International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 07, July-2016

Design, Analysis and Optimization of Race Car Chassis for its Structural Performance

Chandan S N[1]
M.Tech., Student (Machine Design),
Department of Mechanical Engineering,
Nitte Meenakshi Institute of Technology,
Bangalore-64, India.

Sandeep G M[2]
Assistant Professor,
Department of Mechanical Engineering,
Nitte Meenakshi Institute of Technology,
Bangalore-64, India.

Vinayaka N[3]
Assistant Professor,
Department of Mechanical Engineering,
Nitte Meenakshi Institute of Technology,
Bangalore-64, India.

***Abstract*- Formula Student Racing competitions are held at various Formula SAE circuits globally. Chassis serves as the important component in the race car design. Thus a solicitous analysis is expected out of the formula car. It is also noted that the weight of the car is inversely proportional to the performance of the car hence need of optimization. A high speed protection system plays a major role in the race car design such as front impact, rear impact, side impact and roll over analysis. Also, there exists a problem of the torsional rigidity as far the dynamics is considered. This paper aims at the design aspects and the analysis insights of the race car. The car is modeled according to the 95th percentile male that can fit inside the cockpit of the chassis. As the car travel at the high speed, the protection has been designed to the car in such a way that stresses are minimum and the performance is maximum. Finite element methods are used for the analysis and the design of experiments is created for the optimization of the chassis. Instead of using the regular taguchi method of optimization, and poisons and orthogonal continuity model is used for the optimization for the reason that the taguchi considered the samplings as the discrete model. But orthogonal and the poisons model will be modeled to consider the sampling as the continues points. The validations of the FEM result are given using the H-type space step convergence methods. The engine acts as the excitation box in case of the chassis. This can be checked using the industrial best practices such as Campbell diagram.**

Keywords: Design, finite element analysis, torsional rigidity, tubular space frame chassis, and optimization

1. INTRODUCTION

Chassis is the supporting member for all the components in the car. It supports the body, engine and other parts which make up the vehicle. Chassis lends the complete vehicle support and rigidity. The propose of automotive chassis is to take care of the form of the vehicle and to support the varied hundreds applied to that the protection of the chassis may be a major facet within the style, and may be thought of through all stages. Chassis is taken into account to be one among the many structures of associate automobile. It is sometimes fabricated from a steel frame that holds the body associated motor of an automotive vehicle. To be precise, automotive chassis or automobile chassis could be a frame that bolts numerous mechanical elements like engine, tires, brakes, steering and shaft assemblies. Generally, the essential chassis sort contains backbone, ladder, space frame and monocoque, differing kinds of chassis style result the various performance.

2. DESIGN METHODOLOGY

A Space frame chassis was chosen over a alternative variety of chassis. The fundamental principle of a chassis design states that the chassis is to be designed to achieve the torsional rigidity and light weight in order to achieve good handling performance of a race car. By the definition, torsional rigidity is refers to the capability of chassis to resist twisting force or torque. In the other words, torsional rigidity is the amount of torque required to twist the frame by one degree. During the corner entry, if the torsional rigidity is too small then the chassis will be thrown off. If the torsional rigidity is too large, then the corner entry is difficult and leads to the under steering tendency. These parameters conjointly applied to space frame chassis. Generally, the result of the torsional rigidity on space frame is totally different to the monocoque, thanks to their construction format. Space frame chassis is light weight, as its manufacturing is cost-effective, requires simple tools and damages to the chassis can be easily rectified.

2.1 Basic Design

During the initial stages of chassis style four major cross sections of the chassis specifically, the front roll hoop, the main roll hoop, the front bulk head and therefore the rear bulk head were mounted. The position of the most roll hoop was mounted considering the engine mounting points and the drive shaft positions that were mounted earlier a blank minimum area was utilized for the engine and therefore the drive train elements and provided most area within the driver cockpit space for higher comfort.

The size of the cockpit was taken from SAE rulebook with great deal of tolerance to incorporate 95th percentile male driver and bigger cockpit space to keep batteries and install

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 07, July-2016

fuel tank. First and foremost step for the look of the chassis is to seek out the boundary conditions and therefore the putting of the elements. Keeping this in mind we've began to draw line diagram so transferred them into a CATIA model. Although analysis was on the far side our horizon at this point once several iterations and discussion, we've come back up with the ultimate chassis style that has the capability to possess reduced stress (The analysis a part of the report can concentrate a lot of on the reduction of stress)

The design is modeled in Catia software. The final chassis obtained is:

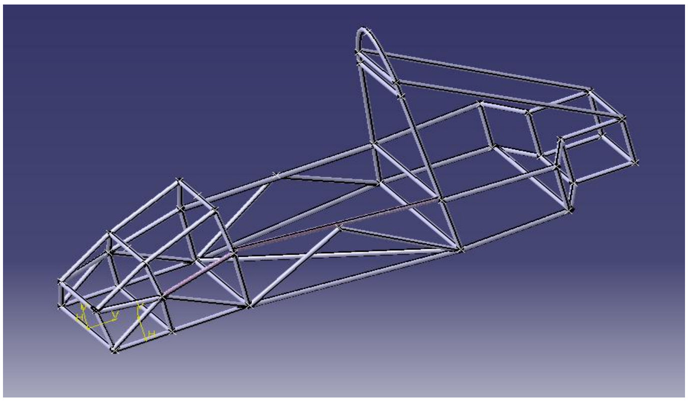


Figure 1: Final Chassis Tubing

3. MATERIAL SELECTION

The key for the good chassis is to select good materials, in-fact the best. This made us to think twice before selecting the material. For this purpose we did extensive research on the materials. The main factors for our comparison were completely based on strength, weight, cost, availability, corrosion resistance and weldability. 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. Based on weld strength and availability. Hence steel is always suitable. By coating the appropriate material, corrosion can be resisted. We found out AISI SAE 1018 is suitable for our application.

The properties of chosen materials are

Table 1: Material properties

Material	SAE 1018
Tensile strength	630 MPa
Yield strength	385MPa
Poisson's ratio	0.29
Modulus of elasticity	210 GPa
% elongation	27
Carbon	0.182%
Manganese	0.645%
Sulphur	0.64%
Phosphor	0.03
Geometry	Circular Hallow tube
Weld ability	Good

4. ANALYSIS

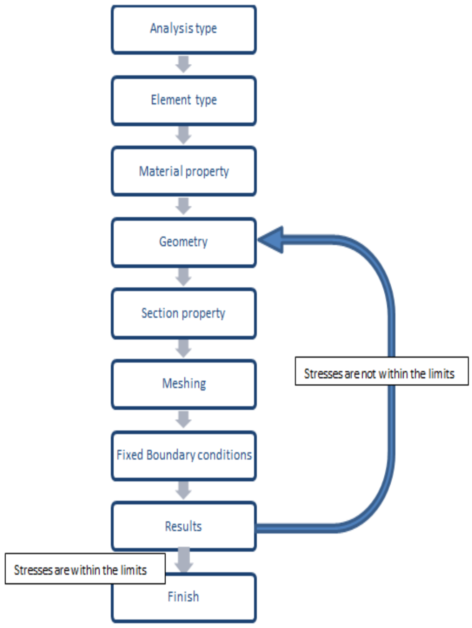
Hand theoretical calculations of the whole chassis are going to be extremely tough due to complexity in handling the equations, so as to scale back the human effort, the machine ways are widely used for analysis and validation. Finite Element Analysis is one among the prominent type of computational methods which are available in the market for commercial use. ANSYS APDL Mechanical 16.0 software package has been chosen to try and do analysis of the chassis.

Types of Analysis:

1. Front impact fixing suspension pick-up point
2. Side impact with the wall at other end.
3. Roll over analysis
4. Rear impact analysis.
5. Torsional rigidity
6. Modal analysis.

General Steps done during the analysis:

The following steps are used for analysis



This procedure has been used for the analysis, Sampling points used for design of experiments are calculated by doing the sensitivity analysis.

4.1 Front Impact analysis

It has been assumed that the vehicle has front collision with other stationary vehicle of 300kg, considering our vehicle is moving at its maximum speed 60 kph and stops at 0.1 sec. The force acting on the vehicle is calculated and found 35312N or 12G load.

Table 2: Showing results of the front Impact.

Force acting	35312 N
Type	To the front 4 Nodes
Fixing points	Suspension pick up points
Max von mises stress	202.87MPa
Factor of safety	1.897
Max deflection	1.224 mm
Mesh size	60 divisions per line
Convergence criteria	By varying space step(H-type)

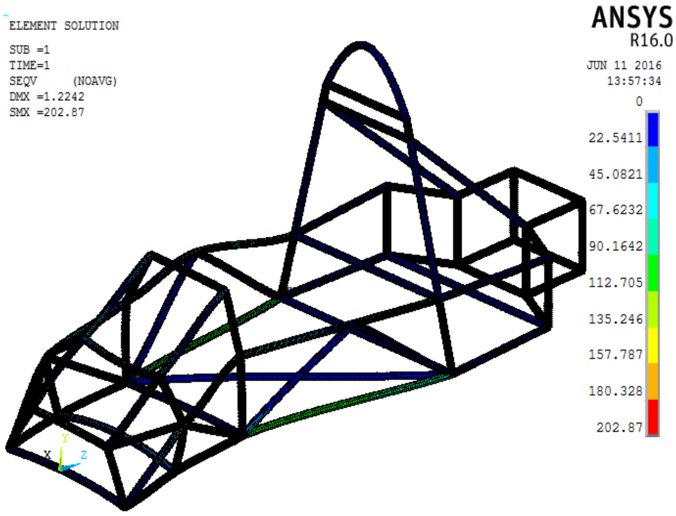


Figure 2: Von-mises stress

4.2 Rear Impact Analysis

It has been assumed that the vehicle collides with other stationary vehicle of 300kg, considering our vehicle is moving at its maximum speed 60 kph and stops at 0.1 sec. The force acting on the vehicle is calculated and found 8829N or 3G load.

Table 3: Showing results of Rear impact analysis

Force acting	8829 N
Type	To the rear 4 key points
Fixing points	Suspension pick up points in front
Max von mises stress	272.391MPa
Factor of safety	1.413
Maximum deflection	4.957mm
Mesh size	60 divisions per line
Convergence criteria	By varying space step(H-type)

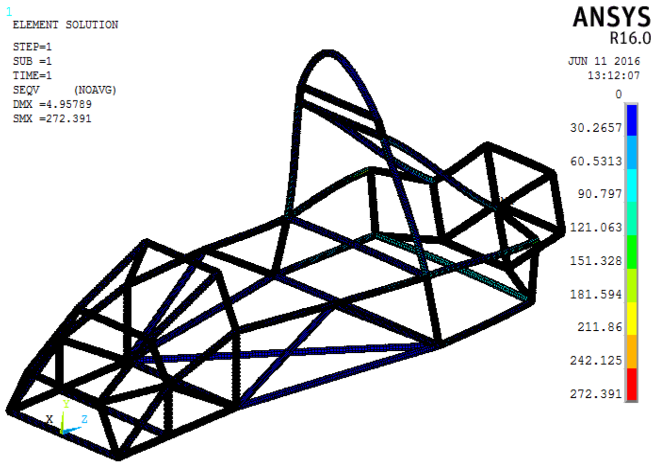


Figure 3: Von-mises stress

4.3 Side Impact of the Chassis

It has been assumed that the vehicle collides with other stationary vehicle of 300kg, considering our vehicle is moving at its maximum speed 60 kph and stops at 0.1 sec. The force acting on the vehicle is calculated and found 7357.5N or 2.5G load.

Table 4: Showing results of Side impact analysis

Force acting	7357.5 N
Type	To the side impact members
Fixing points	Other side of side impact members
Max von mises stress	193.112 MPa
Factor of safety	1.99
Maximum deflection	3.8628 mm
Mesh size	60 divisions per line
Convergence criteria	By varying space step(H-type)

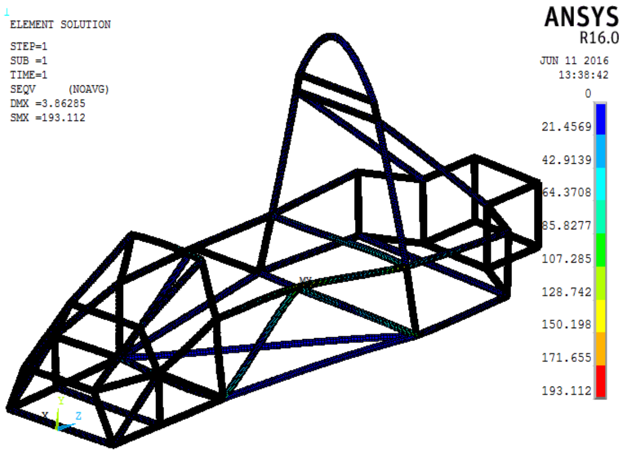


Figure 4: von-mises stress

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 07, July-2016

4.4 Roll over analysis

It has been assumed that the vehicle collides with other stationary vehicle of 300kg, considering our vehicle is moving at its maximum speed 60 kph and stops at 0.1 sec. The force acting on the vehicle is calculated and found 8829N or 3G load.

Table 5: Showing results of Roll over analysis

Force acting	8829 N
Type	Acting on front and main roll hoop
Fixing points	Bottom of the chassis
Max von mises stress	101.66 MPa
Factor of safety	3.787
Maximum deflection	0.4602 mm
Mesh size	60 divisions per line
Convergence criteria	By varying space step(H-type)

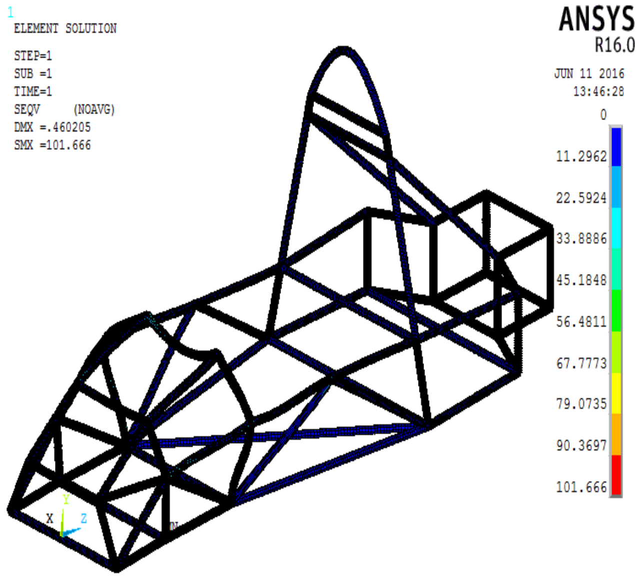


Figure 5: von-mises stress

4.5 Torsional rigidity of chassis

Torsion is one of the main considerations while designing chassis, torsional rigidity of the chassis is found by applying the force at the front end as a couple and fixing the rear end.

$$Torsional\ rigidity = \frac{F \times L}{\tan^{-1}\frac{\delta}{L}}$$

Force = 1000N

L = 560mm

Applying the force and getting deflection from Ansys, taking the mean deflection as δ.

Mean deflection is half of the maximum deflection. Then the torsional rigidity is found out to be 1463.37Nm/deg.

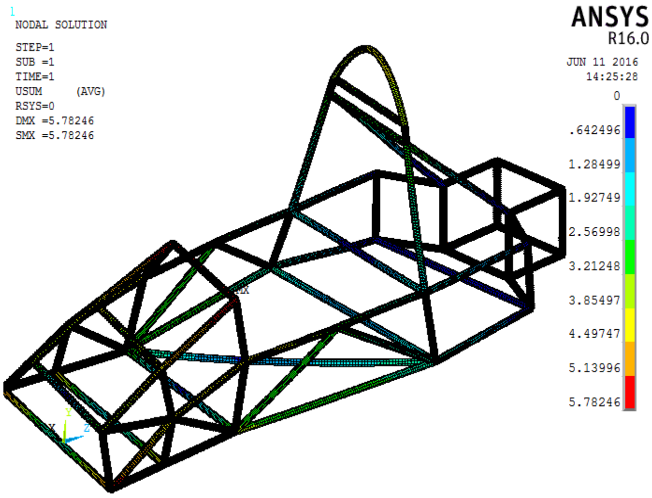


Figure 6: Deflection due to torsion.

The analysis results are shown in table

Table 6: Finite Element Analysis Results

Test	Maximum deformation (mm)	Maximum Von Misses Stress (MPa)	Factor of Safety
Front impact	1.244	202.87	1.897
Rear impact	4.957	272.391	1.413
Side impact	3.8628	193.112	1.99
Roll over	0.4602	101.666	3.787

4.6 Modal Analysis

Modal analysis determines the vibration mode shapes and corresponding frequencies. It is well known that (mechanical) structures can resonate, i.e. that small forces may end up in necessary deformation, and presumably, harm will be elicited within the structure. Resonance is often the cause of, or at least a contributing factor to many of the vibration and noise associated problems that occur in structures and operating machinery. To better understand any structural vibration problem, the resonant frequencies of a structure ought to be known and quantified. Today, modal analysis has turn out to be a sizeable means of finding the modes of vibration of a system or structure.

Modal analysis has been performed after creating the chassis finite element model. The mode shapes are shown below

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 07, July-2016

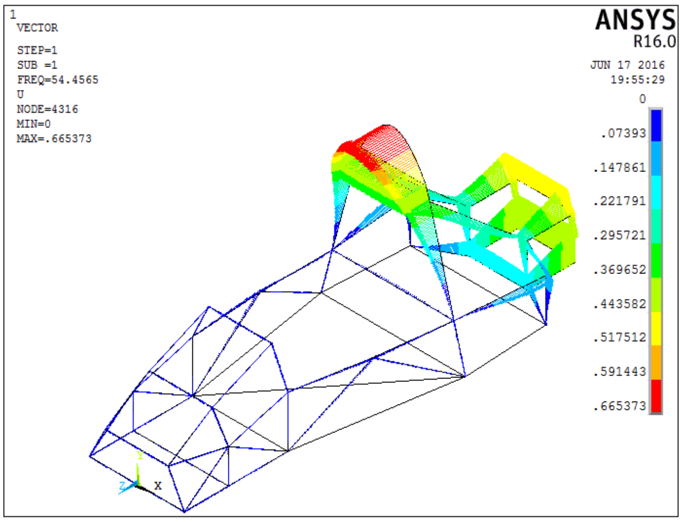


Figure 7: 1st mode displacement at the 54.45Hz frequency

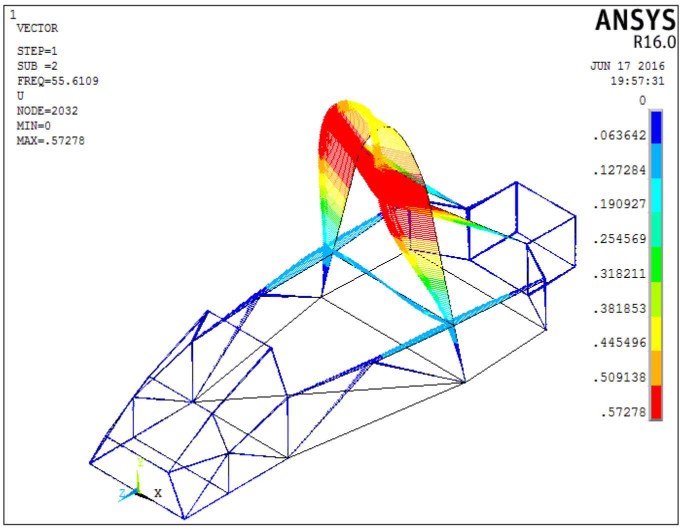


Figure 8: 2nd mode displacement at the 55.611Hz frequency

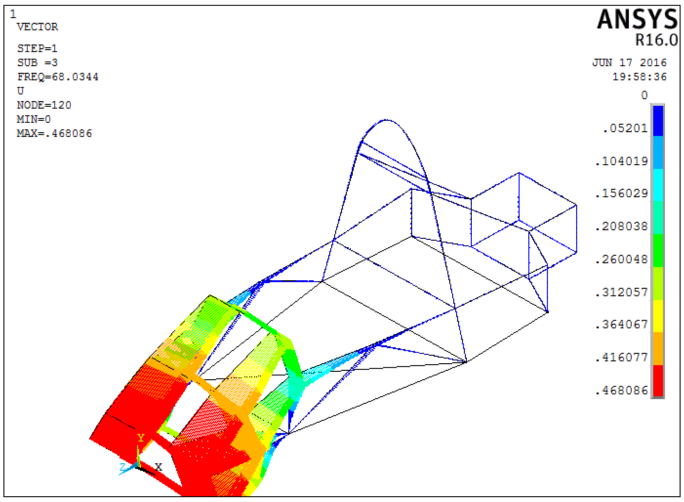
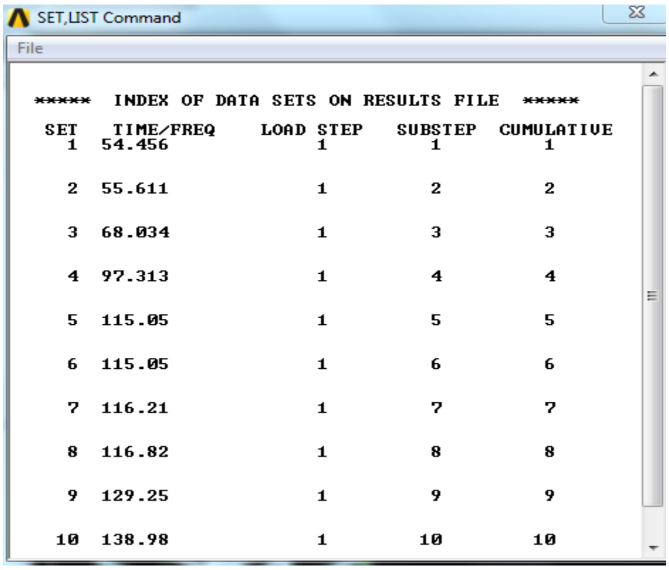


Figure 9: 3rd mode displacement at the 68.034Hz frequency

The first 10 modes of frequency are shown below


SET,LIST Command

File

***** INDEX OF DATA SETS ON RESULTS FILE *****

SET	TIME/FREQ	LOAD STEP	SUBSTEP	CUMULATIVE
1	54.456	1	1	1
2	55.611	1	2	2
3	68.034	1	3	3
4	97.313	1	4	4
5	115.05	1	5	5
6	115.05	1	6	6
7	116.21	1	7	7
8	116.82	1	8	8
9	129.25	1	9	9
10	138.98	1	10	10

4.7 Campbell diagram

A Campbell diagram plot represents a system's response spectrum as a function of its oscillation regime.

Campbell diagram is a plot between the excitation frequency from the 0-max speed with respect to the natural forced vibration of the chassis. The evolutions of the natural frequencies corresponding to a mode are drawn in function of the rotation speed of the shaft.

The 10,000rpm is the engine rpm at the max, usually considering the idle speed of the engine is not at all allowed as the engine speed is always changing. The natural frequency of the chassis doesn't change with respect to the engine speed where it have no control over hence the chassis frequency is considered to be constant for all rpm.

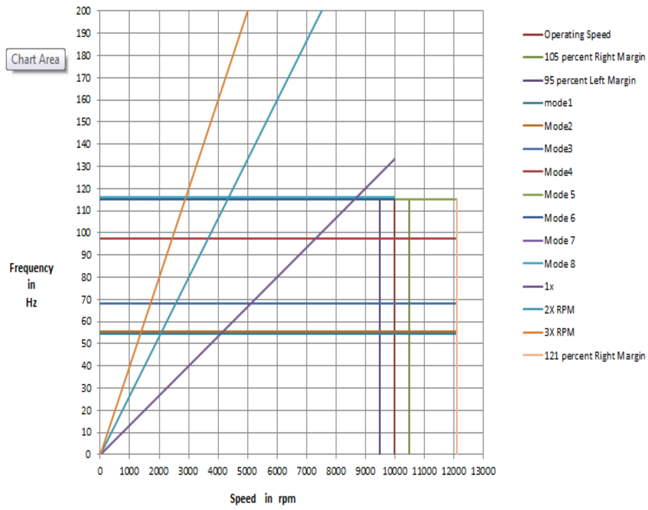


Figure 10: Campbell diagram

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 07, July-2016

It can be seen very clearly that the 1x mode is resonating with respect to the 1st mode at the speed of 4800rpm and 5th mode at 93% speed. Also, till 4x speeds there pose no danger to the natural frequency of the chassis expect the 1st mode and the 1x resonance. But as the resonating speed is 50% lesser than the operating speed pose no danger to the overall structural integrity of the system.

5. OPTIMIZATION

Choosing the best solution from the available solution. Minitab software is used for the optimization here. DOE is created using the factors influence for the stresses. Design points are constructed as per the model. Orthogonal arrays were proved to be more efficient compared to the other arrays used in screening but are more tedious. L9, L16, L25, L36 … can be used for the optimisation purpose depending on the inputs. It is noted that the design points are again iterations carried out in Ansys. L16 array would be good and sufficient enough to determine the best solution with least error and residuals. Hence L16 array is considered and each of the design samples for each type of analysis is tabulated here.
From the sampling points, the optimisation can be done. Orthogonal regression model uses the algebraic equations for creation of the continuity between thickness, Diameter and stress. If the thickness is chosen is chosen to be as the continuous predictor then the model is called as the horizontal continuous model. If the radius is chosen as the continuous predictor then the model is called as the vertical continuous model.

In the poisons regression is used instead of the orthogonal model then the equations used are not of linear form but are logarithmic. And thus obtaining the continuity. A target value of 200MPa is chosen as the desired stress value for the optimisation.

This method gives the optimisation and the results of sampling points and the optimised results in all the models.

Front Impact Design points and optimization:

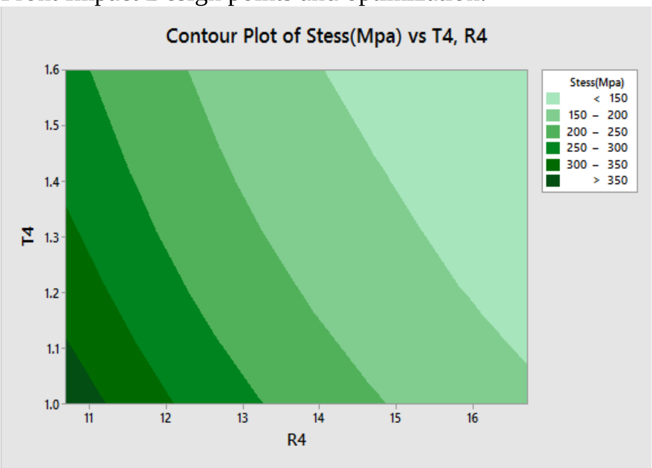


Figure 11: contour plot of the variation of stress with R4 and T4.

Observation Table 7:

Model	Orthogonal Horizontal	Orthogonal Vertical	Poisons Horizontal	Poisons Vertical
R square Value	97.40%	93.83%	99.50%	98.91%
R adjusted value	96.46%	91.58%	98.54%	97.95%
Radius Value(mm)	14.7	13.5160	12.7	13.9652
Thickness Value(mm)	1.05035	1.4	1.47983	1.2

Side Impact Design points and optimisation:

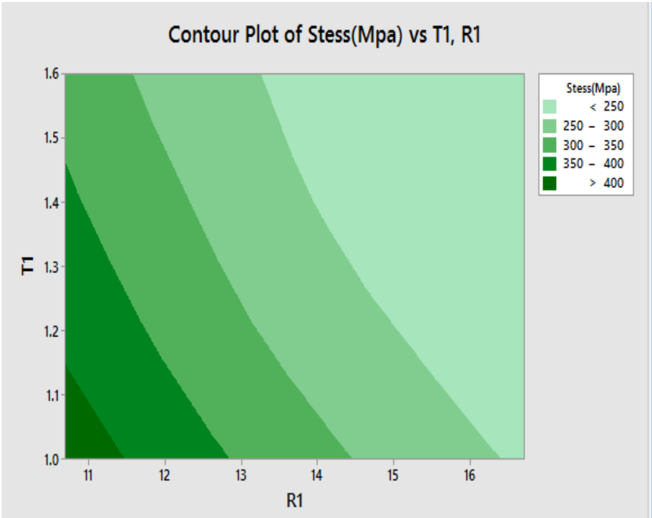


Figure 12: contour plot of the variation of stress with R1 and T1.

Observation Table 8:

Model	Orthogonal Horizontal	Orthogonal Vertical	Poisons Horizontal	Poisons Vertical
R square Value	96.63%	94.04%	98.11%	97.16%
R adjusted value	95.41%	91.88%	96.36%	95.41%
Radius Value(mm)	16.7	16.6867	16.7	15.3366
Thickness Value(mm)	1.34635	1.2	1.3470	1.6

Rear Impact Design points and optimisation:

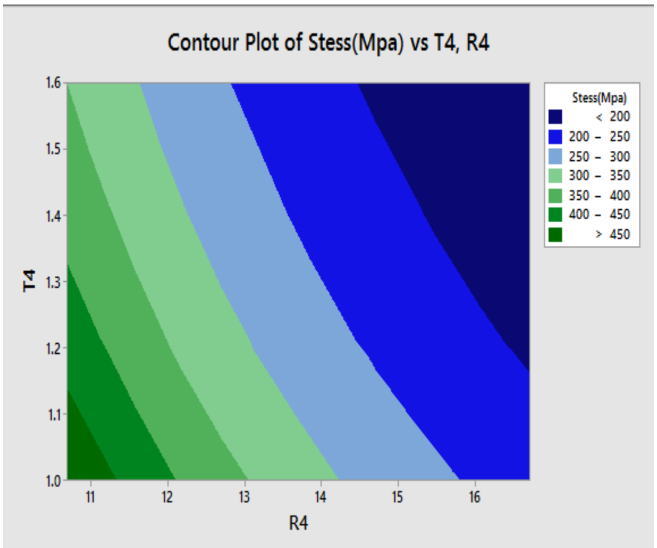


Figure 13: Contour plot of the variation of stress with R4 and T4.

Observation Table 9:

Model	Orthogonal Horizontal	Orthogonal Vertical	Poisons Horizontal	Poisons Vertical
R square Value	98.50%	96.05%	99.86%	99.60%
R adjusted value	97.95%	94.61%	99.05%	98.01%
Radius Value(mm)	16.7	16.2659	14.7	14.6354
Thickness Value(mm)	1.2252	1.2	1.5436	1.6

Roll over Design points and optimisation:

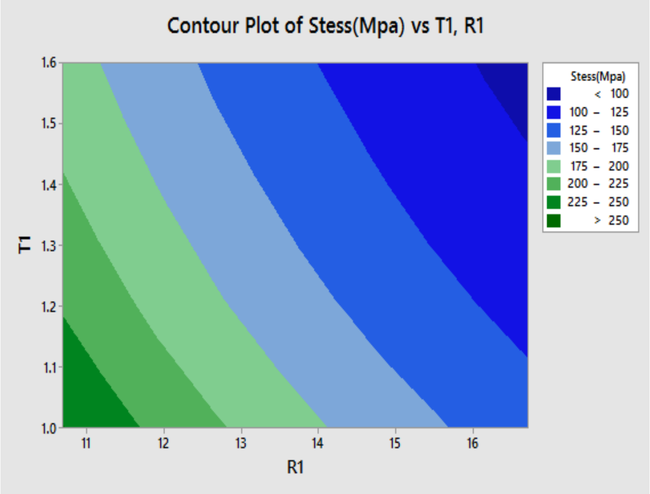


Figure 14: Contour plot of the variation of stress with R1 and T1.

Observation Table 10:

Model	Orthogonal Horizontal	Orthogonal Vertical	Poisons Horizontal	Poisons Vertical
R square Value	99.19%	98.31%	99.71%	99.76%
R adjusted value	98.89%	97.69%	97.58%	97.63%
Radius Value(mm)	10.7	13.0471	12.7	11.6922
Thickness Value(mm)	1.4737	1.0	1.0114	1.2

6. CONCLUSION

From the above table it is clear the model having the highest accuracy that is R-Square value will have reduced root mean square error. From the optimisation, these values are concluded as the best possible results for the chassis with the reduced stress and the weight with target stress values.

Table 11: Optimum solution

Radius	Value(mm)	Thickness (mm)	Value(mm)
R4(Front)	13.30	T4(Front)	1.35
R4(Rear)	13.10	T4(rear)	1.98
R1	13.10	T1	1.45
R2	13.10	T2	1.4
R3	12.7	T3	1.4

REFERENCES

[1] Mohd hanif Mat, Amir Radzi Ab. Ghani "Design and analysis of "Eco" car chassis" Automotive research and testing centre (ARTeC), Univeristi teknologi MARA shah Alam, Malaysia. International Symposium on Robotics and Intelligent Sensors 2012 (IRIS 2012). Procedia Engineering 41 (2012) 1756 – 1760, Elsevier
[2] Mohammad Al bukhari mazuki, Mohd Arzo Abu bukar, Mohammad Firdaus Mohammed Azmi " designing space frame Race car chassis structure using natural frequencies Data from ansys mode shape results analysis", international journal of information systems and engineering, Volume 1(No 1), April 2015 ISSN 2289-2265
[3] Ravinder pal Singh, "Structural performance analysis of formula SAE car" Journal Mekanikal No 31, 46-61
[4] Simonetta Boria, university of Pisa. "Numerical simulation of crash-Test for a formula SAE car" has claimed about the crash test of FSAE car chassis. Paper number 09-0152
[5] Brendan J Waterman, university of Western Australia, Master thesis "Design and construction of a space frame chassis"
[6] Jannis D.G van kelchoven, Master's thesis, Technische universiteit Eindhoven "Design of a formula student race car chassis"
[7] AA Faieza, S.M sapun, MKA Ariffin, BTHT Baharudin and EE Supeni in the paper "Design and fabrication of a student competition based racing car" Scientific research and Essay Vol 4 (5) pp. 361-366, ISSN 1992-2248, Academic journal.
[8] Abrams, Ryan, "Formula SAE race car analysis-simulation & testing of the engine as a structural member", F2008-SC-005.
[9] The book "Machine Design" by NORTON.