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
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Make them SIMPLE!
Supports, Enclosures, Pressure Vessels

• Supports
  – Take load
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• 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
  
  - **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* \( f = 3 \)
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 best option.

Coupler point: move it to get the coupler curve to be the desired shape.

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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

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

CableClamp US Patent 6,101,684 (www.cableclamp.com)
- a) Note the nifty flexural pin/busket
- 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 (θ) 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: θ = 0.1”, H = 4”, θ = 1.4 degrees, and Δ = 0.0012”

Abbe’s Principle is used to the advantage of the designer!

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\[ \Delta = H/(1 - \cos \theta) \approx \frac{\theta^2}{2H} \]
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 jamming, 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

Bryn 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
Linear Motion

• McMaster-Carr
  – Order online
  – CALL for help!
Bearings & lubrication

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

[picture of bearing and bushing]

Graph showing coefficient of friction vs. velocity.
Commercial Solutions
MK Automation

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

www.MKprofiles.com
Macrobench and Microbench

- NOT cheap
- GREAT alignement
- 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