Design Concepts

Spectrum 3847

History of Design Contests

What we are doing isn't really new. There are lots of design contests.

- Paper Airplane Contest
- Cardboard Boat
- MIT Class (see next slide)
- Auto Racing - Formula 1 (first auto race was in 1895)
- Drag Racing
- Air races

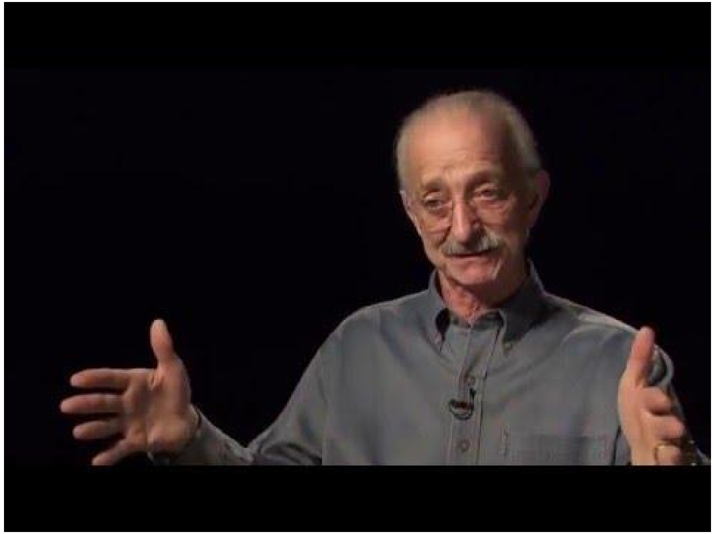
Robot contests are relatively new

Robot Contests

Woodie Flowers Father of Competitive Robotics

In his MIT Course 2.70, he developed a way to inspire students to work extremely hard, use engineering principles, compete like crazy, and work together with even their opponents.

Short



Long but really good

Robot Contests

- VEX IQ, VEX
- FLL, FTC
- BEST
- MATE
- Trinity Fire Fighting Robots
- Battle Bots
- Maze solving robots
- Robocup
- RoboMaster
- Grand Challenge Cars
- Grand Challenge Walking Robots

FIRST Robotics Competition

The varsity level of high school robotics.

Building a quality robot and having a good season is hard. It's supposed to be hard. That’s the challenge. You have to put in the work to get the reward at the end.

It’s not just a robot

Our goal on the team isn’t just the robot. The robot is important but what’s more important is that we strive to be a good team.

That means

- Our students are learning, being inspired, and having fun
- We are helping other teams to become better teams
- We are working in our community to make the world better
- We are efficient & effective with our resources
  - money, supplies, space

Things you should learn

Most of what you learn on this team isn't going to come from anyone standing at a whiteboard teaching you. It's going to come from you putting in the time to learn it.

- Using Google Drive
- CAD/ Solidworks/ GrabCAD
- Basic Shop Tools
- 3D Printing
- CNC Router
- Lathe
- Video Editing
- Live Streaming
- Confidence
- Basic Electronics
  - Voltage/Current/Soldering/etc
- Basic Programming
- Photo Editing
- Communication
- Public Speaking
- How to take a good photo
- Talking to Strangers
- Kindness / Compassion

So what are we doing?

We are designing an entire program, not just a team. That means every year, every month, and every day. We should always be trying to make our program better.

What can you do today to make our team better?

Improving as a team requires everyone's effort, which can be shown by designing a new feature for a robot, tagging photos, cleaning the lab, taking photos, creating a team handbook, etc.

Be passionate about making Spectrum better!

Design is a Passionate Process

- Believe that what you are doing is important. Is this a problem worth solving? Do you feel a **need** or **yearning** to solve it?
- “Passion is a necessary, but not sufficient, component of a good design engineer’s effort to solve a problem. “
- “Most design processes typically involve repeating essentially the same steps as the design funnels down from broad concepts to details. “
- “A good design process should be simple, flexible, and applicable to just about any problem one can think of.”

[Full Slide Deck on Design is a Passionate Process by Alexander Slocum]()

"Enthusiasm is one of the most powerful engines of success. When you do a thing, do it with all your might. Put your whole soul into it. Stamp it with your own personality. Be active, be energetic, be enthusiastic and faithful and you will accomplish your object. Nothing great was ever achieved without enthusiasm."

Ralph Waldo Emerson

[Karthikk TED Talk]

[Full Slide Deck on Design is a Passionate Process by Alexander Slocum]

Speak UP!!!

- If you believe you have a good idea, SPEAK UP!
- If you see a flaw in the idea that the team is moving to, SPEAK UP!
- Your team is depending on you to provide your input. Your idea or suggestion may be what's needed to push the team in a better direction.

Focus

- “The ability to focus on a problem helps one create a good working solution in an appropriate amount of time using an appropriate amount of resources.”
- “Just as the optical term implies, focusing on a problem means to define a field of view, clearly see what needs to be done, and then do it in depth!”

Full Slide Deck on Design is a Passionate Process by Alexander Slocum

Maximize aquatic avian linearity

- "Get your ducks in a row"
- Dissect the problem into its components and requirements

Maximize avian termination with a minimum number of projectiles:

- "Kill two birds with one stone"
- Systematically generate solution strategies and machine concepts
- Look for similarities between elements of the problem
- 118 in 2015 - Can stacker mechanisms

Full Slide Deck on Design is a Passionate Process by Alexander Slocum

Lacerate bovine growth by-product:

- “Cut through the bulls#!t”
- Identify the primary tasks that must be completed to succeed
- Establish a set of goals and work efficiently to meet them
- “Avoid complexities and make everything as simple as possible”

Minimize deceased equine flagellation:

- “Do not beat a dead horse”
- Learn to recognize when an idea is destined to be intractable given your allowable resources, and then drop it
- Keep your ego in check, and learn to put your failures on the front page next to your successes

[Full Slide Deck on Design is a Passionate Process by Alexander Slocum]

Impactus maximus ad gluteus maximus

- "Give the project a BIG kick in the butt and do not delay starting!"
- Maintain momentum and strive to finish ahead of schedule!
- Help others to get focus
- Put in the hours
- Be effective & Be diligent

Design of Prose - George Orwell

- Never use a metaphor, simile, or other figure of speech which you are used to seeing in print.
- Never use a long word where a short one will do. If it is possible to cut a word out, always cut it out.
- Never use the passive where you can use the active.
- Never use a foreign phrase, a scientific word or a jargon word if you can think of an everyday English equivalent.
- Break any of these rules sooner than say anything outright barbarous.

Full Slide Deck on Design is a Passionate Process by Alexander Slocum

Deterministic Design

- Everything has a cost, and everything performs (to at least some degree)
  - If you spend all your time on a single tree, you will have no time for the forest
  - If you do not pay attention to the trees, soon you will have no forest!
  - You have to pay attention to the overall system and to the details
- Successful projects keep a close watch on budgets (time, money, performance)
  - Do not spend a lot of effort (money) to get a small increase in performance
    - “Bleeding edge” designs can drain you!
  - Do not be shy about taking all the performance you can get for the same cost!
- Stay nimble (modular!) and be ready to switch technology streams
  - It is at the intersection of the streams that things often get exciting!
    - Example: Going from limit switches to encoders, more complex but may be needed to solve the problem.
  - “If you board the wrong train, there’s no use running along the corridor in the opposite direction” - Dietrich Bonhoeffer

Full Slide Deck on Design is a Passionate Process by Alexander Slocum

Deterministic Design: Play!

- Engineering is often a tactile, visual, verbal, cerebral, and physical activity:
  - Play with the field, game elements, and the kit parts.
    - You get a better understanding when you actually feel the items.
    - Listen to the sounds the objects and parts make.
      - Some things will just sound right, and you can often find problems by small noises, or a change in sound.
  - Sketch ideas (back of a napkin, MS Paint).
  - Play the game with people.
  - Talk about all your ideas. Your idea may spark someone else's next idea.

Full Slide Deck on Design is a Passionate Process by Alexander Slocum

Value of failure

- Design instinct isn't something you're born with. It takes practice and it takes gaining knowledge to be able to see the right design and to quickly find the flaws in the wrong ones.
  - Look at lots of robots (Watch video, read books, ready CD, etc)
  - Build a design library in your head
- Work to be wrong, try to fail, and fail fast. Design your prototypes, your CAD sketches, etc., to find the flaws in your design. The more often you're wrong now the quicker you'll be right the next time.
- Listen to your crazy ideas and sketch them on paper. Then ruthlessly attack them to find what's wrong with them.

Full Slide Deck on Design is a Passionate Process by Alexander Slocum

Reverse Engineering

Try to understand how the game designers designed the game.

This is crucial; ask lots of question about the game design.

- Why is the field laid out a certain way?
- Why are the vision targets located where they are?
- Why are the tape lines the way they are?
- Why are the height limits set as they are?
- Envision the strategies the GDC thought of to play the game and look for ones they may have missed that give an advantage.

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Disruptive Technologies

- Is there something new or from a different industry/field that can give you an advantage?
  - The Paintball hopper systems that inspired 971/125/1323/148 in 2017 are a good example of this.
- Is there a design that guarantees a win? (Choke Hold Strategy)
  - 71 in 2002
  - How do design to beat that strategy? Multiple robots working together?
- How risky is this new design or strategy?
- Do you have the technology to implement it?
- Driver practice is always a disruptive advantage

[Full Slide Deck on Design is a Passionate Process by Alexander Slocum]

Best Engineering Practices

“Random Results are the Result of Random Procedures”

Prevent problems before they occur

- Follow the process
- Document everything
- Performance (You only need to prototype the parts of your robot you want to work.)
- Reliability
- Repairability (keep it simple and have spares)
- Field Tolerances (We couldn’t drive over the hopper plates in 2017)
- Costs (keep within your budget)

[Full Slide Deck on Design is a Passionate Process by Alexander Slocum]

Schedules

- FRC has hard deadlines at every competition. It has to work during the match, or you aren't going to get any points.
- In FRC you can get creative with your schedule if you have the resources. Robot rebuilds or system rebuilds are common. Learn from others and never stop improving.
  - 558 Full Rebuild

Risk Management

- Constantly be looking for risks in every design choice, especially those made by other people on the team (more especially those made by Allen).
- Which element, if defined or designed wrong, will neutralize the machine?
- Which element will be hardest to replace/upgrade during the season?
- Which element is most crucial to the robot success?
- Spend time doing the design work to mitigate those risks.
  - More prototypes, more computations, more testing, etc.

Engineering Design Process

1. Evaluate your resources
2. Study the problem (solve the right problem)
3. Create possible **Strategies**
4. Create **Concepts** that can implement the best strategies.
5. Develop **Modules** - 2D Sketches and PROTOTYPE!
6. Develop **Components** - 2D Sketches
7. Detailed Design, Manufacturing, Drawings
8. Build, Test, Modify, Repeat
9. Document and create manuals

What do we have?

- Team size, knowledge, experience?
- Meeting hours and days?
- Shop size and access to tools?
- Materials, parts, etc. on hand?
- Budget?
- Events attending?
- Sponsors/Friends/Parents/etc.?

1. Evaluate your resources

What are we trying to do?

- READ THE RULES!!!!
- Study the field
  - Watch the field tour videos, talk to people that see the real field in Manchester
  - Look through the CAD models, field drawings, and team drawings
  - Document the important field dimensions
    - E.g. goal heights, auton driving distances, game piece sizes, feeder station heights, shot distances and angles, obstacle heights
- READ ALL THE RULES!!!
  - Game, Robot, & Tournament rules can all help you.
- Document all penalties and restrictions

2. Study the problem

Analyze the scoring

- How many ways can we score points?
- What is the maximum number of points we can score?
- How can we score the most points?
- What is a realistic goal for the amount of points we should score?
- What is a realistic goal for our alliance to score?

Create Possible Strategies

- Imagine motions, interactions, match flow
- Ask lots of questions WHAT, WHY, HOW, WHERE
- Mock up the problem (game) with other people or on your desk, etc.
- You want to find every strategy, even ones you don't use, so you can defend them.
- Take a shower, take a walk, run, stretch, do yoga, journal, or anything that allows you to think differently.

Create Possible Strategies

- Research
  - How is this similar to past robot games?
  - What are the key differences between this game and similar games?
  - How did teams succeed in similar games?

Time Analysis

- How long is a match?
- How many points can we score in Autonomous?
- How long does it take to score a disc in the low goal? Mid goal? High goal?
- How long does it take to get a disc from the feeder station? Four discs?
- How long does it take to get a disc from the floor? Four discs?
- How long does it take to climb 1 level, 2 levels, or 3 levels on the pyramid?
- How long does it take to score in the PYRAMID Goal?
- How can we speed up these tasks?
- For each method, how long does it take to score a certain amount of points?
- Think about success rates (will you miss shots, will you fail?)

3. Create possible Strategies

Trade - offs

- Speed vs. Torque (Move Fast or Push Hard)
- Reach vs. Stability (Tall and easily tipped or short and stable)
- Wide vs. Long Drive Base
- Reliability vs. Complexity
- Practice Time vs. Build Time

3. Create possible Strategies

Cost Benefit Analysis

- Difficulty vs. Benefit
  - How much does it cost in $, lbs, volume, time, center of gravity, and many other constraints?
  - How much does it help you win a match?
- The easy stuff that's worth a lot is the best

The MOST critical thing you can do in a robot design contest is study the scoring algorithm and determine which are the most sensitive parameters!

In 2017 - Climbing and Gear Cycle times
In 2016 - Defense Crossings and then high goal cycle times
In 2014 - 3 Assist cycle times were critical
In Ultimate Ascent - ????

3. Create possible Strategies

Karthik’s Golden Rules

- **Golden Rule #1:** Always build within your team’s limits
  - Evaluate your abilities and resources honestly and realistically
  - Limits are defined by manpower, budget, experience
  - Avoid building unnecessarily complex functions
  - On the other hand, as you get more experienced, start cautiously pushing a few boundaries
- **Golden Rule #2:** If a team has 30 units of robot and functions have maximum of 10 units, better to have 3 functions at 10/10 instead of 5 at 6/10

3. Create possible Strategies

Strategy Comparison Tables

Discs

Strategy	Score Potential	Auto Score Potential	Difficulty (1-10)	Risks	Countermeasures

3. Create possible Strategies

Strategy Comparison Tables - 2013 Example

Discs

Strategy	Score Potential	Auto Score Potential	Difficulty (1-10)	Risks	Countermeasures
Low Goal Cycles	4-6 cycles * 4	6	2	Not a lot of points	Defense, or big climb score
High Goal Ground	4-6 cycles * 12 * accuracy	18-42 * accuracy	8	Ground pickup is hard	Have a human load as well, but that could be harder
High Goal Cycles	4-6 cycles * 12 * accuracy	18 * accuracy	4	Accuracy, driving has to be better,	
Full Court Mid Goal	(~90 sec / 2 sec / disc) * 2 * accuracy	(12 or 18) * accuracy	7	accuracy, defense, tall (can't drive under pyramid)	Full back robot, tall, high release from back of the robot
Full Court High Goal	(~90 sec / 2 sec / disc) * 3 * accuracy	18 * accuracy	9	accuracy, defense, tall, (can't drive under pyramid)	Full back robot, tall, high release from back of the robot

3. Create possible Strategies

Design in Multiple Steps

Strategies -> Concepts -> Module -> Components

- Strategies - How you plan to play the game
- Concept- A specific idea for a machine that can perform the strategy
- Module - A subsystem of the robot that performs a certain task
- Component - An individual part of the robot

The design process is done of each of these steps. Sometimes you may have to go back up a step because a lower function reveals a flaw or is not obtainable with your resource or requirements.

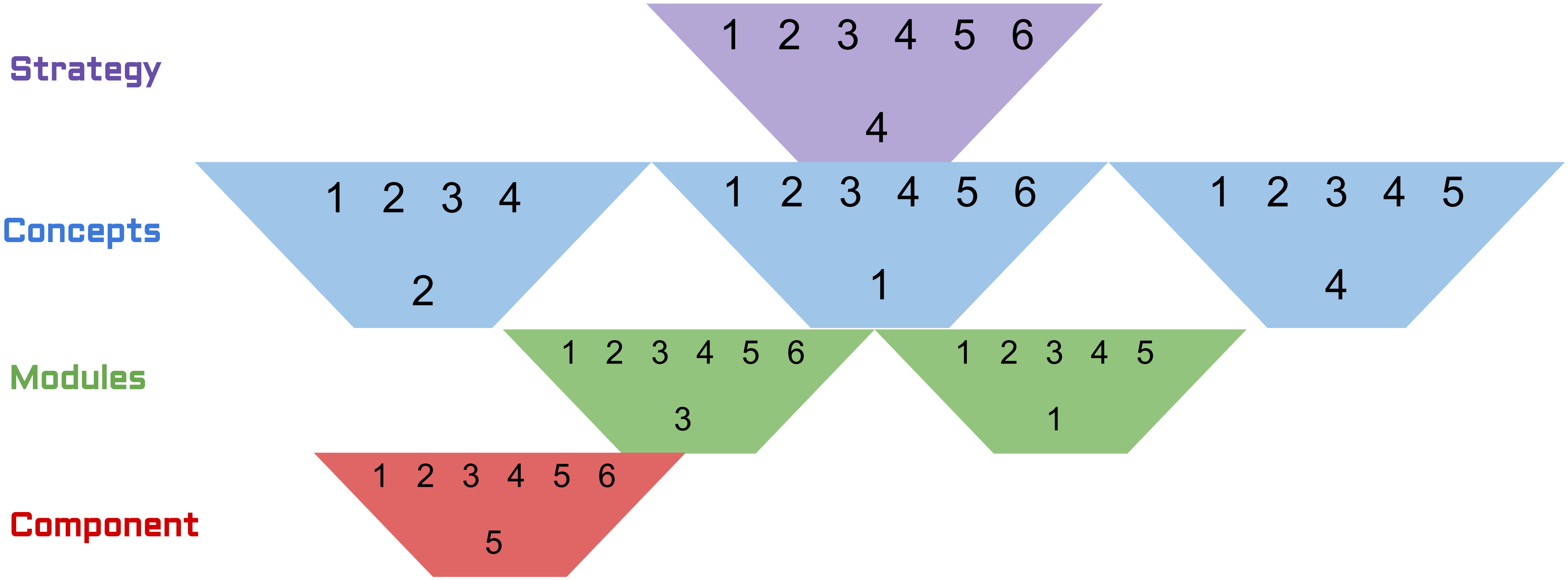
Coarse-to-Fine

Planning a robot is like planning a party

- ▲ **Strategy** - Cater, Restaurant, Potluck, **Prepare a Meal**
- ▲ **Concepts** - Cook-out, Buffet, Family Style, **Sit-down and Serve**
- ▲ **Modules** - Roast Beef, Mashed Potatoes, Lasagna, Mixed Veggies
- ▲ **Components** - All the individual ingredients

Make broad decisions that enable you to plan the next level of detail. Sometimes you'll have to make estimates before you know all the details and you will have to make adjustments as you go.

Coarse-to-Fine



FRDPARRC Chart

- Functional Requirements (events)
- Design Parameters (design ideas)
- Analysis
- References
- Risks
- Countermeasures

Functional Requirements (FR)

Things the design must do

- Should be expressed in words

Examples

- Comply with Robot Rules
  - weight, size, wiring, materials, etc.
- Drive around the field
- Score points
- Acquire/hold game pieces
- Play defense

Design Parameters (DP)

- At least one Design Parameter for each Functional Requirement (FR).
- These are the ideas for how to accomplish each FR.
- These should be independent of the other DPs
- These can be sketches or words

Analysis

- Here is where you show your work.
- CAD sketches, lots and lots of CAD Sketches
- Max. score math, motor usage, gear calculations
- Motion sketches
- Analysis can be used to create DPs!

[Full Slide Deck on Design is a Passionate Process by Alexander Slocum]

References

- Anything can help develop the idea
- Look at past robots, books, youtube videos
- Outside examples like construction equipment, design books, etc.

Risk

- High, Medium, or Low and Why?

Countermeasures

- How do you plan to mitigate each risk?

Sample Chart

Pliers – FRDPARRC 3

Functional Requirement	Design Parameter	Analysis	References	Risks	Countermeasure
Mechanical Advantage	Length of jaws and handles	Lever / balance of forces and moments	Mechanics	Insufficient range of motion	Identify minimum required mechanical advantage and range of motion
Comfortable Grip	Coated or molded handles	Minimum edge fillet on contact faces	Experience, Human Factors Handbook	Slippery hard surface or overly compliant soft surface	Textured metal or thin rubber coat
	Maximum required finger spread	Max handle spread less than max finger reach	User's hand size, Human Factors Handbook	People have different hand sizes	Accommodate with different handle geometry and sizes
Easy to operate	Does not jam	Aspect ratio of diameter to length of engagement, and distance between force points in pin joint.	Saint Venant's Principle	Can't hold object properly when jammed	Remember golden rectangle for baseline sizing

Image Source

Sample Charts

Functional Requirements	Design Parameters	Analysis	Refrences	Risks	Countermeasures
Shoot Frisbees	1.Linear Shooter w/ 2 wheels	How accurate shots are	Linear Shooter -	Innacuarcy (Disk Wobble)	Keep consistent speeds
	2.J/U Shooter	Time to shoot disc	Frisbee players	Low shot speed	Get a better gear ratio
	3.Catapult	Time to reload shooter	J/U Shooter - 1986, 118	Getting blocked	Build a taller robot/shooter, change angle of shot
		Wheels for shooter		Wrong angle	Get an adjustable angle or test to find the perfect shot
		Wheel speed		Shooting too short	Get a better gear ratio
		Time of disk contact with wheels		Low Disk/Second	Conserve moment of inertia, increase load speed
				Disk Jamming	Too much gap space in hopper,

Functional Requirements	Design Parameters	Analysis	Refrences	Risks	Countermeasures
J Shooter	Contacts wheel at an angle	Effect of angle of contact	1986, 118	Less angle = less time of contact, removes purpose of the j shooter	Design prototype with adjustable angles, test multiple angles and measure what works
	Wheels spin to shoot the frisbee	Change of wheel speed on speed and distance of the frisbree		Not enough wheel speed = not far enough, not consistent	Use Talon SRX and smart code to prevent loss of speed
	Compresses the frisbee	Compression on frsibee change on velocity		Too much compression results in loss of forces	Test compression effect
	Angle of wheel	Angled wheels contrain the wheels		Angling the wheels makes the area of contact smaller, less speed transfered	See the effect of the angling of wheels
	Load up the shooter	Speed of loading, keeps the frisbee in line		Load speed = bad, frisbees are uneven when loading	Make sure there is no room to leave, passive way of directing frisbee
	Store frisbee	Size of frisbee holder		Frisbees moves/can be knocked out	Be sure to measure the frisbee holder, keep everything in place

You can always evolve your strategy

- As you learn more about the game, your strategy should evolve.
  - More teams are doing one thing, and you think of a way to stop them.
  - The field acts differently than you thought
    - How is the PYRAMID going to be held together?
    - What if the goals start to overfill during all your matches?
- Don't be discouraged. Stay passionate! Keep working to be better!
- You may end up rebuilding large parts of your robot.

FUNdamental Principles

- Occam's Razor
- Simple Machines
- Newton and Conservation
- Abbe's Principle
- Saint-Venant's Principle
- Golden Rectangle / Ratio
- Symmetry
- Reciprocity
- Self Principles
- Stability
- Parallel Axis Theorem
- Repeatability, Accuracy, Resolution
- Sensitive Directions & Reference Features
- Structural Loops
- Preload
- Centers of Action
- Exact Constraint Design
- Elastically Averaged Design
- Stick Figures

[Full Slide Deck on Fundamental Principles by K. Craig]()

Occam's Razor

- "Plurality should not be assumed without necessity."
  - William of Occam (1284-1347) – English philosopher and theologian
- A problem should be stated in its most basic and simplest terms.
- Complexity is to be minimized in both design and manufacturing.
- The **less thought** and **less knowledge** a device requires for production, testing, and use, the simpler it is.
- Of course, it may take **lots of thought and knowledge** to get to a design requiring little of either – that is design!

Fundamental Principles of Mechanical Design by K. Craig

Occam's Razor

- Create designs that are explicitly simple. Keep complexity hidden.
- Two common techniques for keeping things simple by keeping complexity hidden are:
  - Purchasing rather than making components
  - Specifying components by standards (use standard bolt sizes, parts, materials, etc)
- Intrinsic complexity is is buried and invisible
  - Screw threads are complex but we don't think about it.

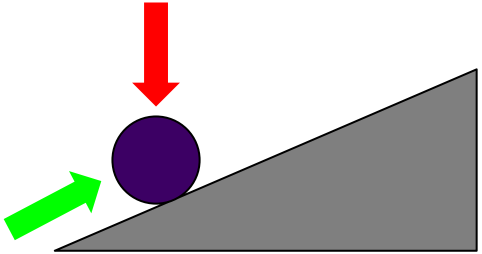
Fundamental Principles of Mechanical Design by K. Craig

Simple Machines

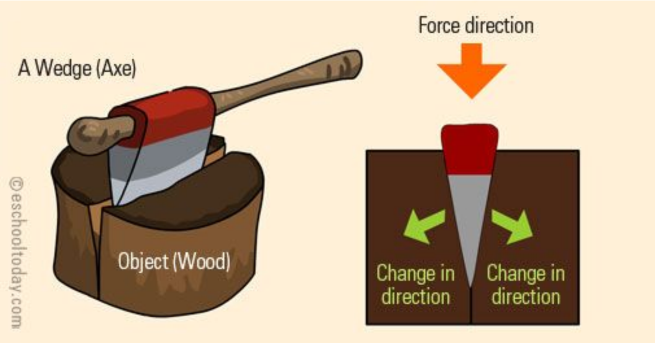
- Super Basic Definition: “They make work easier”
- Broader Definition: “They provide mechanical advantage”

- Less force over a greater distance instead more force over a short distance

Ramp and Wedges

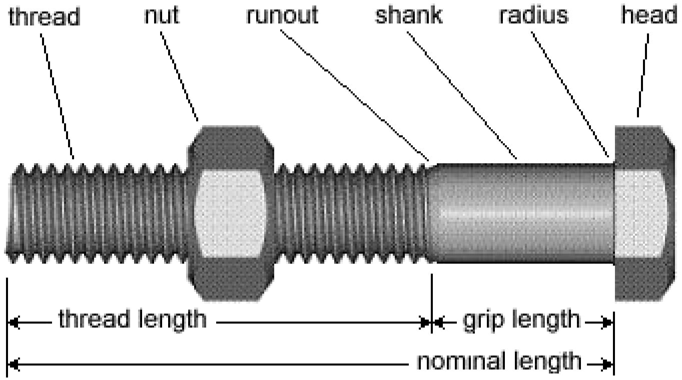


- In their simplest form they force things apart.
- Pushing objects up a ramp is easier than lifting straight up
- A nail or axe works in reserve because you are pushing the wedge instead of moving an object up the ramp.



Screw

▲ A screw is a spiral ramp. It can take rotary force (torque) and turn it into linear force.



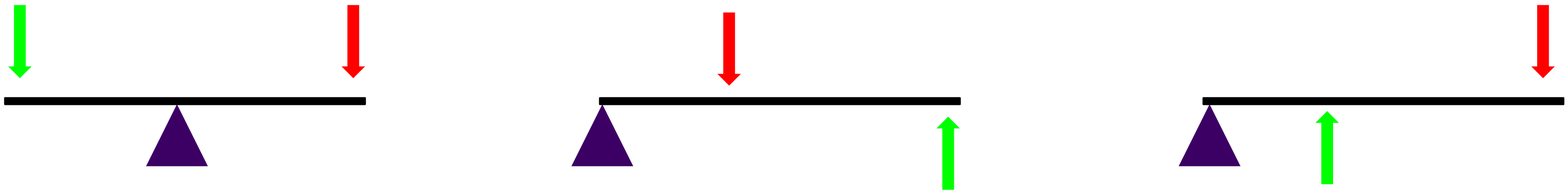
Screw

- Either the bolt can rotate in a stationary material
  - Wood screw going into wood
- Or the threaded nut can rotate on a stationary screw.
  - Nut turning onto a bolt
- Or both could rotate opposite directions
  - When you turn a bolt head and nut at the same time
- Mechanical Advantage = Circumference/Pitch (1/ threads per inch)

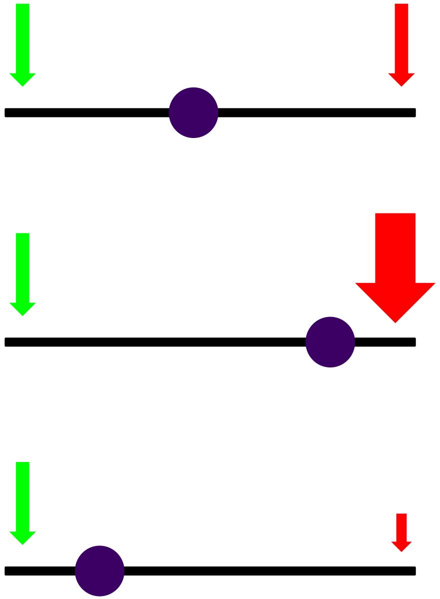
Lever

- Load + Fulcrum(pivot) + Force = Lever

- Power transmission elements such as gears, belts and pulleys, chain and sprockets, driven wheels, etc are all levers.
- By exerting force at one end of the lever, force is applied to the other end of the lever.



Lever



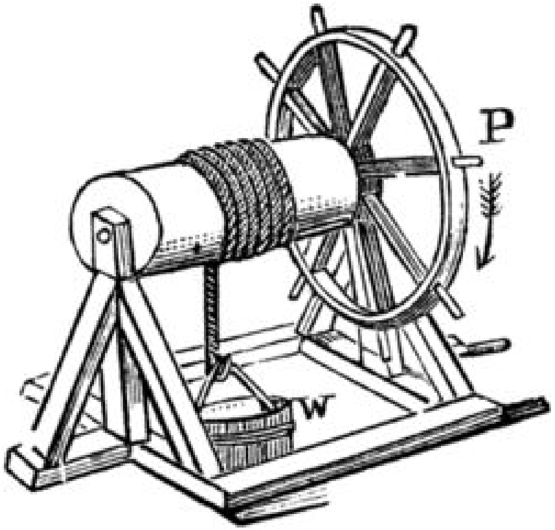
Ratio of the Lever Arms (distance the forces are from the pivot) is how we determine our mechanical advantage.

$$\frac{\textbf{Force Lever Arm}}{\textbf{Load Lever Arm}} \ \textbf{x} \ \ \textbf{Force} \ \ \textbf{>=} \ \ \textbf{Load}$$

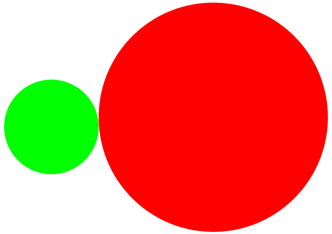
Critical in designing pneumatic actuations

Wheel and Axle

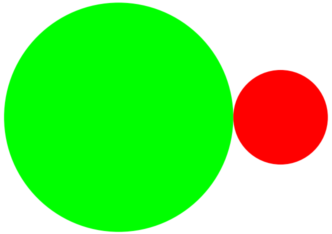
- Reduces friction when used to push things (such as a dolly or cart)
- A version of a lever
- Mechanical advantage = ratio of the diameter of the wheel and axle



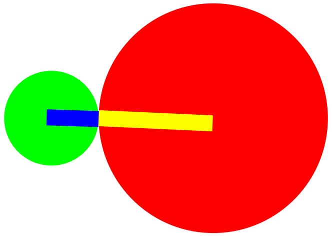
Gear Ratios are Levers / Wheels and Axles



Small input gear, increases force but reduces distance



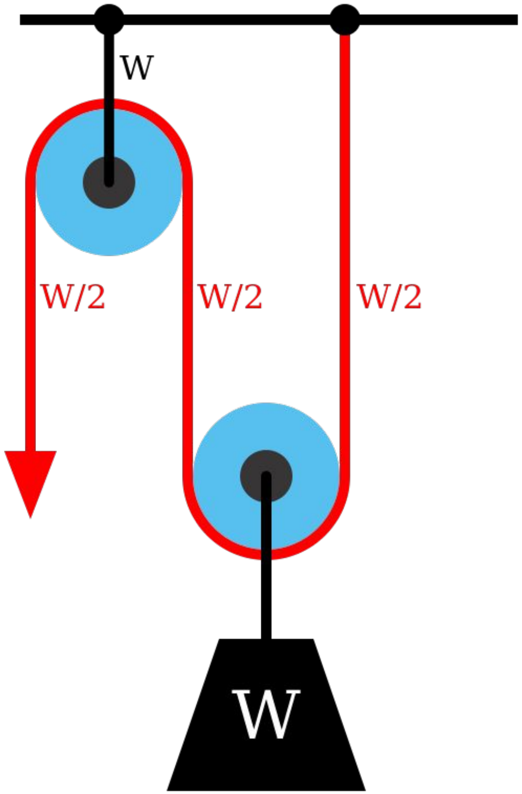
Big Input gear, reduces force but increases distance



Pulley

- A wheel and axle with a cable
- Can help change direction of force
- Multiple floating pulleys can divide the force and provide mechanical advantage.

With just a single pulley you are just redirecting force. 2 pulleys as shown to the right allow you to use ½ the force over 2x the distance to lift an object.



Newton’s Laws

Basics of Mechanics - lots of our problems can come down to Newton’s laws

Newton's 1st Law

"Every body persists in its state of rest or of uniform motion in a straight line unless it is compelled to change that state by forces imposed on it."

An object in motion tends to stay in motion.

Newton’s 2nd Law

“The acceleration of a body is directly proportional to the resultant force acting on it and parallel in direction to this force and that the acceleration, for a given force, is inversely proportional to the mass of the body.”

Force = Mass x Acceleration

Force = Moment of Inertia x Acceleration

Newton's 3rd Law

"To every action there is always opposed an equal reaction or, the mutual actions of two bodies upon each other are always equal and directed to contrary parts."

Conservation of linear and angular momentum

- Conservation of linear momentum –
  - If no force is applied, then momentum is constant
- Conservation of angular momentum
  - If no torque is applied to a body about an axis, angular momentum is constant about that axis • A force coincident with an axis does not apply torque about that axis

Golden Rectangle

- Discovered by Pythagoras (he also has a theorem)
- A rectangle whose sides are in proportion such that when a square is cut from the rectangle, the remaining rectangle has the same proportions. (Roughly 1.6:1)
- Donald Duck: Mathmagic Land
- Helps when designing the overall proportions of a module.

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Motors vs. Pneumatics

Motors

- Rotary motion
- Use a VersaPlantary Gearbox
- Can have more power than pneumatics for less weight and size
- Doesn’t provide constant force well
- Harder to control
- Infinite positions
- Limited to ~14 motors max.
- Speed/Power is controlled using a speed controller (such as a Talon SRX, etc.)

Pneumatics

- Linear motion
- Normally two positions
- Repeatability is assured
- Force can be changed with a regulator
- Provides constant force
- Speed can be changed with flow control valves
- Simpler and cheaper than motors
- In theory you can have unlimited pneumatic actuations

<u>Motors</u> vs. Pneumatics

- Rotary Motion
  - If you need to spin something a lot, this is perfect
  - Especially if you need to spin it fast
- Use a VersaPlantary Gearbox
  - Times you shouldn't use a VP
    - Need a lot of torque and multiple big motors, CIMs and MiniCIMs
    - Needs to be a very small or light mechanism
- Can have more power than pneumatics for less weight and size.
- Doesn't provide constant force well
  - Stalling the motors is normally not good
- Harder to control
- Infinite positions
  - This can be a feature and a problem
- Limited to ~14 motors max.
- Speed/Power is controlled using a speed controller (such as a Talon SRX, etc)

Motors vs. Pneumatics

- Motors

CIM Motor

miniCIM Motor

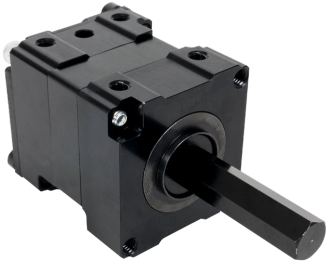
BAG Motor

775pro Motor

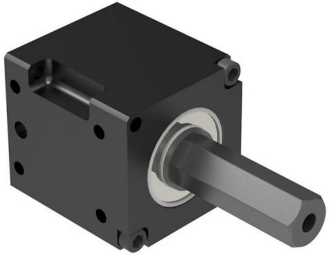
<u>Motors</u> vs. Pneumatics

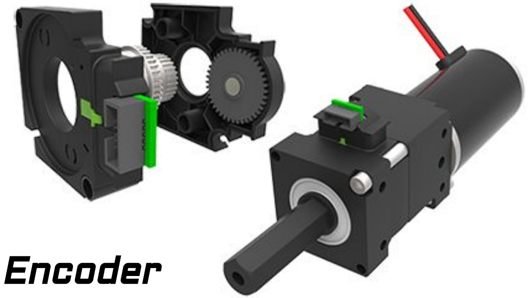
- VersaPlanetary (VP) Gearbox

v2

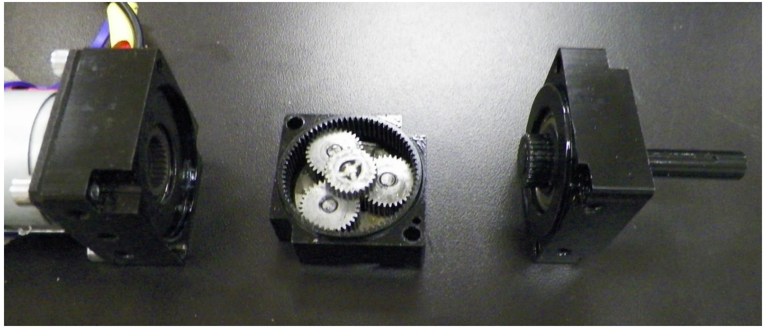


v1





VP Encoder

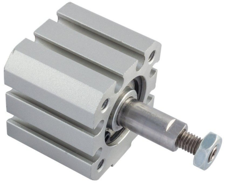


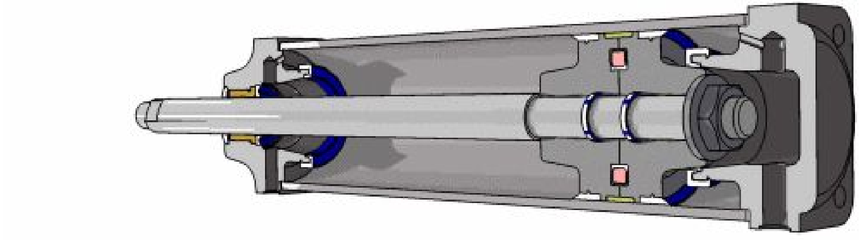
Motors vs. Pneumatics

- Linear Motion
  - Never use a rotary pneumatic actuator
- Normally two positions
  - Can be more if you can add stops or dog two cylinder together.
- Repeatability is assured
- Provides constant force
- Force can be changed with a regulator
- Speed can be changed with flow control valves
- Simpler and cheaper than motors
  - Than motor+motor+controller, etc.
- In theory you can have unlimited pneumatic actuations.
- Max working pressure: 60psi; Max storage pressure: 120psi

Motors vs. Pneumatics

- Cylinders

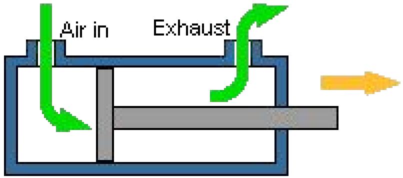




Motors vs. Pneumatics

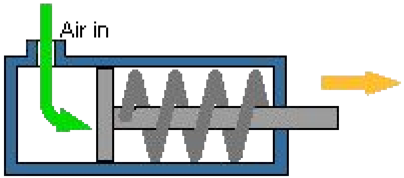
Double Acting Cylinders

- Air is used for both extension and retraction
- Equal forces both ways
- Uses more air



Spring Return Cylinders

- Air is used for extension, but a spring is used for retraction.
- Doesn't have equal forces both ways
- Uses less air
- Spring extend cylinders do exist but they are rarer.



Motors vs. Pneumatics

- **Force can be changed with a regulator**
  - Changes the pressure
  - Ideally use the lowest functioning pressure
  - Less pressure uses less air if the volume remains the same


- **Speed can be changed with flow control valves**
  - They normally control the air being released from a cylinder. So if you want to slow down the extension you flow control on the retraction side (nose) of the cylinder


Abbe’s Principle

“If errors in parallax are to be avoided, then the measuring system must be placed coaxially with the axis along which the displacement is to be measured on the workpiece.”

Small errors in angle are amplified as you get far away from the origin.

It was discovered when working on manufacturing better microscopes.

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Abbe’s Principle

The implications of this observation on the design of instruments and machines are profound:

- Always try to place the measurement system as close to the line of action (the process) as possible.
- Always try to place bearings and actuators as close to the line of action (the process) as possible.
- A small angular deflection in one part of a machine quickly grows as subsequent layers of machine are stacked upon it…
  - A component that tips on top of a component that tips…
  - If You Give a Mouse a Cookie…

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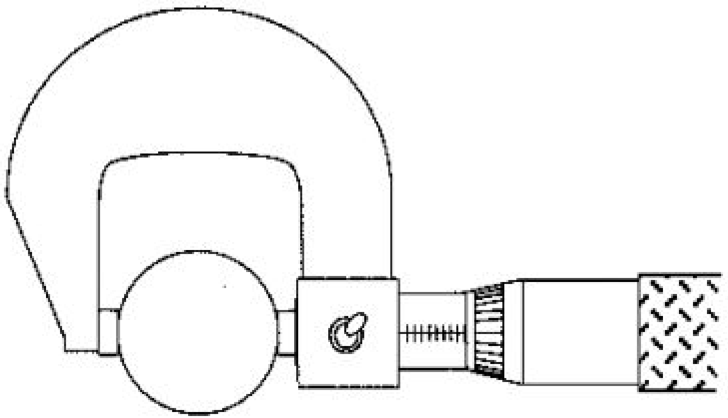
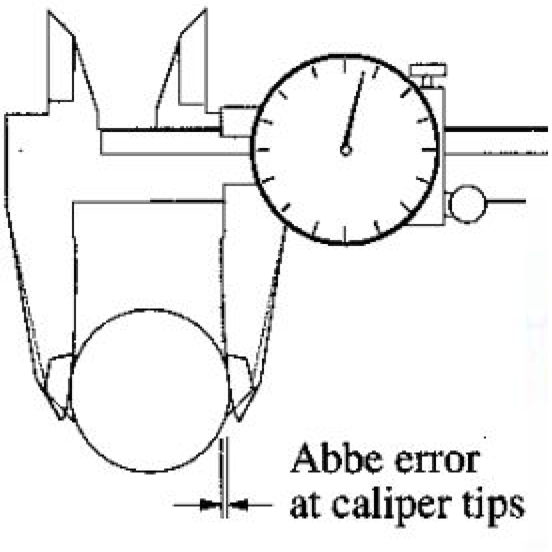
Abbe's Principle





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Abbe's Principle

Abstractions can be taken to other systems as well.

- When measuring temperature, it is important to place the temperature sensor as close as possible to the process to be measured.
- The idea is the same for pressure, flow, voltage, current, etc.
- In each case, the farther away you are from the process to be measured, the greater the chance for errors to reduce the accuracy of the measurement

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Saint-Venant’s Principle

▲ The principle says that several characteristic dimensions away from an effect, the effect is essentially dissipated.
▲ Or if an effect is to dominate a system, it must be applied over 3-5 characteristic dimensions of the system.

▲ To NOT feel something’s effects, be several characteristic dimensions away!
▲ To DOMINATE and CONTROL something, control several characteristic dimensions

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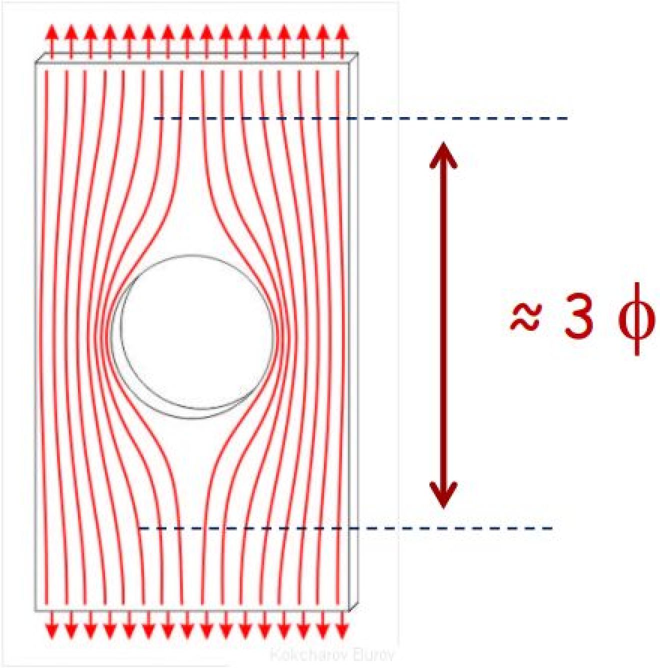
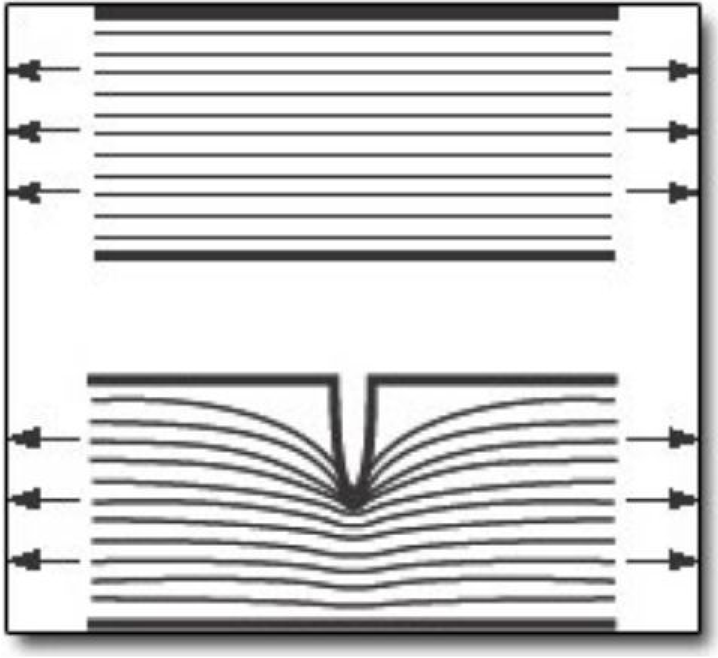
What’s a characteristic dimension?

- It depends
  - Often it’s diameter
    - Examples, shaft diameter or bolt diameter.
  - Sometimes it’s width or height, if the object isn’t round.

- Basically it’s the cross sectional dimension that you are looking at.

Saint-Venant's Principle





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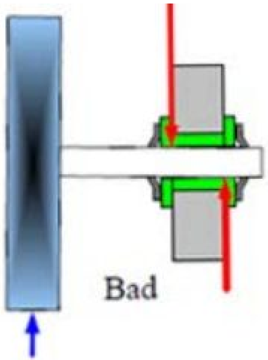
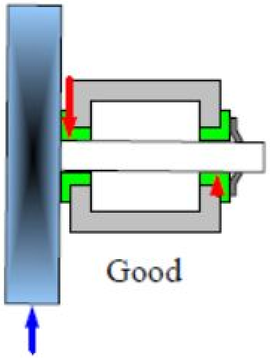
Saint-Venant's Principle - Applications

- When mounting bearings to support a shaft, the bearings should be spaced 3-5 shaft diameters apart if the bearings are to effectively resist moments applied to the shaft.



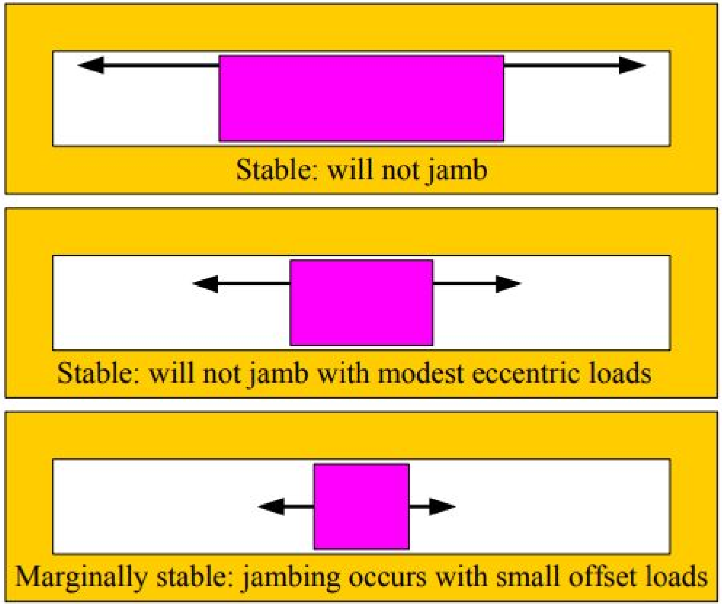


[Full Slide Deck on Fundamental Principles by K. Craig]

Saint-Venant's Principle - Applications

- Linear slides with large contact areas compared to their width will not jam.

- Linear Slides that have two small a contact area will jam when they are twisted even the slightest amount.



[Full Slide Deck on Fundamental Principles by K. Craig]

Self-Principles

Self principles utilize the phenomena the machine is trying to control to help control the phenomena.

A design that uses the inputs to assist in achieving the desired output

4 basic types of self principles:

- Self-help
- Self-balancing
- Self-protecting
- Self-checking.

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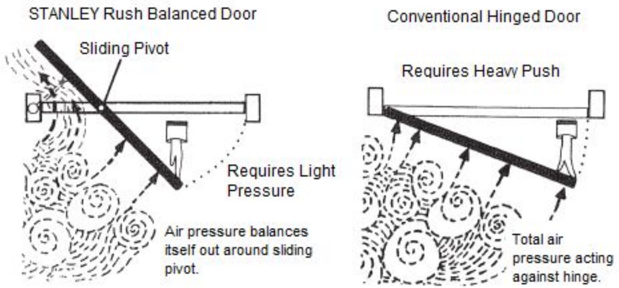
Examples of Self-Help

- Pressure systems such as boilers and airplanes
  - Putting a door in them is scary (it might cause a leak) but you can use the pressure to ensure a seal.
- Ice tongs
- Scissors force the blades together
  - Left handed scissors are mirror images of right handed ones
- Balanced doors can be opened easily in the wind



[Full Slide Deck on Fundamental Principles by K. Craig]

Accuracy, Repeatability, and Resolution

Accuracy: the ability to tell the truth

- Can you hit the target

Repeatability: the ability to tell the same story each time

- Can you hit the same spot every shot

Resolution: the detail to which you tell a story

- How small of an adjustment can you make

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Accuracy, Repeatability, and Resolution

1. Design for the needed resolution of your goal.
   a. How your sensors are mounted.
   b. How you adjust shooter angle, wheel speed, etc.
2. Design that your machine can be repeatable.
   a. lots of compression is normally worse for repeatability
   b. Test lots of shots
   c. Have the ability to mark, reset, and remember your positions/settings.
      i. Create a setting log google form, or spreadsheet, etc, to document critical settings
3. Adjust your system until you are accurate.
   a. Use your resolution to fine tune your device till it’s accurate.

Full Slide Deck on Fundamental Principles by K. Craig

Sensitive Directions

- Identify the variables in which accuracy and repeatability are most important.
  - For 2013 the altitude (vertical angle) was the most sensitive directions.
  - Velocity and azimuth (horizontal angle) were less sensitive when shooting in a straight line and having a wide target. (not assuming full court, Abbe tells us that full court is harder)
- When making parts, know which dimensions are critical and in what direction.
  - Shafts that are held in place by shaft collars can be longer than needed but not shorter.
  - Parts can often be smaller at the edges if nothing interacts with the edges but may run into something if they are made too big

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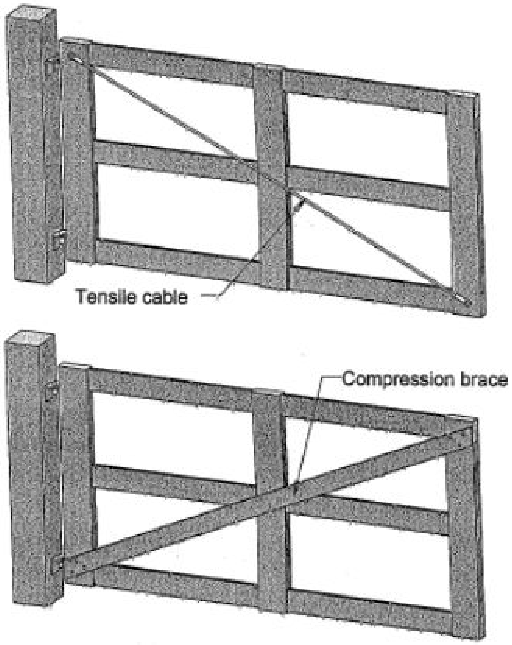
Triangulate for Stiffness

- Triangulate parts and structures to make them stiffer.
- Consider a swinging fence gate. Triangulating members prevent, or correct, sagging.
    - A tensile cable connects the lower outer corner to the upper inner corner, and transmits load to the gatepost.
    - Alternately, a compression brace can be added to the diagonal to transmit the load to the gatepost.



[Full Slide Deck on Fundamental Principles by K. Craig]

Centers of Action

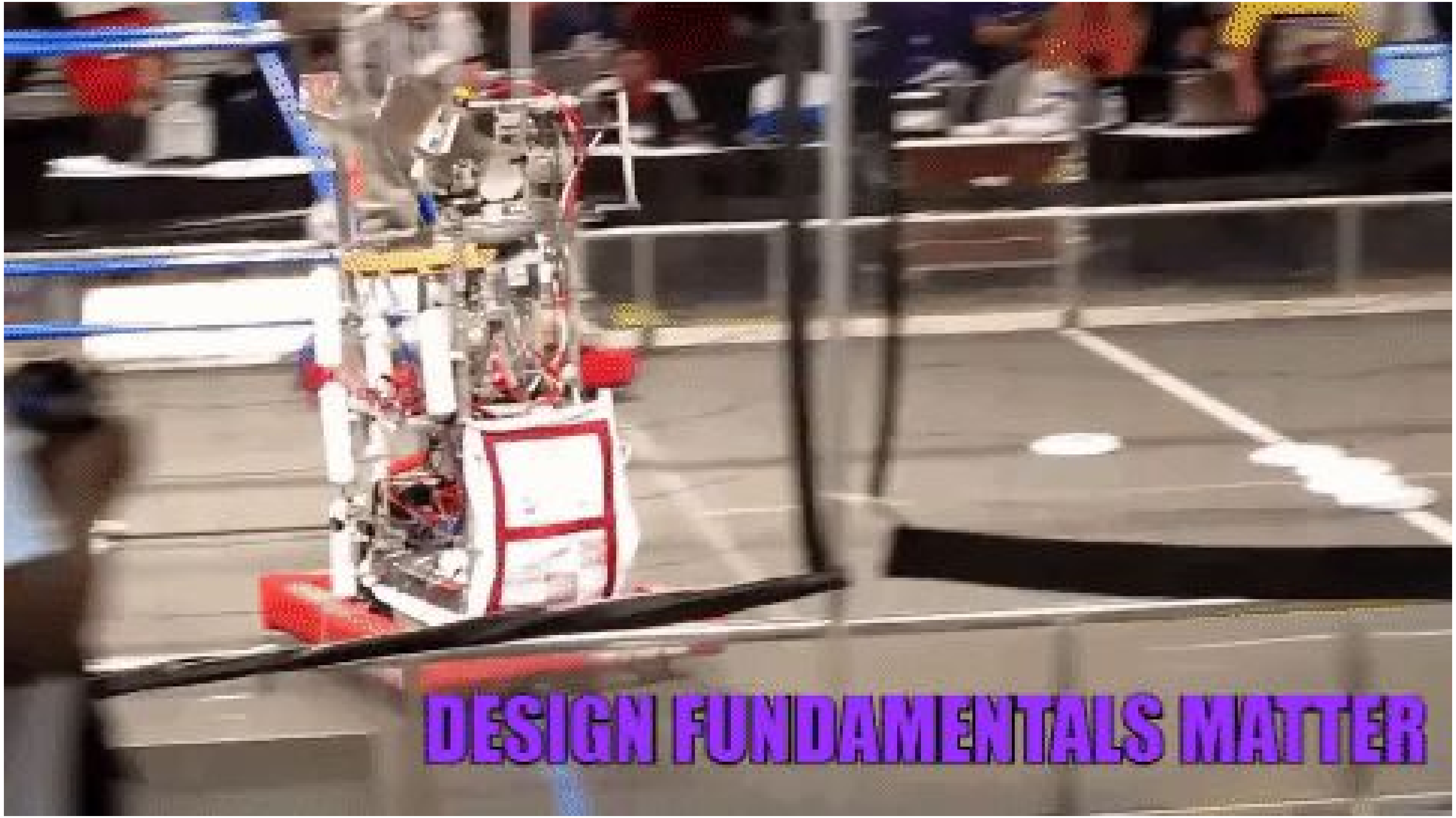
- Minimizing twisting forces (moments) on a system reduces angular motion, which reduces angle errors (Sine errors) and makes designs more robust.
- Centers of Action = virtual points within an object (a body) such that forces applied through them generate no moments on the object.
  - Center of Gravity (Center of Mass)
  - Center of Stiffness
  - Center of Friction

Full Slide Deck on Fundamental Principles by K. Craig

Center of Gravity

- Mount your heavy stuff low towards the ground when possible
  - The Battery is the most dense (heaviest for it’s size) part of your robot.
  - Compressor, and motors are your next heaviest items
- Ideally your mass should centered left-right and front-back.
  - This will make your robot the most predictable.
  - There may be reasons to move your CoG forward or backward based on game mechanics such as if you are going to have to lift something heavy during the game. You’d want your normal CoG on the opposite end of where you lift the heavy object to keep you stable while lifting.
- To high a CoG and your robot will do wheelies and might tip over
  - It will also be hard to control as it will start to rock when you try to accelerate or turn

Center of Gravity



Bumpers are your friend

- Be cautious of anything that is designed to deploy outside your bumpers/frame perimeter
  - Use lexan where possible because it is more forgiving to bending loads and impact than sheet metal
- Things that stay inside of your frame don’t have to be as robust
  - Still analyze if they may take impact based on the game, field, other robots, etc. and build accordingly.

Acquisition Zone

- The effective intake area of the robot
- The bigger the better!
- How will the object react to the robot, field, intake device?
- Can the driver pick up an object 50ft away without a direct line of sight?

"Touch it, Own it!" should be your goal

[1678 - Strategic Design Full Workshop]

Continuous intake > Single Intake

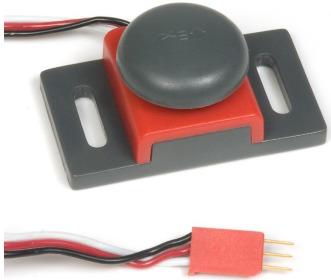
- Rollers and wheels are better than claws, grippers, etc
- Allow you to pick up multiple game pieces quickly
- Are much easier on your driver and they are faster.
  - Speed is always important in FRC
- Easier to automate rollers and wheels than claws and grippers.
- Also we have lots of motors and spinning things is easy.

Sensors

- Plan for sensors from the beginning
  - “Failing to plan is planning to fail”
- VersaPlanetaries are easy now with VP encoders
  - Encoders allow you measure position and/or speed of rotary mechanisms.
  - We use one to measure position of gear intake
- Pneumatics don’t have to have sensors but their mechanisms could
  - The trigger on our 2017 gear back pack is a good example of a pneumatic mechanism that uses a switch to activate it.
- Current is super useful feedback
  - TalonSRX and PDP both give current feedback
  - You can tell when a motor has resistance like from grabbing a game piece, etc.
  - We detected when we had a gear in our intake by monitoring for the current spike.

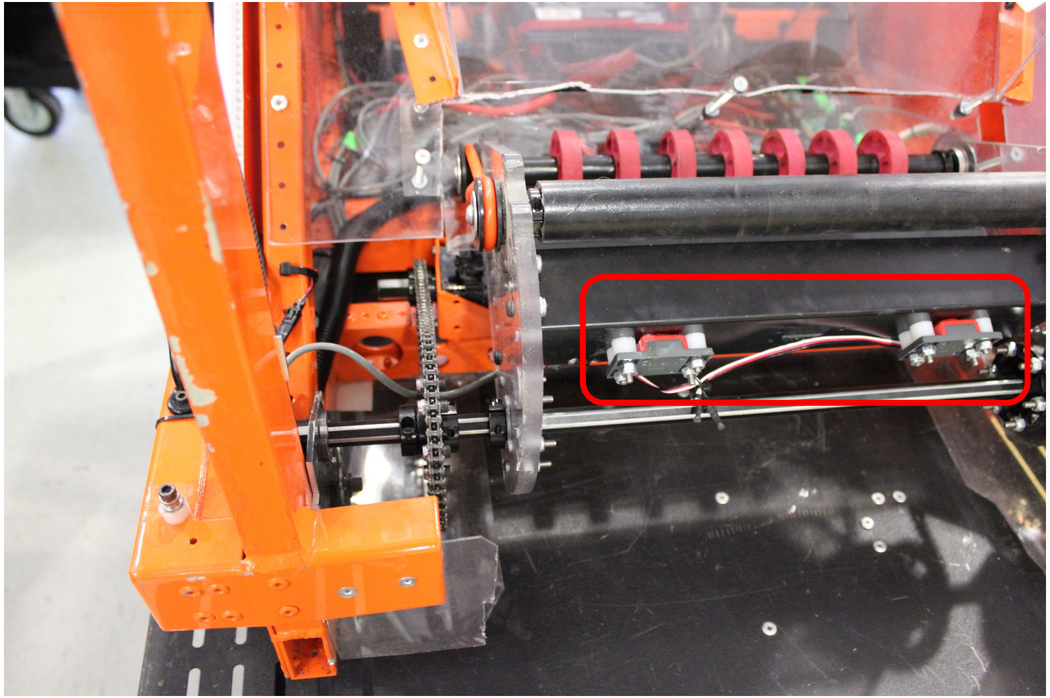
Simple Sensors

- **Limit Switch / Bump Switch / Switch**
  - Detect when something runs into them
  - Digital Sensors either true/false (1/0)



Simple Sensors

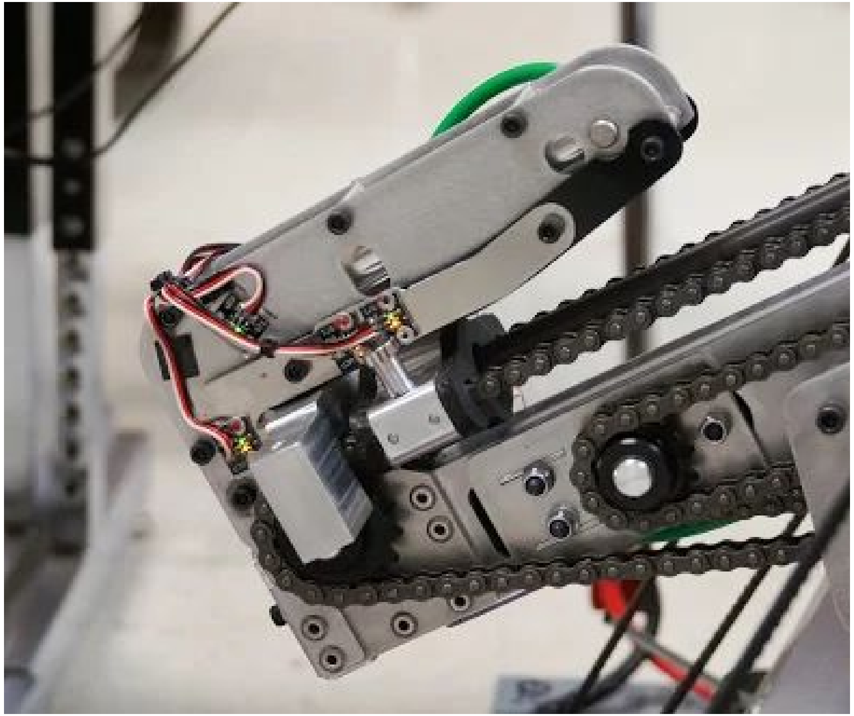
- Limit Switch / Bump Switch / Switch

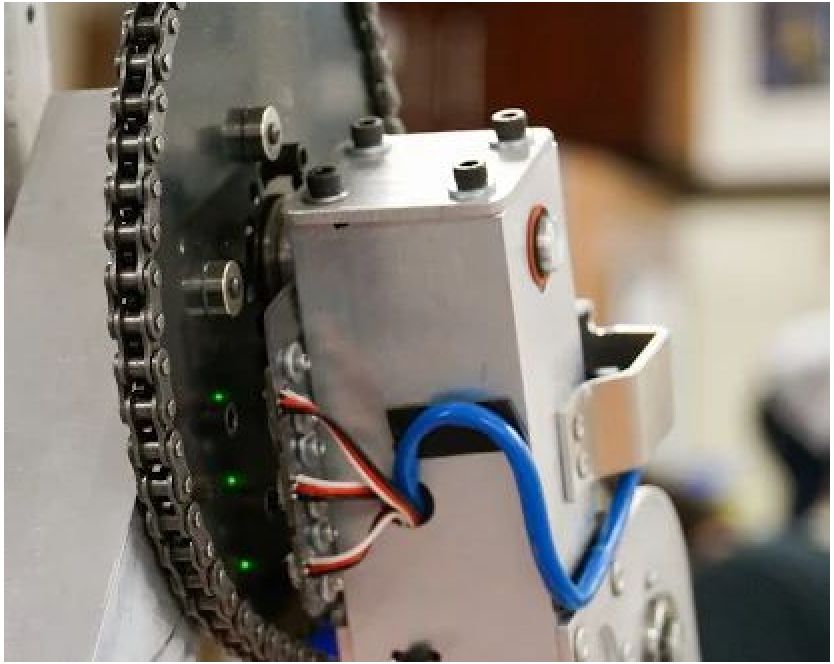


Simple Sensors

- Proximity Switch / hall effect switch/ inductive proximity sensor
  - Detect a magnet or ferrous metal depending on the sensor
  - Similar uses to limit switch but no contact is needed.
  - The magnet or metal need to be very close to the sensor

Proximity Sensors

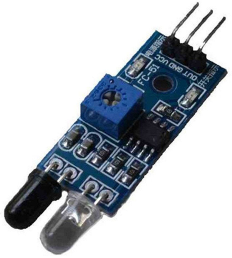


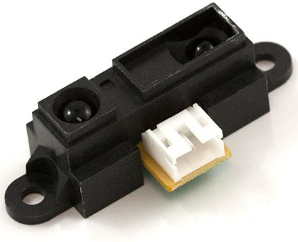


[Proximity Switch Mounting #971 2016 Robot]

Reflective / IR / Light Sensors

- Detect objects crossing a path
- Digital sensors like switches or analog sensors give distance



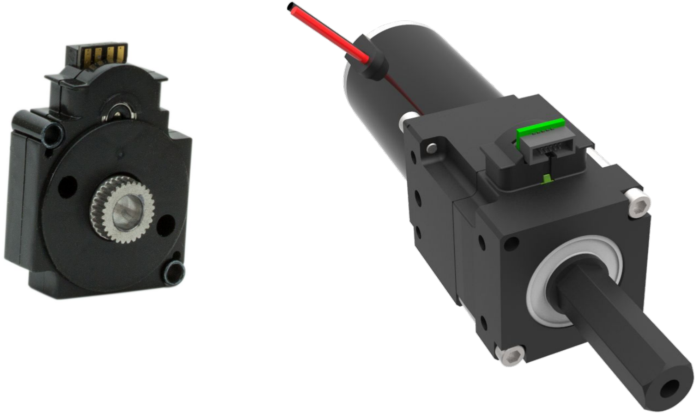


Encoders

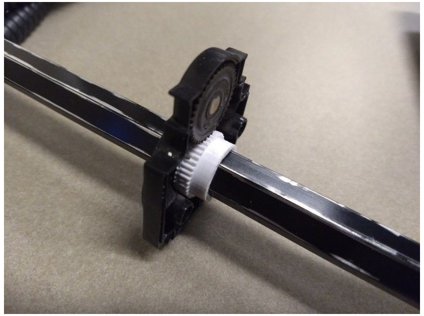
Give you rotational speed or displacement (how many times has it turned)

Chinese LPA3806 Encoders

VersaPlanetary Encoders

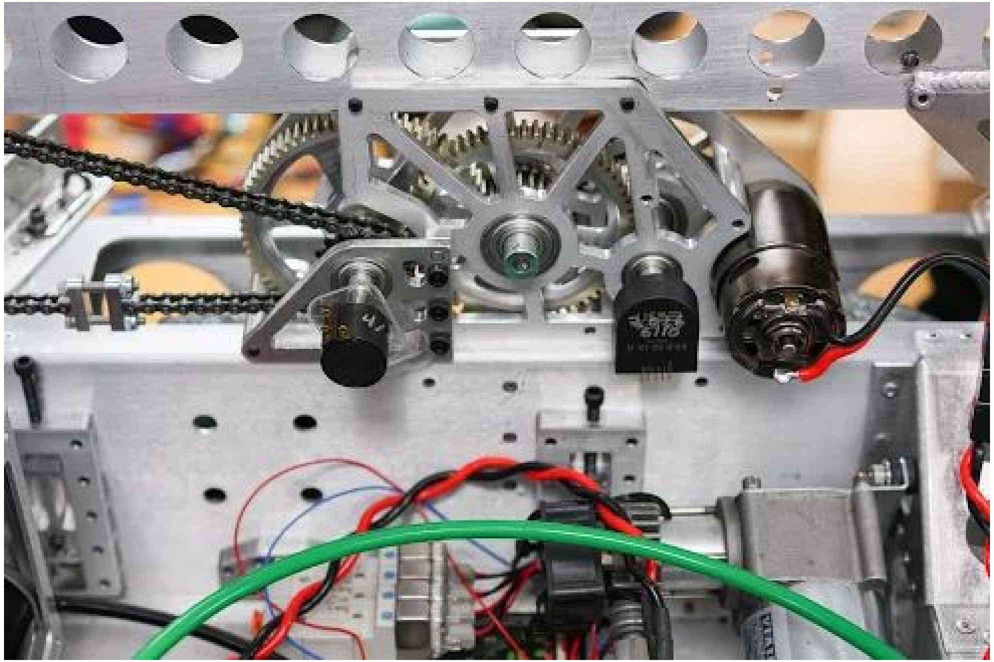


Modified VersaPlanetary Encoders with 3D printed gear for hex shaft



[How encoders work Sparkfun Video]

Encoders

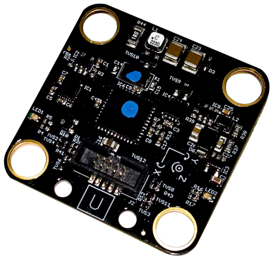


Encoder mounting #971 2016 Robot

Gyros / IMUs

- IMU (Inertial Measurement Unit) combination of gyros and accelerometers
- Like in a phone or Wii-mote, etc
- Gives rotational displacement (how far you turned)

Pigeon IMU connects to Talon SRX



Nav-X connects to RoboRIO MXP port

FIRST Choice Analog Devices Gryo

Fuses vs. Breakers

What is a fuse: https://www.youtube.com/watch?v=2MWwwrOQOUc

How the main breaker works -
https://www.youtube.com/watch?v=KNWFCxhootY

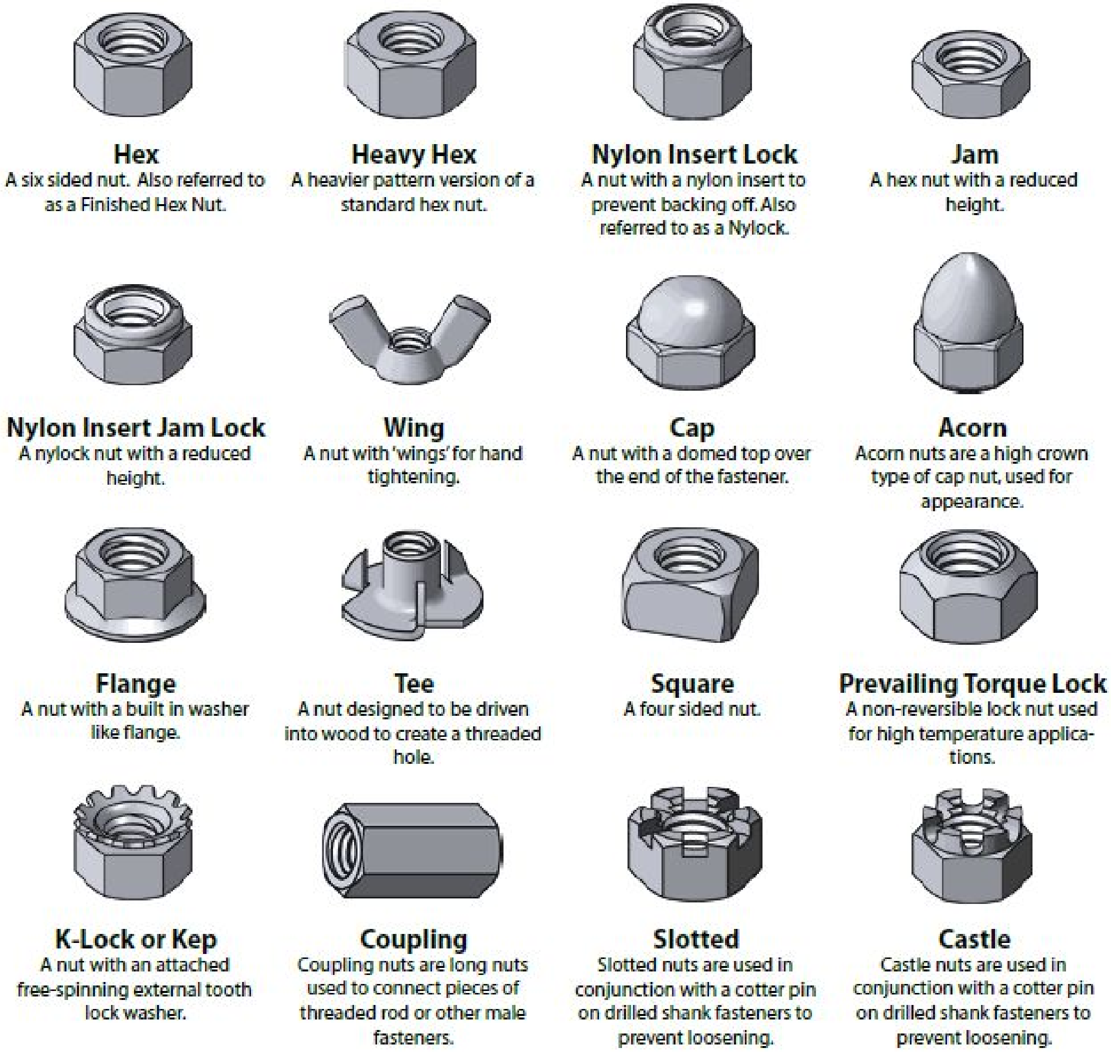
- Fuses don't reset, you have to throw them away.
- Breakers can be reset, on the robot they self reset(except main 120A breaker).

Bolt Types


SOCKET HEAD CAP SCREWS
SHOULDER SCREWS
FLAT HEAD SOCKET SCREWS
BUTTON HEAD SOCKET SCREWS
SOCKET SET SCREWS
PRESSURE PLUGS
DOWEL PINS

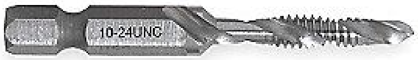

Wood Screws
Screws with a smooth shank and tapered point for use in wood. Abbreviated WS
Machine Screws
Screws with threads for use with a nut or tapped hole. Abbreviated MS
Thread Cutting Machine Screws
Machine screws with a thread cutting (self tapping) point.
Sheet Metal Screws
Fully threaded screws with a point for use in sheet metal. Abbreviated SMS
Self Drilling SMS
A sheet metal screw with a self drilling point.
Hex Bolts
Bolts with a hexagonal head with threads for use with a nut or tapped hole. Abbreviated HHMB or HXBT.
Carriage Bolts
Bolts with a smooth rounded head that has a small square section underneath.
Lag Bolts
Bolts with a wood thread and pointed tip. Abbreviated Lag.
Socket Screws
Socket screws, also known as Allen Head, are fastened with a hex Allen wrench.
Set Screws
Machine screws with no head for screwing all the way into threaded holes.
Eye Bolts
A bolt with a circular ring on the head end. Used for attaching a rope or chain.
Eye Lags
Similar to an eye bolt but with wood threads instead of machine thread.
J-Bolts
J shaped bolts are used for tie-downs or as an open eye bolt.
U-Bolts
Bolts in U shape for attaching to pipe or other round surfaces. Also available with a square bend.
Shoulder Bolts
Shoulder bolts (also known as stripper bolts) are used to create a pivot point.
Elevator Bolts
Elevator bolts are often used in conveyor systems. They have a large, flat head.

Nut Types

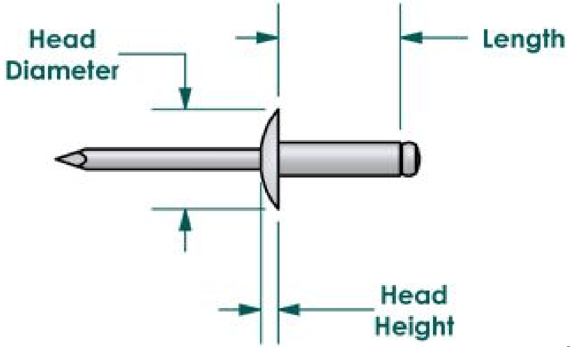

Hex
A six sided nut. Also referred to as a Finished Hex Nut.
Heavy Hex
A heavier pattern version of a standard hex nut.
Nylon Insert Lock
A nut with a nylon insert to prevent backing off. Also referred to as a Nylock.
Jam
A hex nut with a reduced height.
Nylon Insert Jam Lock
A nylock nut with a reduced height.
Wing
A nut with 'wings' for hand tightening.
Cap
A nut with a domed top over the end of the fastener.
Acorn
Acorn nuts are a high crown type of cap nut, used for appearance.
Flange
A nut with a built in washer like flange.
Tee
A nut designed to be driven into wood to create a threaded hole.
Square
A four sided nut.
Prevailing Torque Lock
A non-reversible lock nut used for high temperature applica-tions.
K-Lock or Kep
A nut with an attached free-spinning external tooth lock washer.
Coupling
Coupling nuts are long nuts used to connect pieces of threaded rod or other male fasteners.
Slotted
Slotted nuts are used in conjunction with a cotter pin on drilled shank fasteners to prevent loosening.
Castle
Castle nuts are used in conjunction with a cotter pin on drilled shank fasteners to prevent loosening.

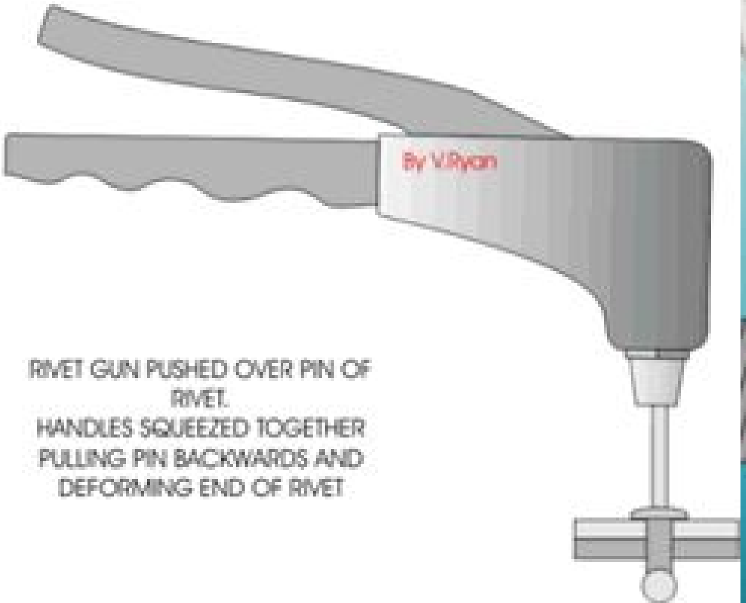
Taps and Dies

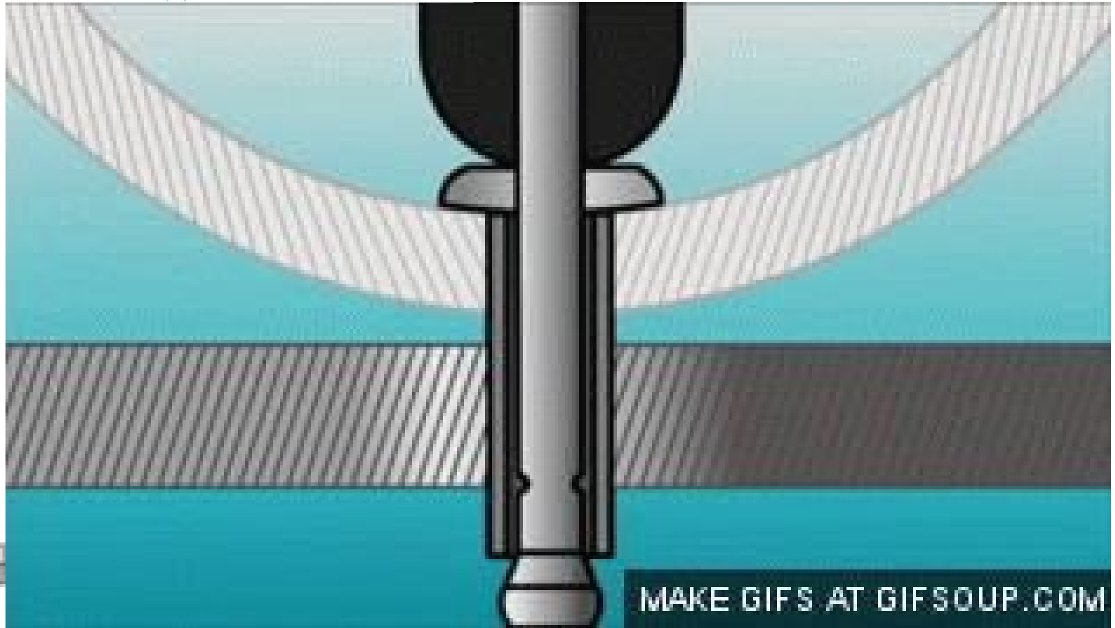
- Taps allow you to form threads inside a hole
- Dies cut threads on the outside of a shaft (we rarely need these)
- Speed taps or machine taps can be used with drills or lathes
- Always use lubrication when cutting threads (using a tap)
- Look at a Tap size chart to know what hole to drill.



Rivets


Head
Diameter
Length
Head
Height


By V.Ryan
RIVET GUN PUSHED OVER PIN OF RIVET.
HANDLES SQUEEZED TOGETHER PULLING PIN BACKWARDS AND DEFORMING END OF RIVET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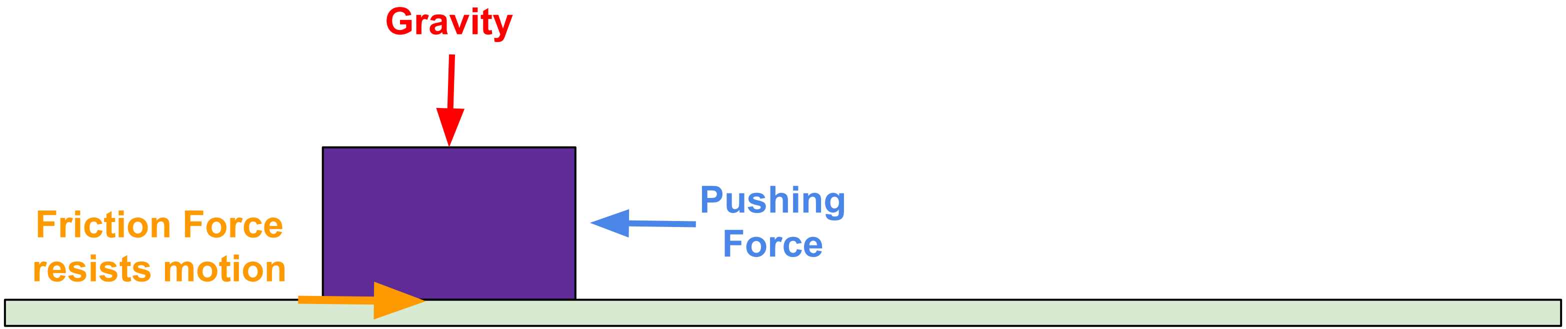
Manage Friction

You will have friction in any mechanism design. What is Friction?



- Friction = **μ * Perpendicular Force (sometimes gravity, but not always)**
- **μ** = Coefficient of Friction (how well the two objects grab each other)
- For real object interactions there are more forces but we can use this as an approximation

[Full Slide Deck on Fundamental Principles by K. Craig]

Manage Friction

- Avoid sliding friction where possible
  - Wide variation in friction coefficients due to surface finishes, damage, etc
  - Uncontrolled lubrication statuses and effects
  - Stick-slip behavior because of static vs dynamic friction
- Rotary motion is easier to manager than linear motion.
- Bearing use rolling friction instead of sliding friction. Use rolling elements whenever possible

[Full Slide Deck on Fundamental Principles by K. Craig]

Manage Friction

Rolling Friction in Linear Motion

- ▲ High Quality tool boxes use ball bearing drawer slides
- ▲ Cheap tool boxes have plastic linear slides

Use our two different red toolboxes to feel the difference

[Full Slide Deck on Fundamental Principles by K. Craig]

Ball Bearings

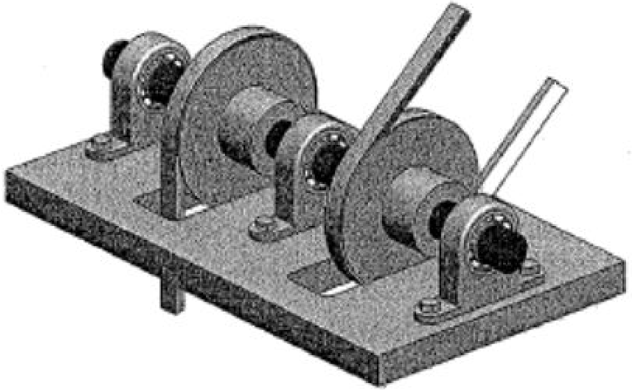
- Simple way to reduce friction
- Whenever possible use ball bearings for rotational motion
- When not to use ball bearings
  - Low speed, low load applications (small pivots)
  - When space is very tight; plain bearings are smaller
  - Quick bench tests
- Some Bearing features
  - Hex bore
  - Flange to prevent them from coming out

Plain Bearings (aka bushings)

- Use sliding friction but with oil impregnated materials that reduce friction normally bronze
- Can have small diameters than bearings for the same shaft diameter.
- We used them on our climber in 2017.

Over Constraining

- Three bearings on one shaft won’t work, the system is overconstrained.



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Exactly Constraining

- Ideally all systems should be exactly constrained, only the degrees of freedom (movable parts / directions a thing can move) that you want to move should be able to.
- Exactly constrained machines
  - No binding
  - No play (wiggle)
  - Repeatable positions
  - No internal stress
  - Loose-tolerances on parts
  - Easy Assembly
  - Robustness to wear and tear

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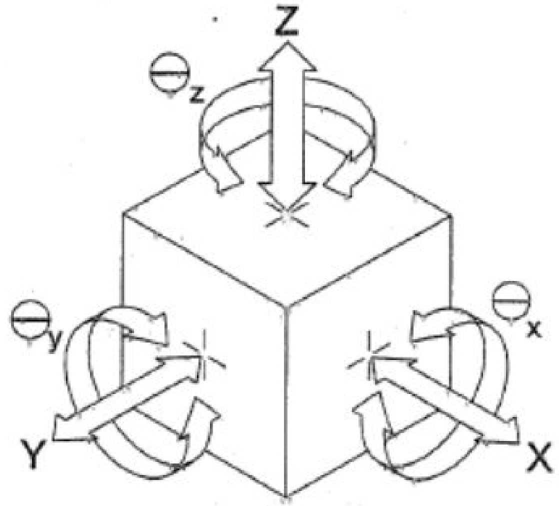
Exactly Constraining

- 3D (three-dimensional) objects have 6 degrees of freedom
  - 3 translations and 3 rotations
- Constrain the motions you don't want to allow for the motions you do want (rotations, slides, etc)



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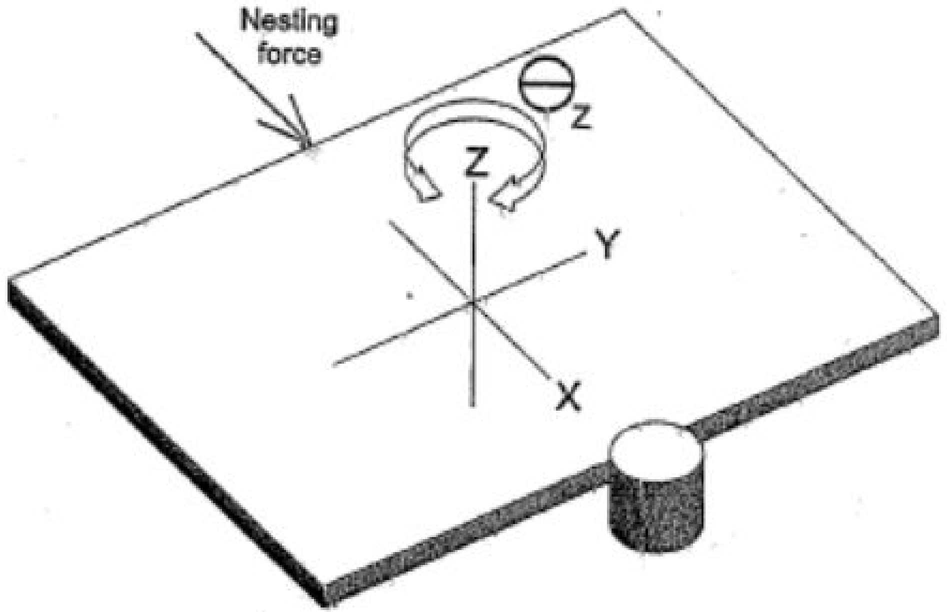
Exactly Constraining

- 2D Example

one constraint:
x motion



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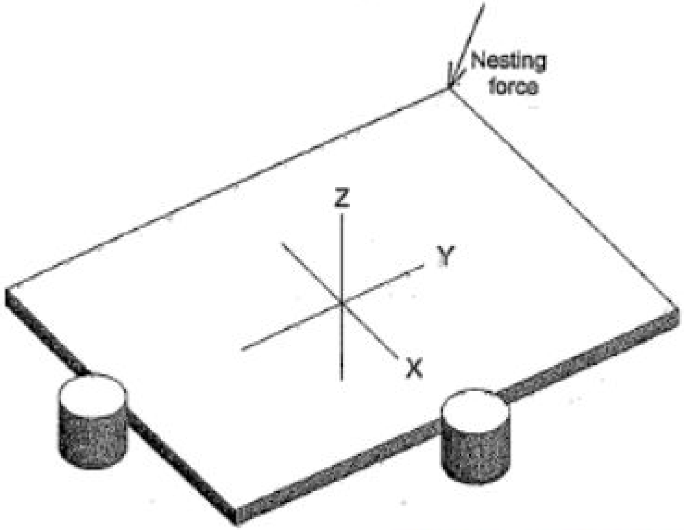
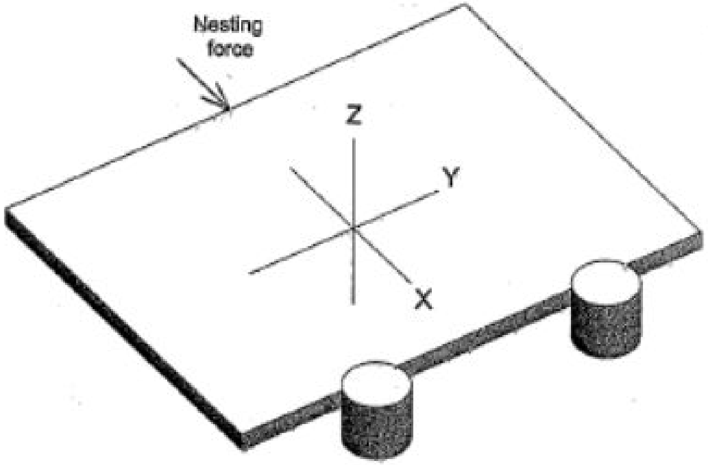
Exactly Constraining

- 2D Example



two constraints:
x motion and y motion



two constraints:
x motion and rotation

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Exactly Constraining

- 2D Example

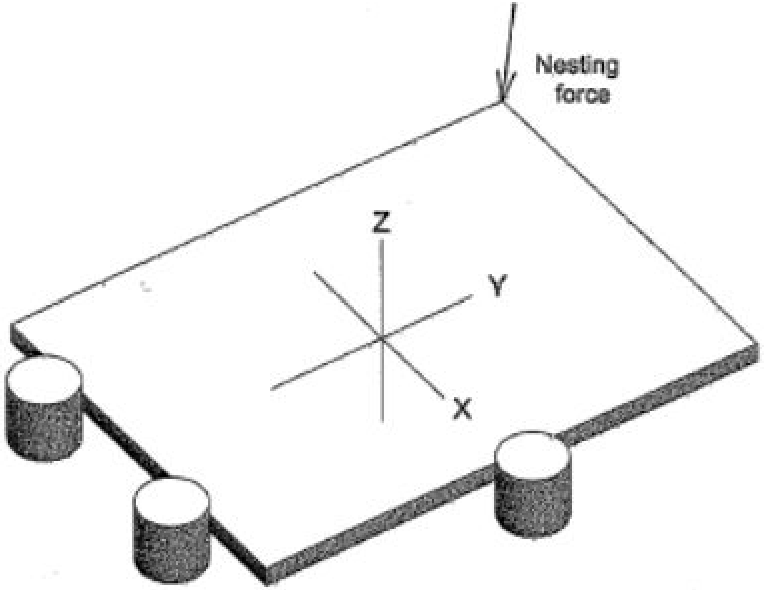
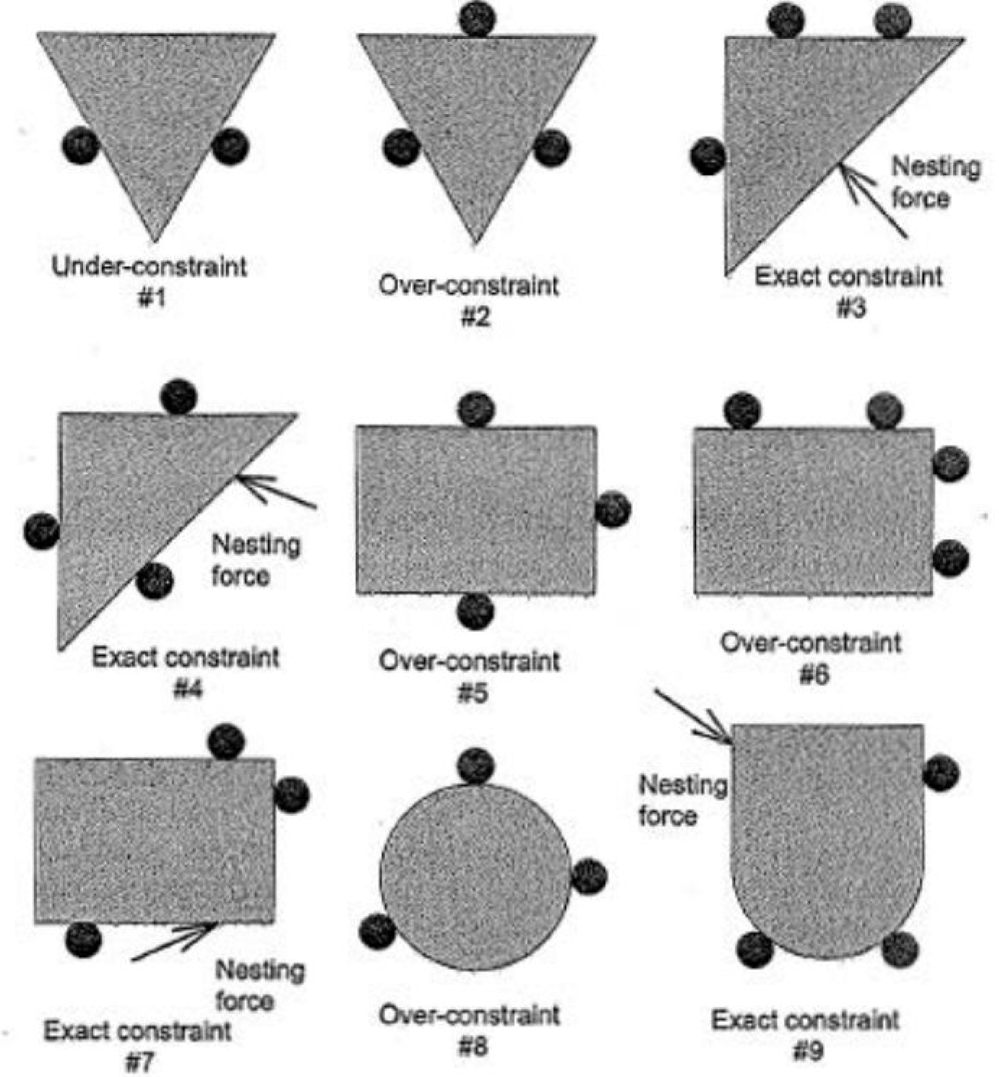


plate fully constrained in two dimensions

[Full Slide Deck on Fundamental Principles by K. Craig]

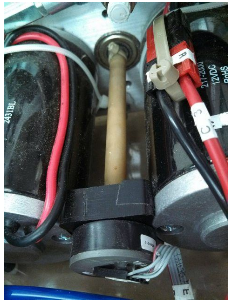
Examples

[Full Slide Deck on Fundamental Principles by K. Craig]



Constraint Design Notes

- ## Nesting Forces
  - Can't just be another post.
    - They are either too big or too small never exactly the right dimension
  - In practice nesting forces are created using weight, cams, wedges, springs, or screws.
- ## Constraints in Practice
  - Never Over-constrain, unless it's done with parts that can deform to mitigate the constraints
  - Over-constraining a motor and shaft with multiple bearings is common in FRC. Designing for flexing in the motor mount, bearing mounts, or shaft coupling is needed to avoid binding.



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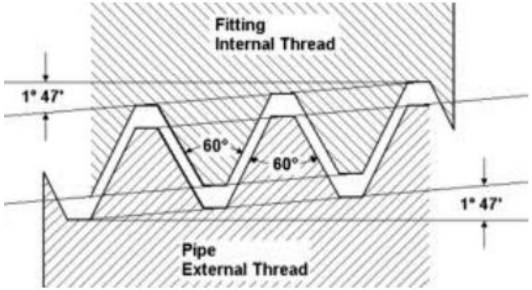
Elastic Averaging

- "When there are many compliant elements, each of which locally deforms to accommodate an error, in total they can form a very rigid and accurate system."
- 5 wheeled office chairs are over-constrained since all 5 won't be on the floor at the same time if the structure were rigid. The feet flex to allow all 5 wheels to contact the ground.
- Gears, bearings, screws, all use elastic averaging



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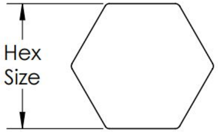
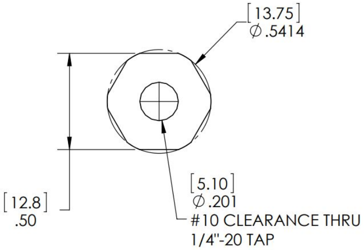
Torque Transfer

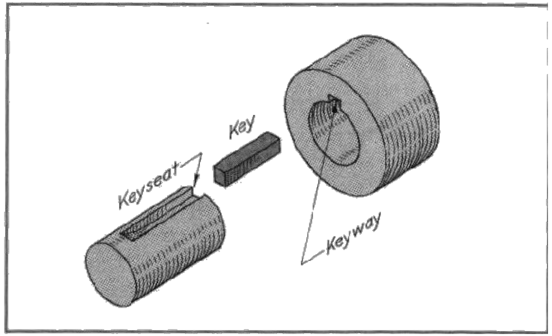
- Hex Shafts



- ThunderHex



- Keyways



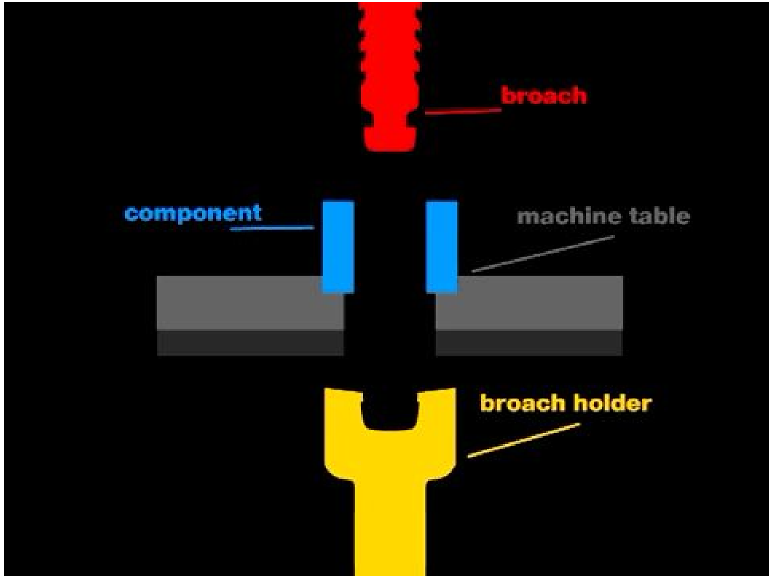
- D-shafts

-Double D Shaft

- Splines

Hex Broach

- Little sharp edges slowly cut the correct profile into the hole.
- Keep the broach straight and use lots of lubrication to avoid breaking the broach.
- This is a broach machine, we will just push the broach through but it's the same concept.



Hex vs Thunderhex

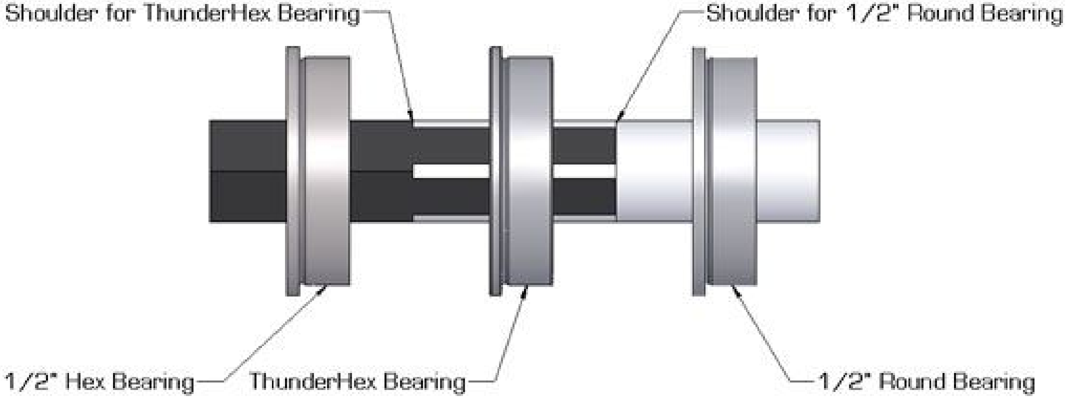
Hex

- Regular Hex stock with sharp corners
- Allow you to transfer torque without using keys, etc
- Most FRC parts now have ½” hex bores
- Regular hex shafts don’t fit into Thunderhex bearings without modifications

Thunderhex

- Upgraded with rounded corners so they fit in 13.75mm Bearings
- Round bearings are more concentric and stronger than hex bearings.
- Thunderhex fits into hex bearings and hex bores
- Thunderhex bearings are round but they have a bigger Internal Diameter than ½” round bearings. Don’t get these confused.
- Any shaft in a bearing shouldn’t wiggle around at all.

Hex vs Thunderhex

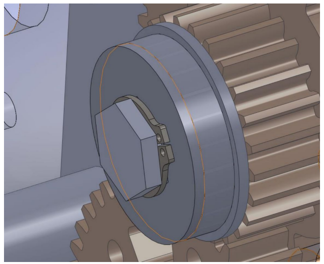


Spacing and securing shafts

- **Shaft Collars**


- **Snap Rings**
  - Grooves cut into a shaft






- **Spacers**
  - Hex Spacers from VEXpro

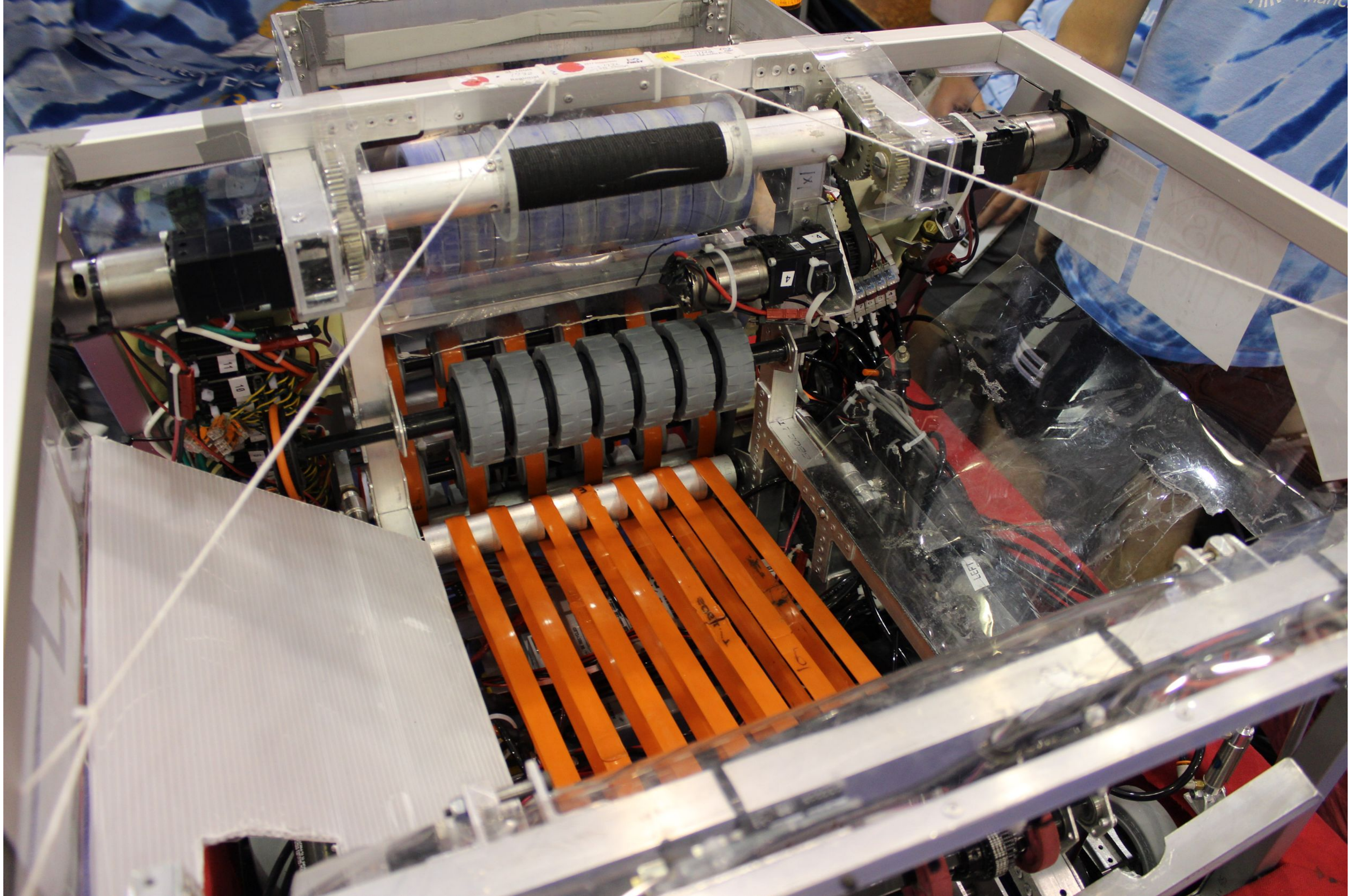
  - Cut Tube
  - 3D printed Spacers

Spacing and securing shafts

- Retaining Rings (CIM pinions only)
    a. They don’t take lateral forces well

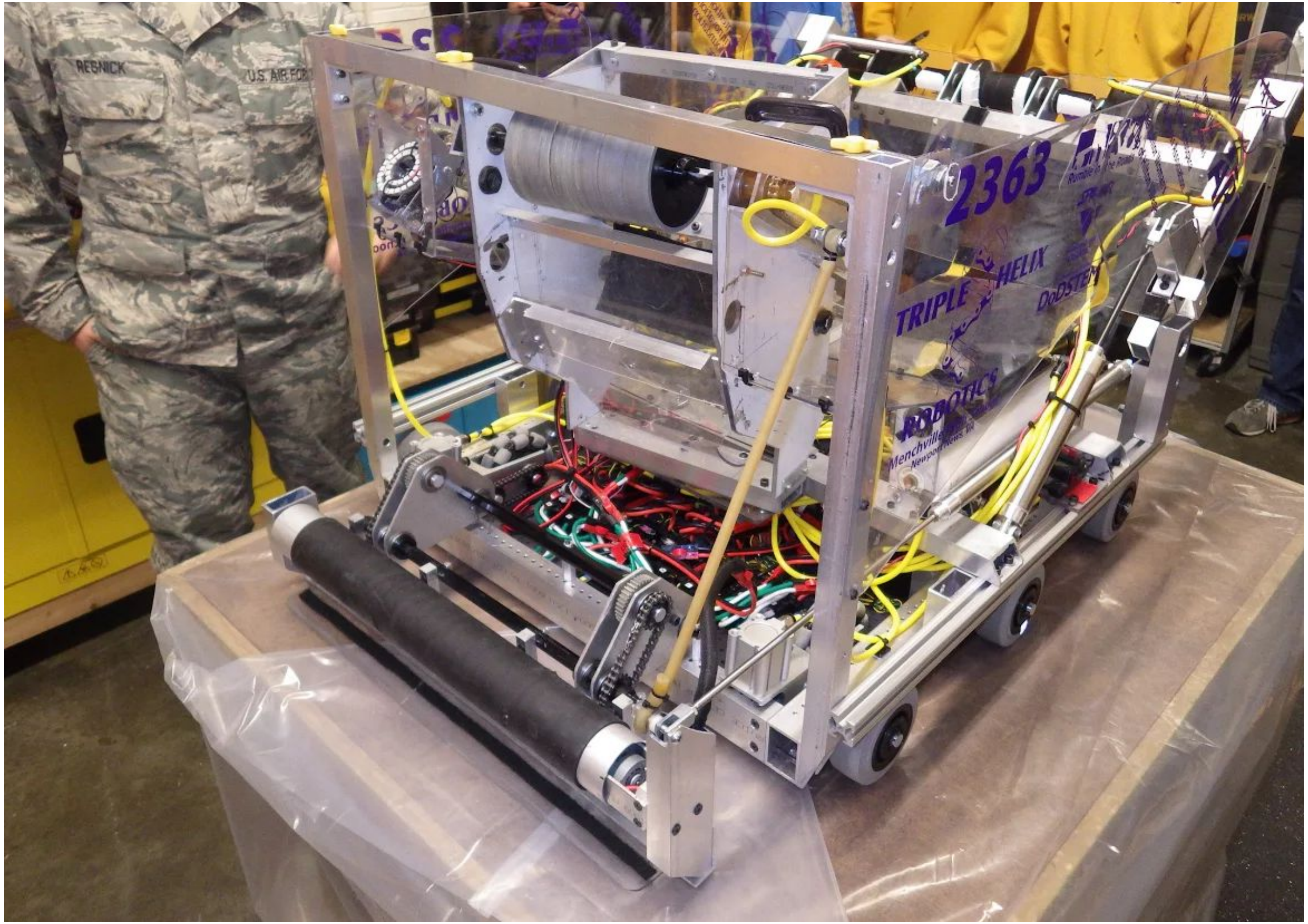
- Tapped threads + bolts and Washers

- Shoulder Bolts


LEFT

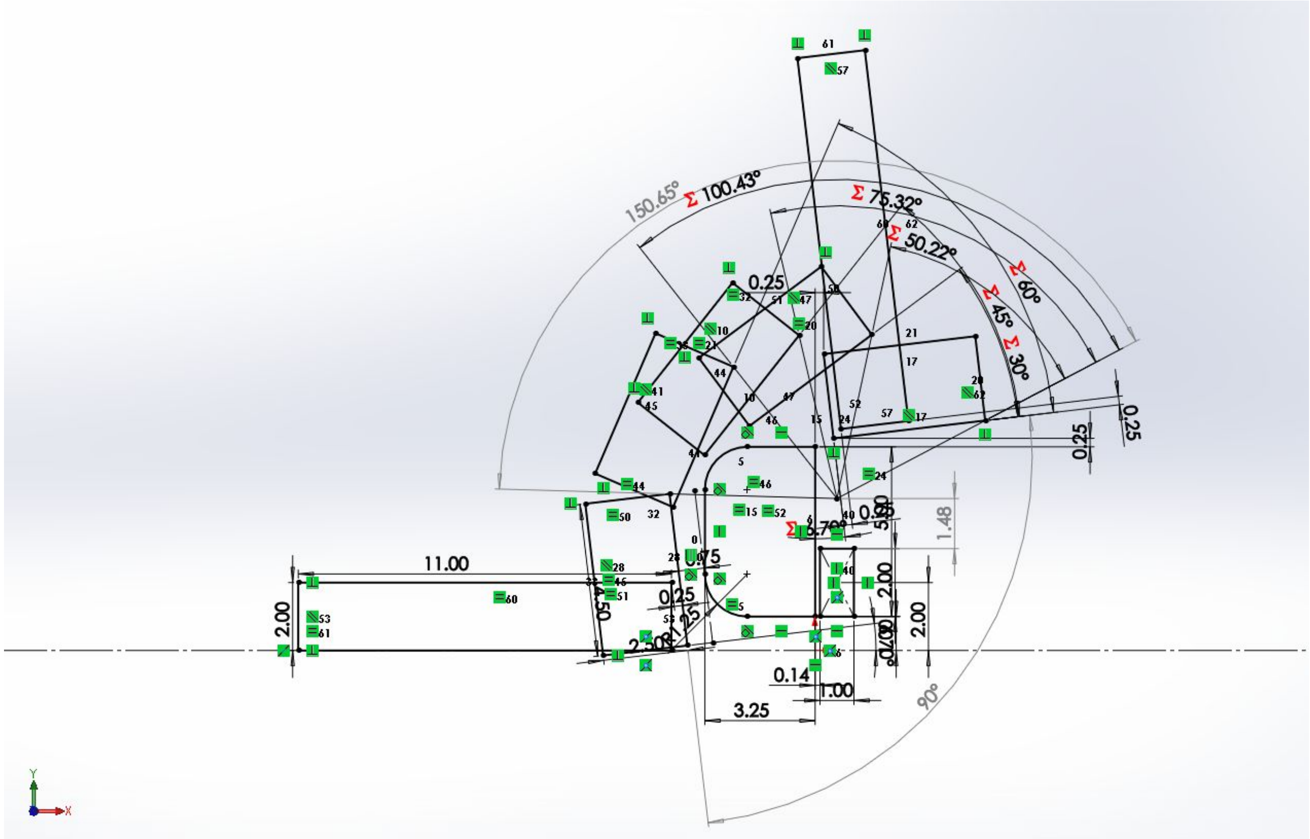
Triple-Helix Gear linkage - Example

- [Video]
- [Full Img]



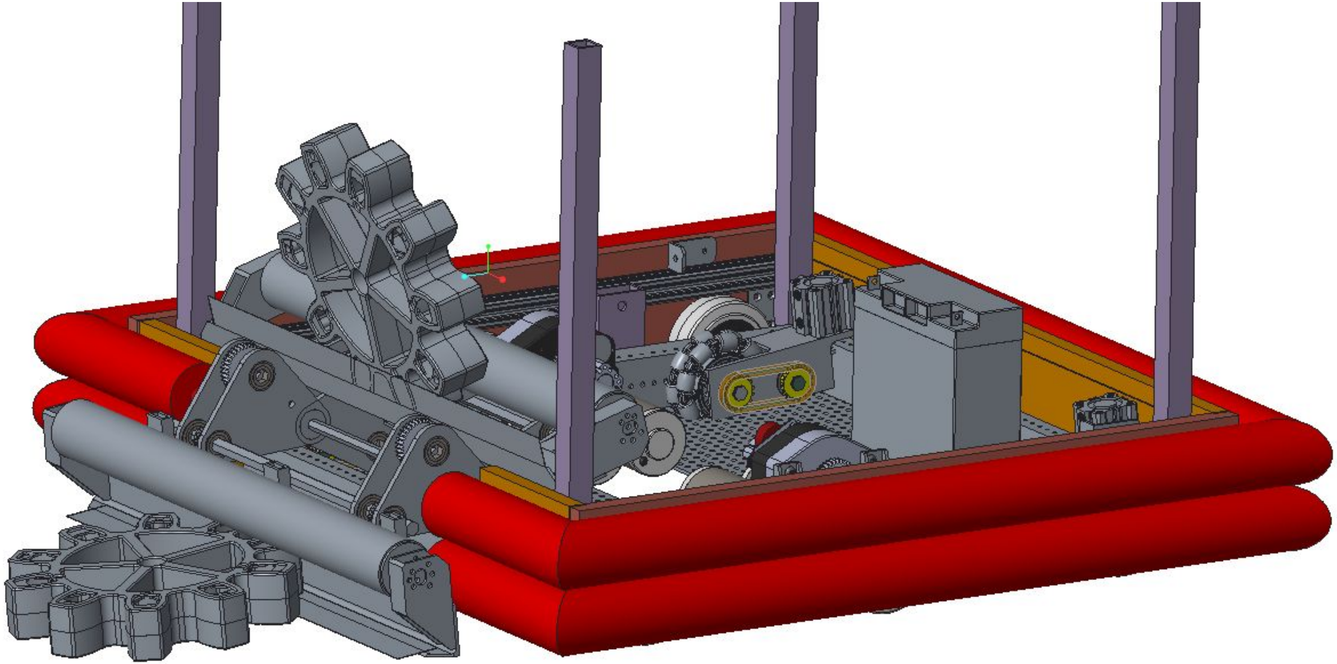
Triple-Helix Gear linkage - CAD Sketches

- [Video]()



Triple-Helix Gear linkage

- CAD Link

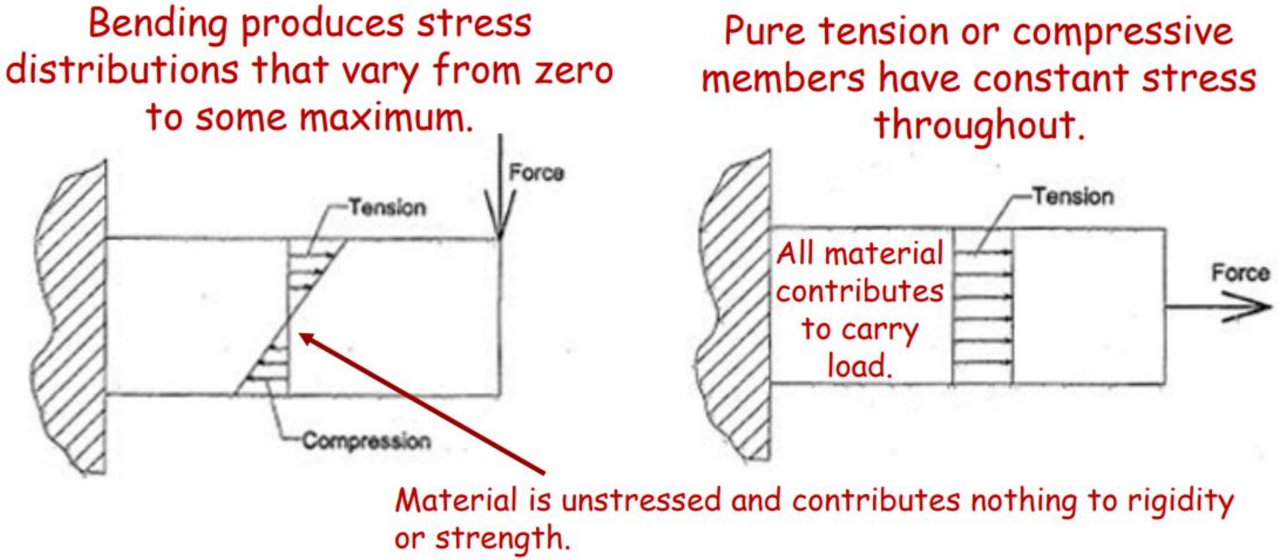


How would we modify this?

- Material selection?
- Reduce Cost?
- Exact Constraints?
- Line of Action?
- Lever Arms?
- Gearbox Selection?

Avoid Bending Stresses

- Tension and Compression are better stresses on materials.



This is why the hole in Thunderhex shaft doesn't weaken it much.

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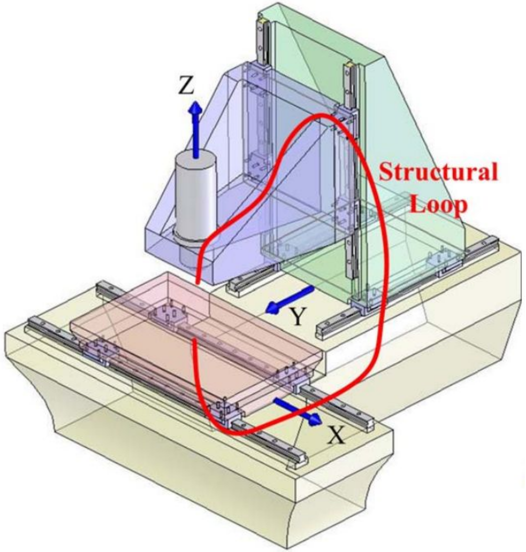
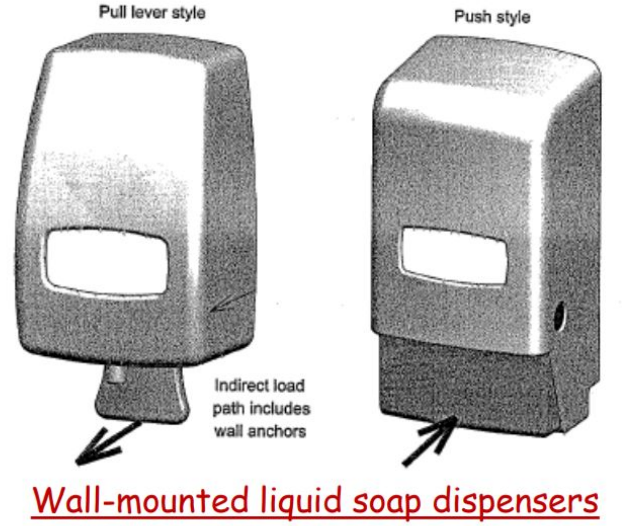
Load Paths or Structural Loops

- Plan the load paths in parts, structures, and assemblies
- Load Paths should be
  - Short
  - Direct
  - In a line or in a plane
  - Symmetric
  - Non-redundant or elastic
  - Locally Closed
  - Easily Analyzed





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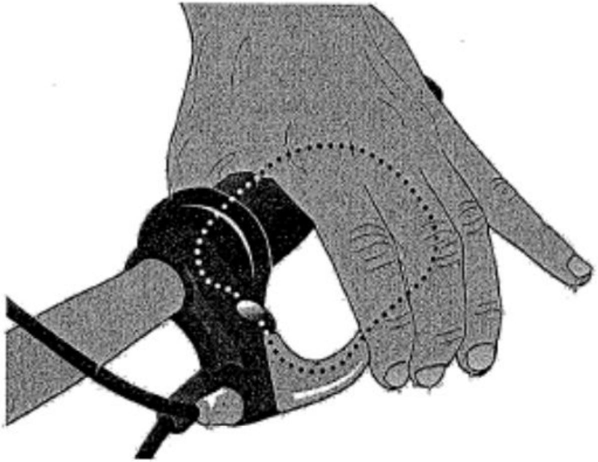
Load Paths or Structural Loops

- Imagine if bike brakes were a push or pull operation instead of a squeeze.
- You'd have to resist the force on the handlebars with your other hand or your body to the seat, etc.
- The closed load path allows you to break without inadvertently steering the bike.



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Preload (why structural bolts should be tight)

- [Best Explanation on Preloaded Bolts]
- What do we expect to happen in C?

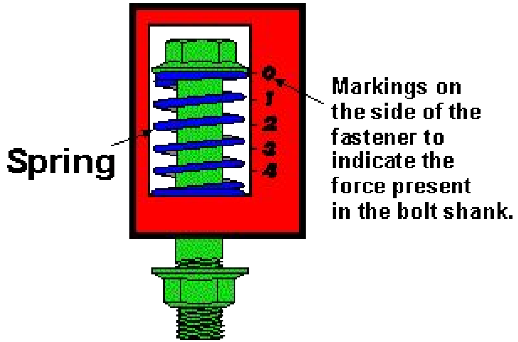


Figure 2A

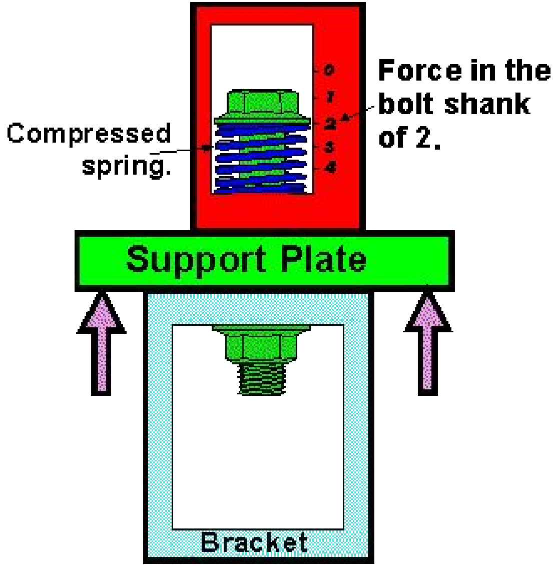


Figure 2B

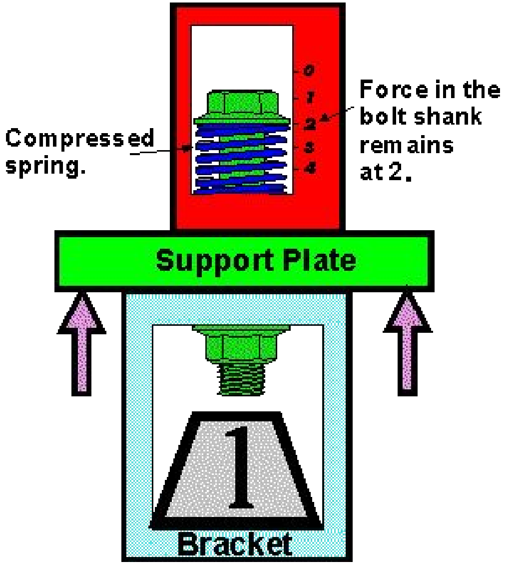


Figure 2C

Preload (why structural bolts should be tight)

- Best Explanation on Preloaded Bolts
- What do we expect to happen in C?

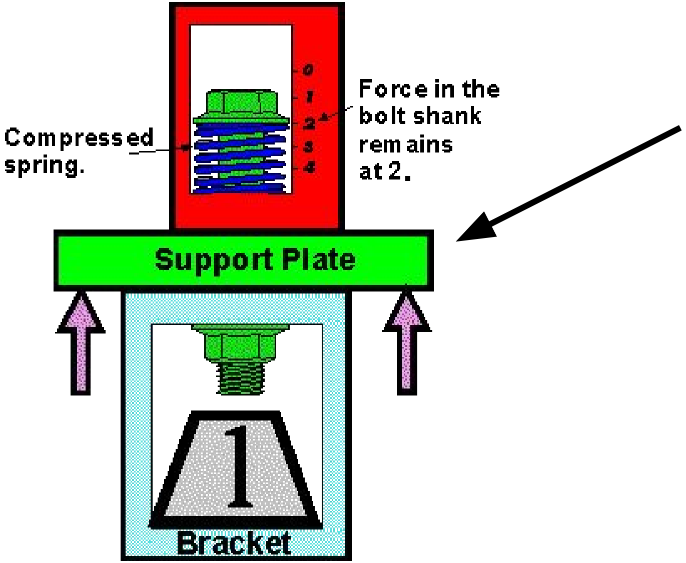


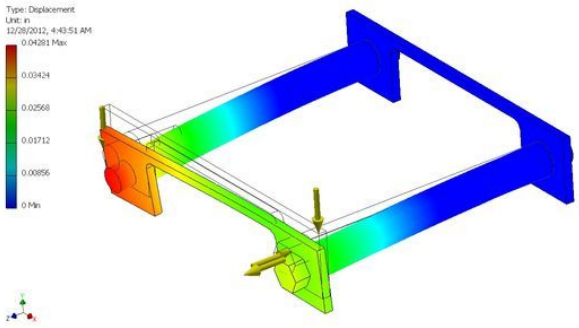
Figure 2C

The clamping force between the plate and bracket is reduced by 1

With no load applied the clamp force is 2 units, with the load applied this decreases to 1 unit of force. *The bolt would not actually 'feel' any of the applied force until it exceeded the bolts clamp force.*

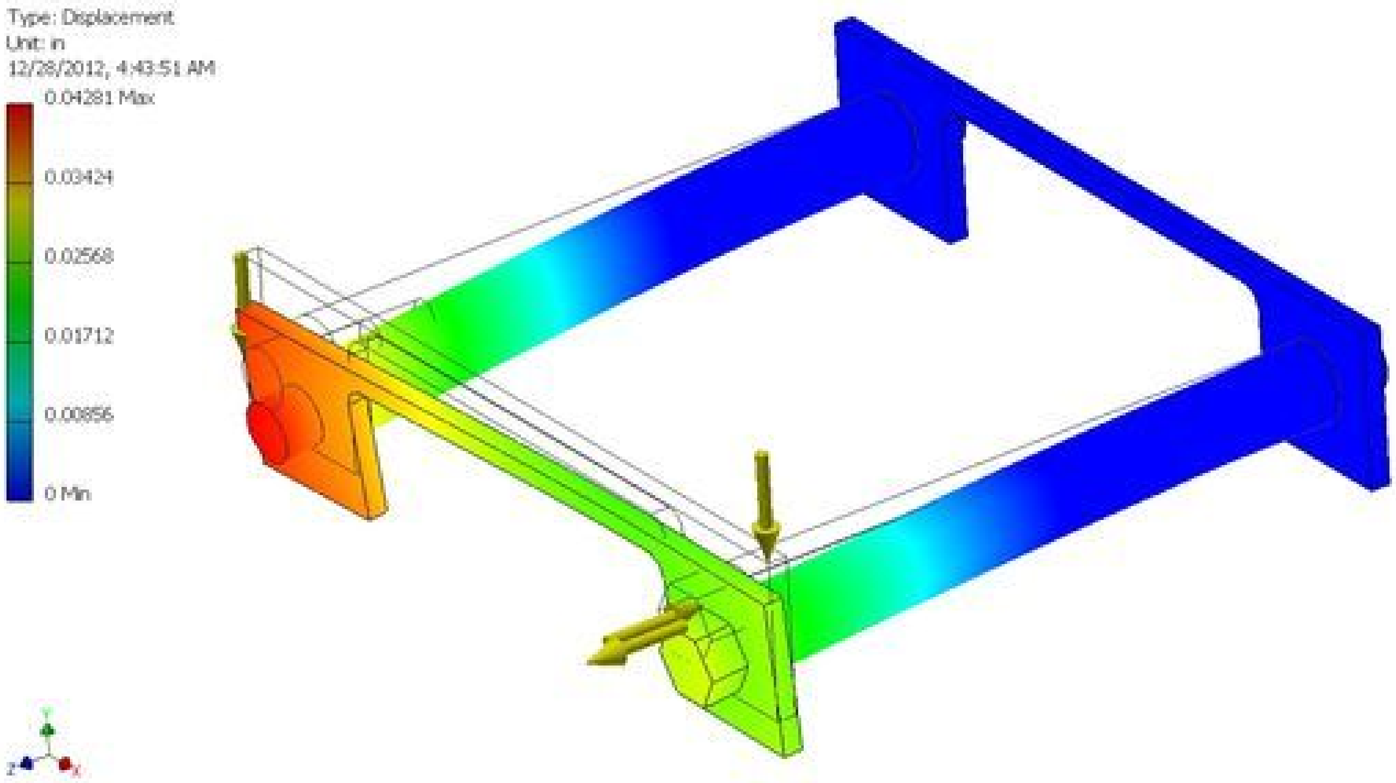
Spacers vs standoffs

- Standoffs have internal threads
- Spacers are just tubes.
- By bolting through a spacer you get the advantages of preload forces.
  - When tight the outside of the spacer undergoes compression.
  - Bending forces will cause less deformation when it preloaded.
  - Rigid steel bolt is now the core of the tube also harder to bend and takes some of the bending forces.
- TIGHTEN THESE BOLTS!
  - ¼-20 Grade 8 bolts can take 108 in. lbs. of torque
  - Remember levers, so the longer your tool the less you force you need.



[How to build your "everything" really really fast]

Spacers vs standoffs (Intro to FEA)



[How to build your “everything” really really fast]

Live Axle vs Dead Axle

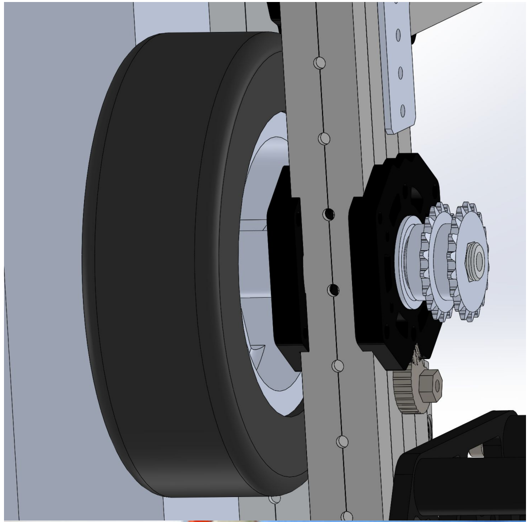
Live Axle

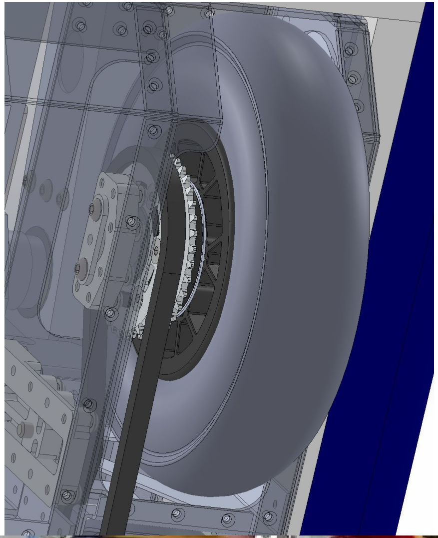
- Axle spins and transfers torque to objects, wheels, etc.
- Shaft is in bearings that are mounted to the robot.
- Has a weaker shaft
- Shaft must be removed from the side and everything must come off the shaft
- Shafts can often be a little too large and it's not a problem.
- Hex bearings and shafts
- More expensive

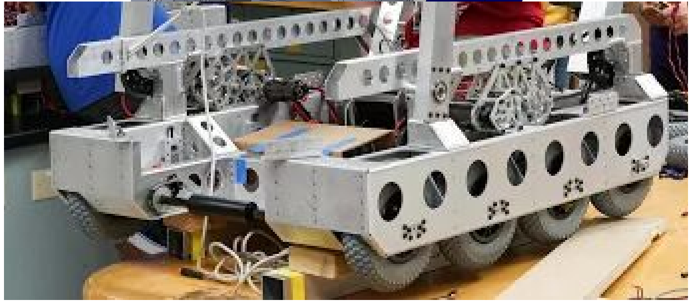
Dead Axle

- Axle remains motionless and wheels, etc spin on the axle.
- Bearings go in the wheel
- Shaft is mounted with a bolt going through it.
- Provides a stronger shaft support and helps stiffen the frame.
- Shaft, spacers, wheels, etc are removed as one unit from the top or bottom.
- Shafts must be the exact right length
- Sprockets/Gears must attach to wheels
- Round bearings and shafts
- Normally Less expensive

Live Axle vs Dead Axle





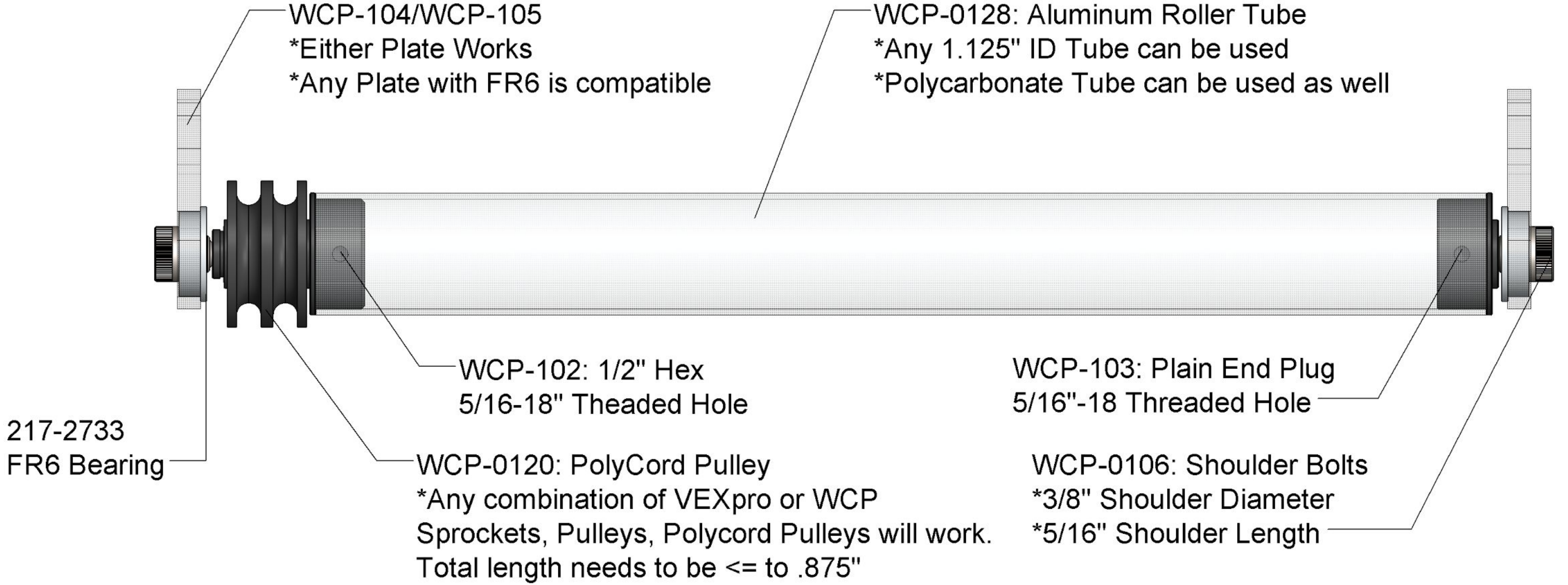


Shoulder Bolts and Bearings

- This is a combination of the two methods.
- The shaft spins but it’s still bolted into the place.
- The shoulder bolts spin in the bearings instead of the shaft.
- Uses a hex shaft but with smaller round bearings (⅜” ID).
- About the same price as live axle once you account for shoulder bolts.
- Make sure to put Loc-Tite on the shoulder bolts or they will spin loose.

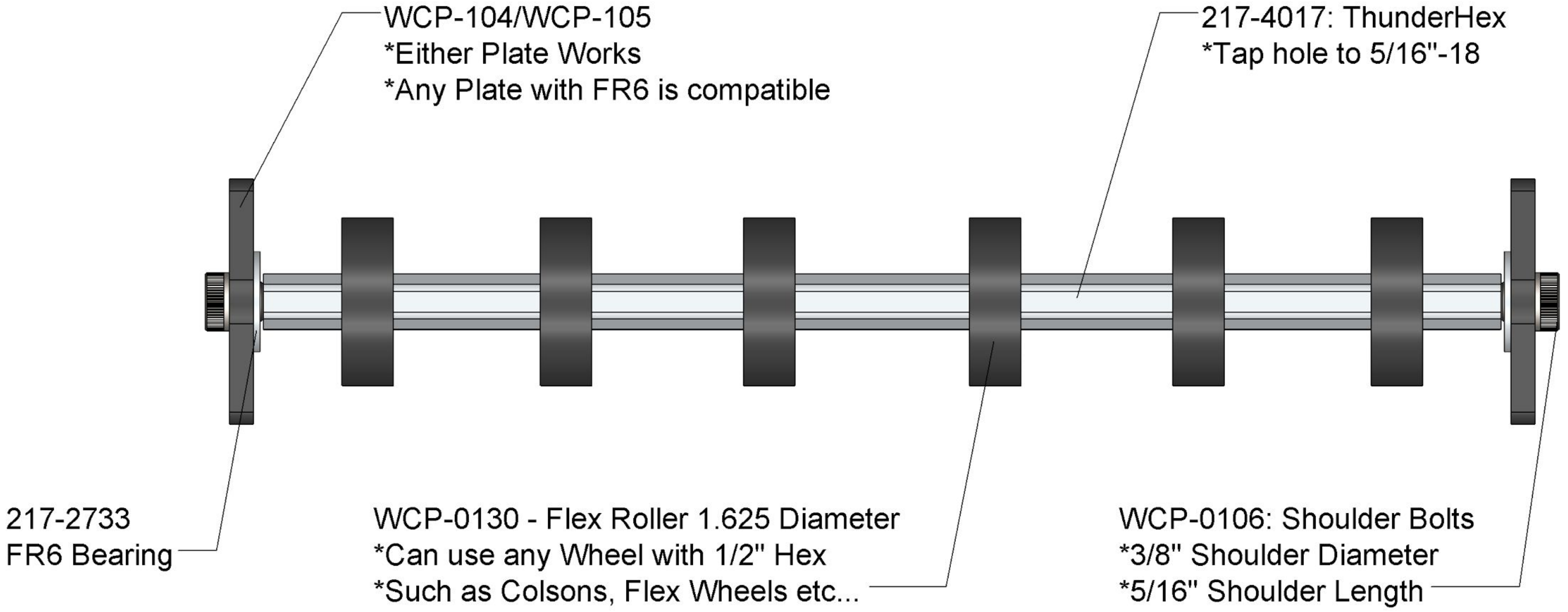
WCP Shoulder Screw Roller System

⅜" Shoulder Bolt + ⅜" Bearing + Hubs/Shaft with 5/16-18 tapped holes



WCP Shoulder Screw Roller System

⅜” Shoulder Bolt + ⅜” Bearing + Hubs/Shaft with 5/16-18 tapped holes



Power Transmission: It’s all just ratios

Sprockets/Pulleys/Gears are all just levers. We will use the word gear for a bit but know it applies to sprockets and pulleys too.

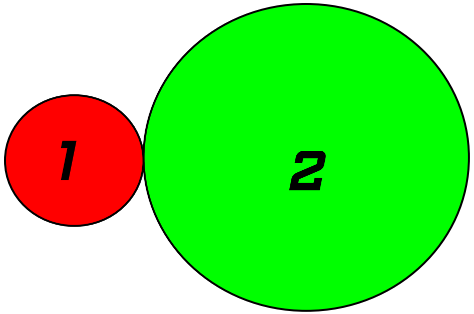
If they are same size they just transfer power at the same speed and torque. This is called 1:1 (1 to 1) gearing.

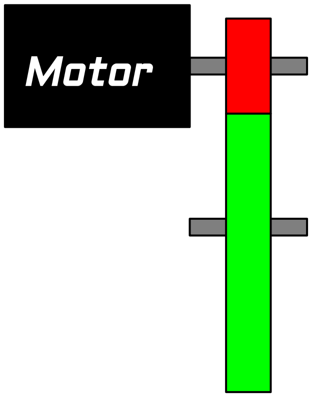
If the powered gear is smaller you increase torque but decrease speed. This is called “gearing down” or the motor is “geared down to” some RPM.

If the powered gear is larger you decrease torque but increase speed. This is called “gearing up” or the motor is “geared up to” some RPM.

Gearing Problems

If the red gear is driven by the motor, How fast will the green gear turn in relation to the motor?

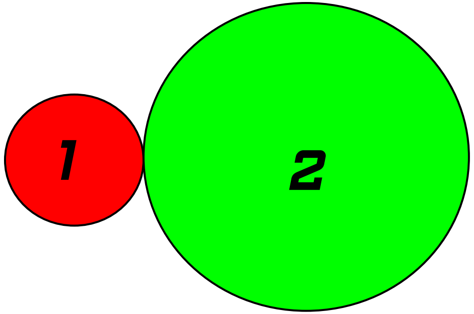


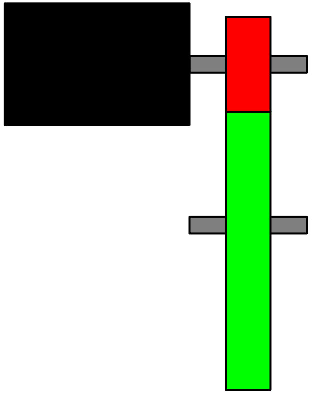


Gearing Problems

If the red gear is driven by the motor, How fast will the green gear turn in relation to the motor?

2:1



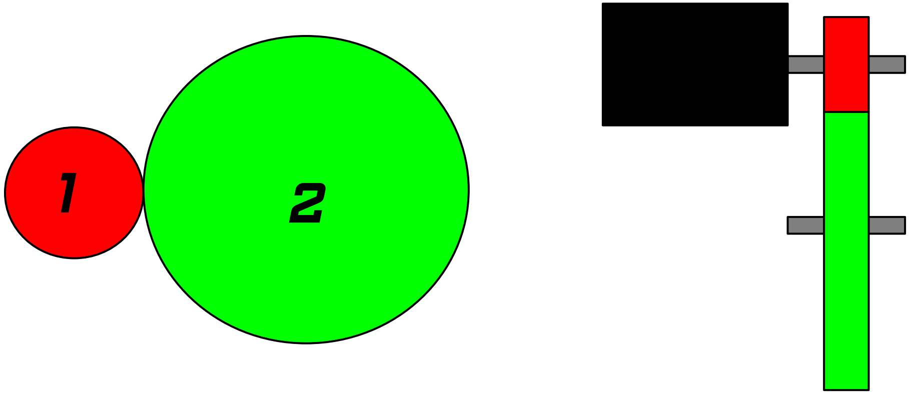


It's 2:1 (2 to 1) because it's stated that the motor has to spin 2 times for each time the output spins once. It's a 2:1 reduction.

Gearing Problems

If the red gear is driven by the motor, How fast will the green gear turn in relation to the motor?

2:1

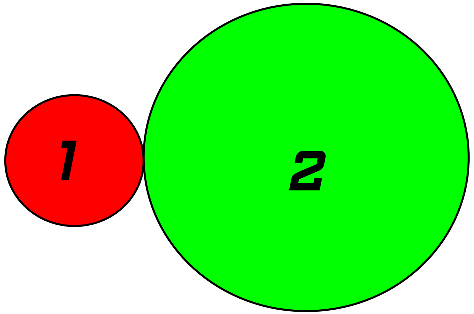


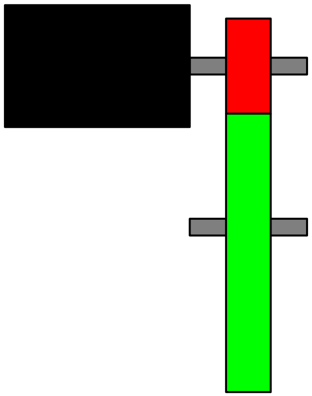
If the motor is spinning at 5,000 RPM (Rotations per Minute) how fast is the green gear turning?

Gearing Problems

If the red gear is driven by the motor, How fast will the green gear turn in relation to the motor?

2:1

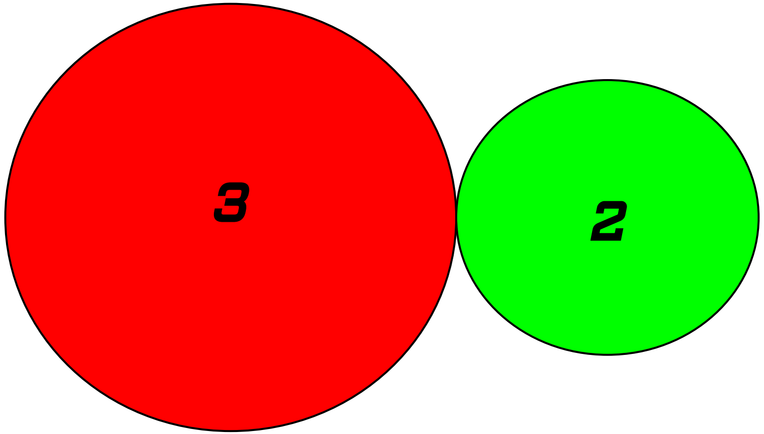


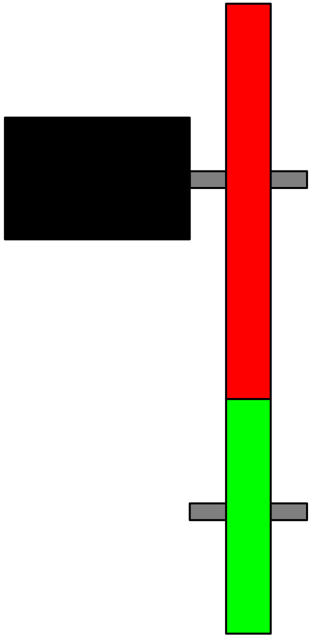


If the motor is spinning at 5,000 RPM (Rotations per Minute) how fast is the green gear turning? **2,500RPM**

Gearing Problems

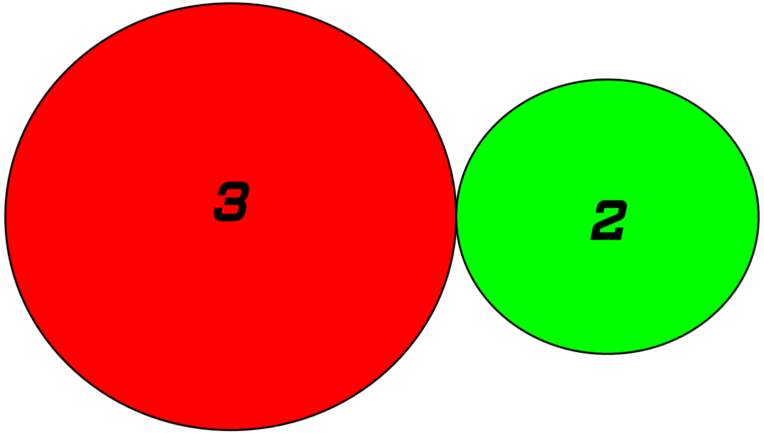
If the red gear is driven by the motor, How fast will the green gear turn in relation to the motor?

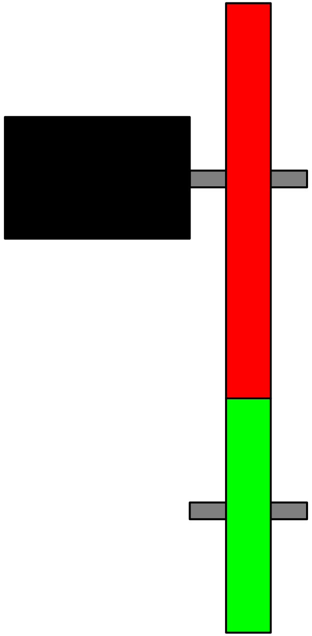




Gearing Problems

If the red gear is driven by the motor, How fast will the green gear turn in relation to the motor?





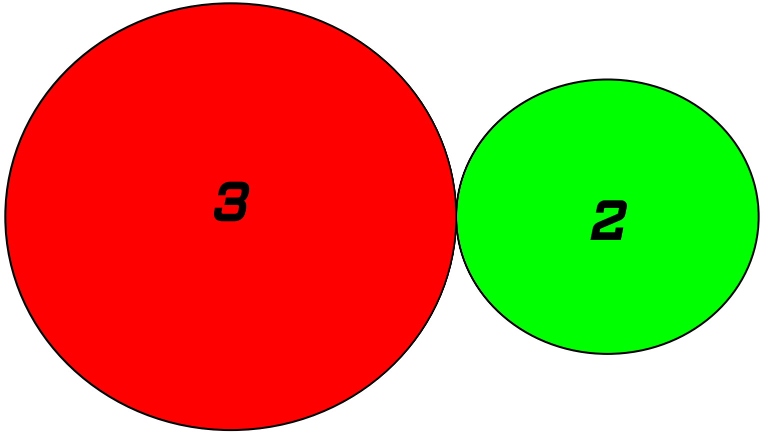
3:2

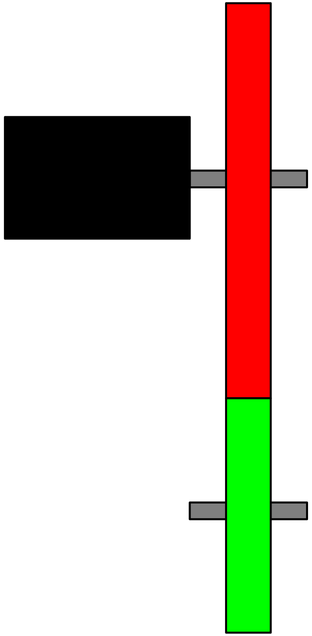
1.5:1

Motor is spinning at 1000 RPM.
How fast is the green gear spinning?

Gearing Problems

If the red gear is driven by the motor, How fast will the green gear turn in relation to the motor?

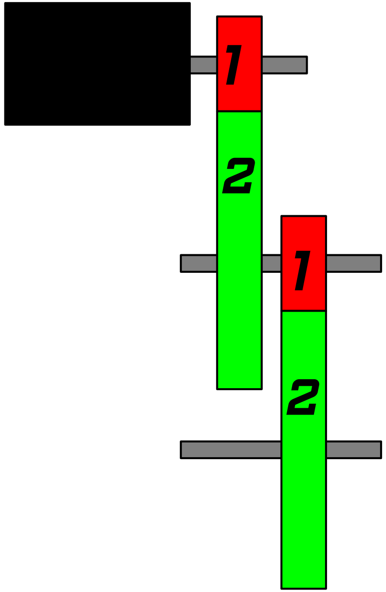




Motor is spinning at 1000 RPM.
How fast is the green gear spinning?

1500RPM

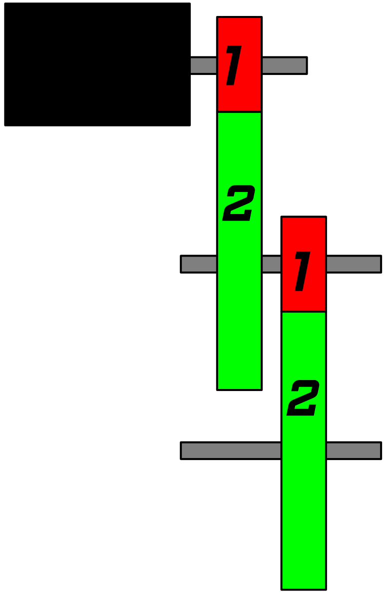
Compound Gears



If you gear multiple times you just multiply the ratios.

What's the ratio?

Compound Gears

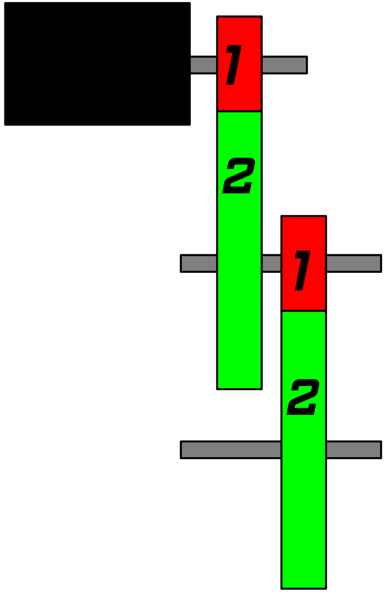


If you gear multiple times you just multiply the ratios.
What's the ratio?

$$2:1 \times 2:1 = 4:1$$

If the motor is spinning at 2,000 RPM (Rotations per Minute) how fast is the green gear turning?

Compound Gears



If you gear multiple times you just multiply the ratios.
What's the ratio?

2:1 x 2:1 = 4:1

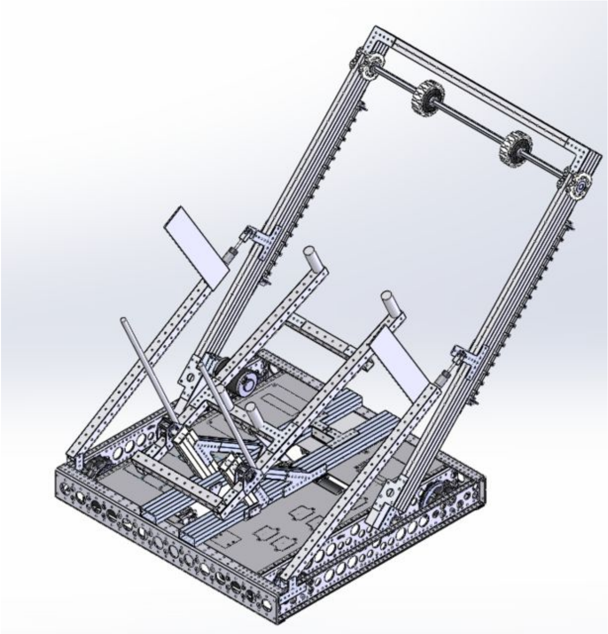
If the motor is spinning at 2,000 RPM (Rotations per Minute) how fast is the green gear turning? **2000 / 4 = 500RPM**

Gussets and Tubing Construction

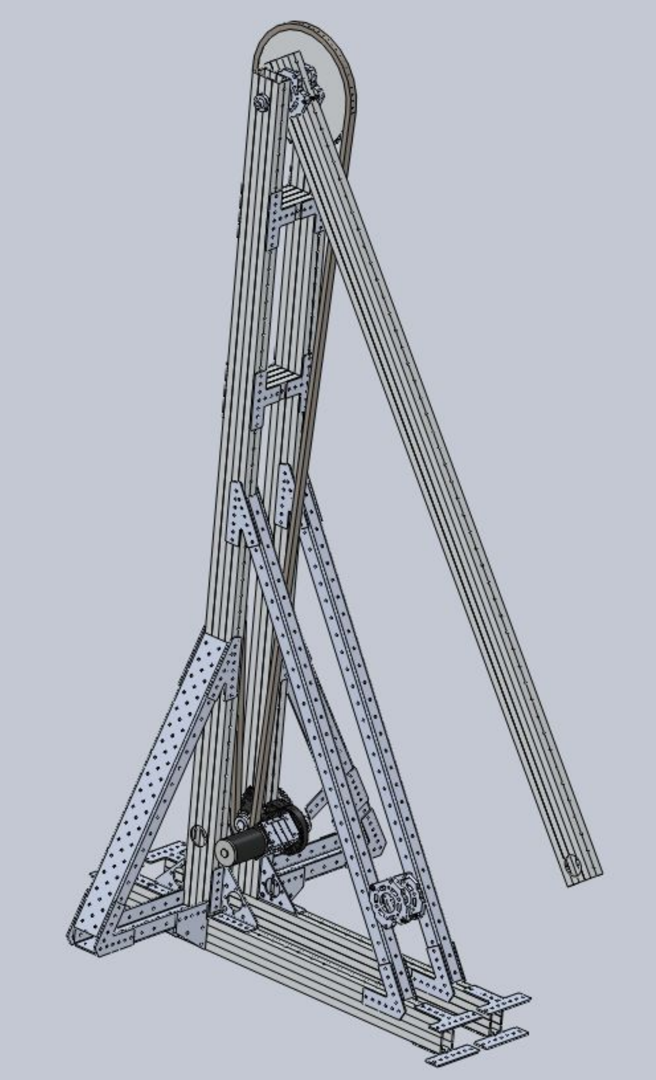
- VersaFrame is the COTS example of this.
- Quickly design and build mechanism with standard parts.
- We don't own all the brackets, etc but we can route and bend them when needed.
- Look at Drawings on VEX website for examples on how to use these

VersaFrame Examples

Build Blitz JVN Robot -
https://www.youtube.com/watch?v=Gm96S8gdhR0



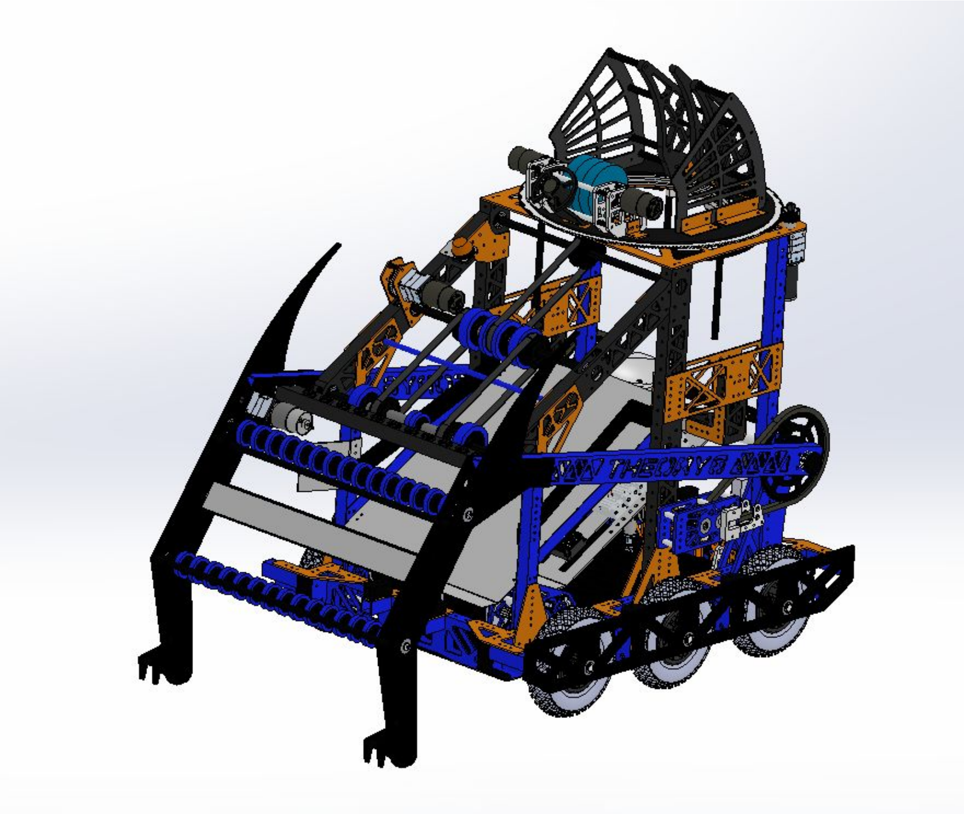
VersaFrame Examples



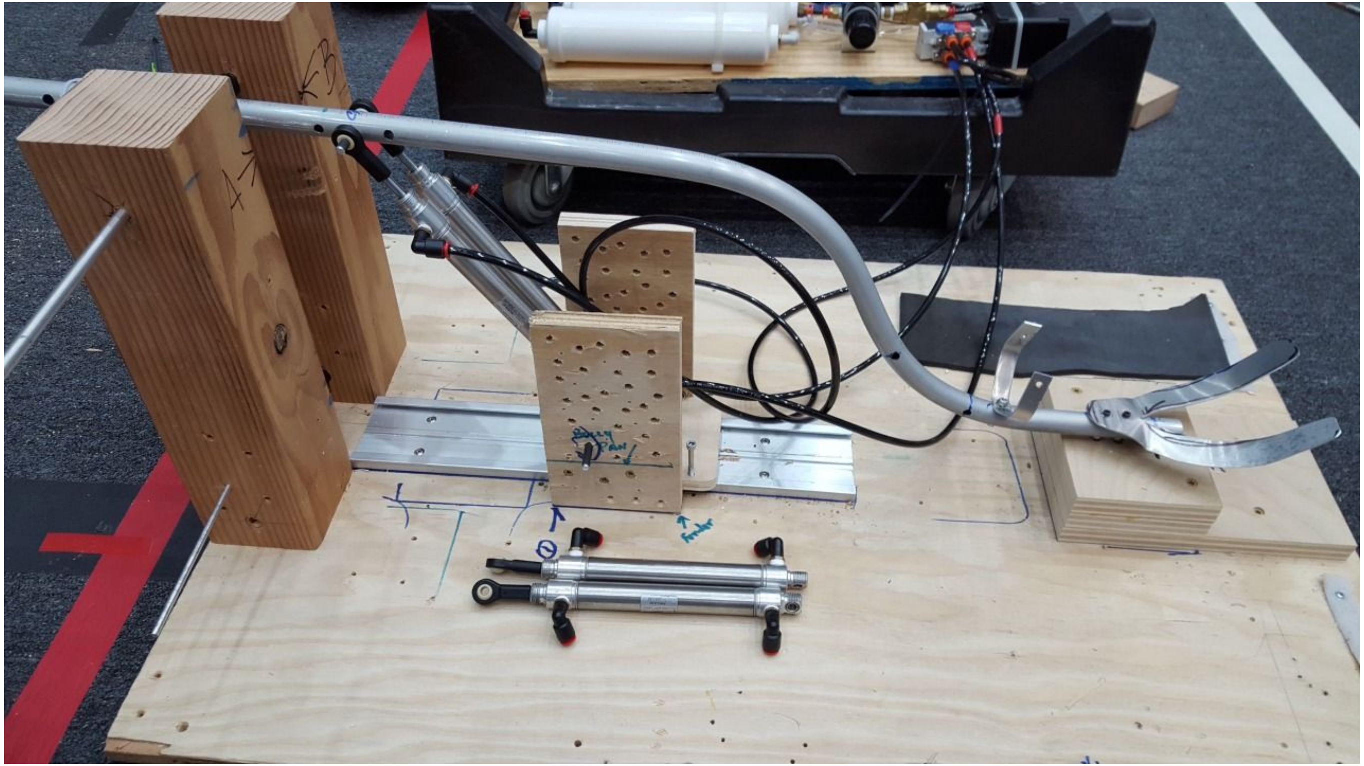
CAD Walkthrough

1241 - 2016 Robot

[CAD Thread on Chief]

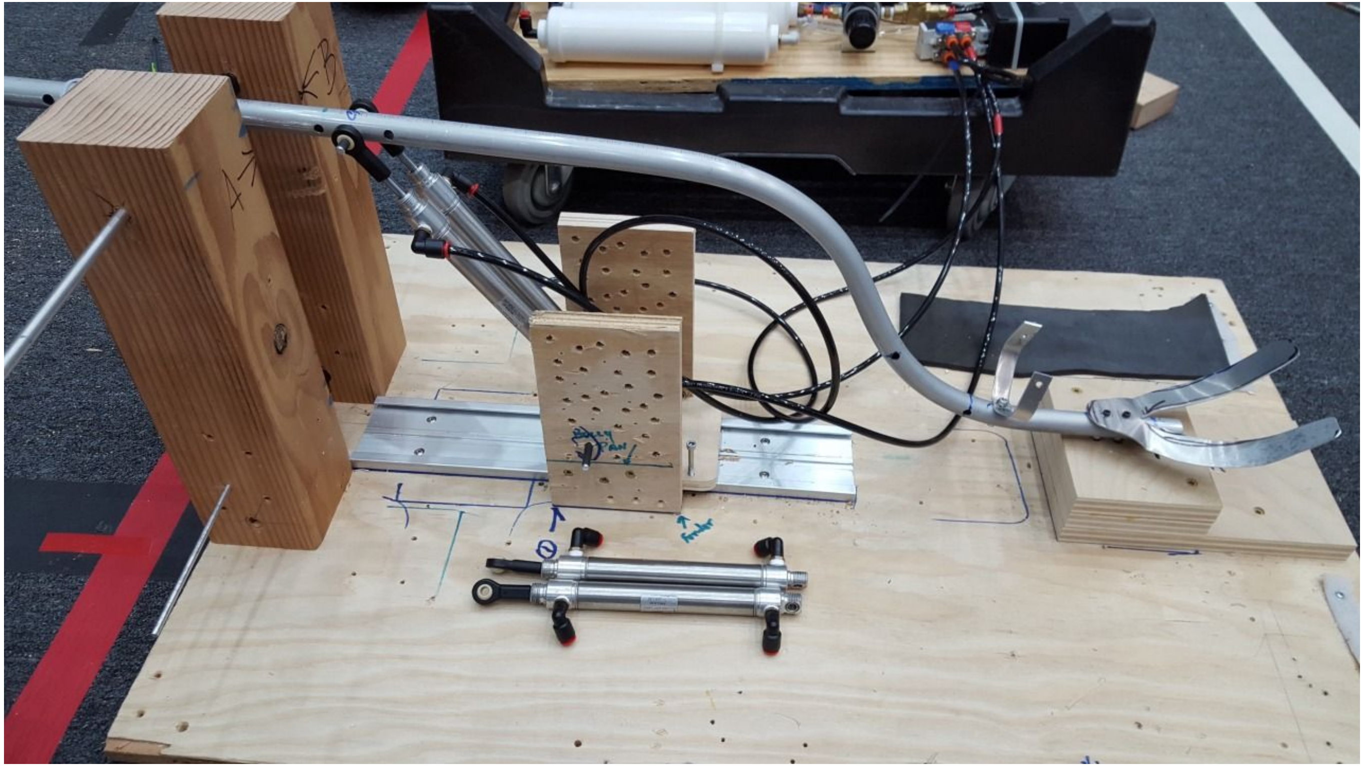


Adjustable Prototypes



[118 Build Blog 2016]

Adjustable Prototypes



118 Test Catapult 2016

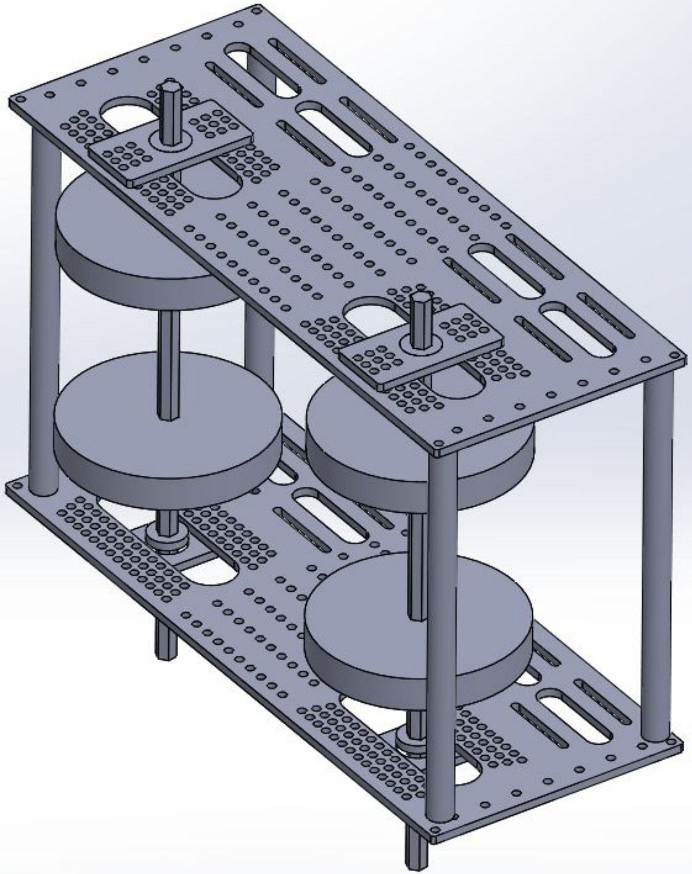
- The slide allows for the angle of the cylinder to change.
- Multiple holes allow for the height to change.
- Multiple holes on the catapult arm allow for the force to change as well.
- Regulator lets you change force
- Multiple cylinders so you can change stroke length

[118 Build Blog 2016]

Adjustable Prototypes

2848 Designed Test Jig from 2016

- ▲ Rows of holes allow for ⅛” compression distance changes.
- ▲ Slots at the rear end allow for easy chain tensioning.
- ▲ Vertical Wheel spacing can be adjusted with shaft collars
- ▲ Can test compression, wheel diameter, wheel spacing, wheel speed, etc.



Power Transmission

Pitch - Roughly the size of the tooth in the power transmission system. There are multiple ways to measure pitch and they are different for gears, sprockets, & pulleys. **Don’t mix match pitch.**

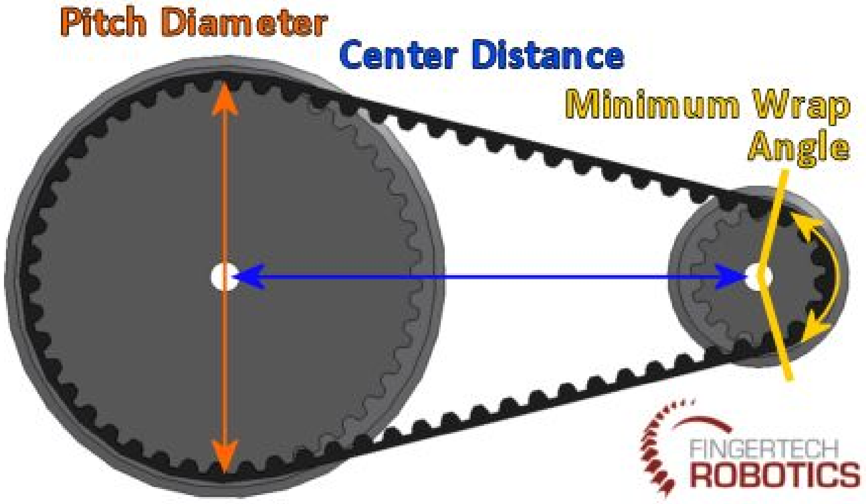
In FRC we basically have a big and small version of each of these. Make sure the teeth on your pulleys/gears/sprockets all are the same size.

Timing Belts and Pulleys

- ▲ Better at high speeds and quiet operation compared to chain
- ▲ Efficient power transfer
- ▲ Can 3D print pulleys
- ▲ Lighter than chain and sprockets
- ▲ 3mm can be used directly off 775pro or BAG motor with a pressed on pinion pulley
- ▲ Have to buy the right belt length for each application
- ▲ Belt lengths are often spec'd as arc length. Divide by pitch to get the number of teeth.
  (500mm long, 5mm pitch belt is 100 teeth)
- ▲ Belts don't need lubrication

Timing Belts and Pulleys

- Pitch = Distance between teeth on the belt.
- Width = Belts come in different widths. Larger width transfer more torque.
- Pulleys width need to be at least as big as the belt width.
- Multiple belts can be on one pulley if the pulley width is big enough.
  - Such as two 9mm belts on a 18mm wide pulley



Timing Belts and Pulleys

- Profile = There are various types of tooth profiles. Don't use any trapezoidal belts (MXL, XL, etc). Use only round tooth profiles like HTD, GT2, & GT3.
- GT2 is an advanced version of HTD.
- Gates is the original designer of the belt specs and holds some patents so you may see them named slightly different things depending on the vendor.

Timing Belts and Pulleys

5mm Pitch HTD (bigger teeth)

- ▲ VEXpro and AM sale 5mm HTD Belts.
- ▲ KOP Drivetrain uses 5mm x 15mm wide HTD belts.
- ▲ Most of our 5mm belts are 15mm wide.
  - ▲ 2017 shooter bed uses 5mm HTD x 15mm wide belts

3mm Pitch GT2 / HTD (smaller teeth)

- ▲ West Coast Products sales 3mm GT2 pulleys and belts
- ▲ Great for high speed applications
  - ▲ Our 2017 shooter uses 3mm GT2 x 9mm wide belts
- ▲ Many 3D printers use 3mm HTD pulleys
- ▲ For small torque loads interchanging GT2 and HTD will work but they will be less efficient.

Timing Belts and Pulleys

Calculating Belt Distances

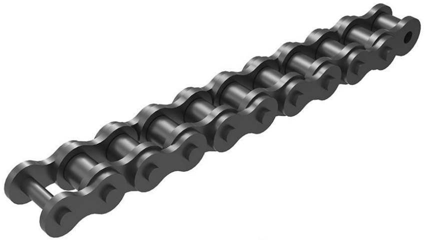
- Use the Spectrum Robot Design Sheet
- Use the exact Center to Center (C-C) distance given by the calculator.
- This only shows the belts that VEXpro and WCP sale. There are many other sizes of belts so you can type in a custom belt length at the bottom of the calculator.

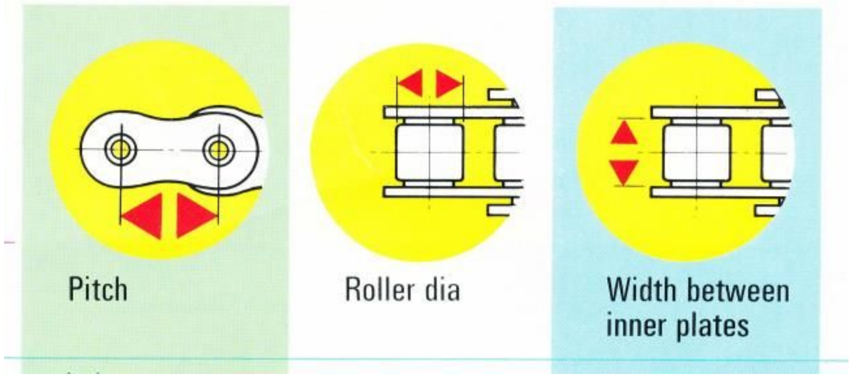
5mm Belt Calculator	
Pulley 1 Teeth	18
Pulley 2 Teeth	36
Raio	2.0000
Pitch Diameter 1	1.1279
Pitch Diameter 2	2.2557
Teeth on belt	*Center Distance*
60	3.1990
70	4.1950
80	5.1860
90	6.1760
100	7.1630
104	7.5580
110	8.1500
120	9.1370
130	10.1230
140	11.1080
150	12.0940
160	13.0790
170	14.0640
180	15.0490
190	16.0340
200	17.0190
225	19.4810
250	21.9420
Custom Length Belt Teeth	
60	3.1990
Custom C-C Distance (in)	
3.199	59.9932

3mm Belt Calculator	
Pulley 1 Teeth	12
Pulley 2 Teeth	24
Raio	2.0000
Pitch Diameter 1	0.4511
Pitch Diameter 2	0.9023
Teeth on belt	*Center Distance*
45	1.5790
50	1.8770
55	2.1740
60	2.4710
70	3.0630
85	3.9510
90	4.2460
100	4.8380
105	5.1330
110	5.4290
120	6.0200
Custom Length Belt Teeth	
120	6.0200
Custom C-C Distance (in)	
4.878	100.6800

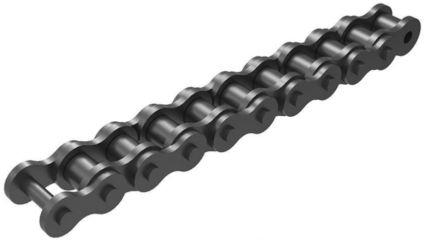
Chain and Sprockets

- Very common power transmission.
- Commonly used in bicycles and motorcycles.
- Transfers high torque loads.
- Chain pitch is width between drive links.
- Easy to adjust length, since you can break chain and connect it to the size you need.





Chain and Sprockets



#25 Chain - 0.25" Pitch (smaller teeth)

- ▲ Tensile Strength = ~780 lb (HD chain is stronger)
- ▲ Easy to derail due to misalignment
- ▲ Approximately 0.104 lb / ft

#35 Chain - 0.375” Pitch (bigger teeth)

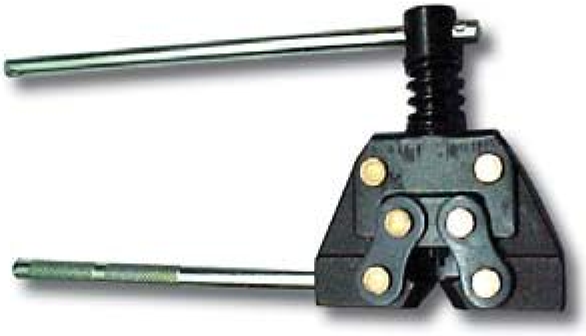
- ▲ Tensile Strength = 1,760 lb
- ▲ Very difficult to derail due to misalignment.
- ▲ Approximately 0.21 lb / ft

Pitch (inches)	Pitch expressed in eighths	ANSI standard chain number	Width (inches)
1/4	2/8	25	1/8
3/8	3/8	35	3/16

Chain and Sprockets

Working with chain

- Use a chain breaker or punch to push out one of the pins
- With certain tools you can push back in the pin to make seamless chain
    - VEXpro Chain Tools
    - How to use a chain tool



Chain and Sprockets

Master Links

- If you don’t have a tool to make seamless chain use a master link to reattach the chain.
- 3 Parts, the link, the plate, & the clip. You need to use all three of these.

Half Links

- If you need an odd number of links you have to use what is called a half link. It attaches to a master link and has a small pin with a cotter pin to secure it on the other side. Try to avoid half-links.

Chain and Sprockets

Calculating Chain Distances

- Use the Robot Design Sheet to determine chain lengths.
- Add .012" to the result to have a tight chain.
  - This number is basically made up. It really varies by the chain, chain type, how long the chain run is, etc. 0.012" is a good start.
  - This also help account for tolerance stackup and we assume a slightly too tight chain is better than a too loose chain.

Designing with Chain

- Larger sprockets have less chain tension (larger lever arm) and distribute load to more teeth.
- Attempt to get as much chain wrap as possible on the sprocket. Larger sprockets could have less % since more teeth are engaged.

Sprockets & Chain	
#35 Sprockets	
Hub	12,15
Double Hub	12,15
Plate	22,24,26,28,30
	32,33,36,42,44,48,54,60
#35 Chain (.375 pitch)	0.375
Height:	.358"
Width:	.463"
#25 Sprockets	
Hub	16,18,22
Plate	32,34,36,38,40
	42,44,48,54,58,60,64,66,72
#25 Chain (.25 pitch)	0.25"
Height:	.232"
Width:	.354"
Calculators	
Add .012 to the chain calcuations	
Number of Whole Links	
Chain Pitch (in)	0.250
Sprocket #1 Teeth	12
Sprocket #2 Teeth	12
Center Distance (Inches)	3.875
Result: Number Whole Links	43.000
Center to Center Distance	
Chain Pitch	0.250
Sprocket #1 Teeth	12
Sprocket #2 Teeth	12
Links	44
Result: Center Distance (in)	4.000
Differance: Links-CC	0.125

Chain and Sprockets

Mounting to chain

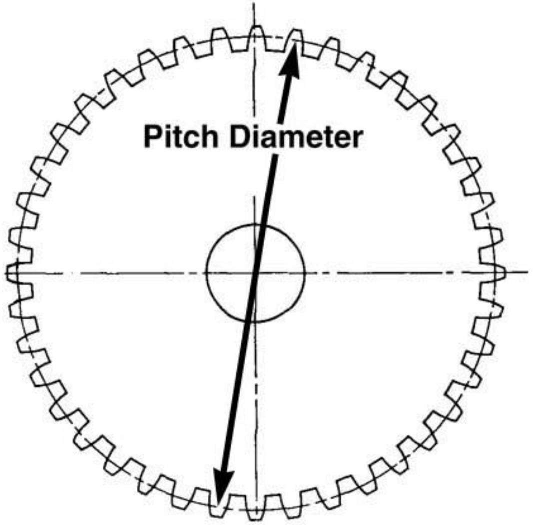
- When using chain to power a lift or other mechanism you may need to mount to the chain itself.
- You can bolt directly through the chain loops, remember you won't be able to continuously spin this any more but it can power an elevator or other mechanism.
- There are also special attachment links, that let you Attache to the chain as well.

Gears

- Can be used for speed or torque.
- Common on our drive trains and other mechanisms.
- Only work next to each other not at a great distance.
- Very reliable since there is just metal to metal contact. Nothing has to be tensioned, etc.
- Make sure to lubricate gears! (more later)

Gears

- **Pitch Diameter**
  - This can used to determine where two gears should be located next to each other. If their pitch diameters are coincident then they are in the right place.
- **Diametral Pitch (DP)**
  - Ratio of the number of teeth to the pitch diameter. Could be measured in teeth per inch or teeth per centimeter, b
    conventionally has units of per inch of diameter. Where the module, m, is in metric units.
- **Pressure Angle**
  - Just know that this needs to be the same as well as DP. For all gears sold by FIRST suppliers they are the same for a given DP.



Gears

20 DP (bigger teeth)

▲ Most common size for FRC
▲ Most of our gears are 20DP, CIM pinions, drive gears, etc
▲ VEXpro, AM, WCP all sale 20DP gears

32 DP (smaller teeth)

▲ Used as 775pro pinion gears.
▲ WCP and AM sale 32DP gears
▲ Most mate to another 32DP gear

Gears

Calculating Gear Distances

- Use the Spectrum Robot Design Sheet
- The design sheet does the .002 center add for you.
- Make sure you set which DP gear you are using to either 20 or 32

Gears	
CIM	11,12,13,14
775Pro 32 DP	12
.5" Hex 20 DP	18,20,22,24,26,28
Bold = Steel or Al	30,32,34,36,38,40
Underline = Versa	42,44,46,48,50,52
	54,56,58,60,62,64
	66,68,70,72,74,76
	78,80,82,84
1.125 Bearing	48,54,60,64,66,70
Versa Key	72
.375" Hex 32DP	20,40,60,80,100
.375" Hex 20 DP	14,16,18,20,22,24
30,32,34,36,38,40,42,44,46,48,50,52,54	
Ball Shifter	34,44,50,54,60
Dog Gears	40,44,50,60
Bevel Gear 12DP	15t - 3/8 hex
Calculators	
WCP Gear Calculator	
Gear 1	
Diametral Pitch(DP)	20
Tooth Count	18
Outer Diameter	1
Pitch Diameter	0.9
Pitch Radius	0.45
Gear 2	
Diametral Pitch(DP)	20
Tooth Count	36
Outer Diameter	1.9
Pitch Diameter	1.8
Pitch Radius	0.9
Gear Ratio	2.000
Center Distance	1.35
.002 Center Add	1.352

Quiz

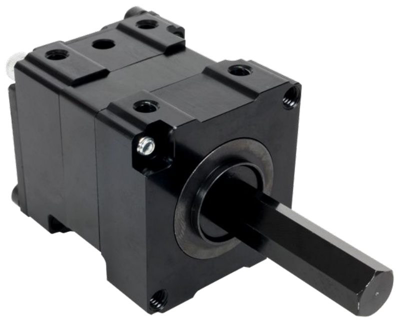
- What are the two pitches of chains common in FRC?
- What are the two pitches of belts common in FRC?
- What are the two pitches of gears common in FRC?
- If you have a high speed application what power transfer should you use?
- If you have a high torque application what power transfer should you use?

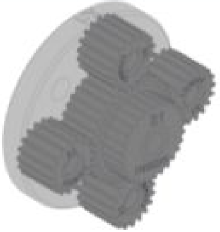
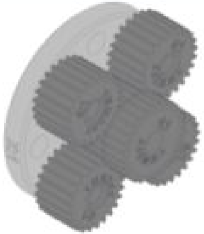
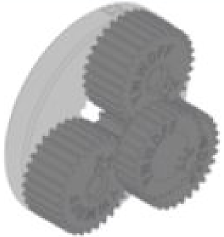
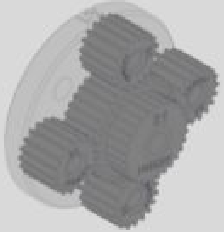
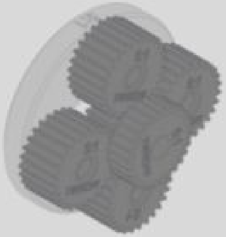
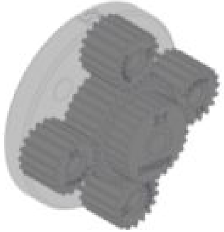
Planetary Gears

How planetary gears work - https://youtu.be/ARd-Om2VyiE

The VersaPlanentary is our standard planetary gearbox. It can be customized by interchanging and stacking gear sets.

VP User Guide - Read this if you are using VPs



Stage	Example 1	Example 2	Example 3
Stage 1	 3:1	 4:1	 7:1
Stage 2	-	 3:1	 5:1
Stage 3	-	-	 3:1
Overall Reduction	3:1	12:1	105:1

VP Customization Options

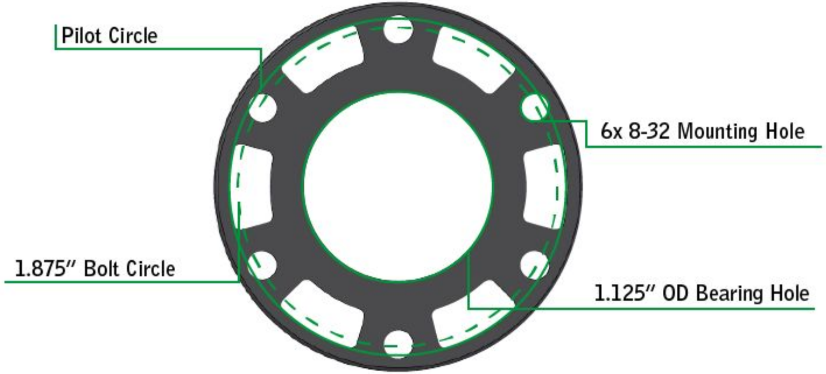
- Use with BAG, 550 Series, 775 Series and AM-9015 motors
- Interface with the CIM, Mini CIM, or Nidec Brushless motors with the VersaPlanetary CIM Adaptor
- Dozens of gear ratios from 3:1 to 300:1
- Output shafts options
  - ½" Hex, ⅜" Hex, ½" Round, 8mm Round
  - Universal Female Adapter - ½" hex, ⅜" hex, ¼" Square
- Dual Motor Input available
- 180° Drive Adapter available
- Rachet slice adapter available
- VP-Lite Plastic input, output, and ring gear slices available

VP Videos

- Greasing VP Gearboxes
- Changing a gear set

VEXpro VersaKey system

- "All VEXpro "Versa" products have the innovative VersaKey mounting system with holes that makes it easy to mount wheels to sprockets, gears, shafts, and bearings. The pattern pilots items together without relying on screws. There are 6x 8-32 screws on a standard 1.875" bolt circle. There are 3x male and female keys on each side that transfer torque and pilot items together."



Lubrication

Lubrication - using a substance to reduce the friction between two surfaces.

VP lubricant - TRI-Flow, just a few drops on each gear.
Chain Lubricant - TRI-Flow, just a few drops on the sprockets

Gearbox Lubrication - blueWorks spray in as you rotate the gearbox, try to coat all the teeth.

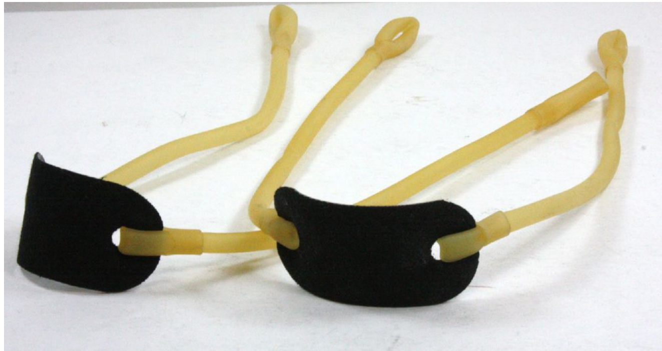
CADing Shafts

973 Adam Heard Method - https://youtu.be/e2TK3_XMcdU?t=725

Springs

Variable Force

- Coil Springs (retract or extend)
- Elastic Bands (retract)



Constant Force

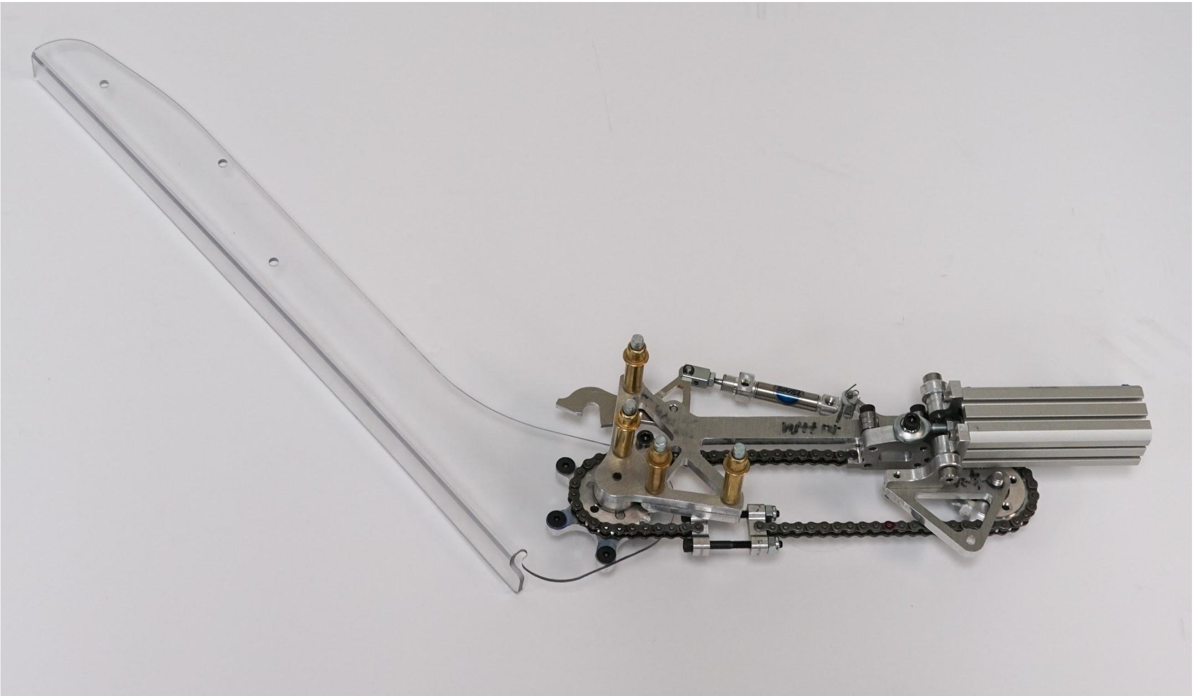
- Constant Force Springs (retract)
- Gas Springs (extend)

Springs - Counterbalances

- Use springs to counteract the force of gravity on your mechanisms so the motor only moves the mechanisms and the springs support the weight.
- Makes controlling them easier.

Pneumatic to Rotary Motion

- 971 attached pneumatics to a chain so they can deploy a mechanism. With less space than needed.



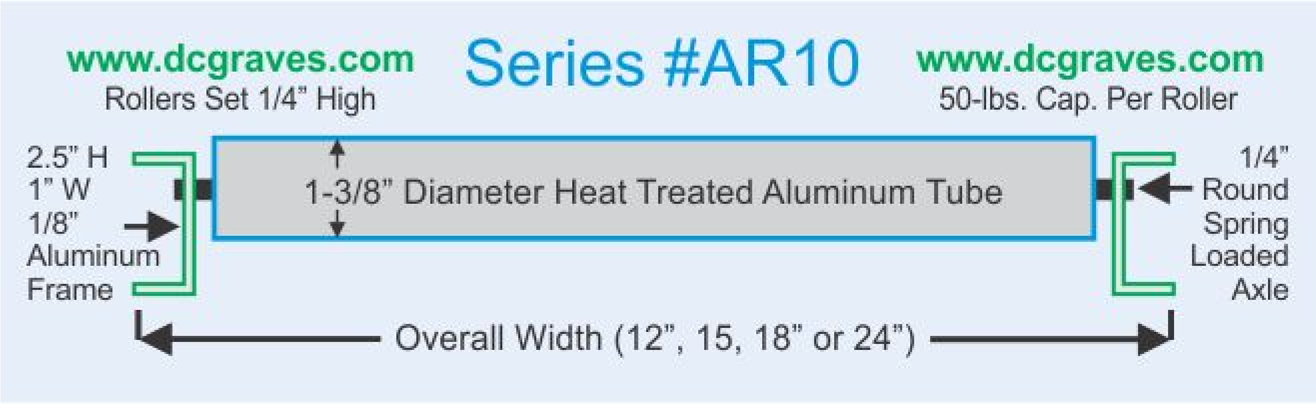
Star Nuts

Mounting tubes to plates.

You insert the nut and then the bolt expands the fins into the side of the tube stopping it from coming out.

Spring Loaded Rollers

- Simple rollers to use for prototypes and devices.
- [McMaster Link]
- [Video of how to remove them]
- [Shrink Fit Conveyor Covers]



Compliant roller mount

Lead Screws

- Create linear motion from rotary motion
- Ball screws are better than lead screws (rolling friction++)
- CNC machines use lead screws for high precision motion

3d printing

SLA - https://www.youtube.com/watch?v=NM55ct5KwiI
SLS - https://www.youtube.com/watch?v=9E5MfBAV_tA

FDM (what we use, most desktop printers) - https://www.youtube.com/watch?v=WHO6G67GJbM

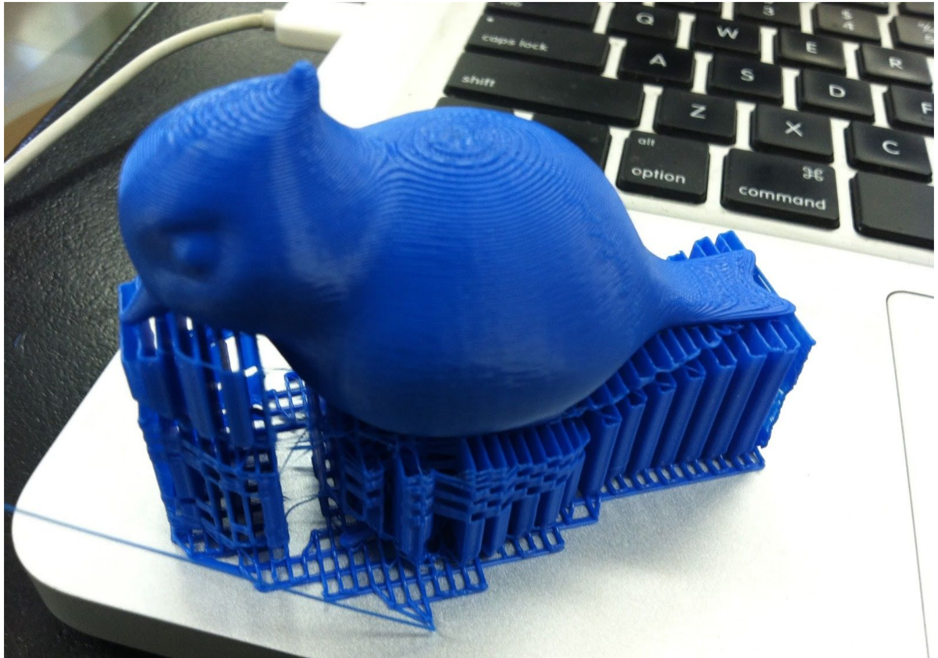
3D Printing

Filament - the material used for printing. Different plastics in thin strands that can be melted and deposited on to the build plate.

- PLA/ABS - most common materials
- PETG - same plastic as soda bottles, strong, easy to print, what we use on the Davinci (red printer)
- Polycarbonate - lexan, really strong, harder to print, what we use on the airwolf

3D Printing

Supports - material that you break away since you can't print in thin air.



Designing for 3D printing

- Bed adhesion is the hardest thing. Always remember to apply glue stick to the bed before printing. THIS IS IMPORTANT!
- Avoid overhangs (greater than 45deg) so you don't have to print supports. Some things can be printed without supports. Often turning a part can avoid overhangs. Holes are overhangs as well.
- Remember that the layer adhesion can be weaker. So design for it not to take stresses.
- Read more - https://www.onshape.com/cad-blog/top-5-tips-for-designing-for-3d-printing https://www.3dhubs.com/knowledge-base/how-design-parts-fdm-3d-printing

References

- Fundamental Principles by K. Craig
- Design is a Passionate Process by Alexander Slocum
- How to Build Your Everything Really Really Fast
- Spectrum Robot Design Sheet
- 610 Design Tutorials
- Spectrum Recommended Reading