Design Tips

Or how to curse less and get more done
Overview

- Conceptual Tricks
  - Saint-Venant’s Principle
  - Abbe’s Principle
  - Self-Help and Reciprocity

- Constraints
  - Exact Constraint
  - Elastic Averaging

- Design for Assembly

- Rules of Thumb
A Note on References

- Many slides taken from Prof. Slocum’s undergraduate design class (2.007)
  - pergatory.mit.edu/2.007
In general, phenomena extend over 3-5 characteristic lengths

“Characteristic Length”
- Plate thickness
- Hole diameter
- Thread pitch
Conceptual Tricks – Saint-Venant

Bad

Good

Strain cones

45°  60°

4D

D

1.5D

Courtesy of Prof. Slocum’s notes
Angular errors are magnified over distance
- Position errors can make for huge forces!

Stay near “principal axis” to avoid problems
- Measurement axis
- Line connecting structural loads

Angular errors can cascade quickly
Abbe’s Principle: *Locating Components*

- Geometric: Angular errors are amplified by the distance from the source
  - Measure near the source, and move the bearings and actuator near the work!
- Thermal: Temperatures are harder to measure further from the source
  - Measure near the source!

On Brown & Sharpe’s vernier caliper: “It was the first practical tool for exact measurements which could be sold in any country at a price within the reach of the ordinary machinist, and its importance in the attainment of accuracy for fine work can hardly be overestimated”

- Thinking of Abbe errors, and the system FRs is a powerful catalyst to help develop DPs, where location of motion axes is depicted schematically
  - Example: Stick figures with arrows indicating motions are a powerful simple means of depicting *strategy* or *concepts*

\[
\theta = \arcsin\left(\frac{F_H}{H}\right) \\
\Delta = H(1 - \cos\theta) = \frac{\delta^2}{2H} \\
3 - 12
\]

Courtesy of Prof. Slocum’s notes
Conceptual Tricks - Reciprocity

- Philosophical approach to design
- What seems like a weakness could actually be a strength!
- Sometimes your idea could work better upside-down, or even inside-out!
- Example: micro-calorimeter
  - Evaporation causes heat loss
  - Use evaporation for sensing???
Self-Principles

- The manner in which a design reacts to inputs determines its output
  - Reciprocity would philosophically tell us to look for a solution where a potentially detrimental result can be used to cancel the effect
  - Martial artists practice this principle all the time!
- **Self-Help**: A design that uses the inputs to assist in achieving the desired output
  - An initial effect is used to make the device ready for inputs
    - The supplementary effect is that which is induced by the inputs, and it enhances the output
  - **Example**: Airplane doors act like tapered plugs
  - When the door is shut, latches squeeze the seal, making the cabin airtight
    - As the plane ascends and outside air pressure decreases, the higher inner air pressure causes the door to seal even tighter
  - **Example**: Back-to-back angular contact bearings are thermally stable
  - **Example**: Ice tongs
  - **Example**: A better mousetrap!

Other self-principles similarly exist:
- **Self-Balancing**, **Self-Reinforcing**, **Self-Protecting**, **Self-Limiting**, **Self-Damaging**, **Self-Braking**, **Self-Starting**...
Constraints - Overview

- Every rigid body has 6 degrees of freedom
  - 3 translational
  - 3 rotational
- Flexible bodies may have additional DOFs
  - Only count if very compliant!
- A body at rest has at least 6 constraints
  - Some may be from friction or be compliant
Constraints - Exact

- For maximum control, apply exactly 6 constraints to each body
  - Rotational constraints must be able to apply torque
- Watch out for unintentional extra constraints!

Courtesy of Prof. Slocum’s notes
Constraints - Exact

Ball – Groove Couplings

3-Tooth Coupling

Courtesy of Prof. Slocum’s notes
Constraints - Elastic

- Use many constraints, and let elastic deformation average out any errors
  - Very strong and stiff
  - Must manage errors to avoid plastic failure

Examples
- Lego blocks
- Pressure vessel lids
- 5-legged chairs
Design for Assembly

- Maintain access to nuts, bolts, and screws
- Use only enough screws to do the job, and no more
- Be careful to maintain tolerances
- Don’t forget to leave space for wires and tubes
- Connectors require enough space to fit your hand
- Watch for sharp edges near access points
Rules of Thumb

- Bolts have a 60 degree “cone of influence”
  - Overlap the cones for even deformation
  - Also overlap when sealing is required

Courtesy of Prof. Slocum’s notes
Rules of Thumb

- Keep all holes at least one diameter away from edges or other holes
  - Minimizes stress concentrations
- Countersinks are pretty; counterbores are strong