Design Basics

or how to put together simple things simply

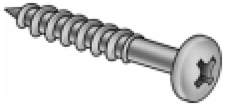
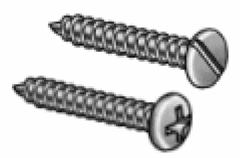
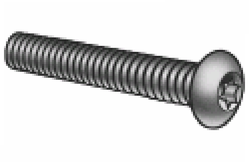
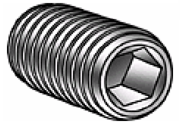
Outline

- Attaching things (permanently and temporarily)
- Simple structural supports and enclosures, sealing (o-rings)
- Designing things that have to move (bearings, tracks, jamming issues)
- Modular solutions (MK, macrobench, dexion)

Permanent Attachment

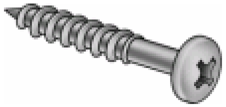
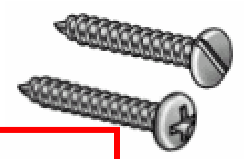
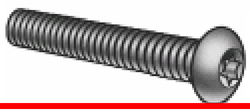
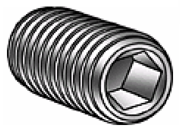
- Welding (later)
- Brazing (later)
- Rivets
- **Glue**
  - **Epoxy**
  - **Superglue**
  - **Solvent-based adhesives**

Temporary Attachment

- Wood screws 
- Sheet metal screws 
- Machine screws 
- Set screws 
- Thumb screws

Go to www.mcmaster.com !!!

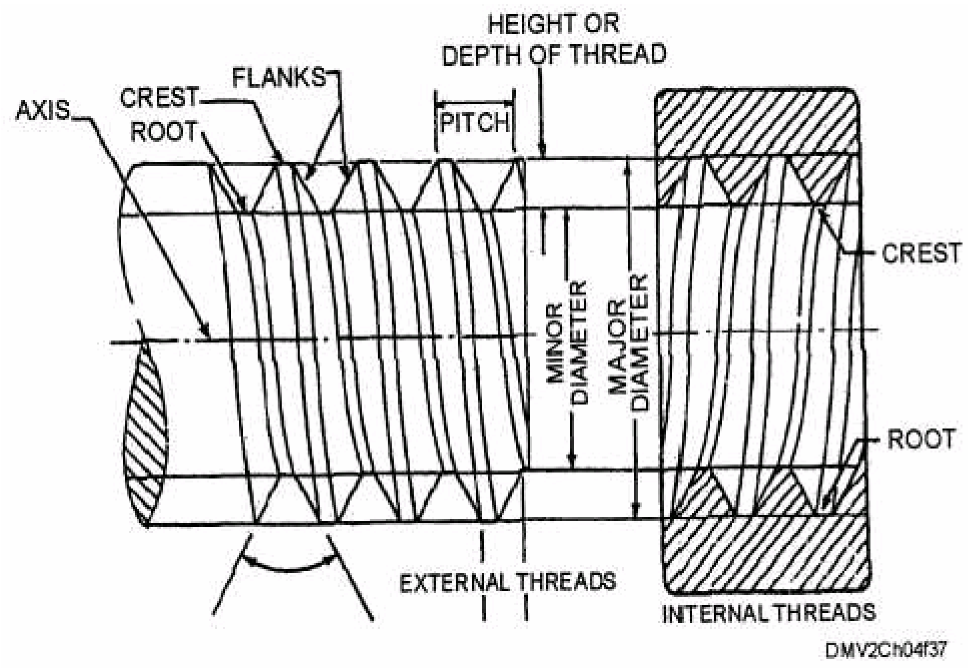
Temporary Attachment: Fastening with Screws

- Wood screws 
- Sheet metal screws 
- Machine screws 
- Set screws 
- Thumb screws

Go to www.mcmaster.com !!!

Screws & Bolts

- Terminology



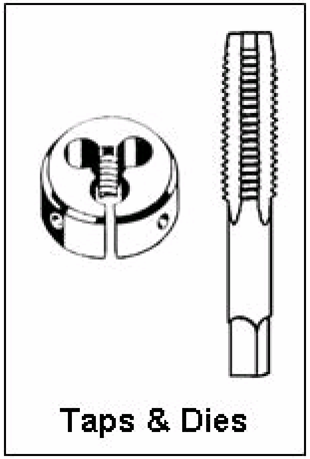
Attachment with Screws & Bolts

- Calculate forces according to textbooks like **Mechanical Engineering Design by Shigley & Mischke** to find the correct size until you have a good gut feeling

Examples of attachment on blackboard

Screws & Bolts

- How to create threads: tap and die set



Supports, Enclosures, Pressure Vessels

- Supports
  - Take load
  - Look nice
- Enclosures
  - Visually clear or not
  - Thermal isolation
  - Pressure isolation

Supports, Enclosures, Pressure Vessels

- Supports
  - Take load
  - Look nice

Make them SIMPLE!

- Enclosures
  - Visually clear or not
  - Thermal isolation
  - Pressure isolation

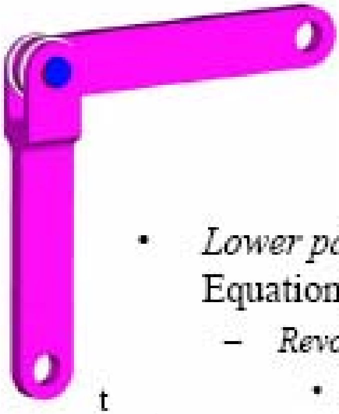
Supports, Enclosures, Pressure Vessels

- Supports
  - Take load
  - Look nice
- Enclosures
  - Visually clear or not
  - Thermal isolation
  - Pressure isolation

Parker Seals

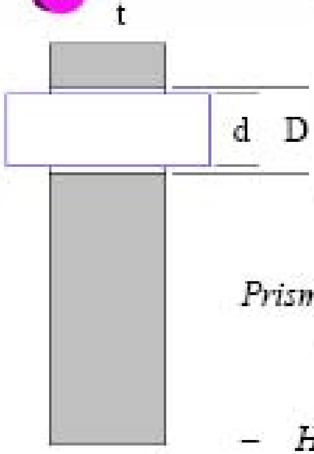
http://www.parker.com/sg/sgcatalogs.asp

Things that MOVE

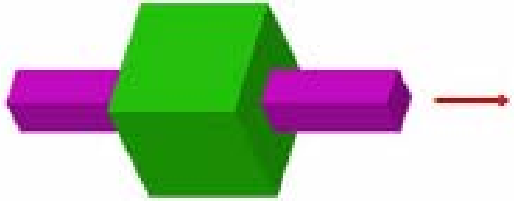


Joints: *Single Degree-of-Freedom*

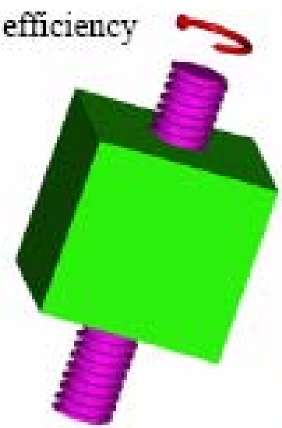
- *Lower pairs (first order joints)* or *full-joints* (counts as $f = 1$ in Gruebler's Equation) have one degree of freedom (only one motion can occur):
  - *Revolute (R)*
    - Also called a pin joint or a pivot, take care to ensure that the axle member is firmly anchored in one link, and bearing clearance is present in the other link
    - Washers make great thrust bearings
    - Snap rings keep it all together
    - A *rolling contact* joint also counts as a one-degree-of-freedom revolute joint

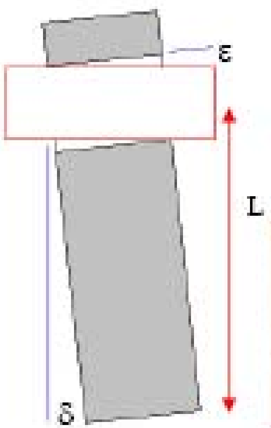


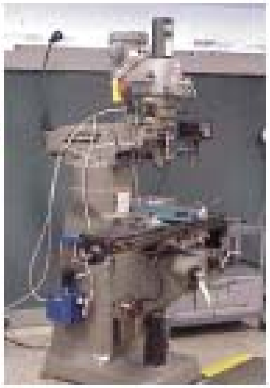
  - *Prismatic (P)*
    - Also called a slider or sliding joint, beware Saint-Venant!



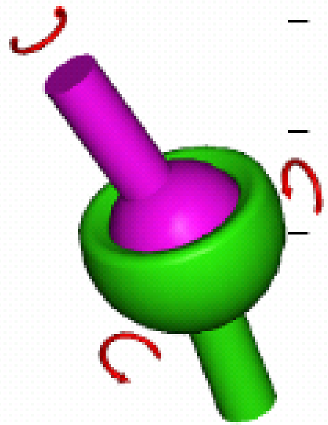
  - *Helical (H)*
    - Also called a screw, beware of thread strength, friction and efficiency



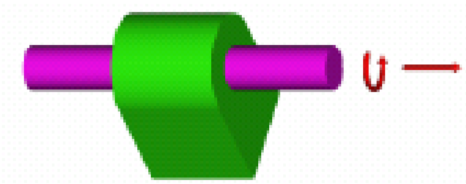


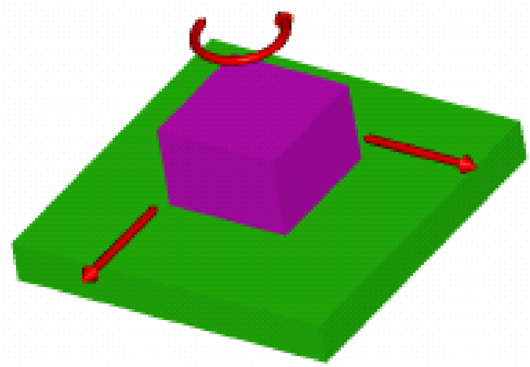


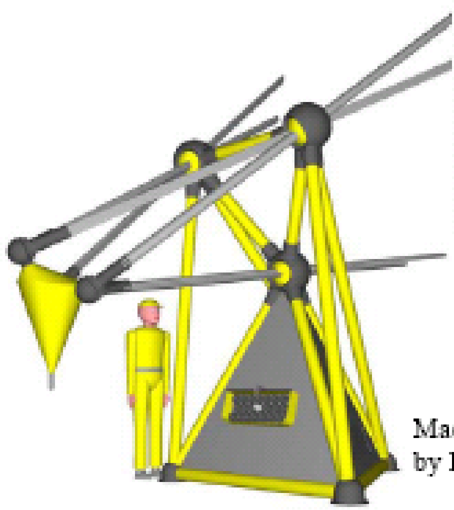
Joints: *Multiple Degree-of-Freedom*



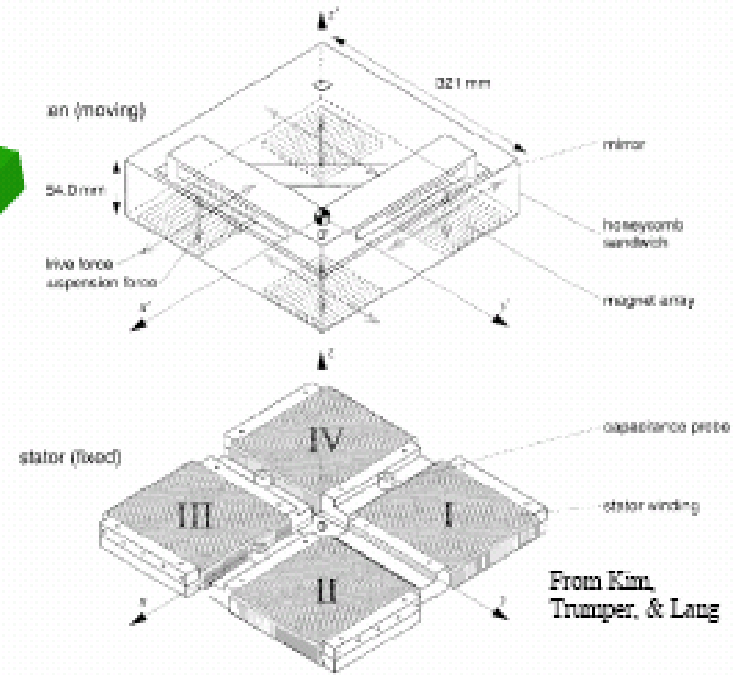
- *Lower Pair* joints with multiple degrees of freedom:
  - Cylindrical (C) 2 DOF
    - A *multiple-joint* ($f = 2$)
  - Spherical (S) 3 DOF
    - » A *multiple-joint* not used in planar mechanisms ($f = 3$)
  - Planar (F) 3 DOF
    - A *multiple-joint* ($f = 3$)







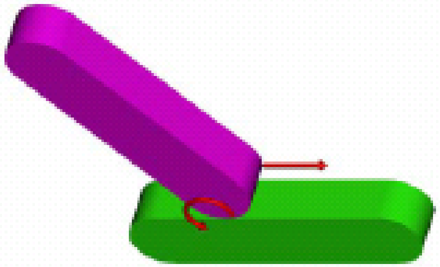
Machine concept by Peter Bailey

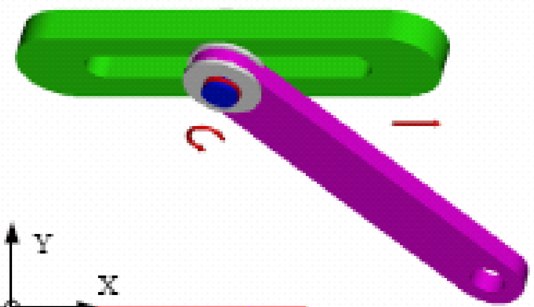


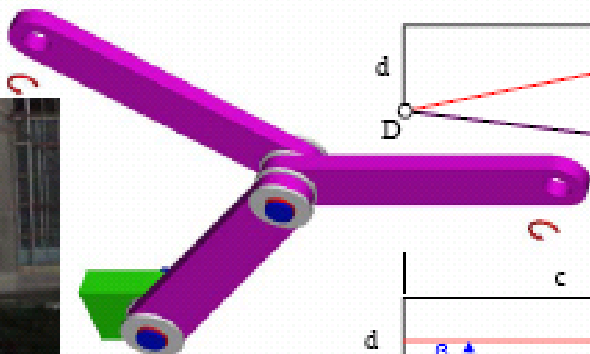
From Kim, Trumper, & Lang

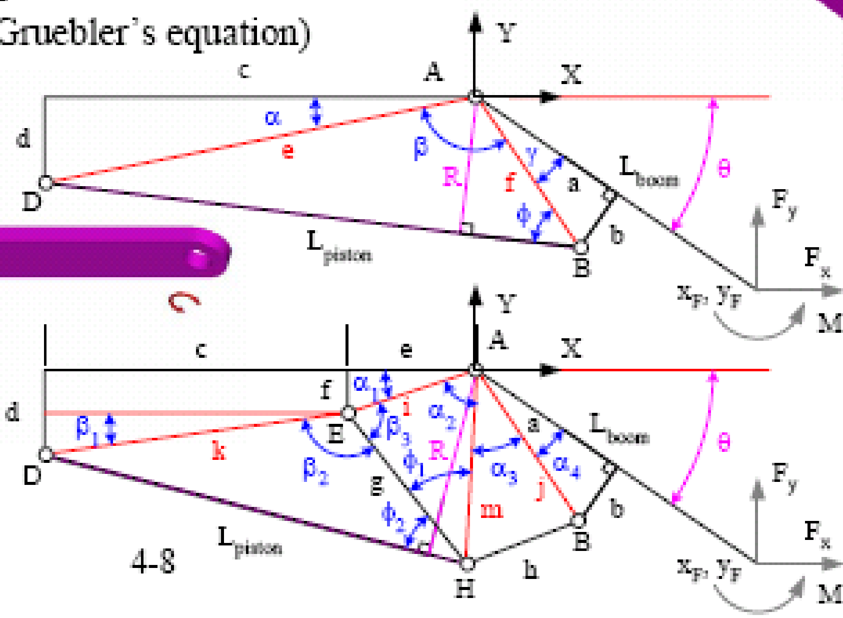
Joints: *Higher Pair Multiple Degree-of-Freedom*

- *Higher Pair* joints with multiple degrees of freedom:
  - Link against a plane
    - A force is required to keep the joint closed (force closed)
      - A *half-joint* ($f = 2$ in Gruebler's equation)
    - The link may also be pressed against a rotating cam to create oscillating motion
  - Pin-in-slot
    - Geometry keeps the joint closed (form closed)
      - A *multiple-joint* ($f = 2$ in Gruebler's equation)
  - Second order pin joint, 3 links joined, 2-DOF
    - A *multiple-joint* ($f = 2$ in Gruebler's equation)

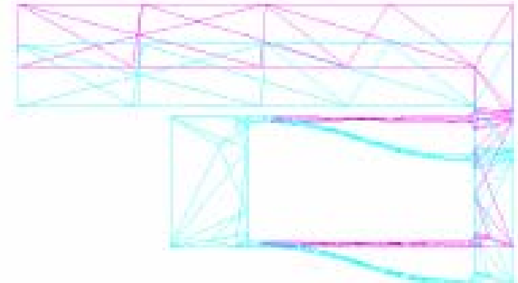




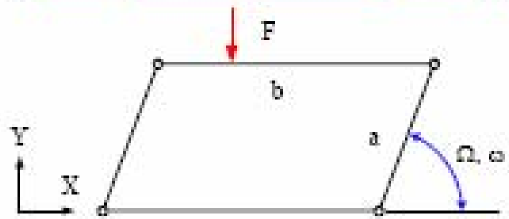


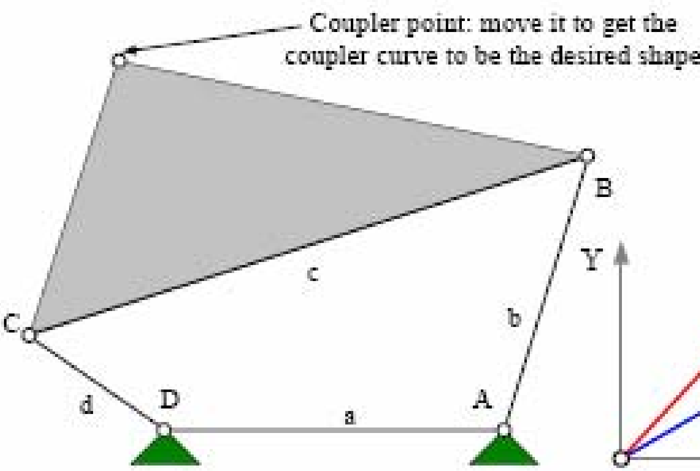


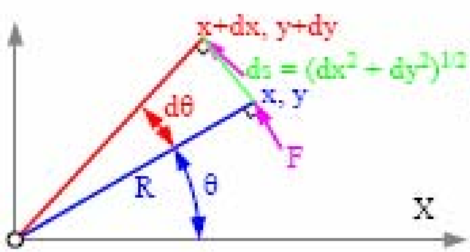
4-Bar Linkages

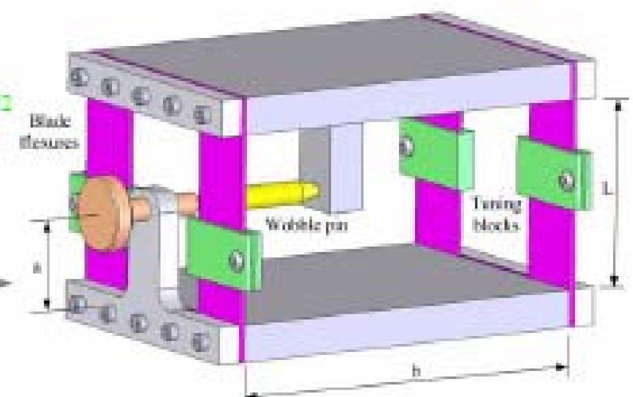


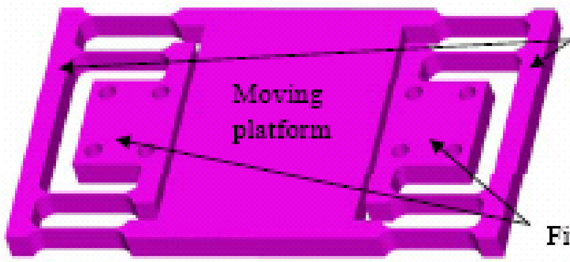
- 4-Bar linkages are commonly used for moving platforms, clamping, and for actuating buckets on construction equipment
- They are perhaps the most common linkage
  - They are relatively easy to create
  - One cannot always get the motion and force one wants
    - In that case, a 5-Bar or 6-bar linkage may be the next be





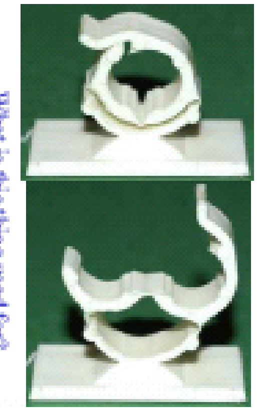




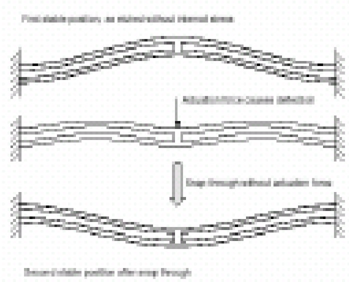


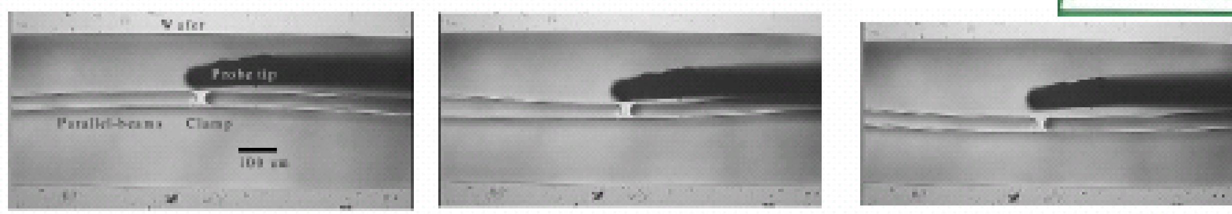
Compliant Mechanisms

- The pin joints in linkages are often the major source of error motions
  - See page 10-24 and the flexure design spreadsheets!
- When only small motions are required, the pin joints can be replaced with flexural elements, thus forming a *compliant mechanism*
  - Extremely high accuracy small range of motion devices can be made this way
  - Many *Micro Electro Mechanical Systems* (MEMS) use tiny silicon flexures



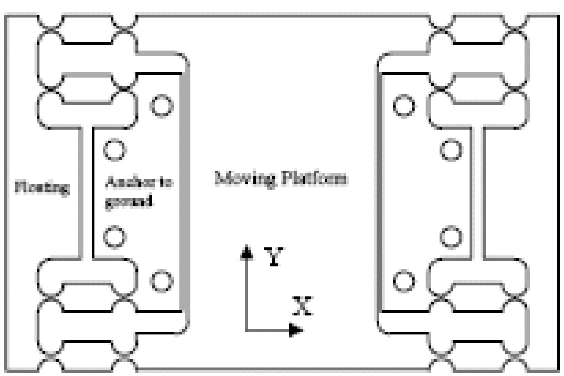
What is this thing used for?





(a) The mechanism as etched; the probe is ready to pass

(b) Deflection as the probe pushes the mechanism.

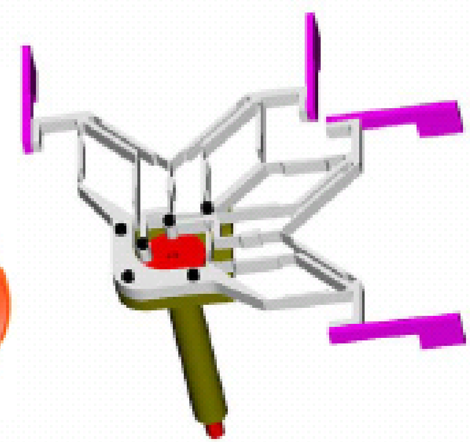


CableCuff® US Patent 6,101,684 (www.cableclamp.com)

a) Note the nifty flexural pawl/ratchet

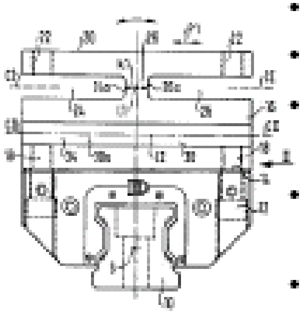
b) Could the pivot have been made as a snap-fit or a "living" (flexural) hinge

c) If patented and so simple (machines could make and assemble) can it be made domestically?



Linear Motion

- A 3-Bar linkage (is there really a "3-bar" linkage?!) system can minimize the need for precision alignment of bearing ways
  - Accommodates change in way parallelism if machine foundation changes
  - US Patent (4,637,738) now available for royalty-free public use
    - Round shafts are mounted to the structure with reasonable parallelism
    - One bearing carriage rides on the first shaft, and it is bolted to the bridge structure risers
    - One bearing carriage rides on the second shaft, and it is connected to the bridge structure risers by a spherical bearing or a flexure
    - Alignment errors (pitch and yaw) between the round shafts are accommodated by the spherical or flexural bearing
    - Alignment errors (δ) between the shafts are accommodated by roll (θ) of the bearing carriage
    - Vertical error motion (Δ) of the hemisphere is a second order effect
    - Example: δ = 0.1", H = 4", θ = 1.4 degrees, and Δ = 0.0012"
    - Abbe's Principle is used to the advantage of the designer!



US patent 5,176,454

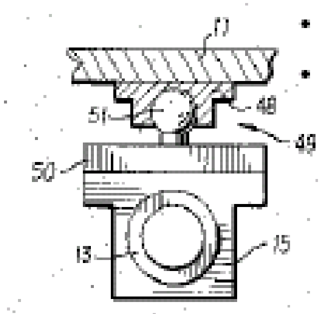
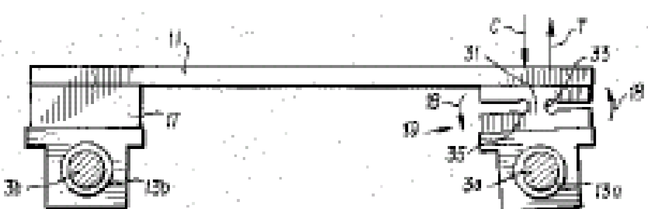
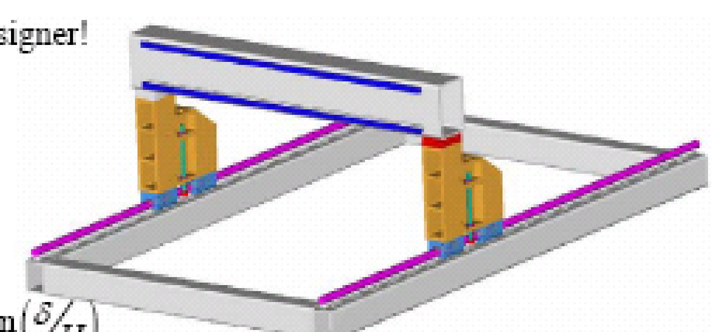


FIG. 9



US patent 4,637,738

FIG. 3



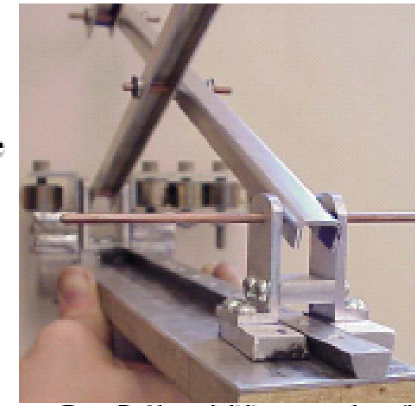
$$\theta = \arcsin\left(\delta / H\right)$$

$$\Delta = H(1-\cos\theta) \approx \frac{\delta^2}{2H}$$

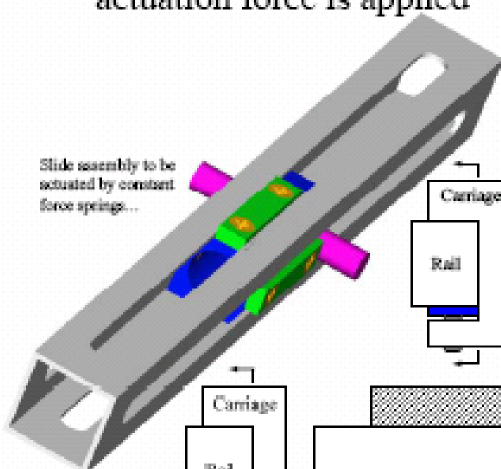
Linear Motion

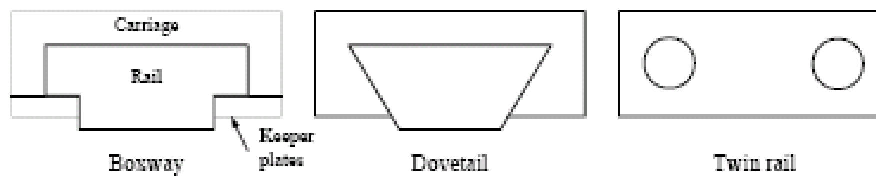
Sliding Contact: *Linear Motion*

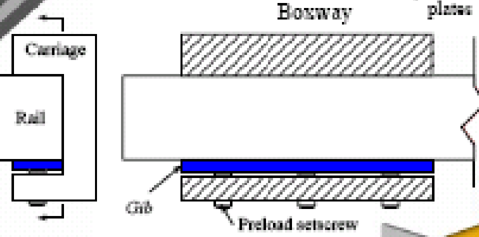
- Linear bearings are essentially rotary bearings with a really large radius of curvature
  - There are many configurations: boxway, dovetail, twin rails…
  - Clearance between bearing and rail or shaft can be removed by circumferential clamping or with *gibs*
- To prevent jambing, apply *Saint-Venant's* principle to the ratio of the length of the carriage to the spacing of the bearings
- Beware *centers of mass, stiffness, friction*, and where the actuation force is applied

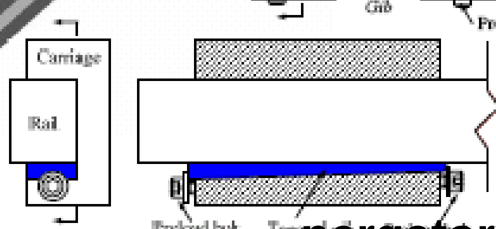


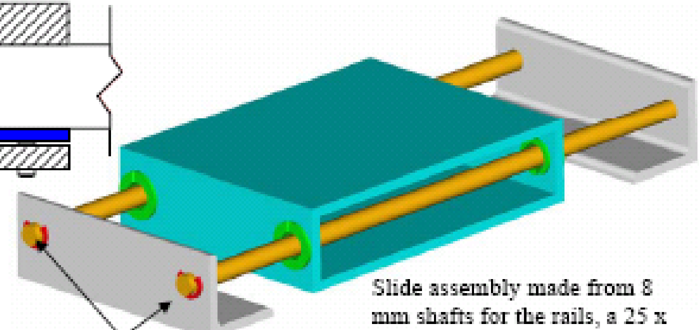
Bryan Ruddy used sliding contact dovetail bearings to guide his scissor linkage









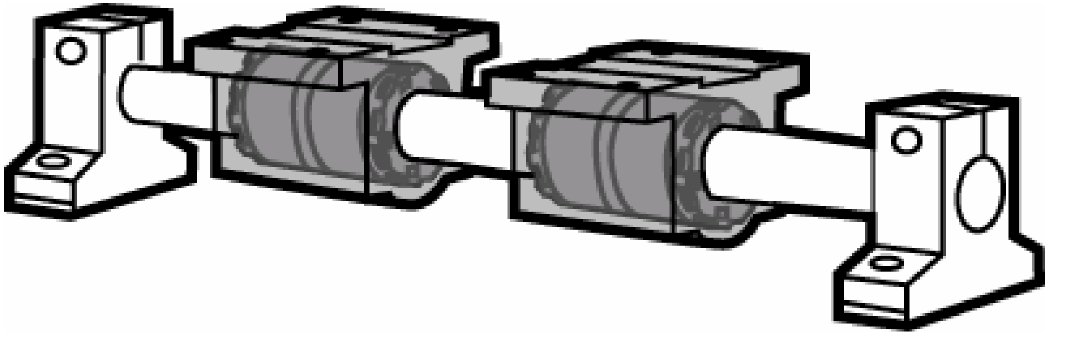


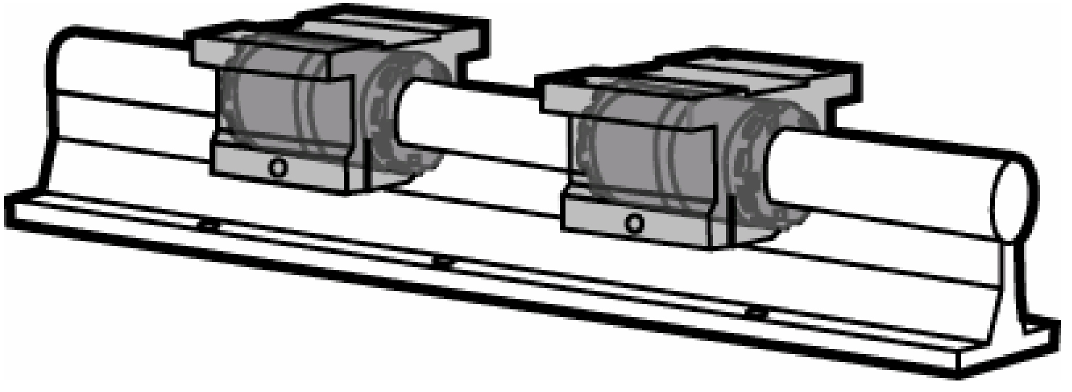
Slide assembly made from 8 mm shafts for the rails, a 25 x 100 mm box extrusion for the carriage, and Nylon bushings

10-5

Linear Motion

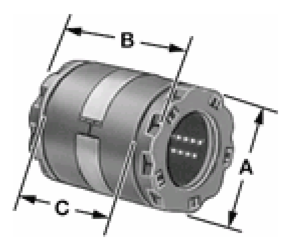
- McMaster-Carr
  - Order online
  - CALL for help!

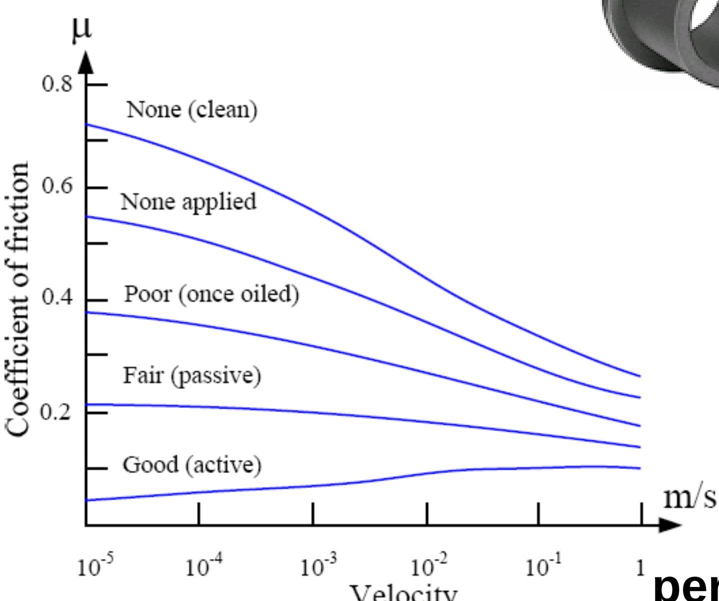




Bearings & lubrication

- Rotational & Linear Motion
  - NEVER put aluminum on aluminum!
  - USE a BUSHING or BEARING





pergatory.mit.edu/2.007

Commercial Solutions

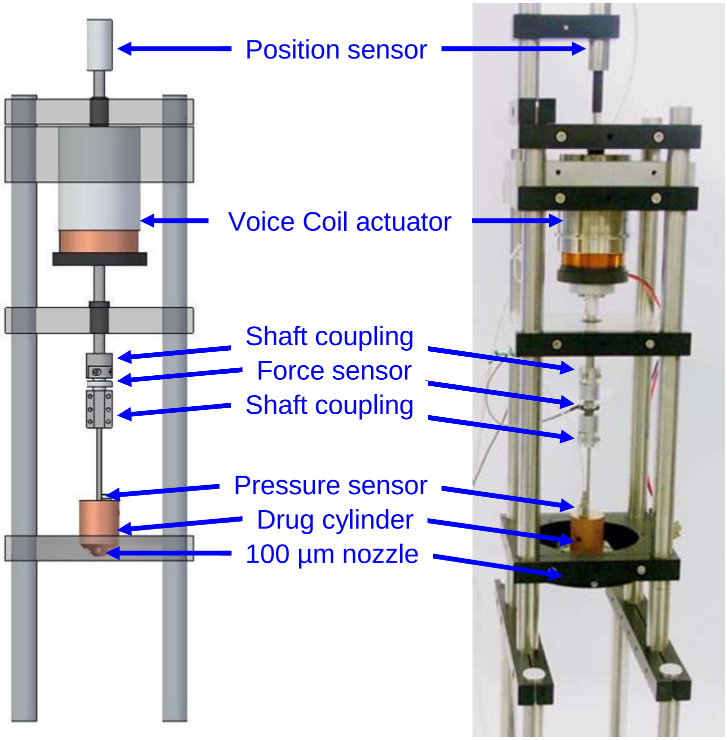
MK Automation

- easy attachment
- modular
- not too cheap
- GREAT for enclosures, structures

www.MKprofiles.com

Macrobench and Microbench

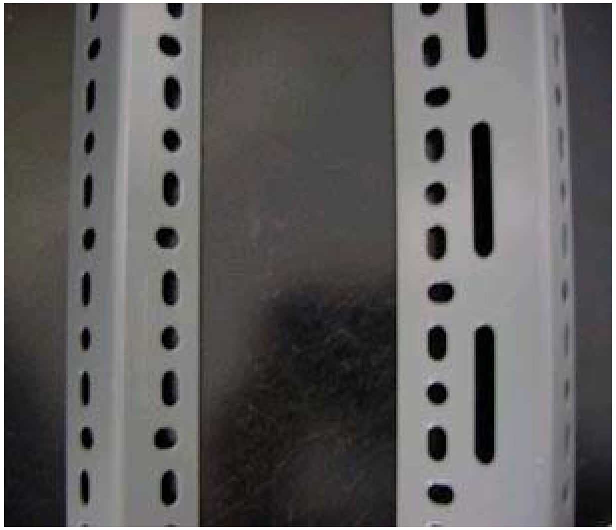
- NOT cheap
- GREAT alingment
- GREAT for optics
- Different sizes available



www.linos.com

Dexion

- Easy to use
- Not very structural
- Not as “pretty” as other options



www.dexion.com

REFERENCES

- BEST DESIGN TEXTBOOK EVER!
  - **Mechanical Engineering Design** by Joseph Shigley and Charles Mischke
- Design Website
  - pergatory.mit.edu/2.007
- Parts/Info
  - www.mcmaster.com
  - www.parker.com/SG
  - www.MKprofiles.com
  - www.linos.com
  - www.dexion.com