DRIVE SYSTEM TEST OF 3 REDUCTION RATIOS

CYBER BLUE – FRC 234
FALL SPECIAL PROJECT
Test Report
29 December 2013

INTRODUCTION

In the fall of 2013, Cyber Blue 234 completed a project to determine and compare the acceleration rates and top speed of three gearbox ratios. The project was based around "Design of Experiments" methodology where there was a detailed plan and structure put in place to support the testing and isolate the key variables to improve the accuracy and conclusions of the testing. For the testing, we used gearbox ratios of 5.3:1, 6.0:1 and 7.0:1, single speed gearboxes.

OBJECTIVES OF TEST

The objective of the testing was to determine acceleration rates and top speeds of three gearbox reduction ratios. There were two high level goals: 1) Gain a better understanding of acceleration and top speeds to assist in gearbox and drive designs in future games; 2) Gain an understanding of how to conduct testing to isolate specific variables to provide a higher level of confidence in the results.

Test Methodology

The high-level test process goals were:

1. Build a robot drive chassis and control system that could be adapted for each test.
2. Minimize the changes to the robot drive chassis for each variation of the test.
3. Follow a prescribed test sequence to minimize the test process impact on the results.

To accomplish this, the following steps were taken:

1. A specialized 2 WD robot chassis was built so that the gearboxes could be easily changed with minimal other changes to the chassis / drive system.
2. A weight plate was made to get the test chassis very close to 120 pounds.
    a. Actual test weights were 122.2 to 122.6 pounds.

3. The motors were marked for location so they could be installed in the same location for each series of tests.

4. An autonomous program was written to run each test case to assure each was run in an identical process.

5. A "test track" was identified so each run was in the same location.

6. The same battery was used for each test, after a full charge.

    a. Actual battery voltage at the start of the tests was 12.7 to 12.9 Volts.

Managed Variables

The following parameters were managed with each test.

This list is variables that were held constant.

Variables - Held Constant	
Chassis System	Software
Wheels	Test Track / Test Surface
Belt Drive Sprockets	Motors
Belt Drive Belts	Motor Locations
Battery and Charge Level	Weight
Weight Distribution	

This list is variables that changed with each test.

Variables	
Gearboxes and Ratio	Battery Voltage
Spacers for Gearbox Height	Operator
Date / Time / Temp	

Test Cases

1. 7:1 Reduction VEXPRO Gearbox PN 217-2752, 37 – 42 Tooth Belt Sprocket Step Up, 4” AM Performance Wheels, Blue Nitrile Tread, 4 CIM Drive, Single 12V *FIRST* Battery.
2. 6:1 Reduction VEXPRO Gearbox PN 217-2748, 37 – 42 Tooth Belt Sprocket Step Up, 4” AM Performance Wheels, Blue Nitrile Tread, 4 CIM Drive, Single 12V *FIRST* Battery
3. 5.3:1 Reduction VEXPRO Gearbox PM 217-2745, 37 – 42 Tooth Belt Sprocket Step Up, 4” AM Performance Wheels, Blue Nitrile Tread, 4 CIM Drive, Single 12V *FIRST* Battery

TEST CONFIGURATION 1:

The team conducted the first series of testing on one gearbox pair and then reduced the data for review. Visual observations of the test itself, plus the data, showed a significant spin / slip of the driven wheels. We believed this was due partly to the weight distribution on the robot, with more of the weight plate being carried by the front wheels, which were not driven. Due to the observations, only one set of test data was taken with this configuration.

TEST CONFIGURATION 2:

To minimize / eliminate the spin / slip of the driven wheels, a modification to the mounting of the weight plate was made to place more weight over the rear (driven) wheels. This change reduced the slip, but there was still slip present in the data. All three gearboxes were tested and data captured with this configuration.

TEST CONFIGURATION 3:

Since there was still some slip observed with Configuration 2, an additional modification was made to convert the robot to 4 Wheel Drive. This was an easy modification as the sprocket on the gearboxes were wide enough for two belts and the front wheels used on the robot already had sprockets attached.

TEST CONDUCT AND DATA RECORDED

The data was taken by running an autonomous program to go quickly from 0 to 100% power. The same code ran every test.

The cRIO recorded a time stamp and encoder count (left and right) for the test run. All of the reported data is for the left encoder count for consistency.

Before beginning the testing, the encoder count was set to zero and the robot was pushed for a measured 50-foot distance. This gave a very accurate encoder count for the full 50-foot course and also provided an accurate measure of counts per foot for the data analysis. This encoder count was 11900, which calculates to 238 counts per foot.

Each test was run 3 times and the data set captured and recorded in case there was an error in a data set. All of the reported data is from the first run for consistency.

Data was corrected for only one “error”. Some cycles were not recorded at exactly 20 mS, so the recorded values were corrected by a factor of (actual time / 20 mS). This smoothed the interim data values for plotting but did not change the total time to distance.

Data was then analyzed to find the time to 5, 10, 25, 40 and 50 feet. The time to 50 feet was used to determine an average speed for the ratio. The block time from 40 feet to 50 feet (time to travel 10 feet) was used to determine the peak speed. The Calculated Peak speed was determined by using the standard of 5310 RPM for the CIM motor peak output, the ratios for 39 and 42 tooth sprockets, and 4” OD wheels. A calculated percentage was calculated by comparing the Peak Speed observed to the Calculated Peak.

RESULTS

There are several results and conclusions from the data. The results below are from the 2 Wheel Drive version with the all three gear reductions and from the 4 Wheel Drive version from the 5.3:1 and 7:1 only.

ACCELERATIONS AND TOP SPEED DATA

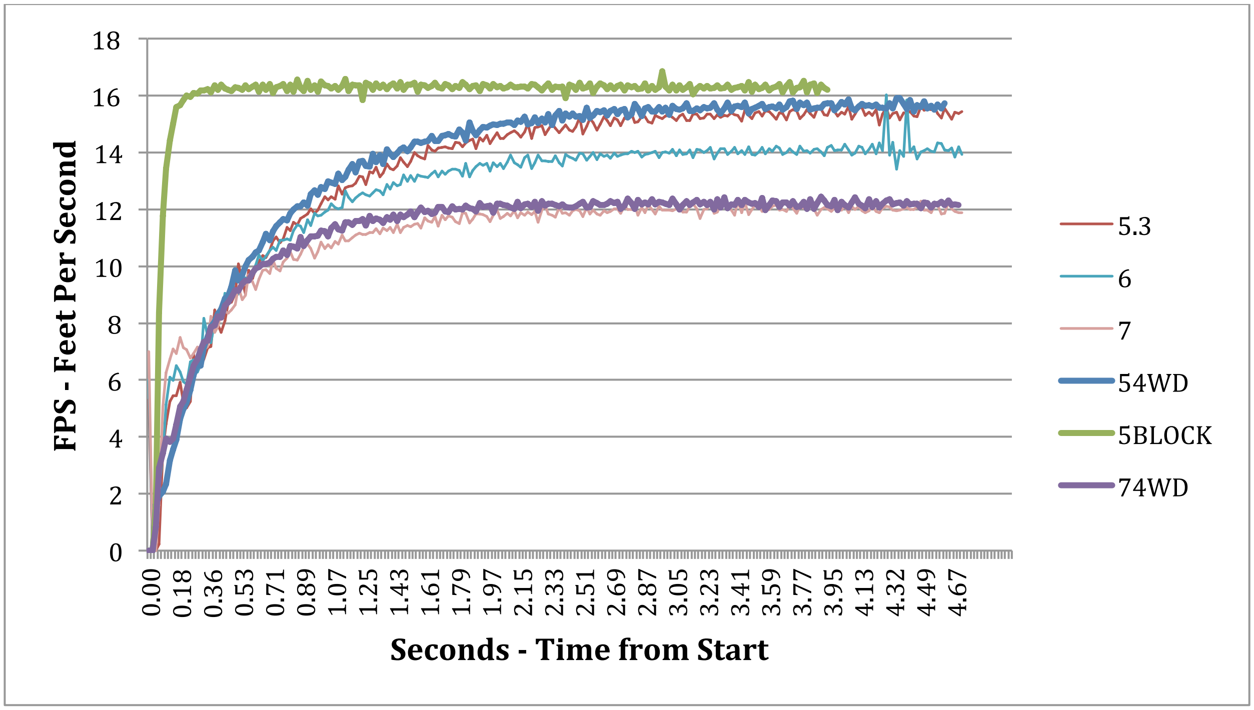
The data table below shows data for 6 tests. Distance points are total time (seconds) to the distance.

ACCELRATION AND TOP SPEED DATA							
	7 to 1	6 to 1	5.3 to 1	5.3 FREE	5.3	7 to 1	
	2WD	2WD	2WD	2WD	4WD	4WD	
5 Feet	0.66	0.66	0.67	0.36	0.70	0.70	(seconds)
10 Feet	1.14	1.10	1.09	0.68	1.11	1.17	(seconds)
25 Feet	2.42	2.24	2.17	1.60	2.16	2.42	(seconds)
40 Feet	3.68	3.32	3.17	2.52	3.13	3.65	(seconds)
50 Feet	4.50	4.02	3.81	3.12	3.78	4.47	(seconds)
Avg Speed (FPS)	11.11	12.43	13.11	16.03	13.30	11.21	FPS
Peak Speed (FPS)	12.02	14.07	15.19	16.31	15.59	12.20	FPS
Calculated Peak (FPS)	12.29	14.34	16.23	16.23	16.23	12.29	FPS
Calculated Percentage	0.98	0.98	0.94	1.005	0.96	0.99	PCT
Calculations - Below							
Reduction CIM to Shaft	7.00	6.00	5.30	5.30	5.30	7.00	5310 rpm
Shaft RPM	759	885	1002	1002	1002	759	39 tooth
Wheel RPM	704	822	930	930	930	704	42 tooth
Calculated Peak FPS	12.29	14.34	16.23	16.23	16.23	12.29	4' dia

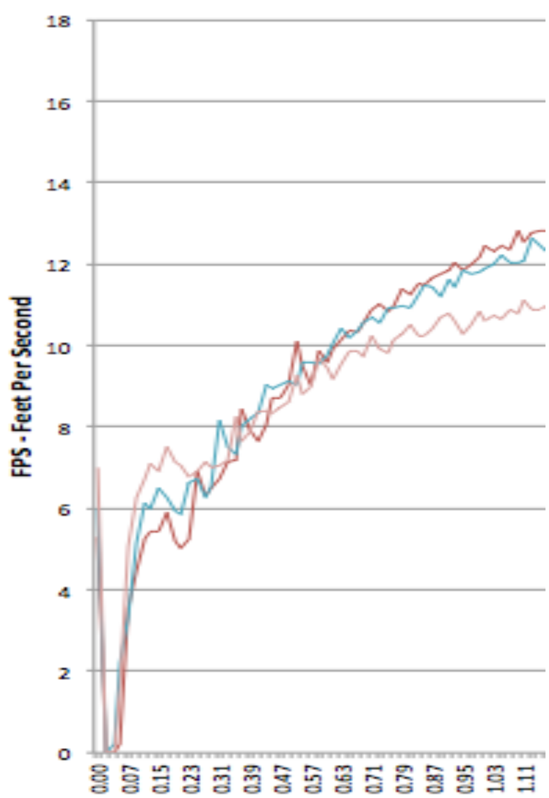
The two plots below show:

1. All 6 sets of data plotted in FPS vs. Time.

2. Spotlight of just the 2WD configurations showing the wheel slip and recovery.



All 6 Data Sets – FPS v Time



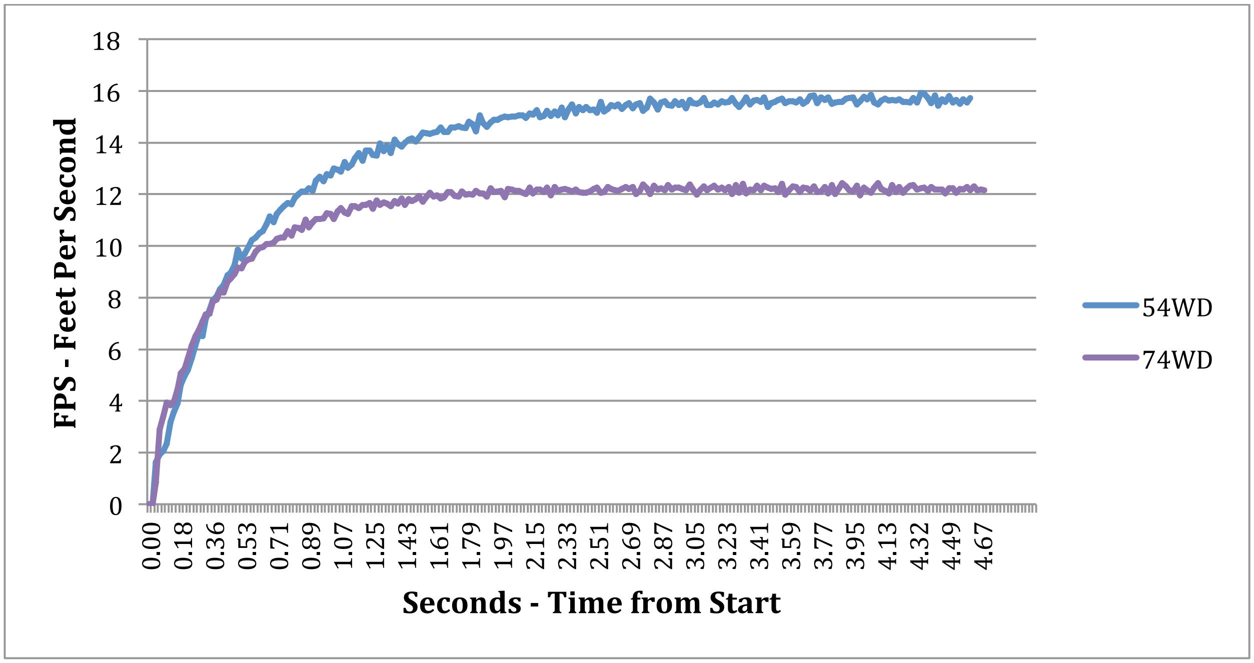
Spotlight of 2WD Configurations showing "slip"

ANALYSIS

This first plot shows all data sets. The second "spotlight" plot shows that the 5.3, 6 and 7:1 gearboxes, in 2WD configuration increase rapidly in speed, then do a step down and recovery. This is believed to be from the wheels slipping as the power is applied, and then recovering and moving the robot after this slip period. Due to this slip, the 4WD version of the robot was build and tested.

4WD TESTING

The plot below shows only the 5.3:1 and 7:1 data from the 4 WD configuration.

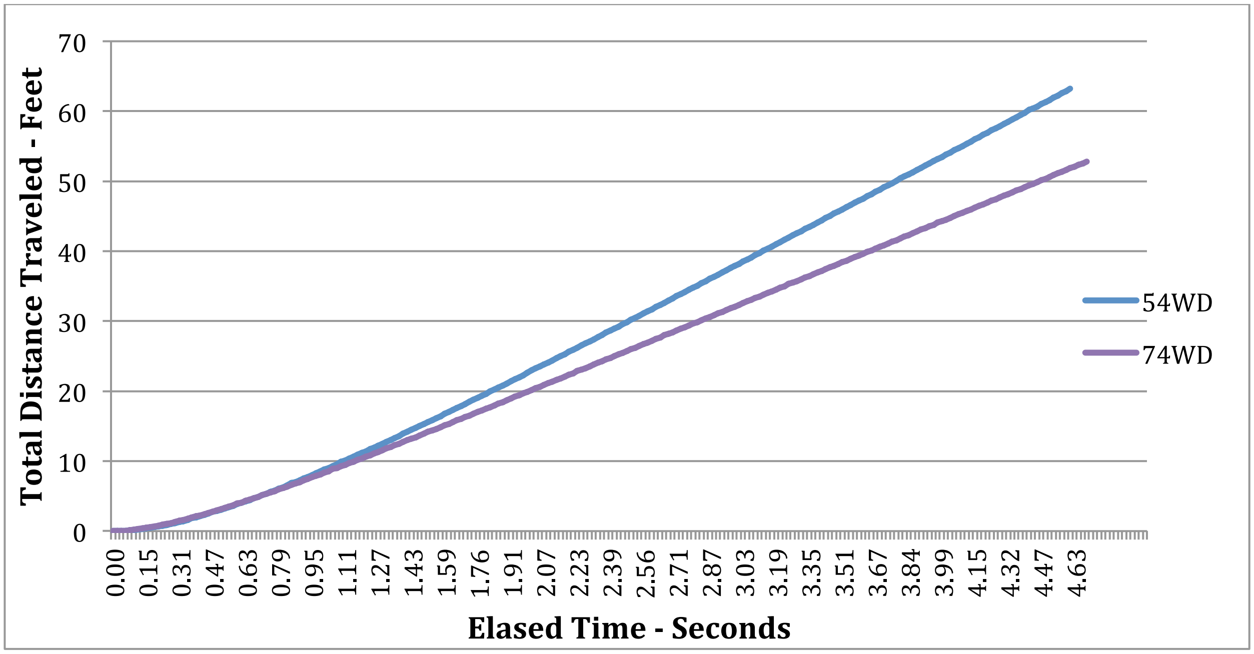


4WD Test Data – FPS v. Time

This data shows that both drives increase in speed rapidly. At approximately 10 feet and 1.1 seconds, the two curves begin to separate. The 7.0:1 reaches peak speed at approximately 1.5 seconds and 13.9 feet. The 5.3:1 reaches peak speed at approximately 2.7 seconds and 32 feet.

SPEED / DISTANCE

The plot below shows distance traveled v. time for the 5.3:1 and 7.0:1 ratios. The table below the plot identifies the specific data points of 10, 20, 30, 40 and 50 feet.



DISTANCE (feet)	7.0:1 - 4WD (time - sec)	5.3:1 - 4WD (time - sec)	Difference (sec)
10	1.17	1.11	0.06
20	2.01	1.82	0.19
30	2.83	2.49	0.34
40	3.65	3.13	0.52
50	4.47	3.78	0.69

ANALYSIS

As shown with the other data plots, the two ratios are very similar in acceleration up to 10 feet and 1.1 seconds. At that point, the acceleration rate of the 7.0:1 ratio slows and the speed begins to level. The 5.3:1 ratio continues to accelerate until reaching top speed and then stabilizing.

CONCLUSIONS / DISUSSION / DESIGN DECISIONS

This testing was conducted to gather data and learn. The information will be useful in future robot design decisions when determining the most important parameters of the drive design. There are no 'absolute best' decisions that can be made from the data, as the decisions on drive system depend on several factors for the game and design goals for each team.

There was less distinction between the acceleration rates of the 3 ratios than we expected. This could be due to the small difference in ratios tested.

By definition, the 7.0:1 ratio will provide more maximum torque (climbing power, pushing power) than the 5.3:1 ratio. If the travel distances are expected to be less than 10 feet, then the 7.0:1 ratio might be a 'better' answer because the time to travel 10 feet is similar.

If the travel distance is in the 10 – 25 foot range, then other factors need to be considered. The 5.3:1 is quicker to these distances, but if there is also a need for high torque (climbing, pushing), then there may be a trade-off evaluation needed. For uninterrupted travel distances greater than 25 – 30 feet, the 5.3:1 ratio provides a significant advantage in speed.

A team needs to consider the uninterrupted travel distance in their decision. If the field is long, but has several starts and stops, or if defense is expected that can cause shorter distances, then the decision should be made around the uninterrupted travel distances and not the total field size.

There are also shifting gearboxes that provide the option of having both a low ratio for speed and a higher ratio for torque. Addition of a shifting gearbox adds this capability, but also increases drive system weight and complexity.

DRIVE SYSTEM EFFICIENCY

Based on the data taken, drive system efficiencies of .94 to .99 were calculated. This is likely higher than the actual efficiency of the drives. The calculation was made using the published 5310 rpm output speed of the CIM motors and this speed is likely low for this motor set.
One set of data was taken with the robot on blocks, and if we assume this was a 100% efficient drive (no load on the wheels), then the back-calculated motor speed is approximately 5335. The true speed is likely higher than this because there are losses through the gearbox and belts and wheel axles. A follow on test will be to determine the actual speed of the motors used in the test.

DESIGN OF EXPERIMENTS

Design of Experiments is a methodology for testing that identifies specific variables in a test that are required to change to completed the required analysis, and what variables in the test could impact the results but could be fixed or closely controlled.

For this test, the key variable was the gear ratios in the gearboxes. Due to the design, the gears could not be changed individually so the complete gearboxes were changed. The gearboxes were the key variable we needed to isolate so as much as possible, everything else in the system was maintained from test to test.

For example, the same chassis, wheels, belts and sprockets were used. An autonomous code was written to avoid differences in the driver. We used the same battery for each test, taking it to a complete charge before beginning. Due to slight differences in size and weight of the different gearboxes, we added or removed small weights to keep the weight consistent.

CONFIGURATION

The table below identifies the details of the test robot.

TEST CONFIGURATION			
Components	**Qty**	**Definition**	**PN**
Chassis	4	AM Kit Chassis	
Gearbox (per test)	2	VEXPRO 7:1	217-2752
Gearbox (per test)	2	VEXPRO 6:1	217-2748
Gearbox (per test)	2	VEXPRO 5.3:1	217-2745
Wheel	4	AM Performance	AM0394
Tread	4	McMaster - Blue	599K851
Sprocket - Gearbox	2	Gates HTD - 39 tooth	AM2361
Sprocket - Wheel	4	42 Tooth	AM2234
Belts - Front	2	McMaster	890-5M-15
Belts - Rear	2	McMaster	740-5M-15
Encoder	2	US Digital - 250 Ct	
Motors	4	CIM	AM-0255
Speed Controller	4	Victor	888

PHOTOS

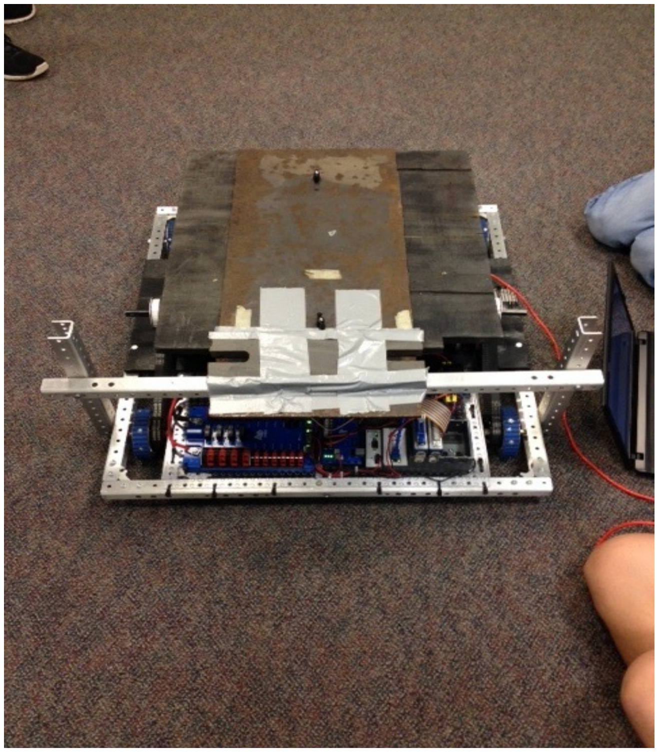


PHOTO 1 - Test Robot Ready for a Test Run.

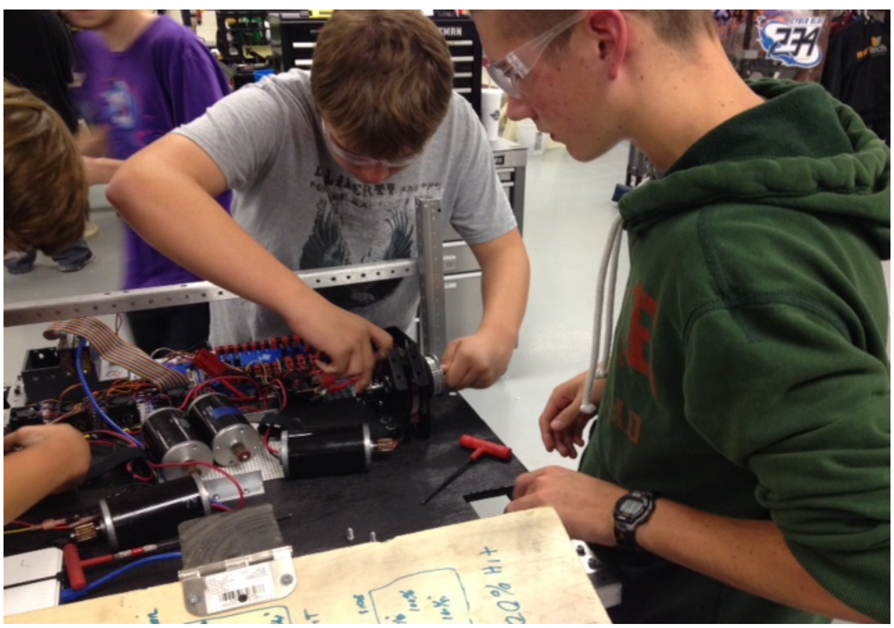


PHOTO 2 – Team Members change out the gearboxes between tests.

PHOTO 3 – Data being downloaded to a laptop after a test run.

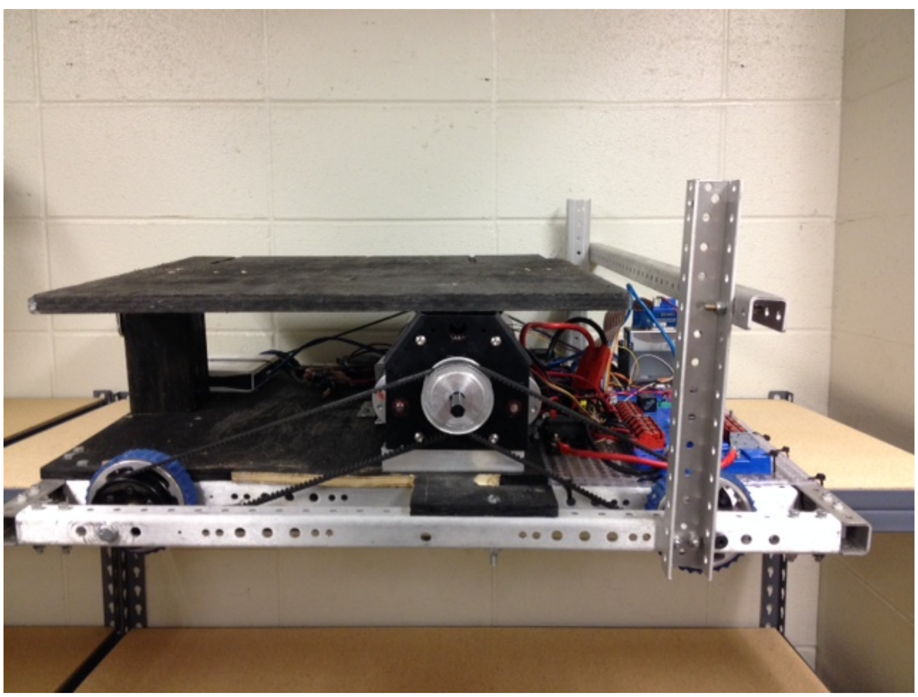


PHOTO 4 – Test Chassis after testing completed (weight plate removed).