Watts Up?

Understanding and optimizing torque with FTC Electronics

Who are we?

Davy Hallihan

16461 Alumni

- Former Electrical and Design leads on Infinite Turtles.
- Current Senior in Computer Engineering at UNC Charlotte
- Mentor to:
  - FTC 16461 Infinite Turtles, Matthews, NC
  - FTC 7842 Browncoats, Huntsville, AL
  - FTC 1002 Circuit Runners, Marietta, GA
  - FTC 16377 Spicy Ketchup, San Antonio, TX
- Serial volunteer!

Asher M.

16461 Controls Member

- Fresh recruit to 16461!!
- Current Code+Controls team member on Infinite Turtles.
- Current Sophomore in Charlotte, NC
- Microelectronics and Web Design Hobbyist
- Designer for 16461's new site!! Check it out at:
  - https://16461.mcr.club

All of the topics that we will cover today can be accomplished with Addition, Multiplication, Subtraction, and Division- **The Math is not complicated, but setting up the equations is a different skill-set.**

This presentation is extremely dense conceptually. We will try our best to explain it all today, but will make these slides available for reference on the 16461 website, https://16461.mcr.club (also linked at the end of the slide deck)

Given the complicated nature of the topics, we don't expect everyone to get the exacts of the concepts today, so we are leaving you with **action items.** There will be one box highlighted in green like this on most slides that give you a direct plan of action/tip to take away.

Final Tip: **ASK US QUESTIONS DURING AND AFTER THIS PRESENTATION**. We have 40 minutes to go over 7-8 slides of content, so can linger slightly. If too many questions are asked, we won't get to the end of the presentation, but we would rather have audience understanding of a few topics than audience confusion about many.

Terminology and Basic Electrical Concepts

Voltage

Abbreviated with (V), Voltage is the difference in electrical pressure/potential between two points.

What you need to know:

- FTC Robots operate on a **12 Volt** system.
- 12 Volt system does not mean everything is 12 Volts constantly, but that around there is where everything operates.
- **Our batteries are typically operational from 10-14V.**

Amperage

Abbreviated with (A) or (Amp) and used in equations as (I), Amperage is the amount of electricity flowing at a point.

What you need to know:

- We have **20A fuses** on FTC bots, that mean we should avoid exceeding 20A. **(Fuses are segments of a circuit that break at a certain value)**
- 20A fuses do not break at exactly 20A. They break at 20A sustained amperage, and break under spikes of 40-60A.

Wattage

Watts (W) are a unit to measure overall power, whether mechanical or electrical.

What you need to know:

- W = V * I
- Fuses while typically rated for amperage are truly broken at certain wattages. If V decreases, I can go higher before popping a fuse.

Resistance

Resistance (R) is the opposition to electricity flow through a circuit.

What you need to know:

- The only common use we have for Resistance in FTC is dealing with battery health and Internal Resistance.
- Resistance effects voltage and amperage with Ohm's Law, which states V = I * R, which we'll get into more later.

Batteries

Let's start with Batteries so you can see why knowing your robot's electric system is useful.

FTC Nickel Metal Hydride (NiMH) Batteries, the only type legal, supply a certain voltage, typically between **10-14V**. At below 10V, your robot's systems will typically begin to fail functioning.

They also have a hidden value to users using standard chargers called "internal resistance" (IR). If you start to see strange behavior from a battery, or think a battery is "bad", IR is typically the issue at hand.

How do we read IR?
Some chargers have functionality to read IR, but the most common tool used by FTC and FRC teams alike is the battery beak sold by Andymark, pictured to the left. 120$ makes it an expensive piece of equipment, but it's extremely convenient to have a student carry around at competition on a lanyard, to know whether a battery is appropriate for use on your robot.

How do we restore IR?
If a battery's IR is bad, you can put it on some special/high end chargers and "cycle" it, fully discharging and fully charging it again. 2-3 cycles will typically restore a battery's IR to be a usable value, and our team uses 5 cycles as a last ditch attempt to save a battery with a horrible IR. If a battery's IR does not recover after cycling, keep it for just practice or scrap the battery.

Brownouts

Brownouts, formally defined as "a temporary drop of Voltage in a power system", are what we normally refer to unintentional drops in voltage on FTC batteries as. Any extreme usage of a mechanism or pushing match between robots will typically cause a temporary brownout.

We know that a 14V battery can drop 4 Volts before it hits 10V and the robot starts having issues.

$$V = I * R$$

Governed by the above equation, Ohm's law, we can use our Battery's IR as R for resistance, and our 4V drop as our Voltage. Let's say that our IR is 0.16, a typical battery used by FTC teams.

$$4 = I * 0.16$$

$$I = 25$$

When we solve the above equation, we find that the maximum amperage for our robot to still be functional and not completely brownout is 25 amps.

What is a typical range of internal resistance values?

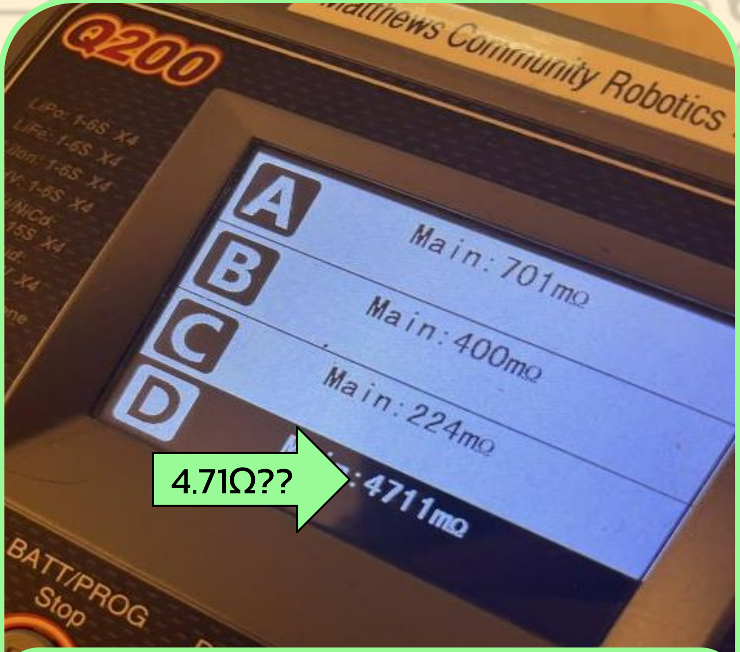
- 0.08 Ohms is typically the holy grail of internal resistance for FTC batteries. It's basically impossible to keep a battery here.
- Up to 0.12 Ohms is what Turtles uses for competition batteries. These are good batteries that will supply a lot of energy and last a full match, or even two.

What should you actually do to prevent brownouts?

First of all, you should make sure that you aren't using too much amperage/current, as we will go over soon.

Second of all, if you want numbers to go by, we recommend that batteries over 0.16 Ohm Internal Resistance are never used in competition.

Horrific Internal Resistance



This battery is a little past it's due date to be recycled/disposed of properly....

Do some research on the most environmentally friendly way to dispose of batteries in your area!
Some batteries like this one to the left just aren't recoverable....

As a bit of a math example for why this is bad: if we have 4.7Ω IR, that means that with a 14V battery we can pull about 0.8A before we brownout.

That means that you could almost use a singular servo on this battery!!!! Isn't that great? (sarcastic of course, this is a **really** bad battery)

$$I = \frac{V}{R}$$

$I = 0.849076629166$

$$V = 14 - 10$$

$V = 4$

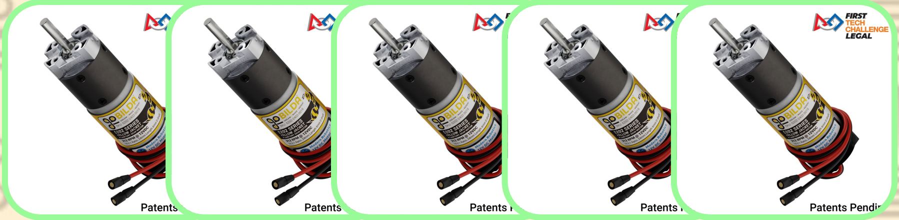
$$R = \frac{4711}{1000}$$

$R = 4.711$

Motor Current Pull

So now we know that on a standard FTC battery, you can pull about 25A before browning out, and only up to about 20A before we are surpassing our fuse's standard operating load. These numbers don't have much context for you yet though.

goBILDA motors, probably the most common motors in FTC, stall at 11A and reach peak power at 5.5A (more on that later). This means that before you are browning out your robot you can operate.... **5 motors at peak power? Really?**



25A is a TINY limit for FTC robots. To have a robot's best function, conscious decisions about torque and amperage are NEEDED.

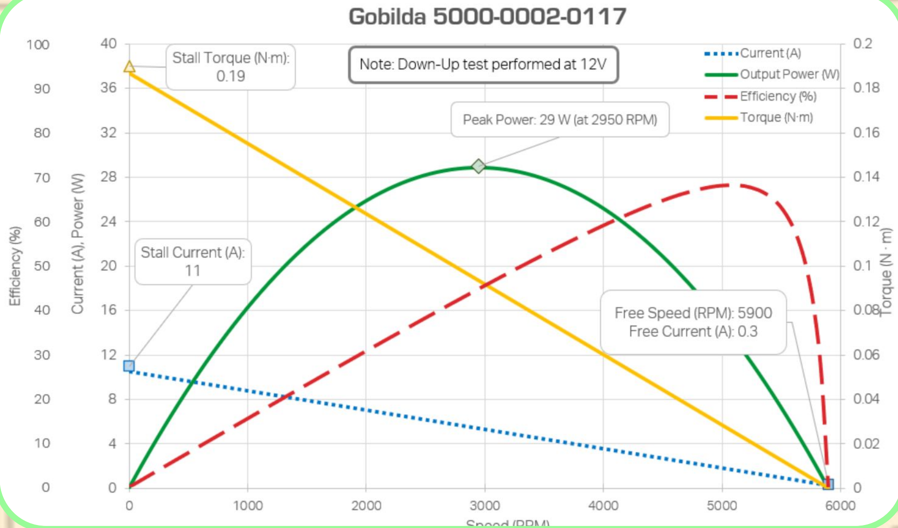
Side Note: We won't be talking about servos much today, but servos pull about 2A at 6V while moving and 0.2A at 6V while standing still with no load, which is equivalent to 1A and 0.1A from the battery. Treat servos as such, and expect this amperage pull.

Motor Efficiency

You may look at goBILDA motors that you are buying and see their "stall torque" value for each RPM. This is the amount of torque that will get them to stop moving. But this is a bit of a deceiving number. A standard 312rpm motor stalls at 24.3kg/cm. You may have had a use case of a mechanism that needed 20kg/cm, bought a 312, and had it function, but in reality this is not a good practice.

You may recall we mentioned the difference between mechanical and electrical wattage. Mechanical wattage is a measure of energy, just as electrical is. Our motors can only convert electrical energy to mechanical energy at a certain rate.

The maximum rate that goBILDA motors (and most other motors) can convert electrical to physical energy is **~70%.** This occurs at the top of a parabola on a motor curve graph, pictured right. The red dashed line depicts efficiency and the green line depicts power. This parabola will almost always peak at exactly half of the stall amperage and stall torque. As you use more electrical power at this point, the physical power output DECREASES.



DESIGN RULE:
Motors output the most power at half of their stall torque. If you exceed this, you are WASTING VALUABLE WATTAGE.

More Motor Efficiency

Here are some examples for efficiency with goBILDA motors.

25% STALL	50% STALL	75% STALL	90% STALL	AT STALL TORQUE
V = 12 A = 2.75	V = 12 A = 5.5	V = 12 A = 8.25	V = 12 A = 9.9	V = 12 A = 11
In -> 33W Out <- 20W	In -> 66W Out <- 29W	In -> 99W Out <- 20W	In -> 118W Out <- 9W	In -> 120W Out <- 0W
60.6% Efficiency	43.9% Efficiency	20% Efficiency	7.6% Efficiency	0% Efficiency

DESIGN RULE:

Motors are most efficient at half of their stall torque. If you exceed this, you are WASTING VALUABLE WATTAGE.

Bonus: Mathematical Battery Life

If you know how much amperage your robot pulls during normal use (you can use an ammeter or use the REV hub's measurement utilities (DcMotorEX.GetCurrent()), you can tell about how long your battery is going to last.

FTC batteries are all 3000mAH batteries, or 3AH. This value of 3 Amp Hours means that you can pull 3A from a battery for one hour before its fully discharged. Pulling 20 Amps continuously from a battery means it will last for about 9 minutes before it's fully discharged. Realistically, your robot will only function well and not brownout for the upper half of this discharge process, so half all of your expected battery life values to get how long you should expect a robot to last.

Did You Get All That?

This was an cool, practical intro to electrical engineering! This is DC (Direct Current) circuit analysis, something taught in Sophomore year of college. These are the type of practical skills that FIRST can give you in middle and high school, in a digestible manner. If you gained knowledge of even one or two concepts from this class, that's an absolute win! You're learning ahead of the game :)

Key Takeaways to Summarize

Don't Overdo Torque	Motors output the most power at half of their stall torque. If you exceed this, you are WASTING VALUABLE WATTAGE.
Consider Amperage	Really study how much amperage your robot uses during normal operation– ignore spikes or "transients".
Battery Health	Now you know how important battery health can be– take care of your batteries!
Brownouts	Consistent, severe brownouts are a sign you're using too much current/torque and should tone back how many things you're running at once, use a different motor, or add another motor.

@infiniteturtles_16461

Contacts and Help

We are both from 16461, a team based in Southeast Charlotte, and are occasionally able to help in-person in the Charlotte Metro area.

We can be contacted with our emails at **asher@mcr.club** and **davy@mcr.club**, please CC a coach on your communications.
We can be contacted on discord **@ashermyers** and **@daevii.** , preferably being pinged on the NCFTC or 16461 discord.

Teams can join our discord and gain access to a help channel at https://discord.gg/nEFb7X5BUR
We recommend teams join the NCFTC discord for help from other state teams at https://discord.gg/cEhWHYBmvU
We also recommend teams join the global FTC discord, partially moderated by our team, at https://discord.gg/first-tech-challenge

This presentation and all other 16461 kickoff presentations can be found on 16461's website at https://16461.mcr.club

https://discord.gg/cEhWHYBmvU

https://16461.mcr.club
https://discord.gg/nEFb7X5BUR

https://discord.gg/first-tech-challenge