Society of Automotive Engineers (SAE) Baja Collegiate Competition: Drivetrain

NAU Northern Arizona University — Office of Undergraduate Research and Creative Activity

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Abstract

At Northern Arizona University, the drive train sub team has developed an original gearbox and chain drive design for and off-road vehicle for the 2023 SAE BAJA Capstone. Our team will compete in Washougal, Washington at the end of May competing against 99 other universities to determine which team designed the most economical, and capable vehicle, to pass the required competition testing. The competition includes a multitude of tests including acceleration, braking, hill climbing, suspension, and endurance tests. The team is composed of nine students were divided up amongst each sub-team and focused on different aspects of the vehicle to help complete design work. The drive train sub-team worked with a chain setup to become all-wheel drive compatible and added a CVT gearbox component to optimize the final speed, acceleration, and torque. Using individual finite analysis on weights, varying forces and speeds our team calculated values that prove our final designs would be competitive in Washougal. The result is a vehicle that can compete in every event while being durable enough to allow for multiple tests in strenuous conditions.

Customer Needs / Engineering Requirements

To be competitive this year in the 2023 SAE BAJA competition, our drivetrain sub-team had to make our vehicle all-wheel drive (AWD) compatible. This requirement alone improved complexity of the unique designs we have crafted. In table 1 below we have listed a series of customer needs that we met by the end of the build. Final weight is not known at this time, but we will most likely exceed 330 lbs. with the driver in the vehicle.

Table 1: Engineering requirements and customer needs.

•To reduce the weight ; 330 lbs.	•To improve complexity.	•Reducing material usage.
•Increasing durability and reliability for Safety	•Team cohesiveness ; splits the workload evenly.	•Reducing production time
•Adhering to the rules.	•Increasing handling and Maneuverability.	•Competitive Vehicle.

Calculations

When we started making the gearbox calculations our goal was to maximize torque and speed. We used a series of equations that produced an overall speed of 29 mph. We will validate our calculations in testing when we are able to use tools like a tachometer to measure output speed and a speedometer overall speed of the vehicle. Shaft calculations were vital to understanding the different stresses that went into the gearbox. Among these calculations we know that the gears also will produce the torque needed to achieve the hill climb and other tests that will take place at competition.

Shaft Calculations

Table 3: Safety factors of safety and stress calculations of the shafts inside the gearbox

$$A = \sqrt{4(K_f M_a)^2} \qquad B = \sqrt{3(K_{fs} T_m)^2}$$

$$n = \frac{\pi d^3}{16}\left(\frac{A}{S_e} + \frac{B}{S_{ut}}\right)^{-1}$$

Ultimate Stress	Sut	85	kpsi
Yield Stress	Sy	65.5	kpsi
	Se'	42.5	

Nubers Constant			
Bending	Sqrt(a)	0.076900363	EQN 6-35
Torsion	Sqrt(a)	0.057790363	EQN 6-36

Fatigue Correction Factors				
	Load Correction		kc	1
Surface Correction	A	2	ka	0.762686552
	b	-0.217		
	Temp. Correction		kd	1
	Reliability Correction		ke	0.702

Factors of Safety

n	1.072	Shaft 1
n	1.337	Shaft 2
n	1.128	Shaft 3

Gearbox Calculations

Table 4: Safety factors calculated from each gear

SF (requirements)	>1.5
SC (requirements)	> 1.2

GEAR 2 (Input Pinon)	Safety Factors:	GEAR 3 (Middle Gear)	Safety Factors:
SF	1.55	SF	3.32
SC	1.34	SC	1.63

GEAR 4 (Middle Pinon)	Safety Factors:	GEAR 5 (Output Shaft)	Safety Factors:
SF	3.32	SF	8.74
SC	2.03	SC	2.23

Machining / Methods

Most of the parts for the drive train system were made in the NAU machine shop. The gear box housing, shafts, the brake mounting system, engine supports, tabs, and the chain supports were all made in house. We attained stock from our SAE club as well as buying stock online. The shafts, gear box housing and chain supports were worked on with the mill, lathe and CNC lathe. Our engine supports and tabs were made in house with left over steel. Mounting was done in house by certified members of the team. Other outsourced materials like the engine, gears, bearings, CVT, and screws were bought from different vendors due to complications in making them in house due to limitations caused by small errors in tolerances.


Figure 1: Inside gearbox


Figure 2: Gears meshing together

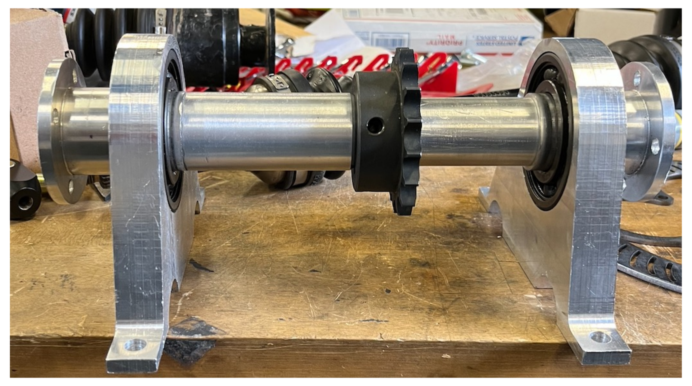
Figure 3: Chain drive holder for front axle attachments

Vehicle

The images below show the final assembly of the vehicle. Everything fits into the rear compartment of the car, with the gas tank being elevated to prevent excess heat from the exhaust causing combustion issues.

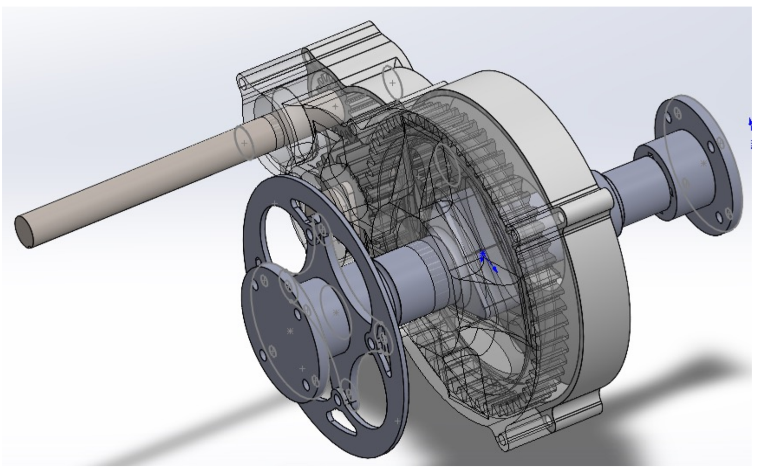
Figure 4: Gearbox 3D model from SolidWorks

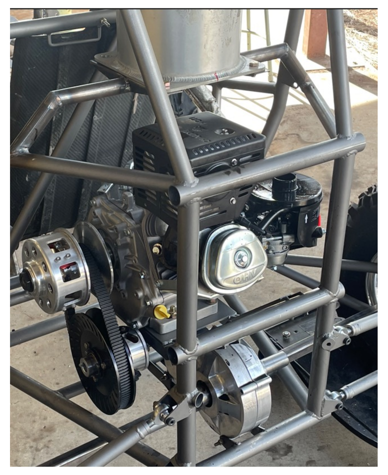
Figure 5: Display of fitment in the rear

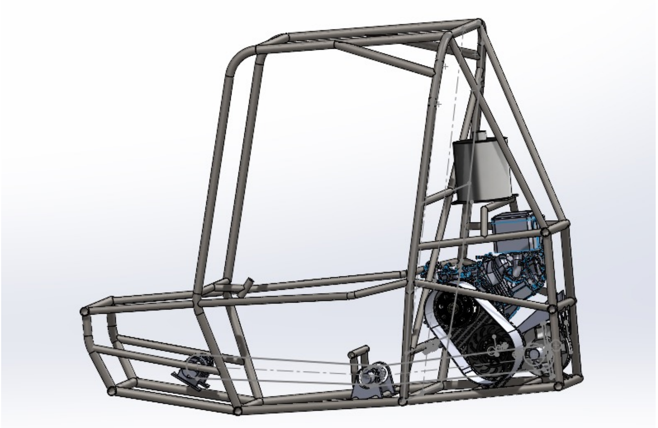
Figure 6: 3D model of the assembly

Testing

Acceleration Testing: The acceleration test will be answering how quickly our car can get from a resting position to the max speed. We will measure using a tachometer (figure 7) to measure the rpm of the output. Measure the maximum rpms of the output shaft using a tachometer, measure how long it takes the output shaft to go from rest to the max rpm, calculate the speed, and use the time acquired to calculate acceleration.

Hill Climb Testing: The hill climb test assesses the vehicle's power, traction, and overall performance on difficult terrain. We will be taking the vehicle out to a hill of cinders (figure 8) that will replicate washed out terrain. We will do trials of timed testing to measure the amount of time it takes for us to climb. From there we will work on as many improvements as possible with the chain drive to improve on time.

Wear and Tear: A wear and tear test involves tracking the wear and tear of drivetrain and other components throughout testing. Wear can indicate system inefficiency and we would like to observe potential issues before competition. This will be looked at intermittently between trials. If no weaknesses are observed the components tested will pass.


Figure 7: Tachometer device used to measure speed


Figure 8: Cinders hill climb


Figure 9: Wear observed on gearbox

Conclusion

The final design for the car completes all the requirements for the competition and passes all design regulations. The car will be capable of competing in all the events occurring in Washougal, Washington, including hill climbs, acceleration tests, brake tests, and endurance tests.


Figure 10: CAD of full assembly

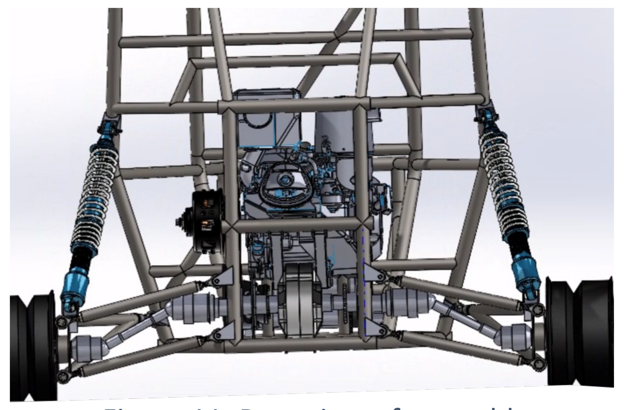
Figure 11: Rear view of assembly


Figure 12: Current state of vehicle

References

[1] *Baja SAE*. [Online]. Available: https://www.bajasae.net/.

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[3] R. BUDYNAS and K. Nisbett, *Shigley's Mechanical Engineering Design, 11th edition, SI units*, 11th ed. MCGRAW-HILL EDUCATION (AS, 2020).

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