Overview of Assemblies:
Rigid and Articulating Joints

24-370 - Spring 2011
Professor Steve Collins

Reminders and Announcements

• Rev 2 and Addendum due now...
  – Please bring up your plastic boxes
  – Parts look much improved!
• Testing of Rev 2 parts Monday
• AutoDesk info session today 4:30 SH 224
  – Free pizza and drinks...
• HW4 assigned today: materials and assemblies
• Project 2 assigned today...
Project 2 Overview

• The Swinging Gripper!
  – Team project (groups online)
  – Sketch Description...

• Deadlines:
  – Rev 1 Prototype testing March 21\textsuperscript{st} (5 weeks)
  – Rev 2 Prototype and Group Report due April 4\textsuperscript{th}
  – No conflicts, to my knowledge

Assemblies, continued

• Review:
  – Allow movement, manufacturing, separability
  – Can add complexity, reduce strength and accuracy
  – Loading implications: keep attachment forces low

• Tolerances
• Constraints
• Overview of joint types
• Rigid joints
• Articulating elements
## Assemblies and Tolerances

- **What are tolerances?**
  - From possible errors in parts
  - From uncertainty in connections
  - Other types of “slop”
- **Stacking**
- **Geometry of attachments very important**
  - Displacement errors affected by geometry, stacking
- **Some examples and exercises**
  - Mounting a shaft
  - A high-precision gear-box frame

## Assemblies and Constraint

- **Engineering materials are stiff**
  - Small displacements can cause large forces
- **Over-constraint can increase stress**
  - Inducing bending
  - Less-desirable element taking stress
  - Unforeseen force multipliers
- **Some examples and exercises**
  - Billy-Bob’s Miller sign, revisited
  - Perfectly-constrained cantilevered beam
  - Perfect constraint using indexing surfaces
## Overview of Rigid Joints

- **Common methods**
  - Machine screws, bolts, nuts, setscrews, rivets, retaining rings, pins, keys, welds, adhesives

- **Modes of connection**
  - Normal (tensile or compressive) load transfer
    - Best, where possible
  - Shear load transfer
    - Usually to be avoided
  - Friction load transfer
    - Better than shear where normal impossible

## Overview of Articulating Joints

- **Common methods**
  - Bearings, springs

- **Degrees of freedom**
  - One rotational d.o.f., i.e. hinge joint
    - Usually best, where possible
  - One linear d.o.f., e.g. linear slide
    - Usually to be avoided due to bulk
  - Multiple rotational d.o.f., e.g. ball joint
    - Usually to be avoided due to control difficulties
  - Multiple linear d.o.f., e.g. gantry... oh no!
### Nuts and Bolts of Rigid Joints

- **Threads**
  - Pitch - distance between adjacent threads (or inv.)
  - Major Diameter - outer diameter
  - Tap or Die Diameter - pre-threaded diameter
  - Typically single-threaded, right-handed
  - Standardized, e.g. UNS

- **Common Choices**
  - Socket cap screws (machine screws) with hex drive
  - Also, flat or button head
  - e.g. 4-40, 6-32, 8-32, 10-32, ¼-20

### Nuts vs. Threaded Holes

- **Threaded holes usually better in robotics apps**
  - Fewer parts
  - Better tolerances
  - Lower mass

- **Nuts and bolts better in some applications**
  - Cost
  - Manufacturing
  - Careful reusing nuts - built to yield

- **Rule of thumb for threaded holes:**
  - 3 full threads - min
  - 2 diameter’s depth - best for alignment
Socket Cap Screws

- Strength
  - Simple model of screw in tension?
    - \( \sigma = F \frac{1}{A} \), \( A \) = tensile stress area
  - Stress concentrations: fatigue; F.O.S.
  - See, e.g., Shigley pp. 419 for detailed estimates
- Tension and torque in screws
  - Think of as a vise or jack, model as a wedge
  - Relate torque to force using pitch and friction
  - See, e.g., Shigley pp. 437 for equations

Rigid Shaft Clamping

- Setscrews - screw pushing on side of shaft
  - simple, but weak and self-loosening
- Pins - radial hole and cylinder
  - more complex, small shear area
- Keyways - slots and rectangular key
  - complex, hard to get good fit
- Split-hub clamps - one-sided slot and screw
  - high-torque, low-slop, robust, but big
- Retaining ring - springy ring in groove
  - axial only, adds complexity to shaft
Detail Design of Articulating Joints

• Rotational joints
  – Plain bearings
    • Low-friction, low-wear material, often polymer
    • Cheap, strong, small, light, and easy
    • Still, higher friction and less precision
  – Ball bearings
    • Small rolling balls between inner and outer race
    • Very low friction, high precision, high speed
    • Low load, high mass and size
  – Needle roller bearings
    • Like ball, but higher load, lower precision, mass and size

Detail Design of Articulating Joints

• Linear joints
  – Same types of elements
    • Plain, ball, needle roller
  – Also have rotationally-constraining tracks
    • Two rails
    • Square rails with features
  – Did I mention I don’t like linear bearings?
Capturing Articulating Elements

- Don’t want to interfere with desirable motion
- Securing, e.g., outer race
  - Press fit - careful with induced stresses
  - Slip fit and glue - careful with glue
- Securing, e.g., inner race
  - To be avoided, unless using angular contact bearing
- Securing against, e.g., axial shaft motion
  - Use normal contact and (thrust) washer
  - Commonly: retaining ring or gear face pushes against plain thrust bearing or needle bearing

Accompanying Readings

- Shigley Chapter 8 - Fasteners
- Shigley 7-7 - Shaft clamping
HW4

• Assigned today
• Due in class next Wednesday, February 23rd
• Covers:
  – Material selection
  – Assembly geometry, strength and tolerances
  – Common joining elements and constraints