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Design and Fabrication of an Upright for Student Formula Car

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***Abstract*: This project is all about fabrication of an Upright (Suspension part) for Student formula car. An upright is a part of the wheel assembly which holds the hub and allows rotation of the wheel. The forces from the tire contact patch are transmitted by the Upright to the suspension links. We have fabricated an Upright for the Students formula competition named "SAE SUPRA" where SAE stands for 'Society of Automotive Engineers', an association which conducts this competition for various colleges and universities across India. The Upright developed and fabricated by us has 5-degree castor angle and 6-degree camber angle. These suspension geometries are explained in the upcoming chapters. A-arms are connected to the Upright which is the connection between the upright and the chassis. These are bolted to the chassis and with the Upright. The movement of the A-arms is based on the distance between their connections in the Upright. Separate Uprights are used for front and rear tires. Front upright consists of steering rod and the rear upright consists of Drive shaft connected to it. Both the Uprights has brake calipers fixed on it. The material we have used is mild steel which is cost effective and has high strength comparatively. Analysis has been done with simulation software ANSYS with the given conditions. Our main aim is to design and develop an Upright for its best performance in the racetrack and to choose the material in lowest and also satisfying the purpose.**

***Keywords*: Caliper, Degree of Freedom, Suspension.**

1. Introduction

A. Upright

An upright is a part of the wheel assembly which holds the hub and allows rotation of the wheel. The forces from the tire contact patch are transmitted by the Upright to the suspension links. Uprights are used in Automobile parts for holding the wheel hub and it controls the suspension geometry in the vehicle. The suspension geometry of a standard FSAE race car has been used for the calculation of the forces. The target values for concerning and braking have been set according to the tracks present in the FSAE International events. Tire data has been used to find out the friction coefficient at the contact patch which varies to the normal load on it.

Fig. 1. Upright assembly

B. Links in upright

A-arms are the connecting parts for the chassis and the upright. A-arms are otherwise called as Suspension arms. They are made on the basis of the calculation made in the suspension geometry. They are connected to the upright by the means of a bracket made of the required material. Front upright has the steering link where the steering rod is connected which tends to rotate the wheel in the respective directions as the steering wheel is turned. Rear upright has the fixture for the brake caliper which is fixed according to the braking calculations made and also with reference to the piston travel distance.

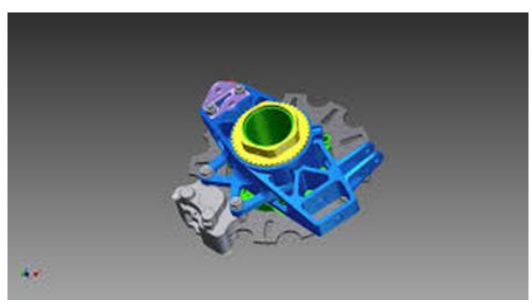


Fig. 2. Upright with brake caliper

C. Wheel hub

Wheel hub is the part which connects the wheel, Upright and the drive shaft. This wheel is also made according to the suspension parameters and developed according to the material used. Drive shaft is connected directly to the wheel hub through the upright. The drive shaft is used where the differential part has been set for the rear wheel.

Fig. 3. Drive shaft

2. Scope of the Project

Every product in this world is made with some creative designs. So, without design no product can exist in the world. We have designed this product for the student formula competition in which we had participated and learnt about quite a few things which will be established in this project.

3. Literature Review

Design of formula SAE suspension components [1] 2002-12-02 This paper is an introduction to the design of suspension components for a Formula SAE car. Formula SAE is a student competition where college students conceive, design, fabricate, and compete with a small formula-style open wheel racing car. The suspension components covered in this paper include control arms, uprights, spindles, hubs, pull rods, and rockers. Key parameters in the design of these suspension components are safety, durability and weight. The 2001 Lawrence Technological University Formula SAE car will be used as an example throughout this paper.

Dalhousie university formula SAE design report [2] 2012 The 2012 Dalhousie University Formula SAE Team is competing in Formula SAE, Michigan, for the third consecutive year. The team decided to maintain the use of 13" wheels, to provide room for the upright and A-arm configuration, despite the added weight of this larger wheel. The uprights are designed to be universally compatible with only changes to the mounting plates required in order to change suspension geometry. Finite Element Analysis (FEA) was conducted on the uprights to ensure these components could withstand the necessary applied loads with the material selection of 6061 aluminum.

Tohoku university formula team [3] 2013 In 2013, Tohoku University took part in Student Formula Japan for the first time and entered the electric car class, which is established this year. As a result, we succeed in achieving the geometry whose camber angle change is lower than 0.1 ° for stroke ± 35 mm. We also aimed to make parts as few as possible to reduce the cost and make the production process easier. Moreover, by making the process of dismantling and set up easy, we able to make time took for test run's preparations shorter.

Florida international university FSAE chassis and suspension final report [4] 2015 The team will be developing the 2015 chassis and suspension for the Florida International University Formula SAE vehicle. An FSAE chassis and suspension design is done yearly by every team that intends to compete. There are various design types that have been explored that offer their own benefits and costs. In general, the vehicle's wheelbase, which is the distance between the axis of the front and rear wheel, must be 60 inches. Typically, a small amount of negative camber is desired, as it counteracts the positive camber that is gained when the chassis rolls and results in the most amount of grip between the tire and the road when cornering [2, 4]. Toe-in increases front line stability of the vehicle, while toe-out generates better turn-in and cornering response. Toe angles are typically tuned on vehicle based on the track [4].

Vehicle wheel suspension knuckle assembly Jin-Yeng Lin [5] 2016 A vehicle wheel suspension knuckle assembly to match with car spring system in suspending a car wheel, which includes a treble knuckle comprising an upper pivot hole for connection with a car wheel at a point opposite to the car suspension system, an intermediate pivot hole for connection to a car frame through a forked suspension knuckle arm, and a bottom pivot hole for connection to the same car frame through a lower suspension knuckle arm. While running through uneven ground surface, the car wheel will be respectively driven by the suspension knuckle assembly and its original suspension system to constantly maintain the wheel in a vertical position.

Method of mounting a wheel hub bearing assembly to the knuckle of a vehicle suspension standard, andreas rutter, [6] 2017 There is disclosed a method of mounting a wheel hub bearing assembly to the knuckle of a vehicle Suspension standard by forcefully inserting the outer race of the bearing in a bore in the knuckle. The Snap ring is fitted over the hub at an axial location between the axially outer end portion of the bearing outer race and a portion of the hub facing said end portion; at least one axially tapered sliding surface is provided between said facing portions. The Snap ring is radially compressed on the tapered sliding Surface to the radial dimension of the knuckle bore, whereby the tapered sliding Surface cooperates Such that the radial compression of the Snap ring sets an axial preloading to the axially inner set of rolling elements. Finally, the hub is pressed to fit the bearing in the knuckle bore and the Snap ring into the knuckle groove.

From the above literature's we could understand that the suspension geometry plays a vital role in the performance of the race car. So, our project comes into which these geometries can be adjusted to provide an efficient performance at low cost material. Even though, suspension components are attached to the chassis of the car, there should be minimum vibrations attracted towards it. This can be achieved by the adjusting the camber and castor angles. For the focus in Students formula competition, we have developed an upright with the suitable performance.

4. Description of Equipment's

A. *Steel material*

It is an alloy made from Iron and Carbon. There are over 3,500 different types of steel, which can be separated into four groups depending on its chemical content or metal alloy contents.

Steel is an alloy but it is the level of impurities and elements such as nickel, magnesium, molybdenum, silicon, copper, vanadium that helps to determine the grade of each steel.

For Example: MS 1018, MS 1020 etc. MS 1018.

AISI 1018 mild/low carbon steel has excellent weld ability, produces a uniform and harder case and it is considered the best steel for carburized parts. AISI 1018 mild/low carbon steel offers a good balance of toughness, strength and ductility. AISI 1018 hot rolled steel has significant mechanical properties, improved machining characteristics and has a high Brinell hardness measure.

B. Machinability

The machinability of AISI 1018 mild/low carbon steel is graded at 78% of B1112.

C. Weldability

AISI 1018 mild/low carbon steel can be instantly welded by all the conventional welding processes. Welding is not recommended for AISI 1018 mild/low carbon steel when it is carbonitrided and carburized.

Low carbon welding electrodes are used in the welding procedure. Post-heating and pre-heating are not necessary; although pre-heating can be performed for sections over 50 mm. Post-weld stress-relieving also has benefits, like the pre-heating process.

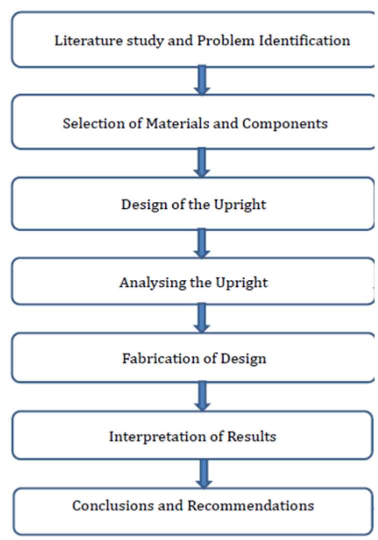
5. Design Parameters

A. Design parameters to be considered before designing of an upright component

There are various parameters that are to be included in it. Irrespective of other details the main design parameters determine mostly the performance, adaptability with the environment, mates with the sub-component in an assembly, space occupancy etc. They are Special consideration and often are the constraints which are to be met. The parameters that molded the design of the upright were:

1. Include castor angle of 5 degree along the vertical axes of upright.
2. Project the brake caliper mounts at one side of upright.
3. Provide sufficient thickness to brake caliper mounts to endure sudden torque from the disk rotors.
4. Check alignment of the brake caliper mount on both of the uprights i.e. Left and Right uprights. Since the brake caliper doesn't have plane of symmetry along its center, brake mounts will have different spacial arrangements along the side of both uprights.
5. Steering arm mount be on the opposite side that of the brake caliper mount of the respective uprights.
6. Twin steering arm mount be provided to facilitate double shear for steering arm bolts.
7. Dual bolt holes will be provided to counteract the moment in the steering arm.
8. Have sufficient fillet radius throughout the design to minimize notch sensitivity.
9. Length of upright will be taken as per the suspension design that gave the optimum results.
10. Upper and lower wishbone mounting will be dependent on the kingpin inclination obtained from the suspension geometry.
11. Bore is provided to accommodate the stub axle.
12. Press fitting tolerance to be provided in the central bore diameter to press fit the stub axle.
13. Enough wall thickness to make the component rigid, unsusceptible to external moment.
14. Design optimization will be done after the component is analyzed for various loading cases to relief weight.

6. Methodology



7. Design Calculation

A. Force calculation

For the calculation of loads and load paths in wheel assembly, we need to take parameters from the geometry of the car, the track and the procured components such as Tire-data. The following data have been obtained from standard FSAE race car:

The acceleration during various actions of the car (i.e. braking, cornering and throttling) are calculated using three equations of motion, considering acceleration as constant throughout the particular event. Data from Suspension Geometry.

$$v = u + at$$
$$s = ut + \frac{1}{2}at^2$$
$$v^2 = u^2 + 2as$$

The braking acceleration is calculated when the car de-accelerates from a speed of 60kmph to 0kmph in a braking distance of half the skid-pad circumference. Similarly, lateral acceleration is calculated assuming the maximum cornering speed as 40kmph and a lateral acceleration of around 1.4g has been obtained. The various speeds assumed are from standard FSAE race cars participating in the event. The coefficient of friction has been obtained from tire data which varies according to the normal load on the tire (FZ).

B. Calculation of the forces during various maneuvers

The upright takes longitudinal force during braking and acceleration, and lateral forces during cornering. Hence, extreme forces are considered for a situation, when the car brakes during cornering. The total amount of traction is considered constant. The Circle of Traction shows the total amount of traction distributed between lateral forces and longitudinal forces.

1) longitudinal force calculation

The longitudinal forces are developed by an upright during acceleration and deceleration. It is evident that a driver experience more g's of force during deceleration (braking). The mass transfer during braking has been calculated using the following equation: (Mass Transfer) * 'g' * Wheel Base = (Mass of the Car) * Braking g's * 'g' * Centre of Gravity (Z). The coefficient of friction is a variable obtained from the tire data which depends on the net normal force, FZ after mass transfer. The system is considered as a beam with Frictional Force and the reaction forces on upright.

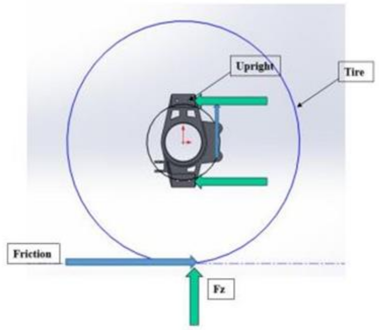


Fig. 4. FBD during Braking (Side View)

The distances between the reaction forces and frictional force are obtained from the Suspension Geometry and Tire Specifications (such as Tire Diameter, Aspect Ratio, etc.) The equations were put in MS Excel and the longitudinal forces during braking were obtained.

2) Lateral force calculation

The lateral forces are developed by an upright during cornering or while steering. The mass transfer during cornering has been calculated using the following equation:

(Mass Transfer) * 'g' * Track Width = (Mass of the Car) * Cornering g's * 'g' * Centre of Gravity (Z). Since the track-width of front and rear are different the load transfer is different in both cases. The reaction forces here as well are calculated considering beam structure. And the distances were again taken from the data extracted (Tire Data, Suspension Geometry, etc.).

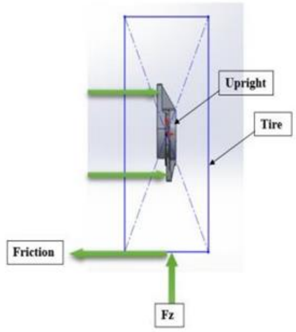


Fig. 5. FBD during cornering (Front view)

3) Linkages force

The linkages in a corner of a FSAE race car consist of two wish-bones having four links, a tie/toe rod and a push/pull rod. The tire forces are transferred to the links through upright. Since there are no bending forces, axial forces are developed in all linkages.

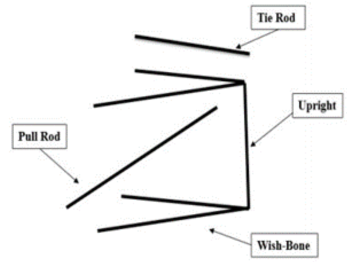


Fig. 6. Linkages in corner of car

A model has been generated which can be used for any suspension geometry just by changing the coordinates of the suspension point and other vehicle parameters such as mass of the car, center of gravity distance, weight bias etc. Manual calculations have been developed to calculate the forces on all the links. Factor of safety for each link has been calculated by using the forces obtained by FEA Analysis. These forces are essential to design the upright and other suspension components such as upright clamps, bell cranks, hubs for any car using double wishbone suspension

8. CAD Design

A. Front upright (left)

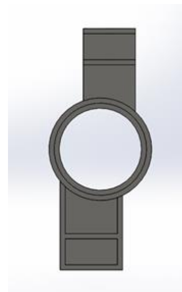


Fig. 7. Front view of Left front upright

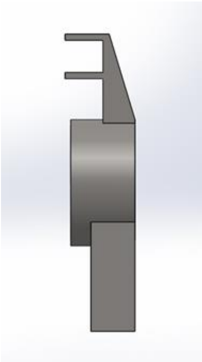


Fig. 8. Side view of Left front upright

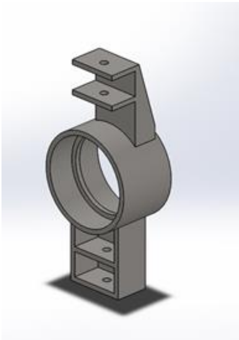


Fig. 9. Isometric view of left front upright

B. Front upright (Right)

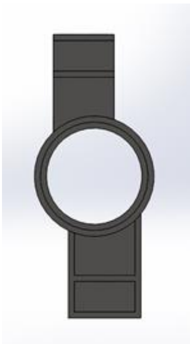


Fig. 10. Front view of Right front upright

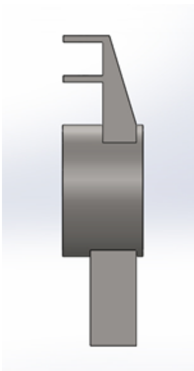


Fig. 11. Side view of Right front upright

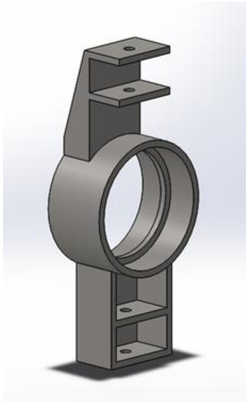


Fig. 12. Isometric view of Right front upright

C. Rear upright (Left)

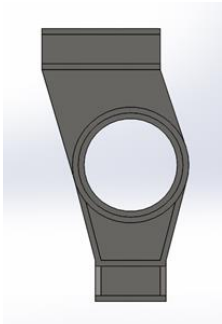


Fig. 13. Front view of Left rear upright

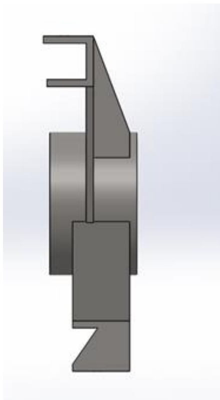


Fig. 14. Side view of Left rear upright

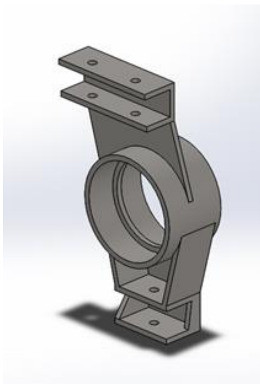


Fig. 15. Isometric view of Left rear upright

D. Rear upright (Right)

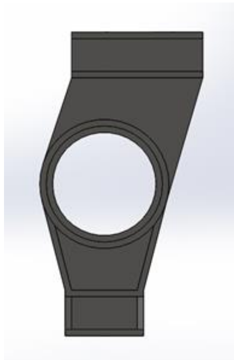


Fig. 16. Front view of Right rear upright

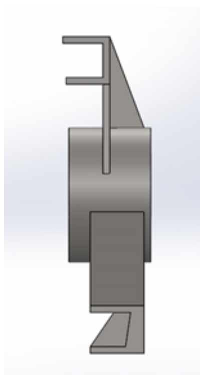


Fig. 17. Side view of Right rear upright

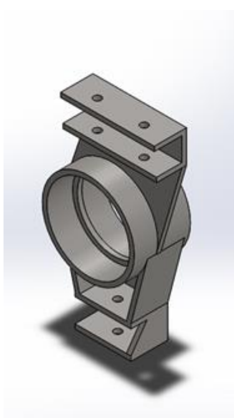


Fig. 18. Isometric view of Right rear upright

9. Analysis

A. Static analysis results

The results of the static analysis showed that the factors of safety for the front and rear uprights were 1.13 and 1.26 respectively. The maximum deformation for the front upright was 0.59587mm and for the rear upright was 0.33695mm.

B. Equivalent stress analysis

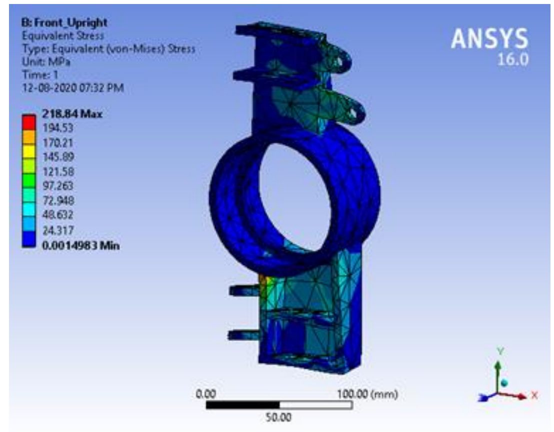


Fig. 19. Static Stress analysis result for front upright (Maximum=218.84Mpa)

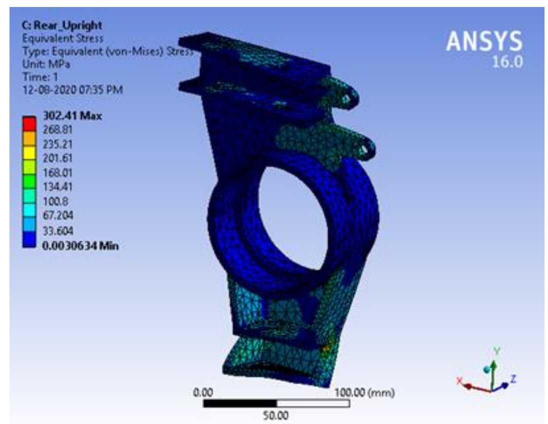


Fig. 20. Static Stress analysis result for rear upright (Maximum=302.41Mpa)

C. Total deformation analysis

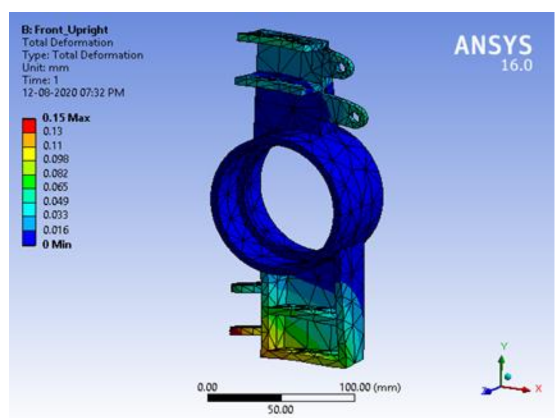


Fig. 21. Total Deformation analysis result for front upright (Maximum=0.15mm)

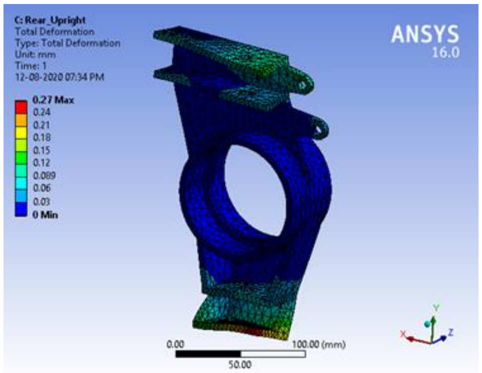


Fig. 22. Total Deformation analysis result for rear upright (Maximum=0.27mm)

D. Factor of safety analysis

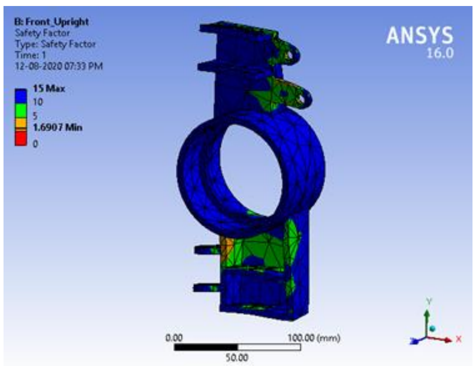


Fig. 23. Factor of Safety of front upright (Min=1.6907, Max=15)

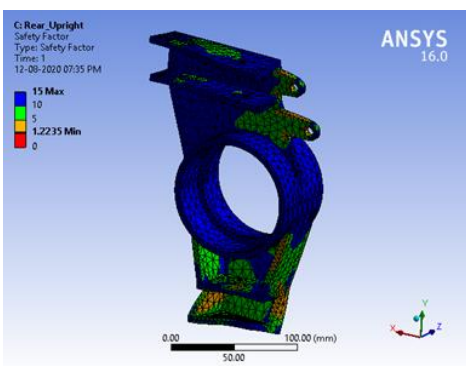


Fig. 24. Factor of Safety of rear upright (Min=1.2235, Max=15)

E. Shear stress analysis

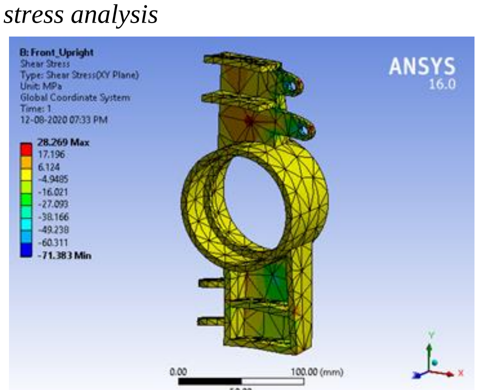


Fig. 25. Shear stress analysis of front upright (Max=28.269MPa)

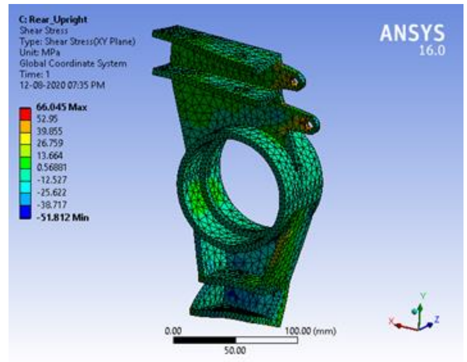


Fig. 26. Shear stress analysis of rear upright (Max=66.045MPa)

10. Fabrication of Upright

A. Fabrication process

The Upright is made of MS 1018 by the following operations

- Facing
- Turning
- Boring
- Drilling
- Cutting
- Welding

Fig. 27. Fabricated upright

The Fabrication process starts with the facing of the MS plate of thickness 6mm respectively. 1mm is removed by facing. A hole is made at the center of dia 40mm for the seating of the bearing. The holes are drilled as described in the design.

Then according to the resulted castor angle of 5 degree and camber angle of 6 degree a hole of 4mm has been drilled on top of the plate

Each pieces of the upright have been fabricated using the Laser cutting process with the CAD drawings.

B. Assembling process

The Upright and the sub assembly parts are assembled together. The sub assembled parts are 2 X SKF ball bearings, Wheel hub. These are assembled together.

C. Advantages

1. Feasible to use (easily remove and fix the wheel).
2. Economically low cost for production.

3. Strength to withstand high torque is increased.
4. Easily weldability.

D. Applications

1. Upright is used between the tire (wheel hub) and chassis of the Formula student car to hold the wheel and to connect the wheel to the transmission shaft.
2. Upright is also used to mount the A arms to the chassis.
3. It controls the suspension geometry of the vehicle.

11. Future Scope

Upright is now fabricated by the material of MS 1018 but in the future the material can be changed as ANSI 7075-T6 which is of increased strength and the design can also be optimized by removing the unwanted material after changing the material. If the material used (ANSI 7075-T6) according to the cost requirements the upright will be developed which will have less weight without sacrificing the strength.

Also, design change can be made in which material reduction and structural change can be driven to get the optimized component.

12. Conclusion

Lighter weight of upright assembly and required stiffness is achieved by optimum design calculations and less complex design. Proper material selection of AISI 1018 is important factor in reducing the cost of the component which is the main aim of our project without sacrificing the strength and hardness of the component.

Analysis of upright component is done by using ANSYS software and results obtained from analysis are within limits of requirement. Means, Upright assembly proves its stiffness and durability under stress consideration. Thus, Good performance to weight ratio is achieved.

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