International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 7 Issue 06, June-2018

Design and Analysis of Space Frame Chasis for Formula Student Race Car

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Abstract **- Conventionally chassis is made up of AISI1018 steel .As the level of progress in improvising the efficiency of engine has come to saturation point. It is important to study the different aspect to enhance the overall performance of an automobile .As chassis forms the base mount all the automotive components like engine, transmission, braking and steering systems ,it must be able to take the entire weight of components efficiently .Using steel grades gives us necessary strength. Considering the fact that the car to be manufactured is a sport car, it is necessary to eliminate the factors which may hamper the performance of a car .So one of the important alternative is to change the material and it must be chosen in such a way that it imparts necessary strengths and also keep entire weight under limit .The main purpose of this project is to test AISI4130 steel for a space frame chassis to withstand all forces experienced under realistic experience condition .A complete analysis by using AISI4130 steel is to be carried out as to compare it with AISI1018 steel for ensuring improved performance.**

I. INTRODUCTION

The chassis of an automobile is defined as frame supported on springs and attached to the axle that holds the body and engine of vehicle. Chassis is a French word and was initially used to denote the frame parts or basic structure of an automobile. It is the back bone of the vehicle. It is the main mounting for all the components. So it is also called as Carrying unit. The chassis of an automobile consists of following components suitably mounted:

1. Engine and the radiator.
2. Transmission system.
3. Suspension system.
4. Wheel Assembly.
5. Steering System.
6. Brakes System.
7. Fuel Tank.
8. Other Miscellaneous Components.

All the components listed above are mounted in either of the two ways, viz., the conventional construction, in which a separate frame is used and the frameless or unitary construction in which no separate frame is employed. Out of these, the conventional type of construction is being used presently only for the heavy vehicles. While for the car same has been replaced by the frameless type or the monocoque chassis.The purpose is to design and manufacture tubular space frame chassis that should be strong enough to absorb the energy when front, back, side, torsional loads are applied. For the purpose of the application on a high performance racing car, it has to meet the following criteria:

1. Minimize the weight to stiffness ratio
2. Maintain Low Center of Gravity
3. Reasonable material and manufacturing costs
4. Create a solid base chassis to evolve on for years to come
5. Aesthetically pleasing design Chassis

II. LITERATURE REVIEW

2.1 The Chassis

The chassis is possibly the most important part of any vehicle. Its main role is to provide the vehicle with a main structure which all other components can be fixed to. The chassis must be rigid in both torsion and bending and must be able to resist twisting and sagging. The chassis must be able to accommodate and support all the components of the vehicle and any occupants and must absorb all loads without excessive deflection.

2.2 Types of chassis design

2.2.1 Ladder Frame Chassis

The ladder frame chassis was the earliest type of chassis used. It was widely used for the earliest cars until the early 60s. The design is, as the name suggest, similar to a ladder. There are two longitudinal rails running the length of the vehicle which are connected together by several lateral and cross braces.

2.2.2 Space Frame Chassis

The space frame was the next logical step up from the ladder frame. A space frame has a number of features that distinguish it from a ladder frame and add massive advantages. A perfectly designed space frame would have the tubular sections arrange so that the only forces on them are either tension or compression.

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Fig.2

2.2.3 Monocoque Chassis

The Monocoque style of chassis is used by almost all car manufacturers today. A Monocoque is a one-piece structure that defines the overall shape of the vehicle. This type of chassis is very attractive to mass production as the process can be automated very easily. The structure also has very good crash protection as crumple zones can be built into the structure itself.

2.2.4 Backbone Chassis

A backbone chassis is a simple style of frame that uses a central backbone running the length of the chassis that connects to the front and rear suspension attachment areas. The backbone usually has a rectangular cross section. The body of the vehicle is then placed onto of the structure. This type of chassis is used sometimes for small sports cars however it provides little or no protection against a side impact and so requires the body to be designed to accommodate this.

III. DESIGN CONSIDERATIONS

3.1 Various Loads Acting On Chassis

1. Weight of the vehicle and passengers, which causes vertical bending of the side members.
2. Vertical loads when the vehicle comes across a bump or hollow, which results in longitudinal torsion due to wheel lifted (or lowered) with other wheels at the usual road level.
3. Loads due to road camber, side wind, cornering force while taking a turn, which result in lateral bending of side members.
4. Load due to wheel impact with the road obstacles may cause that particular wheel to remain obstructed while the other wheel tends to move forward, distorting the frame to parallelogram shape.
5. Engine torque and braking torque tending to bend the side members in the vertical plane.
6. Sudden impact loads during collision, which may results in a general collapse.

3.2 Estimated Load of the Vehicle

The various load which is acting on the vehicle are estimate according to the center of gravity of the vehicle. As the various load acting on the vehicle are distributed are shown in the below table.

Sr.No.	Components	Mass (Kg)
1.	Driver	80
2.	Engine & Radiator	45
3.	Drive train	25
4.	Chassis	40
5.	Steering & Suspension	25
6.	Body work	25

By considering miscellaneous masses such as the wishbones (front & rear), wheels, fuel tank etc. The weight of the car is considered to be approximately 250 kg.

3.3 Other Design Consideration

There are several factors that must be considered when designing the frame.

1) Safety

Fortunately, the FSAE rules committee has set up a group of rules requiring certain tubing sizes in areas of the frame critical to driver safety in the event of an accident. These rules define outer diameters and wall thicknesses for the front bulkhead, front roll hoop, main roll hoop, side impact tubing, roll hoop bracing, and front impact zones. The stated rules are adhered to without deviation so that the driver may be safe and the car can pass technical inspection at competition.

2) Stiffness

Normally, a race car chassis should be as stiff as possible to withstand torsion. This is to facilitate easier suspension tuning. When determining the handling qualities of a race car, one of the most effective methods of adjusting the amount of over-steer and under-steer is the adjustment of roll stiffness, front-to-rear. By increasing front roll stiffness while decreasing rear roll stiffness, both rear tyres are more equally weighted than the front tyres. The force on the outside front tyre quickly overwhelms the traction available to it, and the car under-steers. Conversely, with a large amount of rear roll stiffness and a small amount of front roll stiffness, the inside rear tyre is lifted during a turn, the amount of available rear traction is reduced, and the car over-steers. By tuning the stiffness of the anti-roll bars, it is possible to affect the balance of the car.

3) Torsional Stiffness

Torsional order to design a car of maximum torsional stiffness the basis or generalized equation for torsion must be examined.

Stiffness is the resistance of the frame to torsional loads. FEA was used to analyze the torsional stiffness of the chassis.

$$T = \frac{G\theta J}{L}$$

The above equation is a simple formula that relates the angle of twist to the applied torque, with J representing the shafts polar moment of inertia, with θ denoting the resultant twist of the shaft, G representing the shear modulus of the material and L being the length of the shaft. Now a chassis can be made extremely stiff by adding significant amounts of material to the frame. However, this additional material might degrade the performance of the car because

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of the added mass. Therefore while designing a race car chassis it is important to get a balance between the weight and stiffness of the chassis.

4) Weight

As discussed earlier, wherever possible, weight should be minimized. All tubing sizes not dictated by the rules were chosen to be as light as possible while remaining structurally sound and suitably stiff. Just as important as weight, is mass moment of inertia. A car with a lower mass moment of inertia will be able to turn more quickly. In order to reduce mass moment of inertia, all weight on the chassis is pushed as far as possible towards the centre of the vehicle.

5) Triangulation

Triangulation can be used to increase the torsional stiffness of a frame, since a triangle is the simplest form which is always a structure and not a mechanism. Obviously, a frame which is a structure will be torsionally stiffer than a mechanism. Therefore, an effort should be made to triangulate the chassis as much as possible. Visualizing the frame as a collection of rods which are connected by pin joints can help frame designers locate the mechanisms in a design.

6) Ergonomics

Ergonomics, or the study of human-machine interfacing, is important to vehicle design because the ultimate control of the vehicle belongs to the driver. When designing this 'interface' between person and machine, several aspects should be taken into account so that the best system of control is produced.

7) Seating Position/Field of View

A key input to the interface is the driver's vision and that of any co-driver (i.e. Rally). The field of view, as shown in diagram below, should include visibility ahead and to the sides of the vehicle (Approximately 180 degree arc– more is even better) and visibility of the road surface.

The driver needs a sufficient level of information about the nature of the oncoming road surface and what is occurring beside them through peripheral vision to drive confidently. If the driver must strain their neck to see enough to feel confident, their field of view is inadequate.

8) The design goals of the seating position are:

- To enable the driver (and co-driver) to see clearly ahead and beside themselves through standard and peripheral vision.
- To provide a position of comfortable leverage for the driver so they do not become tired due to operating the controls from an awkward position.
- To enable the driver to adequately see the side mirrors in their peripheral vision (At a minimum) so that the driver need not continuously take their eyes off the road ahead to gauge an opponent's position behind them. Ideally the side mirrors should be far enough forward to enable direct viewing by a driver glancing at them.
- To enable easy visual access to gauges and other visual feedback in the forward looking line of sight.
- To minimize CG height to optimize handling

9) Control Positions

Vehicle controls should be within a comfortable reach of the driver (and co-driver if applicable) and be comfortable to operate. Controls that are awkward to reach or difficult to operate will distract the driver/co-driver and potentially result in more driving mistakes.

IV MODELING OF CHASSIS

4.1 Rulebook Compliance

4.1.1 General Requirements

Among other requirements, the vehicle's structure must include two roll hoops that are braced, a front bulkhead with support system and Impact Attenuator, and side impact structures.

4.1.2 Node-to-node triangulation - An arrangement of frame members projected onto a plane, where a co-planar load applied in any direction, at any node, results in only tensile or compressive forces in the frame members. This is also what is meant by "properly triangulated".

4.1.3When seated normally and restrained by the Driver's Restraint System, the helmet of a 95th percentile male (anthropometrical data) and all of the team's drivers must:

a. Be a minimum of 50.8 mm (2 inches) from the straight line drawn from the top of the main hoop to the top of the front hoop.

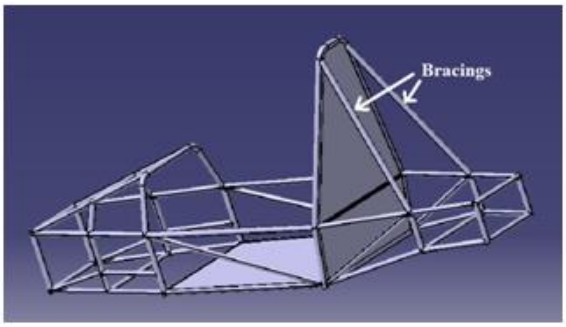
b. Be a minimum of 50.8 mm (2 inches) from the straight line drawn from the top of the main hoop to the lower end of the main hoop bracing if the bracing extends rearwards.

4.1.4 In the side view of the vehicle, the portion of the Main Roll Hoop that lies above its attachment point to the Major Structure of the Frame must be within ten degrees (10°) of the vertical.

4.1.5 In the front view of the vehicle, the vertical members of the Main Hoop must be at least 380 mm (15 inch) apart (inside dimension) at the location where the Main Hoop is attached to the Major Structure of the Frame.

4.1.6 In side view, no part of the Front Hoop can be inclined at more than twenty degrees (20°) from the vertical.

4.1.7 The Main Hoop must be supported by two braces extending in the forward or rearward direction on both the left and right sides of the Main Hoop.



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ISSN: 2278-0181
Vol. 7 Issue 06, June-2018

4.1.7 In the side view of the Frame, the Main Hoop and the Main Hoop braces must not lie on the same side of the vertical line through the top of the Main Hoop, i.e. if the Main Hoop leans forward, the braces must be forward of the Main Hoop, and if the Main Hoop leans rearward, the braces must be rearward of the Main Hoop.

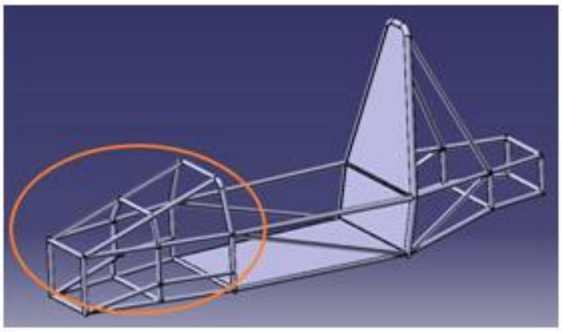
4.1.8 The Main Hoop braces must be attached as near as possible to the top of the Main Hoop but not more than 160 mm (6.3 in) below the top-most surface of the Main Hoop. The included angle formed by the Main Hoop and the Main Hoop braces must be at least thirty degrees (30°).

4.1.9 The top-most surface of the Front Hoop must be no lower than the top of the steering wheel in any angular position.

4.2.0 The Front Hoop must be no more than 250 mms (9.8 inches) forward of the steering wheel. This distance shall be measured horizontally, on the vehicle centerline, from the rear surface of the Front Hoop to the forward most surface of the steering wheel rim with the steering in the straight-ahead position.

4.2.1 The attachment of the Main Hoop braces must be capable of transmitting all loads from the Main Hoop into the Major Structure of the Frame without failing. From the lower end of the braces there must be a properly triangulated structure back to the lowest part of the Main Hoop and the node at which the upper side impact tube meets the Main Hoop. Structure must meet the minimum requirements for Main Hoop Bracing Supports or an SES approved alternative. Bracing loads must not be fed solely into the engine, transmission or differential, or through suspension components.

4.2.2 The Front Hoop must be supported by two braces extending in the forward direction on both the left and right sides of the Front Hoop.



4.2.3 The Front Hoop braces must be constructed such that they protect the driver's legs and should extend to the structure in front of the driver's feet.

4.2.4 The Front Hoop braces must be attached as near as possible to the top of the Front Hoop but not more than 50.8 mm (2 in) below the top-most surface of the Front Hoop.

Cockpit Opening

In order to ensure that the opening giving access to the cockpit is of adequate size, a template shown in Figure 8 will be inserted into the cockpit opening. It will be held horizontally and inserted vertically until it has passed below the top bar of the Side Impact Structure (or until it is 350 mm (13.8 inches) above the ground for monocoque cars). No fore and aft translation of the template will be permitted during insertion.

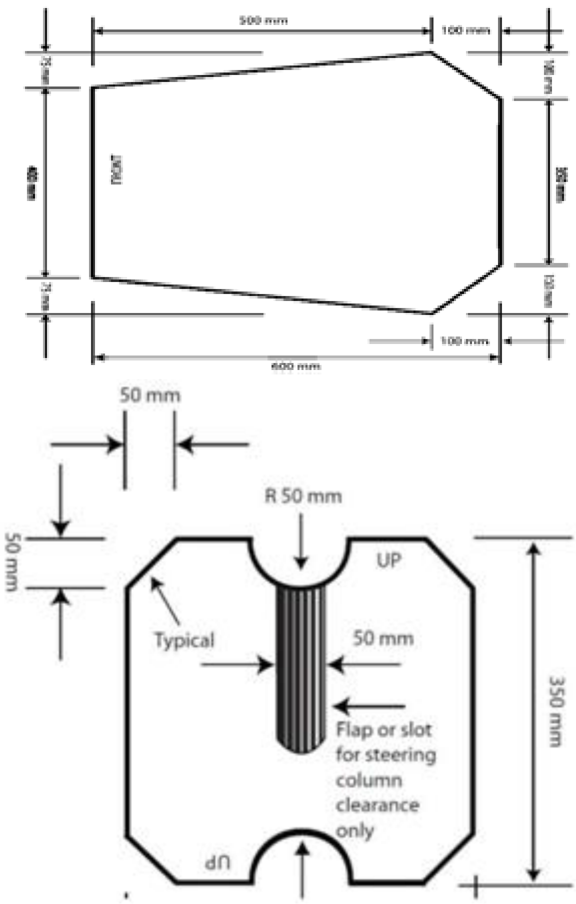


Fig.5.10 Cockpit opening template

Cockpit Internal Cross Section

A free vertical cross section, which allows the template shown in Figure 9 to be passed horizontally through the cockpit to a point 100 mm (4 inches) rearwards of the face of the rearmost pedal when in the inoperative position, must be maintained over its entire length. If the pedals are adjustable, they will be put in their most forward position.

4.2 Benchmarking and CAD modelling

1. Basic layout of the chassis

This step includes fixing main components of the vehicle. The vehicle's structure must include two roll hoops that are braced, a front bulkhead with support system and Impact Attenuator, and side impact structures.

2. Measurements and fixing fundamental parameters

This step decides the approximate dimensions of the two roll hoops i.e. Front hoop, Main hoop that are braced, a front bulkhead with support system and side impact structure.

3. Selection of frame

The selected frame may be of Channel section, Tubular section or Box section. The Channel Section is good in resistance to bending, while the Tubular Section is good in resistance to torsion. The Box Section is good in resisting both bending and Torsion

4. Drawing of wireframe on CAD software

Wire framing is one of the methods used in geometric modelling systems. A wireframe model represents the shape of a solid object with its characteristic lines and points.

5. Checking whether it is satisfying design goals

This step is to cross verify the design with the Formula Student Rulebook. And to check whether the design is satisfying the design goal.

6. Final 3D model on software.

After finalizing the final structure of the Chassis the 3D model is drawn on the CAD software such as Catia V5, SolidWorks and Siemens NX etc.

V MATERIAL SELECTION

Properties	AISI 1010	AISI 1018	AISI 4130	AISI 4140
Tensile Strength (MPa)	365	440	560	655
Yield Strength (MPa)	305	370	460	415
Elastic Modulus (GPa)	190-210	210	190-210	190-210
Poisson's Ratio	0.27-0.30	0.29	0.27-0.30	0.27-0.30
Brinell Hardness	105	126	217	197
Density (g/cm^3)	7.87	7.87	7.85	7.85
Elongation (%)	20	15	22	26

1. After load approximation, next step was the selection of material to construct a chassis.

2. Availability is one of the main factors which dominate the material selection process. Working on this single, list of different desirable and available material was prepared. Steel and aluminum alloys are always the choice of most of the times. After reviewing mechanical properties, availability, cost and other significant factors, Steel AISI 4130 was selected.

3. AISI/SAE 4130 grade is a versatile alloy with good atmospheric corrosion resistance and reasonable strength up to around 600° F (315° C). It shows good overall combinations of strength, toughness and fatigue strength.

4. The following datasheet provides comparison of available material.

VI. CONCLUSION

The function of the chassis is to protect the driver and support front and rear suspension systems, engine, drive train, steering system and other systems in the vehicle. The objective of the chassis design was to satisfy these functions while meeting the Formula Student regulations with special considerations given to safety of the driver, quality, weight, ergonomics and aesthetics. The complexity of design and the arrangement of the components contribute a waste space which not makes the car more compact and improvement in the chassis to overcome problems faced in assembly and maintenance. The purpose of this this project is not only to design the roll cage for the Formula Student Competition, but also to provide an in depth study in the process taken to arrive at the final design. During the design process, we must achieve a compromise between cost, manufacturing, performance, and design time so that the car will be competitive in all aspects of the FS competition. However, we should understand that it will take several iterations to converge on a satisfactory design.

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