Design and optimization of FSAE chassis using FEA

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Abstract. According to the statistics of FSAE, teams prefer using spaceframe chassis because it is cheaper and easy to fabricate. The only disadvantage of the spaceframe chassis over a monocoque is the greater weight of spaceframe chassis. A spaceframe chassis also makes it easy to define the suspension hard points as the chassis members can be welded together according to whatever points are needed hence making its design easy. This work will be focusing on the spaceframe chassis. Analysis of different designs for the FSAE chassis based on all the design aspects including all rules and safety aspects of the car will be carried out. The analysis will be based on various conditions that the chassis may face during its use. These conditions include the roll, pitch and yaw conditions. The chassis would be analysed for frontal and side impact situations. Also, it would be made sure that all the chassis designs meet up with the optimum value of torsional stiffness. Our work aims at providing the optimum range for the torsional stiffness which can act as a guideline for other Formula student teams in the world. Also, this paper will define the parameters that need to be considered while designing, analysing, fabricating and testing the FSAE chassis.

1. Introduction

Depending on its shape and manufacture, a chassis exhibits a certain resistance to deformation, which is stiffness. The term chassis stiffness or rigidity generally indicates resistance to bending or flexing while torsional stiffness indicates resistance to twisting. To obtain good handling performances in the vehicle all we need is the optimum torsional stiffness with lightness in weight and accurate weight distribution along the members which is one of the most important properties of a chassis [1]. The optimum range of torsional stiffness by making the chassis as much lightweight as possible by changing the design and position of the structural members is achieved in this present work. This paper focuses on the different design of chassis used in FSAE competition and its behaviour when the chassis is employed with front impact, side impact and torsional stiffness by following the rules provided by the Formula SAE competitions.
2. Frame
Figure 1-3 shows the chassis frame designed based on the FSAE rulebook. The first design is based on the chassis of ZEV 2.0, the latest vehicle of team 4ZE Racing, official formula student electric team of SRM University. The second and third concepts are based on the rulebook with alterations in basic chassis parameters such as no of members, member alignment, driver positioning, varying chassis tube cross sections etc.

Many teams in FSAE design and build a carbon fibre monocoque chassis which helps to reduce the weight and improve stiffness but the capital investment is high. Hence, we decided to stick with spaceframe structure. The spaceframe structure of an FSAE car is constructed by using tubes of various cross sections and materials like alloys of steel and aluminium. While on the other hand monocoque structure is a unibody design and is mostly constructed by using materials such as carbon fibre and aluminium. The major advantage of a spaceframe structure over a monocoque one is that the spaceframe is less costly than monocoque. Even the modification process is also simpler in spaceframe in comparison to monocoque one. The building of a spaceframe structure also requires less time in comparison to the monocoque. While on the other hand monocoque structures have its own importance. Although they are costlier than spaceframe these structures are much lighter than spaceframe and also the strength to weight ratio of the monocoque is much higher in comparison to space frame [2].
3. Rules and Regulations

The first step towards making the chassis is to read and understand the rules and regulations thoroughly. Since the safety of the driver is important, following rules and regulations give necessary information and ideas towards safety. Building a race car practically is a great challenge in engineering field so these rules give us proper direction to step ahead [3].
Various major rules that must be taken into considerations are:

3.1 Primary Structure:
The rule book defines following frame members as the primary structure of the chassis:
1. Front Bulkhead
2. Main Hoop
3. Front hoop
4. Roll hoop Bracings (figure 4)
5. Front Bulkhead supports
6. Side Impact structure
7. All members transferring load from driver restraint system to members mentioned above (1-6)

3.2 Wheelbase:
All the car should have at least 60 inches of wheel base.

3.3 Track width:
The smaller track width must be no less than 80% of wheel base.

| Item or application                                                                 | Minimum wall thickness | Minimum area moment of inertia |
|-------------------------------------------------------------------------------------|------------------------|--------------------------------|
| Main and front hoops, shoulder harness mounting bar                                | 2.0mm                  | 11320mm²                       |
| Side impact structure, front bulkhead, roll hoop bracing, driver’s restraint harness attachment (except as noted above) EV: Accumulator protection structure | 1.2mm                  | 8509mm²                       |

Table 1. Tubing Requirements for chassis members.
Table 1 shows the minimum tubing requirement for chassis members used in our design.

3.4 Material property (steel) must not be lower than the following

Bending and buckling strength calculations:

Young’s Modulus (E) = 200 GPa (29,000 ksi)
Yield Strength (Sy) = 305 GPa (44.2 ksi)
Ultimate strength (Su) = 365 GPa (52.9 ksi)

If the Front Hoop leans rear wards by more than ten degrees (10°) from the vertical, it must be supported by additional bracing to the rear.

3.5 Percy:

Percy is the basic outlook of driver’s seating position. Therefore, 95th male percentile (Fig. 5) or 5th percent female percentile is the one important step towards designing phase. Seating positions of driver can be normal or restraint according to some parameters like comfort, egress timing, view angle, handling. Therefore, the minimum requirements of Percy are given as per rules given in rulebook.
3.6 Cockpit Dimensions:

Figure 6 and 7 shows the 2 cockpit templates used to measure the driver’s cell area. One is inserted vertically from the top up to the side impact upper member. Another one is inserted horizontally past the steering column up to 100 mm from pedal assembly.

Figure 5. 95th Male Percentile Percy.

Figure 6. B Cabin Cockpit Template.
4. Physical Analysis

The main aim is to find the optimum torsional stiffness value and test for the side and frontal impact. Torsional stiffness is the torque required for unit twist hence to do so the ANSYS 18.1 software has been used. The objective is to fix the rear wishbone points and torsion twist is provided on the front wishbone points hence for a particular Nm torque they will be 1 degree of deflection that will be the torsional stiffness of the vehicle [4].

The vehicle handling operation frequency is observed to be generally less than 2Hz. The twisting loads in the chassis are introduced due to the steer inputs, such as step and impulse steering inputs. Therefore, chassis torsional stiffness has a significant influence on vehicle handling [5].

The chassis from the previous vehicle of team 4ZE Racing was tested for torsion stiffness using a simple jig setup. The setup included the use of four weighing machines and small mild steel plates of 1mm thickness. Now, the procedure of the test included placing the vehicle such that all the four wheels lie on the weighing scales. 25 Plates are placed between both the front or rear wheels for two separate tests on each side. Now gradually, start moving plates from one side of the vehicle to the other one by one. This is continued until the load on any one wheel becomes zero [6]. Torsion calculations can be done using the equations (1), (2) and (3).

\[
\text{Torsion angle} = \left\{ \frac{2 \times (\text{No. of shims transferred} \times 180)}{\text{Track width}\,(\text{mm}) \times \pi} \right\} \text{ deg} \quad (1)
\]

\[
\text{Torque} = (\text{Weight change in left tire} + \text{weight change in right tire}) \times g \times \text{Track width}\,(\text{m}) \text{ Nm} \quad (2)
\]

\[
\text{Torsional stiffness} = \frac{(\text{Torque on front wheels} - \text{Torque on rear wheels})}{\text{Torsion angle}} \quad (3)
\]
Table 2 and 3 shows the results of the torsion testing done on the original chassis acquired from team 4ZE Racing.

**Table 2. Torsional Stiffness Front.**

| Trackwidth (mm) | Initial Shims [mm] | Shims at which Rear Load at One Wheel Becomes Zero [mm] | Angle (deg) |
|-----------------|--------------------|------------------------------------------------------|-------------|
|                 | Left | Right | Left | Right |                         |
| Front           | 1220 | 0     | 0    | 0     | 0.0000000                |
| Rear            | 1220 | 25    | 25   | 36    | 1.0332026               |

| Front | Initial Corner Weights (kg) | Corner Weights when Rear Wheel Load is Zero (kg) | Torque (Nm) |
|-------|----------------------------|--------------------------------------------------|-------------|
|       | Left | Right | Left | Right |                         |
| Front | 46.2 | 50.1  | 59.8 | 0     | 762.3743000             |
| Rear  | 75.8 | 71.1  | 45.1 | 113.1 | 870.0881400             |

| Delta Force (Nm) | Chassis Torsional Stiffness (Nm/deg) |
|------------------|--------------------------------------|
| 1532.4634800     | 1580.002324                           |

**Table 3. Torsional Stiffness Rear.**

| Trackwidth (mm) | Initial Shims [mm] | Shims at which Rear Load at One Wheel Becomes Zero [mm] | Angle (deg) |
|-----------------|--------------------|------------------------------------------------------|-------------|
|                 | Left | Right | Left | Right |                         |
| Front           | 1220 | 25    | 25   | 36    | 1.0332026               |
| Rear            | 1220 | 0     | 0    | 0     | 0.0000000                |

| Front | Initial Corner Weights (kg) | Corner Weights when Rear Wheel Load is Zero (kg) | Torque (Nm) |
|-------|----------------------------|--------------------------------------------------|-------------|
|       | Left | Right | Left | Right |                         |
| Front | 47.2 | 49.9  | 75.2 | 0     | 932.3727000             |
| Rear  | 75   | 71.8  | 45.8 | 99.5  | 680.0905800             |

| Delta Force (Nm) | Chassis Torsional Stiffness (Nm/deg) |
|------------------|--------------------------------------|
| 1512.3133800     | 1561.468573                           |
5. Analysis on ANSYS:
Figure 9-11 shows the analysis of chassis. Stiffness and weight are compromises. The more the weight more is the stiffness. Hence an optimization was required to reach the targets. Chassis FEA was done on ANSYS workbench. The frame was modeled as a structure made from beams. Hence the technique beam analysis was used. The frame was simulated for pure torsional forces that originate from front suspension [7]. The rear of the frame was fixed supported. To improve the accuracy of results the suspension was also modeled with elements as truss. After running simulations few members were added to reduce deflection and improve stiffness [8]. Final weight of 34 kg and stiffness of 1600Nm/deg was obtained.

Figure 8. Analysis of Chassis 1.

Figure 9. Analysis of Chassis 2.
6. Conclusion

In this paper two models of the designed chassis is presented and individual analysis of these two models are carried out and the chassis is tested by applying front and side impact. The effect of torsional stiffness on the vehicle dynamics is presented. Simulation of the behaviour of the chassis under analysis confirms that the steady state characteristics and the frequency response of the chassis under the assumption of stiff chassis is rather inaccurate which implies that to obtain the torsional stiffness within the permissible range the chassis must be neither too stiff or too soft. From the analysis of two models of the chassis by fixing the rear wishbone points the torsional stiffness obtained at the operating frequency of around 2Hz are 1580 and 1561.4 Nm/deg. This range of torsional stiffness is within the standards of a formula SAE vehicle. Based on the test results acquired, we found that there is 10% error in the values attained from analysis on ANSYS and the test was done on the actual chassis provided by team 4ZE Racing. This is due to the fact that ANSYS is based on some assumptions which are not encountered in the method that we used for actual testing. Thus, this can be used as a reference for other teams to design the chassis keeping in mind the error in the analysis so that the required value is attained on the actual model.

7. References

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