Review on Design, Analysis and Fabrication of Race Car Chassis

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Abstract - *This paper reviews the developments in a race car chassis in recent years. In an automobile, chassis was considered to be the backbone of any vehicle. Chassis was the main supporting structure which carries all the loads, forces and transmits them to ground through wheels and tyres. The issues related to chassis are the mounting of the components in a proper place so that the vehicle was properly balanced. At the same time, it needs to be light weight for best performance without compromising the safety of the driver. Chassis should be stiff to resist against all bending forces and torsional rigidity should be high enough to avoid failure of the vehicle. Various designing and analysis procedures have been studied and stated in this paper.*

***Key Words*: light weight, stiff, torsional rigidity, solid works, ANSYS etc.**

1. INTRODUCTION

SUPRA SAE was an event organized by the Society of Automotive Engineers to give an opportunity to the engineering students for enhancing and implementing their practical knowledge by designing and fabricating formula vehicle in order compete with other students which are participating in the event.

It was important to keep in mind while designing a chassis that any good chassis must have several things:

- Acceleration was directly dependent on the mass of the vehicle, the chassis comprises most of the weight of the vehicle, and hence the chassis should be light in weight.
- Rigidity was important to maintain precise control over the suspension geometry. To keep all four of the wheels firmly in contact with the ground.
- Weight and rigidity are often in direct conflict, finding the best compromise between these two was known as the science of race car engineering.
- Safety of the driver was also the main criteria for designing, using FEA analysis the designed frame was validated to ensure the best possible geometry for safety and performance.

Chassis should be structurally sound and well triangulated for proper force distribution throughout the structure. This means that nothing will ever break under normal conditions. Protect the driver from external intrusions.

Before the process of design of a Formula Student car had started, the science and research papers were analyzed, which were in accordance with the topic. In the paper, the method of manufacturing formula student frame was described. When the frame was made physically, an experimental test on torsional stiffness was done, and then the precise value of torsional stiffness was determined. The paper based on the previous reference contains the comparison between the numerical method of ANSYS and Finite Element Analysis (FEA) and experimental methods of designing the torsional stiffness. In various research papers, Dynamic Frequency Analysis of frame was done which helps in determining the frequency of waves generated in the frame after the impact. Also, the principal of manufacturing frame was using clamping tools, which are made of wood, was explained in some papers.

2. LITERATURE REVIEW

P.K. Ajeet Babu, et al. [[1]] performed a comparison of chassis types by inspecting the chassis types and by making benchmark; tubular space frame chassis is preferred for formula student teams. Ladder chassis is very weak for torsion. Self-support chassis is suitable for mass production for companies and manufacturers. For hand made cars like formula student, two of these types are convenient; space frame and monocoque. Monocoque chassis have good rigidity and very lightweight. But its complex structure and price are disadvantages. Space frame structures are slightly heavier than monocoque but they are still considered as light weight. For formula student races, acceleration was very important. Also, road holding capabilities must be as high as possible. Considering all these arguments, space frame chassis was the most convenient chassis type for formula student teams.

Mohamad, et al. [[2]] studied for Formula Student competition, the baseline material was steel and the regulations and rules are held regarding alloy steels. It was also possible to use another material but in order to use them, the alternative frame rules should be considered. There are much more rules, regulations and required tests for the use of alternative materials. The most common chassis materials are steel and composite in Formula Student. With an increase of usage of composites, more than half of teams use steel for their chassis. Aluminium has the advantage of being lighter than steel and cheaper than composite, it was very hard to find aluminium that meets the requirements of rules. And to provide enough stiffness, the larger size of aluminium must be used and this does not make aluminium to be a very convenient choice. The volume of material becomes larger and it increases the price. Composite chassis is a very good option for teams. Because they are light and considered that composite monocoque chassis are hard to prod stiff. But the material was very expensive. The most convenient choice was using steel to produce a space frame chassis. It was easy to machine and prepare the tubes. It may not require a complex fixture for production. With using correct material, any post process was not necessary. After all, steel was very cheap and has good availability.

Table -1: Properties of Material:-

Properties	AISI 1018	AISI 1080	AISI 4130
Density[kg/m^3]	7.8	7.8	7.8
Young's Modulus[GPA]	210	210	210
Brinell Hardness	120	174	200
Yield Strength[MPA]	360	375	460
Ultimate Strength[MPA]	420	450	560
Strength to weight ratio[KN-m/Kg]	55-60	55-60	72-75
Cost per meter	250	200	500
Elongation at break[%]	19	11	26

Edmund F. Gaffney et al. [[3]] covered some of the basic concepts of suspension and frame design and also highlighted the approach used by the team when they designed its 1996 suspension and frame. 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. Stated the importance of stiffness while designing of chassis, the suspension is designed to keep 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. They found that in most cases, 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.

Raut et al. [[10]] stated that the main aim of the project was to make a safe chassis which can be used to support various components like engine, suspension, wheels etc. to make up complete formula student race car which can be used for racing competition. The various material available in the market can be optimized to choose the one which suits our purpose for the race vehicle and was not much costly so as a financial burden to a team member. From paper, we know that the design process of any roadworthy vehicle being with the tyres are the only point of contact between the vehicle and the road. They also suggested that while selecting the materials for motorsports application the most common factor consider are strength, cost and weight to design a competitive vehicle, it must be light and yet strong. They suggest the material AISI1080 alloy steel. Because this material was stronger and more ductile it also exhibits better welding properties leading to simpler manufacture of chassis. The triangulated frame elements also allow wider distribution of applied and translated stresses throughout the design of the chassis. A final detail was the cockpit area, was lower than the front and the rear control arm mounting areas.

Mariotti et al. [[11]] discussed the design of the cockpit and ergonomics study for the cockpit of a FSAE race car chassis. In this use to design a cockpit suitable for people within the range of 95th percentile male and 5th percentile for female. In this, the cockpit ergonomics are very important. The cockpit was designed with considering driver safety, seating position, seat clock angle, thigh angle, steering location, dash height and clearance to the floor width of the cockpit at seat legs shoulder, pedal height and position and shifter location. They performed the ergonomics study to determine cockpit dimensions. They analyzed their previous race car and they find seat dimension so they can determine the cockpit dimension. Then they set a goal for the cockpit so they can make it as for the comfort of the driver. They design the ergonomics apparatus to allow the subject to sit in the adjustable cockpit. Seat lock, thigh angle, steering location, dash height and pedal assembly they were adjustable in the ergonomics apparatus.

Ghosh et al. [[4]] stated the material selection based on the structural properties, after the selection of materials they explained about various types of analysis to be performed to ensure its stability under various conditions. They are mentioned below: -

i. Front impact analysis
ii. Rear impact analysis
iii. Side impact analysis
iv. Front torsional analysis
v. Rear torsional analysis
vi. Modal and frequency analysis
vii. Static vertical bending analysis
viii. Acceleration test

ix. Lateral bending analysis

They also explained about the steps involved in the analysis process and how to calculate the loads encountered by various structures and elements. They gave focus on "impulse-momentum equation"An impulse was equal to the net force on the object times the time period over which this force was applied. Below, we derive impulse from the equation F = ma, which comes from Newton's second law of motion. This equation helps for determination of forces which will act on the frame for Front-impact, Rear impact, Side-impact Analysis. It was being observed that the selection of material plays a vital role in chassis stability and its behaviour during loading conditions. The factor of safety should always be considered for proper designing of a race car chassis. They carried out some analysis and in all of them except for Modal analysis; the maximum stress developed was much less than the material AISI 4130. Torsional rigidity was important because a soft chassis was more prone to failure and the suspension actuation may get affected with twisting or bending action of chassis. Modal analysis was also performed to check that the frequency of engine and chassis should not match to avoid resonance.

Lozica Ivanović, et al. [[5]] study showed designing of Formula student frame and analysis of the frame using a finite element method. They stated that Industrial design was a creative activity, whose goal was to define the formal quality of industrially produced products. These formal qualities contain outside shape, but they especially refer to structural and functional elements, and the relations between them, which one system makes into the whole assembly. They observed that the selection of the outside dimensions and shape and their compatibility with all systems was very important not only for aesthetic but for better performance of the vehicle (aerodynamic, stability control, speed and acceleration).In the paper, the method of manufacturing Formula student frame was described. When the frame had been made physically, an experimental test of torsional stiffness was done and then the precision value of torsional stiffness was determined. The dynamic frequency analysis of the frame was done.

Hubbard D. Velie, [[8]] while the general effects of chassis torsional rigidity on vehicle handling and performance was known by them, exact guidelines to determine the appropriate chassis stiffness for a given vehicle was still not known. The report investigates the effects of chassis torsional rigidity on vehicle handling and performance for The University of Michigan's Formula SAE race car with the goal of determining a chassis stiffness design target. Investigations included open-loop simulation of steady-state cornering and speed trace simulation of transient cornering events using VI-Grade Car Real-Time. Simulation outputs included tire forces, vehicle path and driver inputs which were used to determine the limits of acceptable stiffness values. In conclusion, a theoretical design target for chassis torsional rigidity was determined that is designable while taking into account that the design must be buildable and FSAE rules compliant to be used in future Formula SAE race cars by them. The method with which the value is determined is presented in a reproducible way, should the vehicle characteristic change in the future and warrant re-investigation of these effects by future team members.

Singh, [[6]] introduced several concepts of frame's load distributions and consequent deformation modes. Static and dynamic load distributions were calculated analytically followed by extensive study of various boundary conditions to be applied during diverse FEA tests. Stress distributions, lateral displacements during static, dynamic and frequency modes were analyzed and found the considerable factor of safety as required. He observed depending upon the application of loads and their direction, chassis is a deformed respectively are as follows :1)Longitudinal Torsion 2)Vertical Bending 3)Lateral Bending 4)Horizontal Loading. From this, he concluded that if torsional and vertical bending stiffness is satisfactory, then the chassis structure is expected to perform well. After his literature review, it was brought in view that normally FSAE car parts are designed to withstand 3.5 g bump, 1.5 g braking and 1.5 g lateral forces. These loads have to be considered individually and combined. He later estimated an individual and a total load of various components and car as a whole.

David Rising, et al. [[7]] their study was to determine the risk of injury to the driver during a front impact in a Formula SAE race car. As per FSAE rules stipulate the use of an impact attenuator to absorb energy in the event of a front impact. These rules mandated an average deceleration not to exceed 20-g from a speed of 7.0m/s (23 ft./s), but do not specify a specific time or pulse shape of the deceleration not to exceed 20-g from a speed of 7.0 m/s (23ft/s), but do not specify a specific time or pulse shape of deceleration. The pulse shapes tested in this study includes an early high-g, constant-g, and late high-g pulse. The tests were performed using the deceleration sledge at Crash Safety Centre. This study examined the driver's risk of injury about neck and femur loads, head and chest accelerations, as well as kinematic analysis using high-speed video. The tests were repeated with and without using HANS's device.

University of Leeds, [[9]] this paper has presented an extensive application of CAE technology in the design and development of F15 race car and impact attenuator. The methodology was implemented by them right from the initiation of the design process for conceptual design's and then throughout the development. Firstly topology optimization was successfully applied using Altair optistruct to generate efficient load paths for the chassis. Since this technique does not normally produce the shape of the final design but only gave vital hints because load paths, gauge otherwise known as topometry optimization was therefore used to determine the optimum thickness and outer diameter for each tube member. Two main concepts were generated: all-tube design- concept 1&2, tube and sheet component- concept 3. The first design gave a mass reduction of about 5 kg compared to F14 chassis with torsional stiffness being increased by more than 200% giving a specific torsional stiffness of 42.68 Nm/°kg. Furthermore, slightly different combinations of tube dimensions were implemented to create concept 2 leading to an additional 1.5kg mass saving with a small loss in torsional stiffness compared to concept 1. A more unique design was proposed (concept 3) which incorporated the use of sheet component to mimic the load paths between the front roll hoop and front bulkhead. Unfortunately, this design is the least stiff and heaviest. Besides, all the conceptual chassis have been designed such that all structural requirement was met. It was therefore concluded that the CAE technique has proven to be effective, having the capability to suggest an optimum concept design for the merely starting from a huge design space.

3. CONCLUSION

In conclusion, from the literature survey and methodology, we find that chassis stiffness significantly affects vehicle behaviour and handling. As the chassis gets less stiff the vehicle behaves in an increasingly undesirable manner to driver inputs and becomes increasingly hard to drive. Through the analysis of these trends, with manufacturing error is taken into account, we can conclude that future design developments should be made to increase the stiffness of the overall chassis. Stiffness's greater than the designed value results in added weight for diminishing returns, while stiffness less than the designed value put the car in danger of entering a regime in which the stiffness has a significant effect on vehicle behaviour. The analysis method has shown to be quite effective, and significant confidence was had in the results due to their proximity to the ideal chassis stiffness developed earlier. As per the literature survey and the initial design, it was concluded that the force which was acting on the chassis after the impact was much greater than normal which affects the stiffness. Not only stiffness and torsional rigidity was important, but Clearance and Compliance stacking was also a phenomenon which affects the chassis as well. The suspension point design was also an important factor which should be considered.

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