DESIGN AND ANALYSIS OF A PUSHROD SUSPENSION SYSTEM FOR A FORMULA RACING CAR

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ABSTRACT

This paper is an introduction to the design, analysis, and fabrication of a Pushrod suspension for use in the Formula Hybrid SAE competition held in New Hampshire, USA. This paper sets down a basic guideline on designing almost any type of Formula SAE race car suspension. All references are based on Team Astra Racing's 2015 FHSAE entry.

INTRODUCTION

Suspension is a very important component of any car as it should keep the tire in contact with the road while encountering forces acting on the tires. The type of suspension used decides how these forces are transferred from the tires to the chassis. Suspensions vary from simplistic leaf springs to complicated electromagnets to dampen the forces acting on the chassis. Pushrod suspension designs are used mostly among open wheel race cars because of the aerodynamic and adjustability advantages it gives. They consist of an inboard mounted spring a push rod and a bell crank assembly. The proven design is a type of inboard pushrod suspension when space is limited and the shock cannot be mounted in the most beneficial location. Opposed to the normal type outboard suspension, the inboard design transmits the wheel forces through a pushrod and bell crank to transfer the motion of the wheel to an inboard mounted spring and shock assembly. A pushrod suspension has just a pushrod between the wishbones allowing more space for reducing the track width and also the possibility to use unequal length wishbones which results in a negative camber and better cornering ability. The suspensions are mounted inboard towards the CG axis hence lowering the center of gravity of the car. Also the mounting positions of the springs allow higher adjustability.

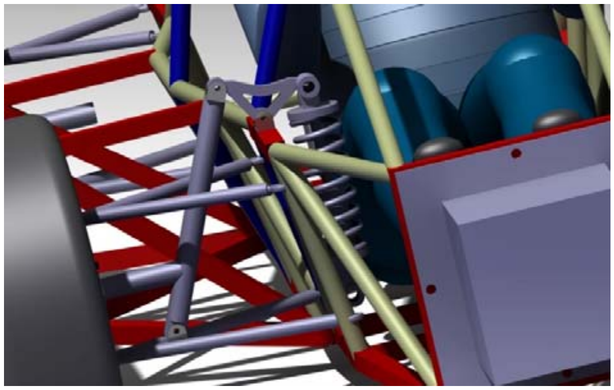
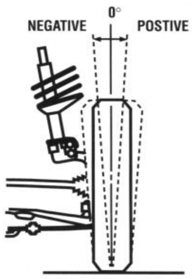


Fig. Front suspension CATIA model.

DESIGN and ANALYSIS

Most passenger cars on the market today use a form of the double wishbone, McPherson strut or multilink suspension design. Everyday passenger cars use these types of suspensions when standard handling performance is desired, as well as space and cost are taken into account. Whereas most high performance sports cars today utilize a type of unequal length double wishbone design. This type of suspension design is suited well for track use because it allows for greater adjustment and can be set up to achieve negative camber to accommodate the roll that a car encounters during hard cornering. Lengths of the wishbones determine the camber angle as shown below. This is easier to achieve with a pushrod suspension.



By using a shorter upper control arm and the correct suspension geometry, the tire will actually gain negative camber as the cornering forces increase, therefore increasing its cornering ability. The above discussed configuration can be simulated using various softwares.

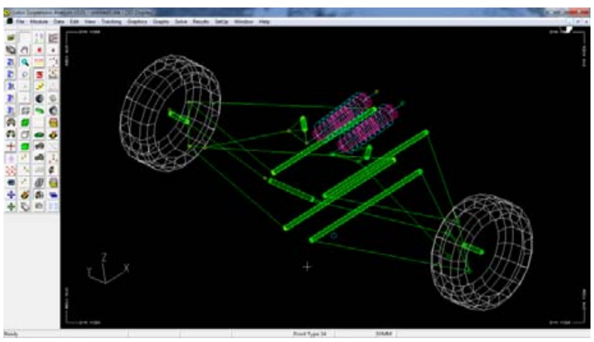


Fig.1 LOTUS simulation of a double wishbone pushrod suspension.

Design starts with the estimation of wheel travel, motion ratio and load on the springs from the wheels. These parameters can be used to determine the spring travel that has to be achieved.

$$Motion\ Ratio = \frac{Spring\ travel}{Wheel\ travel} = \frac{\Delta x_s}{\Delta x_w}$$

Motion ratio is 1 and wheel travel is 1.3 inches which gives a spring travel of 1.3 inches.

Using Hooke's law the stiffness is given as,

F=kx

Where **F** is the load acting on the wheels, **x** the deflection and **k** the stiffness of the spring.
Hence assuming 60 Kg load on the front springs, the stiffness would be around 17.83 KN/m.
For the rear, the load was assumed to be 90 Kg and the stiffness is around 26.73 KN/m.

One important factor to be kept in mind is that the angle between the pushrod and the rocker should be equal to the angle between the spring and the rocker. The forces through each component can be calculated with a simple force polygon. Since the entire system is along a single plane, the forces are calculated as below.

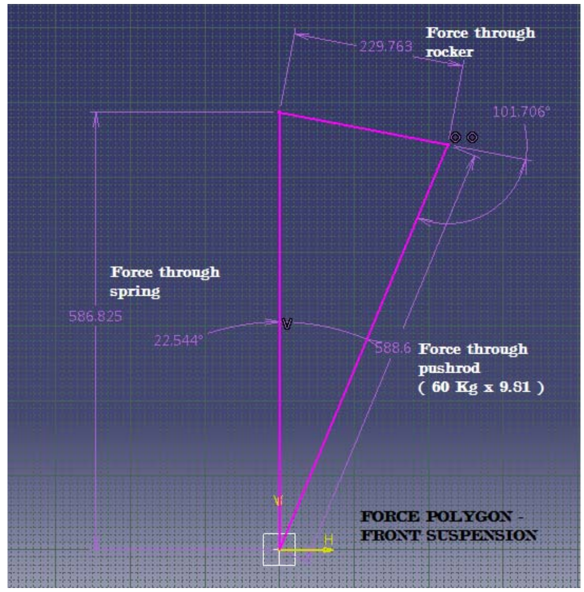


Fig. 2 Forces through front suspension.

Similarly for the rear suspension,

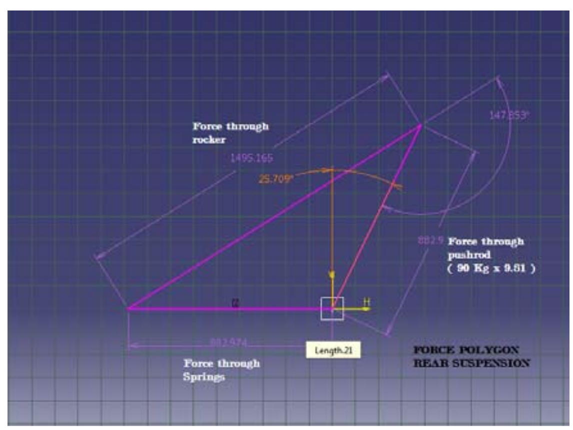


Fig.3 forces on rear suspension

From the above diagrams it is noticed that for the front system for a load of 588.6N, the force acting on the bell crank is 229.76N and the force through the spring is 588.6N.

Similarly for the rear, for a load of 882.9N, force through the rocker is 1495.165N.

Based on the forces calculated, materials for pushrods and bell cranks are chosen.

Materials for both pushrods and Bell cranks can vary. Depending on the load and an appropriate factor of safety, materials can be chosen. They could be steel aluminum or composite materials. Steel has a higher ultimate strength hence could be used for the pushrods. For the rockers, aluminum is suitable as they can do with lower yield strengths and also keep the weight of the system in check. Composite materials like Kevlar composites or Carbon composites are the best bet but cannot be used because of high cost of obtaining and fabricating such components.

Pushrod material: **SAE 4130 steel**

Dimensions	¾ inch OD, 1.5 mm wall thickness
Density	7.85 g/cc
Hardness, Brinell	197
Hardness, Rockwell B	92
Tensile Strength, Ultimate	670 MPa
Tensile Strength, Yield	435 MPa
Modulus of Elasticity	205 GPa
Bulk Modulus	140 GPa
Poisson's Ratio	0.29

Pushrod undergoes higher tensile loads hence a material with high ultimate tensile strength is chosen.

Bell crank material: **Aluminum 6061 T6**

Density	2.7 g/cc
Hardness, Brinell	95
Hardness, Rockwell	40
Ultimate Tensile Strength	310 MPa
Tensile Yield Strength	276 MPa
Modulus of Elasticity	68.9 Gpa
Poisson's Ratio	0.33
Fatigue Strength	96.5 MPa

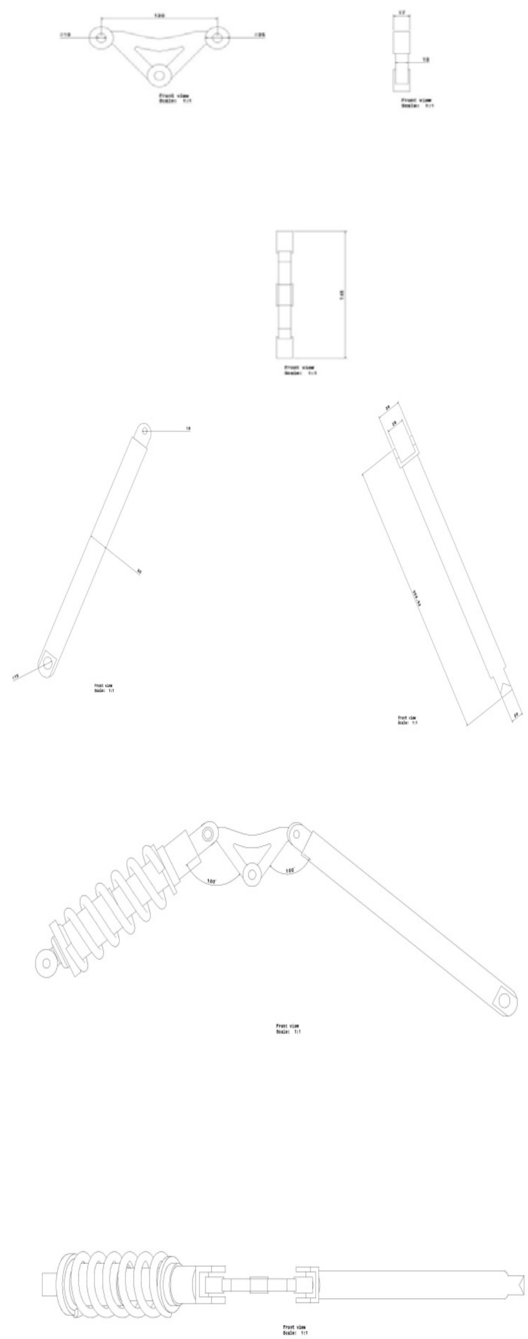


Fig.4 CATIA drafts of each component, the angles are maintained equal.

FABRICATION

The SAE 4130 is chosen for its weld ability and hence the pushrods are manufactured using a CNC laser cutting machine. A finished pushrod can be previewed by a 3D render using CATIA.

Fig.5 3D rendering using CATIA

Aluminum rockers are fabricated using a CNC machine. The dimensions of the eye of the rockers are determined by the size of the stock suspensions being used.

The finished assembly is then mounted on the chassis. The finished product would look something like this.

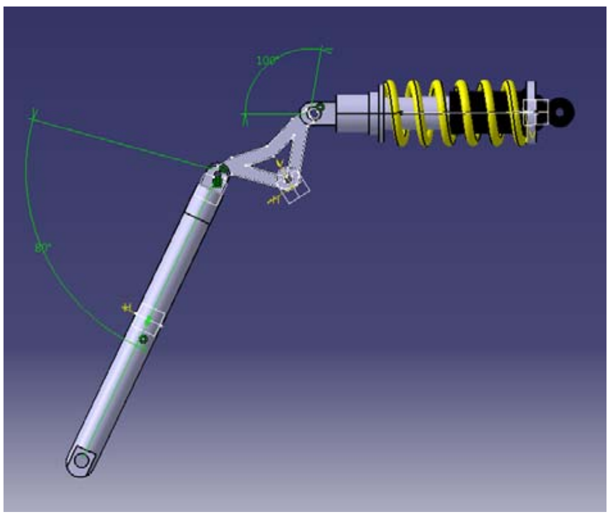


Fig 6 CATIA model of the finished assembly.

CONCLUSION

Only after the suspensions are mounted the unsprung components like the wishbones and wheels and brakes can be fixed to the car and the car can finally be lowered to the ground. This lets us determine and adjust the ride height clearance and other parameters. This also allows us to analyze the parameters dynamically which is basically dynamic testing of the car. It also allows one to adjust camber and toe in the wheels.

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