Adding a speed sensor within a VersaPlanetary gearbox

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FIRST Robotics Competition Team 2363

Figure 1: A BaneBots RS-550 motor is attached to the input stage of a VexPro Versaplanetary gearbox; the input stage is modified to include a speed sensor.

NEED

Since VexPro's introduction of the VersaPlanetary (VP) gearbox to the competition robotics market in 2012, FRC teams have found them extremely useful for powering robot mechanisms. Triple Helix is no exception; at one point in the 2015 season we were using 5 of them on our robot, and there could have even been as many as 6 had the build season gone somewhat differently. Much of this gearbox's usefulness comes from their extreme adaptability to many different motor and gearing configurations.

To gain closed-loop control of motor-driven mechanisms, FRC teams often use sensors to measure rotation at some point in the mechanism powertrain. In this document, we describe a design which embeds a geartooth-type speed sensor within the input stage of the VP gearbox.

An encoder "stage" for the VP is not a new idea—many have already proposed this concept and requested it as a future VexPro product. This document describes a robust and inexpensive (perhaps even commercially viable) implementation of this idea. The purchase price of this design is significantly less than the cost of the typical high-quality optical encoders used in FRC.

The document is presented as a step-by-step DIY guide to perform a set of very specific modifications to several Commercial Off-the-Shelf (COTS) parts. These modifications can be done by a moderately capable FRC team, in a reasonable amount of time, and without use of external machining resources, which makes it possible for most high-performing teams to use this technology during the FRC competition season.

View Single Post Thread: Fantasy Product's-what u wish was made

02-06-2015, 10:36 #13

mman1506
Team Captain/Mechanical
AKA: Marcus Quintilian
FRC #0865 (Warp 7)
Team Role: Engineer

Join Date: Mar 2012
Rookie Year: 2012
Location: Toronto
Posts: 537

An incremental encoder "stage" for a VersaPlanetary that is linked directly to the output shaft.

2014 Waterloo Regional Winner (254 & 2056)
2014 Curie Semifinalist (118, 359 & 4334)
2014 Fall Fiesta Finalist (2056, 4476)
6 X Gracious Professionalism Award Winner

Figure 2: In a Chief Delphi thread in June 2015, Marcus Quintilian makes a request for a speed sensor stage for the VP.

DESIGN OUTLINE

The square aluminum housing that forms the “input stage” of the VP is basically a spacer with a funky shape. Its job is simply to:

1. Adapt the motor body, via a motor adapter plate, to the rest of the gearbox
2. Contain a bronze shaft coupler that fixes the rotation between (a) the motor output shaft and (b) the sun gear in the next stage of reduction

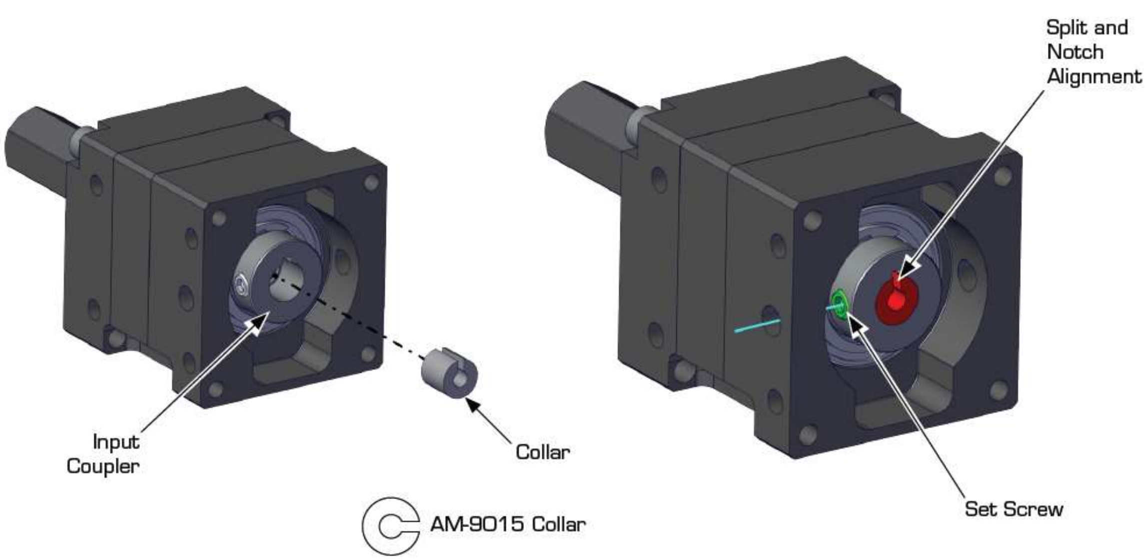

Figure 3: The VP input stage is simply a spacer. Note the bearing located behind the retaining clip; this bearing is no longer supplied with the VP input stage, leaving a space where a sensor can be installed.

In past versions of the VP gearbox, the input stage might have also served a 3rd function: to hold the bronze shaft coupler concentric with the gearbox housing. Evidence of this can be found in vestigial features of the parts—there is room between the bronze shaft coupler and the aluminum body of the input stage to fit a No. 6803 (17mm ID x 26mm OD x 5mm wide) ball bearing, and there is a groove in the bronze shaft coupler for a retaining ring that have could been used to retain this bearing. This bearing appears in the graphics in the VP user manual, but for some reason it is no longer supplied with the VP input stage and no explanation can be found which might explain its absence.

Fortuitously for us, the lack of bearing leaves a convenient cavity within the VP input stage where a sensor can be installed. The sensor is primarily made up of two parts:

1. Two independent "gear tooth" type Hall effect sensors which are packaged into a single IC. The IC is embedded within the aluminum body of the VP input stage. Each of these gear tooth sensors contains an internal magnet which is able to move very slightly when ferrous materials pass by; this motion of the magnetic field induces a current in the Hall effect sensor. No external magnet is required to produce the Hall effect. The two gear tooth sensors are offset from one another by a small amount in the direction of rotation of the steel gear. Like a quadrature optical encoder, both speed and direction can be determined by comparing the square waves which are output from each sensor.
2. A steel gear with teeth that pass very near the branded face of the IC; the following modification instructions will produce an assembly where the gear teeth approach to within 1 mm (.039 in) of the gear tooth sensor. The gear is fixed to the bronze shaft coupling.

Figure 4: A collection of parts used in the design. From left to right: a steel gear, modified from its COTS state, is secured to the OD of the bronze shaft coupler; an as-yet unmodified VP Base kit from VexPro, still in its packaging; an Allegro ATS605LSG gear tooth sensor, partially unpacked.

DIY PROCEDURE

The following steps describe how to modify a VP gearbox to include an embedded speed sensor. FRC teams should be aware that these modifications necessarily alter parts from their Commercial Off-The-Shelf (COTS) state into a fabricated state per the Fabrication Schedule section of the FRC Competition

Manual, so care must be taken to ensure all applicable rules are followed if the modified assembly is to be entered into competition.

Modifications to the VersaPlanetary input stage

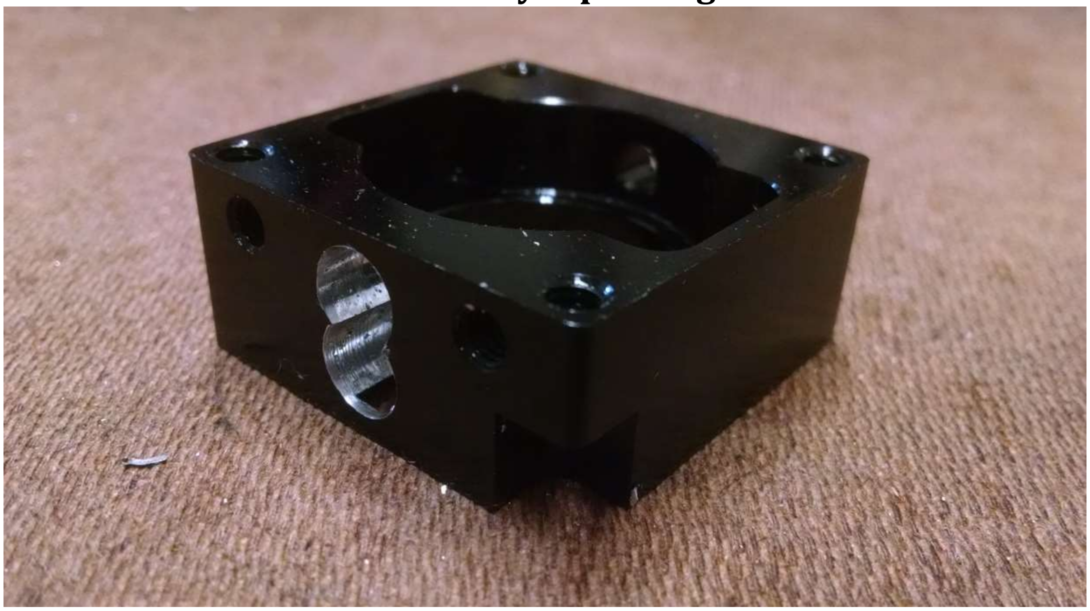

Figure 5: Modifications to the aluminum housing of the VP input stage.

Two holes must be drilled into one face of the aluminum housing VP input stage. If you are proficient at layout work, you can drill these holes in a drill press. The first article, pictured above, was worked in Triple Helix's manual mill for the convenience of the machine's DRO.

Table 1: Parameters of the holes placed into the aluminum housing of the VP input stage.

Hole	Diameter	Location	Depth	Reference
A	5/16 drill	Concentric with the existing access hole for the shaft coupling set screw (.217 in axial direction from motor mounting surface and centered in transverse direction)	Through to central cavity of housing	Upper hole in Figure 5, above
B	5/16 drill	.468 in axial direction from motor mounting surface and centered in transverse direction	.313	Lower hole in Figure 5, above

Because these holes intersect with each other and with other part geometry, it is generally recommended to start with a center drill, then use a small drill, and then enlarge gradually to the final hole diameter in several steps. Since Hole A is located concentric with an existing hole, you may simply enlarge gradually to the final hole diameter in one or two steps.

Figure 6: Enlarging Hole A to the final diameter in one step.

Modifications to the gear tooth sensor

Figure 7: The leads of the Allegro ATS605LSG gear tooth sensor are bent 90 degrees.

The four leads of the Allegro ATS605LSG gear tooth sensor should be bent 90 degrees at a location just after the width of the leads transitions from thick to thin. The direction of bend should be away from the branded face of the IC.

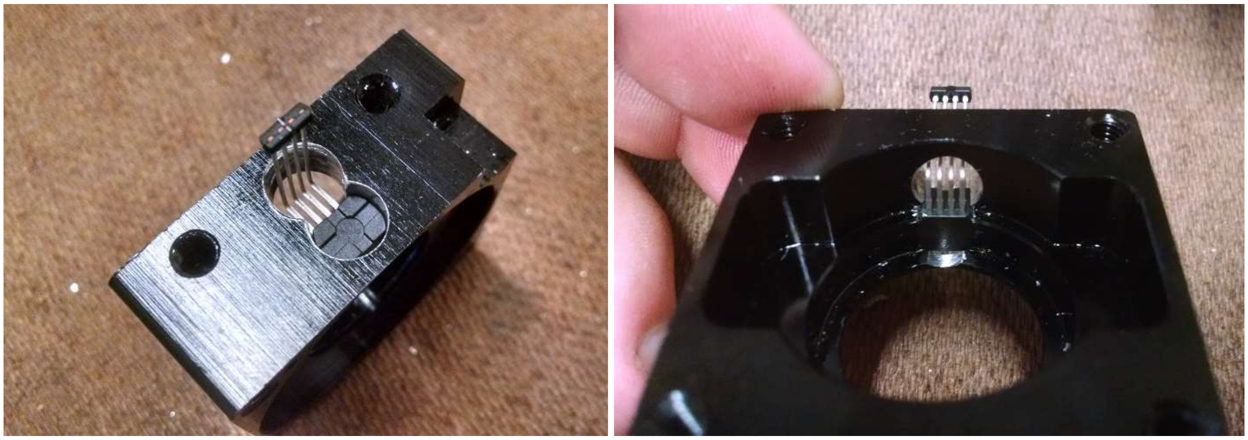

Figure 8: Test fitting the Allegro ATS605LSG gear tooth sensor into the VP input stage.

The sensor may be test fit into the aluminum housing of the VP input stage at this time. The sensor should fit snugly into Hole B and should be prevented from dropping into the central cavity by several sharp features remaining at the tapered bottom of the blind hole. There should be clearance in all directions around the sensor leads, which exit the housing through Hole A. The remaining space in Holes A and B will be later filled with potting epoxy.

Figure 9: Lead extensions are added to the Allegro ATS605LSG gear tooth sensor.

The plastic bar which holds the ends of the sensor leads may be cut away at this time. Next, the leads are extended and insulated in accordance with standard practice. The sensor is now ready to install.

Modifications to the steel gear

Figure 10: The 21 teeth, 24 pitch, 14.5° pressure angle spur gear in COTS condition.

A steel spur gear with 21 teeth, 24 pitch, and 14.5° pressure angle must be modified to fit over the bronze shaft coupling of the VP input stage. This modification involves two lathe operations, which may be performed in either order. We decided to perform the steps in the following order since (1) the number of gear teeth is divisible by 3, which allows easy chucking in a 3-jaw chuck, and (2) the final bore is larger than the hub diameter.

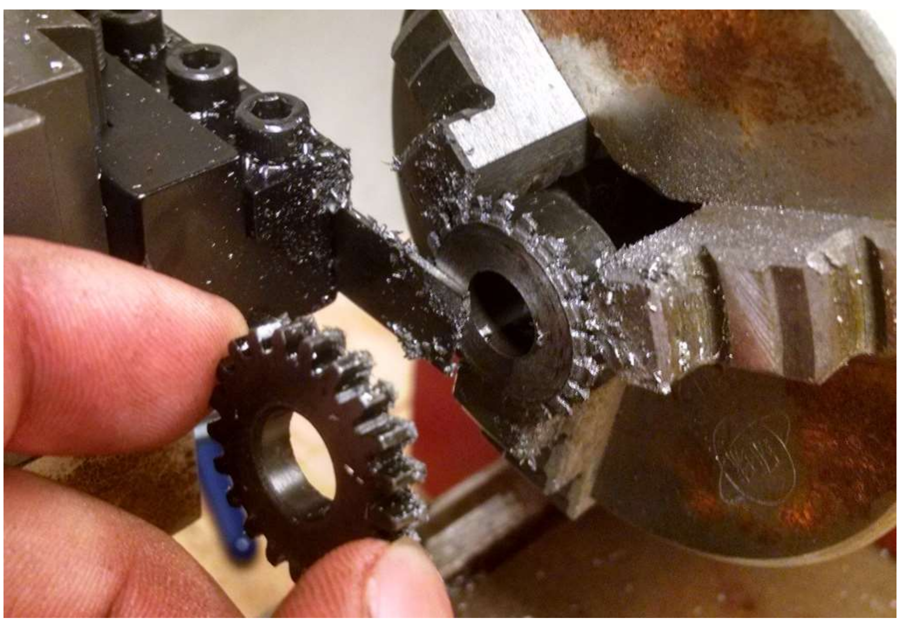

Figure 11: A 3/16" thick slice is removed from the gear.

First, a parting tool is used to remove a toothed wafer, 3/16” thick, from the gear.

Figure 12: The bore of the gear is enlarged to fit over the 17mm OD of the bronze shaft coupling.

Next, the wafer is chucked and the bore is enlarged from 3/8” so that it may fit over the 17mm (.670 in) OD of the bronze shaft coupling. A boring tool can (and probably should have been) used for this step, but it was decided to gradually enlarge the bore to the final diameter in several steps using a series of drill bits. At the final diameter, a 17mm reduced shank drill bit (commonly called a Silver & Deming bit) is used.

The gear may now be test fit onto the bronze shaft coupling of the VP input stage. The gear may be located anywhere between the flanged end of the coupling (furthest from the motor) and the central groove.

Figure 13: Shaft retaining compound is used to lock the rotation of the gear with respect to the bronze shaft coupling.

Finally, shaft retaining compound is used to cement the gear into its proper location. This assembly should be left to cure before using.

Potting the sensor into the VP input stage

To fix the Allegro ATS605LSG gear tooth sensor into the aluminum housing of the VP input stage, the following steps are followed.

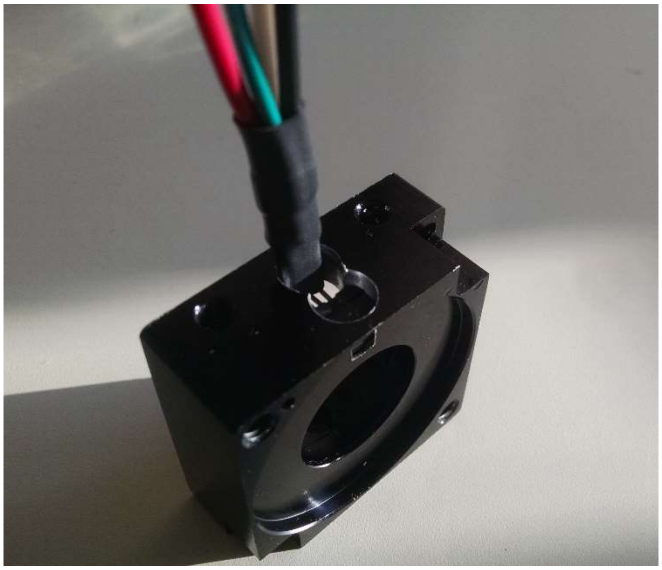

Figure 14: Sensor is dry fit into the VP input stage.

The components, which have been modified in previous steps, are assembled.

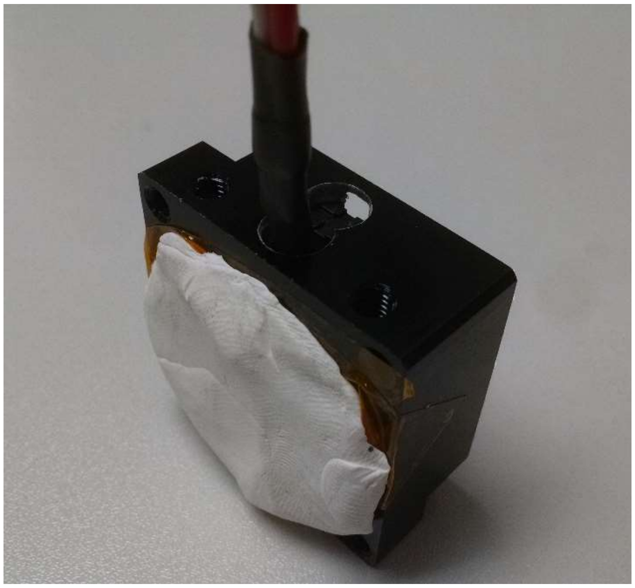

Figure 15: Openings are covered with Kapton tape, and then putty is packed into the cavity to reinforce the tape.

All but one opening into the sensor cavity are sealed to prevent the epoxy from leaking out. The openings are first covered with Kapton tape, then the tape is reinforced with putty.

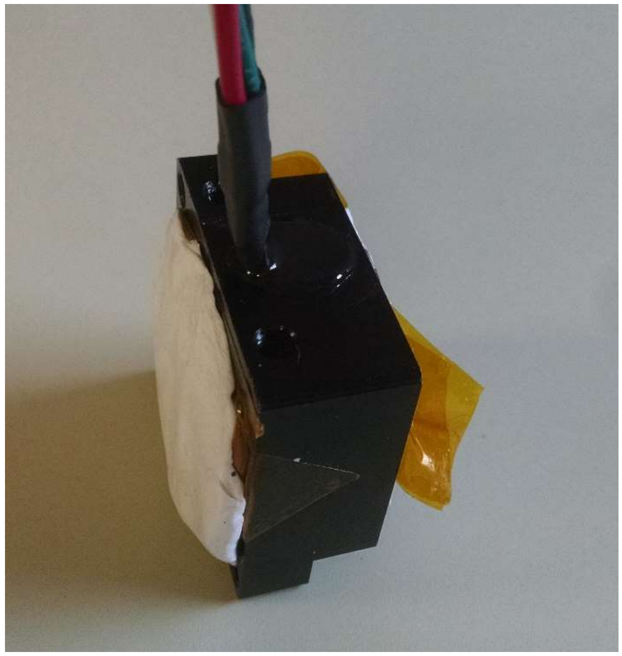

Figure 16: The sensor cavity is filled with epoxy.

Next, a two-part epoxy is mixed and poured into the sensor cavity. The epoxy is specially formulated for use as a potting material for electronics; it has a high dielectric strength and a high thermal conductivity. Because the epoxy will shrink as it cures, epoxy is added until the wet surface is convex.

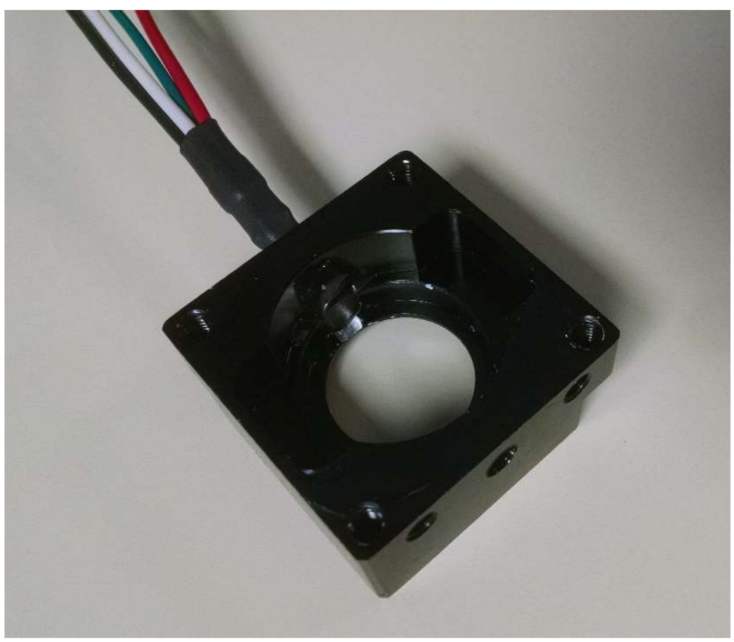

Figure 17: Sensor is potted into the VP input stage.

After the epoxy has cured, the putty and tape is removed. The gearbox is now ready for final assembly.

Final assembly

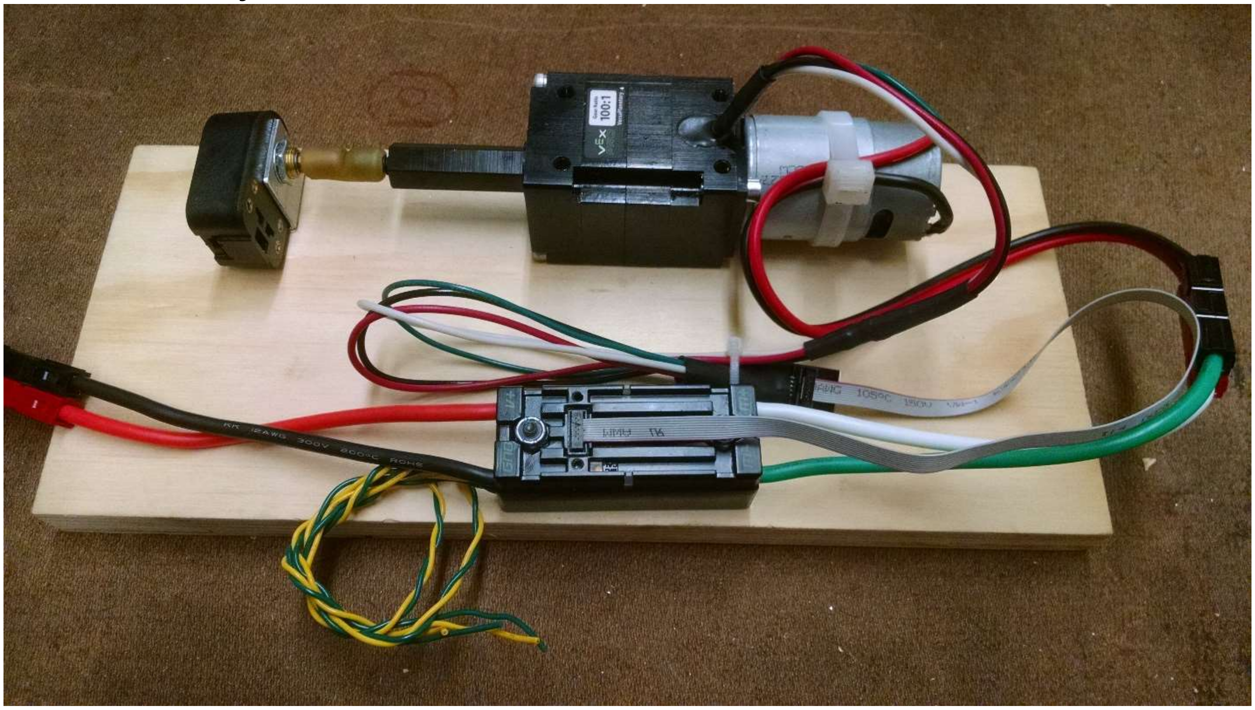

Figure 18: A test board outfitted with a 100:1 VP gearbox with internal speed sensor and RS550 motor, an external optical encoder, and a Talon SRX speed controller.

The VP gearbox can now be assembled in accordance with the VexPro instructions.

PERFORMANCE

A test board, shown above, was developed to compare the output of the internal speed sensor with an optical encoder of the type typically used in FRC. Both encoders are coupled to a VersaPlanetary 2-stage gearbox with a 100:1 total reduction and an RS550 motor. The RS550 motor is selected for the testing because it has the highest no-load RPM of the allowed motors of the 2015 FRC season. The 100:1 gearbox ratio is selected for mathematical convenience.

Table 2: Comparison of sensors used on the encoder test board.

	Optical encoder	Gear tooth sensor
Name in test code	optEncoder	vexEncoder
Sensor manufacturer and p/n	US Digital S5-360-250-NE-S-B	Allegro ATS605LSG
Cost	$93.50	$30.17 (see materials list)
Counts per revolution at sensor	360	21
Reduction between sensor and motor	100:1	1:1
Counts per revolution at motor	3.6	21

Both encoders are wired to roboRio DIO pins. The RS550 is driven by a Talon SRX which is controlled via CAN from a roboRio. All components in the control pathway were standard equipment from the 2015 FRC season.

A key snippets of code used during the testing is provided below. 'Distance per pulse' is set for each encoder such that 1 unit of distance is equivalent to 1 rotation of the RS550 motor. Thus, for the US Digital optical encoder:

$$\left[\frac{revolutions\ at\ motor}{pulse}\right]_{optEncoder} = \left(360\frac{pulses}{revolutio\quad at\ sensor}\right)^{-1}\left(100\frac{revolutions\ at\ motor}{revolution\quad at\ sensor}\right)$$

Since the gear detected by the Allegro ATS605LSG gear tooth sensor is located on a shaft coupler that necessarily rotates at the same speed as the RS550 motor output shaft, the distance per pulse for this sensor is simply equal to the number of gear teeth.

$$\left[\frac{revolutions\ at\ motor}{pulse}\right]_{vexEncoder} = \left(21\frac{pulses}{revolutions\ at\ sensor}\right)^{-1}\left(1\frac{revolutions\ at\ motor}{revolutions\ at\ sensor}\right)$$

Table 3: Test code

```
public class Robot extends IterativeRobot {
private CANTalon motor = new CANTalon(0);
private Encoder vexEncoder = new Encoder(0, 1);
private Encoder optEncoder = new Encoder(2, 3);
private PowerDistributionPanel pdp = new PowerDistributionPanel();
    /**
     * This function is run when the robot is first started up and should be used for any initialization code.
     */
    public void robotInit() {

     vexEncoder.setDistancePerPulse(-1 / 21.0);
     optEncoder.setDistancePerPulse(-1 / 3.6);

    }
```

Some results of the performance testing are shown in the below screenshot. Testing was performed using a fully-charged standard FRC battery. At time 0, the motor speed was increased to 100% speed. The motor remained at this speed for approximately 1 minute before the below screenshot was captured. 'Encoder Distance' is reported in revolutions and 'Encoder Speed' is reported in revolutions per second. The graphed value 'Difference' is simply a ratio of the two Encoder Distances.

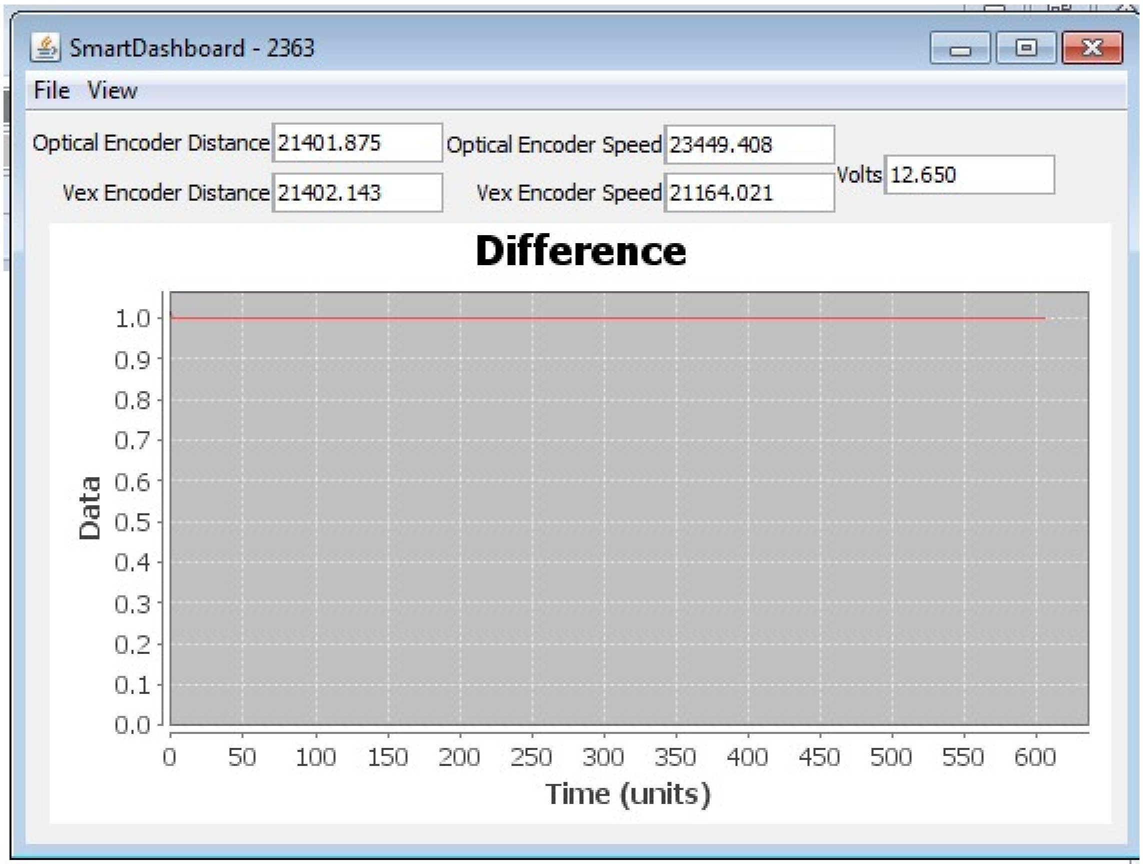

Figure 19: Results of encoder testing

As shown in the above figure, the difference between number of counts recorded by the two encoders is less than .3 revolutions in more than 20k revolutions (less than 13 parts per million). From this result it is clear that both encoders are reporting the same data without either sensors 'losing counts' due to sampling errors or other failure.

COMPLETE MATERIALS LIST

All prices are as of time of writing and do not include shipping costs.

Parts

Item	Description	Vendor and p/n	Cost
VersaPlanetary input stage	-	VexPro	Varies [1]
Sensor	Allegro ATS605LSG	Digikey 620-1560-1-ND	$8.60
Gear	21 teeth, 24 pitch, 14.5° PA	McMaster-Carr 6325K64 or similar	$21.57
Lead extensions for sensor			

[1] The Base VersaPlanetary 1:1 with 3/8” hex, 1/2" round, or CIM output shaft is available for $34.99. The Base VersaPlanetary 1:1 with 1/2” hex output shaft is available for $39.99.

Consumables

Item	Vendor and p/n
Shaft retaining compound	Loctite 609 or similar
Potting epoxy	STYCAST 2850FT or similar
Teflon tape	
Putty	Scotch Removable Mounting Putty or similar

Specialty tools

Item	Vendor and p/n	Notes
Reduced shank drill bit, 17mm	McMaster-Carr 3091A37	Commonly called a Silver & Deming drill. May use boring bar instead.