Independent Rear Suspension for Baja SAE Vehicle

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Abstract
The current Northeastern Baja SAE vehicle was nationally successful in 2012 competitions, but its rear solid axle, swing arm setup is unable to articulate and struggles to keep both rear wheels grounded on uneven terrain. The scope of this project was to design and manufacture an independent rear suspension for a new Baja SAE vehicle. The design aims to combine the favorable flat-ground handling of the current vehicle with the articulation inherent in an independent rear suspension. Twelve independent suspension systems and concepts were considered and the choice was narrowed to a three-link or a double-A arm with the aid of a design matrix. Attempts to optimize the desired suspension characteristics (toe, camber, roll center, etc.) throughout the shock travel eliminated the three-link from consideration. The final suspension geometry design selected was a double-A arm type suspension. This geometry was converted into physical links with tie-rod ends that connect to the frame and wheel knuckle. To transmit power to the independent wheels, a new drivetrain system was also designed and developed. The drivetrain includes a central spool hub mounted with custom bearing carriers, articulating driveshafts, and wheel hubs. Basic mechanical design calculations and finite element analysis were used for material selection and component configuration. The majority of the suspension and drivetrain system components were manufactured in house using the Baja team’s resources. Future work consists of collecting and analyzing suspension load data from strain gages mounted on the current Baja SAE vehicle’s rear suspension. The results will be used to perform more accurate finite element analysis models and verify the design.
The Need for Project

In recent years, the obstacles encountered in the Baja SAE competitions have been tailored to vehicles that implement independent rear suspensions (IRS). Baja SAE consists of three intercollegiate competitions held in three different locations in the United States. Typical obstacles include telephone poles, railroad tracks, rock gardens, mud bogs, water, and jersey barrier drop offs. The suspension system is an especially vital component because it separates the main body of the vehicle from the ground. The suspension must be capable of providing adequate ground clearance, while maintaining vehicle stability and absorbing multi-directional impact loads. An independent rear suspension (IRS) will allow for greater adjustability and improved vehicle dynamics over the current swing arm suspension.

The Design Project Objectives and Requirements

Design Objectives

The main objective of this project is to develop an IRS for a rear wheel drive Baja SAE vehicle that maintains the desirable handling characteristics associated with a swing arm rear suspension. The IRS must be capable of adjusting to all obstacles encountered in the Baja SAE competitions.

Design Requirements

A comprehensive list of design requirements was developed at the beginning of the project based on the needs of the Baja SAE team, the Baja SAE rulebook, and the needs of designing for an off-road environment. A ranking matrix was established to determine the main design requirements, with the top four requirements listed below (Rep. 4.3):

- Fully Independent - wheels are in contact with the ground at all times.
- Impact Loading - IRS must be capable of absorbing any loads faced in the competition.
- Adjustability - ability to easily tune and adjust the suspension set up.
- Drivetrain Efficiency - competition rules limit the vehicle to 10 hp. System must limit power losses from the transmission to the wheel.
Design Concepts Considered

Existing suspension types in industry and design concepts were considered; the top candidates were narrowed to double-A arm and three-link concepts.

The team researched eleven different suspension types and brainstormed concept suspensions that might be a potential solution to the problem statement. A decision matrix was constructed based on the design requirements and the double A-arm and three-link IRS concepts best fit the requirements.

Concept #1: Double A-arm

The double A-arm consists of two A-shape structures. The double A-arm allows for easy, independent adjustability of the camber and toe via the toe links and tie rod joints. Due to the double A-arm shape, the links are inherently strong from triangulation (Rep. 3.4.7).

Concept #2: Three-Link

The three-link is a trailing link based suspension with two camber links. The three-link allows for camber adjustability, and toe adjustability in a curved line. The three-link is a simple design, and the swing arm motion naturally absorbs any impact loads (Rep. 3.4.6).

Recommended Design Concept

The double A-arm suspension system best fit the design requirements and hit every target parameter of the suspension characteristics. A spool hub and CV driveshafts will be used to power the independent wheels.

The design of the double A-arm suspension system included the suspension links and wheel knuckle. Additionally, an accommodating drivetrain system was designed to transfer power from the transmission to the rear wheels. The drivetrain system includes the spool hub, bearing carriers, drive axles, and wheel hubs.

Design Description

To minimize the required axle articulation and improve the vehicle’s handling, the spool hub was positioned as close to the belly of the vehicle as possible (Rep. 5.3). The spool hub design is a three-part assembly that consists of a 6061 aluminum hub with two thermally fit 4340 steel sleeves. Off-the-shelf ball bearings support the spool hub, and are mounted to the frame by custom 6061 aluminum bearing carriers.

The drive axle selected uses a pair of continuously variable (CV) joints for each driveshaft to transmit power. The CV joint allows for axle length changes as well as articulation through suspension travel. Polaris Sportsman 500 axles were chosen because they allowed for clearance room in the dish of the wheel and appropriate track width of about 54 inches (Rep. 5.4). The team selected an aftermarket axle by
Gorilla Axle that allows for up to 38° of articulation (in comparison to 30° of a stock Polaris axle).

Based on the team’s research for off-road vehicles, the suspension geometry was designed to meet the following suspension characteristics (Rep. 3.1) throughout the entire travel of the suspension (roughly 10 inches):

1. Toe = 0° (± 0.5°)
2. Camber = 0° (+1° to -5°)
3. Roll Center Height > 6.5 inches
4. Scrub < 3.5 inches

The upper A-arms were constructed out of 4130 1” x 0.065” round tube. The lower A-arms were constructed out of 4130 1” x 0.083” round tube. A thicker wall was used for the lower A-arms because they are more prone to direct impacts from obstacles. The links are connected to the frame using off-the-shelf rod ends, which provide 55° of misalignment and allow for tuning of the toe and camber (Rep 5.6.5).

The wheel hub design incorporates a one-piece all 7075 aluminum design, which is lightweight and resistant to oxidation. The one-piece design also allows for fewer parts and interfaces (Rep. 5.5). The custom hub allowed for a 50% weight reduction from the stock Polaris hub. The hub contains an internal, EDM cut spline that connects to the drive axle.

The wheel knuckle uses a two-part design. The main body is a cylindrical piece of 4130 steel that houses the bearing for the wheel hub. It connects to the suspension links using sheet metal (.125 in. gage) tabs welded to the outside of the cylinder. The welded arms are oriented in plane with the rod ends to reduce the misalignment needed in the joints (Rep. 5.7). 4130 steel was chosen because of it is relatively easy to weld.

**Analytical Investigations**

The suspension geometry was modeled in SolidWorks and the suspension characteristics were analyzed using Optimum Kinematics suspension software. SolidWorks was used to spatially incorporate links and solve for link lengths through the suspension travel. Over 100 modifications were made in attempts to meet all the suspension
Torsional strength analysis was performed on the half shaft’s splines to ensure that the selected material can withstand any expected loads. A safety factor of 3 was found for the spool hub and 3.8 for the wheel hub (Rep. 5.5). Also, a shrink fit analysis was performed on the spool hub that determined a maximum amount of torque of 1000 ft-lb could be transmitted with a yield factor of safety of 1.5 (Rep. 5.3).

Preliminary finite element analysis was performed using an estimated worst-case scenario on the wheel hub, knuckle, and suspension links to help reduce stress concentrations and aid in material selection.

A fastener analysis was performed between the spool hub flange and sprocket, ensuring the shear strength of the bolts (Rep. 5.3).

**Experimental Investigations**

A National Instrument’s CompactRIO data acquisition system was used to acquire load data on the 2010 Baja vehicle’s rear suspension system. The swing arm was instrumented with strain gages and then calibrated to determine the wheel loads. The collected data will be used to perform more accurate finite element analysis.

**Key Advantages of Recommended Concept**

The double A-arm concept provides ease in adjusting the camber and toe of the vehicle. Its design successfully hit every suspension characteristic parameter. All of the accommodating system components promote strength, adjustability, and manufacturability.

The prototype cost of the new independent rear suspension was determined using the Baja SAE standard costing template. The cost of the suspension system and the associated drivetrain was found to be $2,647. As a comparison, the past swing arm suspension cost about $1,837. The increase in cost is caused by the added complexity and additional components of an IRS suspension system (Rep. 7.2).

**Recommended Improvements**

More in-depth load data acquisition testing will take place in the future, and the results of this testing may lead to future improvements.