iJRASET
International Journal For Research in
Applied Science and Engineering Technology

# INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

**Volume:** 8 **Issue:** XII **Month of publication:** December 2020

**DOI:** https://doi.org/10.22214/ijraset.2020.32629

www.ijraset.com

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 8 Issue XII Dec 2020- Available at www.ijraset.com

# Design and Analysis of Power Train for All-Terrain Vehicle (ATV)

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***Abstract:** Power train is an interlinkage of mechanism that transmits, power and torque from Engine to the Wheels of an automobile. Power train is also known as Transmission system. The objective of transmission is to provide required power, consistently and efficiently, to overcome every severe terrain conditions. An All-Terrain Vehicle (ATV) is a single seat, open cockpit vehicle, which is used for Off-roading purpose.*

***The ATV designed for BAJA SAE competition was aimed at providing complete safety, dynamic stability, sustainability and reliability. This paper provides detailed information about Designing, Mathematical analyzing and fabrication of power train for ATV.***

***The application of modern designing technique like CAD and FEA assisted in determining the critical point in design and possible failure location. This encouraged in discovering new methods of fabricating and assembling components and ensured clear understanding of project.***

***The paper enlightens about various types of power trains with their advantages and disadvantages, and optimum use of available resources for designing affordable ATV.***

***Keywords:** ATV, Gradeability, CVT, Tractive Effort, Transmission system*

## I. INTRODUCTION

The ever-increasing universal demand for rugged, energy efficient, stable and economical All-Terrain Vehicle (ATV) requires developing current ATV's with significant changes. ATV's are built for their exclusive performance in all type of terrain conditions and thus their design plays a crucial role. They are used for adventurous sports, military exercises and can be used in agricultural fields. Society of Automotive Engineers (SAE) organizes BAJA SAEINDIA in which undergraduate college students participate to compete and showcase their own designed and fabricated ATV's. The ATV's are designed and build for their optimum performance during the competition.

As ATV's are designed for any severe terrain conditions, the power train should be capable of transmitting power to the wheels. The Power train thus becomes a crucial section, which needs to be designed carefully. It consists of several power generating and power transmitting components.

It includes Engine, Clutch, Gearbox, Propeller shaft, Universal joints, Differential, Axles, Wheels. Broadly, Transmission is referred to only as gearbox and is classified as Manual Transmission and Automatic Transmission. Manual Transmission works on principle of shifting gears manually to obtain different gear ratios. While in Automatic transmission, there is no need to manually change the gears. Automatic Transmission operates basically by controlling vehicle speed and engine load.

### *A. Advantages and Disadvantages*

1) Manual transmissions are less complex, more efficient and weigh less than automatic transmission but due to space restriction in cockpit the gear lever would have proved discomfort for the driver.
2) Automatic Transmission proves beneficial because it does not require gear shifting mechanism to change the gear but they are more complex and costly. Moreover, they require more maintenance than manual transmission.

The main objectives aimed for designing ATV was light weight, affordable and energy efficient ATV. The overall weight of ATV with driver was targeted around 300 kilograms.

The mounting of Manual and Automatic Transmission on chassis was an issue due to their weight and size. A type of automatic transmission, CVT was considered which required low space and was affordable and light weight. CVT can obtain any desired speed ratio within its operating limits. So, the selection of CVT was finalized.

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## II. CONCEPT SELECTION AND DESIGN

### *A. Selection of Engine*

Internal Combustion Engine is the power generating component from which power is transmitted to the other parts of power train. For SAE BAJA competition, Engine was one of the constraints and only use of Briggs and Stratton OHV engine model was permitted. It is a four-stroke, air cooled engine having following specifications: -


Fig – Engine

1) MODEL - 19L232-0054 G1
2) DISPLACEMENT -305 CC
3) BORE/STROKE - 3.12” / 2.44”
4) ENGINE TYPE - OHV
5) COMPRESSION RATIO - 8.1 TO 1
6) MAX POWER - 10.0 HP
7) MAX RPM - 3,800 RPM

### *B. Selection of CVT*

The Advantages and Disadvantages of Manual Transmission and Automatic transmission were noted and considering them CVT was finalized. Continuous Variable Transmission (CVT) is a form of automatic transmission which can select any desired gear ratio within its operating limit. It consists of pair of pulleys of which input shaft is coupled with engine shaft and output is coupled with gearbox. A rubber belt runs over the two pulley and transmits required power. Research and Market survey about the CVT was carried out and CVTech CVT was selected. The diameter of Engine output shaft and ID of hole of primary pulley was same. Following are the specifications of CVT: -

| | |
|---|---|
| Company | CVtech |
| Model | Series 6 |
| Ratio | 3:1 to 043:1 |
| Material | Al- 6061-T6 |

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Fig – CVT Dismantled

Fig – CVT Assembled

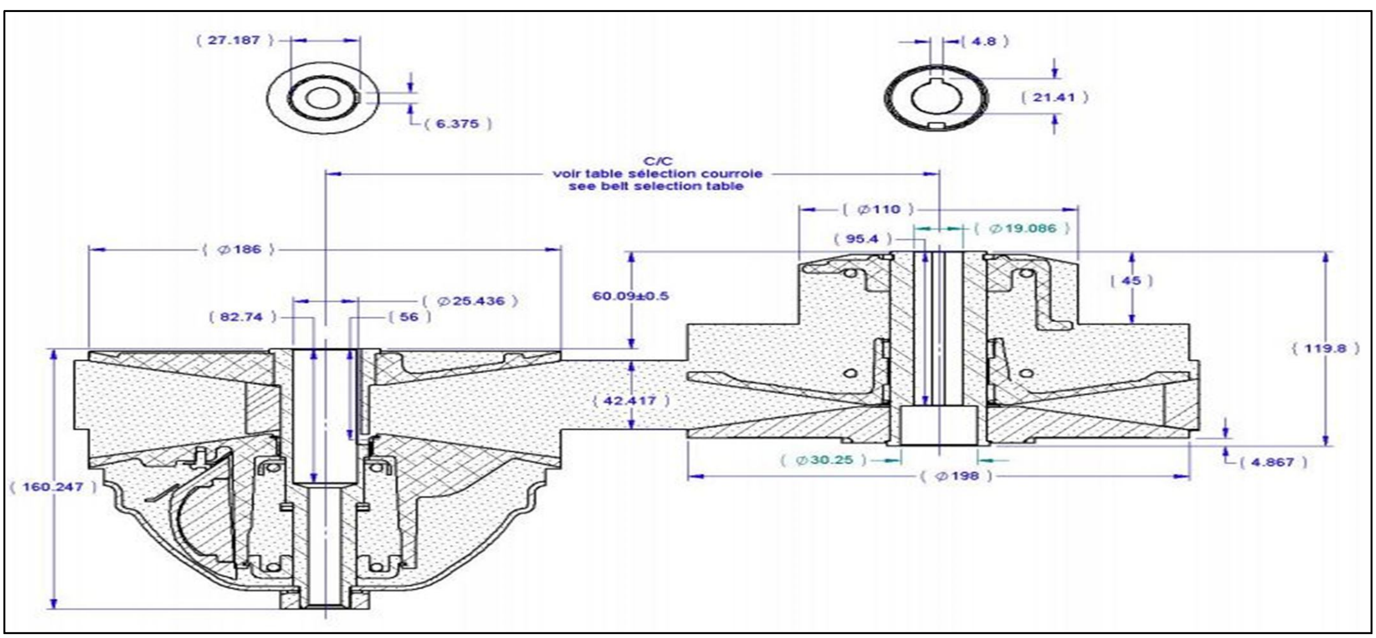


Fig – CVT Layout

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Fig – Engine power vs RPM vs Torque

## III. CALCULATION OF GEAR RATIO

N: Speed of the engine (rpm)
P: Circumference of Wheel (m)
E: Transmission Efficiency (%)
C. R.: C.V.T Ratio
G.R.: Gear Ratio
T: Max engine Torque (Nm)
T: Engine Torque (Nm)
R: Radius of Wheel (m)
W: Weight of Vehicles (N)
m: Mass of the vehicles (kg)
α: Pressure angle
Z: No. of Teeth
PCD: Pitch Circle Diameter (mm)
M: Module of gears

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Vehicles should not exceed the speed of 60 Km/hr as per the SAE BAJA2020 rules. So, gearbox should be design to attend maximum speed of 60 Km/hr. Maximum engine rpm is 3800 at this condition CVT ratio is 0.53:1.

Maximum engine rpm (N): 3800

CVT ratio @3800 rpm (C): 0.53:1

Maximum desired speed (V): 60 Km/hr

Wheel perimeter (P): $\pi$X D= 3.14x 0.533 =1.676 m

Gearbox ratio

$$V = \frac{N*P*60}{1000*C.R.*G.R.}$$

$$60 = \frac{3800*1.676*60}{1000*0.56*G.R.}$$

G.R. = 12
Therefore, Gear ratio = 12:1
Hence the first stage and second stages of gearbox should be 3.4 and 3.5 respectively.

*A. Design of Gear*

| | |
|---|---|
| Gearbox Type | 2 stage compound gearbox |
| Gear type | Spur gear |
| Gear ratio | 12:1 |
| 1st stage reduction ratio | 3.4 |
| 2nd stage reduction ratio | 3.5 |
| Pressure angle | 20 degree |
| Module | 2 |

For the selected gear ratio 12:1 the Pitch circle diameter (PCD) and No. of teeth (Z) is given by the following calculation.

$$\text{Stage 1 gear ratio} = \frac{\text{No. of teeth of gear 1}}{\text{No. of teeth of pinion 1}}$$

$$= \frac{62}{18}$$

$$= 3.4$$

PCD for Gear 1
PCD = Z * M = 62 X 2 = 124 mm
Same approach is done to get the rest values

| | Stage 1 | | Stage 2 | |
|---|---|---|---|---|
| | Pinion 1 | Gear 1 | Pinion 2 | Gear 2 |
| No. of teeth | 18 | 62 | 18 | 63 |
| Face width | 20 | 20 | 20 | 20 |
| PCD (mm) | 36 | 124 | 36 | 126 |

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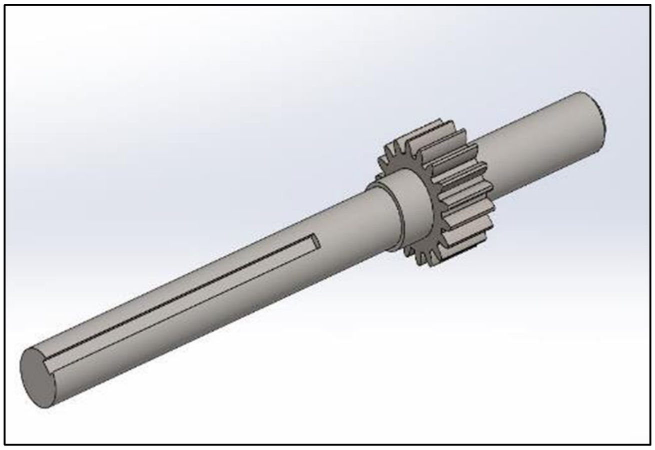

Fig - Stage 1 Pinion

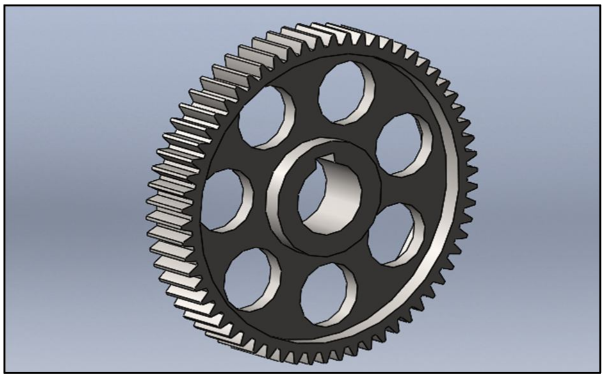

Fig - Stage 1 Gear

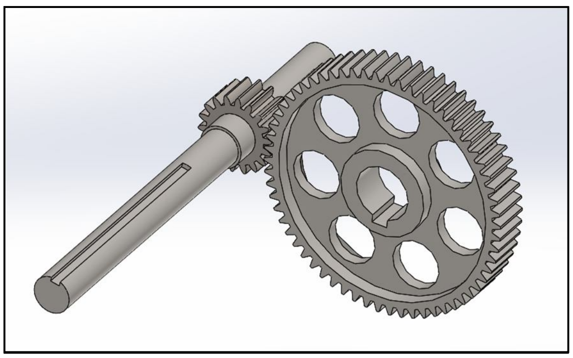

Fig - Stage 1 Assembly

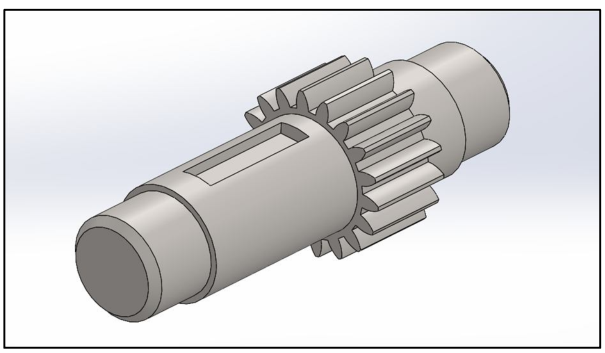

Fig - Stage 2 Pinion

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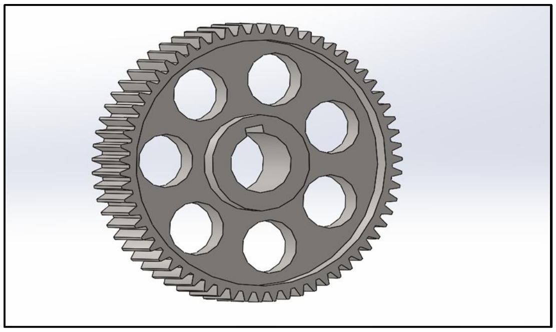

Fig - Stage 2 Gear

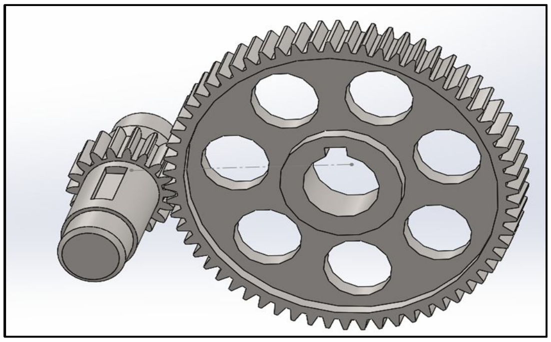

Fig - Stage 2 Assembly

## IV. GEAR MATERIAL SELECTION

Gear material selection is based on the amount of total load which acts on the gears or on gear tooth. The load which acts on the gears and gear tooth while dynamic events and endurance race in the BAJA competition may cause the failure of the gears and breakage of gear tooth. The gear material should have sufficient strength to resist this failure & avoid breakage of the tooth.

Therefore 30CrNiMo8 (DIN 1.6580) Material has been selected for gears.

| | Gear material | Casing material |
|---|---|---|
| Material | 30CrNiMo8 | Al-6061 |
| Tensile strength | 1250 Mpa | 124 Mpa |
| Yield strength | 1050 Mpa | 55 Mpa |
| Poisson ratio | 0.28 | 0.33 |

## V. ANALYSIS OF GEAR

Analysis has been done in Solidworks 2020.

| Component | Max. deformation (mm) | Max. stress ($N/mm^{2}$) | Factor of safety |
|---|---|---|---|
| 1st stage gears | 0.155 | 108 | 9.7 |
| 2nd stage gears | 0.155 | 516 | 2.04 |

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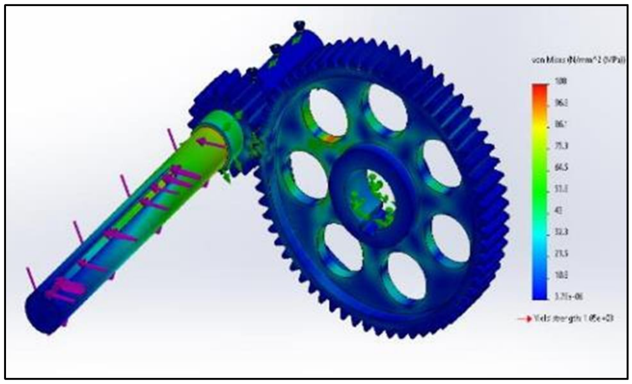

Fig - Stress analysis of 1st stage gears.

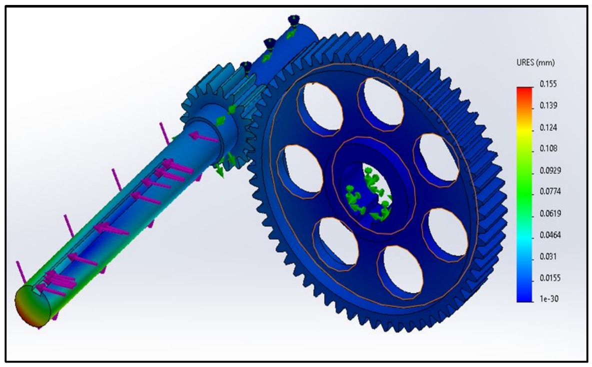


Fig - Deformation analysis of 1st stage gears

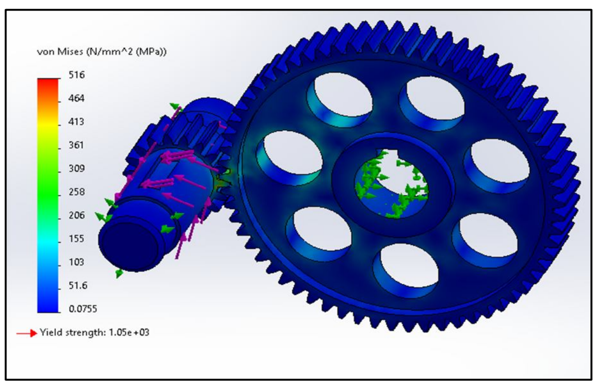


Fig - Stress analysis of 2nd stage gears.

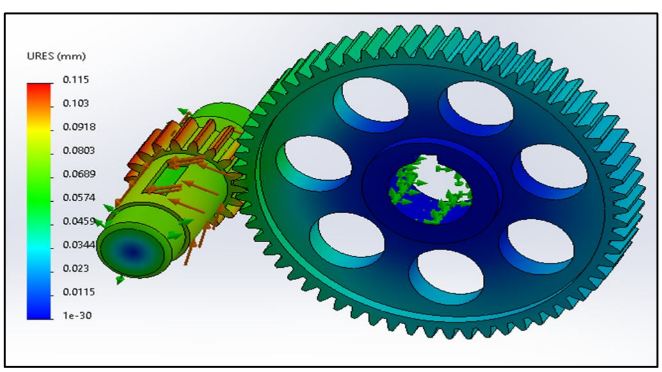


Fig - Deformation analysis of $2^{nd}$ stage gears

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Calculation of theoretical parameters after designing Gearbox

*1)* Max. Speed of Vehicles $= \frac{N * C*E*3.6}{C.R*G.R*60}$

$$= \frac{3800 * 1.676 * 0.95 *60}{0.56*12*1000}$$

$$= 54.02 \text{ Km/hr.}$$

*2)* *Acceleration*

*a)* *Tractive Effort:* It is the force which acts at the rims of the driving wheels of moving vehicles. It is required to accelerate the vehicle mass horizontally.

Tractive effort (T.E) $= \frac{T* C.R * G.R * E}{R}$

$$= \frac{19 * 3 * 12 * 0.95}{0.2667}$$

$$= 2436.45 \text{ N}$$

*b)* *Rolling Resistance:* It the force resisting the motion when a body rolls over the surface.

Rolling Resistance (R.R) = W * μ

= 300 * 9.81 *0.08

= 235.44 N

*c)* *Air Resistance:* Air resistance describes the forces that are in opposition to the relative motion of a vehicle as it passes through the air.

Air Resistance (A.R.) $= \rho * A * Cd * V^2 /2$

$=1.1644*1*0.4*2.02^2/2$

=0.95 N

*d)* Total Resistance (T.R) = A.R + R.R

= 0.95 + 235.44

= 236.39 N

*e)* Acceleration $= \frac{T.E - T.R}{m}$

$$= \frac{2436.45 – 236.39}{300}$$

$$= 7.33 \text{ m/s}^2$$

*f)* Gradeability: The ability of the vehicles to climb the slope is gradeability.

Gradeability $= \frac{100 * (T.E – T.R.)}{W}$

$$= \frac{100 * (2436.45 – 236.39)}{300 * 9.81}$$

= 74.75 %

*g)* Maximum Torque on Wheels (T.W)

= T *C.R.*G.R.* E

= 19* 3 * 12* 0.95

=649.8 Nm

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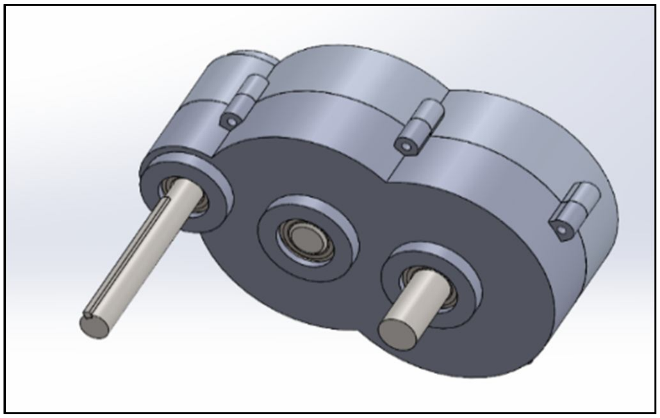

Fig – Gearbox Casing

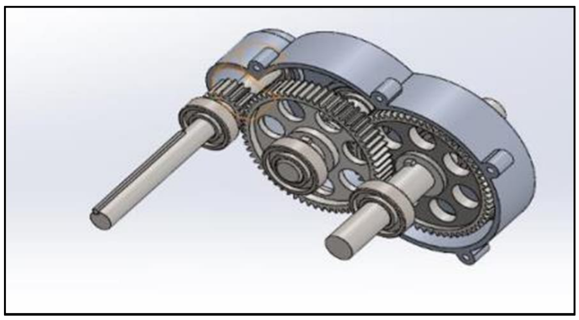

Fig – Gearbox cross-sectional view

## VI. RESULT

From all the Design, Analysis and calculations, following results are obtained:

| Engine RPM | Engine Torque | CVT Ratio | Secondary CVT RPM | Secondary CVT Torque | Gear box Ratio | Gear box input RPM | Gear box input Torque | Gear box output RPM | Gear box output Torque | Wheel RPM | Wheel RPH | Vehical Speed | Vehical Speed m/s | Tractive Force(N) | Air Drag (N) | Rolling Reistance | Extra tractive force available | Acceleration | GRADEABILITY (%) | Gradeability |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1800 | 18.5 | 3 | 600.00 | 55.5 | 12 | 600.00 | 55.5 | 50.00 | 666.00 | 50.00 | 3000.00 | 5.02 | 1.40 | 2247.47 | 0.45 | 294.30 | 1952.72 | 6.51 | 66.35 | 33.56 |
| 1900 | 18.5 | 3 | 633.33 | 55.5 | 12 | 633.33 | 55.5 | 52.78 | 666.00 | 52.78 | 3166.67 | 5.30 | 1.47 | 2247.47 | 0.51 | 294.30 | 1952.66 | 6.51 | 66.35 | 33.56 |
| 2000 | 18.5 | 3 | 666.67 | 55.5 | 12 | 666.67 | 55.5 | 55.56 | 666.00 | 55.56 | 3333.33 | 5.58 | 1.55 | 2247.47 | 0.56 | 294.30 | 1952.61 | 6.51 | 66.35 | 33.56 |
| 2100 | 18.6 | 3 | 700.00 | 55.8 | 12 | 700.00 | 55.8 | 58.33 | 669.60 | 58.33 | 3500.00 | 5.86 | 1.63 | 2259.62 | 0.62 | 294.30 | 1964.70 | 6.55 | 66.76 | 33.73 |
| 2200 | 18.7 | 3 | 733.33 | 56.1 | 12 | 733.33 | 56.1 | 61.11 | 673.20 | 61.11 | 3666.67 | 6.14 | 1.71 | 2271.77 | 0.68 | 294.30 | 1976.79 | 6.59 | 67.17 | 33.89 |
| 2300 | 18.8 | 3 | 766.67 | 56.4 | 12 | 766.67 | 56.4 | 63.89 | 676.80 | 63.89 | 3833.33 | 6.42 | 1.78 | 2283.91 | 0.74 | 294.30 | 1988.87 | 6.63 | 67.58 | 34.05 |
| 2400 | 18.8 | 3 | 800.00 | 56.4 | 12 | 800.00 | 56.4 | 66.67 | 676.80 | 66.67 | 4000.00 | 6.70 | 1.86 | 2283.91 | 0.81 | 294.30 | 1988.81 | 6.63 | 67.58 | 34.05 |
| 2500 | 18.9 | 3 | 833.33 | 56.7 | 12 | 833.33 | 56.7 | 69.44 | 680.40 | 69.44 | 4166.67 | 6.98 | 1.94 | 2296.06 | 0.88 | 294.30 | 2000.89 | 6.67 | 67.99 | 34.21 |
| 2600 | 19 | 3 | 866.67 | 57 | 12 | 866.67 | 57 | 72.22 | 684.00 | 72.22 | 4333.33 | 7.26 | 2.02 | 2308.21 | 0.95 | 294.30 | 2012.96 | 6.71 | 68.40 | 34.37 |
| 2700 | 19 | 2.8 | 964.29 | 53.2 | 12 | 964.29 | 53.2 | 80.36 | 638.40 | 80.36 | 4821.43 | 8.08 | 2.24 | 2154.33 | 1.17 | 294.30 | 1858.86 | 6.20 | 63.16 | 32.28 |
| 2800 | 19 | 2.6 | 1076.92 | 49.4 | 12 | 1076.92 | 49.4 | 89.74 | 592.80 | 89.74 | 5384.62 | 9.02 | 2.51 | 2000.45 | 1.46 | 294.30 | 1704.69 | 5.68 | 57.92 | 30.08 |
| 2900 | 18.95 | 2.4 | 1208.33 | 45.48 | 12 | 1208.33 | 45.48 | 100.69 | 545.76 | 100.69 | 6041.67 | 10.12 | 2.81 | 1841.71 | 1.84 | 294.30 | 1545.57 | 5.15 | 52.52 | 27.71 |
| 3000 | 18.9 | 2.2 | 1363.64 | 41.58 | 12 | 1363.64 | 41.58 | 113.64 | 498.96 | 113.64 | 6818.18 | 11.42 | 3.17 | 1683.78 | 2.34 | 294.30 | 1387.14 | 4.62 | 47.13 | 25.24 |
| 3100 | 18.8 | 2 | 1550.00 | 37.6 | 12 | 1550.00 | 37.6 | 129.17 | 451.20 | 129.17 | 7750.00 | 12.98 | 3.61 | 1522.61 | 3.03 | 294.30 | 1225.28 | 4.08 | 41.63 | 22.60 |
| 3200 | 18.7 | 1.8 | 1777.78 | 33.66 | 12 | 1777.78 | 33.66 | 148.15 | 403.92 | 148.15 | 8888.89 | 14.89 | 4.14 | 1363.06 | 3.98 | 294.30 | 1064.78 | 3.55 | 36.18 | 19.89 |
| 3300 | 18.6 | 1.5 | 2200.00 | 27.9 | 12 | 2200.00 | 27.9 | 183.33 | 334.80 | 183.33 | 11000.00 | 18.42 | 5.12 | 1129.81 | 6.10 | 294.30 | 829.41 | 2.76 | 28.18 | 15.74 |
| 3400 | 18.4 | 1.3 | 2615.38 | 23.92 | 12 | 2615.38 | 23.92 | 217.95 | 287.04 | 217.95 | 13076.92 | 21.90 | 6.08 | 968.64 | 8.62 | 294.30 | 665.72 | 2.22 | 22.62 | 12.75 |
| 3500 | 18 | 1 | 3500.00 | 18 | 12 | 3500.00 | 18 | 291.67 | 216.00 | 291.67 | 17500.00 | 29.31 | 8.14 | 728.91 | 15.44 | 294.30 | 419.17 | 1.40 | 14.24 | 8.11 |
| 3600 | 17.7 | 0.6 | 6000.00 | 10.62 | 12 | 6000.00 | 10.62 | 500.00 | 127.44 | 500.00 | 30000.00 | 50.25 | 13.96 | 430.06 | 45.37 | 294.30 | 90.39 | 0.30 | 3.07 | 1.76 |
| 3700 | 17.7 | 0.6 | 6166.67 | 10.62 | 12 | 6166.67 | 10.62 | 513.89 | 127.44 | 513.89 | 30833.33 | 51.64 | 14.35 | 430.06 | 47.92 | 294.30 | 87.83 | 0.29 | 2.98 | 1.71 |
| 3800 | 17.7 | 0.53 | 7169.81 | 9.381 | 12 | 7169.81 | 9.381 | 597.48 | 112.57 | 597.48 | 35849.06 | 60.04 | 16.68 | 379.88 | 64.78 | 294.30 | 20.80 | 0.07 | 0.71 | 0.40 |

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| | |
|---|---|
| Gear material | 30CrNiMo8 |
| Gear casing material | Al-6061 |
| Gearbox type | 2 stage compound spur gear |
| Overall gar reduction ratio | 12 |
| 1st stage reduction ratio | 3.4 |
| 2nd stage reduction ratio | 3.5 |
| Module | 2 |
| Pressure angle | 20 |
| Face width | 20 |
| Max. speed | 54.02 |
| Acceleration | 7.33 $m/s^2$ |
| Gradeability | 74.75% |
| Torque on wheel | 649.8 |
| Total weight of gearbox | 5.8 Kg |

## VII. CONCLUSION

From the above calculations and analysis, it can be concluded that optimization had been successfully done in gear design to reduce the overall weight of gearbox and to increase the performance of ATV. Overall gear reduction of 12 is achieved. The power train is essential in not only providing required speed and torque but also to provide stability to vehicle as 40-50% weight of ATV is contributed by power train. Selection of gear material may differ the analysis result so proper choice should be made during selection process. All customized parts were designed and analyzed on solidworks software. The center of gravity (C.G.) should be placed at lower height from ground to achieve vehicle stability. The kerb weight of ATV is reduced by application of CVT transmission and optimizing gearbox. Due to decrease in weight, ATV's speed and efficiency is increased. The main motive of Affordable ATV production was achieved. Various unwanted components which increased the cost and weight of ATV were reduced or cut-offed without compromising in driver's safety and vehicle stability.

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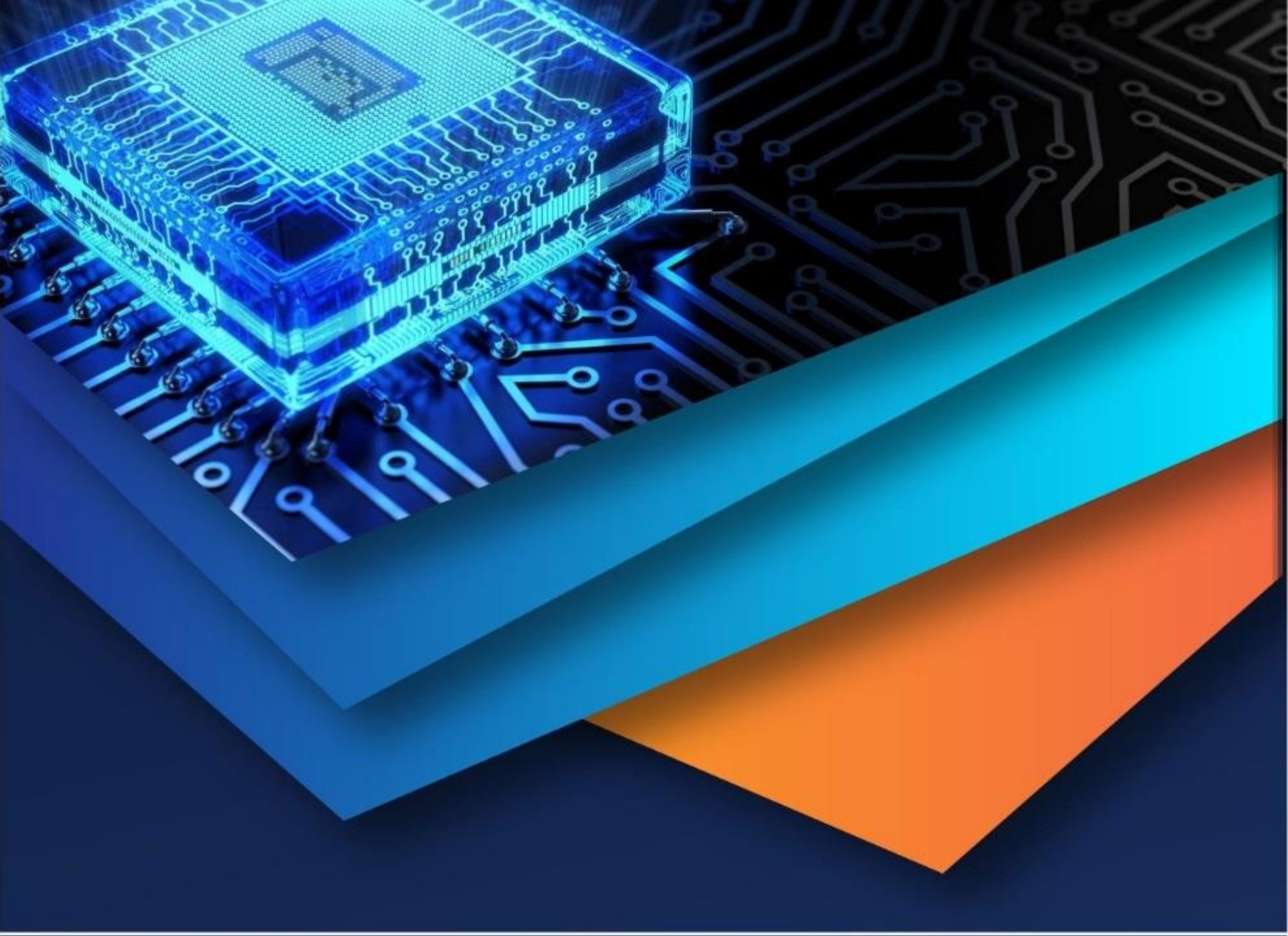

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