Robot Design and Simulation: Battery Voltage Modeling
Also: My thoughts on choosing the correct gear ratio

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Introduction

Many teams do at least basic calculations of their gear ratios before deciding exactly what ratio to use. Some people do this by hand, calculating the theoretical speed of a drivetrain, others use spreadsheets which calculate speed loss, traction limited current draw, and many other important factors. However, many people still design around a single number: Top speed, or high gear and low gear speed in the case of 2-speed transmissions. That is not optimal for many games, due to acceleration and the time it takes to reach top speed.

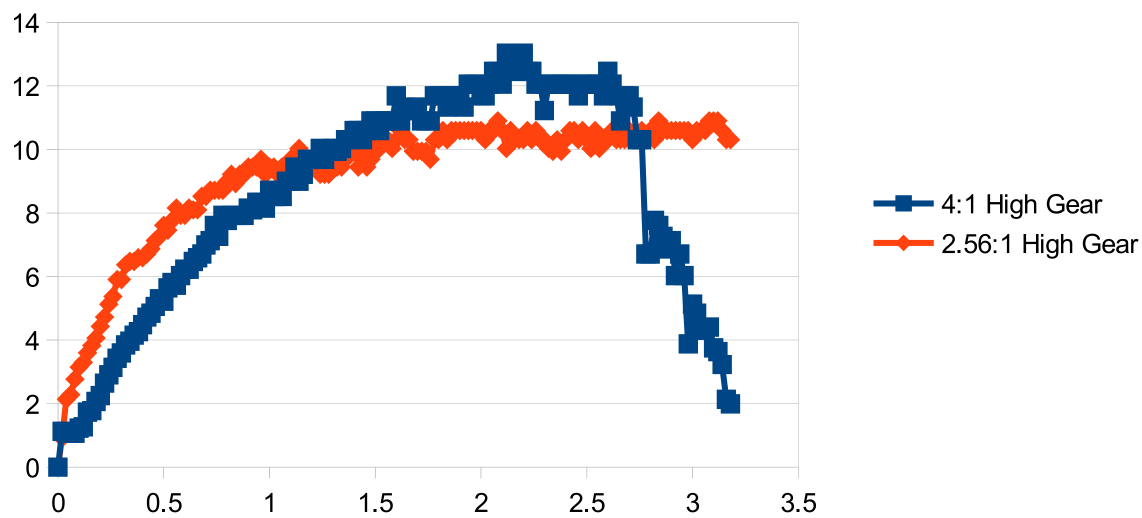
Part 1: The Wrong Ratio

Team 33 chose the wrong gear ratio early in the 2012 design process. This is due to several reasons. To start, Bryan and I wanted to go fast. Our strategy talks made us think we should design around a longer average travel distance. We also did all of our initial drivetrain math with 6 drive motors (4 CIM 2x 550-size), and assumed a charged battery as the motor voltage. We chose the 4:1 ratio spread AM shifters with a 12:18 final drive to 4" wheels. Our sprint distances were long, our assumption of a fully charged battery was wrong, and we later removed the extra drive motors for weight. After removing the extra motors, we re-geared the final chain drive somewhat (from a 12:18 final drive to 12:22). We found that our acceleration was less than ideal for many tasks in Rebound Rumble. Our initial fix was to replace the front wheels with lower traction wheels twice (from 2" wide IFI roughtop-treaded to 2012 KOP then to 2008 KOP with turned round edges). We were still unhappy, so we changed the final drive sprocket to a 24 tooth one, but were unable to put in a larger sprocket because of diameter and chassis clearance.

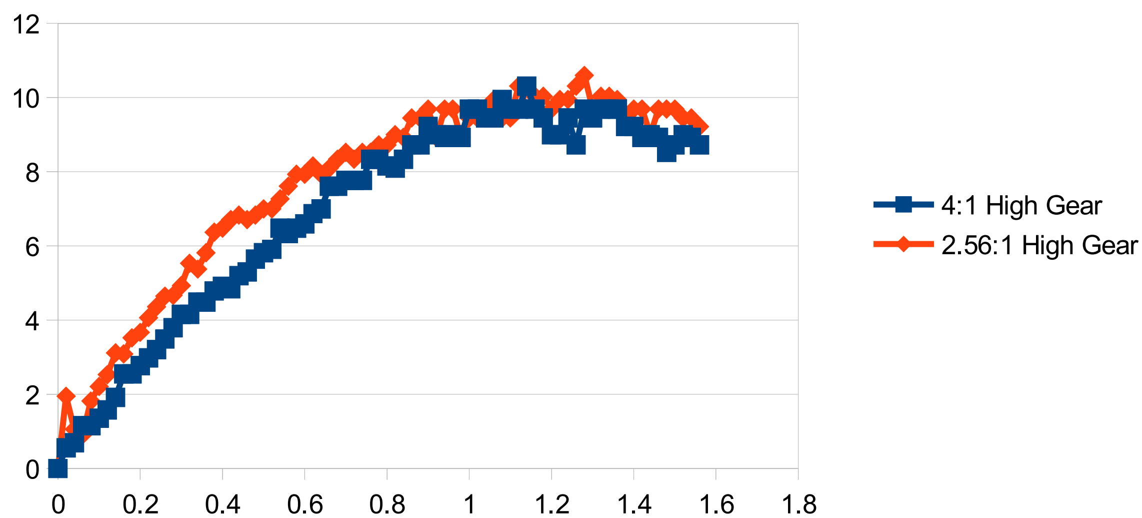
Part 2: Data Collection

We needed some data to compare our actual performance against theoretical, and find a better optimal solution. Tinkering worked, but we wanted to change the 4:1 high gear for the standard 2.56:1 high gear, which would require us to remove both drive transmissions in the pit at St. Louis. We wrote a datalogger for our dashboard, which had a LOT of bugs but worked well enough for us, and spit out space-delimited text files which we could read in Excel. We collected data on the practice robot. The highest speed reached in a sprint-distance test was 13.46fps, and it took 2.40seconds and over 30 feet to reach that speed. We changed the high gear (which only took ~1.5hrs to complete), and collected more data post-change. We were very happy with the results. In the same distance sprint, we reached our peak speed of ~10fps in 1.25seconds. The following graphs show our long-distance and short-distance acceleration test runs, in velocity (fps) vs time (seconds):

Long Distance Velocity



Short Distance Velocity



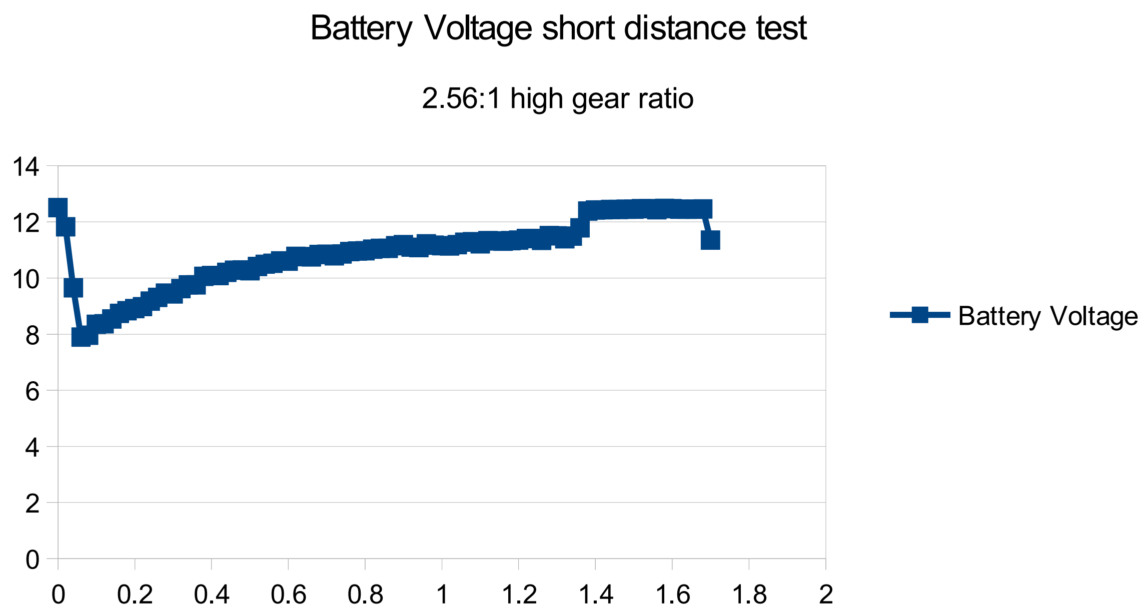
As you can see, the long distance acceleration is better with the new gear ratio, even though we never travel the full distance of the long-distance test. In the short distance run, the new slower gear ratio is better, and both ratios reach the same peak speed. However, neither curve matched our theoretical calculated numbers, and our data (while showing a great improvement) wasn't near our calculated acceleration. We weren't properly simulating everything involved.

Part 3: Simulating Battery Voltage

I suspected that the lurking variable is the battery voltage. I implemented a battery voltage simulation in my copy of JVN's Mechanical Design Calculator to simulate the battery voltage drop based on total drivetrain current and estimated battery internal resistance. I didn't know exactly what resistance to use, so I used a value of 0.03 ohms. The spreadsheet I used is attached to this paper on Chiefdelphi.com

The battery voltage drop is calculated (independently for low and high gear) based on the drivetrain current draw of the previous iteration. Since the motor torque for this iteration will be dependent on battery voltage, there is a lot of noise in both the battery voltage and output torque data, so I filtered the battery voltage change to smooth the resulting voltage. The battery voltage simulation correlated to the actual log data for our test.

The battery voltage data collected confirms that the battery voltage drops significantly.



This graph shows the battery voltage with a freshly charged battery, during the same short-distance acceleration run used above. As you can see, if we choose to use 12v as our battery voltage (even though a fully charged battery may be over 13v), the battery is almost never at that level. Whenever under drivetrain load, it peaks at around 11.5v. The simulation using battery voltage settles at around the same place.

Part 4: Process of choosing a gear ratio

There are many opinions scattered around Chief Delphi on how to choose the best gear ratio. There really are many ways to do this. The process I now use for high gear in two-speed drivetrains is simple:
-Don't care about top speed at all
-Design around a sprint-distance, the exact distance is determined by strategy
-Validate design decisions with time-to-speed, time-to-current, and time-to-voltage

Each criteria is set based on design objectives. I don't care about top speed because the purpose of a drivetrain (in high gear) is to get you from point A to point B as fast as possible. When designing, we set a design distance of our estimate average distance between points A and B, based on our interpretation of gameplay. We call this the sprint distance. Through simulation, we estimate the time from point A to B from a standstill, as this simulation includes almost everything we can quantify in a drivetrain. Motors, battery, and physics (acceleration, mechanical speed loss) are all modeled enough to get us a reasonable number for comparison.

The validation criteria are set by design objectives as well. The time to speed is used to validate our acceleration targets. Even though we design for a sprint distance, we also want to make sure we can get to a shorter distance in a reasonable time. That's where acceleration comes in.

Time to current is used to verify that my design won't trip breakers. The individual motor breaker current and main breaker current are both included in this. I choose a reasonable current threshold for simulation, such as 40a/motor, and look at the times. This is mostly subjective, I do not compare this time to any breaker data, although it would be good to have a rough idea of the breaker capabilities.

The time-to-voltage is an indication of how hungry a robot will be for batteries. A voltage drop in the battery is based on current flowing out of the battery. This number is also an indication of poor acceleration. Again, this is subjective.

The sprint distance target is highly game and field dependent. I usually use a number between 10' and 20', for FRC, depending on the game. In VRC Gateway, I used 3', which worked well. This distance should be estimated based on the distance to perform common actions. In Rebound Rumble, we estimated that 16'-20' would be a good number to use because we thought half-field runs would be common. In reality, a number around 12' was more appropriate, since many driving actions resulted in short segments between balls and the key or fender.