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A Vibration Analysis Of Vehicle Frame

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Abstract

Importance in the development of off-road racing vehicle for the SAEINDIA's BAJA competition has raised the value of dynamic analysis under severe uneven loading. The dynamic analysis is carried out by the finite element method simulation thereby predicting failure modes of the vehicle frame under vibration analysis. This work investigates the vibration characteristics of the frame including the natural frequencies and mode shapes.

Keywords: Finite element method, dynamic analysis, failure modes, mode shapes.

Introduction to SAE BAJA & Vehicle Frame

Baja is a collegiate competition sponsored by the Society of Automotive Engineers, India (SAEINDIA). The object for the team of students to develop a dynamically balanced vehicle to withstand all kind of terrain during its mobility. The SAE BAJA vehicle development manual restricts us about the vehicle weight, shape and size, and dimensions. The objective of SAE BAJA competition is to simulate real world engineering design projects and their related challenges. The objective is to develop not only the best performing vehicle but also the rugged and economical vehicle frame that will comply all the SAE BAJA design requirements [1]. During actual road performance, any vehicle is subjected to loads that cause stresses, vibrations and noise in the different components of its structure. This requires appropriate strength, stiffness and fatigue properties of the components to be able to stand these loads. On top of that, quality of a vehicle, as a system, which includes efficient energy consumption, safety, riding dampness and provision of comfort to the driver is highly desired.

Frame forms the structural base of a racing off road vehicle. The frame here developed for the event is of O section type. The strength and rigidity of the O section is higher than any other form like I, T, C section. The theory of the bending and torsion explains that circular section is always a perfect one to resist the twisting and the rolling effects. Cross section of the pipe element of the frame is shown in the fig 1.

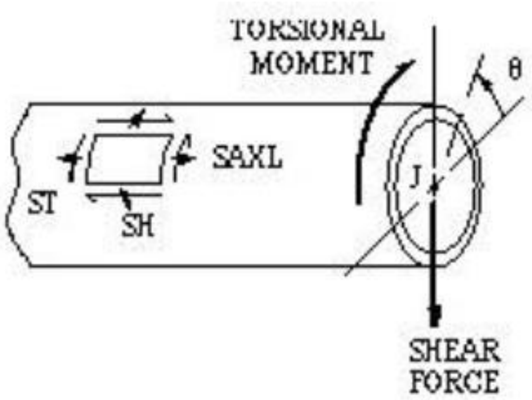

Figure 1, Cross section of frame used

Circular section is preferred comparatively for torsional rigidity for its higher polar moment of inertia compared than any other section as per the following formula

$$T = \frac{\pi}{16}\tau d^3$$

where, T= twisting moment or torque applied;
τ = shear strength of the material;
d = diameter of the pipe section;

Material and Modelling of Vehicle Frame

The weight of the material is also a limiting parameter for the SAE BAJA vehicle, because if a higher weight material is used, it could raise the overall weight of the vehicle frame. The specifications of the material used for the vehicle frame development are tabled below in table 1, at 25°C reference temperature

Properties	***Value***
Density(x1000 kg/m^3)	7.7-8.3
Poisson's Ratio	0.27-0.30
Elastic Modulus (GPa)	190-210
Tensile Strength (MPa)	394.7
Yield Strength (MPa)	294.8
Hardness (HB)	111
Impact Strength(J) (Izod)	123.4

Table 1, Mechanical Properties of AISI 1020 Steel [2]

The dimension of the pipe frame is given in table 2.

Pipe diameter (mm)	25.4
Wall thickness (mm)	3.05

Table 2, Dimensions of pipe section

Vehicle Frame modelling for SAE BAJA is done in ANSyS Mechanical, with structural discipline of testing. The use of pipe-16 element which is a uniaxial element with tension-compression, torsion, and bending capabilities and has six degrees of freedom at two nodes: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z axes [3] is used in the pre-processing steps of the ANSyS. The other properties of the material and the size of section frame are provided in the real constant and material menu of pre-processing steps. Modelling is done via co-ordinates plotted, followed by the lines joining the points to develop the geometric model of frame [4] shown below in fig 2.

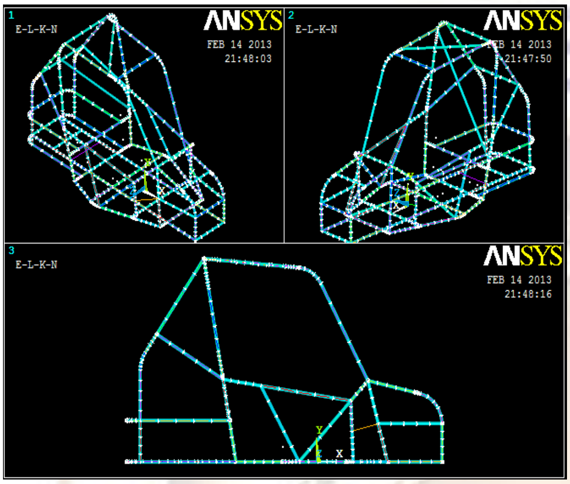

Figure 2, Geometric Model of vehicle rollcage

Theory of boundary conditions applied to Vehicle Frame

The natural frequency of vibration of a machine or structure or frame, when coincides with the excitation frequency of the forced vibration, there occurs a phenomenon known as resonance, which leads to excessive deflections and failure. A lot of failures brought about by resonance and excessive vibration of components and systems [5].
The frame is fixed at the lower base of the vehicle frame to know the different mode shapes of the upper substructure. As the wheels and suspension is mounted at the axles, so it will have no motion and hence the DOF of the lower base is restricted to zero.

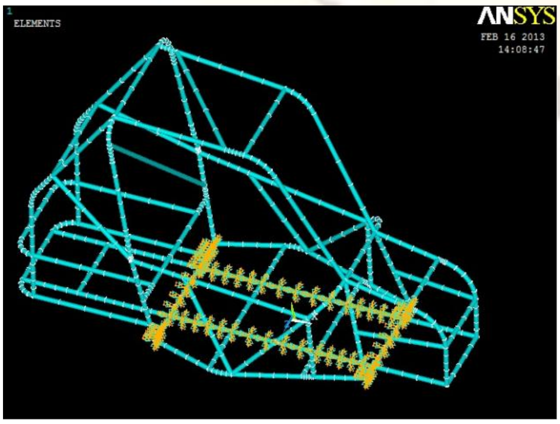

Figure 3, Meshed model with boundary conditions

This model is then solved for the modal analysis to know the natural frequency of the model under its self weight. In general the natural frequency can be calculated using the equation

$$Wn = \sqrt{\frac{k}{m}} = \sqrt{\frac{g}{\delta}}$$

where, k and m stand for stiffness and mass respectively.

Results

Diesel engine provided for the SAE Baja vehicle, is known to have the operating speed varying from 10 to 330 revolutions per second (rps) [6] for the different interval, as at idling it rolls at 10-20 rps where as at full throttle it runs at 250-300 rps.

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

SET	TIME/FREQ	LOAD STEP	SUBSTEP	CUMULATIVE
1	26.156	1	1	1
2	28.166	1	2	2
3	37.905	1	3	3
4	51.032	1	4	4
5	55.264	1	5	5

Figure 4, List of frequencies w.r.t. mode shapes

The first mode shape explains the deformation phenomenon on the upper part of the frame acquiring the longitudinal vibrations of natural frequency 26.155Hz, which is the lowest natural frequency where as the highest value is 55.264 Hz under the effect of gravity and deformation under the self weight.

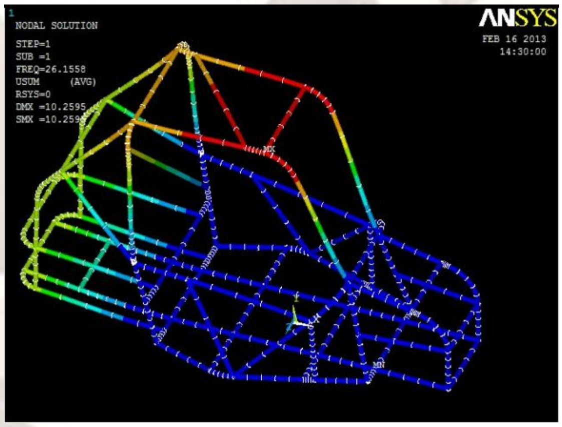

Figure 5, First mode shape of vibration

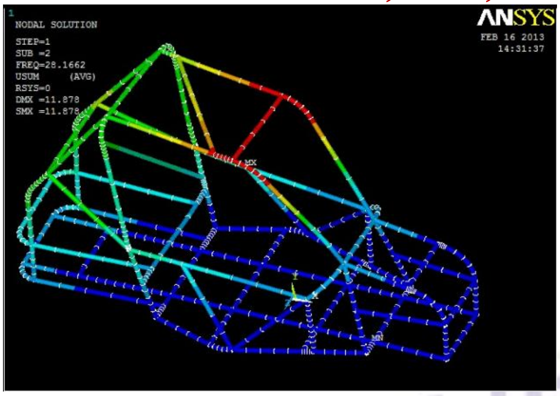

Figure 6, Second mode shape of vibration

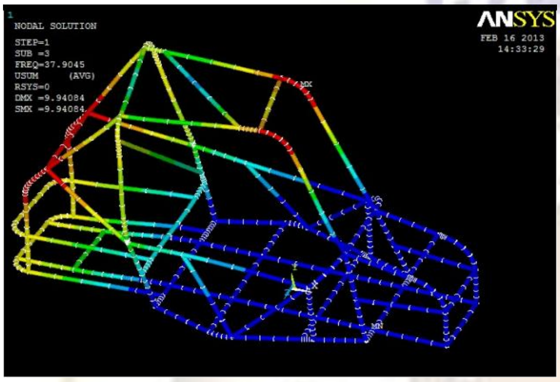

Figure 7, Third mode shape of vibration

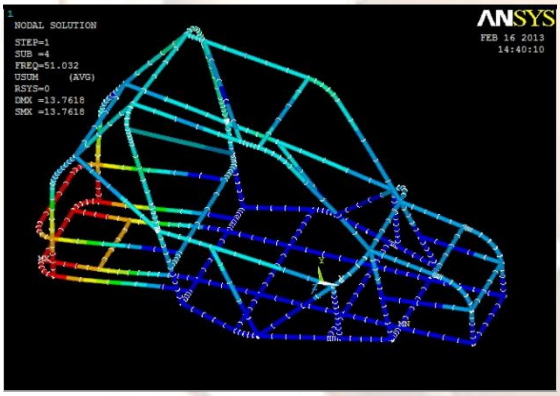

Figure 8, Fourth mode shape of vibration

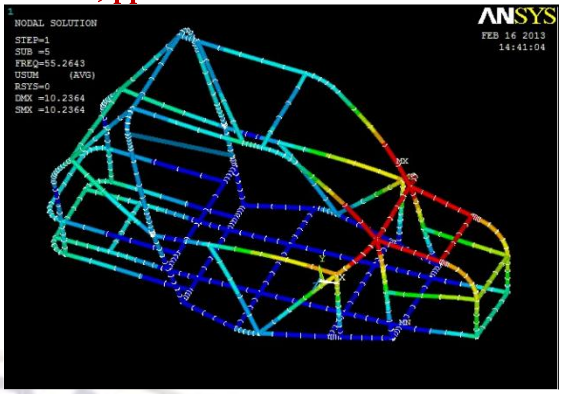

Figure 9, Fifth mode shape of vibration

Conclusion

The results developed states that the frame's dynamic behaviour caused by change in usage with finite element method using ANSyS. Frequency modes of the frame that determine its dynamic behaviour are below100 Hz and vary from 26.156 to 56.254 Hz. For the first two modes, the frame experienced longitudinal vibration on the roof pillars. The vibrations of the vehicle frame include longitudinal, transverse and torsion at different nodal points. The local bending vibration occurs at the top hat cross member where the engine is mounted on it. Since the installation of other components and accessories will be mounted, which will increase the total mass, therefore the natural frequencies will fall out of the natural range that can be compensated with increasing the chassis stiffness and will place the excited frequencies below natural range. This concept value implies the safe value of applied loads vibrations and deformations.

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