Robot speed analysis

FIRST FRC #1018

2018 build season

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This report was prepared prior to publication, not during development.

The purpose for this work was to choose wheel size, gear ratios, and motor selections for the robot drive base. Our testing results led us to also select current limits and understanding the implications of the current limits on robot speed performance.

The starting point for this work was a simulation that was published prior to build season.

Reference: https://www.chiefdelphi.com/forums/showthread.php?t=160902

Initially, we wanted to explore gear ratios, including shifting solutions, as well as motor selections. The robot definition consists primarily of the robot weight. The analysis assumes four wheels are used for mobility and that all four wheels have equal weight with equal traction.

The simulation approach is essentially to define the mechanical robot system as seen at the motor shaft, simulate the acceleration of the motor, and reflect the motor shaft characteristics out to the robot system. The simulation assumes that all motors are acting simultaneously; drawing the same currents, producing the same torques, and spinning at the same speeds. In this way, we should be able to look at any number of gearboxes and any number of motors per gearbox. One of the considerations we wanted to include is shifting gearbox solutions.

We defined three metrics to consider in evaluating the simulation results:

1) terminal (half field) speed – we determined this at a range of 30 feet,
2) time to a specific speed – we chose 10 feet per second, and
3) time to a specific distance – we chose a distance of 2.5 feet

These were used as criteria to compare simulation results.

When examining the 'UserInterface' tab, there are two cell color codes that are used for data entry.

Cells that are shaded in light blue are direct number entries; for example a starting battery Voltage might be 13.25 Volts, where the present value is 12.5 Volts.

Cells that are shaded in light tan are pull-down menu selections. To change these cells, select the cell and then select a data item from the pull-down menu.

Cells that are not shaded should not be changed directly! It is very likely that the value in the cell is a result from a computation; changing these values will probably not result in a change to the simulation results!

Using the simulation for design

At this point, we were able to perform a series of simulations to identify our mobility solution for this year's robot; we chose 6 inch wheels, 8.5:1 gearboxes – one per side, and 3 CIMs per gearbox – a total of 6 CIMs. With 6 CIMs for the drivebase, we included the ability to limit motor current.

On the UserInterface tab, below the performance graphs, you can see the numerical results we observed as we traded various parameter selections, Reference rows 60 through 90.

Early on, we chose a limit of 20 Amps per motor; this was a safe level that avoided any brown-out conditions on our batteries.

Late in the build season we ran into a weight challenge – this lead us to change the CIM motors to miniCIMs, which was reflected as an update to the data table. Prior to championships we revisited the motor current limits on the drive motors.

Testing the simulation

One of the dangers with any purely analytical simulation approach is that the results may not hold up when the hardware solution is built. To mitigate this risk, we performed hardware testing.

As a separate testbed, we had an AndyMark Nano Tube drivebase, reference:

http://www.andymark.com/product-p/am-0764.htm

By this time, we had decided to use a combination of traction and omni wheels for the robot. We replaced the Mecanum wheels of the drivebase kit with traction wheels - specifically am-0940a HiGrip wheels. We then ran this drivebase through testing to characterize the robot speed and acceleration. Upon testing, the indicated wheel velocities exceed the simulated wheel velocities – we ran the testbed directly into a wheel-slip condition.

This resulted in a series of computations being added to the simulation. In particular a slip/grip computation was embedded into the numerical simulation. The slip condition is based upon the wheel coefficient of friction and the robot weight – the resulting torque limit is reflected to the single motor shaft and is used in the simulation. We guessed at the dynamic coefficient of friction, and used that as the basis for a grip condition. If the motor torque is found to exceed the slip torque, the motor (really the wheel) is slipping; if the motor torque is less than the grip torque, the motor is gripping.

The testbed robot was:

51 pounds,

Used 4 motors,

Each motor was a CIM,

Used 10.5:1 (e.g. 'ToughBoxNano1') gearboxes – for both low and high speed gearboxes i.e. single speed,

The battery was at 12.5 Volts

For this test, we did not use a current limit – set the current limit parameter to 100 Amps

Once these changes are incorporated in the 'UserInterface' tab, focus on the 'Robot Velocity vs Time' plot.

The green and red traces are the measured data from the robot controller – converted from rpm to feet per second. An immediately useful result is that the simulated robot speed, the dark blue trace, matches the measured robot speed in steady-state – for example between 1 and 1.5 seconds.

The purple trace indicates a slip condition is detected when 1, and a grip condition when 0. When the wheels are slipping, the wheel and robot speeds are decoupled; when the wheels transition from slip to grip, the motor and wheel speeds are coupled to the robot speed.

While the wheels are slipping, the wheel speed exceeds the robot speed; this is depicted by the light blue curve riding on top of the dark blue curve. An interesting observation is that the measured data curves seem to form an envelope to the wheel speed data while the wheels were slipping.

Championship preparation

Prior to attending championships – Detroit – we re-visited our drive motor current limits. We ran our district events with 20 Amp current limits on all motors; how could we improve our acceleration performance?

Note that to see this, the competition robot dataset needs to be restored:

150 pounds,

Used 6 motors,

Each motor was a miniCIM,

Used 10.5:1 (e.g. 'ToughBoxNano2') gearboxes – for both low and high speed gearboxes i.e. single speed,

Initially, the current limit should be set to 20 Amps.

We investigated the impact of the current limits upon the robot performance – reference rows 100 through 130 on the 'UserInterface' tab. We found that an increase of the current limit from 20 Amps to 28 Amps per motor resulted in a 20 percent improvement in the speed at 2.5 feet metric and a ~ 30 percent reduction in the time to 10 feet per second metric.