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Design and development of solid axle system for FS car

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Abstract
Earlier, FS cars used to have independent suspension system which involved chassis and differential system. Our solid axle system provides a dependent suspension system consisting of less number of moving components and reduced weight of the system.
This is achieved by designing a single component capable of performing all the operations that a chassis and differential system can perform.
The design is further simplified by removing constant velocity joints and tripod assemblies.
This component results in an increase in reliability, effectiveness as well as efficiency and further reduces cost of the system.

Keywords:*Suspension system, Solid axle, rear setup ofFSAE car, spool drive, integrated brake systems.*

1. Introduction

A very good example of dependent suspension system is a solid axle system. In this system a lateral connection by a single beam or a shaft is made with the wheels. In FS competitions track surfaces are flat. There are no potholes, therefore solid axle is beneficial and can be implemented easily in FS car. Also solid axle setup is simple to design and manufacture as well as it is cheaper. The main purpose of suspension system in a car is to constantly maintain the contact patch of the tire with the road. This system is also responsible for the comfort of the driver/occupants, but in a racecar it is of quite lesser importance.

1.1 Problem Statement

Design and development of rear solid axle system for FS car which will reduce the weight and number of components in the system and increase the overall reliability and effectiveness.

1.2 Objective

The suspension geometry was designed to control the tire's contact patch, and static camber was kept zero degrees at the rear and negative 1.5 degrees at the front. Springs with the required stiffness were manufactured to meet the weight distribution characteristics. Adjustable dampers were procured to allow for tuning the dynamic behavior. It was made sure that the handling is suitable for the skill level of

Driver training and suspension tuning were given due importance. Driver feedback was utilized to get the balance just right, to suit their driving style. With sustained driving on good surfaces, the drivers were able to correct their line using the throttle, and hold speeds for longer by taking advantage of predictable

student drivers. The setup is sufficiently soft to keep the car planted and stable at high speeds as well as over rough patches, yet responsive enough to quick driver inputs. The drivers will be able to focus more on the track, and not worry about the car's behavior.

Complications were avoided while integrating the suspension into the chassis. A fully dependent beam axle rear suspension was used with high mounted dampers with planar actuation using pushrods. Manufacturing was done using sheet metal bending and welding with proper FEA and optimizing weight. The front driver cell required using the conventional wishbone setup with the dampers to be mounted high, and be actuated using pushrods. The damper actuation mechanisms were kept planar to design safer brackets.
The design process gave a lot of precedence to saving weight. Forces in all the wishbone links and connecting links of the beam axle were calculated using vector matrix methods considering maximum cornering, bump, acceleration and braking scenarios.

These were used to select the required tube dimensions for the wishbones. FEA along with topology optimization was performed on the bell cranks as well, which were then manufactured in sheet metal using AISI 1020, to keep their weight to a minimum. The uprights, hubs, different brackets and mounts were all analyzed and optimized using FEA software.
trail braking. Constant speed cornering was improved by using springs to match the corner weights.

1.2 Scope

In recent years, the obstacles encountered in the Formula Student competitions have been tailored to

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vehicles that implement independent rear suspensions (IRS).

This kind of project has not been tried before. The complexities have been eliminated and the design has been made simple. If successful the components, weight and the cost can be successfully reduced. Of the shelf components such as hyper racing, solid axle, independent rear suspension setups are available in market in both categories (mild steel and aluminum) as a base material but these axles cost around Rs. 1 lakh. But we have estimated our final cost for this project and it comes around Rs. 6,820. This kind of setup will be beneficial for new Formula Student teams who are willing to make simple, reliable, cheaper and yet efficient design.

1.3 Methodology

While designing solid axle suspension setup, it is really important to control wheel motion precisely. In order to maintain correct center to center distance between front sprocket and rear sprocket is a tough job but we have managed to adjust the chain slackness by implementing idler in our system.

. Literature Survey

A suspension system serves-

- Maintains uniform contact of the wheels on the road.
- Steering and handling control is improved.
- Driver gets the knowledge of driving conditions.
- It is cheaper and adapts very well.

They have good efficiency in high performance vehicles and offer good wheel response. They also offer better traction control but it fails in handling and also it is very expensive. However, in case of Formula Student cars the track is even and smooth.

The vehicles which use independent rare suspension technology should at least take some practice to learn the vehicle handling before actually taking the vehicle for a high speed spin. It performs well on uneven surfaces and each wheel does not affect the movement of other wheel. Sogood traction is maintained. However, the track used for the Formula student competitions is smooth. So the above points mentioned are not applicable for such a car.

Comparison of dependent and independent suspensions:

Table No 1.

Sr No.	Other systems	Solid Axle Systems
1.	They contain a lot of components and are hence complex.	They contain less number of components.
2.	They are difficult to manufacture	They are comparatively easy to manufacture.
3.	They are costly.	They are cheap.
4.	They increase the weight of the car.	They reduce the weight of the car due to less number of components.
5.	More number of moving components and hence low dynamic life.	As moving components are less, component wear is less and hence life increases.

3. Proposed Design

Our final drive reduction ratio is 3 and there are two other reductions primary reduction and secondary reduction. Primary reduction is in main gear box which changes according to every gear as driver demands for more torque for more speed; secondary reduction for KTM 390 engine gearbox is 2.66.

Table No 2.

Gear	Gear ratio
1	2.6667
2	1.8571
3	1.4210
4	1.1429
5	0.9565
6	0.8400

$$T_{output} = T_{engine} \times (R_p \times R_g \times R_s \times R_d)$$

Equation No 1.

Basic hand calculations were done by considering all the data mentioned above. Our basic hand calculations consist of weight transfer, torque at the output stage and wheel load (in bump, cornering, braking, acceleration etc.).

Weight transfer calculations:

Longitudinal load/weight transfer, $\Delta □ = \frac{[□ \times □ \times □]}{□}$ N

Where, W = car weight with driver (N)

A = Longitudinal acceleration in g's

h = C.G. height

t = Track width mean

Therefore weight transfer at 1g lateral acceleration is,

$\Delta □ = \frac{[246 \times 9.81 \times 1 \times 0.38]}{1.09}$ = 1094.98 N

1 Estimated values of parameters:

Table No 3.

Parameter	Estimated Value
Bending force due to chain tension	7000 N
Torque on axle at launch	1000 Nm
Cornering Load at contact patch	2650 N
Load due to wheel bump	1200 N
Load due to friction force between tire and ground	1700 N

Maximum radial load on bearing	4458.905 N
Maximum axial thrust on bearing	2650 N

3.2 Loading, SFD, BMD

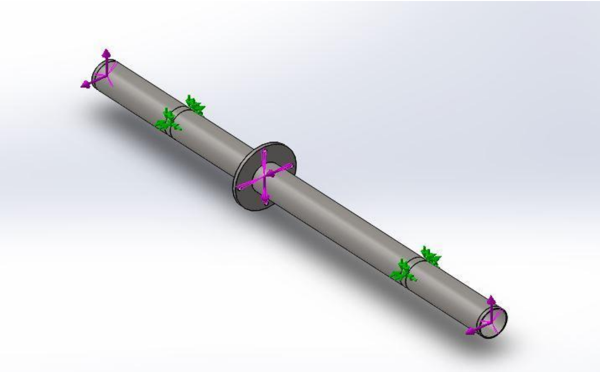

Figure No 1.

Above figure represents actual loading on solid axle rear suspension setup which is represented by solid works CAD model.
Load conditions are applied according to table no. 3.1.1.
Loads and rigids for the simulation are represented by pink color in the figure and constraints are represented in green.
By considering this 3D axle load case, horizontal free body diagram, vertical free body diagram and accordingly SFD and BMD have been drawn as mentioned below.

For the figures below
Units are:
Force/reaction: kN
Length: m
Moment/couple: kN-m

Horizontal Loads:

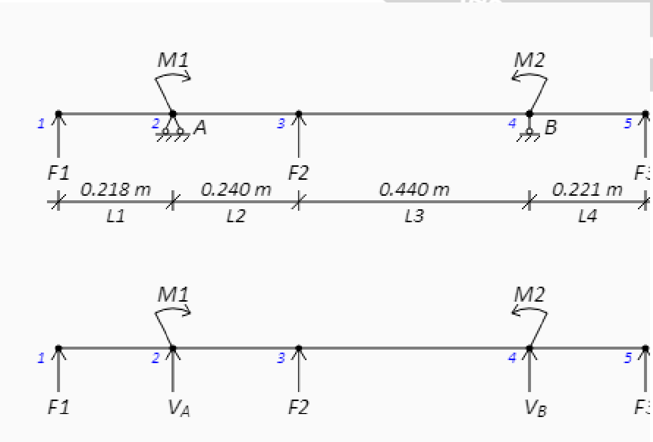

Figure No 2.

3.2.1 Horizontal Loading diagram

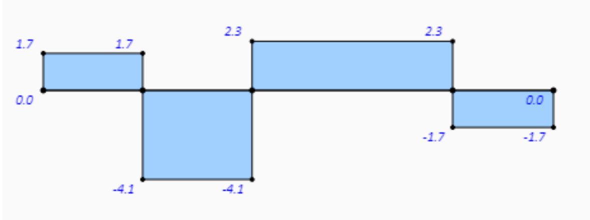

Figure No 3.

3.2.2 Horizontal Shear Force Diagram (SFD)

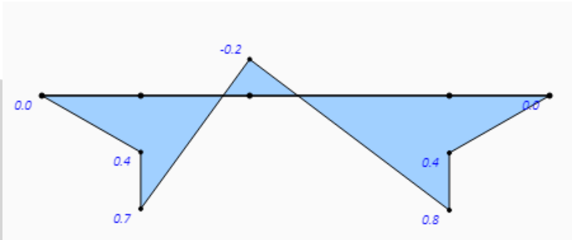

Figure No 4.

3.2.3 Horizontal Bending Moment Diagram (BMD)

3.2.2 Vertical Loads:

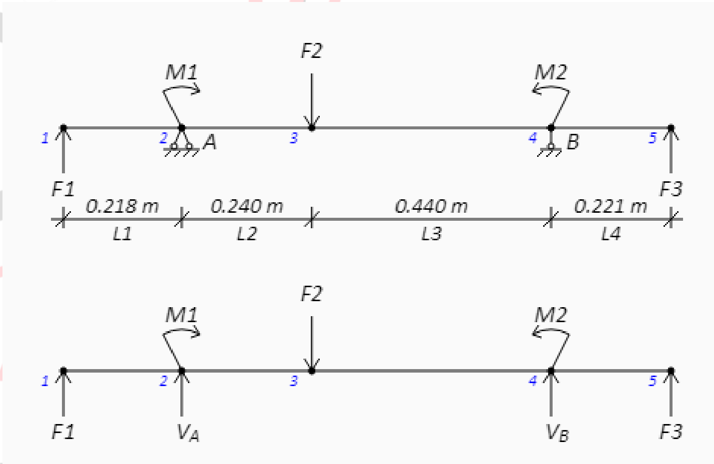

Figure No 5.

3.2.4 Vertical Loading Diagram

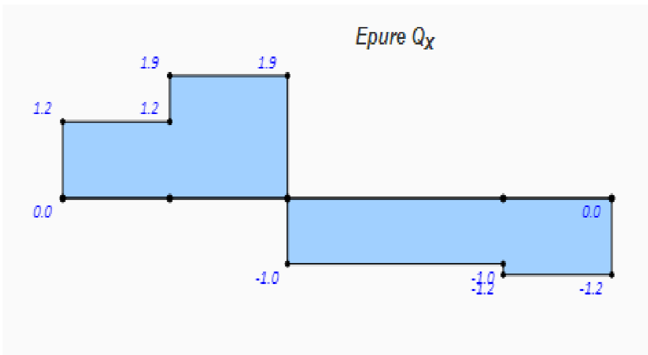

Figure No 6.

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3.2.5 Vertical Shear Force Diagram

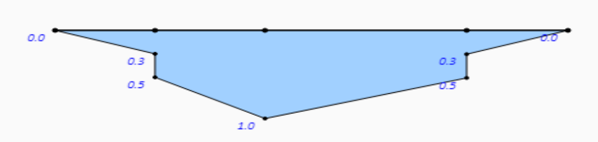

Figure No 7.

3.2.6 Vertical Bending Moment Diagram

4. CAD Model

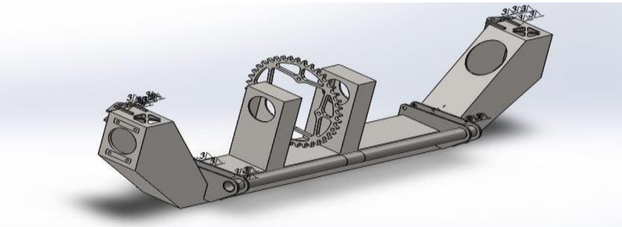

Figure No 8.

4.1 Iteration 1

In the initial stages of design, for first iteration we decided to implement solid axle using beam axle suspension setup as shown in fig. above. The major advantage of this setup is, as support reactions are close enough to reduce bending moment. Hence smaller area moment of inertia hence smaller outer diameter was needed but, at the same time beam axle suspension setup weight increased from 6.2 kg to 8.8 kg. Our main design goal is to reduce weight so, we went for loaded axle suspension setup.

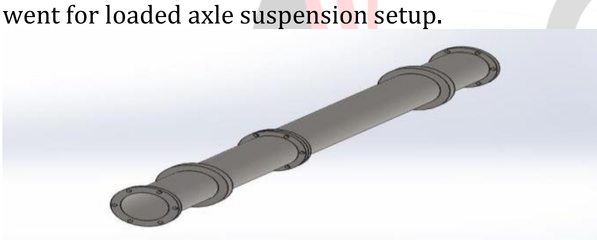

Figure No 9.

4.2 Iteration 2 (integrated axle)

In integrated axle suspension setup as shown above we were planning to integrate sprocket flange, wheel flange, bearing sleeves into one complete axle. After conducting market survey, our design was incurring us more cost. To keep it simple and easy to machine it was really important to switch over the other design which would have simplicity and cost effective simultaneously.

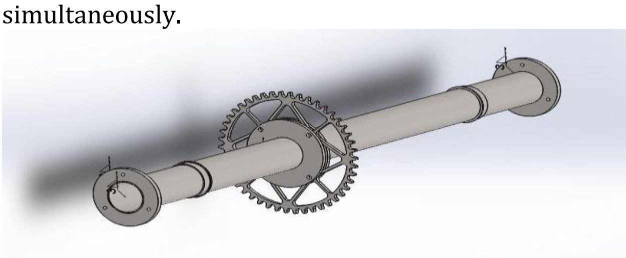

Figure No 10.

4.3 Iteration 3

This is the final iteration we are currently working on which contains simple turning on lathe machine and laser cutting operation which is way more cheaper than integrated axle design but, to overcome manufacturing errors such as welding contraction, weld porosity etc. We are going to implement various jigs and fixtures to manufacture our first prototype.

6. Conclusion

A very good example of dependent suspension system is a solid axle system. In this system a lateral connection by a single beam or a shaft is made with the wheels. In FS competitions track surfaces are flat. There are no potholes, therefore solid axle is beneficial and can be implemented easily in FS car. Also solid axle setup is simple to design and manufacture as well as it is cheaper. The system has been tested theoretically using FEA software. We are going to test our system practically by fitting it on an FS car and take reading for 150 km in running condition. We are expecting errors between theoretical and actual results not more than 5%. We are conducting a market Survey to decide final caliper. Then we are going to decide brake disc size depending on caliper specifications. Calculations of effective radius and breaking torque is also going to be done in future. Design of final shaft assembly is subjected to variations in parameters. Manufacturing of first prototype and testing it on the vehicle for at least 150 km is our final aim.

7. References

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