2020 Bearcat Baja – Drivetrain System

Senior Design Project submitted to the
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by

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Problem Statement

With Baja SAE modifying the rules in 2021 to where each vehicle must have 4-wheel drive capabilities, we are to design, fabricate, and assemble a 4-wheel drive drivetrain system for a Baja vehicle that meets the requirements for Baja SAE while being lightweight and cost efficient. Due to the COVID-19 pandemic, we are to complete a virtual design of the drivetrain system in hopes that next year's senior will pick up where we left off and finish the Baja car.

Background and Customer Needs

A Baja car is an off-road vehicle that can withstand all terrains. Baja SAE is an intercollegiate competition where students design, build, and race their built vehicles. The design and production of the Baja vehicle must be done by students and must follow all the up-to-date rules, provided by Baja SAE. In the competition, there are two categories of events: static events and dynamic events. The static events consist of a technical inspection, design judging, a sales presentation, and a total cost analysis. The dynamic events include an acceleration test, hill climb test, a suspension test, and finally, the endurance race. Due to the recent COVID-19 outbreak, the 2020 competitions have been cancelled.

Some major rules have been added or changed for the upcoming season. A new material for the fuel tank is required and the requirement to use an alternator has been removed. Any electronics can be powered by a battery. Starting in 2021, all Baja vehicles entering the competitions must have four-wheel drive capabilities. This simply means that the powertrain system must be capable of providing power to both front and rear wheels.

All previous year's cars have been rear-wheel drive. Because of the 2021 rule change, stating that all cars must have 4-wheel drive capabilities, we decide decided to get a jump start by building a 4-wheel drive car this year. By doing so, we are basing our design off a Polaris ATV. During the design and build, we have used Polaris, Cincinnati Gearing Systems, and 1819 Innovation Hub as resources for information and manufacturing. For our design, we wanted to make sure our driver was able to accelerate easily, while reaching a top

speed of at least 30 miles per hour, able shift between 2 and 4-wheel drive while buckled up in the driver seat, and make sure that all the components are assembled so that it easy to perform maintenance and repairs of the car.

Figure 1 – 2019 UC Baja Car

Design Specifications and Selection

According to the updated Baja SAE rules, by 2021, it is mandatory for all cars to be 4-wheel drive. The drivetrain system can either be a permeant all-wheel drive or a selectable 4-wheel drive, meaning the car can shift between 2 and 4-wheel drive. Either system is acceptable by Baja SAE, provided that each wheel is capable of being powered at the same time. Our design for the 2020 car is a selectable 4-wheel drive system.

The design for our 4-wheel drivetrain system consists of six major components. These components are the engine, the continuously variable transmission, the gearbox, differentials, driveshafts, and CV axles. The engine will be mounted over the gearbox. The CVT will be connected to both the engine and the gearbox on the side. A front and rear driveshaft will extend out of each side of the gearbox connecting to both the front and rear

differential. The CV axles extend from the differentials and rotate the wheels. Figure 2, below, a full model of the drivetrain system assembled to the frame.

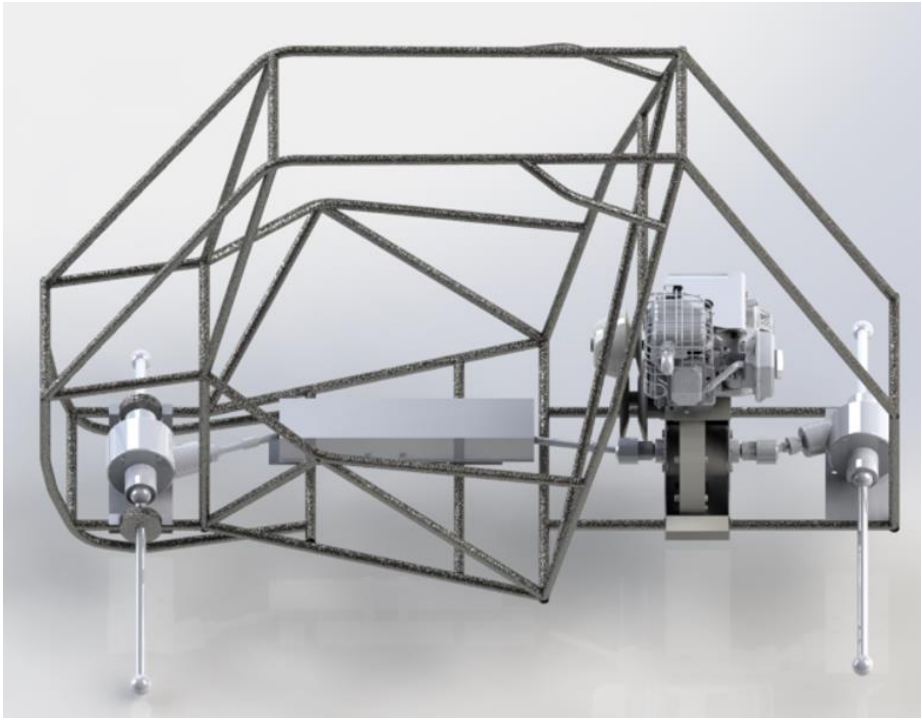

Figure 2 - Full Drivetrain Design

Table 1, below, shows the full material list and material budget for the drivetrain design system.

Part	Price	Quantity	Total
Polaris Sportsman 450 Propshaft	$ 179.35	2	$ 358.70
Polaris Sportsman 450 CV Axle	$ 74.99	4	$ 299.96
Polaris Ranger Sportsman Differential	$ 949.00	2	$ 1,898.00
6061 Aluminum 13in x 15in	$ 448.55	2	$ 897.10
Alloy Round 4140 HR Annealed - 12in	$ 105.52	1	$ 105.52
Alloy Round 4140 HR Annealed - 1in	$ 194.71	1	$ 194.71
Hot Rolled Round 1045 Steel - 12in	$ 94.21	1	$ 94.21
Hot Rolled Round 1045 Steel - 1in	$ 157.72	1	$ 157.72
Bearings - 1in	$ 13.92	2	$ 27.84
Bearings - 1in	$ 12.77	2	$ 25.54
Bearings - 1in	$ 20.24	2	$ 40.48
			$ 4,099.78

Table 1 - Material List and Budget

Engine, CVT, Fuel Tank

Baja SAE requires all schools competing to use the same engine for performance purposes. The engine of choice is the Briggs and Stratton 10 HP OHV Vanguard Model 19 engine. It is an unmodified, air cooled, four-cycle engine. The engine must remain stock in all ways. Our engine is currently sitting inside the Baja team's tool cage. Only a few things need to be done for the engine to be up and running. We need to install a throttle return spring and a kill switch required by Baja SAE. Once these steps are taken, all we need to do is add gas and oil and the engine will be properly setup. Figure 3, below, shows a depiction of our engine model.

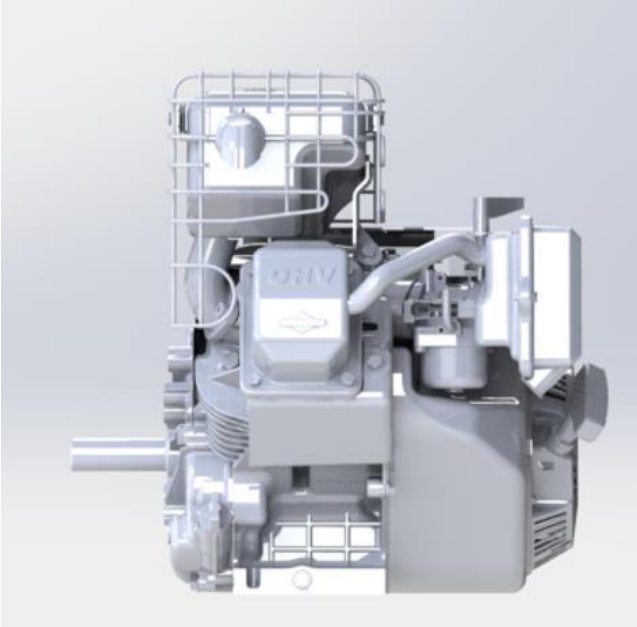

Figure 3 - Engine Model

The continuously variable transmission, or CVT, is connected to the engine and gearbox. The CVT is made up of three components: the driven pulley, the drive pulley, and the belt. The drive pulley is connected to the engine and the driven pulley is connected to the gearbox. Under the correct belt tension, the CVT will be able to seamlessly shift through a continuous range of ratios. All three CVT parts are being used for this year's car are from past cars. The parts are all in-house ready to be assembled.

The fuel tank from last year has been changed from the 1-gallon, plastic Briggs and Stratton fuel tank to the 1.5-gallon, aluminum Pyrotect fuel tank. A larger, more durable fuel tank will allow for fewer pits stop and increase the lifetime of the tank. The fuel tank will be mounted above the engine. A splash shield is also required by Baja SAE. The splash shield prevents fuel from spilling directly on the engine when refueling the vehicle. There has been a change is the way that the splash shield is mounted. The splash shield will need to be mounted lower than the structural member supporting the gas tank and must be no thicker than 0.02 inches thick.

Gearbox and Gears

Our transmission is custom built. Figure 4, below, shows the model of the gearbox design. The housing and gears were designed and mostly manufactured in-house. The custom transmission involves a two gear, single speed gearbox with a 3.75:1 gear ratio. The gear ratio was important to be around 3.75:1 due to the differentials. The differentials have their own gear reduction. By having the gearbox ratio of 3.75:1, it will counter the reduction in the differential, allowing the car to get up a top speed of 34 miles per hour. It has a compact design that will save valuable space and reduce the overall weight of the car. Because it is a single speed, it only has forward moving capabilities. There is no reverse in this car. Members of the team will have to push the car, if the desired direction is reverse.

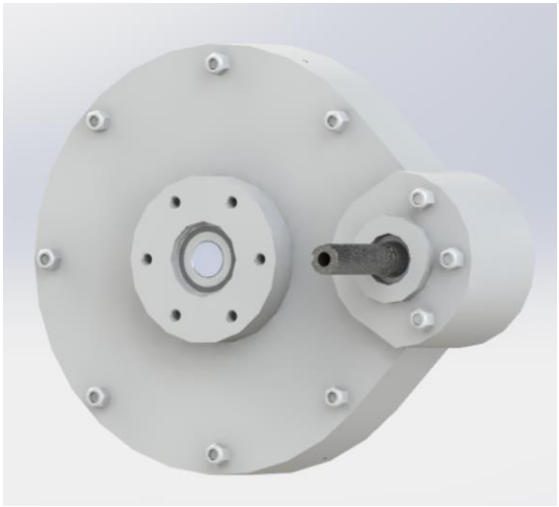

Figure 4 - Custom Gearbox Design

The housing is to be made from two blocks of raw 6061 aluminum. The material was ordered and sent to 1819 Innovation Hub, where we can machine it. 1819 Innovation Hub has CNC capabilities, which will make the process much easier. A design was made, and code was written. Machining was started, but due to the COVID-19 outbreak, machining was halted, and the housing was never finished. The housing is currently at 1819.

The gear assembly inside the housing are comprised of two gears. The pinion gear, with an integral shaft, is connected to the CVT, from which power is received. The pinion gear then transfers the power to the ring gear. The ring gear has a small differential hub, used from an older Baja transmission, bolted to it. The differential hub transfers the power to the driveshafts perpendicular to the gears. Both the pinion and ring gears were manufactured from 4140 hot-rolled annealed alloy steel. The blanks were machined in-house at the Victory Parkway labs. Once the blanks were finished, they were sent to Cincinnati Gearing Systems where the tooth profiles were cut. Both gears are currently in-house at Victory Parkway.

Driveshafts and CV Axles

Two Polaris driveshaft and four Polaris CV axles were ordered. Four CV axles from previous years are also being used for this setup. The two Polaris driveshafts account for the main front and rear driveshafts. Machining is required to acquire the correct length. The old CV joints are used to accommodate the bend in the front shaft and help aligned the rear driveshaft. The bend ensures the front driveshaft can properly connect to the front differential. A bearing block will be mounted to a member of the frame to support to length of the front driveshaft. Some machining is required to get the CV joints to the correct size to fit into the driveshafts. Two CV joints are needed for the bend on the front driveshaft and one CV joint is needed for the rear driveshaft. Power is delivered from the gearbox and is distributed evenly to both driveshafts. The driveshafts then transfer the power to each differential, where the power will be reduced again. The four new Polaris CV axles will connect from both the front and rear differentials and rotate the wheels.

Differentials

Two Polaris Differential were ordered and are currently in-house. The differential ensures equal rotational speed from the driveshaft to each CV axle. The differentials are an essential part to a 4-wheel drive drivetrain system. A simple rear-wheel drive system does not require the use of a differential. Two differentials are used in the design. One is located is the front and one is in the rear. The differentials have a 3.82:1 gear reduction. Therefore, we needed to design a custom gearbox, to contradict the differential reduction. These differentials have electromagnetic activation capabilities. When hooked up to a 12-volt battery, the differential can activate with a flick of a switch. When activated, the current passing through the differential allows a magnet inside to magnetize, allowing the differential to transfer power between the driveshaft and the CV axles. When the differential is off, the driveshaft will continue to spin, but the differential will not transfer the power to the CV axles. A 12-volt battery will allow the use for both differential for approximately 9 hours before needing to recharge. Our selectable 4-wheel drive design is possible through a simple 3-way toggle switch. The 3-way toggle switch allows the driver to switch between 4-wheel drive, neutral, and rear-wheel by simply turning on or off the differentials. Figure 5, below, show the schematic drawing for the toggle switch to activate the differentials.

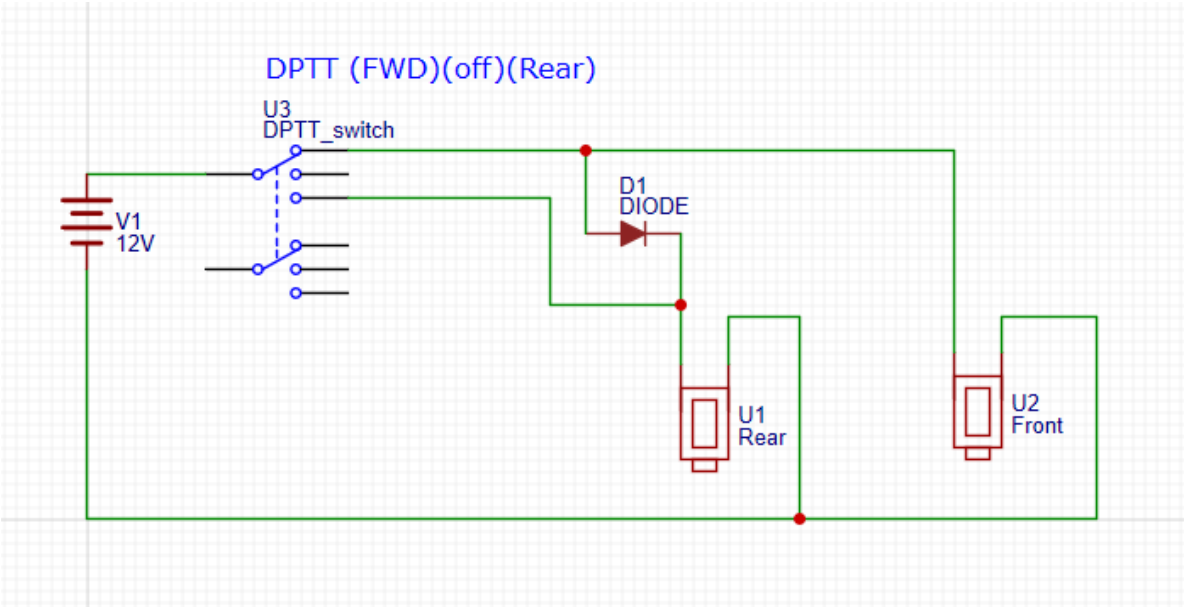

Figure 5 - Schematic for Toggle Switch

Mounting Fixtures and Guards

Mounting fixtures for the engine, CVT, gearbox, and fuel tank has been plasma cut and welding the fixture together was started. It will encapsulate the gearbox while having the engine sit on top. The fixtures are cut from 1/8-inch steel plating material. The 1/8-inch steel plating is strong enough to hold the weight of all the components in the fixture. It is also rigid enough to withstand any damages that may occur during competition races. The fixture will be welded directly to the frame, then the components will be installed after. Figure 6, below, depicts the fully assembled model of the engine and gearbox mounting fixture.

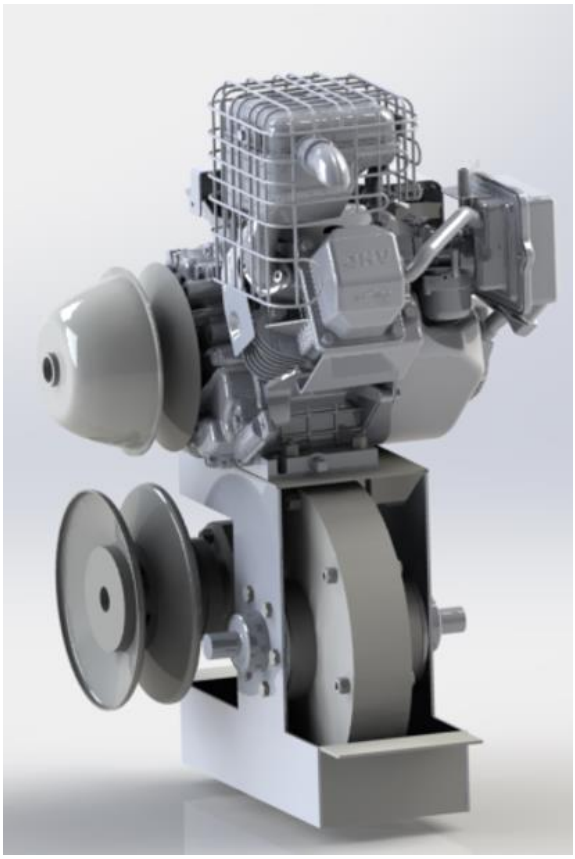

Figure 6 - Engine/Gearbox Mounting Fixture Model

Mounting fixtures for both the front and rear differentials have also been fabricated. The fixtures were plasma cut out 1/8-inch steel plating. The rear fixture is simply a flat plate that will be welded to the back of the frame. The front fixture had a U-shape bend in it, so it

can sit lower than the frame, and notches in the sides to allow the CV axles to have a higher range of motion. Both fixtures will be directly welded to the frame.

A guard for the front driveshaft has been designed, but not fabricated. This guard will protect the driver's hands and legs from getting injured by the spinning driveshaft. As mentioned before, the splash guard for the fuel tank will also need to be fabricated and assembled to the frame. Figure 7, below, shows the driveshaft guard as well as the mounting fixtures for each differential.

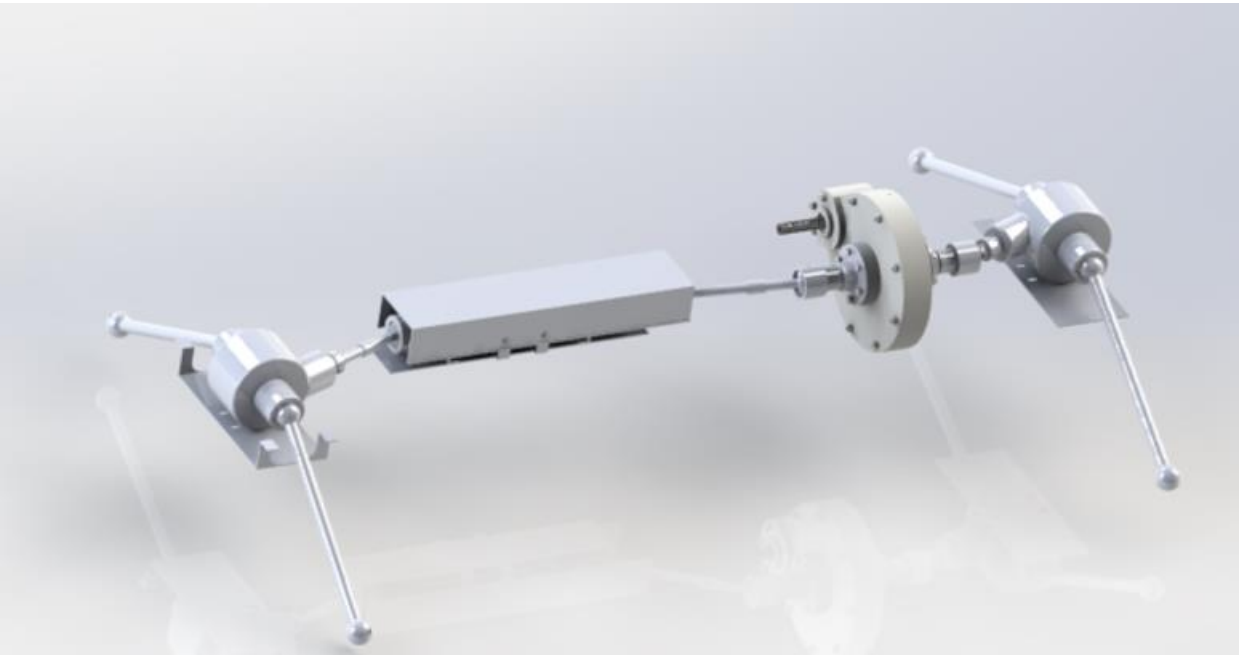

Figure 7 - Driveshaft Guard and Differential Mounting Fixtures Model

Supporting Calculations

Ensure a top speed of at least 30 miles per hour was achieved:

$$\frac{3{,}300\ (Engine\ RPM)}{0.50\ (CVT\ Ratio)} = 6{,}600\ (Input\ Shaft\ RPM)$$

$$\frac{6{,}600\ (Input\ Shaft\ Ratio)}{3.75\ (Gearbox\ Ratio)} = 1{,}760\ (Output\ Shaft\ RPM)$$

$$\frac{1{,}760\ (Output\ Shaft\ RPM)}{3.82\ (Differential\ Ratio)} = 460.7\ (Wheel\ RPM)$$

$$Top\ Speed = 2\pi\left(\frac{2.08\ feet}{2}\right) * 460.7\ RPM * \frac{60\ minutes}{5{,}280\ feet}$$

$$\boldsymbol{Top\ Speed = 34.2\ miles\ per\ hour}$$

To find the top speed, the wheel rpm is multiplied by the circumference of the wheel (diameter is 25 inches or 2.08 feet) and multiplied by a conversion factor to get from rotations per minute to miles per hour.

References

Baja SAE Collegiate Design Series - Baja SAE Rules. (2020, January 26). Retrieved from https://www.bajasae.net/cdsweb/gen/DocumentResources.aspx

SAE International . (2019). Retrieved September 12, 2019, from Baja SAE: https://www.bajasae.net/cdsweb/app/NewsItem.aspx?NewsItemID=c35aa4f5-ef72-4a38-8fda-afcf7624f093

Appendices

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