2013 Baja SAE Drivetrain

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by:

Bryan Vamos

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Thesis Advisor:

Professor Allen Arthur
ABSTRACT

The purpose of this project is to design and build a light, reliable, strong, and efficient drivetrain system for the 2013 vehicle.

INTRODUCTION

The 2013 vehicle will utilize a helical gearbox to transmit the power from the engine, to a set of custom half-shafts. After many weeks of research, it was determined that this option would best suit the expectations of the vehicle. The expectations require that the vehicle be competitively lightweight in order to be a competitive team during 2013 competition.

DRIVETRAIN SYSTEM

OBJECTIVE – Design a drivetrain system that is light, strong, reliable, and efficient. The drivetrain must utilize a gear train reduction designed to achieve 35mph maximum vehicle speed, and permit the vehicle to climb a 20-degree incline. The torque will be transferred through a set of custom axles. These design parameters will ensure competitiveness in dynamic and endurance events.

GEARBOX – A custom gearbox was the initial direction for the gearbox solution. The complexity and cost of the manufacturing resulted in the search for other options. The gearbox selected for the vehicle is an off the shelf unit, manufactured by Dana Corporation. The gearbox key features include helical gear sets, selectable forward, neutral, reverse, and a clutch type auto-locking differential. The auto-locking differential ensures maximum traction, while maintaining maximum vehicle maneuverability. The reverse feature also helps improve vehicle maneuverability. In the event the vehicle becomes immobile due to obstacles or rough terrain, the vehicle can be reversed out of the situation. The gearbox offers three different final drive ratios, which provides convenient speed reduction changes, based on the demands of the operator. The gearbox is compact which helps maintain a lower center of gravity, and a shorter vehicle length. The gearbox is lightweight, only weighing 156 N.

Figure 1: Dana H-12 FNR Gearbox

DRIVE AXLES – The power is transmitted to the wheels through a set of custom sleeved drive axles. The drive axles must be designed to the proper length and allow for adequate articulation and linear plunge. The rear suspension features 279.4 mm inches of travel, which has to be complimented by the drive axles. The most cost effective method to produce a set of axles to meet these requirements is to combine off the shelf CV joints. The inboard CV joint is manufactured by Ariens, and is designed to drive the Gravely Treker 4X4 Utility vehicle, which features the
same Dana gearbox selected for the vehicle. The Treker engine produces 20 hp and 44 N-m of torque, which exceeds the 17.6 N-m of torque output of the Briggs & Stratton engine, making them suitable for the application. Additionally, the CV joint allows adequate linear plunge and articulation, based on the design of the rear suspension. The outboard CV joint is manufactured by Polaris Industries, and is featured on the Sportsman and Hawkeye 300 ATV. The joint is designed to transmit 17hp and allow for 30 degrees of articulation, which is ideal for the rear suspension travel. The two joints and their axle shafts will be coupled together to the correct length, using a welded 4340 steel sleeve. The joints are very small and lightweight, and prove to be a durable and lightweight combination.

**Figure 2: CV Drive Axles**

LOADING CONDITIONS – To verify the strength of the sleeved CV axle shafts, finite element analysis was performed. First, the maximum torque output at the gearbox had to be determined. The engine produces 17.6 N-m of torque at 1800 rpm. A CVT dynamic ratio of 3 at this RPM and a gearbox reduction ratio of 12.58 are considered. Therefore when the engine torque is multiplied by the total reduction ratio of 37.74, the maximum torque output is 666 N-m. This output is multiplied by a CVT efficiency of 75%, to arrive at the actual output torque of 475 N-m. This torque was then used to verify the torsional strength of the axle shafts. The outer end of the shaft was fixed, while the 475 N-m of torque was applied to the inner end. The results yielded a maximum stress of 416.6 Mpa, and a minimum 1.7 factor of safety. This study would be considered worst case considering the likeliness of CVT belt slip or tire slip.

**Figure 3: CV Drive Axles FEA Results**

ENGINE/GEARBOX SUB-FRAME – A sub-frame was designed to securely mount the engine and gearbox to the chassis. The design goal was to design a sub-frame that would be light, rigid, and would ensure a compact drivetrain system. An emphasis on servicing of the drivetrain was considered during design, so that the engine and gearbox can be removed together, still fastened to the sub-frame. This considerably reduces time in the event of engine or gearbox service. The engine and gearbox are mounted with a preset center distance, from engine output shaft to gearbox input shaft. This distance of 292mm is ideal for proper CVT operation, while maintaining a compact system. This center distance can be adjusted to apply more tension on the belt by adding shims, raising the engine height relative to the sub-frame. This is an effective method to adjust the belt tension for proper CVT tuning. The sub-frame is constructed of water jet cut 6061-T6 aluminum plates, then joined using the GTAW process. The total weight of the sub-frame after manufacturing is 27 N.

**Figure 4: Engine/Gearbox Sub-Frame**
LOADING CONDITIONS – To verify the design of the engine/gearbox sub-frame, some basic calculations had to be performed. The same 475 N-m torque used to analyze the drive axles was also used as one of the loading conditions when performing finite element analysis on the sub-frame. The other two loading conditions are impact forces distributed by the engine and gearbox. The impact forces were replicated to simulate a worst-case scenario in the event the vehicle left the ground, and then landed with little to no impact absorption. The engine weight of 334 N was multiplied by an acceleration of 5 g’s, obtaining an impact force of 1668 N. The gearbox weight of 156 N was also multiplied by an acceleration of 5 g’s, obtaining an impact force of 778 N. The combination of torque reaction, engine impact, and gearbox impact were applied at the same instant to replicate a realistic worst-case loading condition. The maximum stress obtained from the analysis was 104.6 MPa, resulting in a minimum 2.6 factor of safety.

**Figure 5: Engine/Gearbox Sub-Frame FEA**

DRIVETRAIN ASSEMBLY – The drivetrain will consist of a compact sealed gearbox, which will perform the ideal speed reduction. The engine and gearbox is supported utilizing a single sub-frame. The sub-frame is composed of 6061-T6 Aluminum to provide a lightweight and durable mounting solution. The fixture will then be fastened to the vehicle chassis, requiring very little special modifications that would add extra weight. The axles are mated to the gearbox utilizing the factory output shaft splines and mating Ariens inboard CV joint. The shafts are custom sleeved to extend them the proper length to connect the wheel hub to gearbox.

**Figure 6: Drivetrain Assembly**

PROOF OF DESIGN – The 2013 vehicle was exposed to over thirty hours of testing and competition in extreme conditions. In testing, the loading conditions used to analyze the drivetrain system were replicated to validate the FEA results. In attempt to replicate the impact forces exposed to the sub-frame, the vehicle was launched into the air using both man made and natural obstacles. The drivetrain withstood the punishment, with zero signs of failure due to stress. During competition, extreme obstacles were built to test the durability of the vehicle. The rear of the vehicle impacted the ground while under full power, creating an impact force translating through the drive axles and sub-frame. This punishment was not enough to affect the integrity of the system. The maneuverability of the vehicle proved to be ideal, and competitive. The reverse feature was utilized in order to complete the suspension and traction event in competition, when the vehicle was stuck on large logs. A 13<sup>th</sup>/100 finish in maneuverability was obtained during competition, validating design.
CONCLUSION

The drivetrain for the 2013 University of Cincinnati Baja SAE vehicle has been designed to be lightweight and durable. In addition, it has proven to ensure maximum maneuverability, traction, and reliability during competition to make the 2013 vehicle a competitive contender. There are improvements that could be made to the system, to make it more efficient, compact, and lightweight. A custom gearbox can provide unique mounting solutions by making the gearbox a structural member. The gearbox would have to be designed prior to the design of the chassis. The weight could be considerably reduced, by performing multiple iterations year after year. The drive axles could be improved by designing custom shafts, instead of a sleeved design. Due to manufacturing complications of involute splines, this was not realistic for the 2013 system. Permitting adequate funds and manufacturing resources, a custom set of shafts would permit a drastic weight lost in rotational weight.

REFERENCES


CONTACT

Bryan Vamos - Drivetrain vamosbp@mail.uc.edu

DEFINITIONS, ACRONYMS, ABBREVIATIONS

FEA: Finite Element Analysis
HP: Horse Power
MPH: Miles per hour
MPa: Mega Pascal (Stress)
N-m: Newton Meter (Torque)
N: Newton
RPM: Revolutions per minute
After many hours of research and consideration of the drivetrain options, a sealed gearbox would be used for the speed reduction. A reliable, compact, and lightweight solution is needed that would need little maintenance and upkeep during testing and competition. The first design idea was to design a completely custom gearbox. This would permit the creation of the lightest gearbox possible, and an unlimited amount of packaging possibilities. After completing most of the design and speaking with manufacturers for the custom gears, it was decided that it would be too costly for this year’s team. Other options would have to be researched. After research, it was decided that the Dana H-12 FNR gearbox would be the gearbox of choice for the 2013 vehicle. Howard Resner of Dana Corporation was very helpful in the decision.

Once deciding on the gearbox, designing the sub-frame that would harness the engine and gearbox began. This would have to be a completely custom component, as there are no aftermarket options. Time researching how others mount their gearboxes was spent, and ended up with the design idea.

The axles would need to be selected or designed for the vehicle. There are axles offered from Polaris that have been proven on other Baja SAE vehicles. For this vehicle, it wasn’t that simple. An axle that had the mating splines for the gearbox and the wheel hub would be required. For this reason, the Polaris Sportsman 300 axles couldn't be used without modification. It was determined that the Polaris Sportsman 300 outboard CV joint would be used, as it mates with the wheel hub. Then, an Ariens inboard CV joint would be used, as it mates with the Dana H-12 gearbox output shafts. These two joints would be coupled together in the form of a simple sleeve, to give the axles the proper length. These axles will provide sufficient articulation and lateral plunge based on product specifications from manufacturer.
**APPENDIX B**

**CUSTOMER REQUIREMENTS**

The drivetrain system will be:
- Safe
- Affordable
- Easy to manufacture
- Easy to service
- Reliable
- Lightweight
- Durable

**CUSTOMER SURVEY**

As an ATV manufacturer, the customer's feedback is vital. The following survey will help the production of the leading ATV on the market.

**How important is each feature to you for the design of the drivetrain?**

1 = low importance   5 = high importance

- Safety
- Reliable
- Quiet
- Performance
- Robust
- Simple
- Compact
- Low Maintenance
- Light

**How often do you ride off-road vehicles? (Circle One)**

Every Day     Often     Seldom     Never

Would you like the drivetrain to include reverse? (Circle One) Yes No

How much would you be willing to pay for a drivetrain system?

$100-$150  $150-$250  $250-$300  $300-$500  $500-$1000  $2000-$3000

Thank you for your time.

**APPENDIX C**

**SCHEDULE**

**APPENDIX D**

**BUDGET**

**MONETARY**

DRIVE TRAINT SYSTEM BUDGET: $4000  
ACTUAL SPENT: $1671

**WEIGHT**

DRIVE TRAINT SYSTEM: 75 LBS  
ACTUAL WEIGHT: 71 LBS
APPENDIX E

SAE RULES AND REGULATIONS

SAE RESTRICTIONS - The competition has mandated restrictions for safety and a level playing field. The following is a summary of the restrictions regarding the drive train (SAE International 2010):

1. All vehicles are powered by one of the four Briggs & Stratton OHV Intek Model:
   • 205232 0036-F1
   • 205432 0536-E9
   • 205332 0536-E0
   • 205332 0536-B1

2. The engine must remain 100% stock except for the following exceptions:
   • Any valve clearance setting between the tappet and valve stem may be set.
   • Valves may be lapped but must remain at the original 45 degree angle.
   • Any armature air gap setting is allowed.
   • The air intake may be relocated using the Briggs & Stratton kit with the air hose shortened to a minimum of 6 inches.
   • The original muffler may be relocated using 1.25 inch ID tubing if it will impinge on part of the vehicle.
   • The recoil starter rope may be extended.
   • Any idle speed is allowed but the governor must be placed in hole #6.
   • If the fuel tank is remote mounted, a shield must be installed over the governor.