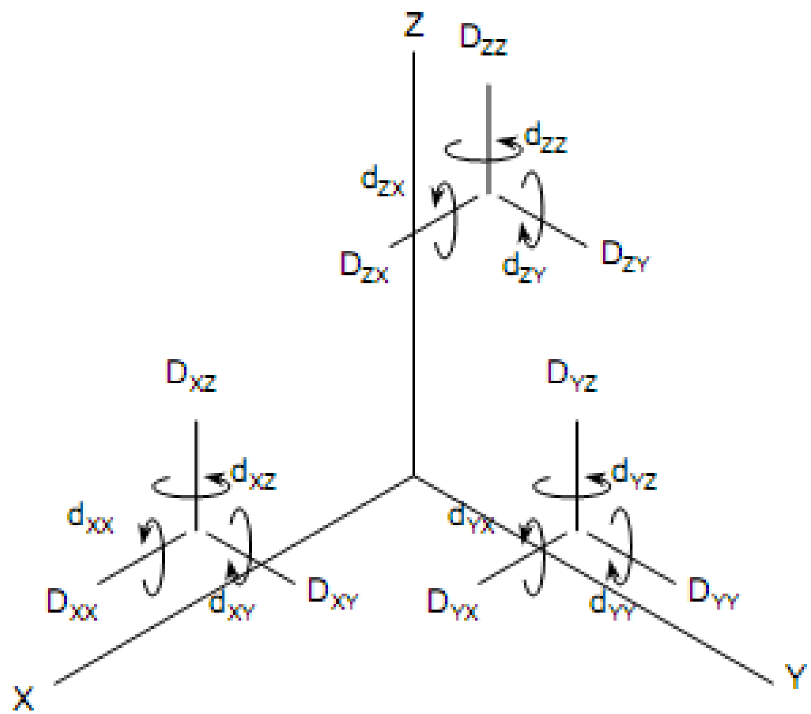
Spindle Rigid Body Relationships



Spindle Error Motion



A Machine Tool with 3 Orthogonal Axes



Error Terms

- Typically, machine tools consist of a combination of
  - spindles
  - linear slides
- A simple three axis machine the mathematical definition of its kinematic errors can become rather complex
  - six error terms per axis
  - totaling 18 error terms for all three axes
  - three error terms are required to completely describe the axes relationships (e.g., squareness)
- A total of 21 error terms for a 3 axis this machine tool.

Relationships Between Axes

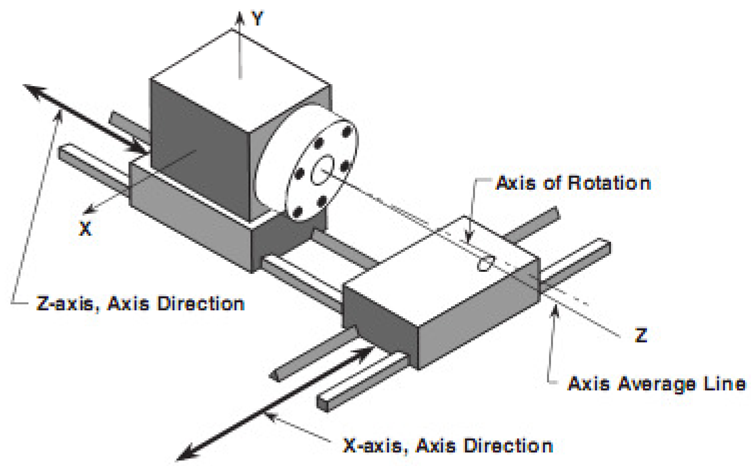
- Squareness
  - a planar surface is "square" to an axis of rotation if coincident polar profile centers are obtained for an axial and face motion polar plot at different radii. For linear axes, the angular deviation from 90° measured between the best fit lines drawn through two sets of straightness data derived from two orthogonal axes in a specified work zone (expressed as small angles).
- Parallelism
  - the lack of parallelism of two or more axes (expressed as a small angle).

For machines with fixed angles other than 90°, an additional definition is used

- Angularity
  - the angular error between two or more axes designed to be at fixed angles other than 90°.

Lathe - 3 Desired Degrees of Freedom

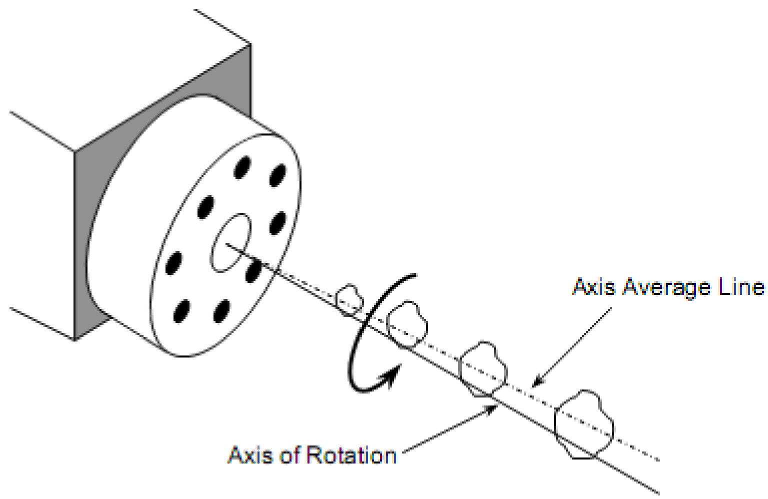
- Two of the axes are translational
- One axis is the spindle rotational axis.



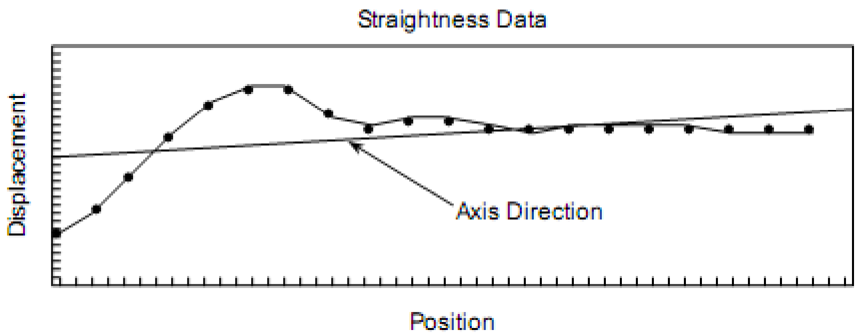
Axis Definitions

- Average Axis Line
  - for rotary axes it is the direction of the "best fit" straight line (axis of rotation) obtained by fitting a line through centers of the least squared circles fit to the radial motion data at various distances from the spindle face.
- Axis Direction
  - the direction of any line parallel to the motion direction of a linearly moving component. The direction of a linear axis is defined by a least squares fit of a straight line to the appropriate straightness data.

Determination of Axis Average Line



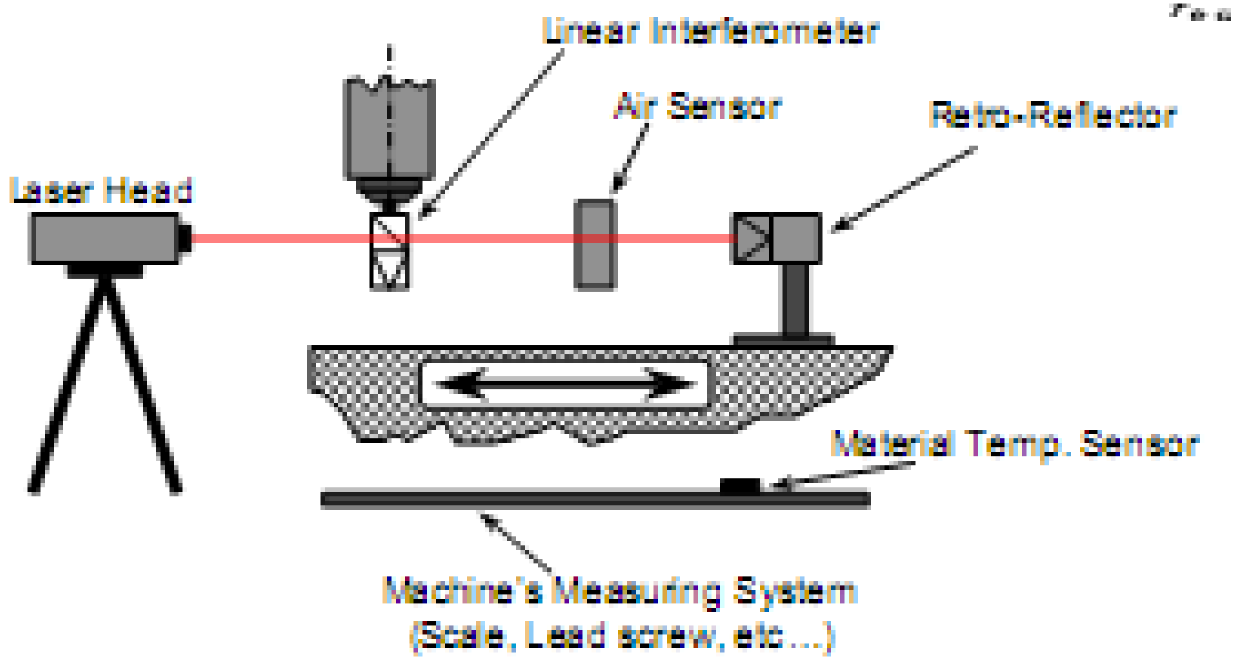
Determination of Axis Direction



Measuring

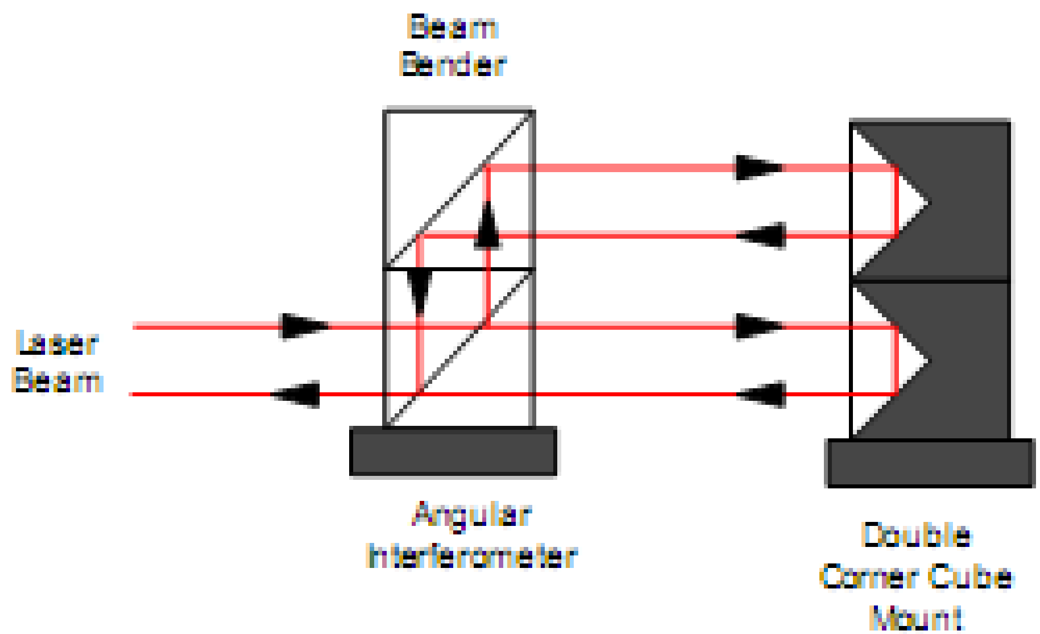
- Laser measurement system
  - a fringe counting interferometer for displacement measurement which uses a laser as a light source.
- Hardware
  - Measurement display
  - Laser head
  - Air Sensor (temp, pressure, humidity)
  - Material sensor (temp)
  - Linear Interferometer & retro-reflector
  - Tuning optics
  - Angular interferometer & reflector
  - Straightness interferometer & reflector
  - Fixturing hardware.

Linear Displacement

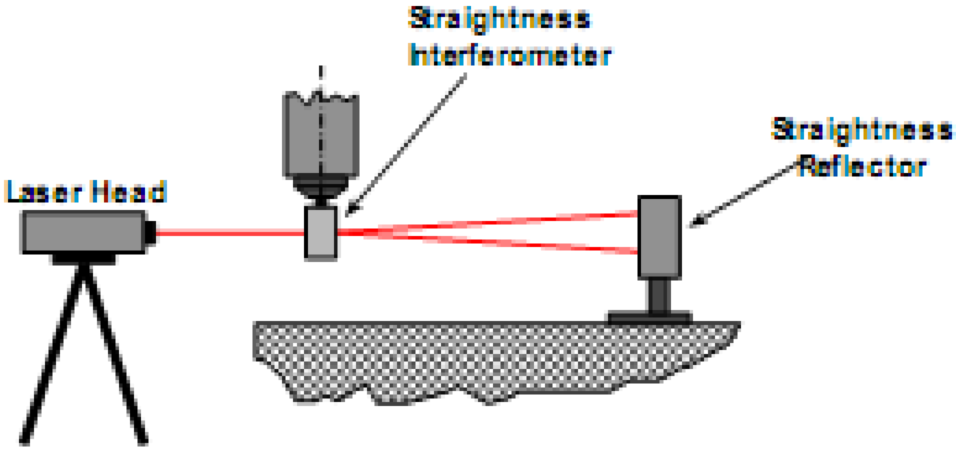


Usually the retro-reflector is the moving element

Angular Interferometer



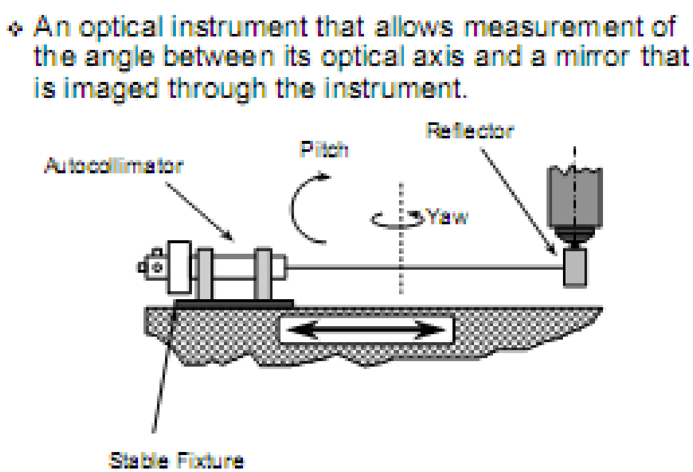
Interferometer-Straightness



The interferometer goes where the tool mounts
The reflector goes where the work piece mounts.

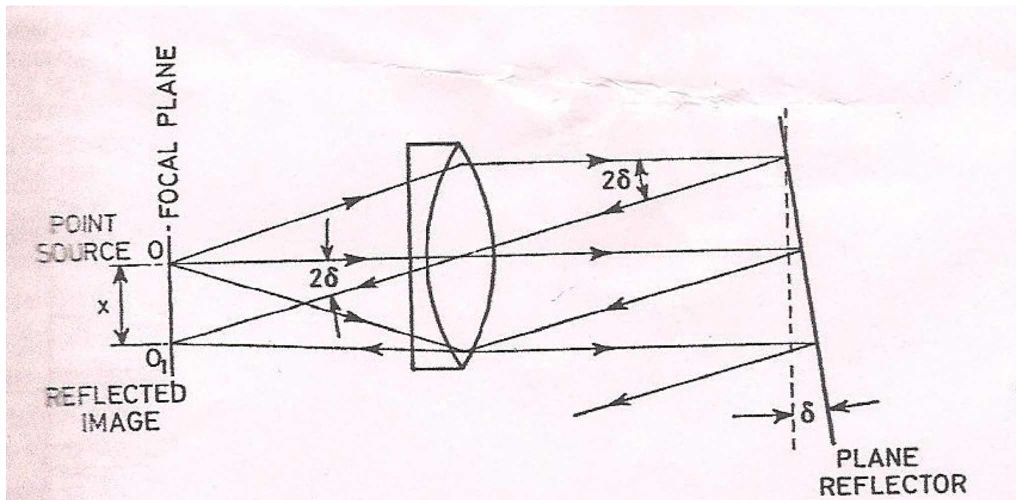
Autocollimator

www.prismindia.com

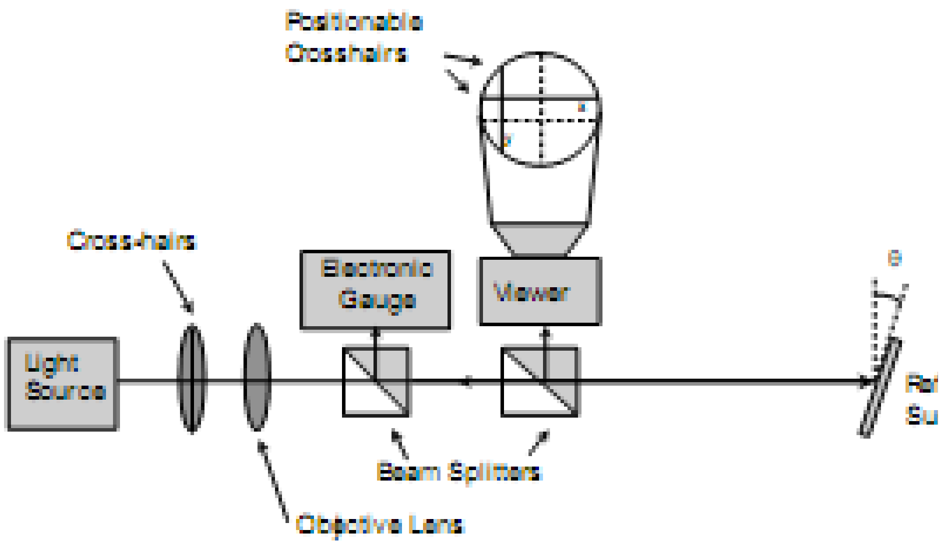


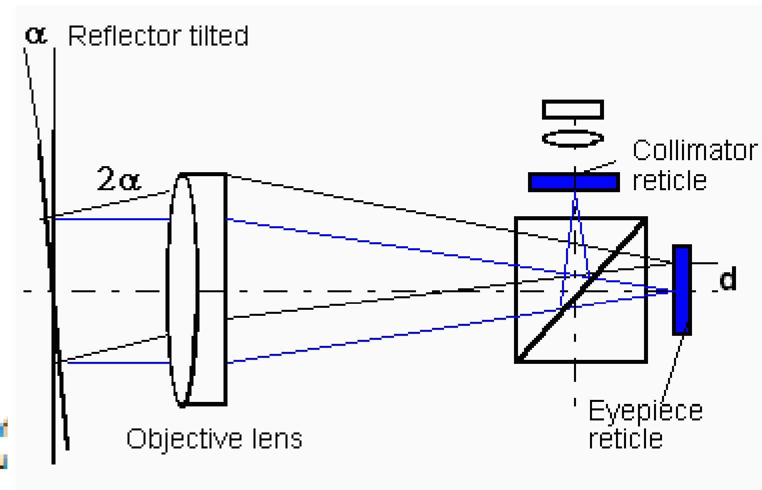
- Projects collimated light
- External reflector reflects the beam back where the beam is focused and detected
- Measures the deviation between the emitted beam and the reflected beam
- A reflector is used to direct the emitted beam to the Eyepiece Graticule of the Instrument.
- Any tilt relative to the optical axis of the collimator displaces the reflected light (visualized against a graticule - usually a crossline)

Principle


FOCAL PLANE
POINT
SOURCE O
x
O_1
REFLECTED
IMAGE
2δ
2δ
δ
PLANE
REFLECTOR

Autocollimator



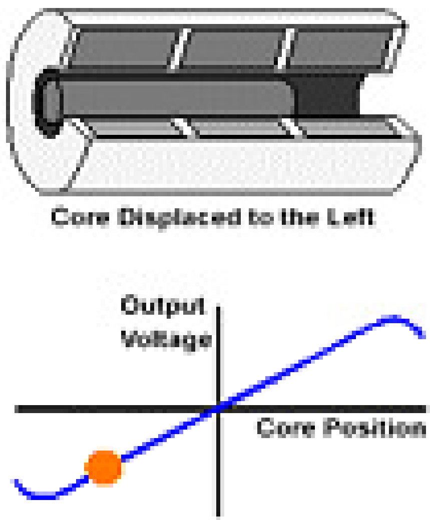


$d = 2\alpha f$

α= rotation angle

f = focal length

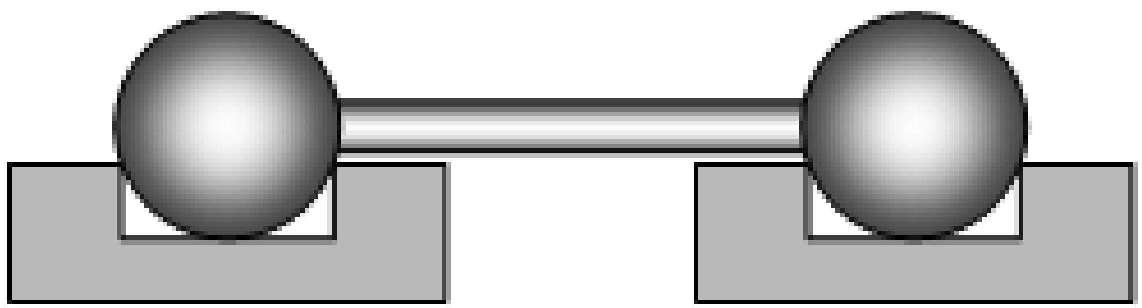
Linear Measurement-LVDT



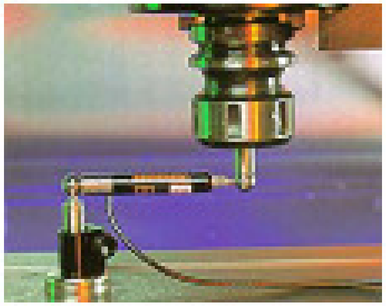
- Linear Variable Displacement Transformer
- No Friction of the Moveable Core
- No Physical Limitation on Resolution
- No Physical Overload Dangers
- Good Environmental Isolation
- Stable Zero Resulting from the Null Point.

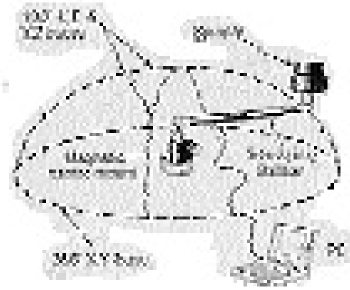
Telescoping Ball Bar

- A gage consisting of two highly spherical tooling balls of the same diameter connected by a rod, that is held by a socket at both ends and contains an accurate displacement transducer permitting accurate measurement of the change of length of the ball bar as one socket moves with respect to the other (ANSI B5.54)

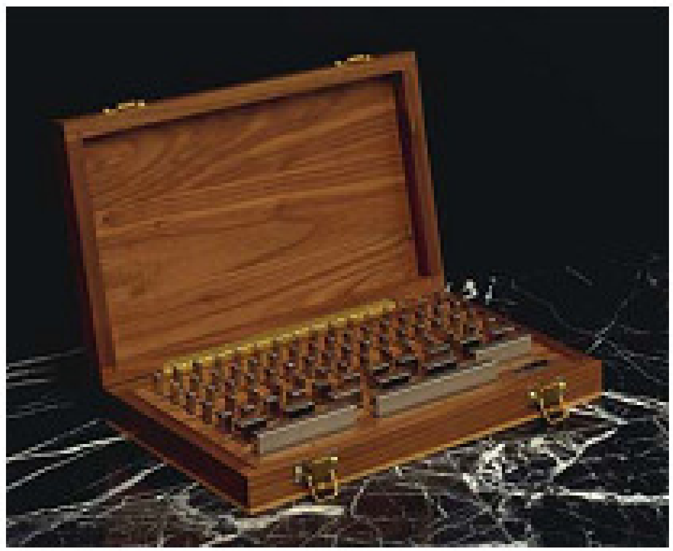


Telescopic Ball Bars





Gage Blocks



Gage Blocks

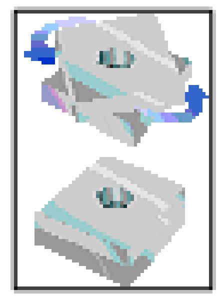
- Reference Standards – Transfer the dimension from the primary standard to gauge blocks of lower accuracy
- Distance Measurement – By combining blocks, the linear dimension of industrial components can be determined
- Tool Verification – Verification and adjustment of a measuring apparatus.

Dimensional Stability

- These gauges exhibit a high degree of dimensional stability, obtained by:
- Material Selection
  - Tungsten Carbide
  - Steel with 1.45% Chromium, 0.35% Manganese, 1% Carbon
- Heat Treatment Process
  - Minimum hardness value of 65 Rockwell C
- Hardened at Measuring End – Slip Gauges

Wringing

- Wringing – The phenomenon of the blocks "sticking together"
- Wringing property due to:
  - Ultra-thin film of oil or moisture between blocks
  - Molecular attraction due to very flat surfaces
- Wringing preparation steps:
  - Clean blocks using mineral spirits
  - Debur measuring faces
  - Maintain temperature



Gage Blocks

- How to wring gage blocks:
  - Clean the blocks using mineral spirits
  - Lay a piece of clean lint-free cloth on a nonabsorbent surface
  - Place two drops of clean light oil on one area of the cloth
  - Rub the measuring face of one of the blocks in the oil
- When combining gage blocks, attempt to minimize the number of blocks used.