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DESIGN OF ALL TERRAIN VEHICLE SYSTEMS

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ABSTRACT

This paper provides in-detail description of the design considerations, dynamic analysis of various components and mathematical data involved in the design of a ATV. Vehiclesystemsthat meets international standards and is also cost effective at the same time. The focus has been laid on the simplicity of design procedure and methodology for high performance, easy maintenance and safety at very reasonable price. Also we have focused on every single system to improve the performance of each component without comprising the final set parameters. This study aims to design, develop and fabricate a roll cage for an All-Terrain Vehicle (ATV) in accordance with the rulebook of BAJA 2015 provided by SAE INDIA. We began the task of designing by conducting extensive research of each main component of the vehicle.[8] We considered each component to be significant, and thereby designed the vehicle as a whole trying to optimize each component while constantly considering how other components would be affected. We used the necessary parameters to create a Qualitative Function Diagram (QFD) to determine which parameters were the most critical. These key parameters ranging from most critical to least critical are safety, reliability, low cost, ease of operation and maintenance, and overall performance;along with design of various parts to meet the set parameters we also done Design Failure Mode Effect Analyses (DFMEA) technique which helped us to improve various systems of our vehicle by implementing the solutions revealed from technique.

Keywords: BAJA SAE INDIA Rulebook, Brake, Finite Element Analysis, Suspension,Roll Cage

I. INTRODUCTION

ATV means an All Terrain Vehicle which is specially designed for a off road driving with very rough terrain, jumps, maneuverability and endurance.The design process of this single-person vehicle is iterative and based on several engineering and reverse engineering processes. The designing work is initiated to achieve the best standardized as well as optimized design possible. Specifications lay down by the standard specifications available foremost concern while designing and selection of the parts. Besides performance, consumer needs of serviceability and affordability were also kept in concern which we got to know through the market and internet research and reviews for all terrain vehicles. [8] After the specifications were set software 3-D model is prepared in solid works software. Later the design is tested against all modes of failure by conducting various simulations and stress analysis with the aid of Ansys Software. Based on the result obtained from these tests the design is modified accordingly.

II. DESIGN CONSIDERATIONS

By keeping following parameters in mind all design specifications are stated to meet it so that ATV will get more endurance in performanceat all stages. [6]

I. Safety and Ergonomics.
II. Standardization and Serviceability.
III. Maneuverability.
IV. Maximum control with suspension design.
V. Optimize power efficiency.
VI. Cost of the components.
VII. Safe engineering practices.

For ease of designing all components were designed individually along with mutual specifications transfer for interchangeability.

I. Roll Cage
II. Suspension System
III. Steering System
IV. Braking System
V. Powertrain arrangement

2.1. Roll Cage

Fig.1Design Methodology of Roll Cage

Roll Cage is askeleton of any vehicle of cross section of pipe which is used for providing primary support for all systems and subsystems of vehicle. As per the market parameters three materials were selected for roll cage materialswhichare AISI 1018, AISI 1020 and AISI 4130 chromoly. Every material having different parameters and properties as follows, from them AISI 4130 is selected due to its advantages over other materials mentioned in following table.

Material → / Properties ↓	AISI 1018	AISI 1020	AISI 4130
Carbon %	0.15-0.20	0.18-0.23	0.28-0.33
Density (Kg/m3)	7.87×103	7.7×103	7.85×103
Tensile Yield Strenght (MPa)	370	350	435
Tensile Ultimate Strenght (MPa)	440	400	560
Modulus of Elasticity (GPa)	205	200	210
Poisson's Ratio	0.29	0.29	0.29

Fig.2Material comparison for Roll Cage material

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Outer Diameter of pipe cross section: 25.4 mm (1 Inch)

Thickness: 2 mm

After selection of material next step is to draw 3-D model of roll cage with all considering set parameters of various systems and sub systems.

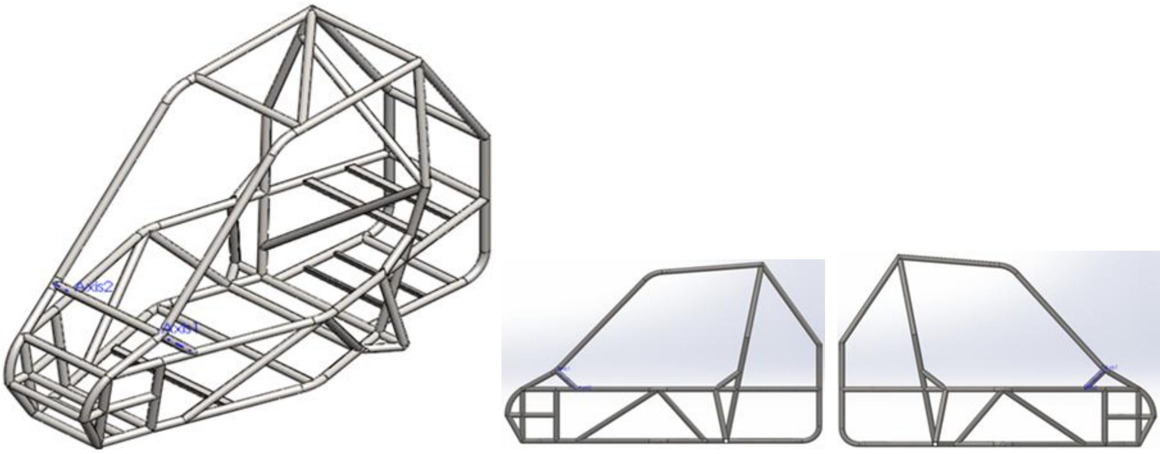


Fig.3Roll Cage 3-D model with both side views.

2.1.1FEA Analysis Roll Cage model in ANSYS Software

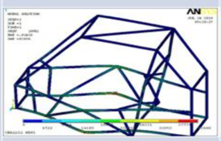
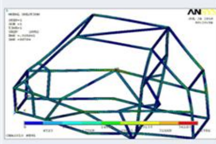
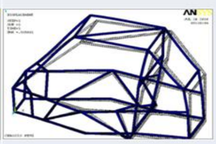
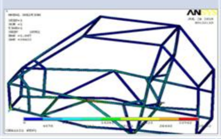
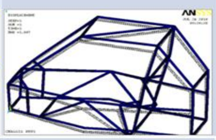
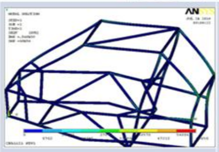
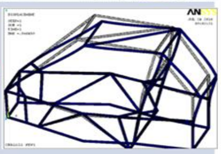
Name	Force (Pounds)	Stress (psi)	Deformation (inches)	F.O.S.	Stress Analysis	Deformation Analysis
Front Impact	3374.09 **(4.5 G)**	442496	0.418	1.50		
Rear Impact	3374.09 **(4.5 G)**	40706	0.935	1.56		
Side Impact	2249.39 **(3G)**	36633	1.047	1.74		
Roll Over Impact	1799.51 **(2.5 G)**	60856	0.560859	1.04		

Fig.4FEA Analysis Roll Cage.

2.2. Suspension System

Fig.5Design Methodology of Suspension system

As we were designing ATV for rough and tidy road where having unequal surfaces, rocks, water and many other obstacles. To clear these types of obstacles with ease and without damage to the vehicle systems for long period suspension system should be that much of rigid and effective to sustain at any adverse condition. For this suspension system is designed by considering 450 kg which is more than the actual weight of vehicle to make is safer during any event.

2.2.1Front Suspension

For front suspension there are many choices to select but from them double wishbone type of suspension had been selected because of its high load handling capacity and rigid support to the wheel geometry. It is ease to control Camber angle, Castor angleand KingPin inclination angle with double wishbone system.[1]For this the parameters which are considered are as follows;

I. Length of spring: 250 mm
II. Total length (spring + damper): 550 mm
III. Wire diameter: 8 mm
IV. Mean coil diameter: 75 mm
V. Allowed travel of spring: 75 mm
VI. No. of active turns: 20
VII. Total no. of turns: 22
VIII. Spring Rate: 11.42 N/m
IX. Wheel Rate: 4.532 N/m
X. Motion Ratio: 0.63
XI. Camber angle: -2 degree
XII. Caster angle: +5 degree
XIII. Toe In: 5 degree

To check whether designed parameters are right or not designed system is analyzed in LOTUS Suspension software which gives accurate motion of wheel and different parameters of suspension from designed system.

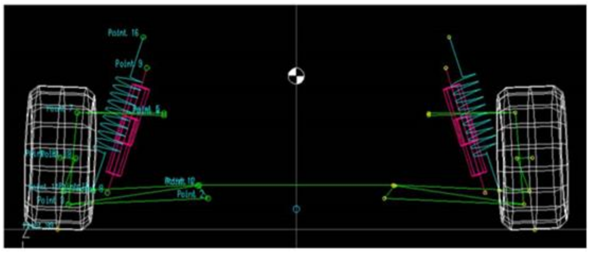


Fig.6 Front suspension analysis in LOTUS Suspension software.

2.2.2Rear Suspension

For rear suspension it should be rigid enough to provide more stiffness to wheel travel otherwise it may create problems for transmitting power to the wheel from gearbox. Also it should not have camber angle and castor angle to transmit power effectively. To meet all these requirements the type of system selected for rear is semi trailing arm suspension which having no camber change phenomenon in damping.[2] For this the parameters which are considered are as follows;

I. Length of spring: 150 mm
II. Total length (spring + damper): 685 mm
III. Wire diameter: 10 mm
IV. Mean coil diameter: 85 mm
V. Allowed travel of spring: 55 mm
VI. No. of active turns: 10
VII. Total no. of turns: 12
VIII. Spring Rate: 9.94 N/m
IX. Wheel Rate: 5.59 N/m
X. Motion Ratio: 0.75
XI. Camber angle: 0 degree
XII. Caster angle: 0 degree
XIII. Toe In: 0 degree

2.2.3FEA analysis of Suspension system in ANYSYS

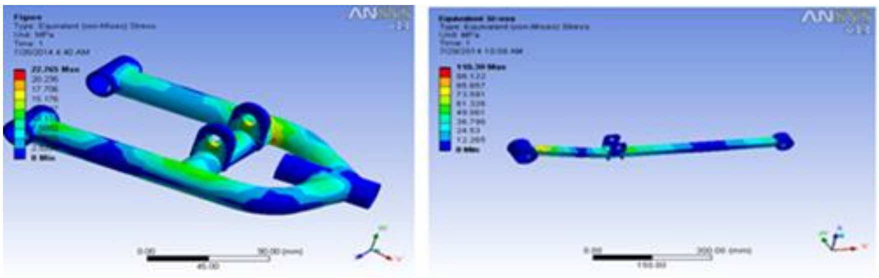


Fig.7 FEA analysis of suspension system in ANYSYS

Force applied: 8829 N (2G) Force applied: 13243 N (3G)

Stress produced: 22.76 N/mm^2 Stress produced: 186.29 N/mm^2

Deformation: 0.019 mm Deformation: 0.050 mm

F.O.S.: 16.25 F.O.S.: 1.28

2.2.4Roll Centre Calculations

At the time of hard cornering at high speed total weight of vehicle get laterally and normally transferredto one side of the vehicle from deviating with C.G.It is having many adverse results of it as it disturbs the handling of driver and also stability of vehicle which may lead to serious accidents or damage to vehicle and driver. So to avoid this there should be minimum deviation of roll center vertically and horizontally.

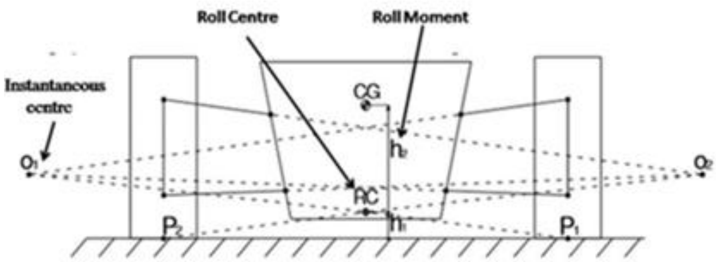


Fig.8 Roll center calculation (Graphical method) [1]

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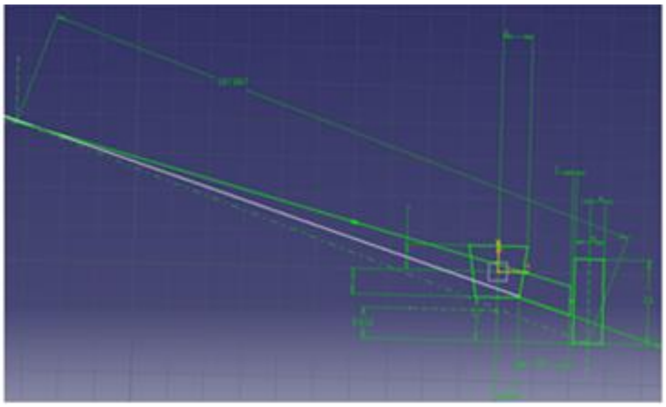
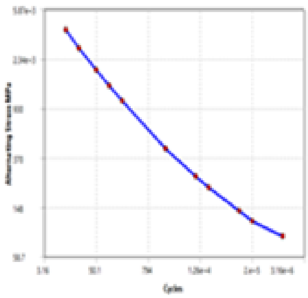


Fig.9 Roll center calculation (In CATIA)



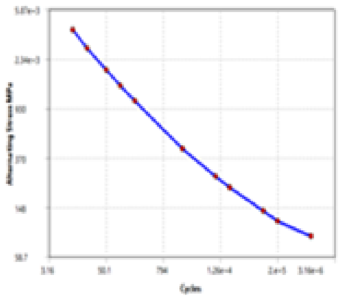


Fig.10Front arm life cycle graph Fig.11 Rear semi-trailing arm life cycle graph

2.3. Steering System

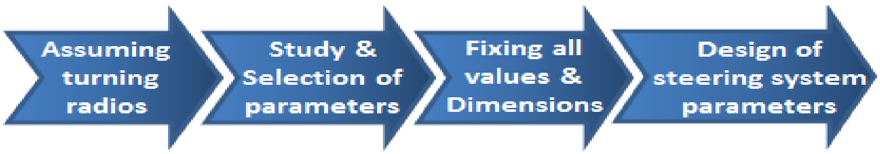
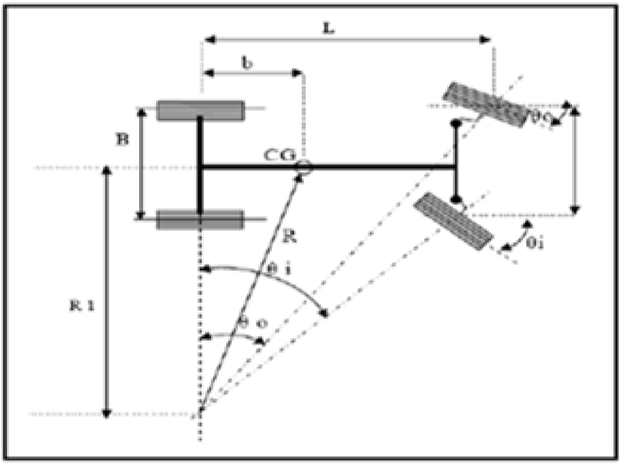


Fig.12Design Methodology of steering system

Steering system is the system used for controlling the direction of moving vehicle to direct vehicle as per required direction. There are many types of steering systems currently used in cars so for selection of proper system we done the comparison of various systems available as follows and selected rack and pinion system for steering with Ackerman's principle.[3]

Steering System	Cost	Availability	Weight	Mechanical Advantage	Performance	Total
RACK & PINION	7	9	7	6	7	36
RECIRCULATING BALL	5	6	6	9	8	34
WORM & SECTOR	5	4	5	7	7	28
TRACTOR MECHANISM	7	8	5	5	8	33

Fig.13 Comparison of various steering systems



$$\frac{1}{tan\theta 0} - \frac{1}{tan\theta i} = \frac{L}{B}$$

$$M.R. = \frac{Xi}{Xo} = \frac{2\pi R}{2\pi r} = \frac{66.16}{10.52} = 6.28$$

Fig.14 Ackerman steering geometry and formula for correct steering [2]

Wheel Track (B)	50 "
Wheel Base (L)	66 "
Castor	+ 5 º
Camber	- 2 º
Toe In	10 mm
Scrub Radios	44 mm
King pin Inclination	0 º
Movement Ratio	6.28 : 1
Load on Each Tie Rod	251.2 N
Steering Wheel Rotation	1.33 Turn

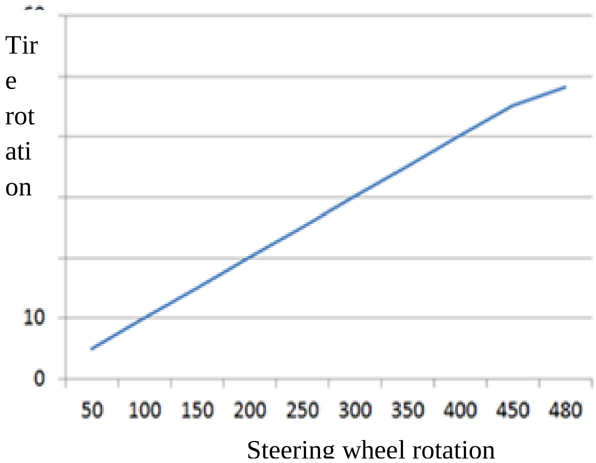


Fig.15 Steering calculations and output parameters

As shown in above table from various calculations the parameters has been selected as per required results and the final system is designed with all dimensions.

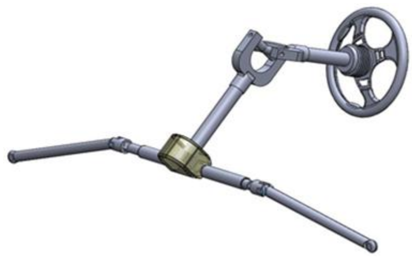


Fig.16 Designed steering system

2.4. Braking System

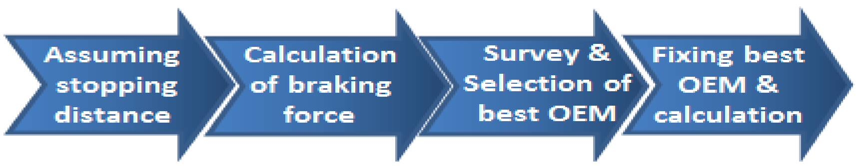


Fig.17Design methodology of braking system

Brakes are used to reduce the velocity of vehicle within less possible time with fewer disturbances in stability of vehicle. As per the design requirements; all wheels should be stopped at same time and should be equipped with hydraulic disc brakes.[6] For to implement this the diagonal system is used with some Original Equipment Manufacturer(OEM) products such as tandem cylinder, discs, brake caliper and fluid lines.[7]

PARAMETER	OEM	VALUE
Master Cylinder	MARUTI 800	25.4 Bore Dia
Caliper	APACHE 180 RTR	29 mm Dia
Disc	APACHE 180 RTR	200 mm
Brake Lines	Maruti 800	-

Fig.18OEM Selected

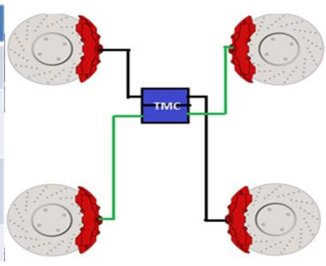


Fig.19Diagonal braking system

$$F \propto \frac{r}{R} \times 2 \times \mu \times \frac{Aw}{Am} \times (Rp \times f)$$

Fig.20 Total force formula to find out force required [4]

PARAMETER	VALUES
Pedal Efforts	294.3 N
Pedal Ratio	6.22 :1
Braking Force	4772.4 N
Braking Torque	895.8 Nm
Master Cylinder Force	1830.546 N
Braking Distance	11.83 m
Time Required	1.8 s
Brake Ratio	73 : 27

Parameter	Front	Rear
Force applied TMC	1317.98 N	494.24 N
Rotor force	1718 N	463.877 N
Torque applied	322.44 N-m	87.06 N-m
Dynamic Force	1433.24 N	530.94 N
Load Transfer	28 % of Weight from Rear to Front	

Fig.21 Output parameters of braking system

2.5. Power Train Arrangement

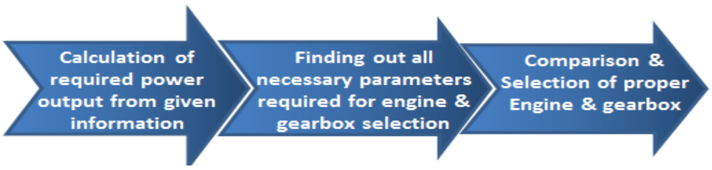


Fig.22Design methodology of powertrain system

The engine provided for vehicle is having 305 cc engine which provides 10.5 BHP power output.[6] It is having of 3800 rpm rated speed. From which gearbox has been selected to meet required parameters,

Transmission		Piaggio Ape Cargo	Piaggio Mini	Mahindra Alfa Passenger	Mahindra Alfa Champion
Engine cc		395	441	395	**395**
Gear ratios	1.	25.5	55.1	25.5	**31.5**
	2.	15.16	32.7	15.2	**18.7**
	3.	9.25	19.95	9.2	**11.4**
	4.	5.96	13.4	6.2	**7.4**
	R	55.08	31.48	30.62	**55**
Max torque(Nm) at half shafts at engine speed of 2600 rpm		237.91	514.08	237.91	**293.89**
Maximum speed(km/hr) for 25" tire dia.		76	33	73	**61**
Cost (Rs)		25000.00	29000.00	25000.00	**24000.00**
Weight (kg)		25	26	28	**28**

Fig.14Comparison of various gearboxes available as per engine output

By this comparison we selected gearbox of Mahindra Alfa champion which is meeting our requirements of power output and also having high performance with cost efficiency.

III. CONCLUSION

When undertaking design of any vehicle; there are several factors to be considered that are common to all engineering vehicles. A vehicle must have a proper scope with clearly defined goal. With such an approach, engineers can come up with the best possible product for the society. The chosen design is the safest & the most reliable car for any long terrain. All the parameters like Safety, Cost, Reliability, Performance, Durability, aesthetics, Standard dimensions & material were also taken in consideration on the same time. Where ever possible finite element analysis was done on the regularly loaded parts & modifications were done accordingly to avoid any type of design failure. Also while designing every individual part DFMEA has been done which improved our quality standard, factor of safety and other safety parameters also.

Also the designed vehicle is able to stand against any road with any difficulty as the suspension system and roll cage systems are designed in very keen manner by considering every future condition to the worst case. For this designing; solid works, Catia, Ansys, lotus software were used to get more clear and accurate output of designed parameters to meet high accuracy and to reduce any type of any unlike situation.

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