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CHAMPIONSHIP

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Think Outside the KOP

Building FTC Robots Using
Alternative Materials

FOR INSPIRATION & RECOGNITION OF SCIENCE & TECHNOLOGY FIRST®

About The Presenters

- Steve Pendergrast
  - Coach/mentor of three FTC teams at Pope John XXIII High School in Sparta, NJ
  - Ten years mentoring in FLL/FTC/FRC/Zero Robotics
  - Teaches AP Physics, Honors Robotics, and sometimes other topics at PJHS
- Gaige Moore
  - Junior at Pope John XXIII High School in Sparta, NJ
  - Lead builder/programmer/driver on FTC Team 247 “Reboot”
  - 2015 Dean’s List Finalist
  - Giving a talk tomorrow on the “All Plastic Robot”

About The Presenters

Contact Information:

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NOTE: DXF files for parts used in this work shop are available by request

Think Outside the KOP!

- In the early days of FTC, allowable materials were highly restricted
  - Most robots were structurally formed mainly from Tetrix metal, Tetrix brackets, etc.
  - A limited amount of sheet plastic was also allowed
- As time went on, these restrictions were successively relaxed
  - Matrix kit added, unlimited plastic, angle, tube and other extrusions
  - Finally, in 2014, arbitrary COTS parts with limited degrees of freedom were made legal

Think Outside the KOP!

- But even with all this new freedom, we frequently see robots that are primarily made from Tetrix metal and maybe a little sheet plastic
- This workshop is based on a simple idea:
  - Tetrix parts are high quality and easy to use, but there are many alternatives that are now legal for FTC
  - Some clear advantages can be obtained by using slotted extrusions along with custom plastic parts, COTS parts, and other materials
- Our teams now use almost exclusively alternative parts

Taking it to an Extreme

- An extreme example is our Team 247 robot this season
- It uses no Tetrix or Matrix parts at all (structurally)
- Every single structural part is CNC router cut out of plastic
  - There is a talk on “The All Plastic FTC Robot” tomorrow at 10:30am
- Most of our robots do use slotted aluminum extrusions which we’ll be working with today as well

Structural KOP Alternatives

- Due to limited time, we'll focus today on a few items we've found to be really useful
  - Slotted aluminum extrusion
  - Manual Fabrication techniques for plastic parts
  - 3D printed and CNC router cut plastic parts
- But this workshop should make you take a second look at some other possibilities:
  - What about intricately carved wood?
  - Some teams are using epoxy cast carbon fiber
  - Theoretically, unusual materials like cast concrete are perfectly legal now. Which would be kind of awesome looking.

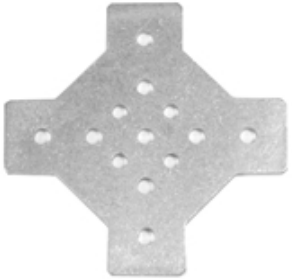
Part 1: About Slotted Extrusions

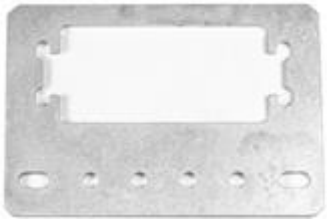
Slotted Aluminum Extrusion

- Have been used for many years in FRC
- Comes in a variety of sizes
- We have found that 15mm is perfect for many FTC structures
- We get ours from Misumi: us.misumi-ec.com but there are many sources such as rev robotics (on andymark), microrax and others
  - Misumi will cut it to any size you want down to one millimeter increments, or sell you full 2 meter pieces for under $8
- Cost comparison:
  - Misumi 15x15 channel: 300mm cut to order (about 1 foot): $1.56
  - Tetrix Channel: 288mm: $14.00

Slotted Aluminum Extrusion

- REV brand 15mm brackets come in many useful shapes, are available on Andymark
- Prices are quite reasonable, for example a corner bracket is quantity 10 for $10, which is typical
- Linear sliders, motor mounts, servo mounts, and other parts also available





Slotted Aluminum Extrusion

- Advantages:
  - Parts can be positioned anywhere along the slot on all four sides
    - This makes meshing gears or making small adjustments especially easy
    - Tetrix channel has lots of holes but they never seem to be in exactly the right place!
  - Lower cost as comparison just showed
  - Quite strong while taking up much less space than channel
  - The slot can be used to make a simple sliding mechanism
  - You can use Tetrix motor mounts with them by using m3x40 screws
  - The hole in the ends can be tapped to accept a 3mm screw for end-mounting of actuators or other items

Slotted Aluminum Extrusion

- Disadvantages:
  - Require plastic or metal brackets to bind together
    - These can be purchased (for example from REV or Misumi)
    - Or you can manufacture them yourself (at a much lower cost but you need the right tools)
  - You need to use 3mm screws to interface with the slots
    - This is a slightly different size than the typical #6 screws most teams use with the Tetrix parts
    - So keep them separate!
  - We've seen cases where a screw is overtightened so much that it pulls through the extrusion. Square m3 nuts are actually less prone to do this but are less commonly found than hex nuts.

Slotted Aluminum Extrusion

Workshop Project #1:

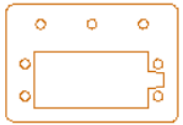
Each person (or small group) take a couple of pieces of extrusion, some 3mm hex screws, tools, and some random brackets, and just learn how to attach things together for a few minutes

Note 1: There are several different kinds of brackets, some of which have mounting holes for servos or motor mounts

Note 2: You can either put the nut in the slot, or you can put the hex head screw in the slot. If you put the nut in the slot, the screw must be a precise length (10mm works well with the ¼ inch plastic brackets)

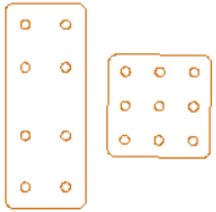
Note 3: Notice you don't need special "nuts" like you do with 80-20, standard 3mm hex screws and nuts slot in nicely

Slotted Aluminum Extrusion



Servo Mount

Mount an upright on a bar



Plates allow strong connections between parallel bars or mechanisms

Corner, connect two bars 90 degrees to make a chassis

Interface with brass bushing for Tetrix Axles

Slotted Aluminum Extrusion

A Problem and Solution:

- Once you assemble a rectangle for a chassis, you may find you need to add more items to a slot, but are blocked by your own plastic brackets from slipping in additional nuts or hex screws
- One way to overcome this is to drill a ¼” hole in the center of the slot. This gives you a way to insert screws.
- Another trick is to put a few loose nuts or hex head screws in the slot before sealing it off with your brackets. Nuts are cheap so if you never use them, no big deal.
- Hint: You may want to put a couple of loose nuts in your art creation.

Slotted Aluminum Extrusion

About those brackets:

- We manufactured all of these plastic brackets using our own CNC router
- We'll be talking more about that later, but these brackets only use pennies worth of plastic each (3 cents per square inch)
- We will provide the DXF files to anyone who wants them
- You could use the DXF files to create brackets using a 3D printer or CNC router
- If you don't have a CNC router, one option is to find a local "maker space" and go in and make a bunch of brackets one day

Part 2: About Plastics

Manual Plastic Fabrication

- Plastic Types
- Advantages and Disadvantages of Plastic
- Cold Bending Plastic
- Hot Bending with a heat gun
- Hot Bending with a Strip Heater
- Discussion of Gluing plastic
- Where to obtain materials and tools for plastic

Types of Plastic

- ABS
  - Opaque, easy to cut and thermoform, somewhat soft, can be cold bent, extremely low cost ($2 to $3/sq ft @1/8”)
- PETG
  - Transparent, easy to cut and thermoform, can be cold bent if thin, very low cost ($3 to $4/sq ft @1/8”)
- Polycarbonate (Lexan)
  - Transparent, easy to cut and thermoform, not good for cold bending, moderate cost ($5 to $8/sq ft @1/8”)
- KYDEX (Acrylic/PVC blend)
  - Opaque, machines and thermoforms very well, does not cold bend well, extremely expensive ($9 to $11/sq ft @1/8”)

More Types of Plastic

- Acrylic (aka Plexiglass)
  - Too brittle for most parts, not recommended except perhaps as decoration because it comes in many cool looking colors
- HDPE/LDPE/Polypropolene
  - Inexpensive, dense, impact resistant, easy to cut and drill, superb for router cutting (cutting boards are often made of HDPE) ($2 to $4/sq ft @1/8”)
  - HDPE is stiffer, LDPE and PP are more pliable
- Nylon
  - Self-lubricating, tough, impact resistant, but expensive compared to others, and can melt if cut too slowly
- Teflon (PTFE)
  - Very expensive, but has the lowest coefficient of friction of any known solid material. Teflon on teflon has the same coefficient of friction as ice on ice! So small pieces could be used to make really nice sliding mechanisms

Even More Types of Plastic

- PVC Pipe or Sheet
  - PVC is allowed in pipe, sheet, or extruded shapes (tube, channel, etc.)
  - Easy to glue, cut, drill, etc. Does not cold bend well. We do not recommend thermoforming PVC
- PLA (polylactic acid)
  - Great for 3D printing, inexpensive, little warping, bio degradable and made from corn
- HIPS (high impact polystyrene)
  - Starting to become more popular in 3D printing, we haven't tried it much yet

Advantages of Plastic

- Light weight (important for mechanisms that must lift)
- Far less expensive and easier to fabricate than metal
- Thermoforming can make it look very professional
- Can form parts that naturally act as springs with a snap-back action
- Some kinds are transparent: see game elements and obstacles through your robot
- Does not block WiFi signals to anywhere near the extent of metal

Disadvantages of Plastic

- If you custom thermoform a part, and that part breaks at a tournament, most tournaments will not allow you to use heat to fabricate a replacement in the pits
  - Any critical part could be duplicated in your workshop and a spare brought
  - Noncritical dimension parts could be patched at a tournament
- Plastic is not as stiff or strong as metal (at the same dimensions) so some applications may be better in metal
  - Although: there is no weight limit in FTC so simply making the plastic part thicker/larger will compensate for the strength in most cases

Cold Bending Plastic

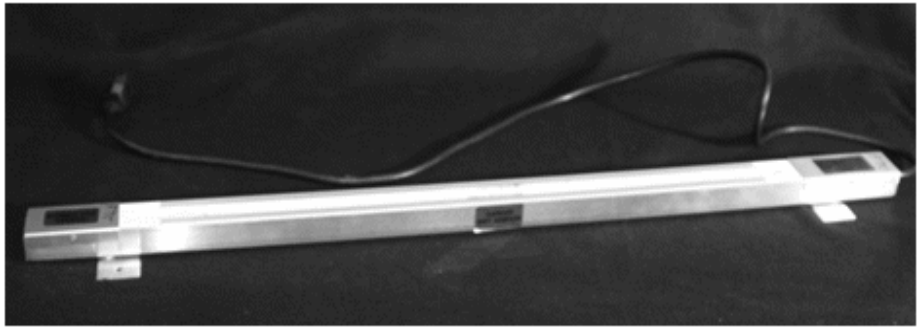
- Always wear safety glasses and work gloves when cold bending in case of shatter
- We do not recommend trying to cold bend Polycarb or KYDEX, or thicker sheets of any plastic (more than 1/16” starts getting impractical)
- Often helpful to use a clamp, pliers, or clamp pieces of scrap wood or metal where the bend is to take place
- Apply *slow* pressure over a period of 1 to 2 minutes
- Bend past where you need to go because there will be some snap back
- Practice on scraps
- DEMO

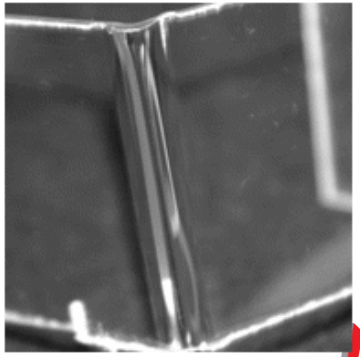
Hot Bending with a Heat Gun

- Only suitable for modest sized parts
- SAFETY: Wear gloves to avoid burns; keep the area clear of other people; have a safe place to set the heat gun down; adult supervision req'd.
- Result will typically not be professional looking, will often look “saggy” or “wavy”
- Move the heat gun back and forth over the spot where the bend is to be made
- When you feel it start to give, remove heat and make the bend

Hot Bending with a Strip Heater

- Very nice, clean bends can be made
- Small strip heaters cost under $100
- Videos are available online to teach you technique
- Same safety precautions as heat guns apply
- DEMO





Planning and prototyping your Bends

- Use poster board to prototype your part
- Include dashed lines for all bends
- Cut it out, bend it, and see if it fits on your robot
- Adjust until it is the right result
- Trace the outline onto the plastic, cut it out, drill holes, then make bends where dashed lines are
- For a more professional look, clean off your sharpie bend marks with alcohol

Gluing Plastic

- Each type of plastic has its own kind of solvent glue
- Make sure you buy the right kind of glue for your plastic
  - Weld-On #3 works with PETG and Polycarb
  - Weld-On ABS 771 works on ABS
  - Etc.
- Well ventilated area, adult supervision req'd
- Online videos show proper technique

Where to Obtain Plastic Products

- McMaster-Carr, www.mcmaster.com
  - Plastic sheet, plastic cements
- US Plastic Corp www.usplastic.com
  - Ditto
- Delvies Plastics www.deliviesplastics.com
  - Strip heaters in several sizes and prices, cements, training videos for using strip heaters and cementing
- Tap Plastics www.tapplastics.com
  - Really nice, big strip heater (but more expensive than Delivies)

Misc. Recommendations

- Buy several thicknesses of each type of plastic (except maybe KYDEX or teflon)
- Some parts are better made with very thin plastic, others may need the thick sheets
- If you buy Acrylic (plexiglass) then very clearly mark it so students know not to use it for structure!
- The thinner the plastic, the easier to cut, bend, and machine, and the cheaper it is to replace, so don't go overboard with thickness
  - The part should be no thicker than it needs to be, with some margin of error
- Keep the poster board prototypes of all plastic parts in a file in case you have to make a new part!

Part 3: CNC Routers vs. 3D Printers

(and how to make your own custom gears and racks)

CNC Routers vs 3D printers

- 3D printers are getting a lot of press, and they are cool and definitely useful for fabricating many kinds of robot parts
- But another technology that is just as cool and in some ways much more useful in competition robotics is the CNC Router
- CNC Routers are now available for under $1000 and they can fabricate extremely rugged 2D and 2.5D parts that are highly useful for FTC
- (Show Video of Router in action)

Comparison

3D PRINTER

- 3D Shapes
- Additive technology (melts)
- Relatively quiet
- Virtually clean, no need for vacuum system
- Parts tend to fracture on layer lines
- Very slow, sometimes hours to print a part
- Plastic material relatively expensive per gram
- Fine level of detail possible

CNC ROUTER

- Primarily 2 and 2.5D shapes
- Subtractive technology (cuts)
- Very loud
- Throws out chips and dust, need a vacuum system
- Parts are fully as strong as the material with no layers
- Much faster, most parts done in minutes not hours
- Plastic sheets much cheaper per gram
- Router bits don’t allow perfectly sharp inner corners

Which should you use?

- In the best of all worlds: BOTH!
- But of the two, we use the CNC Router far more than the 3D printer due to the much higher fabrication speed and much more robust parts
- We only use the 3D printer when a part truly must be 3D and does not undergo large stresses
- However, we often design several 2D parts with screw holes in the right places to form a 3D structure using the router

What kind of plastic?

- For the CNC router, we have almost exclusively standardized on HDPE plastic because:
  - It is reasonably priced, ¼ inch is about $4 per square foot in sheet quantities
  - It is extremely tough, does not shatter
  - It router cuts very nicely with clean edges and little melting if your settings are correct
  - It comes in several nice colors
- For 3D printing, we mostly use PLA because:
  - It has very little odor when printing (unlike ABS)
  - It doesn't shrink or warp very much
  - It is inexpensive, widely available, and comes in numerous colors

Mounting Servos and Motors

- If you want to use Tetrix motor mounts, they do work quite well with slotted extrusion
  - Use 40mm long m3 screws to attach
- However, current FTC legal motors have screw holes in the faces (m3 screw tapped)
- We have DXF files with the screw hole profile and will provide those to any team, although it really only takes half an hour with calipers and a couple of tries to figure it out
- The “all plastic” robot exclusively used face plate mounting and all motors were perfectly stable and never came loose
- One note: The screw must be exactly the right length, sometimes you may need a washer to make fine adjustments. For ¼ plastic m3x8 was perfect

Fabricating Gears, Timing Pulleys, etc.

Gears, Timing Pulleys, etc

- CNC Routers and 3D printers can be used to fabricate precision parts like gears, timing pulleys, cams, etc
- There are free tools to help you do this quickly
- Our team used custom rack-and-pinion and custom gears in FTC, and we have used custom cams and timing pulleys in FRC
- We have found that HDPE plastic really can stand up to competition use and are just as reliable as metal parts if properly designed
  - Example: The main shooting mechanism in one year's FRC game was a custom timing pulley made from HDPE. We made spares, thinking it would wear out under the stress of the game. It never did, not a single tooth was even slightly damaged after an entire season of intense play

Gears, Timing Pulleys, etc

- Advantages of making your own gears:
  - Create custom gear ratios that are not possible with the Tetrix gears
  - Can use large teeth that are much easier to align and space properly
  - HDPE Plastic is naturally self-lubricating
  - Far, far cheaper than metal gears, pennies per gear
  - You can integrate gear teeth into other mechanisms
  - Properly designed, HDPE gears are easily strong enough for FTC and even many FRC mechanisms

Gears, Timing Pulleys, Cams

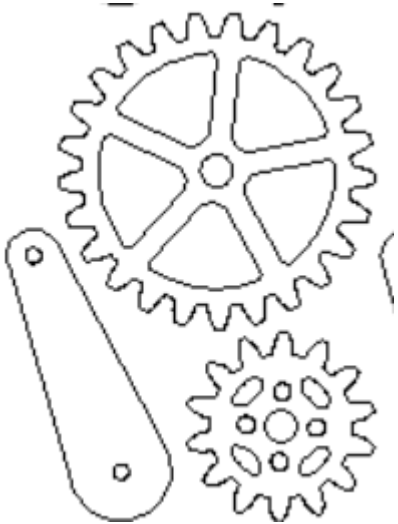
- Tools:
  - GearGenerator
    - $26 registration fee but worth every penny
    - https://woodgears.ca/gear/index.html
    - Demo
  - OpenScad Gear script
    - Openscad is a free open source CAD program that is really a language that generates 3D shapes. Many programs are floating around on the web, especially at Thingiverse.com
  - OpenScad timing pulley script
    - Our FRC timing pulley was made using this and it has options for many different manufacturer's belt tooth profile. We just selected the belt manufacturer part number and it fit perfectly
  - CAD programs like PTC and AutoCAD can also make gears but may require add-on products and definitely require a lot more training than the above tools

Gears, Timing Pulleys, etc

- Bearings for light to medium loads:
  - Nylon spacers, like the ones we have here today, make great bearings for gears
  - Cut the hole for the spacer about a hundredth bigger than the spacer diameter. For example, if you have a 0.25” diameter spacer made for #6 screw, make the gear’s center hole 0.26” diameter. This ensures free spinning but is still very stable.
- Bearings for medium to high loads:
  - Oil impregnated bushings can handle most loads. Cut the center hole in the gear a hundredth bigger than the bearing diameter
  - The main gearbox on the “all plastic robot” used oil impregnated bushings and it could easily lift the entire weight of the robot in the endgame.
- Bearings for high loads:
  - Skate bearings are inexpensive, easily available (Amazon.com and many other sources), and can easily bear any load likely to be put on an FTC robot
  - The “all plastic robot” uses skate bearings for the wheels

Gears, Timing Pulleys, etc

- Gear Tips:
  - Use large, blocky teeth shapes, these give you enough strength for most typical FTC mechanisms
  - If a gear has to bear a lot of weight, double up the plastic. In other words, make two ¼” thick gears and tie them together with screws to make one ½” gear
  - Place center holes an extra 1 to 2 hundredths of an inch farther apart than GearGenerator recommends. This will prevent binding but still be a nice stable mesh.



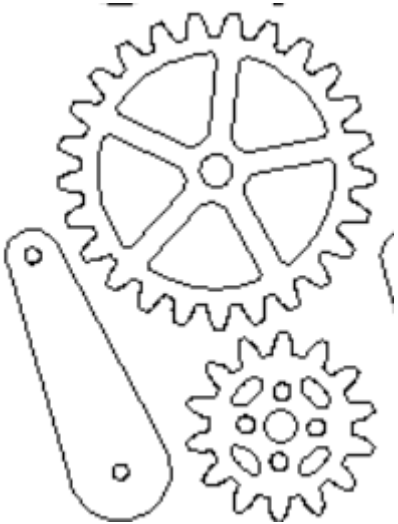
Gears, Timing Pulleys, etc

- Workshop Project:

Build a simple two gear configuration using ¼ inch nylon spacers as bearings

Take one large gear, one small gear, a mounting plate, nylon spacers, and 1” #6 screws

The screws will self-tap into the holes, there is probably no need for nuts unless the flame polishing opened up the holes too much



Gears, Timing Pulleys, etc

- Mounting gears to motors and Servos is easy!
- For motors:
  - The small example gears you have been using already have a Tetrix motor hub hole pattern in them!
- For Servos:
  - You can of course use the hitec servo hub provided by Tetrix which has the same hole pattern as the motor hubs
  - But what if you're using a different brand of servo?
  - In that case, a reliable mounting method is to pocket out a 4-arm servo horn pattern, clipping off some of the plastic horn material for very small gears if necessary, then include the servo horn under the gear
  - (Show example)

Conclusions

- There are many useful alternatives for FTC structural parts that are now legal
- Metal slotted extrusions are cheaper, stronger, and often more easily allow placement of parts
- Custom designing plastic parts with a CNC router and/or 3D printer allows ultimate flexibility in design and teaches students far more about engineering
- Manual fabrication of strong plastic parts requires only common workshop tools
- Practically any part in the world is now available to you (with one degree of freedom): Explore!