ANALYSIS OF STUDENT FORMULA CAR FOR OPTIMUM SAFETY AND PERFORMANCE

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ABSTRACT

The Formula Student competitions are held every year. This paper is the result of the analysis done on the sample car design that can be presented in the Formula Student competition. The purpose of the paper is to provide a final summary on chassis analysis and structural performance. It also talks about all the important analysis that is to be done on a Formula Student car to make it safe and perform well on the track. The design has been made such that it focuses on maximum adjustability, reliability, performance, safety, weight reduction and ease of manufacturing. The analysis was done to make sure the objectives of design are fulfilled.

After going through many papers, documents, blogs and videos we found that many people get confused about the loading conditions and boundary conditions for different types of tests so this paper prioritizes to make people understand about those conditions as well as about the major tests required to perform complete analysis of Formula Student cars.

The weight of the chassis was calculated as 36 kg approximately according to the data obtained from design modeler of Ansys workbench as well as Solidworks. The design sustained all the loading conditions and passed all the tests. Thus, one of the objectives of this paper is to help other universities and passionate students to successfully design and analyze their cars that can pass all necessary tests included in the paper.

KEYWORDS—Formula Student; FEA; Boundary Conditions; Loading Conditions; Ansys; Solidworks

I. INTRODUCTION

Formula student competitions are organized every year at different levels and at different platforms to give the opportunity to students to have a hands on experience on vehicle design, analysis, fabrication and management.

The most popular events being the Formula SAE and Formula Student competitions. The main motto of this competition is that the students have to build and represent their vehicles in such a way that people are likely to buy their products and invest in their future ventures. Thus it also gives the students to showcase their managerial and marketing skills along with the technical skills. The car is expected to perform well in case of ergonomics, acceleration, braking, maintenance etc. The vehicle is also assumed to have a proper security for drivers as well as the people around it. The car is designed for 5th percentile female to 95th percentile man. The impact attenuators, side impact members and other supporting members are essential in ensuring the security and safety of the vehicle as well as the driver. Also the main aim of the chassis analysis is to do the weight optimization as well as making it cost effective and make sure that it is able to withstand all the necessary forces.

This paper is Casted from the work done for Formula Bharat 2019 competition. The work submitted through this paper is the result of the study from different papers as well as books based on chassis design and analysis. Formula Student basic rules, load estimation method, study of stresses and modes of load transfer, concept of deformation, boundary conditions, etc. are taken care off and has been explained in as short as possible way to help other new interested candidates to perform the FEA analysis on their formula cars.

II. MATERIAL SELECTION

Material of chassis was selected as AISI 4130. The factors that dominate in selection of material were its availability and uses in past competitions. After analysis the material properties, cost and other significant factors AISI 4130 was our best option.
| S.N | Property          | Value               |
|-----|-------------------|---------------------|
| 1   | Young's Modulus   | 205e+09 N/m²        |
| 2   | Poisson Ratio     | 0.29                |
| 3   | Density           | 7850kg/m³           |
| 4   | Yield Strength    | 435MPa              |

### III. SOLID MODELLING

The major steps for any analysis is to find the force approximation, selection of material properties, preparing models and analyzing it. The cad model was designed in Solidwork software. The design was made as per the latest rule book specifications. Manikin was also created using anthropometric data and checked under realistic condition. After many iterations the cad model was proposed as shown below.

The tubular space frame chassis model was made of up round hollow cross section tubes of AISI 4130 steel throughout chassis.

### IV. FINITE ELEMENT ANALYSIS

**Fig 1. Thickness and diameter of chassis**

**Fig 2. Dimension of chassis modelled in Solidworks**

**Fig 3. Steps in FEA analysis**
The process of modelling is followed by finite element analysis since the model can be tested and validated. There are other methods such as finite volume method or finite discretization method but we have adopted FEA because of its role in the world of solid mechanics where the equations are dominated with elliptical equations and we are acquainted with it thus making it much familiar. The software we chose for this is Ansys workbench. Ansys is one of the most popular FEA software environment.

The whole model is discretized and the frame is subdivided into elements. The nodes are kept at important points and joints. A meaningful full result is only obtained when orientation, size of element number, load condition and boundary condition are properly dealt.

V. MESHING

Meshing is the process of dividing the whole domain into number of elements so that the loads can be distributed properly to approximate the domain.

### TABLE II.

| S.N | Mesh Quality |
|-----|--------------|
|     | Mesh Detail | Value |
| 1   | Mesh type   | Linear tetrahedral |
| 2   | Mesh size   | 5mm |
| 3   | Skewness    | 0.15 (0-1) where 0 being the perfect result |
| 4   | Aaspect Ratio | 0.9 (0-1) where 1 being the perfect result |

VI. MAJOR FEA ANALYSIS PERFORMED ON CHASSIS

Below are the list of major FEA analysis that are performed on Formula Student car chassis to test its functionality and safety. The loading conditions and boundary conditions have also been explained in the table.

### TABLE III.

| S.N | Tests performed | Boundary Conditions | Loading Conditions |
|-----|-----------------|---------------------|--------------------|
| 1   | Static Shear    | Clamping of rear suspension mounts | Downward force at front bulk head in downward direction. |
| 2   | Acceleration Test | Clamp-front and rear suspension mounts | Force on main roll hoop and front roll hoop in direction opposite to motion of vehicle. |
| 3   | Static Torsional | Clamp-diagonally opposite rear suspension mounts | Force on diagonally opposite front suspension mounts. |
| 4   | Static Overall Bending | Clamp-front and rear suspension mounts | Uniformly distributed loading at driver cabin, engine bay and drive-train section. |
| 5   | Front Impact    | Clamp-rear suspension mounts | Uniformly distributed load on front bulkhead. |
| 6   | Rear Impact     | Clamp-front suspension mount | Uniformly distributed load on rear bulkhead. |
| 7   | Side Impact     | Fix one side of frame | Uniformly distributed loads on side members. |
| 8   | Roll Over       | Fix the lower part of frame | Force at top most part of front roll hoop at angle of 45°. |
| 9   | Modal Vibration Analysis | Clamp-rear and front suspension points | Give the displacement obtained from modal input analysis as to the vibration analysis. |

VII. RESULTS

The results of FEA analysis are given in a tabular form. The input loading conditions has also been explained to help other students to do the analysis on their own and have better understanding of loading conditions.

A. Static Shear Test

Shear test is performed to check the structural integrity of the body.

### TABLE IV.

| S.N | Load Parameters | Value | FOS |
|-----|-----------------|-------|-----|
| 1   | Force(weight of impact attenuator + drivers legs +Steering system +miscellaneous weight) | 1500N | 2.9 |
**B. Acceleration Test**

 Acceleration test is performed to check whether the main roll hoop and front roll hoop can withstand the inertial forces or not.

| Table V. S.N | Load Parameters                          | Value       | FOS |
|--------------|-----------------------------------------|-------------|-----|
| 1.           | Force due to acceleration of vehicle considering weight of driver and engine | 1600N       | 2.8 |

Calculation of Stiffness:
1. Force(F)=Mass of car * ‘G’ force
   Force= 280*3*9.81
   Force= 8240.4 N
2. Maximum displacement on suspension points in vertical Y-axis (D)= 1.56 mm= 0.00156 m
3. The length between diagonally opposite suspension points where loads are placed (L)= 0.45 m
4. Angle of twist(\(\Theta\))= \(\tan^{-1}(D/2*L)\)
   \(\Theta\) = 0.397°
5. Torsional Stiffness= (F*L)/\(\Theta\)
   Torsional Stiffness= (8240.4*0.45)/0.397
   Torsional Stiffness= 9340.5 Nm/degree

**C. Static Torsional Test**

The static torsional test is done to find the deflection on suspensions in y direction so as to find the torsional stiffness of the chassis.

| Table VI. S.N | Load Parameters                         | Value       | Torsional stiffness | FOS |
|---------------|----------------------------------------|-------------|---------------------|-----|
| 1.            | Force acting due to dynamic suspension loads | 3G          | 1.56mm              | 9340.5 Nm/degree | 1.8 |

**D. Static Overall Bending Test**

The static bending test is to find the stresses at points where maximum bending effect takes place so as to find its ability to withstand bending forces.

| Table VII. S.N | Load Parameters                          | Value       | FOS |
|----------------|-----------------------------------------|-------------|-----|
| 1.            | Force due to weight of parts in driver cabin, engine bay and drive train sections. | 1600N       | 1.5 |
E. Front Impact Test
This test is performed to check whether the frame structure is capable of taking the frontal impact from collisions.

| S.N | Load Parameters                                      | Value | FOS |
|-----|------------------------------------------------------|-------|-----|
| 1.  | Force due to impact at 15 m/s with time of impact 0.3 s | 16000 N | 1.2 |

**TABLE VIII.**

Fig 8. Von-mises stress during Front Impact Test

F. Rear Impact Test: The rear impact test is performed to check the structural integrity of the rear part during collision at rear part.

**TABLE IX.**

| S.N | Load Parameters                                      | Value | FOS |
|-----|------------------------------------------------------|-------|-----|
| 1.  | Force due to impact at 11 m/s with time of impact 0.3 s | 11734 N | 1.2 |

Fig 9. Von-mises stress during Rear Impact Test

G. Side Impact Test
The side impact test is done to make sure the driver will be safe even if the car is hit by another body as the loads will be taken by side members.

**TABLE X.**

| S.N | Load Parameters                                      | Value | FOS |
|-----|------------------------------------------------------|-------|-----|
| 1.  | Force due to impact at 10 m/s with time of impact 0.3 s | 10670 N | 1.3 |

Fig 10. Von-mises stress during Side Impact Test
**H. Roll Over Test**

The roll over test informs us about the stability and safety of structure of car during bumps and shocks.

| S.N | Load Parameters                  | Value | FOS |
|-----|----------------------------------|-------|-----|
| 1.  | Force due to bumps and suspension shocks | 3G    | 1.3 |

**Fig 11. Von-mises stress during Roll Over Test**

**I. Modal and Random Vibration Analysis**

This test is performed to find the working range of frequency of formula car in which it will be safe from excessive vibration and unbearable stresses.

**TABLE XII.**

| S.N | Frequency to Avoid | FOS |
|-----|---------------------|-----|
| 1.  | Above 135 Hz        | 0   |

**Fig 12. Von-mises stress during Vibration analysis at extreme frequency**

Note:
1. The forces are obtained by simple physics calculation and use of Newton's law of motion and equations of motion.
2. The 'G' forces can be obtained by doing simulation on software like MATLAB and Simulink, ChassisSim, Adams, etc. If the software is not available to use then maximum G force can be considered for respective analysis through suitable research on vehicle dynamics.
3. The 'G' forces are converted into Newton force by multiplying the whole mass of car body by the times of 'G' force acting on it which is divided between the components taking the load. For e.g. If the total bump force at front is calculated then it is to be divided by 2 since there will be two suspension i.e. one on the right and next on the left taking that force.

**VIII. CONCLUSION**

The FOS has been found to be more than 1 in all the tests thus it is a safe design. Since in all conditions the worst conditions are assumed and also some miscellaneous factors has been considered thus anything above unity is a really good result. It also ensures that the design is weight optimized and all the unnecessary materials has been removed. Similarly as the FOS is not as high as 3 or 4 thus weight optimization is also not required. In case, if the FOS is very high then some parts can be removed or the thickness can be varied for weight optimization. The torsional stiffness is found to be 9340.5 Nm/degree which is also a very good value for stiffness. Thus it is a very good design that can perform very well in case of structural performance.

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