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DESIGN AND ANALYSIS OF TUBULAR SPACE FRAME CHASSIS FOR STUDENT FORMULA RACE CAR

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Abstract – Chassis is the main part of the car; it is used for mounting of all components. It also connects the front and rear suspension attachment points can make handling more difficult. The frame must also provide attachment points which will not yield within the car's performance envelope. There are many different styles of frames; space frames, monocoque, and ladder are examples of race car frames. The most popular style of Students Formula is the tubular space frame. Space frames are a series of tubes which are joined together to form a structure that connects all the necessary components together. However most of the concepts and theories can be applied to other chassis design. A Space frame chassis was chosen over a monocoque in spite of being heavy, as its manufacturing is cost effective, require simple tools and damages to the chassis can be easily rectified. The chassis design started with fixing of suspension mounting coordinates and engine hard points. [1]

1.Introduction

SUPRA SAEINDIA is a national level student competition, organized by Society of Automobile Engineers India, wherein students are asked to design, manufacture and run a prototype of open wheel racing car. This competition is conducted annually in India and about 180 colleges participate every year from all over India. Following the technical inspection are the sub events which include the static events like tilt test, brake test, cost report presentation, engineering design report and business presentation, dynamic events like acceleration test, skid pad, autocross and endurance test. In this high octane scenario a caris expected to perform high on acceleration, handling, braking, aesthetics, ergonomics, fabrication and maintenance with least investment in fabrication without compromising on safety of the driver. The purpose of the thesis isto 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:

- Minimize the weight to stiffness ratio
- Maintain Low Centreof Gravity
- Reasonable material and manufacturing costs
- Create a solid base chassis to evolve on for years to come [3]

2. Literature review

[1] A.harikumar, V.deepanjali, "Design & Analysis of Automobile Chassis", International Journal of Engineering Science and Innovative Technology, ISSN: 2319-5967, Volume 5, Issue 1, January 2016

In present the Ladder chassis which are uses for making buses and trucks are C and I cross section type, which are made of Steel alloy (Austenitic). In India number of passengers travel in the bus is not uniform, excess passengers are travelling in the buses daily due to which there are always possibilities of being failure/fracture in the chassis/frame. Therefore Chassis with high strength cross section is needed to minimize the failures including factor of safety in design.

[2] N. G. Jogi, Akshay P. Take, Yogesh Asolkar, Sheikh M Aftab, "Review work on analysis of F1 car frame using Ansys", IJRET , Apr-2014

The chassis design was carried out on CAD software such as Pro-Engineers. Design model was prepared using anthropometric parameters of tallest driver as 95th percentile male was selected to SAE rules book. Static and dynamic load distributions were calculated analytically followed by extensive study of various boundary conditions to be applied during diverse FEA (Finite Element Analysis) test which was carried out in Ansys. Stress distributions, lateral displacements during static, dynamic and frequency modes were analyzed and found considerably high factor of safety as 3.85.

[3] William B. Riley and Albert R. George," Design, Analysis and Testing of a Formula SAE Car Chassis", SAE TECHNICAL PAPER SERIES 2002-01-3300.

This paper is taken from work completed by the first author as a member of the 1999 Cornell University Formula SAE Team and discusses several of the concepts and methods of frame design, with an emphasis on their applicability to FSAE cars. The paper introduces several of the key concepts of frame design both analytical and experimental. The different loading conditions and requirements of the vehicle frame are first discussed focusing on road inputs and load paths within the structure. Next a simple spring model is developed to determine targets for frame and overall chassis stiffness. This model examines the frame and overall chassis torsional stiffness relative to the suspension spring and anti-roll bar rates. A finite element model is next developed to enable the analysis of different frame concepts. Some modeling guidelines are presented for both frames in isolation as well as the assembled vehicle including suspension. Finally, different experimental techniques are presented to determine what stiffness is actually achieved from a constructed vehicle. A comparison of frames tested in isolation versus whole vehicle testing is made, and a simple whole-car chassis torsion test method is discussed.

[4]Prajwal Kumar M. P1 , Vivek Muralidharan2 , G. Madhusudhana3,DESIGN AND ANALYSIS OF A TUBULAR SPACE FRAME CHASSIS OF A HIGH PERFORMANCE RACE CAR,IJRET,eISSN: 2319-1163 | pISSN: 2321-7308

Formula Student Racing competitions are held at various Formula SAE circuits globally. Students from different colleges worldwide thrive to build a Formula style race car to compete at these events. In lieu to the competition rules and regulations it is important to design the chassis of the car with utmost priority. The major challenge posed is to design and fabricate a light weight car without compromising on the safety of the driver. The car has to be rigidly fabricated at minimal expense. The work in this paper is based on the team NITK Racing's Car; the DICV NR XIV. This paper showcases various methods of material selection, design optimization techniques and Finite element analysis (FEA) using ANSYS. The basic design is based on the anthropological data of the specified human (95th percentile male) allowing fast ingress and egress from the car. Following the final design selection the static structural analysis of the car was done and the consequent results have been plotted. The entire design and analysis process is based on FSAE 2013 rule book and knowledge of designing and manufacturing yesteryear's car.

3. Design Development :The purpose of the frame is to rigidly connect the front and rear suspension while providing attachment points for the different systems of the car. Relative motion between the front and rear suspension attachment points can cause inconsistent handling. The frame must also provide attachment points which will not yield within the car's performance envelope. There are many different styles of frames; space frame, monocoque, and ladder are examples of race car frames. The most popular style for SUPRA SAEINDIA/FSAE is the tubular space frame. Space frames are a series of tubes which are joined together to form a structure that connects all of the necessary components together. However, most of the concepts and theories can be applied to other chassis designs. A Space frame chassis was chosen over a monocoque in spite of being heavy, as its manufacturing is cost-effective, requires simple tools and damages to the chassis can be easily rectified. The chassis design started with fixing of suspension mounting coordinates and engine hard points. **3.1 Design Considerations** The design process of the chassis consists of many steps, from the initial assignment to the task of chassis design to the start of construction. These steps are; to identify the restriction, determine the required performance criteria, research design techniques and methodology, use of CAD software to design chassis and lastly start construction. Throughout these steps, choices must be made based on the targets that are to be achieved to meet the performance requirement. The designer of the chassis must have an idea as to how all components of the car are going to function in relation to each other. As a result, the designer must know how all parts must interact and take this interaction into account when designing the frame. The design of a racing car chassis, or any racing chassis for that matter, is going to be based on suspension points, powertrain layout, driver position controls, safety, etc. These important points must come together to form an effective package for the car to perform as intended. Stiffness - The suspension is designed with the goal of keeping all four tires flat on the ground throughout the performance range of the vehicle. Generally, suspension systems are designed under the assumption that the frame is a rigid body. For example, undesirable changes in camber and toe can occur if the frame lacks stiffness. An image of a frame subjected to a torsional load is superimposed on an undeflected frame. Generally, a chassis that is stiff enough for competition will not yield. However, some care should be taken to ensure that the attachment points of the frame do not yield when subjected to design loads. For example, the engine mounts should be made stiff enough to reduce the possibility of failure

Torsional Stiffness - Torsional stiffness is the resistance of the frame to torsional loads. FEA was used to analyze the torsional stiffness of the chassis. In order to design a car of maximum torsional stiffness the basis or generalized equation for torsion must be examined.

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

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 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.

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.

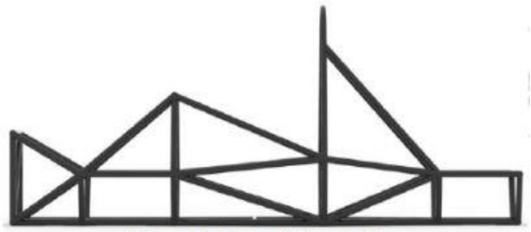


Figure 1: Frame Triangulation

Driver Position and Controls - Another important aspect of chassis design is driver positioning and controls. If the driver is not able to operate the car comfortably, it will not meet its full potential. Designing the frame around the controls, such as the steering wheel and pedals, is a matter of ensuring that the structure of the frame does not interfere with the driver's task. Also, the controls must be adequately supported by the frame so that the attachment points do not yield while the car is being driven. Driver comfort concerns include seating angle, elbow space, head height in relation to the front of the car, and controls operation (pedals, shifter, and steering wheel).

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. [5]

3.2 Design Process A tubular space frame is designed in several steps that are based on the design considerations previously stated. A methodical plan must be followed so that all parameters are considered and the design incorporates every part of the car correctly.

Initial Setup – The design was initiated by determining the height, track width, wheel base, and overall length dimensions of the vehicle. Stemming from these dimensions were roll hoop locations, bulkhead location, cockpit location, engine mounting location, and wheel centerlines for an estimation of weight distribution. Once these dimensions were selected, a series of planes were created in Solidworks at these points so that these locations could be visualized. Some thought was given to the placement of other important or hard-to-package systems. For example, the fuel system had to be packaged near the center of gravity to reduce the effects of its varying mass during the race.

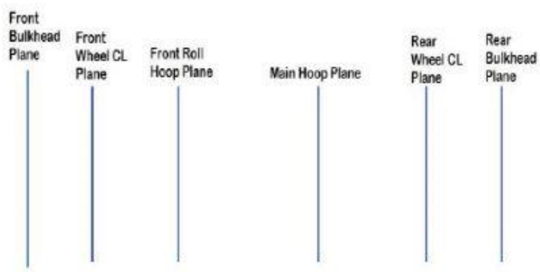


Figure 3: Chassis Planes - Side Views

Modeling of Fixed Elements - Fixed elements include roll hoops, front bulkhead, suspension points, and engine mounts. These features will not be moved around during chassis design iteration so that the number of variables able to be manipulated may be decreased. This allows for a quicker design period so that construction may begin sooner than usual. The roll hoop and bulkhead shapes are decided upon to minimize the length of tubing for the elements. Since the roll hoops and bulkhead are required to be at least 1" OD .095" wall and 1" OD .065" wall, respectively, the lengths of this heavy tubing need to be minimized to reduce weight. Once shapes of the features are decided upon, they are drawn on their respective planes. A structural member feature is added to the sketch and the first tubes of the model are drawn.

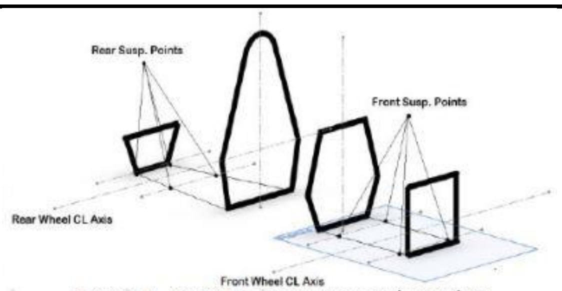
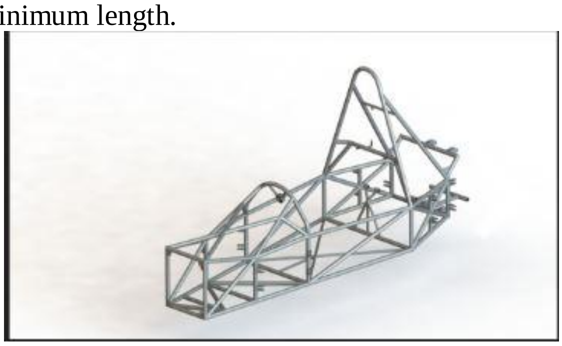


Figure 2: Roll Hoops and Suspension Points

The suspension mounting points are the next to be designed. These are drawn as fixed points in space in the Solidworks model. During suspension design, an optimal a-arm span was determined and this dimension must now be integrated into the chassis. Suspension mounts needs to be welded to the chassis so the position of this mounts are needed to be acquired from the suspension calculation. Engine mounting locations are also decided upon and fixed so that the engine design team can accurately place their individual part models in the car assembly without having to change their parts. This keeps the team from making drastic changes when farther along in the design process.

Modelingof Variable Elements - The next step is to model the tubes that connect the fixed elements to each other. Arrangements of these tubes are variable and careful consideration of weight, manufacturability, and chassis stiffness must be taken, so that the chassis does not become heavy and too flexible. The competition rules must also be taken into account when drawing these connecting tubes. Since the weight of the chassis is critical to car performance, connecting tubes must be kept short and thin. All the connecting tubes must be of the dimensions specified in the rule book i.e., 1" .049" wall. The only connecting tubes that may not be of this size are the required roll hoop bracing tubes which must be 1" .065" wall. These bracing tubes are kept to a minimum length.



4.Material Selection

The chassis undergoes various kinds of forces during locomotion, it has to stay intact without yielding, and it should be stiff to absorb vibrations, also it should resist high temperatures. The material property of the chassis isan important criterion while designing and manufacturing the car. A tubular space frame chassis was chosen over a monocoque chassis despite being heavier because, its manufacturing is cost effective requires simple tools and damages to the chassis canbe easily rectified. The two very commonly used materials for making the space frame chassis are Chromium Molybdenum steel (Chromoly) and SAE-AISI 1018. Both these materials were analyzed for different parameters and finally decided onto use Chromoly steel 4130 for making the tubular space frame chassis because of several reason.

SAE 1018 grade steel is better in terms of Thermal properties but weaker than Chromoly in terms of strength. But the main priority of design is safety for the driver hence the material with better stiffness and strength was chosen. The material should not cause any failure even under extreme conditions of driving as defined in the rule book. Chromoly steel 4130 exhibits better structural propertythan SAE 1018 Grade steel hence the former was considered as the basic material for building a tubular space frame chassis. Even though the cost of Chromoly is marginally higher than that of SAE 1018grade steel, the safety of the driver remains the utmost priority for the team. [4]

Table 1: Material Properties

Properties	SAE AISI 1018	Chromoly 4130 Steel
Density (g/cc)	7.8	7.8
Young's Modulus (GPa)	210	210
Elongation at break (%)	19	19
Brinell Hardness	120	200
Strength to weight ratio at Yield (kN-m/kg)	38	100
Yield Strength (MPa)	360	480
Ultimate Strength (MPa)	420	590
Thermal Conductivity: Ambient (W-m/K)	50	42
Thermal Expansion: 20C to 100C (μm/m-K)	11	12
Specific Heat Capacity Conventional (J/kg-K)	370	370

5.Conclusion

The purpose of this project isto design the roll cage also to provide anin-depth study . With the overall design being carefully considered, and that many design features have been proven effective within the performance requirement of the vehicle. Therefore, Spaceframe is the best option, despite the lack of stiffness. So, tubular spaceframe chassis was chosen as the type of chassis as it was difficult to procure and fabricate carbon fibre monocoque chassis. The material chosen is AISI4130 as it provides greater impact resistance, greater strength, with less weight as compared to AISI1018.

Reference

[1] A.harikumar, V.deepanjali, "Design & Analysis of Automobile Chassis", International Journal of Engineering Science and Innovative Technology, ISSN: 2319-5967, Volume 5, Issue 1, January 2016

[2] N. G. Jogi, Akshay P. Take, Yogesh Asolkar, Sheikh M Aftab, "Review work on analysis of F1 car frame using Ansys", IJRET , Apr-2014
[3] William B. Riley and Albert R. George," Design, Analysis and Testing of a Formula SAE Car Chassis", SAE TECHNICAL PAPER SERIES 2002-01-3300.
[4]Prajwal Kumar M. P1 , Vivek Muralidharan2 , G. Madhusudhana3,DESIGN AND ANALYSIS OF A TUBULAR SPACE FRAME CHASSIS OF A HIGH PERFORMANCE RACE CAR,IJRET,eISSN: 2319-1163 | pISSN: 2321-7308
[5]SUPRA SAEINDIA 2018 rulebook
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[8]Aerodynamics – by L.J. Clancy.