DESIGN, ANALYSIS AND MANUFACTURING OF A SINGLE STAGE OPEN DIFFERENTIAL

Submitted in partial fulfilment of the requirements of the degree of

Bachelor of Engineering

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DWARKADAS J. SANGHVI COLLEGE OFENGINEERING

(Autonomous College Affiliated to the University of Mumbai)
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CERTIFICATE

This is to certify that the project entitled **"DESIGN, ANALYSIS AND MANUFACTURING OF A SINGLE STAGE OPEN DIFFERENTIAL"** is Bonafide work of

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PROJECT REPORT APPROVAL FOR B. E.

This project report entitled "**DESIGN, ANALYSIS AND MANUFACTURING OF A SINGLE STAGE OPEN DIFFERENTIAL**"

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Date:

Place:

DECLARATION

We declare that this written submission represents our ideas in our own words and where other ideas or words have been included, we have adequately cited and referenced the original sources. We also declare that we have adhered to all the principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fast/source in our submission. We understand that any violation of the above will be a cause for disciplinary action by the Institute and can also evoke penal action from the sources, which thus not been properly cited or from whom permission has not been taken, when needed.

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ABSTRACT

D. J. Sanghvi College of Engineering offers a number of co-curricular opportunities for students in every engineering field. There are various teams, which develop different vehicles under the banner of SAE (Society of Automotive Engineers). Out of these one of the teams decided to design and build an All-Terrain Vehicle and we were tasked with designing and manufacturing a single stage open differential for them.

A differential is a device that splits the engine torque and supplies it to the outer wheels, allowing each outer wheel to rotate at different speed. The differential is found on all modern cars and trucks. In automobiles and other wheeled vehicles, the differential allows the outer drive wheel to rotate faster than the inner drive wheel during a turn. This is necessary when the vehicle turns, making the wheel that is traveling around the outside of the turning curve roll farther and faster than the other. The average of the rotational speed of the two driving wheels equals the input rotational speed of the drive shaft. An increase in the speed of one wheel is balanced by a decrease in the speed of the other. The differential has mainly 3 functions: (1) It directs power from the engine to the wheels (2) It acts as the final gear reduction in vehicle (3) The differential transmits power to different wheels while allowing them to rotate at different speeds.

An automobile differential gear system is used to establish a differential motion between left and right driving axle which provides a smooth turning of the vehicle. When a vehicle takes a turn, the wheels at the outermost position have to cover a longer distance as compared to the innermost wheels. This speed variation can be achieved by using a differential gear system. It also transmits the power from the propeller shaft to each axle. A rear-wheel-drive vehicle requires a differential at the rear axle while all-wheel drive vehicle requires differential gear system for each and every axle. We have designed, analysed and fabricated a single stage open differential to be used for a single seater All-Terrain Vehicle. Various calculations of the shaft, gears and bearing were done and the cad was designed by using SolidWorks and later ANSYS was used to finalise the design. Fabrication was done using vertical milling machines and lathes.

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Chapter 1

INTRODUCTION

The concept of the differential to allow wheels mounted on the same axle to rotate independently of each other is an ancient design, with the first known instance of its use recorded in China during the 1st millennium BC. Although this was long before the invention of the automobile, carts, wagons and chariots still suffered from the same problem of one wheel slipping or dragging when cornering, increasing wear and damaging roads. The advent of engines powering front or rear wheels to propel a vehicle instead of merely dragging them via horse added a new problem to overcome – how to allow independent rotation while still being able to power both wheels. The earliest automobiles didn't bother trying; they simply powered only one wheel on an independent axle. But this was far from ideal as it meant they were underpowered and encountered frequent problems with traction on anything other than firm, level ground. Eventually this led to the development of the Open Differential before other more complicated types were developed to overcome more complex driving conditions. Like most things on modern automobiles, the simple piece of gearing known as a differential has seen constant refinement and experimentation - leading to a range of types each with their own advantages and disadvantages.

1.1 Motivation

The team has already been developing a rear-wheel-drive all-terrain vehicle and it was now up to us to take it to another level by designing a four-wheel drive vehicle that would provide better acceleration and an increase in stability and gradeability of the vehicle. This immediately prompted us to look at different types of differentials to transmit the power from the rear end of the vehicle all the way to the front. Being a single seater vehicle, there were immense design restrictions due to the need of it to be compact and yet serve its purpose. After carefully going through various papers and books, we decided to move forward with a single stage open differential

Open differentials are the most common differential found on passenger vehicles and allow the wheels to rotate at different speeds while the vehicle is turning a corner. Open differentials are the original solution to a universal problem. They allow the wheels to turn independently of each other, preventing wheel hop, vehicle instability and excess tire wear.

1.2 Methodology

Research

- The project was first thoroughly researched by referring numerous papers and micro-blogging sites.
- Both the important learnings and shortcomings from these references were noted down.

Calculations and Designing

- Considering the product requirements, we began narrowing down the components and started with their calculations.
- Computer Aided Designs (CAD) were developed using SolidWorks

Analysis

- Analyses of the components were carried out using ANSYS Workbench.
- Factor of Safety (FOS) of each component was selected based on the material used and the forces exerted on it.

Manufacturing

- After material procurement, machining processes were selected for each component based on the machining requirements.
- A suitable machinist was selected for manufacturing.

Assembly

- After receiving the parts from the machinist, visual inspection was done and tolerances were checked.
- All the components were then assembled to develop the final product.

Chapter 2

LITERATURE REVIEW

The literature review is classified into two broad accepts: Research papers published about differential and automobile transmission systems and books that provided us with design methodology and equations which we were alienated from. Various research papers accessed by us have been addressed in the reference section which includes any and all types of automobiles that include a differential system.

Vijay Gautam discussed the design and analysis of an open type differential numerically as well as theoretically for a passenger saloon in which straight bevel gears of different dimensions were used as constituents of the differential. He observed that the Lewis criterion is highly conservative than the American Gear Manufacturers Association (AGMA) and Finite element analysis (FEA) [1]. Massimo Guiggiani investigated the effect of a locked differential on the steady-state cornering behaviour of vehicles. He discussed the handling diagrams obtained for manoeuvres conducted at constant speed, constant steer angle and constant turning radius, showing a strong influence of the manoeuvre itself on the steady-state behaviour and understeer gradient. The analysis described by him represents a theoretical and systematic approach to a classical subject, which in the past was investigated by means of numerical simulations and experimentalground tests only [2]. A. Doniselli, G. Mastinu and R. Cal investigated the problem of traction force distribution between the wheels of a driving axle. He studied the basic features and related limitations pertaining to mechanical systems for traction control. He presented, discussed and classified all the possible arrangements of non-conventional differentials for traction control in terms of left/right torque split ratio and efficiency [10]. Richard A. James discussed the design of a lightweight aluminum differential housing to replace the cast-iron housing used in the Torsen® T-1 [4]. Books used include: Introduction to Machine Design by V.B. Bhandari [7], Design of Machine Elements and by V.B. Bhandari [6], PSG Design Data Book [5].

Chapter 3
THEORY

3.1 DIFFERENTIAL

3.1.1 Working principle of a differential

When an automobile travels around a corner, the distance travelled by the outside wheels is greater than that travelled by the inside wheels. If the wheels are mounted on dead axles so that they turn independently of each other, like the front wheels of an ordinary passenger vehicle, they will turn at different speeds to compensate for the difference in travel. But, if the wheels are driven positively by the engine, a device is necessary which will permit them to revolve at different speeds without interfering with the propulsion system. To accomplish this purpose a system of gears called the differential is provided. The driving axle is one of the cross members which supports the load of the tractor, and has the driving wheels at its ends. The driving axle consists of a housing, a differential, two axle shafts (half axles), and final drives (if required).

The differential is an important component of the driving axle. The main functions performed by the differential system are:

- Further reduce the rotations coming from the gear box before the same are passed on to the rear axles.
- Change the direction of axis of rotation of the power by 90^o i.e. from being longitudinal to transverse direction.
- Distribute power equally to both the rear driving axles when the vehicle is moving in straight direction.
- Distribute the power as per requirement to the driving axles during turning i.e. more rotations are required by the outer wheel as compared to the inner wheel – during turns.

• To increase the tractive effort as per requirement, All-Wheel Drive (AWD) and Four-Wheel Drive (4WD) systems plays an important role to avoid loss of traction force while the vehicle is in action.

3.1.2 Types of differentials

There are four common differentials used between vehicles – open, locking, limited-slip and torque-vectoring.

Here are the four types of differentials:

- **Open differential**

This type of differential *(fig 3.1)* is often found in family sedans and economy cars. It splits the engine torque into two energy outputs to allow the wheels to rotate at different speeds. If one tire loses traction, the other will lose power to maintain traction.

- **Locking differential**

Sometimes also known as a welded differential *(fig 3.2)*, this differential connects the wheels so they spin at the same speed. This typically makes turning a little more difficult. Vehicles that use this type are full-size trucks and Jeep Wranglers.

- **Limited-slip differential**

Offering the best of both worlds, the limited-slip differential operates as an open differential until slippage occurs, then the differential will automatically lock. This type is found in vehicles like the Nissan 370Z and Mazda MX-5 Miata.

- **Torque-vectoring**

Used by the BMW X5 M or Lexus RC F, the torque-vectoring differential uses additional gear trains to send a specific amount of torque to each wheel for added control on turns.

3.1.3 Difference between Open and Locked differential

In an open differential, power from the motor is sent to one wheel or the other depending on which wheel takes less power to spin. This allows the wheels to spin at different speeds, which aids in turning but provides less traction when accelerating. An open differential provides better cornering force since wheels rotate at different speeds. There is an equal power transfer to all wheels according to wheel with minimum traction. Vehicle steering is not restricted and it is also cheaper compared to locked differential.

In a locked differential, power from the motor is sent to both wheels equally. This provides more traction when accelerating but doesn't allow the wheels to turn at different speeds, causing one wheel to drag or hop when turning, especially at low speeds. Less efficient cornering performance since wheels do not rotate at different speeds. Torque transfer according to traction on wheels and vehicle steering is restricted. It is also more expensive compared to open differential.

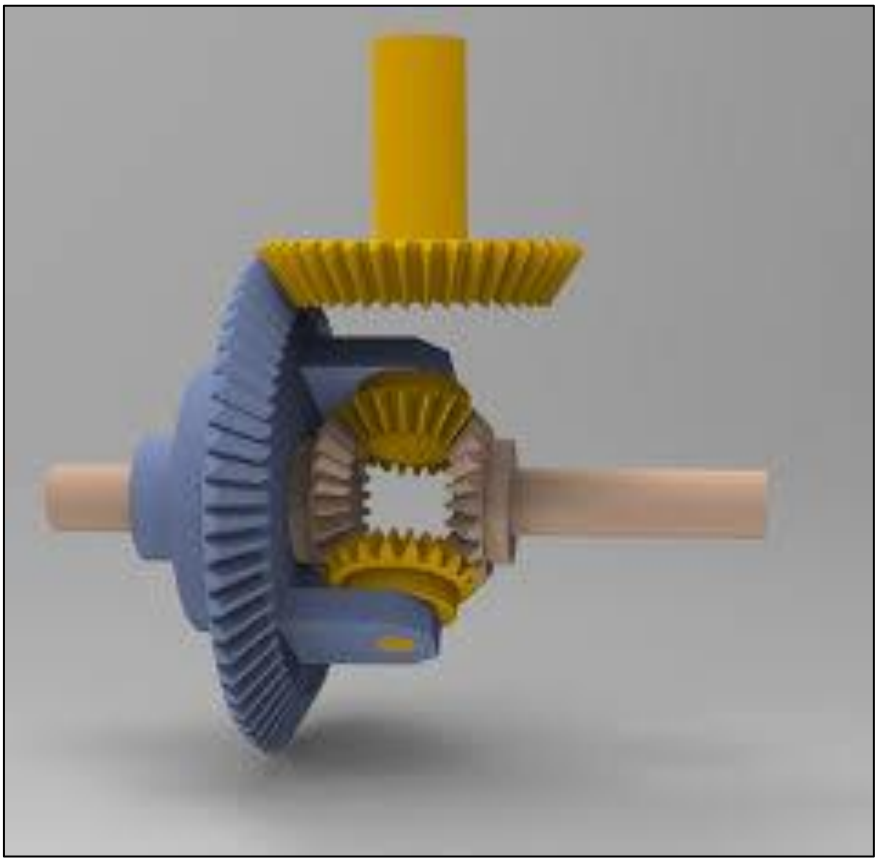


Fig 3.1 Open Differential

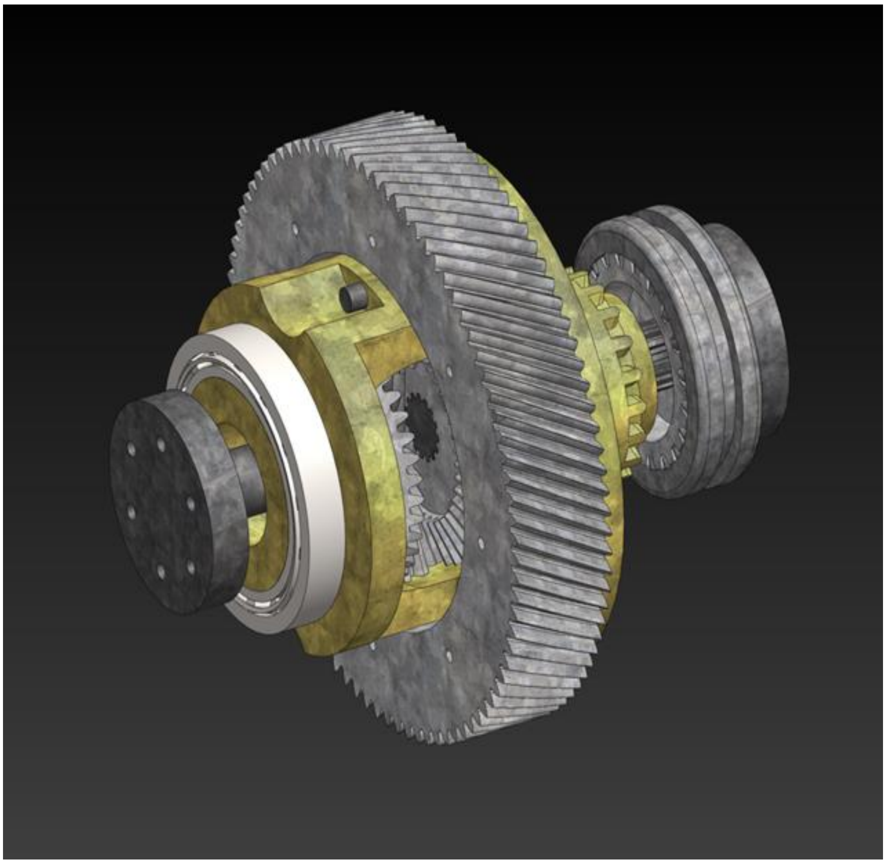


Fig 3.2 Locked Differential

There is also what's called a locking differential, which operates like an open differential during low-speed turns and general driving situations but is able operate like a locked differential when needed.

3.2 GEARS

3.2.1 Theory

A gear is a rotating circular machine part having cut teeth or, in the case of a cogwheel or gearwheel, inserted teeth (called *cogs*), which mesh with another (compatible) toothed part to transmit (convert) torque and speed. The basic principle behind the operation of gears is analogous to the basic principle of levers.[1] A gear may also be known informally as a cog. Geared devices can change the speed, torque, and direction of a power source. Gears of different sizes produce a change in torque, creating a mechanical advantage, through their *gear ratio*, and thus may be considered a simple machine. The rotational speeds, and the torques, of two meshing gears differ in proportion to their diameters. The teeth on the two meshing gears all have the same shape.[2]

Two or more meshing gears, working in a sequence, are called a gear train or a *transmission*. The gears in a transmission are analogous to the wheels in a crossed, belt pulley system. An advantage of gears is that the teeth of a gear prevent slippage. In transmissions with multiple gear ratios—such as bicycles, motorcycles, and cars—the term "gear" (e.g., "first gear") refers to a gear ratio rather than an actual physical gear. The term describes similar devices, even when the gear ratio is continuous rather than discrete, or when the device does not actually contain gears, as in a continuously variable transmission.[3]

Gears help to increase or decrease the speed of a vehicle as per the road conditions. They also help to increase the magnitude of an applied force. Additionally, they help in transmitting the power in different directions.

3.2.2 Types of Gears

There are four common gears used in differentials - spur gear, hypoid gear, bevel gear and worm gear.

Here are the four types of gears:

- **Spur Gear**

Spur gears *(fig 3.3)* are cylindrical shaped toothed components used in industrial equipment's to transfer mechanical motion as well as control speed, power, and torque. These simple gears are cost-effective, durable, reliable and provide a positive, constant speed drive to facilitate daily industrial operations.

- **Hypoid Gear**

A hypoid gear *(fig 3.4)* is a style of spiral bevel gear whose main variance is that the mating gears' axes do not intersect. The hypoid gear is offset from the gear centre, allowing unique configurations and a large diameter shaft. The teeth on a hypoid gear are helical, and the pitch surface is best described as a hyperboloid.

- **Bevel Gear**

Bevel gears *(fig 3.5)* are gears where the axes of the two shafts intersect and the tooth-bearing faces of the gears themselves are conically shaped. Bevel gears are most often mounted on shafts that are 90 degrees apart, but can be designed to work at other angles as well. The pitch surface of bevel gears is a cone.

- **Worm Gear**

A worm gear *(fig 3.6)* is a staggered shaft gear that creates motion between shafts using threads that are cut into a cylindrical bar to provide speed reduction. The combination of a worm wheel and worm are the components of a worm gear. Speed reduction is determined by the number of worm threads and the number of teeth on the worm wheel.

Fig 3.3 Spur Gear

Fig 3.4 Hypoid Gear

Fig 3.5 Bevel Gear

Fig 3.6 worm Gear

Chapter 4
RESEARCH

4.1 Reason for choosing Open differential

Open differentials are the most common differential found on passenger vehicles and allow the wheels to rotate at different speeds while the vehicle is turning a corner.

- **Efficiency**

From an efficiency standpoint, less energy will be lost through the differential versus alternative options.

- **Functionality**

Allows for completely different wheel speeds on the same axle, meaning no wheel slip will occur while going around a corner, as the outside tyre will travel further.

- **Steering**

In an open differential, vehicle steering is not restricted. This allows the driver to take sharp turns and provides better cornering.

- **Cost**

Open differential compared to its counterpart, limited slip differential is fairly less costly and is easy to manufacture since it contains less parts and hence complexity is reduced.

- **Predictability**

The way the open differential works is familiar to most drivers. With predictable behaviour, the driver knows how the car handles and nothing is a surprise.

Unlike the Limited Slip Differential, there won't be any rear-end movement back and forth while traveling over low-traction surfaces. Instead, the open differential spins the wheel without that movement.

4.2 Reason for choosing Spur gear

Spur gears provide several benefits to industrial applications and processes, including:

- **Simplicity**

Spur gears feature a simple, compact design that makes them easy to design and install, even in limited or restricted spaces.

- **Constant Speed Drive**

These gears increase or decrease shaft speed with a high degree of precision at a constant velocity.

- **Reliability**

Unlike other power and motion transmission components, spur gears are unlikely to slip during operation. Additionally, their durability decreases their risk of premature failure.

- **Cost-Effectiveness**

The simplicity of their design also allows for greater manufacturability, making them less expensive to fabricate and purchase even with highly specific or customized dimensions.

- **Efficiency**

Spur gear systems have power transmission efficiencies between 95% and 99% and can transfer large amounts of power across multiple gears with minimal power loss.

Chapter 5

CALCULATIONS AND DESIGNING

5.1 Module calculations

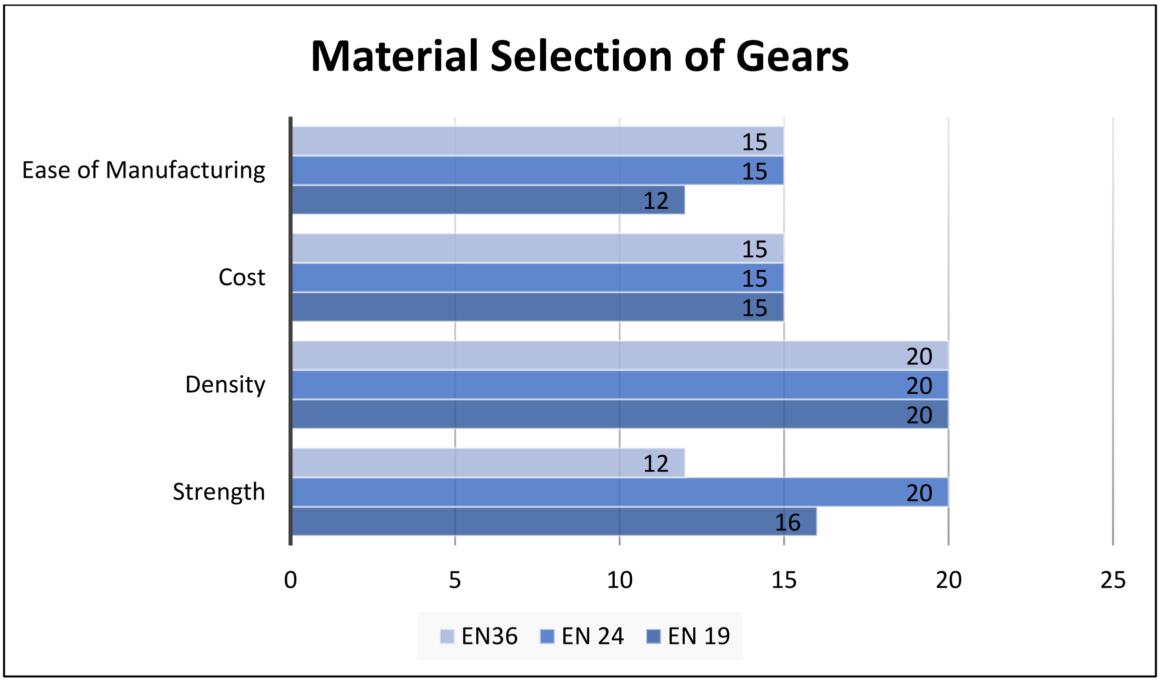
Material Selection:

Material	Density	Ultimate Strength	Tensile Strength
EN24	7840 kg/m^3	1000 N/mm^2	850 N/mm^2

Reason –

GEARS	EN 19			EN 24			EN 36		
Parameters	W	S	W x S	W	S	W x S	W	S	W x S
Strength	4	4	16	4	5	20	4	3	12
Density	5	4	20	5	4	20	5	4	20
Cost	5	3	15	5	3	15	5	3	15
Ease of Manufacturing	3	4	12	3	5	15	3	5	15
Total Score	63			70			62		

W = Weightage; S = Score



Design Process:

Pressure angle selection -

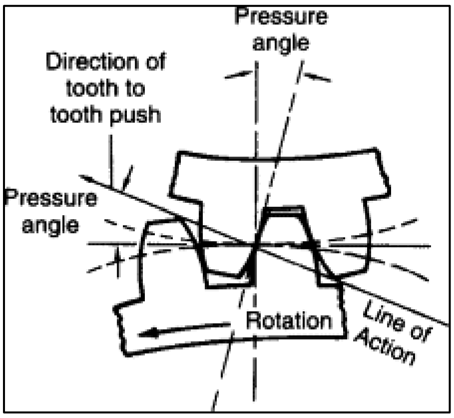


Fig 5.1 Pressure Angle

20 degrees	14 degrees 30 minutes	25 degrees
Noise level not too high while in operation	Noise level is low	Noise level too high
Enough strength for most gear applications	Low strength of gear	High strength of gear
Medium power transmission	Low power transmission	High power transmission
Availability is more	Availability is less	Availability is less

From the above table considering our requirements we opt for **20 degrees.**

Terms Used -

TERMS	**SYMBOLS**	**TERMS**	**SYMBOLS**
tangential force	Pt	tooth thickness	**t**
module	**m**	service factor	Cs
RPM of gear	**N**	velocity factor	Cv
PCD	**d**	beam strength	Sb
bending stress	σ	gear thickness	b
velocity	**V**	number of teeth	**n**
Lewis factor	**Y**		

5.1.1 Module calculation of Spur gear

Data:

Gear ratio = 3.9*2.77

Engine rpm = 3600

d=n*m ,n=16

t=π*m/ 2

h=2.125*m

C_s =1

C_v =5.6 / 5.6+$V^{0.5}$

b=13

STEP 1

P_t = (19.6*3.9*1000*2*2.77*3)/(16*m*3) = 16138.682 /m

STEP 2

N = engine rpm/gear ratio = 3600*3 / 2.77*3*3.9 = 333.24

STEP 3

V = π*d*N60000 = 3.14*16**m*333.24 / 60000 = 0.279m

STEP 4

Y = t^2 / 6*h*m = 0.193

STEP 5

S_b = P_t * C_s / C_v = (16138.682/m) * 1 * 5.6 + $(0.279m)^{0.5}$ / 5.6 ……………..**(1)**

STEP 6

S_b = m*b*Y*σ = m*13*0.193*800 …………………….. **(2)**

On solving **(1)** and **(2)** we get module = **3.06**

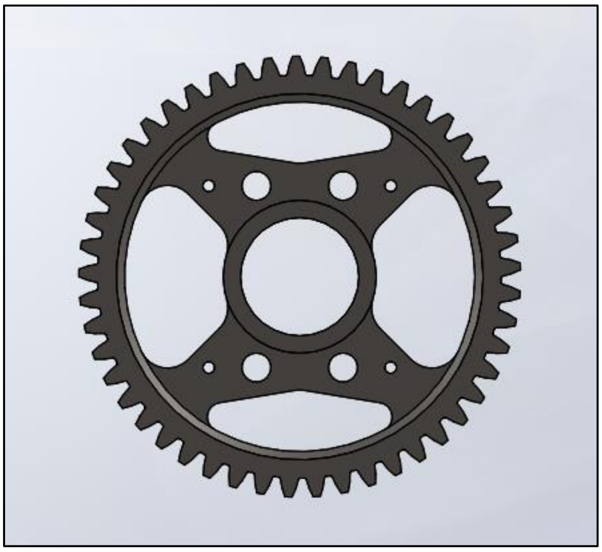


Fig 5.2 Spur Gear Front View

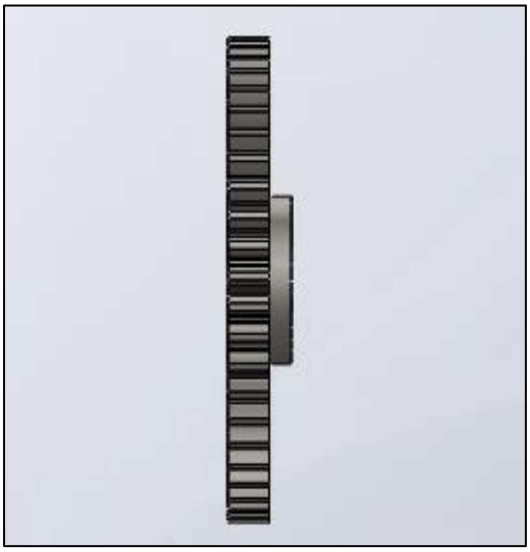


Fig 5.3 Spur Gear Side View

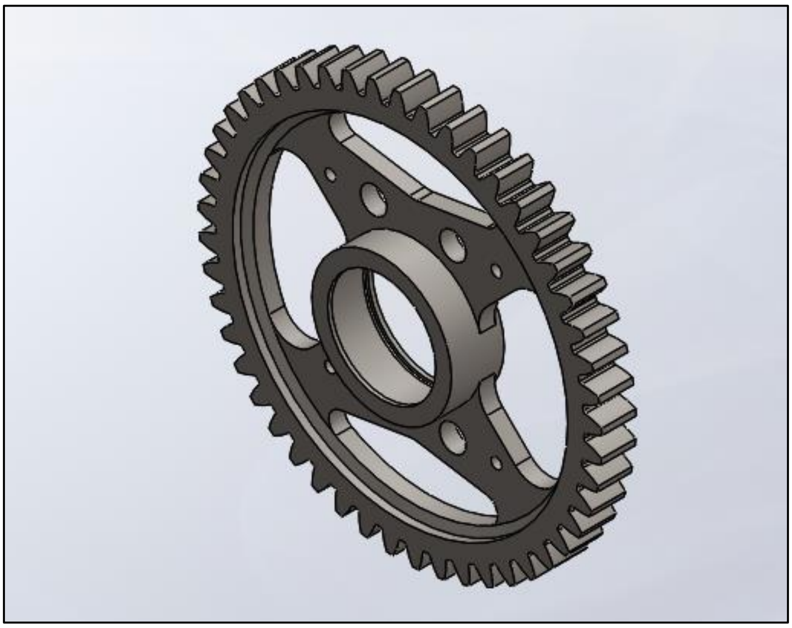


Fig 5.4 Spur Gear Isometric View

5.1.2 Module calculation of Bevel gear

Gear ratio = 3.9*2.77

Engine RPM = 3600

d = n*m, n=16

C_s = 1, C_v = 5.6 / 5.6+ $V^{0.5}$

$b = 13$

$z'_p = z_p / \cos(\gamma_p)$

$z'_g = z_g / \cos(\gamma_g)$

$\gamma_p = 18.26$, $\gamma_g = 71.56$

STEP 1

$C_v = 14.615*10^3 / 0.8375\ m$

STEP 2

N = engine rpm/gear ratio = 3600*3 / 2.77*3*3.9 = 333.24

STEP 3

V = π*d*N/60000 = 3.14*16*m*999.72/ 60000 = 0.8375m

STEP 4

$\gamma_p = 0.484 - 2.87/z'p = 0.484 - 2.87/16.848 = 0.313$

$\gamma_g = 0.484 - 2.87/151.7491 = 0.46508$

STEP 5

$Sb = C_v * C_s / C_v = (17450.74/m) * 1 * 5.6+(0.279m)^{0.5} / 5.6$ ……………..**(1)**

STEP 6

$Sb = m*b*\gamma*\sigma = 333.33*8.4326*m^2*0.46508$ …………………….. **(2)**

On solving **(1)** and **(2)** we get module = **3.06**

5.2 Gear casing

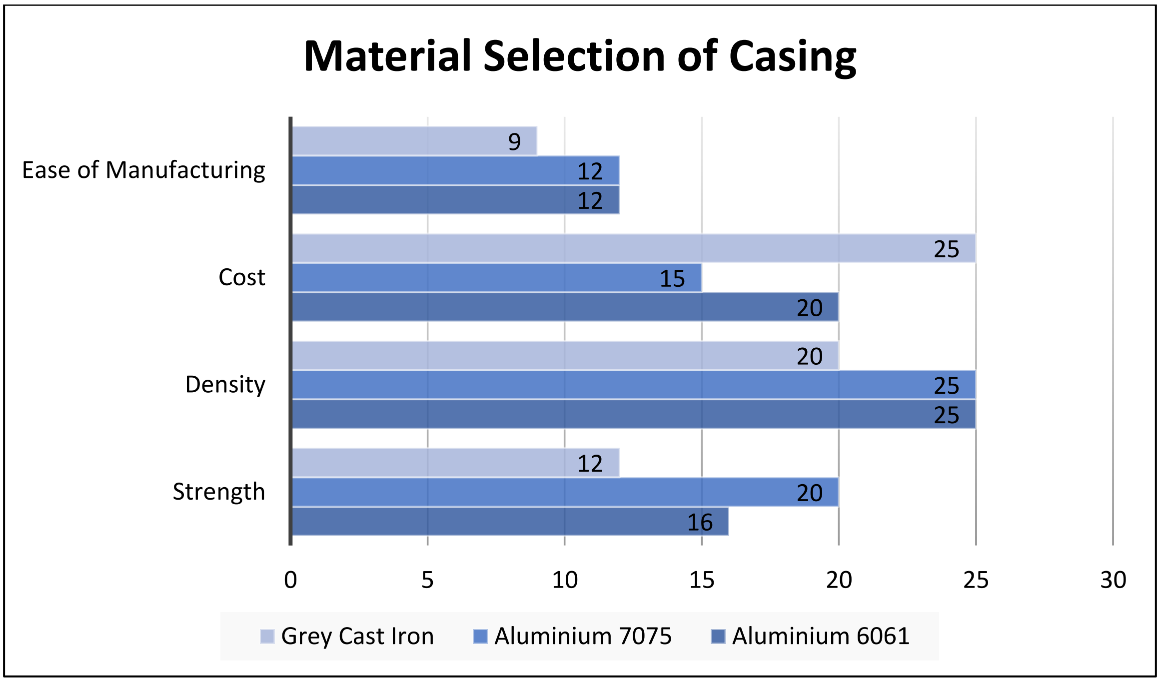
Material Selection:

Material	Density	Ultimate Strength	Yield Strength
Aluminium 6061	2.7 g/cm3	290 N/mm2	241 N/mm2

Reason –

CASING	Aluminium 6061			Aluminium 7075			Grey Cast Iron		
Parameters	W	S	W x S	W	S	W x S	W	S	W x S
Strength	4	4	16	4	5	20	4	3	12
Density	5	5	25	5	5	25	5	4	20
Cost	5	4	20	5	3	15	5	5	25
Ease of Manufacturing	3	4	12	3	4	12	3	3	9
Total Score	73			72			66		

W = Weightage; S = Score



Calculations:

S_{ut} = 290MPa

FOS = 8

$[\sigma_t]$ = 290/8=36.25 n/mm^2

Thickness of casing is decided by using relation of thick cylinder from PSG

$t_c = R_a * [\{\sigma_t] + P_{op} / \sigma_t] - P_{op}\}^{1/2} - 1]$

PCD = n*m =16*3.22 = 51.52 mm

D_a = PCD +2m = 57.96 mm

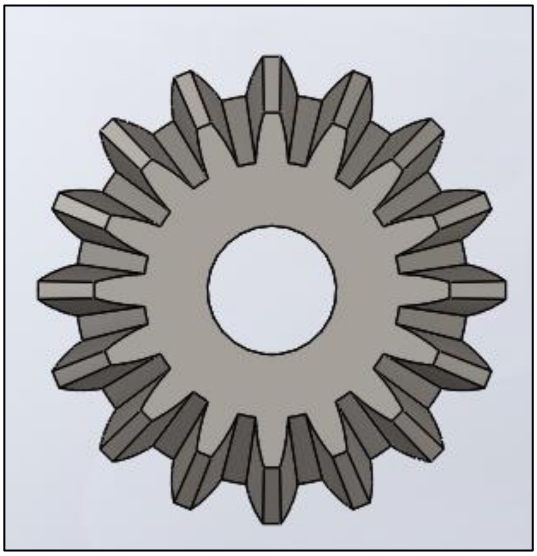


Fig 5.5 Bevel Gear Front View

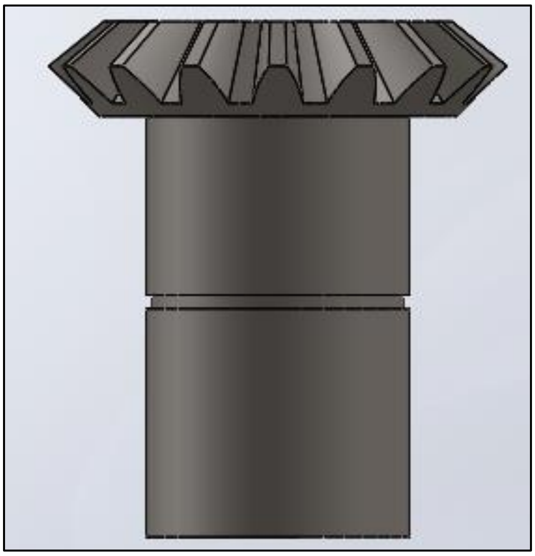


Fig 5.6 Bevel Gear Side view

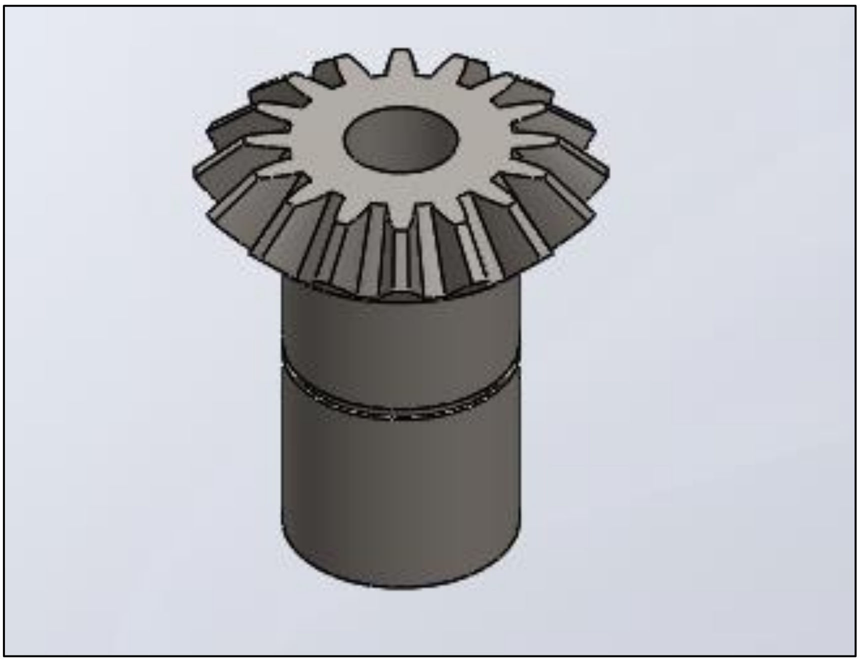


Fig 5.7 Bevel Gear Isometric View

5.3 Front pinion shaft

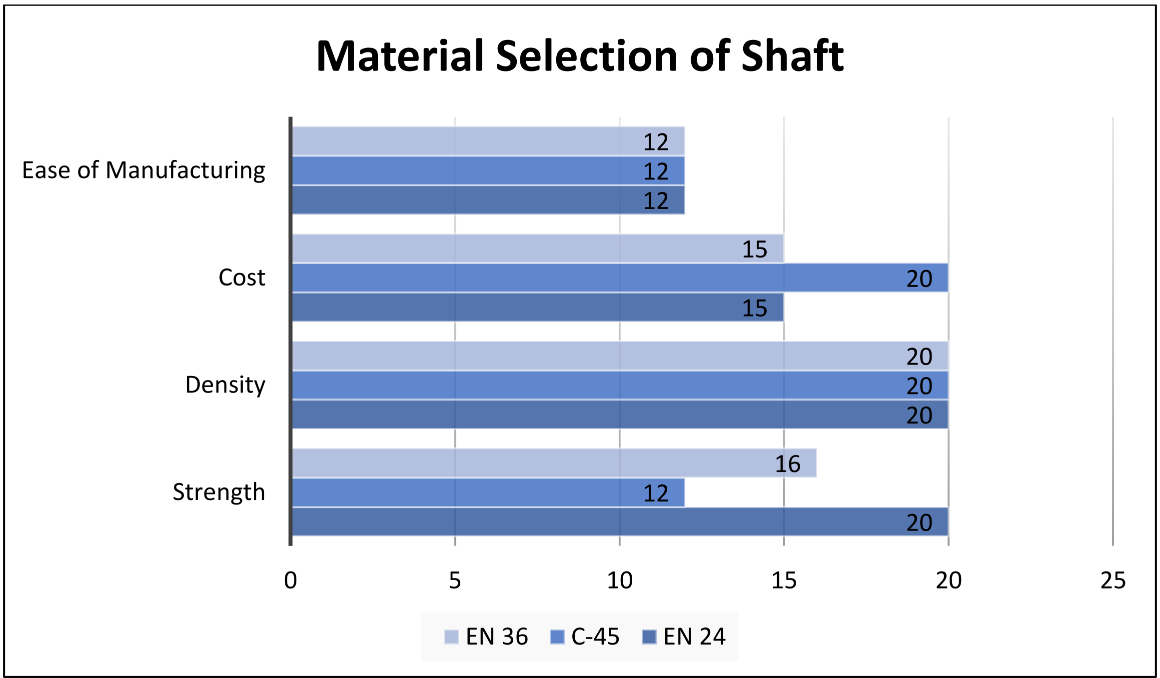
Material Selection:

Material	Density	Ultimate Strength	Tensile Strength
EN24	7840 kg/m^3	1000 N/mm^2	850 N/mm^2

Reason –

SHAFT	EN 24			C-45			EN 36		
Parameters	W	S	W x S	W	S	W x S	W	S	W x S
Strength	4	5	20	4	3	12	4	4	16
Density	5	4	20	5	4	20	5	4	20
Cost	5	3	15	5	4	20	5	3	15
Ease of Manufacturing	3	4	12	3	4	12	3	4	12
Total Score	67			64			63		

W = Weightage; S = Score



N = force due to needle bearing, P = pinion force

A = force due to bearing A, B = force due to bearing B

C = force due to bearing C, D = force due to bearing D

CALCULATIONS

For X plane:	For Y plane:
P_X=-849.72	P_Y=-5706.04

N_X=-4028.5	N_Y=7588.27
$\sum M_B$=0 We get, A_X=4090.35	$\sum M_B$=0 We get, A_Y=-15893.14
And by, $\sum F_y$=0 we get B_X=-61.801 C_X=347.055 D_X=502.67	And by, $\sum F_y$=0 we get, B_Y=8304.87 C_Y=2330.55 D_Y=3375.49
From BMD we can see that the value of bending moment is maximum at point A = M_{BX} = 132794.8	From BMD we can see that the value of bending moment is maximum at point A = M_{BY} = 48708.39

Net maximum bending moment M_r = 141445.98

Thus, considering

T = Torque transmitted = 19.6*3.9*1000*2.77*3/3

FOS = 3.2

M_r = 141445.98

σ = Tensile strength of EN-24

= σ_{max}/FOS = 800/3.2 = 253.17

Considering fatigue,

Tensile strength = 253.17* 0.5, σ = 126.58

Using the equation,

$\sigma = (T + M_r) *16/ (3.14*(D^3))$ where, D=Outer diameter of the shaft= 20.12

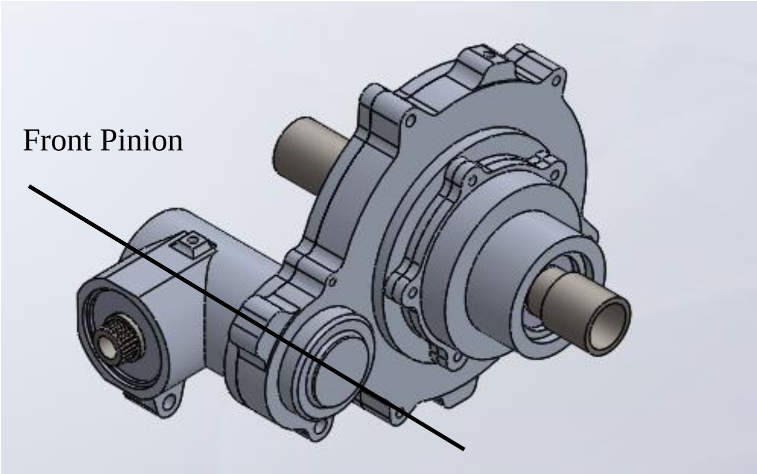


Fig 5.8 Front pinion shaft

5.4 Output shaft from Differential

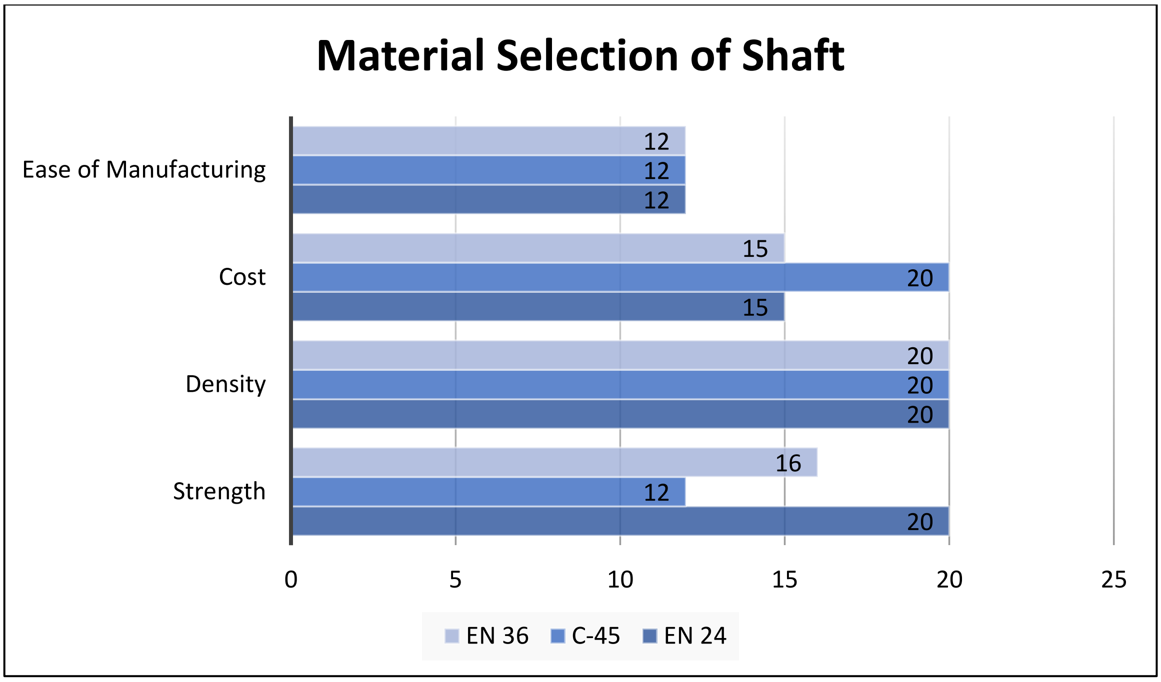
Material Selection:

Material	Density	Ultimate Strength	Tensile Strength
EN24	7840 kg/m^3	1000 N/mm^2	850 N/mm^2

Reason –

SHAFT	EN 24			C-45			EN 36		
Parameters	W	S	W x S	W	S	W x S	W	S	W x S
Strength	4	5	20	4	3	12	4	4	16
Density	5	4	20	5	4	20	5	4	20
Cost	5	3	15	5	4	20	5	3	15
Ease of Manufacturing	3	4	12	3	4	12	3	4	12
Total Score	67			64			63		

W = Weightage; S = Score



G = 1^{st} gear force

A = force due to bearing A

B = force due to bearing B

Calculations

For X plane:	For Y plane:
G_X=849.72	G_Y=5706.04
$\sum M_B$=0 We get, A_X=-615.67	$\sum M_B$=0 We get, A_Y=-4134.3
And by, $\sum F_y$=0 we get B_X=-234.05	And by, $\sum F_y$=0 we get, B_Y=-1571.7
From BMD we can see that the value of bending moment is maximum at point A =	From BMD we can see that the value of bending moment is maximum at point A =

$M_{BX} = 14160$	$M_{BY} = 95089$

Net maximum bending moment, $M_r = 96137.53$

Thus, considering

T = Torque transmitted = 19.6*3.9*1000*2.77*3

FOS = 3.3

$M_r = 96137.53$

σ = Tensile strength of EN-24

$= \sigma_{max}/FOS = 800/3.3 = 241.69$

Considering fatigue, Tensile strength = 241.69* 0.5, σ=120.84

Using the equation,

$\sigma = (T + M_r) *16/(3.14*(D^3))$ where, D = Outer diameter of the shaft

We get,

D = 24.71mm

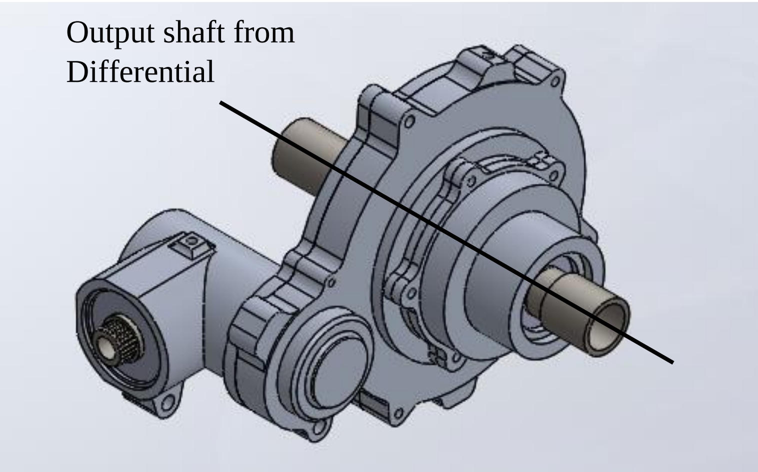


Fig 5.9 Differential output shaft

5.5 Bearing selection

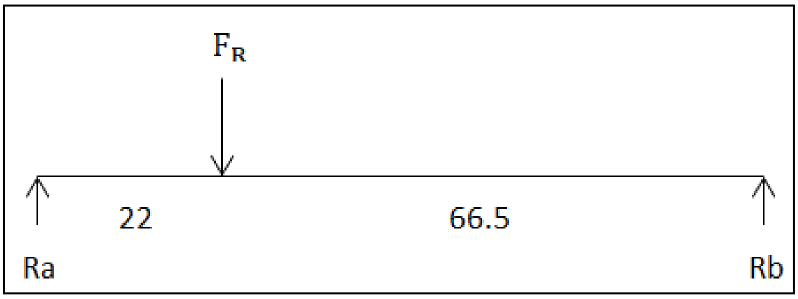
F_t = Tangential Force

F_r = Radial Force

F_R = Resultant Force

R_a = Force due to bearing A

R_b = Force due to bearing B



Fig

$$F_t = \frac{\text{Power} * \text{reduction from CVT} * \text{reduction from gearbox} * 1000}{16 * \frac{m}{2}}$$

$$F_t = \frac{19.6 * 3.9 * 2.7 * 1000}{16 * \frac{m}{2}}$$

F_t = 8600 N

$F_r = F_t * \tan(\Phi)$

F_r = 8600 * tan(20)

F_r = 3130 N

$F_R = \sqrt{8600^2 * 3130^2}$

F_R = 9151.88 N

Resultant force = 9151.88 N

$R_a + R_b$ = 9151.88 N

$R_a = 9151.88 - R_b$

$R_a * 22 = R_b * 66.5$

$(9151.88 - R_b) * 22 = R_b * 66.5$

$R_b = \frac{9151.88 * 22}{88.5}$

R_b = 2275 N

R_a = 9151.88 – 2275 = 6876 N

P = (x * v * F_r + y *F_t) * s *k_t)

P = (1 * 1 * 6876 + 0.73 * 4000) * 1.3 * 1 = 12734 N

$L_{10} = \frac{60 * \text{No. of hours} * \text{N(rpm)}}{10^6}$

$L_{10} = \frac{60 * 8 * 25 * 12 * 2 * 1300}{10^6}$

L_{10} = 374.4 million revolutions

$L_{10} = (\frac{C}{P})^k$

$374.4 = (\frac{C}{12734})^{10/3}$

C = 91779 N = 9177.9 kgf

Selecting Taper Roller Bearing No. 32212A with dynamic load carrying capacity (C) = 10700kgf = 104931.15 N

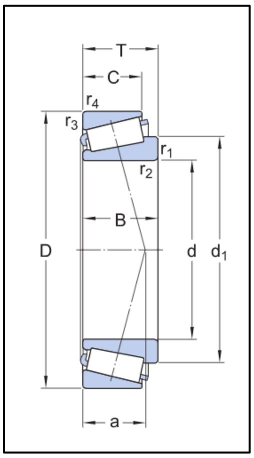


Fig 5.10 Bearing

5.6 Casing design

Material	Density	Ultimate Strength	Yield Strength
Aluminium 6061	2.7 g/cm^3	290 N/mm^2	241 N/mm^2

S_{ut}= 290MPa

FOS =8

[σ_t] =290/8=36.25 n/mm^2

Thickness of casing is decided by using relation of thick cylinder from PSG

$t_c = R_a * [\{\sigma_t + P_{op} / \sigma_t - P_{op}\}^{½} - 1]$………………………. **(1)**

PCD = n*m =16*3.22 = 51.52 mm

D_a = PCD + 2m = 57.96 mm

Assuming Pop = 15 MPa from research paper regarding differential pressure acting on all-terrain vehicle.

Substitute $D_a/2 = R_a$ and P_{op} = 15 MPa in **(1)**

we get t_c = 16.025 mm

Designing and calculating no. of bolts required for casing

$R_a = D_a /2$

$R_p = R_a + t_c/2$

R_a = 28.98 mm; Rp = 36.99mm

Let N_b be no. of bolts, selecting M10 bolts

Max tensile load $F_{max} = F_i + K_b + / K_b + K_c * F_e$

F_i = initial tensile load, F_e = external load acting on it due to operating press

K_b and K_c = stiffness of bolt and the connecting parts respectively

Assuming $K_c = 3K_b$

Fi = $K_c / K_c + K_b * F_{test}$

$F_{test} = P_{test}$ * Gasket area / N_b= $P_{test} = 1.5 * P_{op}$

Gasket area = [2*pi*R_p*t_c] + [t_c*a]   , where a = PCD from PSG book

= 1.5 *15*[({2*pi*36.9925*16.025} + {16.025+51.52})/ N_b] = 85319.493/N_b

F_e = [P_{op} * resisting area of bolt]/ N_b

Resisting area of bolt = (pi * R_a^2) + (a * 2 *R_a)

Substituting all the values we get Fe =84368.034/N_b

F_{max} = 85319.493/N_b + ¼ + 84368.034/N_b ………………………………. **(2)**

Selecting bolt of grade 12.9 and

S_{yt} =1500 N/ mm^2

FOS = 4

σ_t = 1500/4= 375N/mm^2

For M10 bolts dc core diameter = 0.84 * 8 = 6.72mm

Core area of bolt A_c = pi /4 * d_c^2 = pi/4 * 6.72^2 = 35.467mm^2

Fmax = A_c * σ_t= 13300.246 N

Substitute this F_{max} in **(2)**

No. of bolts = N_b = 6 and pitch = [2*pi*R_a + 2*a]/ N_b = 11 mm

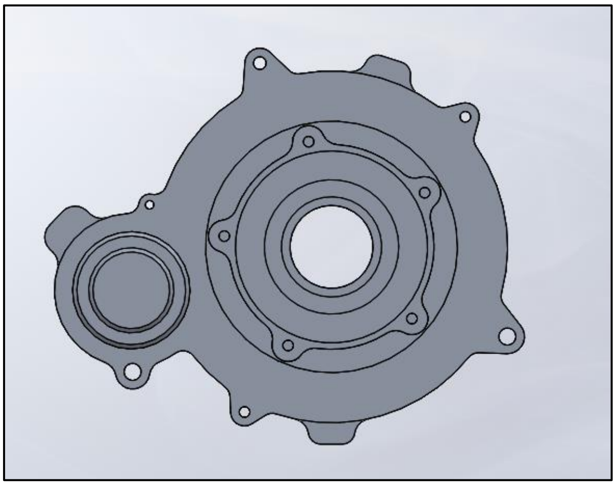


Fig 5.11 Casing Front View

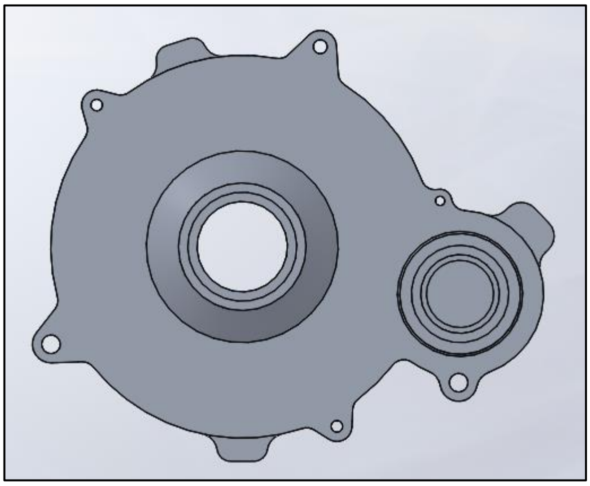


Fig 5.12 Casing Back View

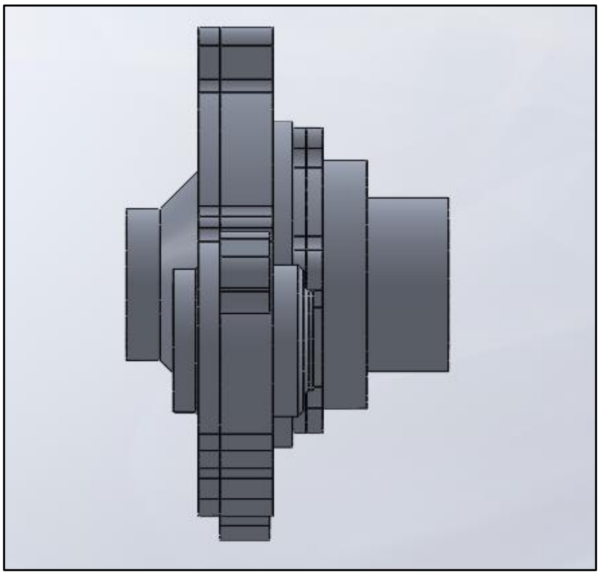


Fig 5.13 Casing Side View

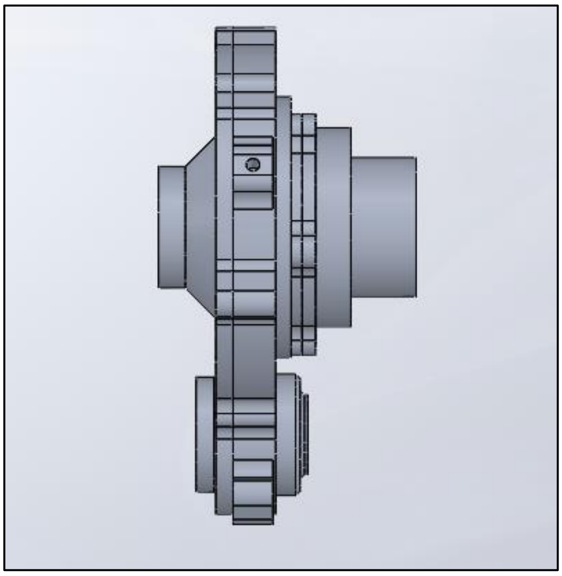


Fig 5.14 Casing Top View

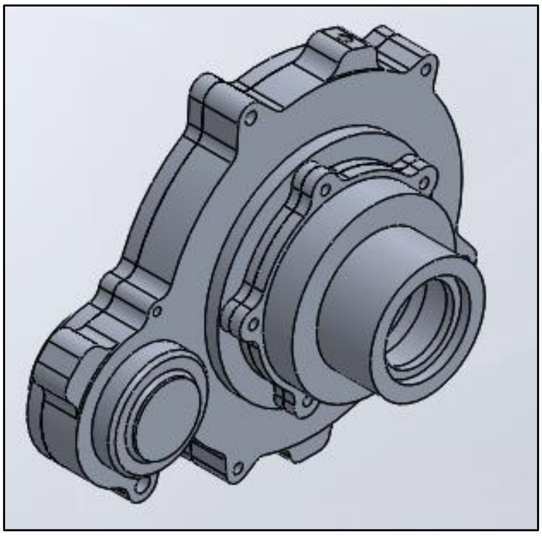


Fig 5.15 Casing Isometric View

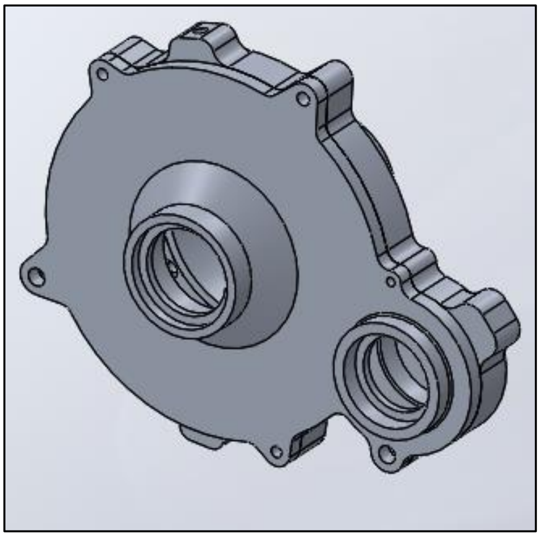


Fig 5.16 Casing Isometric View 3rd Angle

5.7 3D Modelling

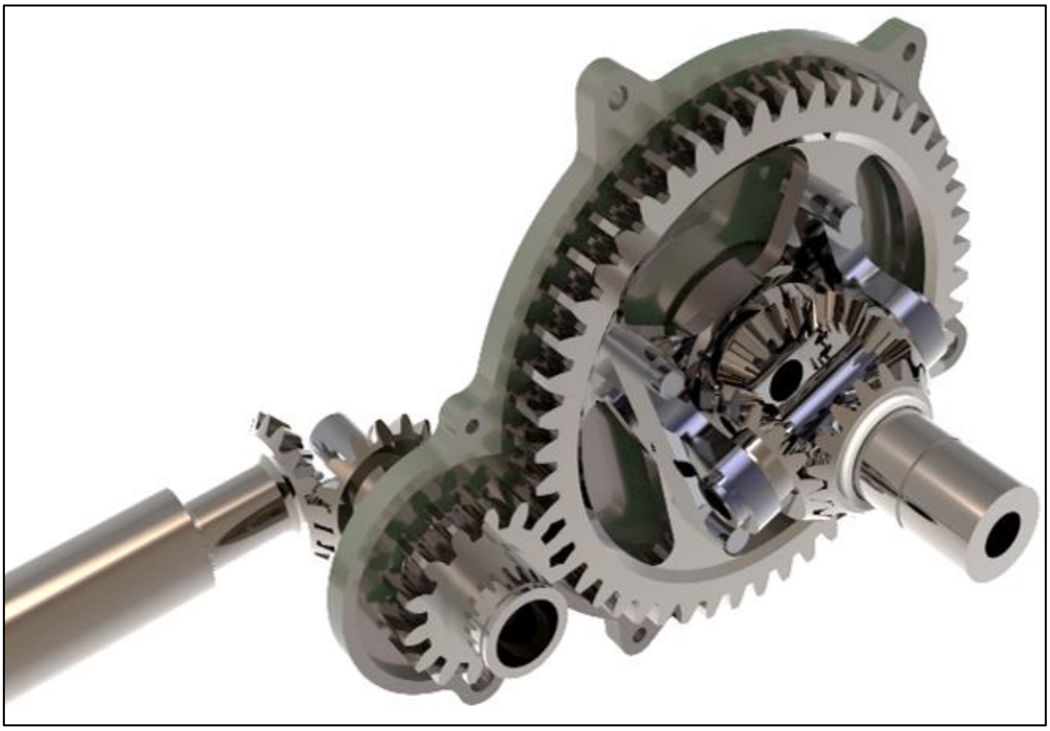


Fig 5.17 Single Stage Open Differential Assembly

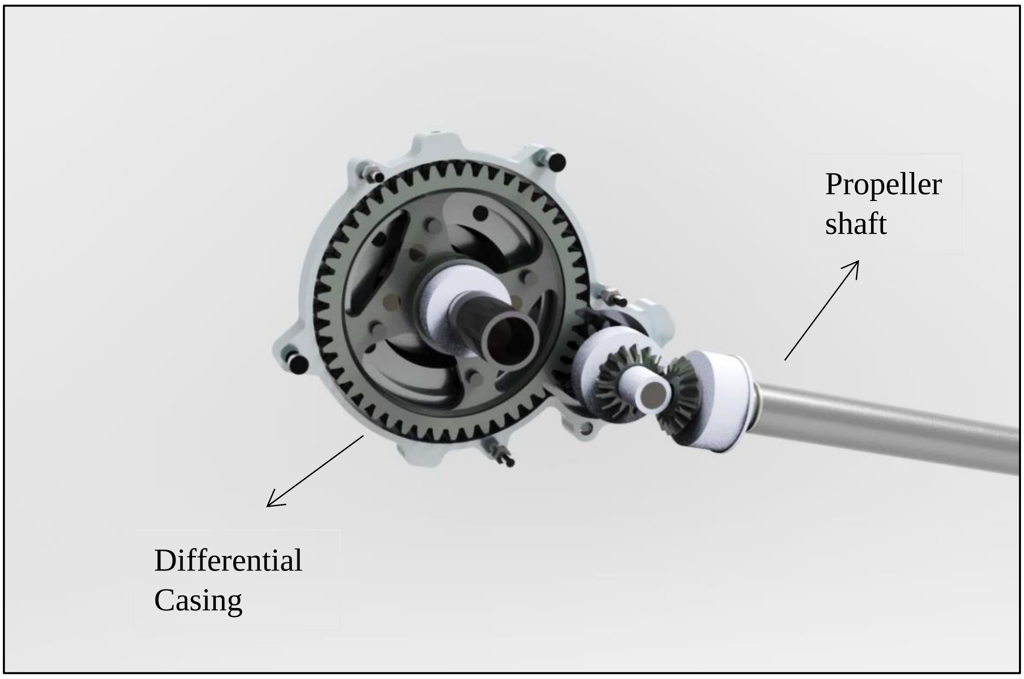


Fig 5.18 Differential Casing

Chapter 6

ANALYSIS

The CAD model of the individual parts is created on SolidWorks software. For ANSYS Workbench to be able to read the CAD model, the SolidWork part file is converted into para solid/igs format. The file is then imported in ANSYS Workbench and material specifications are provided. The geometry is edited in dg modular where the solids are suppressed and the surface bodies are unsuppressed. Since we are creating a 2-dimensional mesh, the thickness of various parts is given as a manual input. The meshing method is selected with an appropriate mesh size and the mesh is generated. Shell element method is used because it has higher accuracy as it incorporates bends in solving problems. Meshing size of 2mm was used. Once the mesh has been generated, we now start performing the various analyses. For each analysis the required forces and constraint points are provided and are ready for solving. Pictorial representation of the analyses performed on various components has been shown below.

Pressure due to the oil was given on the inner most surface and fixed support was provided on the mounting bolts.

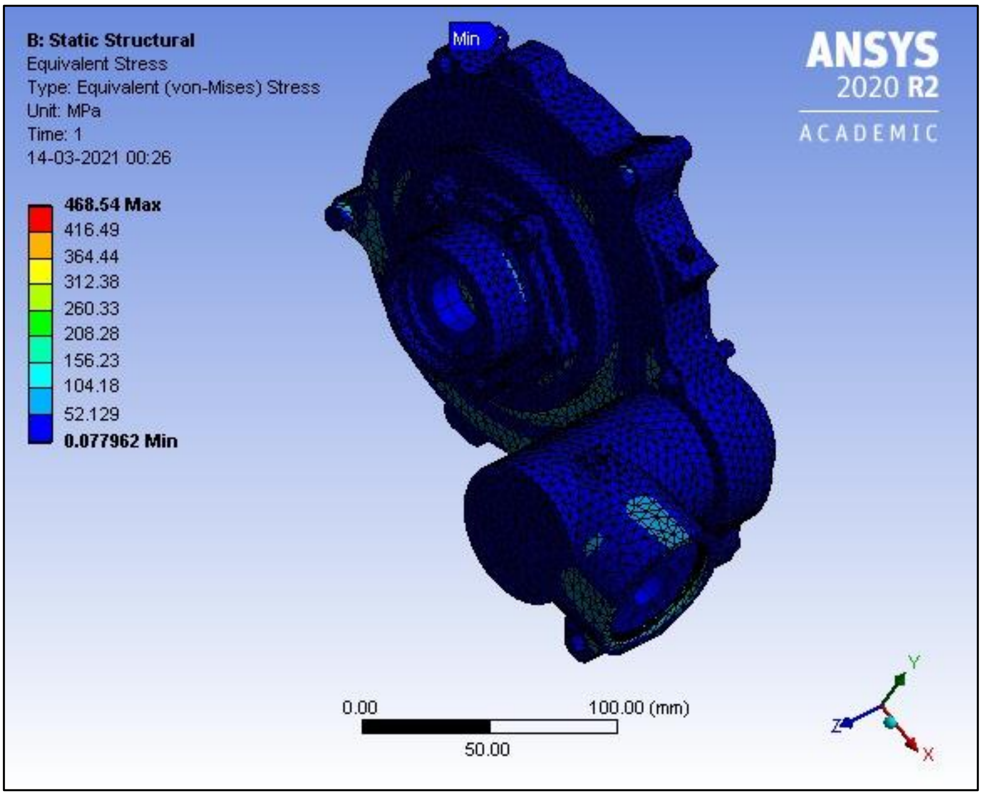


Fig 6.1 Static Structural Analysis of Differential Casing

Analysis was done using ANSYS software wherein we considered that the output shaft is stationary and the force is being transmitted via a single tooth. Hence force was applied on the gear tooth and bearing support was considered,

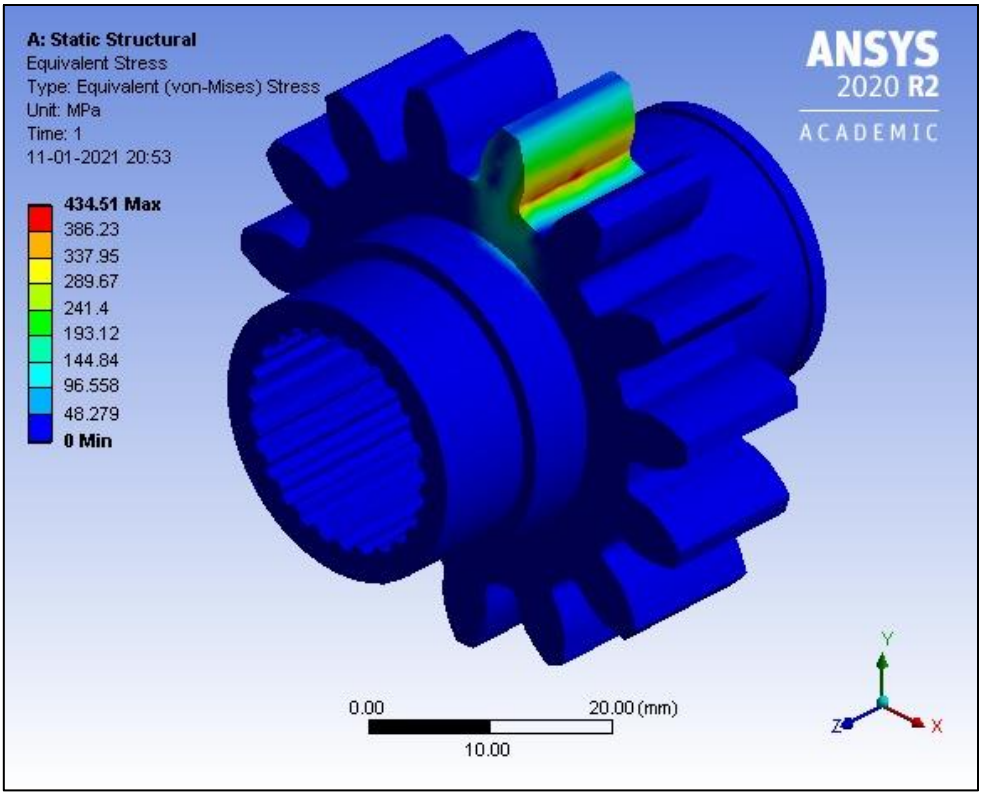


Fig 6.2 Static Structural Analysis of Spur Gear

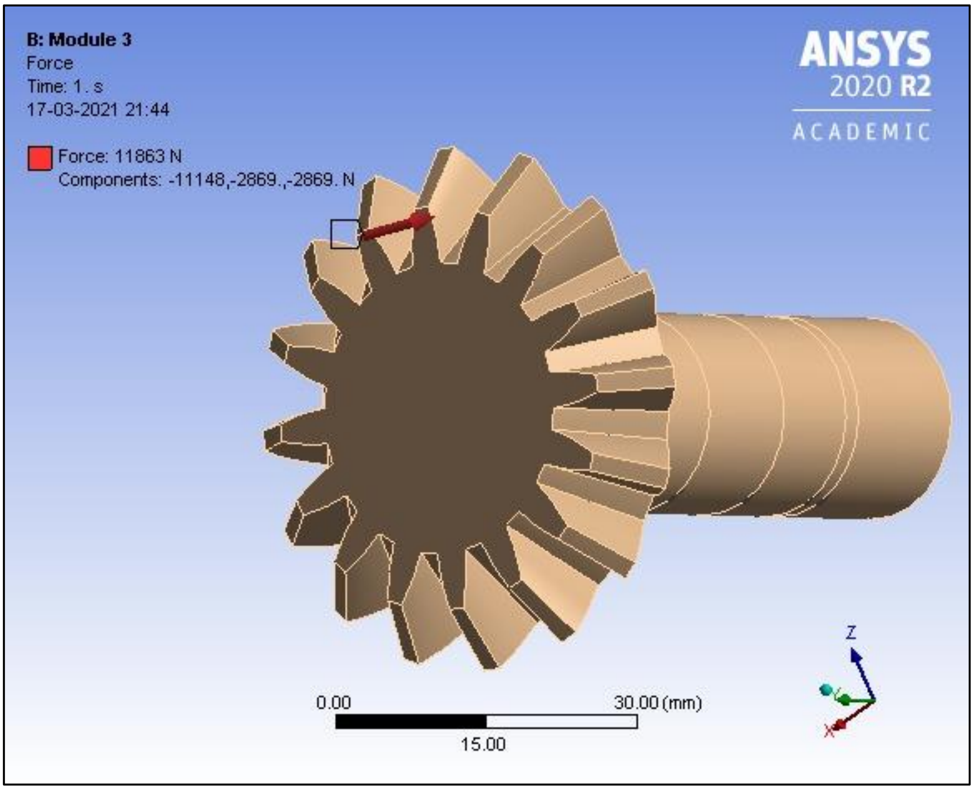


Fig 6.3 Force Analysis of Bevel Gear

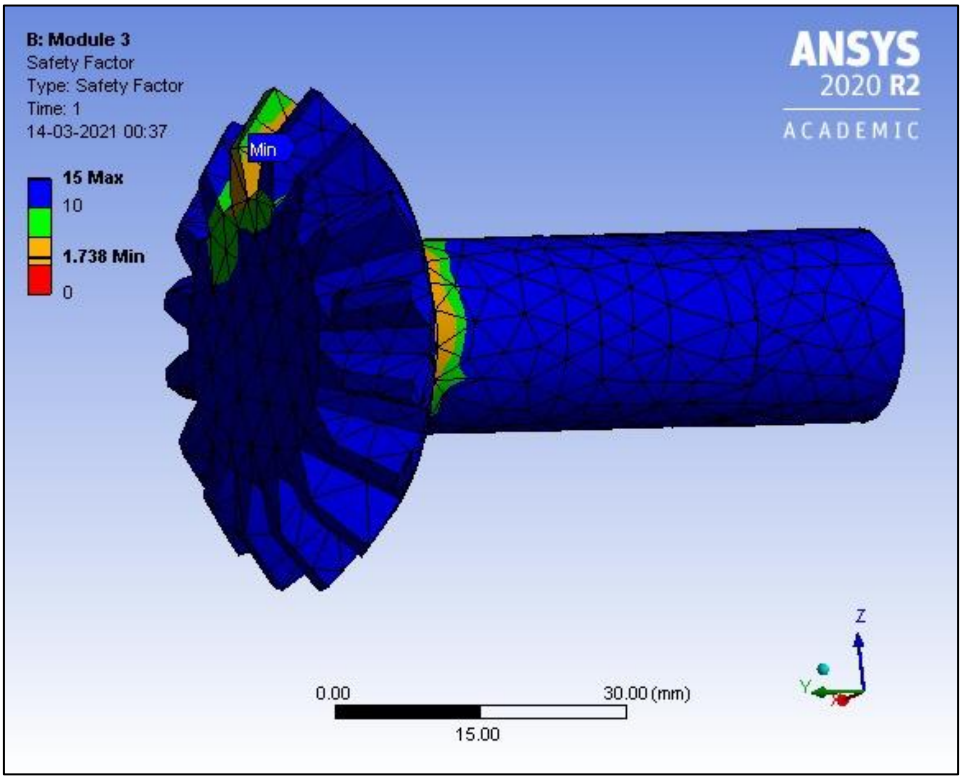


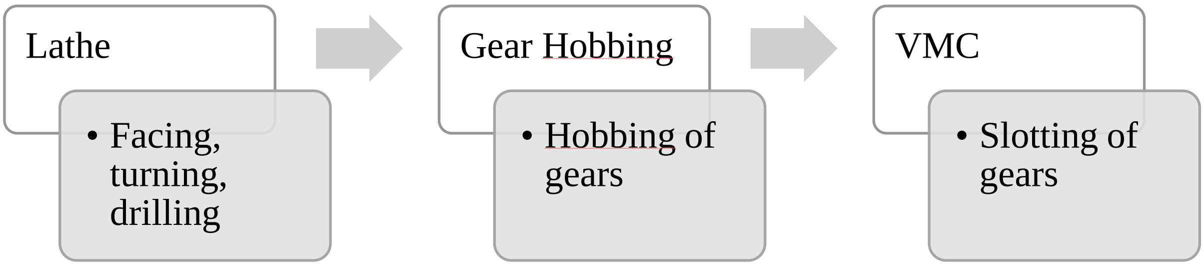
Fig 6.4 Static Structural Analysis of Bevel Gear

Chapter 7

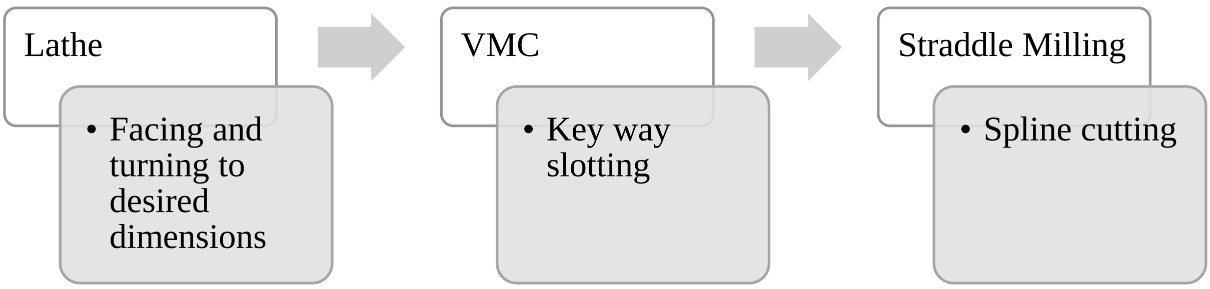
MANUFACTURING

The entire differential system consisting of the gears along with the outer casing has been manufactured. Based on the tolerances required and the material used, appropriate manufacturing processes for each component in the most appropriate sequence had been selected.

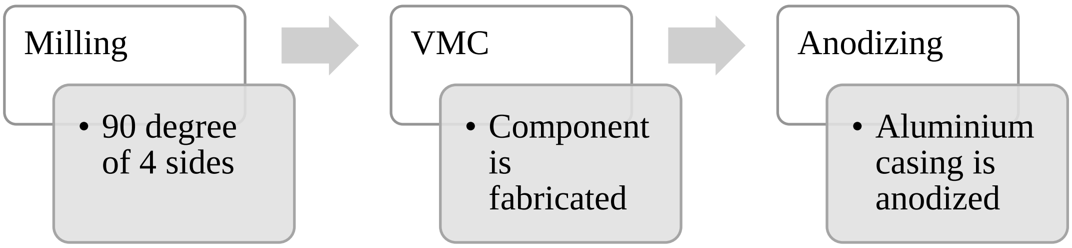
Manufacturing flowchart for gears:



Manufacturing flowchart for shafts:



Manufacturing flowchart for casing:



Manufactured Casing:

Fig 7.1 Differential Casing Assembly

Fig 7.2 Left and Right Casing

Manufactured Gears:

Fig 7.3 Gear Assembly

Fig 7.4 Bevel Gear Assembly

Fig 7.5 Differential Gear Assembly

Chapter 8
CONCLUSION

Putting our engineering knowledge to use, we managed to design, analyse and manufacture a single stage open differential. Designing the differential imparted immense machining and designing knowledge to us and also prepared us to face any design or engineering related problems we might face. The following conclusions can be drawn from the same:

- The single stage open differential was manufactured at a relatively low cost.
- The three piece casing design was beneficial for accessibility.
- The differential also served its purpose of independently turning each wheel, preventing any wheel hop and tire wear.
- The stresses computed from analytical equations are found out to be within permissible limits and agree well with the results obtained from FEA.

Chapter 9
FUTURE PLAN

We have designed, analysed and fabricated this single stage open differential to be used in a single seater off road all terrain vehicle. The use of spur gear to reduce the overall cost and make machining easier proved to be beneficial to achieve our end goal. Keeping that in mind, we have planned the following for our future goals:

1. Implementing and testing the assembly by integrating it with an engine.
2. Measuring the rpm and we get on all the shafts.
3. Implement this design for a small all terrain electric vehicle powered by a bldc motor.
4. Changing gear thickness and trying to make the new design lighter.

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