7RESPONSE OF ATV ROLLCAGE UNDER HARMONIC VIBRATION

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Abstract - *This work is aimed to find the natural frequency and analyse chances of resonance in the rollcage structure. Results of the analysis will help to study the dynamic behaviour of the rollcage with load application/real road condition and to improvise the rollcage structure assembly. Beginning with the designing of rollcage and analysis the requirement is identified and the related concepts were formulated. To conduct the complete work, we made a road map which we followed. A literature survey was then conducted to establish the focus for analysis. A full-scale model of rollcage of ATV was designed in SpaceClaim in ANSYS. All the analysis was done in simulation software package ANSYS 18.2.*

Key Words: **Modal Analysis, ANSYS Workbench, Harmonic response, Rollcage, All terrain Vehicle, SpaceClaim Modelling.**

1. INTRODUCTION

There has been a continuous growth in the research and development in the different aspects of ATV. Many of the major engineering innovations have finally been implemented in ATV, and many are also being done at present. Finite element methods have been used for structural analysis to determine the stress-induced components because of the static and dynamic loads they are subjected to. These structural components also respond dynamically to the loads, measured in terms of their vibration. Once the structure vibrates the air molecules next to it are imparted oscillatory motion and these, in turn, propagate the energy as longitudinal sound waves which are finally incident on the listener's eardrum and then one gets a sensation of hearing. This sound in an ATV is both heard in the vehicle interior by the passenger and the driver as well as outside by the passer-by. A noise control designer aims to reduce these sound pressure levels which are either heard by the person inside the vehicle or outside the vehicle. Several computer-aided design techniques exist for evaluating the performance of such ATV in terms of the noise level they generate. And there exist many engineering methods to mitigate the noise. [1]

2. BACKGROUND

2.1 ATV

ATV which is the acronym for All Terrain Vehicle, is capable to run in all types of non-motorable rough terrains having obstacles like rocks, sand, mud, steep inclines, and shallow water. The vehicle must be able to sustain all the loads that are generally encountered in an off-road scenario both static and dynamic and should possess enough traction to overcome resistance encountered in the off-road scenario. The dynamic stability and ride throughout the uneven rough terrain is also a major consideration for the design of an ATV. [2]

2.2 Roll cage Chassis

Chassis is a French term and was initially used to denote the frame parts or Basic Structure of the vehicle. It is the backbone of the vehicle. A vehicle without a body is called Chassis. Chassis is a structure to protect the driver. The components of the vehicle like Power plant, Transmission System, Axles, Wheels and Tyres, Suspension, Controlling Systems like Braking, steering etc., and also electrical system parts are mounted on the Chassis frame. It is the main mounting for all the components including the body. So, it is also called a carrying unit. The following main components of the Chassis are 1. Frame: - This made up of long members welded together with the help of the number of cross members. 2. Engine or Power plant: It provides the source of power 3. CVT: It connects and disconnects the power from the engine to the transmission system, 4. Gearbox. The frame is the main part of the chassis on which the remaining parts of chassis are mounted. The frame should be extremely rigid and strong so that it can withstand shocks, twists, stresses, and vibrations to which it is subjected while the vehicle is moving on the road. It is also called Rollcage. The frame is supported on the wheels and tire assemblies. The frame is narrow in the front for providing a short turning radius to front wheels. It widens out at the rear side to provide larger space in the body. [3]

2.3 Vibration

In the last two decades, the numerical simulation via finite element methods (FEM) has been well integrated into the product development process (PDP) of the automotive industries. The PDP is currently increasingly driven by numerical simulation as non-linear (such as crashworthiness) and linear cases (such as NVH) are been accomplished. One of the most important attributes for car product development is noise, vibration, and harshness (NVH). NVH response can be classified in various ways: powertrain NVH, road noise, wind noise, component noise, and squeak and rattle. Vibrations are produced when there is an exciting (or compelling force) acting upon an object, causing the body to vibrate. Eliminating an NVH concern is greatly assisted by locating the compelling force (the source of the vibration). The major component groups that produce compelling forces are tire and wheel, driveline, engine and torque converter. A vehicle with a good NVH behaviour often results in a much higher customer satisfaction. In vehicle development, different NVH models are used for different systems and purposes that will assure the quality of the NVH behaviour. In practice, nearly all vibration problems are related to structural weaknesses, which is associated with resonance behaviour (natural frequencies excited by operational forces). The complete dynamic behaviour of a structure (in a given frequency range) can be viewed as a set of individual modes of vibration, each having a characteristic natural frequency, damping, and mode shape. Problems at specific resonances can be examined and subsequently solved by using these modal parameters to model the structure. [4]

3. MODELLING AND MATERIAL

3.1 Geometric Modelling

Geometric modelling is the process of capturing the properties of an object or a system using mathematical formulae. Computer geometric modelling is the field that discusses the mathematical methods behind the modelling of realistic objects for computer graphics and computer-aided design. Geometrical arrangement used in the experiment is presented, where the model of ATV frame(rollcage) is designed according to the rulebook.

Tubular frame with a cross-section of the tubes for primary tube taken as 29.2mmX1.65mm and as for secondary tube, it is 25.4mmX1.2mm. For the mounting of sub-assemblies, tabs of different thicknesses are designed in the rollcage.

Rollcage members are:

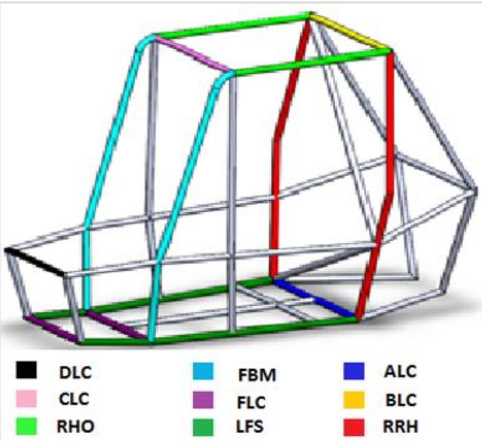

Fig -1: SAE India, 2019. *BAJA India rulebook*

Table -1: SAE India, 2019. *BAJA India rulebook*

RRH	Rear Roll Hoop
RHO	Roll Hoop Overhead Members
FBM	Front Bracing Members
ALC	Aft Lateral Cross Member
BLC	Overhead Lateral Cross Member
CLC	Upper Lateral Cross Member
DLC	SIM Lateral Cross Member
FLC	Front Lateral Cross Member
LFS	Lower Frame Side Members

3.2 Meshing

Meshing is an integral part of the engineering simulation process where complex geometries are divided into simple elements that can be used as discrete local approximations of the larger domain. The mesh influences the accuracy, convergence and speed of the simulation. Furthermore, since meshing typically consumes a significant portion of the time it takes to get simulation results, the better and more automated the meshing tools, the faster and more accurate the solution.

Ansys provides general-purpose, high-performance, automated, intelligent meshing software that produces the most appropriate mesh for accurate, efficient Multiphysics solutions — from easy, automatic meshing to highly crafted mesh. Methods available cover the meshing spectrum of high-order to linear elements and fast tetrahedral and polyhedral to high-quality hexahedral and Mosaic.

Geometric Model of Rollcage

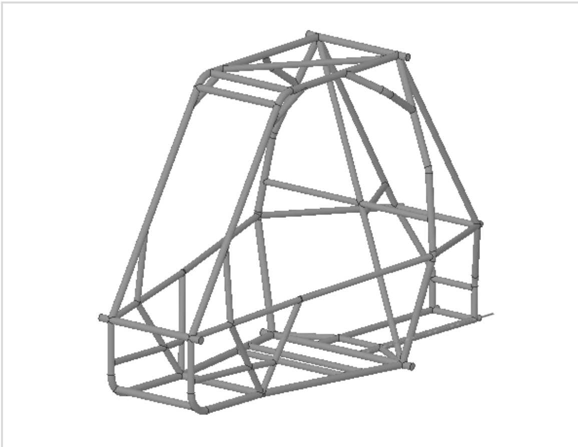

Fig -2: CAD Model of Rollcage for Analysis

Meshed Model of Rollcage

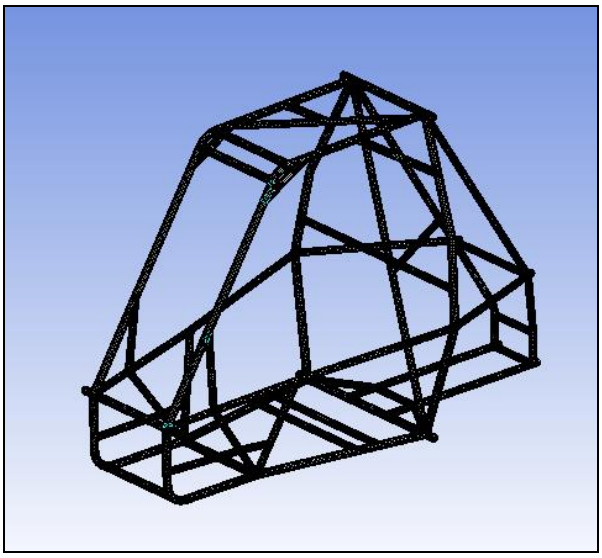

Fig -3: Meshed Model of Rollcage for Analysis

3.3 Material Properties

AISI 4130, Chromoly which is considered while designing rollcage with its specifications-

Table -2: AISI 4130 Material Properties

ELEMENT	CONTENT (%)	
Iron, Fe	97.03 – 98.22	
Carbon, C	0.280 – 0.330	
PROPERTIES	**METRIC**	**IMPERIAL**
Density	7.85 g/cm^3	0.284 lbs./in^3
Melting point	1432°C	2610°F
Tensile strength, ultimate	560 Mpa	81200 psi
Tensile strength, yield	460 Mpa	66700 psi
Modulus of elasticity	190-210Gpa	27557-30458 ksi
Elongation at break (in 50 mm)	15.4%	

4. VIBRATION ANALYSIS

Vibration in an ATV is a persistent problem and exposure to such vibrations over long durations makes the driver susceptible to joint diseases. For rough roads, if the driver is exposed to more than 30 to 35 minutes, it would make the driver uncomfortable. 1. Driving comfort is essential for safety as well as better handling of the vehicle 2. The sources of these vibrations are both external and internal. The contribution of the external sources is less at low speed whereas the internal sources contribute at both high and low-speed conditions of the vehicle. The majority of these vibrations affect the driver through the seat. In this paper, we have reduced the vibration level of an All-Terrain Vehicle caused due to engine, an internal source.

So, to do the vibration analysis of rollcage, first of all, it's needed to find out the mode of vibration of the rollcage and its natural frequency of vibrations, so for this modal analysis are done.

4.1 Modal Analysis

Any complex body can vibrate in many different ways. I.e., there is no one "simple harmonic oscillator". These different ways of vibrating will each have their frequency, that frequency determined by moving mass in that mode. Finding out Different mode shapes, corresponding frequencies and deformations for rollcage.

Natural frequencies of rollcage:

Table -3: Frequency condition pre-stress (none)

	Mode	Frequency [Hz]
1	1.	32.111
2	2.	56.517
3	3.	61.864
4	4.	118.72
5	5.	140.96

After finding the natural frequency of rollcage we can conclude that there is a possibility of resonance to occur, as one mode of vibrating frequency is under the range of 0-35 Hz. So, to avoid this phenomenon there are certain ways which can be done.

a. We can change the design of rollcage by making it stiff and can change the natural frequency of rollcage but it is not an appropriate way as it will make the rollcage over stiff and vehicle bulky.
b. We could alter the engine to change its working frequency range but as per the guideline of Baja SAE, students are not allowed to alter it.
c. So, the final option to minimise its effect by providing maximum damping by engine mounts

(bushing) so, we considered this approach more efficient for our scenario.

4.2 Harmonic Analysis

After studying all of the types of analysis we have analysed that there is a chance of resonance to occur, to predict the behaviour of our rollcage in case of resonance, we have one module to analyse the effect of it which is harmonic analysis. So, we are using harmonic analysis for the prediction of the dynamic behaviour of rollcage while in the working condition of the engine.

Harmonic analysis is a technique to determine the steady-state response of a structure to sinusoidal (harmonic) loads of known frequency.

Input:

- Harmonic loads (forces, pressures, and imposed displacements) of known magnitude and frequency.
- May be multiple loads all at the same frequency. Forces and displacements can be in-phase or out-of-phase. Body loads can only be specified with a phase angle of zero.

Output:

- Harmonic displacements at each DOF, usually out of phase with the applied loads.
- Other derived quantities, such as stresses and strains.

Harmonic analysis is used in the design of: Supports, fixtures, and components of rotating equipment such as compressors, engines, pumps, and turbomachinery. Structures subjected to vortex shedding (swirling motion of fluids) such as turbine blades, aeroplane wings, bridges, and towers. Why should you do a harmonic analysis? To make sure that a given design can withstand sinusoidal loads at different frequencies (e.g., an engine running at different speeds). To detect resonant response and avoid it if necessary (by using dampers, for example). [5]

Table -4: Various materials used for harmonic response are:

TYPE OF ELASTOMER	STORAGE MODULUS (MPa)	LOSS FACTOR
Natural Rubber	3.4	0.03
Neoprene rubber	4.8	0.11
Blend of nitrile rubber, PVC, and DIOP	6.6	0.22
Ethylene acrylic elastomer	5.4	0.27

This table is taken from this research paper "Characterization of Engine Mount Elastomers 2005" by J.P. Szabo, this is the common material which is generally used for isolation of vibration. So, we have considered this and considered the loss factor as a damping ratio.

Frequency is analysed for the engine mounting portion of the rollcage. The load magnitude considered was 250 N as this was the maximum load obtained from dynamic analysis.

Table -5: Ansys setting for harmonic responses:

State	Fully Defined
Range Minimum	0. Hz
Range Maximum	32.111. Hz
Solution Intervals	10
Solution Method	Mode Superposition
Cluster Results	No
Modal Frequency Range	Program Controlled

5. RESULTS AND DISCUSSION

5.1 Harmonic analysis for Natural rubber with a damping ratio of 0.03.

Table -6: Harmonic analysis for Natural rubber with a damping ratio of 0.03:

Frequency	Amplitude
3.2111	2.0136E-02
6.4222	2.0320E-02
9.6333	2.0635E-02
12.8444	2.1097E-02
16.0555	2.1729E-02
19.2666	2.2569E-02
22.4777	2.3684E-02
25.6888	2.5206E-02
28.8999	2.7550E-02
32.111	2.8933E-02

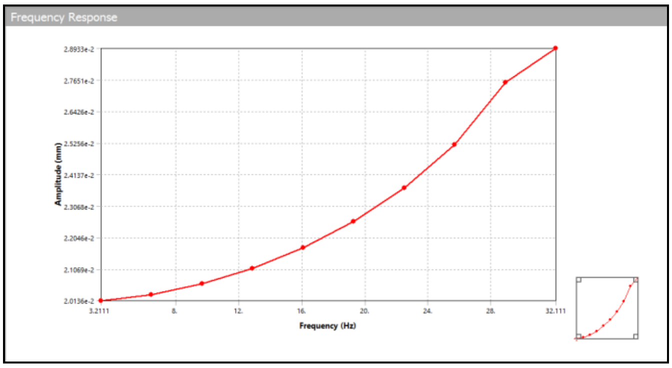

Chart -1: Amplitude vs Frequency graph of natural rubber.

5.2 Harmonic analysis for neoprene rubber with a damping ratio of 0.11.

Table -7: Harmonic analysis for neoprene rubber with a damping ratio of 0.11:

Frequency	Amplitude
3.2111	2.0135E-02
6.4222	2.0314E-02
9.6333	2.0621E-02
12.8444	2.1070E-02
16.0555	2.1681E-02
19.2666	2.2488E-02
22.4777	2.3541E-02
25.6888	2.4915E-02
28.8999	2.6626E-02
32.111	2.7930E-02

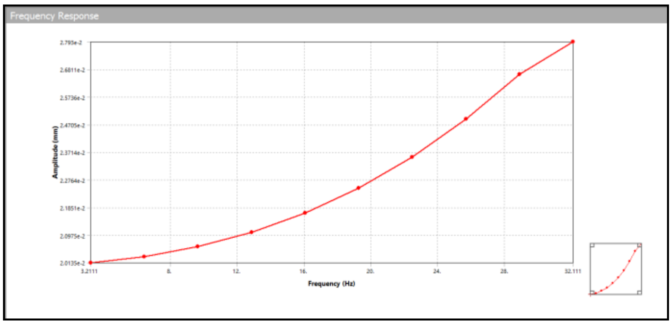

Chart -2: Amplitude vs Frequency graph of neoprene rubber.

5.3 Harmonic analysis for Blend of nitrile rubber, PVC, and DIOP with a damping ratio of 0.22.

Table -8: Harmonic analysis for Blend of nitrile rubber, PVC, and DIOP with a damping ratio of 0.22:

FREQUENCY	AMPLITUDE
3.2111	2.0130E-02
6.4222	2.0295E-02
9.6333	2.0576E-02
12.8444	2.0982E-02
16.0555	2.1529E-02
19.2666	2.2234E-02
22.4777	2.3118E-02
25.6888	2.4187E-02
28.8999	2.5391E-02
32.111	2.6687E-02

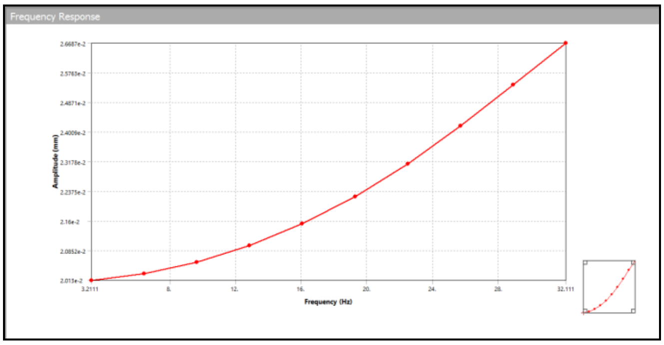

Chart -3: Amplitude vs Frequency graph of neoprene rubber.

5.4 Harmonic analysis for Ethylene acrylic elastomer with damping ratio 0.27.

Table -9: Harmonic analysis for Ethylene acrylic elastomer with damping ratio 0.27:

FREQUENCY	AMPLITUDE
3.2111	2.0127E-02
6.4222	2.0282E-02
9.6333	2.0545E-02
12.8444	2.0924E-02
16.0555	2.1429E-02
19.2666	2.2071E-02
22.4777	2.2858E-02
25.6888	2.3785E-02
28.8999	2.4817E-02
32.111	2.5956E-02

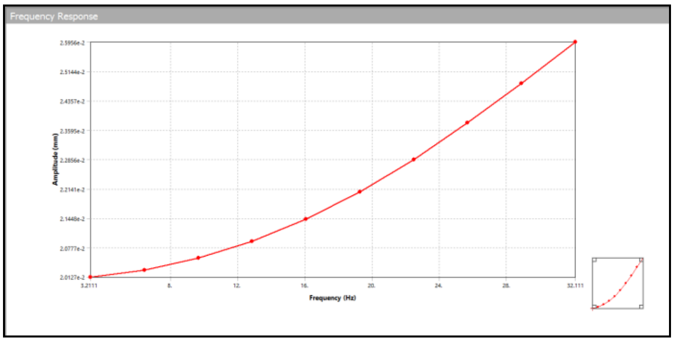

Chart -4: Amplitude vs Frequency graph of Ethylene acrylic elastomer.

3. CONCLUSIONS

After doing the vibration analysis of common viscoelastic materials which can be used for the damping of the engine, we conclude that Ethylene acrylic elastomer material has damping ratio of 0.27 and provided the least amplitude at

32.111 Hz so, we consider this Ethylene acrylic elastomer which is best suitable for bushing of an engine in our rollcage for isolation. The different material of mounting bushing has been used and their behaviour have been studied and best among them is used.

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