DESIGN AND ANALYSIS OF A TUBULAR SPACE FRAME CHASSIS OF A HIGH PERFORMANCE RACE CAR

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Abstract
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.

Keywords: *ergonomics, finite element analysis, roll cage, torsional rigidity, tubular space frame chassis, and validation test setup*

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1. INTRODUCTION

Formula Student racing competitions attracts collegiate racing teams from all across the globe to compete in the Formula SAE events. The competition consists of various sub events for which points are given and cumulative score is recorded for deciding the ranks. 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 car is 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. This paper corresponds to the work carried out by NITK Racing team to build the DICV NR XIV car in order to participate in FSAE Racing events in Europe in 2014. The team has previously cherished a rank of 33 at the Formula Student Hungary Competition in 2012 and is expecting to perform nonchalantly at the fore coming International Formula Student Competition at the Formula Student China during the year 2014. The car is engineered using yesteryear's knowledge and various papers cited abiding by all the rules in the FSAE Rule book 2013 [1].

2. DESIGN METHODOLOGY

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.

2.1 Basic Design

During the initial stages of chassis design four major cross sections of the chassis namely, the front roll hoop, the main roll hoop, the front bulk head and the rear bulk head were fixed. The position of the main roll hoop was fixed considering the engine mounting points and the drive shaft positions that were fixed earlier, a bare minimum space was utilized for the engine and the drive train components and provided maximum space in the driver cockpit area for higher comfort.

The size of the cockpit was decided abiding by the Article 4 of FSAE Rule book 2013 [1] with large amount of tolerance to incorporate 95th percentile male driver and larger cockpit area to keep batteries and install fuel tank.

Front bulk head marks the front end of a tubular space frame chassis. The position of this cross section was fixed based on the length of the manikin's leg room. The front roll hoop was fixed at an angle to have suspension nodes on the members. Links from the front bulk head to the front roll hoop were made such as to include the other two pairs of suspension hard points.

Main roll hoop was roughly designed at same optimum angle with constraint.

Design of the rear side of the car was made to include suspension hard points at the nodes. The design was completed by triangulation of members and abiding by Rule book 2013 [1] and iterating angle of Main roll hoop to get the best fit.

Static structural testing was done using ANSYS Workbench to validate the design. Weaker links and less effective links were improved by modifying their positions and/or adding new links. Structural analysis and modifications to chassis design was done repeatedly till convincing values were obtained.
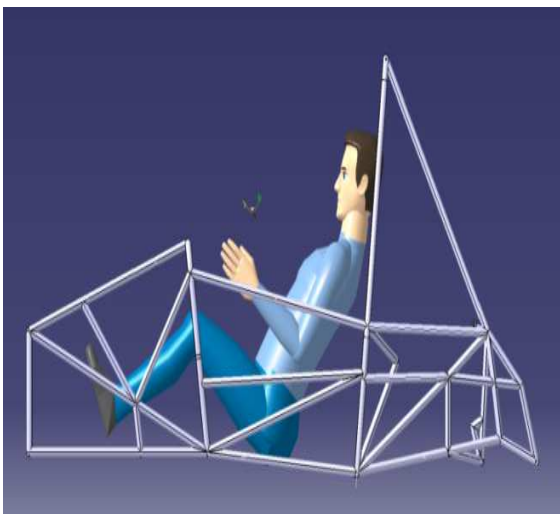

Fig -1: Design dependence on ergonomics

2.2 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 is an 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 can be 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 on to use Chromoly steel 4130 for making the tubular space frame chassis because of several reasons.

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 property than 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 1018 grade steel, the safety of the driver remains the utmost priority for the team.

Table -1: Material Properties

PROPERTIES [2],[3]	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

3. SIMULATION

Structural analysis of the chassis was done along with design optimization until a convincing design with sufficient rigidity was produced and it cleared all regulations by the FSAE Rule book. The static structural analysis was done in ANSYS Workbench under different constraints mentioned in the Article 4.0 in FSAE Rule book 2013 [1]. Methods of Stiffness and rigidity test of the car as explained by Riley and George, 2002 [4] were primarily followed throughout the analysis process. Application of loads over the chassis was in correspondence to the work of R.P. Singh, 2010 [5]. The maximum deformation is well within the permissible limit of not more than 25mm in any direction.

Mesh Structure: Fine
Minimum mesh element length: 1.79×10^{-3} mm
Nodes: 43090
Elements: 20725
Young's modulus: 210 GPa
Poisson's ratio: 0.27

Table -2: Finite Element Analysis Results

Test	Maximum deformation (mm)	Maximum Von Misses Stress (MPa)	Factor of Safety
Load at the top of main roll hoop	5.8934	409.78	1.171
Load at the top of front roll hoop	6.6777	452.06	1.062
Side impact Loading	2.5052	87.207	5.504
Load at Shoulder Harness	6.2169	338.68	1.417
Torsional Rigidity	1.1219	74.752	6.421

The torsional rigidity of the chassis was found out to be 2550 Nm/deg using the method explained by Riley and George, 2002 [3].

Fig -2: Torsional Rigidity using ANSYS Workbench

4. MANUFACTURING

All the chassis members were precisely measured and cut to the design specifications. The 2-D profiling of each member was made in Solid Works. The final profiling of the member ends was completed. The main roll hoop and the front roll hoop were manufactured separately as they had to be bent precisely. The front roll hoop and the main roll hoop were bent into desired shape using a CNC bending machine. Fixtures were then made using hollow mild steel pipes for supporting the members during welding. A 8mm thick flat plate of dimension 3feet x 9feet was taken as a bottom reference plane for manufacturing the chassis. Front bulk head, front roll hoop and the main roll hoop consists of members that lie in the same plane (as in Fig. -3) hence they were placed on the reference plane and welded. Then they were clamped on to the fixtures and all the other intermediate members connecting them were welded in place. The chassis was welded using Gas Tungsten Arc-welding while the fixtures were welded using Shielded Metal Arc welding.
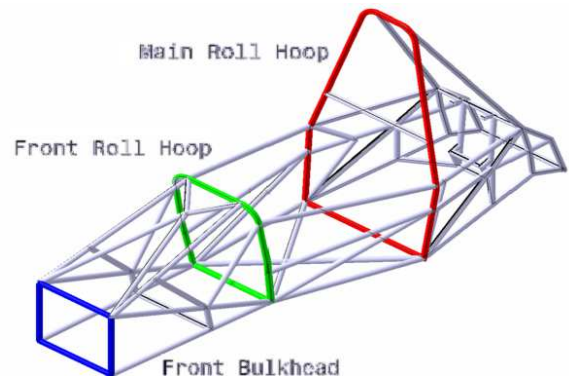

Fig -3: Basic Roll cage element

5. VALIDATION

A Validation test setup was manufactured for experimentally testing the torsional rigidity of the chassis in the manner explained by J.P. Blessing, 2004 [6]. The setup consists of mainly three parts. Two stand supports for constraining each left and right uprights in the front and a swing arm to constrain the rear uprights and to connect a laser pointer to measure deflection. A measuring scale was placed at an optimum known distance from the roll axis. Resolution was be increased by increasing the distance between roll axis and measuring scale.
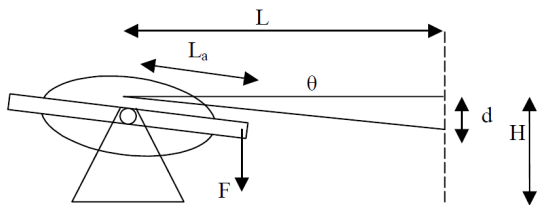
The front left and right uprights were mounted rigidly on the left and right support stands respectively. The laser points the readings on the vertical measuring scale. A known force is applied along the ends of the swinging arm about the roll axis to obtain a known value of moment.

Fig -4: Torsional Rigidity setup

For calculating the torsional rigidity of the chassis, the moment acting along the roll axis is determined using (1). It is basically the product of the mass suspended at the edge of the torsional rigidity setup and the distance between vertical axis containing the suspended mass and the roll axis as shown in

Fig. -5. Angular deviation in the chassis is measured with required resolution using (2) and finally the torsional rigidity or the stiffness of the chassis of the car is calculated using (3).

Rear of vehicle fixed to swingarm

Fig -5: Moment diagram

$$M = F \times L_a \tag{1}$$

M is the moment applied about roll axis measured in N-m

$$\tan \theta = d / l \tag{2}$$

θ is the angular deviation of the chassis about roll axis in degrees

$$K = M / \theta \tag{3}$$

K is the torsional rigidity of the chassis measured in N-m/deg

Fig -6: Chassis mounted on Torsional Rigidity Setup

Experimental values obtained of Moment and deflection was plotted in Matlab and the best suited linear polynomial fit was performed to get the slope from the Moment vs Angle of deflection curve. Experimental results obtained are a good approximation of the analysis carried out using ANSYS.
The Torsional Rigidity or the Stiffness of the chassis obtained from experimental means is about 2314 N-m/degree and it is comparable to the value obtained from ANSYS.
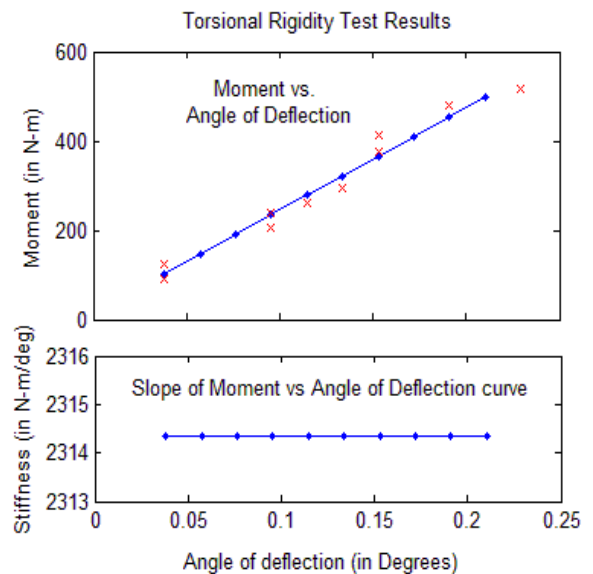

Chart -1: Experimental results

5. CONCLUSIONS

The tubular space frame chassis fabricated for the car DICV NR XIV is safe as it has been analyzed to withstand all possible forces that it might encounter in a racing circuit. It has been made as light as possible while not compromising on the strength of the chassis. The manufacturing of the chassis has been carried out in a very professional manner and the final product adheres to the design. The chassis has also been validated for its torsional rigidity to ensure the final chassis is in tandem with the analysis.

SCOPE FOR FUTURE

The numbers of permutations in which triangulations can be done and the chassis can be designed are infinite and one can try and optimize the chassis design by further reducing the weight. This paper can serve as reference for further improving the design of a tubular space frame chassis.

ACKNOWLEDGEMENTS

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