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Design and Development of Quad Bike Chassis Frame

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A Quad bike is an off-road vehicle used for transportation in hilly areas and farming fields. The current paper presents the design and development of chassis frame of All Terrain Vehicle (ATV) i.e. Quad Bike. As stated by ANSI, a quad bike is an all-terrain vehicle has low-pressure tires, with a seat straddled by the operator having handle bar for steering control. As an ATV, it must be designed for wide variety of terrain over most of commercial vehicles available. In this work, a chassis frame of quad bike is developed and found to be rigid, safe and comfortable to driver. The analysis of designed frame carried out by using ANSYS 16.0 software and testing of the same through FFT analysis shows its suitability to all-terrain operating conditions.

***Keywords*:** Quad bike, Chassis Frame.

1. Introduction

According to American National Standards Institute (ANSI), Quad bike is a vehicle that travels on low pressure tires, with a seat that is straddled by the operator, along with handlebars for steering control. Quad bikes are of two-wheel drive or four-wheel drive and sometimes referred as ‘four-wheel motorbikes’. This bike serve the purpose of transportation of an off-road vehicle that could help in transportation in hilly areas and farming fields. It also able to pull any trailer having weight around 700-800 kg [1].

Fully functional and movable unit of vehicle except its body consisting of all the vehicle systems mounted on it is nothing but a chassis. The chassis frame of the vehicle supports the major systems of the vehicle such as engine, brake, steering, axle, tires, etc. The main purpose of the frame is to make all these subsystems’ constraint and fixed to work properly. It must support all the components mounted, occupants placed and should absorb all kinds of loads imposed on it without deflecting unduly. Additionally, it should absorb the aerodynamic wind forces and road shocks through suspensions [3]. If the engine seems to be the heart of the vehicle, then chassis is nothing but its skeleton and hence, plays the role of a backbone for whole vehicle structure. One can certain on the decision of this frame structure should be of rigid in bending and torsion phenomenon encountered by it during the normal operation of vehicle. The chassis frames are usually made of light steel material or lightweight materials like aluminum and its alloys, carbon fiber, etc. The design of chassis frame is usually focused on safety, serviceability, strength, ruggedness, and standardisation, cost, ergonomics and aesthetics aspects.

As a part of literature survey, few research papers and books have been analysed. An important aspect of designing any system is nothing but appropriate material selection. For a Quad bike, Choudhary (2013) presented an in depth material selection process for quad bike chassis frame. The testing of designed chassis frame against all modes of failure by conducting various simulations and stress analysis with the aid of AutoDesk Multi-physics and explanation about different loading condition of chassis frame is discussed well. In static loading and testing of frame, Bajaj (2014) investigated static structural characteristics of the chassis frame at different loading condition and its responses which include the stress distribution and displacement under various loading condition. A modal analysis of the same for natural frequencies and mode shapes has been performed whereas design part is performed using Creo 3.0 and finite element analysis using ANSYS 14.0.

A design of a single-passenger off-road race vehicle with high safety and low production costs seems to be accomplished by Shrivastava (2014). The most interesting and fundamentally reality of about this vehicle is that primarily conceptualized based design on personal experiences and intuition is verified by subsequent application of engineering principles and design processes to create a vehicle with optimal performance, safety, manufacturability, and ergonomics. In the Quad bike design report of Shaik (2017), step wise procedure of design, methodologies adopted, FEA of frame, material selection criteria, classification according to the property and the considerations made in the entire design process is well mentioned.

Under testing of the quad bike, Bhale (2017) performed static analysis of the Quad bike chassis frame i.e. frontal impact, side impact, rear impact, roll over test, drop test, torsional analysis with the help of simulation software. FEM approach of Mongiardini (2013) on rollover incidents with ATV's precisely determined the vehicle-rider interaction during a variety of different rollover scenarios using computer simulations. Gillespie (1992) has been used since long ago as an ample data about static and dynamics response of chassis on various operating conditions such as C.G location, lateral loading, longitudinal loading, gradability, etc. is well demonstrated.

A refinement to above mentioned studies is necessary with respect to actual and real life operating conditions. Hence, this work is intended to design a quad bike chassis frame and optimise the same under different operating conditions encountered during normal operation. To use the approach of conceptual design based on personal experience and limitations in the existing systems, a detailed study was done on available quad bikes. To test the designed frame by simulating real life operating conditions precisely, team of designers collected data by visiting Mahabaleshwar ATV racing-track and Polaris motors, Pune and also earlier published research work is referred. It was planned to design by considering all the vital aspects such as safety, ergonomics, market availability, material cost, etc.

Under this work, three simple design goals were applied to chassis frame of the quad bike namely durable, light-weight, and high strength. It was essential to optimize the design by avoiding over designing, which would also help in reducing the cost. After successful iterations of results of calculation and simulation of chassis frame design, the actual development of vehicle could be possibly proceeded. The design and development of chassis frame for an All-Terrain Vehicle (ATV) i.e. Quad Bike has been performed step wise as material selection procedure, chassis frame design, stress analysis, manufacturing and testing under diverse operating conditions. According to the ENCAP standards [7], factor of safety for different loading conditions were obtained. Subsequently, solid modeling of chassis frame is carried out in CATIA V5 and ANSYS 16.0 software is used to analyse the same in various operating conditions.

2. Design of Chassis Frame

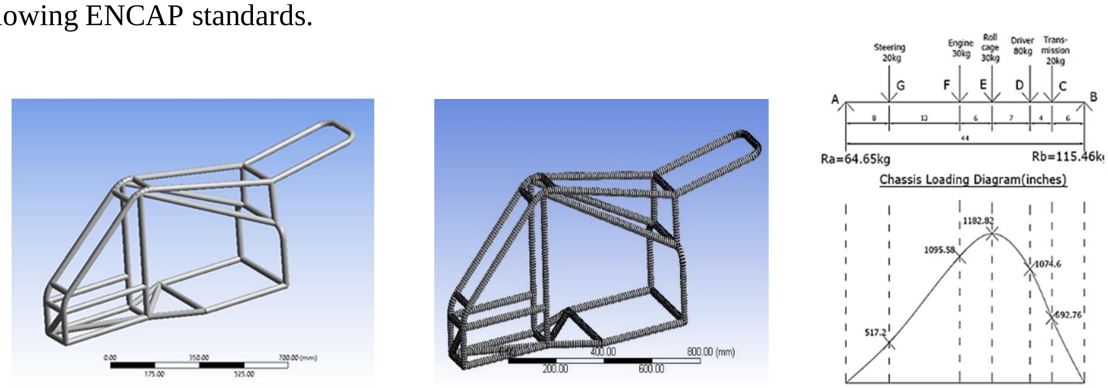
To begin the initial design of the frame, some design guidelines were required to be set. These include intended transmission, steering and suspension systems and their placement, mounting of seat, design features and manufacturing methods. It is also required to keep a minimum clearance between the driver and frame members. The engine used is a Lifan 250cc petrol engine and its specifications were also obtained. It is also necessary to keep weight of the roll cage as low as possible to achieve better acceleration. It is necessary to keep the centre of gravity of the vehicle as low as possible to avoid toppling. Mounting heavier components such as engine, driver seat etc. directly on the chassis is one way of achieving low centre of gravity. Also, it is imperative to maintain the integrity of the structure. This is done by providing bends instead of welds which in turn reduces the cost [8].

For finding different loading conditions of chassis frame, parameters such as centre of gravity, lateral load, longitudinal load, vertical bending, wheel bump load, torsion load, load distribution at low speed acceleration, load distribution at 20^{o} gradability (Θ), dynamic weight transfer while braking were calculated. The design of chassis frame was based upon consideration of different assumptions [9] as given Table 1. The major dimensions of the chassis frame were obtained by considering various operating conditions and constraints according to the rules and regulations given by QBDC2k18 which is mandatory to follow while designing the same. On the same, weight consideration for sprung and unsprung masses and consequent weight distribution were taken on the basis of local and technical experience of the operating conditions under which quad-bike will be used.

Table 1. Overall Specification of the Quad bike

Overall length of chassis, mm	1422
Overall width of chassis, mm	330
Overall height of chassis, mm	635
Engine compartment length, mm	584
Frontal area length, mm	381
Un-sprung mass, kg	38
Sprung mass with driver, kg	182
Total mass, kg	220
Weight distribution	40:60

The solid modeling of chassis frame has been performed in CATIA V5 as shown in Fig.1 (a). In frame dimensions, the front section is kept 15 inches for steering and suspension arms mountings. Middle section of 23 inches is considered for engine compartment and fuel storage tank mountings. A swing arm is provided underneath the seat. All the mentioned dimensions were obtained by following ENCAP standards.



(a) (b) (c)

Fig. 1. Design of Quad Bike: (a) CAD Model (b) Meshing (c) Load Analysis

Material selection for the present chassis frame was done on the basis of strength, cost and availability of the different suitable materials. It was considered that, the selected material must have at least 0.18% of carbon. This is due to the requirements of the suitability of the available methods of manufacturing for the selected material of the chassis frame. After in-depth analysis of properties and characteristics of various materials, AISI 1018, AISI 1020, and AISI 4130 were shortlisted [10-12]. To select a suitable material for chassis frame, a load analysis has been carried out in detail by considering bending loading throughout the length of entire chassis frame as shown in Fig. 1 (c). Assuming wheel base of 44” and 220kg total weight of vehicle, the minimum strength value of material (σ) is calculated as 429.14MPa. Therefore, a selected material should have yield strength more than 429.14MPa. So, AISI-4130 is selected as it has higher strength value equal to 460MPa. AISI 4130, a chromium, molybdenum, and manganese steel having good toughness, impact resistance and fatigue strength; a versatile alloy with good atmospheric corrosion resistance and reasonable strength up to around 315º C (600º F).

Under impact force calculation, it is assumed that the maximum permissible deformation is 1 to 10 mm, minimum factor of safety considered as 1.8 and total vehicle weight is taken as 220 kg. The impact force calculation is carried out for front, side and rear impact whose results as shown in Table 2. The roll over force is calculated as 3237.3N by keeping force acceleration limit as 1.5G. Any dynamic object has infinite number of degrees of freedom (DOF). Finite element method reduces DOF from infinite to finite by means of Meshing i.e., a process of creating nodes and elements on a particular object. For line mesh of chassis frame Fig. 1 (b) is carried out by inserting line diagram of frame in ANSYS 16.0 software. The element size of 10.0mm is chosen for meshing.

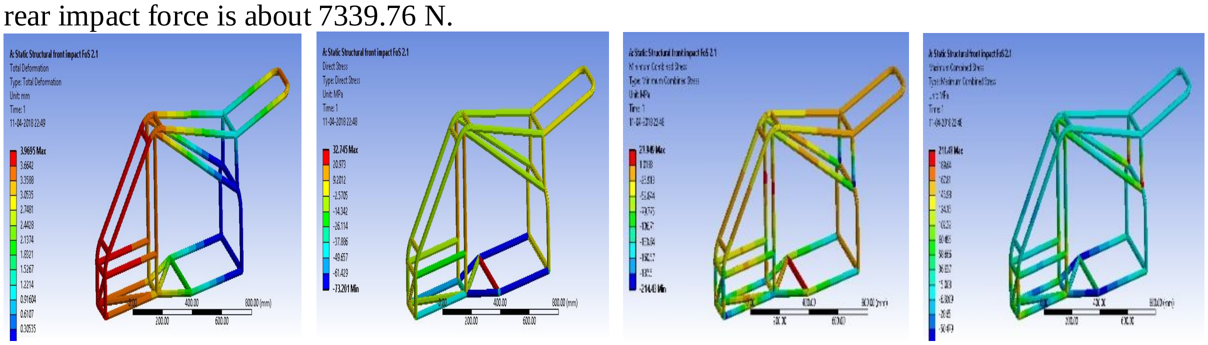
Table. 2. Results of Crash Test

Type of test	Test standards [7]	Impact value
Front impact	Velocity limit = 60 kmph, Acceleration limit = 6.8 G	18301.52 N
Side impact	Velocity limit = 48 kmph, Acceleration limit = 1.35 G	7219.96 N
Rear impact	Velocity limit = 50 kmph	7339.76 N

3. Quad Bike Chassis Frame Analysis

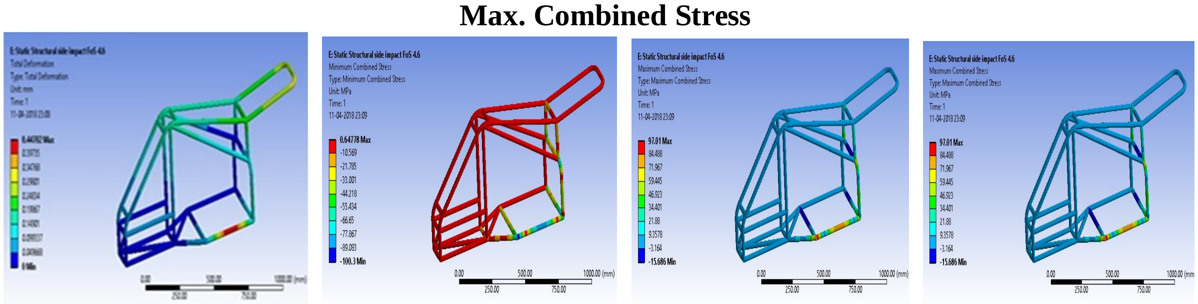
Analytical performance of chassis frame is tested by applying static forces on different locations. This helps to get deformation, stress and factor of safety of chassis frame at that force. Also, weaken area of chassis frame is shown which need to be improved in further design. On road conditions, most of the impacts act at front, rear and side.

In front impact, force is applied at front side, while the rear member is set fixed. The theoretical front impact force is about 18301.52 N. In side impact, force is applied at left side, while the right-side member is set fixed. Moreover, theoretical side impact force is about 7219.16 N. In rear impact, force is applied at rear side, while the front member is set fixed. Henceforth, theoretical rear impact force is about 7339.76 N.



(a) (b) (c) (d)

Fig. 2. Front Impact: (a) Total Deformation (b) Direct Stress (c) Min. Combined Stress (d) Max. Combined Stress



(a) (b) (c) (d)

Fig. 3. Side Impact: (a) Total Deformation (b) Direct Stress (c) Min. Combined Stress (d) Max. Combined Stress

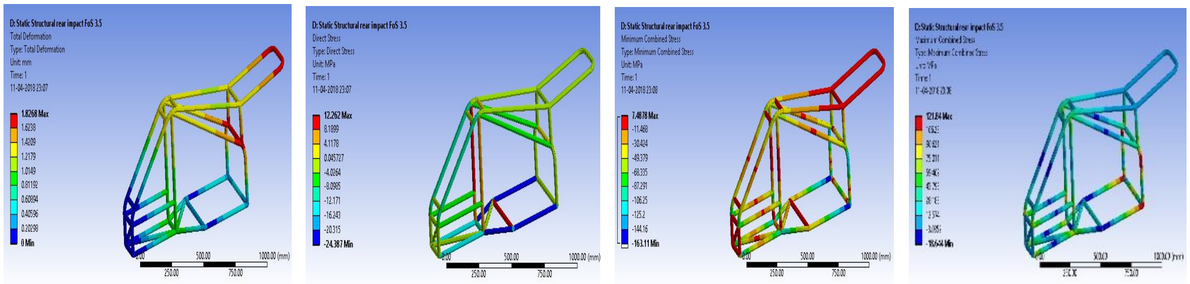


Fig. 4. Rear Impact: (a) Total Deformation (b) Direct Stress (c) Min. Combined Stress (d) Max. Combined Stress

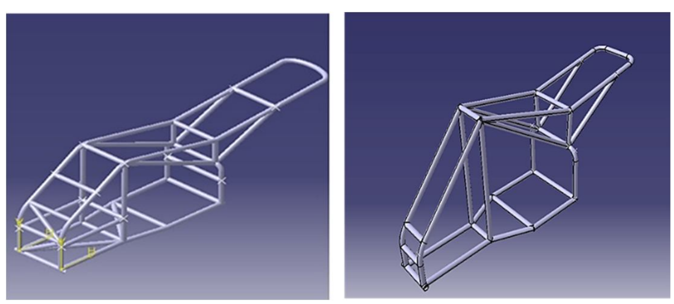
Table 2. Comparison of Impact Test Results

Type of Stress	Old Chassis Frame			New Chassis Frame		
	Front	Rear	Side	Front	Rear	Side
Direct Stress, MPa	39.63	39.64	2.5	32.75	12.26	2.53
Min. Combined Stress, MPa	32.67	33.87	0.62	27.94	7.49	0.64
Max. Combined Stress, MPa	270.46	158.62	108.74	211.46	121.84	97.01

Table 3. Comparison with ENCAP Standards

Parameter	ENCAP Standards [7]	Old Frame (16 kg)			New Frame (12.98 kg)		
		Front	Rear	Side	Front	Rear	Side
Factor of safety	> 2	1.7	2.9	4.23	2.1	3.5	4.6
Total deformation, mm	1 to 10	8.61	9.2	3.60	3.9695	1.83	0.44

Table 3 shows that both chassis frames (old and new) are compared with ENCAP standards which shows that newly designed chassis frame is safer on the basis of obtained values of factor of safety and total deformation. New chassis frame is near about 20% light in weight in nature as compared to old one. Also, due to weight reduction and refined structure over previous one, the new frame is more compact and comfortable to driver over old one. This is because the reduced length of engine and front suspension compartment cause to reduce the overall length of frame. Moreover, front cross-section of new chassis frame is reduced in size as compared to in old one and hence, suspension arm's length is increased lead to increase the suspension travel.



(a) **(b)**

Fig. 5. Structure of Chassis Frame: (a) Old chassis frame (b) New chassis frame

4. Manufacturing of the Quad Bike Chassis Frame

A prototype can serve as a basis for future models and gives an opportunity to designers to research new alternatives and test the existing design to confirm a product's functionality prior to production. Our team got valuable feedback from the experts and users even before the actual project is started.

A PVC material was chosen to make prototype of the designed chassis frame. The prototype as shown in Fig. 6 (a) is made to eliminate ambiguities and improve accuracy in interpretation of frame requirements and functionality. It also helps to identify and address problems early on (e.g.

missing, confusing or misunderstood features) and estimate development costs, timescale, skills and potential resource requirements.

(a) (b)

Fig. 6. Quad Bike Chassis Frame: (a) PVC Prototype (b) Final Frame Structure (c) Experimental Set-up

TIG welding method is selected which usually join almost all metals, with superior weld quality, generally free of defects and free from spatter that occurs with other arc welding processes. It can be used with or without filler metal as required for the specific application. TIG welding provides excellent control of root pass weld penetration and hence, used to produce inexpensive autogenous (fusion) welds with good penetration. It also provides for separate control over the heat input and filler metal additions. This all parameter helps to improve welding strength and also increase the overall strength of chassis frame [12]. Fixtures are used to secure location and support the work, ensuring that all parts produced using the fixture will maintain conformity and interchangeability.

Cold bending is selected to bend the structural members in desired shapes. This is quicker and inexpensive bending method. Using bending instead of prefabricated bends substantially reduces the number of welds needed. This reduces the amount of work required and increases the quality and usability of pipes. Also, joining of the structural members increases the total weight and dimensional inaccuracy due to asymmetric profile edges. Therefore, profiling of the ends of such edges were done to give higher possibility of full welding.

Welding of the members started with arrangement of all the base member on fixture according to the CAD model of the frame. Before starting continuous welding of frame members, all the individual members were fixed with each other by providing a small welding spot at the meeting point of each pair so its position should not be changed during entire welding process. Leveling of structure, welding quality, proper location of each member were carefully checked to retain the quality of chassis frame structure.

5. Experimentation and Testing of Quad Bike Chassis Frame

Testing of performance of chassis frame is usually done by using a Fast Fourier transform (FFT) which is nothing but an algorithm that samples a signal over a period (or space) and divides it into its frequency components. These components are single sinusoidal oscillations at distinct frequencies each with their own amplitude and phase. The result is acceleration/vibration amplitude as a function of frequency, which perform analysis in the frequency domain (or spectrum) to gain a deeper understanding of vibration profile. Most vibration analysis will typically be done in the frequency domain.

5.1 Experimental Set-up

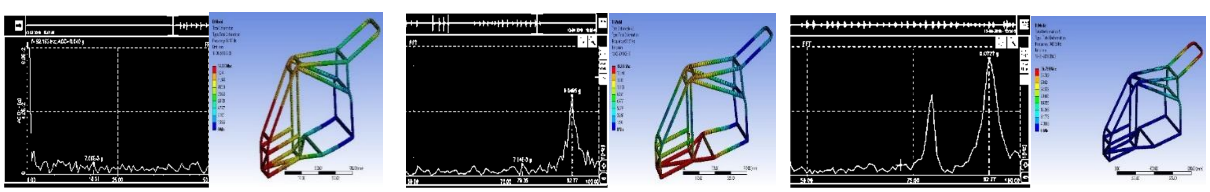
The quad bike chassis frame is mounted on the bench to carry out modal analysis using FFT as shown Fig. 6 (c). The FFT analyser is connected to accelerometer mounted on chassis frame to receive the vibrations. A data acquisition system required to process the signals acquired by accelerometer is synchronized with FFT software to record the frequency spectrum. As an external means of force, vibrations are generated by hammering the chassis frame at different locations. As the hammering creates various vibrations flown throughout the chassis frame, a peak in the level of vibration amplitude is observed in frequency spectrum which is nothing but the natural frequency of chassis frame**.**

5.2 Modal Analysis

The modal analysis is one of most basic and significant part of chassis frame analysis. This method is used to find out natural frequency and mode shapes of the frame structures. The rigidity could be analysed and the resonance in vibrations could be avoided. The main characteristics of each mode of the structure can be figured out through the modal analysis, and the actual vibration response under this frequency range can be predicted. Hereafter, results obtained from modal analysis can be used as reference value for other dynamic analysis like random analysis, harmonic analysis, etc. Correspondingly, solid model of the designed chassis frame is well meshed in ANSYS. In modal analysis, one member of chassis frame is fixed and in the solution total deformation is inserted, where natural frequency as well as total deformation is calculated. The results have been calculated for the first 20 frequency modes as shown in Table 4.

Table. 4 Natural Frequency and Total Deformation at different Modes

Mode	Frequency (Hz)	Deformation (mm)
01	16.143	14.33
02	43.91	17.17
03	68.551	15.237
04	86.488	45.484
05	94.536	36.798
06	96.062	28.517
07	192.26	22.409
08	216.44	22.076
09	246.51	24.41
10	263.35	48.41
11	272.42	33.248
12	288.22	39.357
13	289.72	39.05
14	299.06	34.462
15	323.9	36.73
16	330.98	35.196
17	360.98	25.977



(a) **(b)** **(c)**

Fig. 7 Frequency on FFT and Modal Analysis at different modes: (a) at mode 1 (b) at mode 2 (c) at mode 3

Above result shows that comparison of natural frequency of chassis frame using FFT and modal analysis and Fig. 7 shows the peak value of amplitude of vibration. All the frequencies obtained in FFT Analysis and Modal analysis carried out in ANSYS are nearly same and can be concluded as desirable.

Table. 5 Comparison for Natural Frequencies of the chassis frame

Mode of Frequency	FFT (Hz)	ANSYS (Hz)
1.	18.31	16.143
2.	79.35	68.551
3.	92.77	94.356

6. Conclusions

In this paper, the design and development of Quad Bike chassis frame is carried out to achieve durable, lightweight, and high strength chassis. To achieve these objectives, the detailed study of Quad Bike chassis frame, its various features and force distribution is carried out. This study provides a clear insight in the design, analysis and manufacturing of the quad bike chassis frame. For validation, testing and analysis is performed and results are compared with ENCAP standard and which found to be safe. Consideration of values of old chassis frame while comparing current design with ENCAP standards shows the superiority of the present design over previous design. The result obtained from modal analysis and FFT analysis for natural frequencies are approximately similar which validates the well-developed design. After critical analysis and testing, developed quad bike chassis frame found to be desirable in all terrain operating conditions.

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