Design and Analysis of Suspension Component of F1 Prototype
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Abstract— Suspension is an important part of vehicle design whose function is to absorb the shock. This paper is for design and analysis of suspension systems related with student formula one vehicle including wishbones, damper, bell crank, push rod. This research includes all design considerations, calculations and implementation of various components used in the suspension systems. Suspension systems are designed to meet international standards considering with all safety features. The important factors which are considered during design are for high performance and safety. Various technical requirements are considered for applying boundary conditions that remain effective at very high speed more than 100 km/hr. The design of complete vehicle is started with design of major components individually with reference of other components. Components were modeled in Catia V5 and their analysis is done on FEA solver Hypermesh. The dynamic analysis of suspension is done on Lotus Shark software. This study help to evaluate suspension parameters which effect loading of roll cage at the time of cornering and other static frame members to develop suspension system for student formula one vehicle in accordance with the rulebook of SUPRA 2016 provided by SAE India.

Key words: Formula One Prototype, Bell Crank, Load-Transfer, Lotus Shark V5.01, Von-Misses Stress, Displacement

I. INTRODUCTION
The suspension system is one of the most important systems to consider when designing a car. All accelerations, either lateral or longitudinal, must be put to the ground through the tires, which are held in contact with the ground by the suspension system. The suspension system must therefore keep the largest contact tire patch at all times. If the suspension will not work properly, the car will not perform up to its full potential. A good suspension therefore incorporate a good kinematics design to keep the tire as perpendicular to the pavement as possible, optimal damping and spring rates to keep the tire on the ground at all times, and strong components that do not deflect under the loads induced upon them. So, suspension components are designed using the rulebook which is provided by SUPRA SAEINDIA in which rules are defined using which component designed and other criteria and then analyzed in Hyper mesh software to obtain final optimized components of suspension system. This paper includes the systematic approach required for designing of various components using space in Lotus Shark. Geometry used in paper for reference is double wishbone push rod actuated suspensions and components taken in consideration include knuckle, hub, wishbones, bell cranks and push rods. All forces for analysis are calculated on the basis of worst condition of car discussed in further articles. Apart from this, various geometry angles are also calculated from suspension geometry analysis and are used as reference for designing of hub and knuckle. SUPRA SAEINDIA is a national design competition held annually by the society of automotive engineers. Vehicle which is designed is a prototype of F1 car.

II. DESIGN OF SUSPENSION
A. Suspension Geometry
While designing suspension components, there is requirement for proper double wishbone suspension geometry, which provide proper hard points needed to be taken care for designing of other components. For generating the suspension geometry for the vehicle, we need certain dimension which we have to use as per rulebook and some as per assumption. Along with analysis in software, geometry is also checked in CAD software for compliance of all set parameters. CATIA V5 is being used for checking geometry. Geometry is transferred to Catia v5 from lotus shark through 3D coordinates generated in lotus shark.

Fig. 1: CAD Model
Fig. 2: Actual model of supra vehicle
Fig. 2: Suspension component in lotus shark
Both views of geometry developed in Cad software are analyzed and checked to ensure the hard point which we get are same or, not after that other component are designed. Which we have to use as per rulebook and some as per assumption including track width, wheelbase, tire specifications, and type of suspensions using in vehicle. As
per rulebook the smaller track of the vehicle (front or rear) must be no less than 75% of the larger track. The car must have a wheelbase of at least 1525 mm (60 inches). The wheels of the car must be 203.2 mm (8.0 inches) or more in diameter. The car must be equipped with a fully operational suspension system with shock absorbers, front and rear, with usable wheel travel of at least 50.8 mm (2 inches), 25.4 mm (1 inch) jounce and 25.4 mm (1 inch) rebound. So we take track width for front 1350 mm and rear track 1200 mm, wheelbase(62 inch). After fixing all these parameters, data is transferred to suspension analyzing Software Lotus Shark.

The above figure represents front view of front suspension geometry obtained from analysis in lotus shark analyzer and then draw in Catia V5 which gives the hard point after that these point are plotted on frame for mounting of wishbone, from this we obtain optimum values of different other parameters like castor, camber, toe, kingpin inclination and their change during different dynamic conditions. After obtaining a proper geometry we have hard points or suspension mounting points which we have to be implementing on frame. In push rod actuated suspension system, the mounting points of spring and dampers are not that critical as hard points of wishbones. For complete geometry we require damper, rocker and push rod mounting point.

B. Damper

For the designing of damper we required that it could we capable of taking vehicle weight and give the jounce of 25.4mm and rebound of 25.4mm. Its stiffness could not be too high so that it will not be able to damp or absorb the shock and number of coil per turn in spring is also very important while designing the spring because according to that length of spring decided and then it is checked in that number of coil it will be able to resist the force coming on vehicle. In damper designing weight consideration is very important as we designing the F1 prototype, as the weight of the vehicle kept low its efficiency will be more, so in every component designing we have to check about material. By using lighter material which is stronger in strength, we can reduce the weight of vehicle.

III. LOADING CONDITION

While talking about F1 cars, the most fascinating thing is speed. Turning at very high speed led to development of high centrifugal forces on the body. Now, the turning is always linked with a lateral transfer of weight in body. Similarly, braking led to a weight transfer along the longitudinal axis. So, combining the both, worst condition is taken as braking while cornering. So, we encounter effects of both, lateral transfer as well as longitudinal transfer which will develop maximum force in one of wheel. Besides, the racing tire is capable of generating almost equal force in acceleration, deceleration or cornering. The determination of loading forces started with tire data and loading conditions.

The forces are translated from the contact patch to the upright pickup points into the A-Arms axially. Since a double A-Arm suspension has six members to it. These six members are the upper A-Arm (2 members), the lower A-Arm (2 members), the tie rod and the push rod, which will be attached to the lower A-Arm and act through the lower upright ball joint. Summing forces in three directions and moments about three axes yields the axial forces in each tension-compression member for each given set of tire contact patch forces. These forces are transmitted as reaction forces on the chassis through the A-Arm, which act as axial forces on each member. The first case was calculated using what was assumed to be worst case loading conditions of 1.5g’s lateral acceleration, 1.0g longitude acceleration, and 3.0g’s of bump after calculating these forces through certain formula we get the value of forces and these value are fed into analyses software, like Hypermesh which takes into account yield and buckling, and also includes deflection of the A-Arms.

IV. DOUBLE WISHBONES

The Wishbone is also called A-arm. Wishbones can be used in an all-wheel independent suspension setup. Because two rods are used on the two mounting points it is called a double wishbone setup. The upper arm is usually shorter to
induce negative camber as the suspension jounces. In automobiles, a double wishbone (or upper and lower A-arm) suspension is an independent suspension design using two (occasionally parallel) wishbones shaped arms to locate the wheel. The double wishbone or four bar linkage suspension configuration is probably the most widely used racing suspension design and also makes up a significant proportion in the domestic market. The ends of the two wishbone arms and top end of the shock absorber will mount to the chassis.

A. Analysis of Wishbone

The wishbone are analyzed in Hyper mesh software as per dimension obtained from CATIA V5 after that A-Arm are analyzed in hyper mesh software for determining the stress, displacement in A-Arm. Meshing of A-Arm is also done by considering the forces and the boundaries condition. In this 2D meshing is done considering element size 2 mm and analysis is done in static condition. The following figure represents the analysis of wishbone. Since A-arms are made of rod shape material, for better strength, aluminum is not suitable hence AISI 1018 steel is used for analysis.

![Displacement in A – arm](Image1)

![Stress in A - arm](Image2)

![Meshing in A – arm](Image3)

![A – arm CAD Model](Image4)

Which has yield strength of 472 N/mm² and of density 7800 kg/m³. The maximum stress developed in most loaded wishbone comes out to 2.53 * 10⁴ N/sqm which gives a minimum factor of safety as 1.8. Beside stresses, displacement is also considered in designing. Before checking results it is kept in consideration that in wishbone the allowable deformation is more as compared to upright. In similar manner, all 8 wishbones are analyzed and checked for stability. In case if strength is found insufficient, iterations can be made in diameter or material to achieve optimum strength.

V. Upright

The upright design relies heavily on the choice of bearing and spindle assembly. There are many different ways to configure the half-shaft/spindle interface, mostly due to the live spindle, which is required for a rear upright. Some upright designs incorporate a larger bore in the center to encompass an entirely concentric CV joint/bearing combo. Such a design allows for longer half shafts, which has a few advantages, one of these being a less extreme angle for the CV joint to deal with. We decided this design for a number of reasons. Firstly, it is a easy setup to manufacture it is fitted with press fits. Secondly, placing the CV joints inside the upright would give better support to shaft and full power to wheel. Bore is drilled in middle of upright for fitting the bearings to reduce the power loss. This not only saves weight with smaller bearings, but also allows us to use tapered roller bearings to transfer thrust loads due to lateral grip forces.

![Front upright and rear upright](Image5)

A. Material for Upright

Material decisions were initially looked at for strength and weight. The uprights are typically constructed either from sheet metal or aluminum and these two options are examined to determine best suited for this project. 4130 normalized steel has high strength and stiffness properties relative to those of 6061 aluminum, but the 6061 can have weight advantages over steel, which is the primary area of concern. These properties will drive geometry alterations for the initial upright design. To pick the best design, the models are imported in FEA software to more accurately predict stresses and stiffness. Relative cost of the materials it was determined that on the basis of just raw materials, the aluminum upright materials would cost about twice as much as those of the sheet metal uprights.

![CAD Model of Upright](Image6)

B. Analysis of Upright

Upright is a link between static and dynamic assemblies of vehicle, so analysis of upright is a critical issue. Upright is subjected to many forces. Mounting points in upright experiences forces from suspension wishbones, brake calipers and also from steering tie rod, in front. Since a front upright completely depicts all the forces including the steering forces. Beside this consideration for upright connections to hub via a bearing which may also be taken as a source of loading is taken. Present analysis of knuckle involves two different considerations. First type of analysis is done considering bearing portion to be fixed and applying force in other parts. Front knuckle is used for this analysis. For calculation of forces centre is assumed to be fixed and need to consider forces from suspension arms. The torque from braking caliper is calculated by knowing the brake components specifications, using Pascal’s law.
VI. PUSH ROD

Push rod is used to transmit motion from wheels to bell crank. Basically two different type of actuating mechanism is used in F1 cars. These are push rod and pull rod type actuating mechanism. For this paper push rod is taken in consideration because of the fact that it is more aerodynamic as it reduce the area and above all Push rod is actuated by a compressive force. So, it’s good for strength of system. The length of push rod is decided by the suspension geometry. As push rod is acted upon by a compressive force, it needs to be analyzed for compressive strength and buckling strength. For analysis it is assumed that max load is acting on push rod during cornering and braking and motion is restricted at the other end. Maximum force acting on push rod is taken as 250kgf for worst condition and maximum normal reaction based on conditions described above. For push rod analysis AISI 1018 is used for analysis.

A. Analysis of Rocker Arm

The maximum stress induced is 2.10*10^1 N/sqm and minimum factor of safety obtained is 2.0. So, it can be considered well for design. All things have to be considered while doing analysis for rocker arm because it has to be transfer the load properly. Its material should be strong, lighter in weight which can withstand large forces/stress at bump and braking time and transfer the load properly to damper so that it could be damp properly and absorb shock.

VII. ROCKER ARM

Bell crank or rocker arm is basically the link between push rod and the damping mechanism. Its function is to transfer force from push rod to spring dampers. The bell crank is made of Aluminum 7075 T6 for reference. The bell crank is also designed on the basis of suspension geometry made, by taking the hard points.

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**Table: Result Definition and Values**

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VIII. CONCLUSION

After going through various components of suspension and the paper lay down a methodology for analysis of different components and their designing which help the student in understanding component designing procedure. This paper also give the idea for some critical components in which more than one method are employed to ensure the durability of design. These analysis steps need to be followed many time in single component to obtain a perfect model. Since, the paper covers methodology for analysis of different components along with introduction to load calculation in most of the cases. This paper helps for designing and analyses of suspension component to get better design result and helps in how to do analyses of various suspension components in software to achieve the better result. At last we obtain the best design with good factor of safety and minimum stress in component.

REFERENCES