Performance enhancement through design and analysis of All Terrain Vehicle

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Abstract - *Designing an ATV (All-Terrain Vehicle) involves 5 major sub-systems, Chassis, Suspension, Steering, Brakes and Powertrain. Each system is designed with considering current cons in regards of available ATVs in market. Primary objective is to manufacture a lightweight ATV without compromising on performance whilst conforming to all safety standards. Suspension system, being one of the crucial assemblies of any ATV is designed for better driver comfort and light weight yet robust assembly. Steering system is designed with an objective to provide better maneuvering characteristics to the ATV. The powertrain is designed for higher acceleration as well as speed. Braking system is designed to ensure stable operation during braking at all dynamic conditions. This unique class of four-wheeled vehicle is utilized for amusement and exploration purposes.*

Key Words: Vehicle, All terrain, Performance, Suspension, Steering, Single seat, CAE, Manufacturing.

1. INTRODUCTION

BAJA SAE, the ATV design event provides a platform for undergraduate students to apply the principles of engineering science to expose their proficiency in the automotive world. Team Pegasus always had the solo aim of reeling off the race by designing the best performing, rugged and economical vehicle.

First, a basic design prototype was created while keeping in mind the SAE rules and ARAI guidelines. In order to assess the ergonomics of the driver, a design mockup with anthropometric measurements (including allowances for clothing) of small and large males and females, from BIFMA Ergonomic Guidelines, 2002 was used and Indian standards of safety were applied. The chassis and other components were modeled in CAD. The design was rigorously analyzed in various conditions to obtain optimum safety and excellent durability with minimum weight. To assure safety in such a scenario, a rollover analysis was then performed. Evaluation of static stability and confirmation of adherence to the relevant Indian Standards were part of the rollover analysis. Therefore, the design was completed after safety was established.

The quality of design and the true potential of the ATV is discovered only after a deep CAE analysis of all the components individually as well as a complete unit. Modern CAE technology has made it possible to be able to perform number of complex analysis with ease. The first and most crucial step for performing any finite element analysis is meshing. The geometry and properties of the component to be analyzed have to be studied in detail to select the meshing method which will provide most accurate results. After the meshing was done, the roll cage was tested in numerous iterations of bump, roll-over, torsion as well as modal analysis as shown here. To simulate real life conditions, also performed dynamic impact analysis of roll cage from all sides.

2. ROLL CAGE

The roll cage or body of the vehicle is what determines the perspective of any onlooker as well as the fate of the vehicle in external conditions. all points of scrutiny have been worked upon in multiple stages of action and revision and to come up with the best possible design for the vehicle. To verify the design parameters and to make the vehicle more efficient, extensive CAE analysis of roll cage is performed. The results of these analysis were used to modify roll cage in multiple iterations of design.

2.1 Design Objectives

a. To build a tubular space frame with rigid construction while maintaining low overall weight.

b. To fabricate a frame considering driver safety & ergonomics in accordance with the rulebook.

2.2 Design Consideration

a. Rulebook specifications and driver clearances

b. Theories of failure

c. Structural mechanics of tubes for various materials for optimum rigidity and weight

d. Dynamic analysis of body under application of various loads for validation of the design

e. Provide sufficient space for mounting of drivetrain, suspension & steering assembly

2.3 Material Selection

Since the objective of the roll cage design is to reduce the overall weight of the chassis without compromising strength, extensive survey of materials is done in order to select a cross-section that provides sufficient strength as well as lesser in weight than previous design.

AISI 4130 material is selected for primary & secondary tubes for its high strength as compared to PCS.

Table -1: Material Properties

	Yield strength (MPa)	Bending strength (MPa)	Bending stiffness (N/m)	Dia. of tube (mm)
AISI 1018	365	387.42	2763.47	25.4
AISI 4130	700	652.02 (primary)	2787.87 (primary)	29.2

1.4 CAE:

A 2 dimensional 'Quad-only' mesh is generated for finite element analysis of the roll cage. Thorough element quality check is performed to ensure a geometrically accurate mesh generation which will yield reliable results. Starting with the modal analysis, the roll cage is simulated under various bump, torsional as well as crash conditions. Explicit dynamic analysis is performed over a range of speeds from 30kmph to 60kmph to test the performance of roll cage in all possible circumstances.

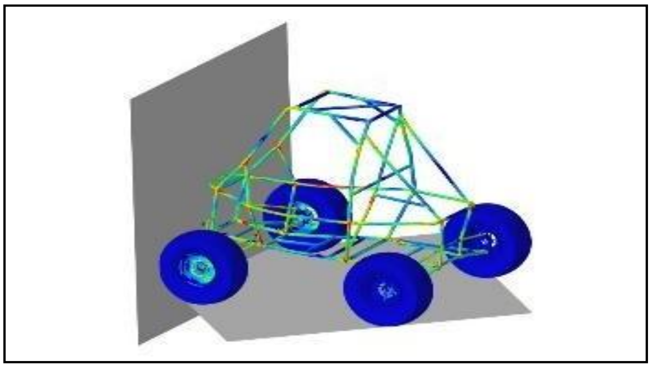

Fig -1 Dynamic Crash Analysis

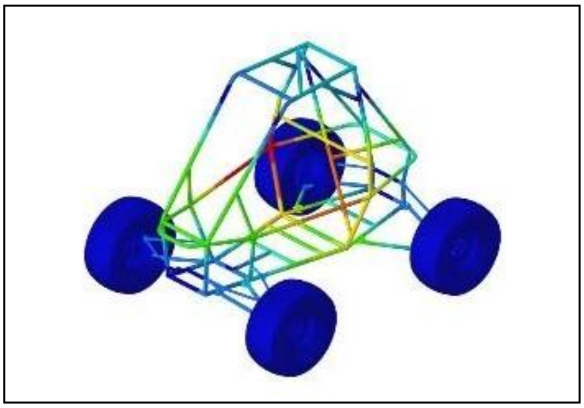

Fig -2 Modal Analysis

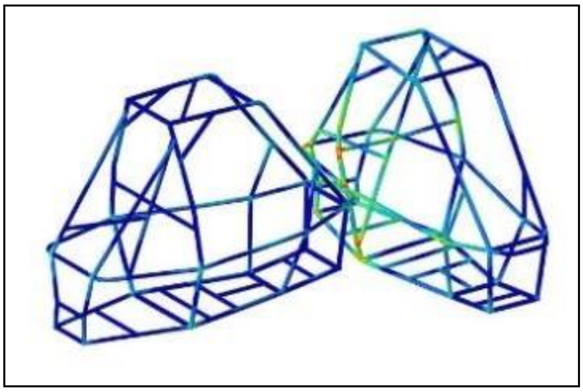

Fig -3 Dynamic Crash Analysis

1.5 Fabrication:

A. A CNC pipe bending machine is used to bend the members as per the design and avoid spring back action of the bent members.

b. Fixtures and profile tracing using templates for precise manufacturing and to avoid distortion while welding is done

c. TIG welding with filler material ER70-S2 is used for its better weld strength and surface finish.

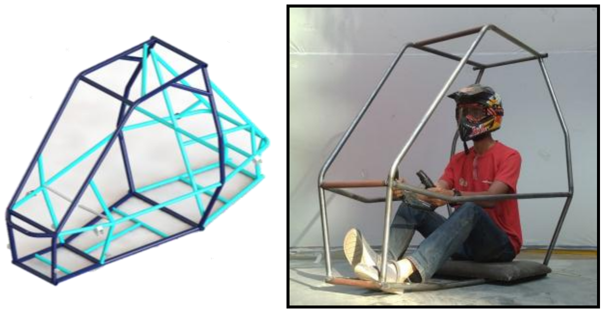

Fig -4 Chassis Prototype

3. SUSPENSION

Once inside the cockpit of the vehicle especially in an ATV, everything that can make or mar the drivers experience is the vehicle stability and vehicle controls. The dynamic stability on an ATV in all kinds of obstacles and harsh terrain is directly governed by the suspension system. To get the best results in terms of vehicle dynamics, a fully independent double wishbone suspension system for each wheel that gives a maximum wheel travel of 9 inches including jounce and bump is designed with a ground clearance of 15 inches which is adequate enough for all challenges.

Performed multibody dynamics of the suspension system and came up with satisfactory results of camber and toe change. Rigorous analysis of the wheel end components and an overall weight reduction of 30% has done thus reducing the unsprung mass.

The motion ratio of 0.7 is designed in such a way that the driver will experience minimum shocks to which the vehicle is exposed. Thus, by considering and revising each & every parameter, an enduring suspension system is achieved.

2.1 Design Objectives

a. To maintain traction (constant contact of wheels with road surface) in all terrains

b. To optimize ride quality and vehicle handling.

c. To ensure stability of the vehicle while pitching or rolling.

2.2 Design Consideration

a. Type of terrain

b. Drive comfort

c. High Fatigue life

2.3 Design Specification

Fully independent double wishbone suspension system is selected for required performance of the vehicle. After surveying the global market and from previous performance experience, FOX FLOAT 3 EVOL (R series) is selected for front and AFCO (rebound adjustable coil over shocks) for rear suspension system.

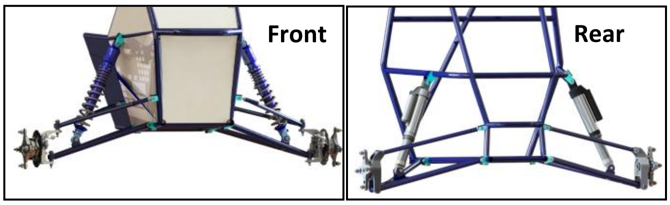

Fig -5 Front and Rear Suspension

Table -2: Front and Rear suspension characteristics

Parameter	Value	
	Front	Rear
KPI(deg)	12.4	7.3
Motion Ratio	0.7	0.7
Scrub Radius(mm)	24	-6
Suspension travel(inch)	7	5.3
Spring rate(lbs./inch)	46.82	116.82
Natural frequency(Hz)	1.18	1.43

Table -3: Wheel Alignment

Camber(deg)	0
Caster(deg)	7
Toe(deg)	0

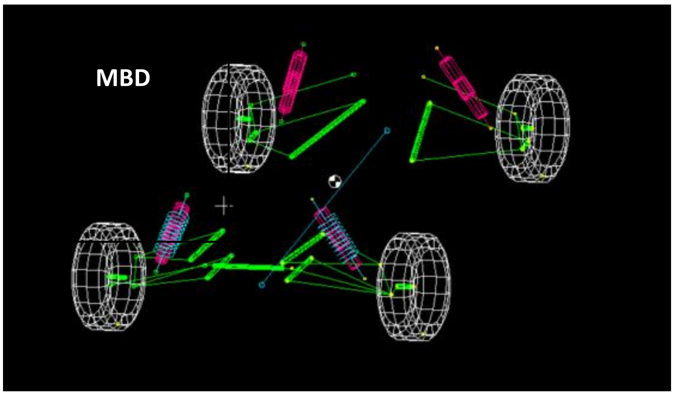

Fig -6 Multibody Dynamics

The sprung mass is calculated as 150 kg and un-sprung as 48kg along with damping ratio of 0.93

Table -4: Spring Design Characteristics

Spring stiffness(N/m)	13370.9
Spring material	Spring steel (IS 4454-2)
Wire diameter(mm)	8
Factor of safety	1.51

1.4 CAE:

To ensure that the suspension design provides sufficient driver comfort, multi-body dynamics (MBD) analysis is performed. The suspension system is tested under dynamic conditions and the performance of each part is recorded over a range of speeds. Fatigue testing is done to determine the durability of all parts and to confirm that the vehicle will not show fatigue breakdown at the event.

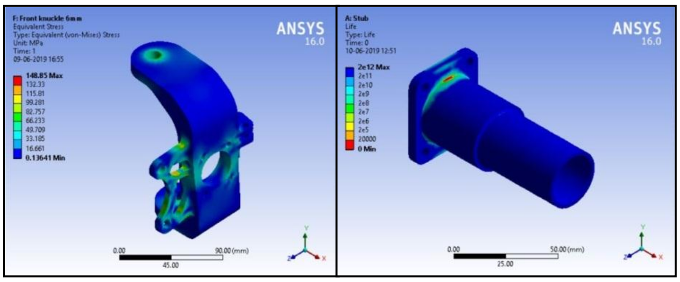

Fig -7 Structural and Fatigue analysis

1.4 Material Selection and Fabrication:

The assembly at each side of the vehicle consists of 3 major parts which are controlling arms (wishbones), Uprights & hubs, and shock absorbers. The controlling arms were made from AISI 4130 tubes of thickness 1 mm and welded by TIG welding process. For Uprights and wheel hubs Aluminum 7075-T6 is used and the components were manufactured on VMC. Also stub axle is made from same material and machined using CNC Lathe m/c.

3. STEERING

Steering The maneuvering characteristics of the vehicle is directly governed by the steering system, which also plays a major role in primary functioning of the vehicle. After analyzing and optimizing years of technical data, a noteworthy benchmark in the steering system is achieved. A rack and pinion having 1 turn lock to lock is used. The rack and pinion are self-designed and has been analyzed with many iterations. Ackerman geometry of steering mechanism is incorporated as it gives one of the best results for all terrain purpose. Multibody dynamics of steering system is performed and got the results in terms of these graphs. Both left and right turns contribute in a limited and a minimum change in camber and toe, most of which is a result of bump steer. Care has been taken to keep the steering effort for vehicle low, so that the driver must not need to be working hard for turning the vehicle. The turning radius of vehicle is 1.5 m, well suited for a good command over the vehicle.

3.1 Design Objectives.

a. Ease of Maneuverability of the vehicle.

b. Reduction in turning radius of the vehicle

3.2 Design Considerations

a. Caster Angle

b. Low steering effort

3.3 Design Specifications

Ackermann steering geometry is selected for better performance and oversteering characteristics depending on which the turning radius of the vehicle is achieved.

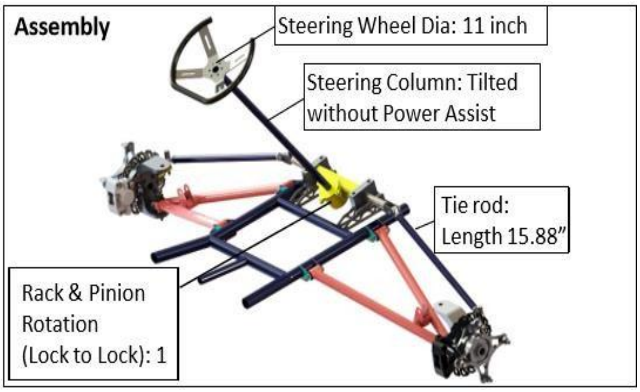

Fig -8 Steering Assembly

Table -5: Steering Specifications

Parameters	Value
Steering type	Oversteer
Steering ratio	4:1
Rack travel(inch)	3.6
Scrub radius(mm)	+24
Turning radius(m)	1.25

3.4 CAE:

Non-linear contact analysis is implemented to obtain the performance of rack and pinion steering under actual conditions. Multi-body dynamics is done to validate the design parameters and check for accurate steering motion at all times.

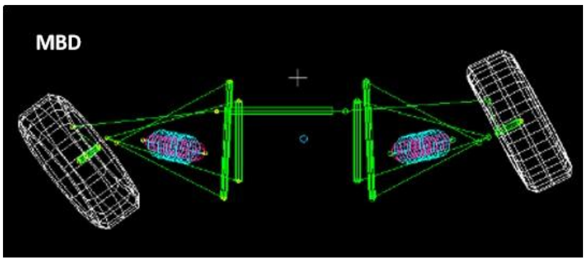

Fig -9 Multi Body Dynamics

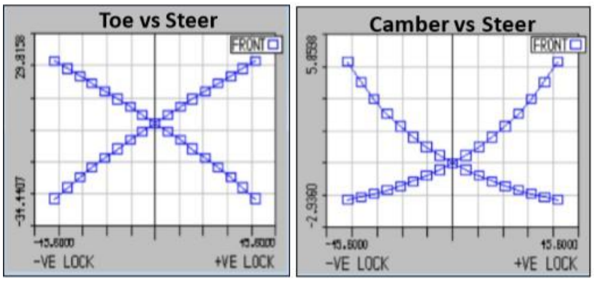

Fig -10 Steering Characteristics

3.5 Material selection & Fabrication

The assembly consists of steering wheel, steering column, rack & pinion, tie rods and steering arms. Steering wheel (increased diameter than previous vehicle for reduction in steering effort) is made from aluminum pipes bent using hand bending and welded together by TIG welding. Steering column is made from AISI 4130 tube with 2mm thickness. 20MnCr5 is selected for rack and pinion and manufactured using gear teeth cutting Tie rods were made from AISI 4130 tubes of thickness 2mm and steering arms were made from MS (Mild Steel) using CNC laser cutting.

4. POWERTRAIN

A roaring powertrain is what the ATV needs and the same has been accomplished during the designing as well as the manufacturing phase. JIT CVT, along with the standard Briggs and Stratton engine, as the low ratio of 3.9:1 provides ample torque and acceleration during pickup and high ratio of 0.9:1 brings great speed under running condition is used. To transmit the output power from the CVT to the wheels, a single speed two stage reduction gearbox which has a reduction ratio of 7.79 is designed. Weighing just below 4.5 kgs, the gearbox design is very compact and is calculated to give a maximum speed of 58kmph for the ATV. Analysis of the entire gearbox is done more than once to validate the design. For further transmission, a tripod joint at the gearbox side and rzeppa ball joint at the wheel end side is incorporated. A single unit shaft is used to increase the shaft strength, that also reduces the weight. This layout has a calculated initial wheel torque of 559Nm and a gradeability of 84% which is adequate for all the dynamic situations. Rubber isolators are used to arrest and dampen the engine vibrations. All the parameters are iteratively calculated and compared with all of the available resources.

4.1 Design Objectives

a. To produce optimum power at the wheels from engine output and limit vehicle speed to 60kmph as per rulebook.

b. To get ample torque at the wheels for maximum acceleration and gradient negotiation

c. To provide sufficient speed for racing

4.2 Design Consideratins:

a. Reduced weight of the assembly

b. Maximum transmission efficiency with CVT tuning for enhanced acceleration

c. Theories of failure

The drivetrain consists of rulebook standard Briggs and Stratton 4stoke, single cylinder, 305cc, air cooled engine which produces a maximum power of 10bhp with speed governor which limits the output speed of engine to 3800rpm according to which design and selection of further assembly is done.

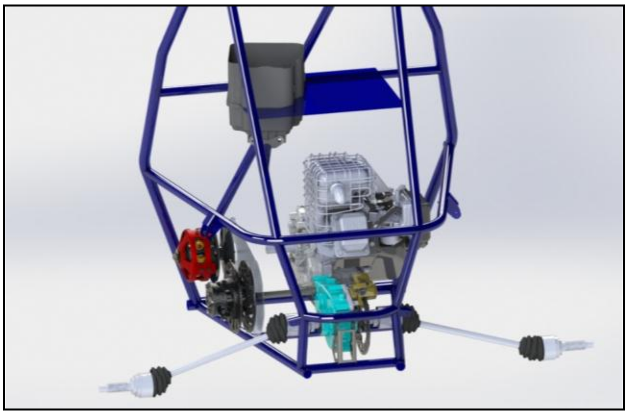

Fig -11 Drivetrain Layout

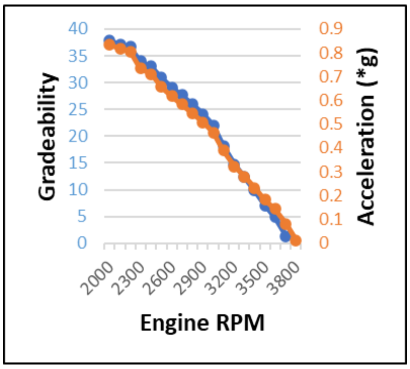

Chart 1 -RPM vs Gradeability vs Acceleration

4.3 CVT

It was selected JIT Solutions custom CVT for ATV. The CVT has a low-end ratio of 3.9:1 and a high-end ratio of 0.5:1. The CVT has efficiency of approximately 85%. The CVT is lightweight and weighs 5kg.

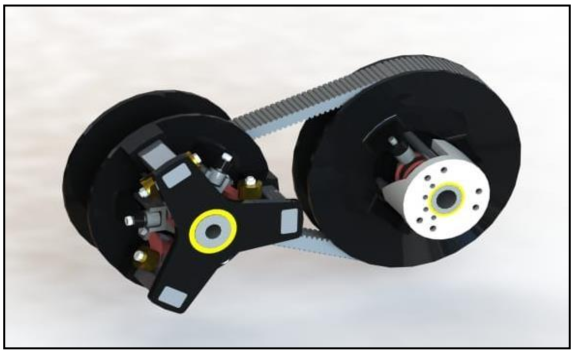

Fig -12 Continuous Variable Transmission

4.4 Gearbox:

A single speed 2 stage (unequal speed ratios) reduction gearbox is designed to produce the required tractive effort at the wheels as well as limit the speed of the vehicle to 60kph. It is designed considering gross weight of vehicle as 200kg and wheel diameter of 23"

Table -6: Gear Box Stages

Stage	Zp	Zg	Speed ratio
1	18	53	2.94
2	18	55	3.05

a. Gears:

Spur gear drive is selected for its highest efficiency and the material selected for these is 20MnCr5 for its strength and availability in the market. (Manufacturing with the help of UMM & hardness up to 55HRC obtained by surface hardening)

b. Shafts

Input, intermediate and output shafts were designed considering maximum shear stress theory of failure. The material for shafts is selected same as that of the gears and feather keys (Material: Mild Steel) were used to mount the gears

c. Bearings:

Selection of single row deep groove ball bearings and roller bearing

d. Lubricant:

SAE 20W40 oil is selected

e. Casing:

Aluminum 6061-T6 is selected for the casing and FEA of casing considering bearing reactions is performed to check the functionality.

4.5 Axle

According to the plunge and articulation requirements for jounce and bounce conditions, TATA Nano Tripod Joint is selected for the gearbox side and Maruti 800 RZeppa joint is selected for the wheel end side. After calculating the length from the line geometry, custom half shafts were designed with material SAE 8620.

4.6 CAE

Designed a robust gear-train to improve the overall performance of the transmission system. Topology optimization is performed on every gear to maintain optimum gear performance even after blanking operation is done. Computational Fluid Dynamics (CFD) under turbulent flow conditions is implemented on CVT casing to ensure proper cooling of CVT during its operation.

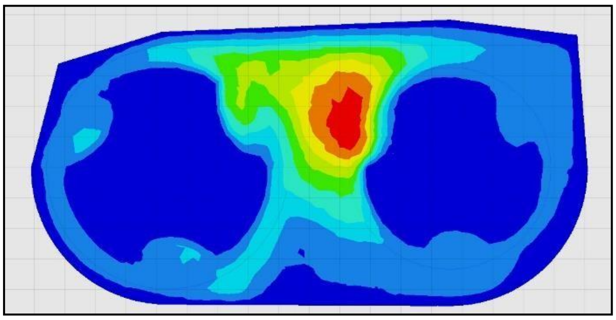

Fig -13 Computational Fluid Dynamics

5. BRAKES

Brake system is of high priority in the vehicle as any breach or miscalculation can directly affect the safety of the driver. With keeping the same perspective in mind, a combination of OEM and self-designed components is used, to keep the brake system as reliable as possible. Designed a Front/Rear split circuit with inboard braking on the rear side. A 2 port Tandem master cylinder with the bore diameter of 19 mm and fixed type brake calipers of bore diameter 30 & 32 mm as they are compact, lightweight and durable is used. The brake discs are designed of 160 mm in the front and 190 mm in the rear that are capable of transmitting the brake torque as well as dissipating the heat that is generated. Keeping in mind the ergonomic considerations while designing the pedal which also sustains repeating cycles of panic braking as shown by the analysis. Therefore, by having a braking torque which is more than the required theoretical value, ATV will be easily able to stop within a distance of 4.9 m.

5.1 Design Objectives:

a. To stop the vehicle by all wheel locking within minimum possible distance using disc brake system provided stability of the vehicle is intact.

b. To design the rotor for optimum heat dissipation and sufficient braking torque.

c. To select appropriate fluid circuitry and components along with electrical wiring for tail lamp (according to the rulebook).

3.2 Design considerations:

a. Braking force by the driver for brake design.

b. Stable braking

c. Stopping distance with 5m when vehicle is running at a speed 50kmph

3.3 Design specifications:

It is decided to use an OEM 2port TMC with 19mm (3/4") bore diameter, adhering to the calculations also it is decided to use fixed type calipers which have bore diameters of 30mm and 32 mm which are rigid, compact and readily available in the Indian market.

By reverse calculating the values after selecting the components and by analyzing the required value of braking torque, the rotor diameters were calculated.

Table -7: Pedal Characteristics

Parameter	Value
Pedal Ratio	6:1
Pedal Force	240N
Pedal Travel	4.25"

Table -8: Brake Specifications

Calculations	Front	Rear
Calliper Type	Fixed	Fixed
Force on Calliper(N)	6395.11	6807.35
Braking Torque (Nm)	172.66	223.281
Disc OD & ID(mm)	160&110	200&128

3.4 Components and material selection:

a. Tandem Master Cylinder (double piston, 2 port, bore*stroke=19*21), fixed type brake calipers, DOT4 brake fluid were selected from performance and cost point of view

b. C45 stainless steel is selected for manufacturing of rotor

c. Mild steel is used for brake pedal

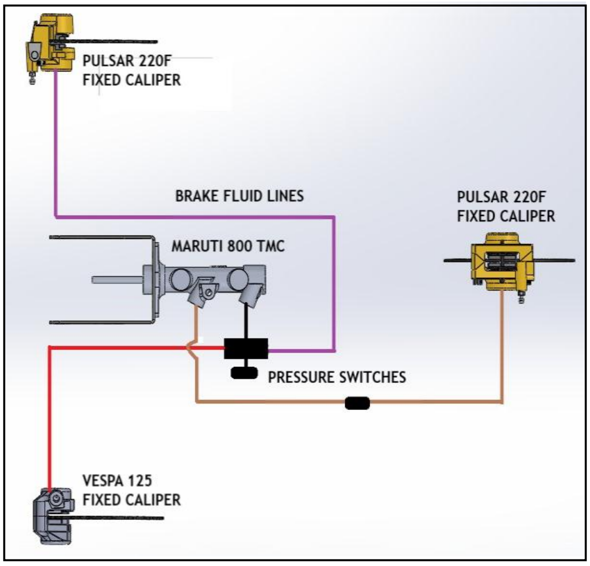

Fig -14 F/R Split Braking Circuit

5.5 CAE:

Transient thermal simulation is done for the brake rotor to determine the rise in temperature during braking. To test the vibrational performance of disc brake assembly, non-linear contact type 'Brake squeal' analysis is performed. It is found that the braking system showed stable, vibration-free operation while braking at all possible vehicle speeds.

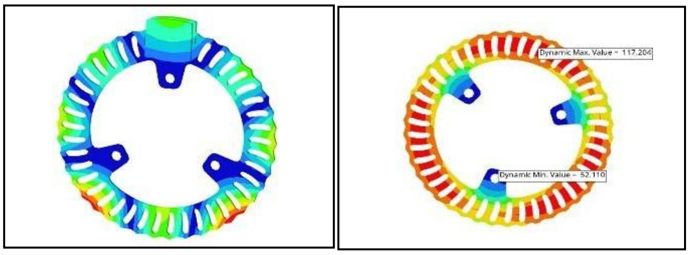

Fig -15 Eigen mode and transient Thermal Analysis

6. CONCLUSION:

This project's primary goal was to develop and produce an all-terrain vehicle employing design and assembly knowledge. Rigorous Analysis was crucial in getting optimum results. The best-optimized design is produced throughout the designing phase in order to increase performance, reduce weight, and take cost-cutting factors into account. The combined extensive research on automobile design has led to the creation of ATV which is worthy of all the extreme terrain conditions. Proper attention is given to even minute details in the vehicle to make it truly customized.

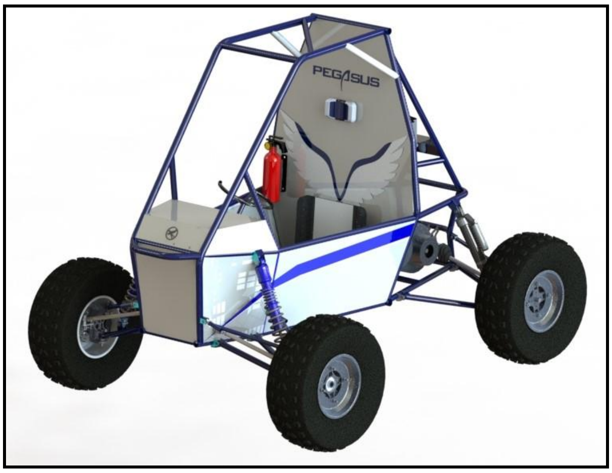

Fig -16 Final CAD

Fig -17 Final Model

7. ACKNOWLEDGEMENT

I would like to take this opportunity to acknowledge and thank the whole "Team Pegasus Racing" of PES Modern College of Engineering, Pune, whose valuable support and contribution has helped me patch this project and make it a full- proof success.

I hope my thesis and analysis can provide meaningful conclusions and do justice to the topic.

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