A Project Report on

Studying Different Types of Differential & Designing an Open Differential

By

Ms. Meghna M. Navghade
[TMB 210] [T19045____]

Mr. Piyush V. Rote
[TMB 221] [T190450984]

Mr. Anukool Shidhore
[TMB 229] [T19045____]

Mr. Abhishek Patil
[TMB 251] [T19045____]

Guide

Prof. P. S. Khade

Department of Mechanical Engineering
Marathwada Mitra Mandal’s College of Engineering, Karvenagar, Pune

[2020-21]

Marathwada Mitra Mandal's
College of Engineering,
Karvenagar, Pune

'येथे बहुतांचे हित ।'

C E R T I F I C A T E

This is to clarify that ***Mr. Piyush Vijaykumar Rote*** with Exam Seat No. ***T190450984*** has successfully completed the Project entitled "***Studying Different Types of Differential & Designing an Open Differential***" under my supervision, in the partial fulfillment of Third Year of Engineering.

- Mechanical Engineering of University of Pune.

Date:

Place: MMCOE, Pune.

Prof. P. S. Khade
Guide

Internal Examiner

Dr. V. R. Deulgaonkar
HOD Department

Dr. N. Gohokar
Principal

ACKNOWLEDGEMENT

We take this opportunity here to thank all those who had helped us in making this project a reality.

First of all, we express our deep gratitude to our project guide Prof. P. S. Khade for his valuable support, help & guidance from time to time during the project work. We are also grateful to our Head of Department, for giving us this opportunity to present this project report.

Last but not the least; we would like to thank our entire teaching and non-teaching staff who assisted us directly or indirectly throughout the duration of this project.

Name of Students

Ms. Meghna M. Navaghade
(T19045____)

Mr. Piyush V. Rote
(T190450984)

Mr. Anukool Shidhore
(T19045____)

Mr. Abhishek Patil
(T19045____)

CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

ABSTRACT

A differential is a device usually, but not necessarily, employing gears, which is connected to the outside world by three shafts, chains or similar, through which it transmits torque and rotation. Except in some special purpose differentials, there are no other limitations on the rotational speeds of the shafts, apart from the usual mechanical/engineering limits. Any of the shafts can be used to input rotation and the other to output it. A simple differential in which gears are equal.

In automobile and other wheeled vehicles, a differential is usual way to allow the driving road wheels to rotate at different speeds. This is necessary when the vehicle turns, making the wheel that is travelling around the outside of the turning curve roll farther and faster than the other. The engine is connected to the shafts rotating at angular velocity. The driving wheels are connected to the other two shafts. If the engine is running at a constant speed, the rotational speed of each driving wheel can vary, but the sum or average of two wheels speeds cannot change. An increase in the speed of one wheel must be balanced by an equal decrease in the speed of the other. If one wheel is rotating backward, which is possible in every tight turn, its speed should be counted as negative.

In a differential transmission including a differential transmission casing with planetary bevel gears supported there in so as to be rotatable about an axis normal to a center axis of the transmission casing, and two center gears arranged at opposite sides of and in meshing engagement with planetary bevel gears the differential transmission casing has at least at one end there of a cylindrical casing extension having an opening which is concentric with the center axis and into which an insert is fitted which has an outer end projecting from the casing extensions and forming an annular bearing section for rotatable supporting the differential transmission casing in an outer transmission housing.

1. INTRODUCTION

The drive axle assembly of a RWD vehicle is mounted at the rear of the car most of these assemblies use a single housing to mount the differential gears and axles. The entire housing is part of the suspension and helps to locate the rear wheels.

Another type of rear drive ale is used with IRS. With IRS the differential is bolted to the chassis and does not move with the suspension. The axles are connected to the differential and drive wheel CV or U-joints, Because the axles move with the suspension and the differential is bolted to the chassis, a common housing for these parts is impossible.

On most RWD cars, the final drive is located in the rear axle housing. On most FWD cars, the final drive is located within the transaxle. Some current FWD cars mount the engine and transaxle longitudinally. Theses configurations use a differential that is similar to the other FWD models. Some FWD cars have a longitudinally mounted engine fitted to a special transmission with a separate differential mounted to it.

A differential is needed between any two drive wheels, whether in a RWD, FWD or 4WD vehicle. The two drive wheels must turn at different speeds when the vehicle is in a turn.

RWD final drives normally use a hypoid ring and pinion gear set that turns the power flow 90 degrees from the drive shaft to the drive axles. A hypoid gear set allows the drive shaft to be positioned low in the vehicle because the final drive pinion gear centerline is below the ring gear centerline. On FWD cars with transversely mounted engines, the power flow axis is naturally parallel to that of the drive axles, Because of this, a simple set of helical gears in the transaxle serve as the final drive gears.

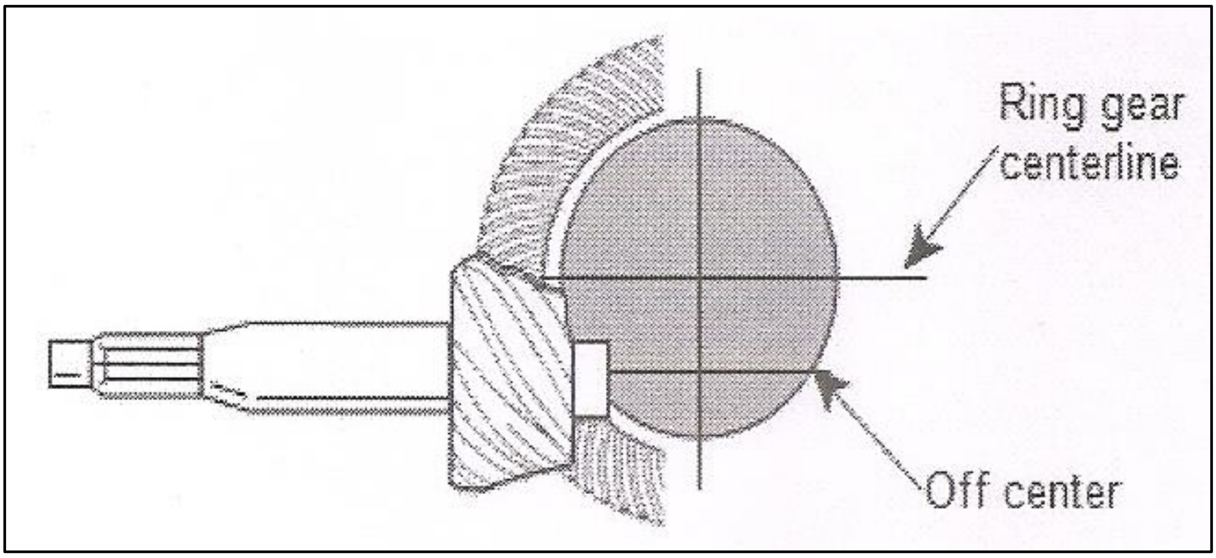

Figure 1. A Hypoid Differential Gearbox

The differential is a geared mechanism located between the two driving axles. It rotates the driving axles at different speeds when the vehicle is turning a corner. It also allows both axles to turn at the same speed when the vehicle is moving straight. The drive axle assembly directs drive-line torque to the vehicle’s drive wheels. The gear ratio of the differential’s ring and pinion gear is used to increase torque, which improves drivability. The differential serves to establish a state of balance between the forces or torques between the drive wheels and allows the drive wheels to turn at different speeds when the vehicle changes direction.

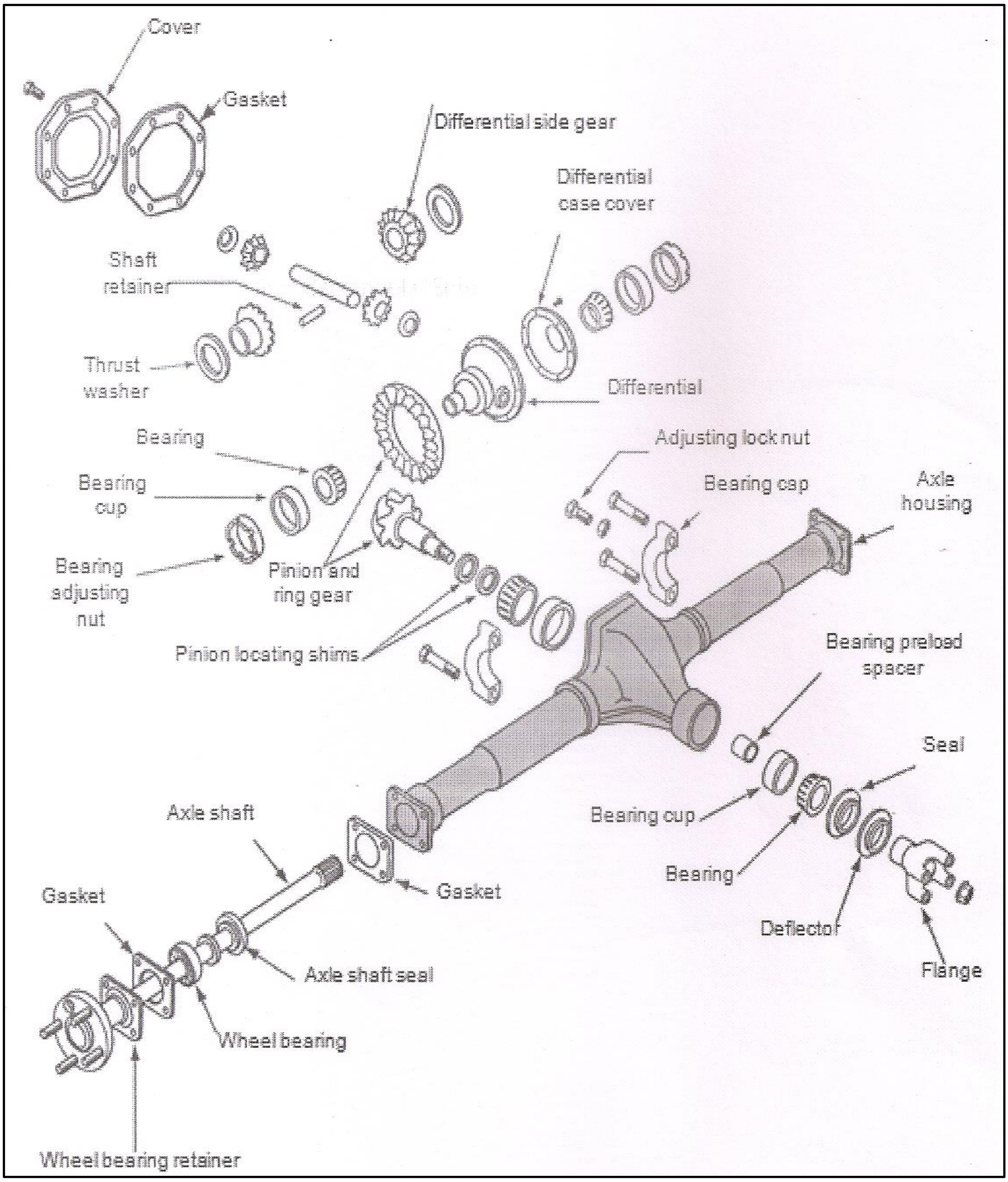

Figure 2. Parts of the Differential

1.1 AIM OF THE PROJECT

The main aim of the project is to focus on the mechanical design and contact analysis on assembly of gears in gear box when they transmit power. To perform design calculations and design a compact and small straight bevel differential. Differential gear is modeled in CATIA V5R21. Analysis is done on the differential by applying tangential and static loads is performed in Ansys Workbench 19.2

2. LITERATURE REVIEW

2.1 TYPES OF DIFFERENTIALS

Following are the types of differentials:

1. Open differential
2. Limited-slip differential
3. Mechanical limited-slip differential
4. Viscous limited-slip differential
5. Active differential
6. Locking differential
7. Torque-vectoring differential
8. Torsen differential
9. Welded differential

- **Open Differential**

The problem occurs when road conditions are not good such as on wet, snow, ice, or sand. Using an open differential in your car, engine torque is transferred even though the wheel has zero traction so that the sliding tire can spin freely.

Open differentials are found in many cars on the road today, so the cost of repairing the differential is less than other types.

Figure 3. Open Differential

Table 1. Advantages & Disadvantages of Open Differential

Advantages of Open Differential	Disadvantages of Open Differential
This allows for different wheel speeds on the same axle, which means there will be no wheel slip when going around a corner, as the outer tire will travel further.	When traction is reduced in one wheel, it substantially limits the amount of power produced by the vehicle. If one wheel cannot dissipate as much power, the other will receive an equally small amount of torque.
From an efficiency point of view, there will be less energy loss through differential than other types.	

- **Limited-slip Differential**

A limited-slip differential works similarly to an open differential. They transfer torque to each wheel independently under good road conditions.

An open differential can cause the tire to slip under hard cornering or heavy acceleration. But a limited-slip differential prevents the amount of torque from passing into the sliding tire (the one with the least resistance).

This is done by the use of clutches and plates within the differential. This allows the vehicle to power through corners whereas a vehicle with an open differential cannot. Race cars, off-road vehicles, and other performance vehicles use a limited-slip differential.

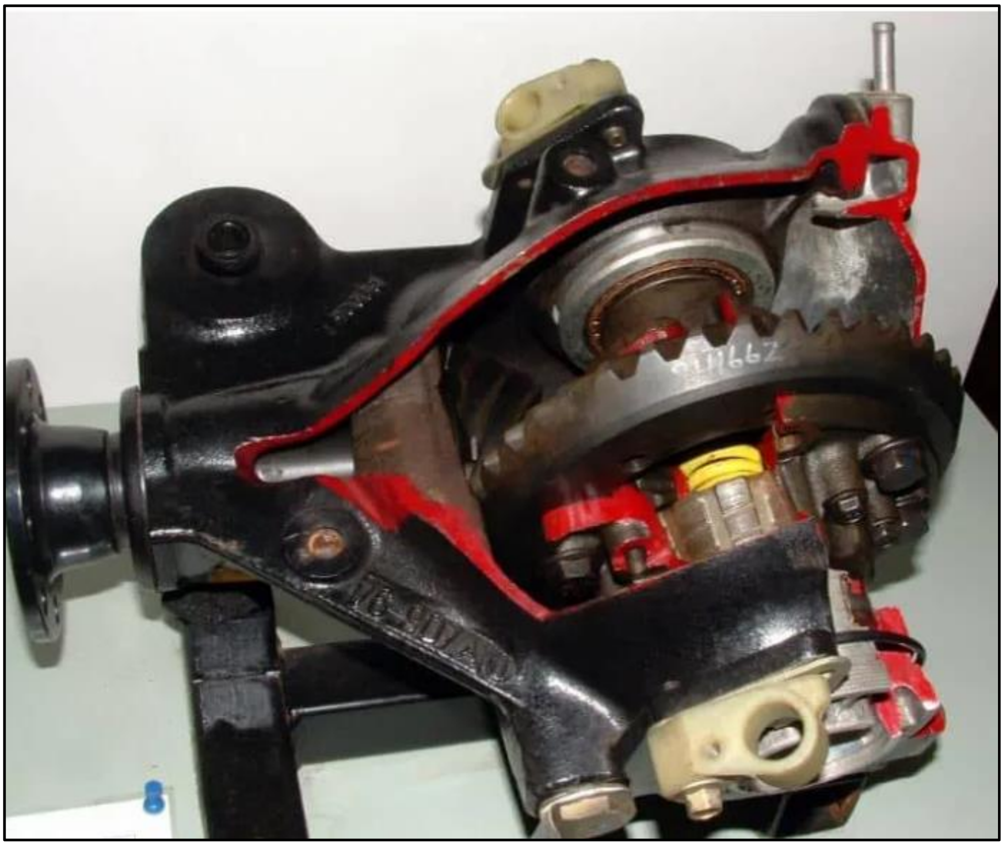

Figure 4. LSD

Table 2. Advantages & Disadvantages of LSD

Advantages of Limited-slip Differential	Disadvantages of LSD
This allows for different wheel speeds on one axle, thus reducing tire wear compared to a locked differential.	It cannot lock completely because the system requires a speed difference between the two sides to transfer torque.
It also allows the wheel to send torque with more traction.	When it is being used too often, the effect of LSD will be reduced.
It offers a very smooth operation, doesn't have the low-speed chunkiness typically associated with other LSD types that navigate a tight area.	

- **Viscous Limited-slip Differential**

When a wheel spins the viscous fluid heats up and gives additional resistance. The effect of this slows the spinning wheel and diverts the torque to the wheel with grip. VLSDs are able to produce torque more effectively to the wheel that has more traction.

- **Mechanical Limited-slip Differential**

The mechanical limited-slip differential provides resistance to the free rotation of the wheels, changing the impact of the differential from open to locked and delivering it with increased traction. This type can work with one-way, 1.5-way, two-way, and even electronic.

- **Active Differential**

The active differential uses a certain mechanism to provide the required resistance for transferring the torque from one side to another. These are activated electronically instead of depending on mechanical force.

It is capable of using electronics to change the mechanical forces of the system by changing driving conditions, thus making them programmable and further controllable. Using a series of sensors throughout the vehicle, a computer can automatically detect which drive wheels require power and when.

It offers greater agility, better handling with exceptional traction. It balances for the varying rotational speed of the rear wheels, especially on curves.

- **Locking Differential**

These types of differentials use a clutch and springs to actuate the lock which sends the same amount of power to each wheel, no matter the traction condition. It essentially forms a solid axle.

At higher speeds this is a drawback but when off-roading or rock climbing, it is a huge advantage. They are found on many off-road vehicles and some performance cars.

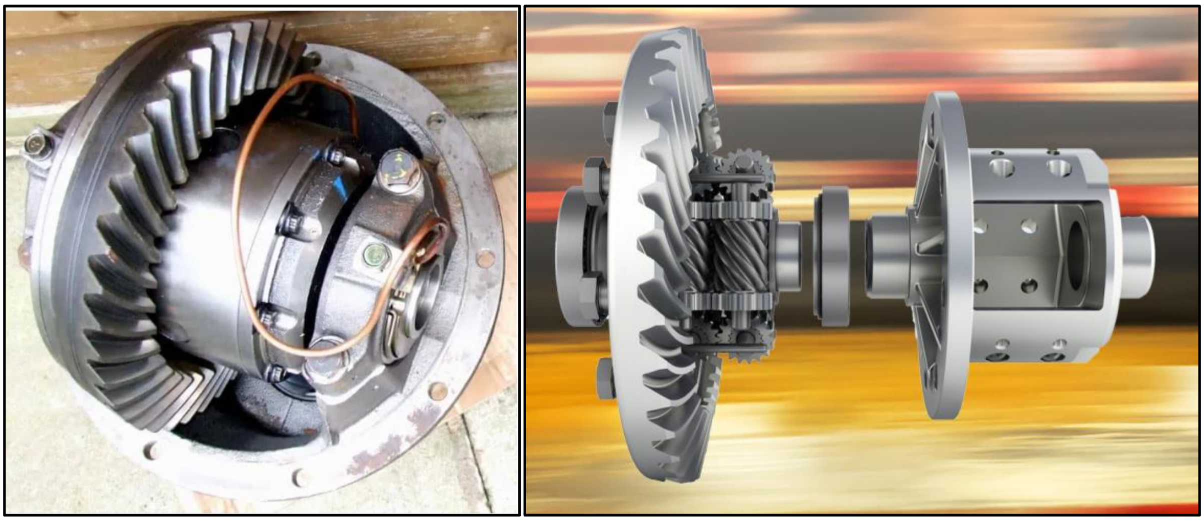

Figure 5. Locking Differential

Table 3. Advantages & Disadvantages of Locking Differential

Advantages of Locking Differential	Disadvantages of Locking Differential
This can provide torque to move up to the wheel with more traction. In various designs, this will allow most of the torque to reach the ground at any given surface condition.	One drawback of the locking differential is that it would not allow for a difference in wheel speed between the right and left wheels. That means additional tire wear, as well as tying up within the drivetrain as a result.
It is robust, simple, and very effective.	
It provides a solution for drifting situations where it is desirable to keep the wheel speed constant on the axle.	

- ## Torque-vectoring Differential

This type of differential uses a set of sensors and electronics to receive data from various matters (road surface, throttle position, steering system, etc.) to activate an electronically actuated clutch and a controller.

They operate in the most efficient manner resulting in a truly dynamic, high-performance driving experience. A torque-vectoring difference is found in high-performance rear-wheel drive and all-wheel drive vehicles.

Table 4. Advantages & Disadvantages of Torque-vectoring Differential

Advantages of Torque-vectoring Differential	Disadvantages of Torque-vectoring Differential
This allows the outer wheel to send more torque as it gets closer to the turn.	Though it does not have any drawbacks, it hits two things which are cost and complexity.
It enables complete control by the designer, the system can choose under what conditions the vehicle will send more torque to any one wheel rather than being reactive.	
It can send up to 100% of the potential torque to a heel.	

- ## Torsen Differential

The Torsen means torque-sensing. These are types of limited-slip differential that use some accelerated gearing to produce an impact without using a clutch or fluid resistance.

This can be achieved by adding a collection of worm gears to a conventional gear setup of the open differential. These worm gears working on each axle provide the necessary resistance to enable torque transfer.

This is achieved by having the worm gears in a continuous mesh with each other through connected spur gears. The continuous mesh between the two sides of the differential has the advantage of delivering quick torque, making it sensitive to changing road and driving conditions.

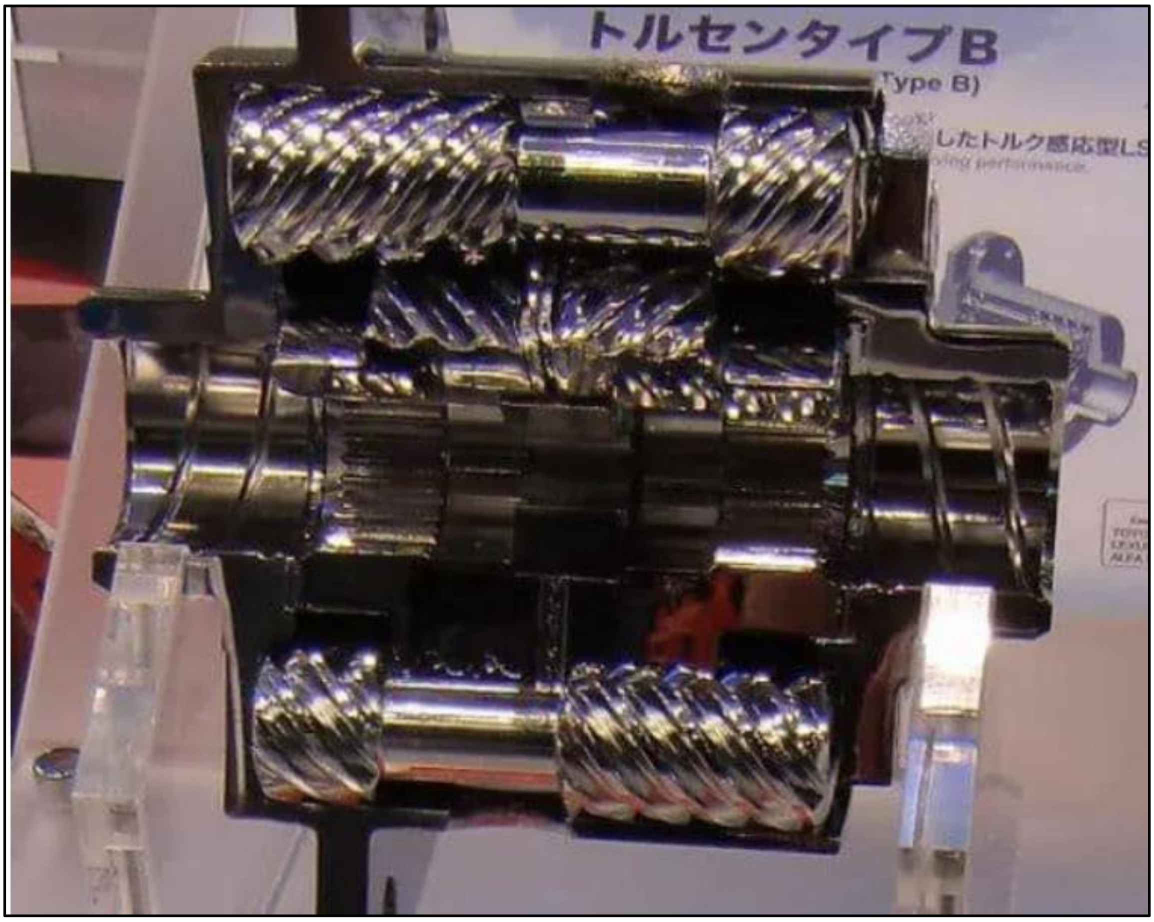

Figure 6. Torque-sensing Differential

Table 5. Advantages & Disadvantages of Torsen Differential

Advantages of Torsen Differential	**Disadvantages of Torsen Differential**
As soon as there is a speed difference between them, it starts sending more torque to the slower wheel. Also, it reacts far more quickly than LSD.	When a wheel is in the air, a Torsen differential works similar to an open differential, and very little torque is transferred to the drive axle. This is perfectly acceptable for road use, but it can be an issue for more purpose-built vehicles on the track.
These systems do not require regular maintenance because differential action is dependent on friction throughout the gear.	

- **Welded or Spool differential**

This is a type of locked differential and is known as a spool differential. It is welded permanently to a fixed axis by an open gap. This is usually done in specific situations where the features of locked differential make it easier for both wheels to spin simultaneously.

This is generally not recommended because the heat from welding can hazard the component’s strength and increase the risk of part failure.

Figure 7. Spool Differential

2.2 FUNCTIONS & COMPONENTS

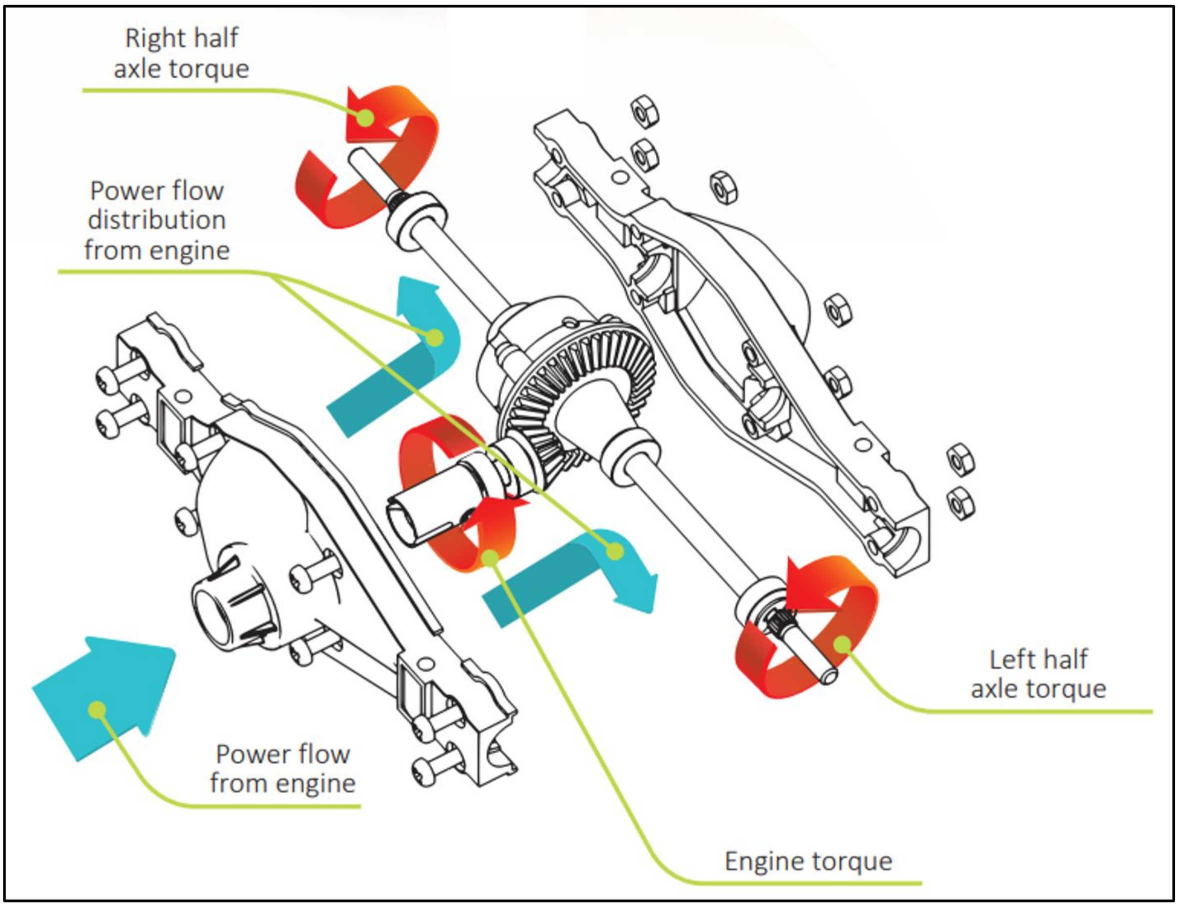

Figure 8. Working of Differential

The differential allows for different speeds at the drive wheels when a vehicle goes around c corner or any time there is a change of direction. When a car turns a corner, the outside wheels must travel farther and faster than the inside wheels. If the compensation is not made for this difference in speed and travel, the wheels would skid and slide, causing poor handling and excessive tire wear. Compensation for the variations in wheel speeds is made by the differential assembly. While allowing for their different speeds, the differential also must continue to transmit torque.

The differential of a RWD vehicle is normally housed with the drive axles in a large casting called the rear axle assembly. Power from the engine enters into the center of the rear axle assembly and is transmitted to the drive axles. The drive axles are supported by bearings and are attached to the wheels of the car. The power entering the rear axle assembly has its direction changed by the differential. This change of direction is accomplished through the hypoid gears used in the differential.

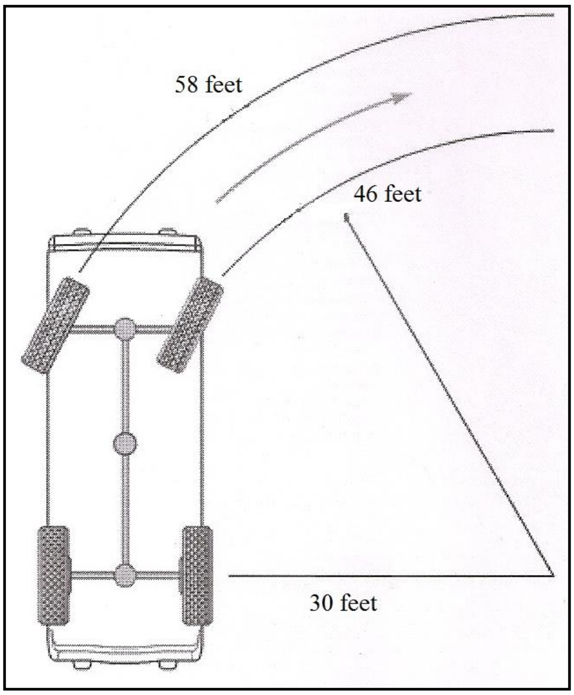

Figure 9. Travel of wheel when a vehicle is turning corner.

The differential of a RWD vehicle is normally housed with the drive axles in a large casting called the rear axle assembly. Power from the engine enters into the center of the rear axle assembly and is transmitted to the drive axles. The drive axles are supported by bearings and are attached to the wheels of the car. The power entering the rear axle assembly has its direction changed by the differential. This change of direction is accomplished through the hypoid gears used in the differential.

Power from the drive shaft is transmitted to the rear axle assembly through the pinion flange. This flange is the connecting yoke to the rear universal joint. Power then enters the final drive on the pinion gear. The pinion teeth engage the ring gear, which is mounted upright at a 90-degree angle to the pinion. Therefore, as the drive shaft turns, so do the pinion and ring gears.

The ring gear is fastened to the differential case with several hardened bolts of rivets. The differential case is made of cast iron and is supported by two tapered roller bearings in the rear axle housing. Holes machined through the center of the differential housing support the differential pinion shaft. The pinion shaft is retained in the housing case by clips or a specially designed bolt. Two beveled differential pinion gears and thrust washers are mounted on the differential pinion shaft. In mesh with the differential pinion gears are two axle side gears splinted internally to mesh with the external spines on the left and right axle shafts. Thrust washers are placed between the differential pinions, axle side gears, and differential case to prevent wear on the inner surfaces of the differential case.

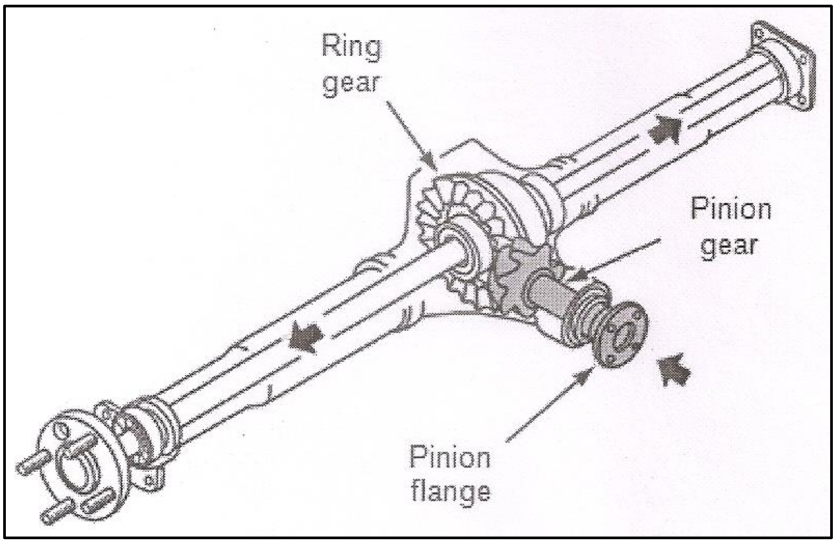

Figure 10. Components of an RWD

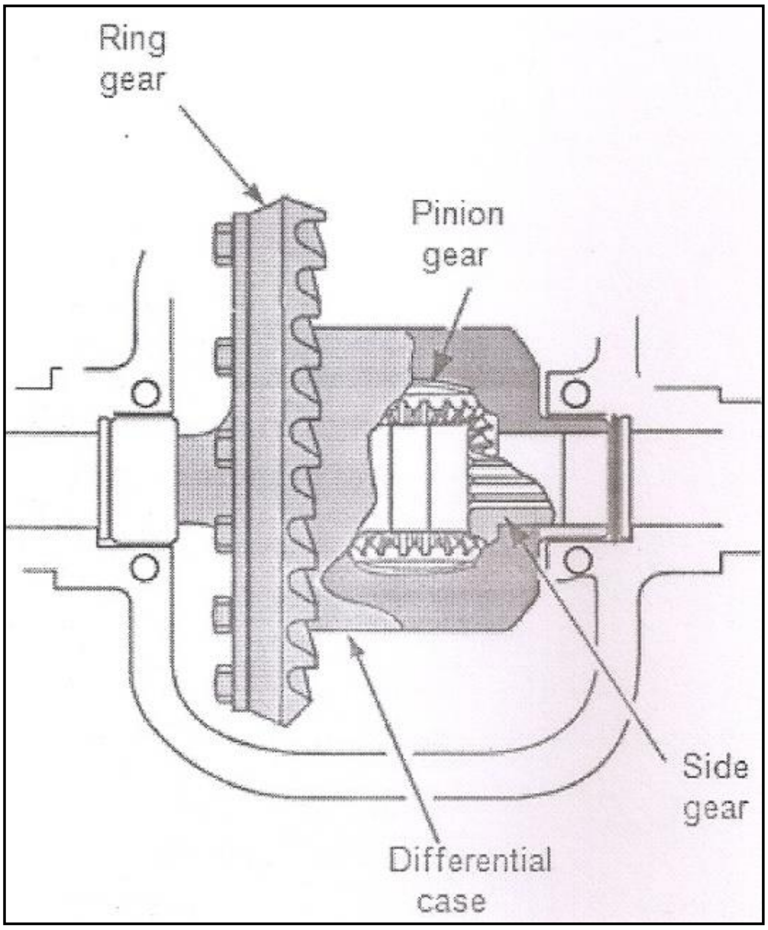

Figure 11. Components of Typical Differential

2.3 DIFFERENTIAL FUNCTION

The two drive wheels are mounted on axles that have a differential side gear fitted on their inner ends. To turn the power flow 90 degrees, as is required for RWD vehicles, the side gears are bevel gears.

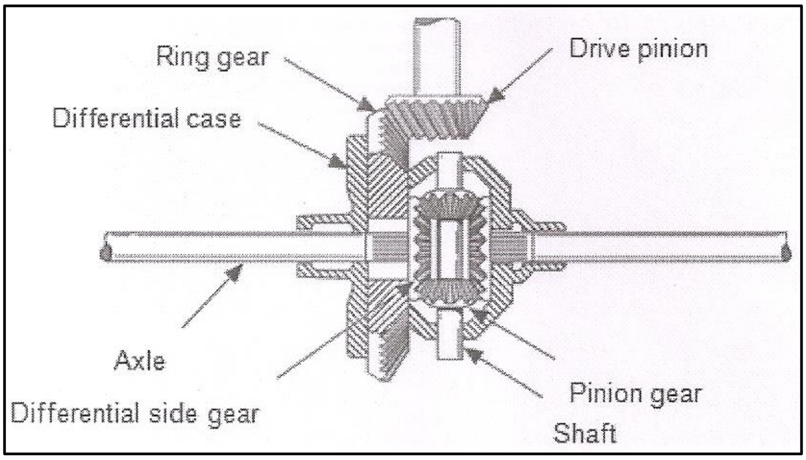

Figure 12. Basic Differential

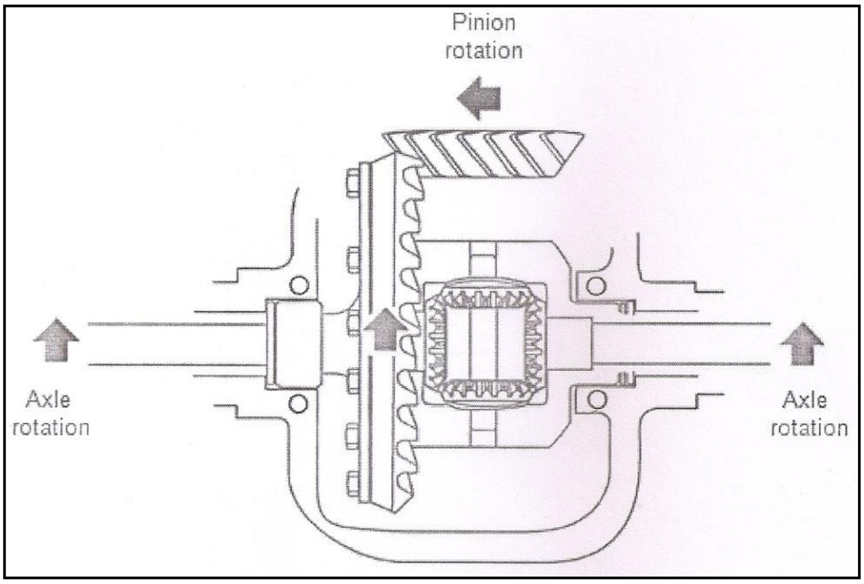

Figure 13. Power flow through a RWD Differential

The differential case is mounted on bearings so that is able to rotate independently of the drive axles. A pinion shaft, with small pinion gears, is fitted inside the differential case. The pinion gears mesh with the side gears. The ring gear is bolted to the flange of the differential case and the two rotate as a single unit. The drive pinion gear meshes with the ring gear and is rotated by the drive shaft.

Engine torque is delivered by the drive shaft to the drive pinion gear, which is in the mesh with the ring gear and causes it to turn. Power flows from the pinion gear to the ring gear. The ring gear is bolted to the differential case, which drives the side gears, pinions and axles as an assembly. The differential case extends from the side of the ring gear and normally houses the pinion gears and the side gears. The side gears are mounted so they can slip over spines on the ends of the axle shafts.

There is a gear reduction between the drive pinion gear and the ring gear, causing the ring gear to turn about one third to one fourth the speed of the drive pinion. The pinion gears are located between and meshed with the side gears, thereby forming a square inside the differential case. Differentials have two or four pinion gears that are in mesh with the side gears. The differential pinion gears are free to rotate on their own centers and can travel in a circle as the differential case and pinion shaft rotate. The side gears are meshed with the pinion gears and are also able to rotate on their own centers.

The small pinion gears are mounted on a pinion shaft that passes through the gears and the case. The pinion gears are in mesh with the axle side gears, which are splinted to the axle shafts.

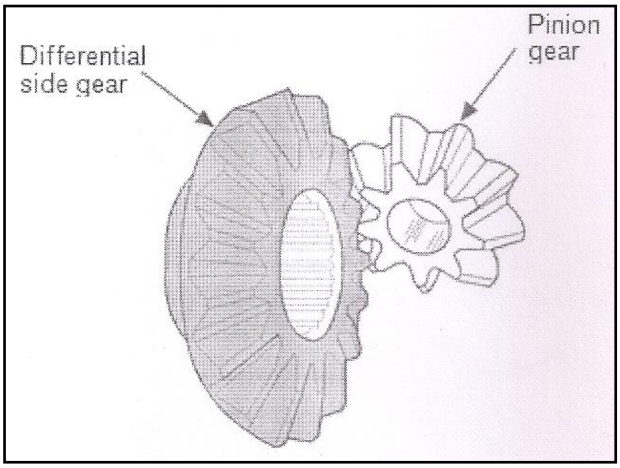

Figure 14. Pinion gears in mesh with side gears

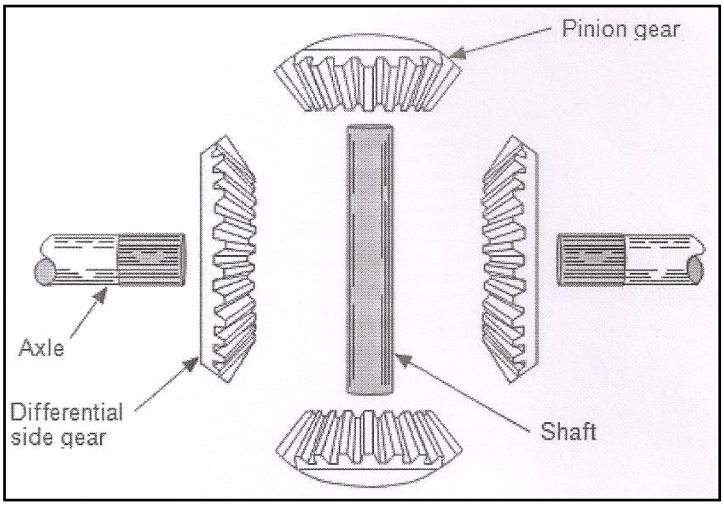

Figure 15. Position of side and pinion gears

In operation, the rotating differential case causes the pinion shaft and pinion gears to rotate end over with the case. Because the pinion gears are in mesh with the side gears, the side gears and axle shafts are also forced to rotate.

When a car is moving straight ahead, both drive wheels are able to rotate at the same speed. Engine power comes in on the pinion gear and rotates the ring gear. The differential case is rotated with the ring gear. The pinion shaft and pinion gears are carried around by the ring gear and all of the gears rotate as a single unit. Each side gear rotates at the same speed and in the same plane as does the case and they transfer their motion to the axles. The axles are thus rotated, and the car moves. Each wheel rotates at the same speed because each axle receives the same rotation.

As the vehicle goes around a corner, the inside wheel travels a shorter distance than the outside wheel. The inside wheel must therefore rotate more slowly than the outside wheel. In this situation, the differential pinion gears will "walk" forward on the slower turning or inside side gear as the pinion gears walk around the slower side gear, they drive the other side gear at a greater speed. An equal percentage of speed is removed from one axle and given to the other however; the torque applied to each wheel is equal.

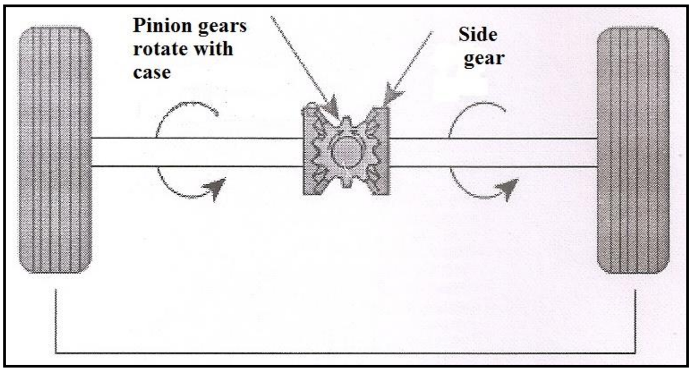

Figure 16. Position of pinion gears in the case causes the side gears to rotate

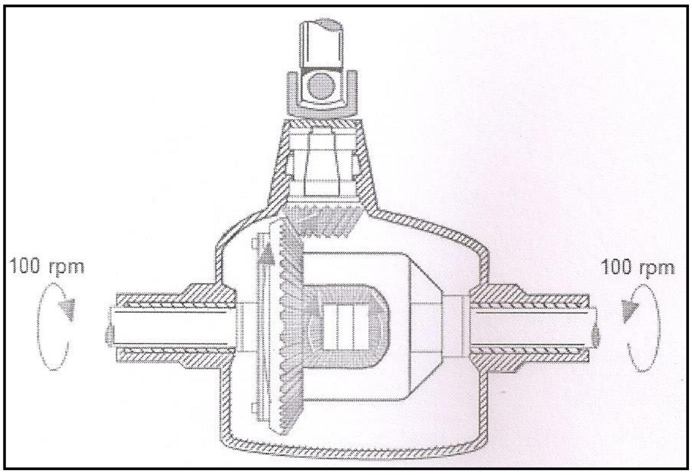

Figure 17. Differential action when the vehicle is moving straight ahead.

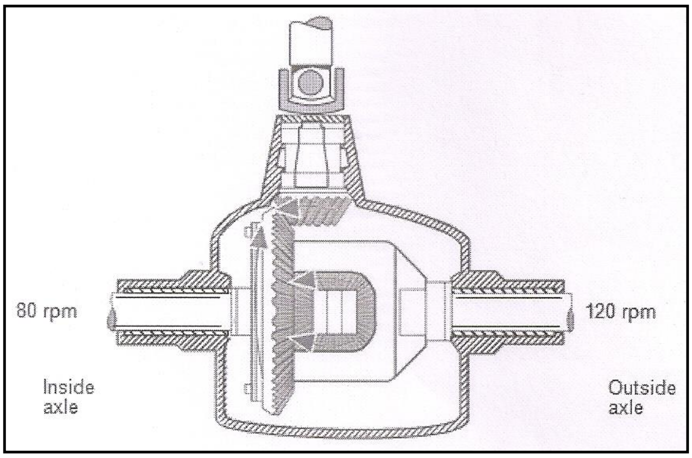

Figure 18. Differential action while the vehicle is turning a corner.

Only the outside wheel rotates freely when a car is making a very sharp turn; therefore, only one side gear rotates freely. Because one side gear is close to being stationary, the pinion gears now turn on their own centers as they walk around that side gear. As they walk around that side gear, they drive the other side gear at twice their own speed. The moving wheel is now turning at twice the speed of the differential case, but the torque applied to it is only half of the torque applied to the differential case. This increase in wheel speed occurs because of these two actions: the differential pinion gears are rotating end over end with the pinion shaft and the action of the differential pinion gears rotating around the differential pinion shaft.

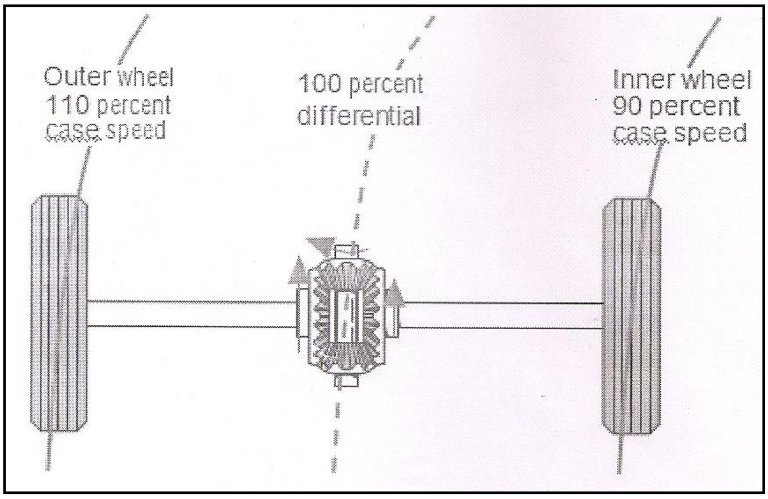

Figure 19. Speed differentiation when turning.

When one of the driving wheels has little or no traction, the torque required to turn the wheel without traction is very low. The wheel with good traction in effect is holding the axle gear on that side stationary. This causes the pinions to walk around the stationary side gear and drive the other wheel at twice the normal speed but without any vehicle movement. With one wheel stationary, the other wheel turns at twice the speed shown on the speedometer. Excessive spinning of one wheel can cause severe damage to the differential. The small pinion gears can actually become welded to the pinion shaft or differential case.

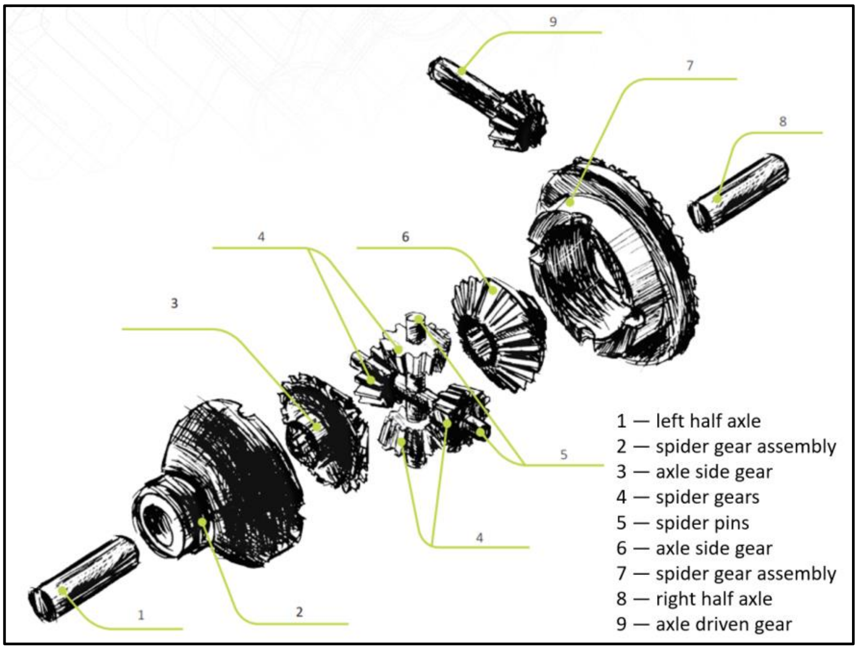

Figure 20. Components of Differential

2.4 AXLE HOUSINGS

Live rear axles use a one-piece housing with two tubes extending from each side. These tubes enclose the axles and provide attachments for the axle bearings. The housing also shields the parts from dirt and retains the differential lubricant.

In IRS or FWD systems, the housing is in three parts. The center part houses the final drive and differential gears. The outer parts support the axles by providing attachments for the axle bearings. These parts also serve as suspension components and attachment points for the steering gear or brakes. In FWD applications, the differential and final drive are either enclosed in the same housing as the transmission or in a separate housing bolted directly to the transmission housing.

Based on their construction, rear axle housings can be divided into two groups, integral carrier or removable carrier. An integral carrier housing attaches directly to the rear suspension. A service cover, in the center of the housing, fits over the rear of the differential and rear axle assembly. When service is required, the cover must be removed. The components of the differential unit are then removed from the rear of the housing.

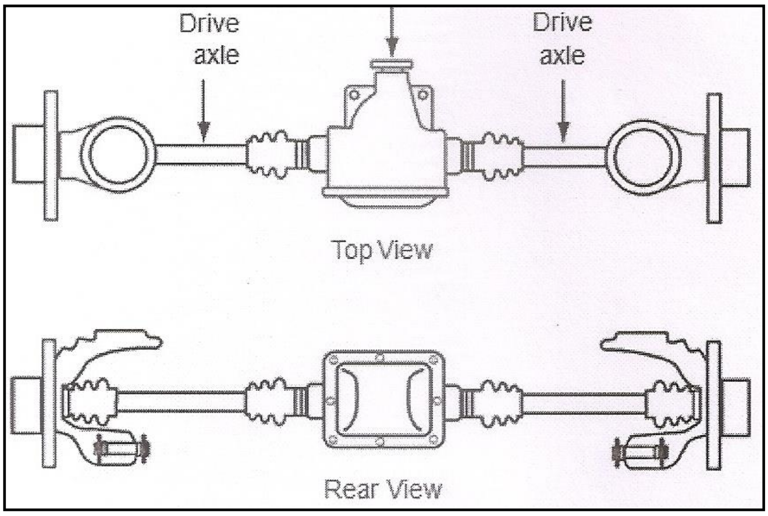

Figure 21. Drive axle assembly on a RWD vehicle with IRS

In integral-type axle housing, the differential carrier and the pinion bearing retainer are supported by the axle housing in the same casting. The pinion gear and shaft are supported by two opposing tapered-roller bearings located in the front of the housing. The differential carrier assembly is also supported by two opposing tapered-roller bearings, one at each side.

The differential assembly of a removable carrier assembly can be removed from the front of the axle housing as a unit. The differential is serviced on a bench and then installed into the axle housing. The differential assembly is mounted on two opposing tapered-roller bearings retained in the housing by removable caps. The pinion gear, pinion shaft, and the pinion bearings are typically assembled in a pinion retainer, which is bolted to the carrier housing.

A typical housing has a cast-iron center section with axle shaft tubes pressed and welded into either side. The rear axle housing encloses the complete rear-wheel driving axle assembly. In addition to housing the parts, the axle housing also serves as a place to mount the vehicle's rear suspension and braking system. With IRS, the differential housing is mounted to the vehicle's chassis and does not move with the suspension.

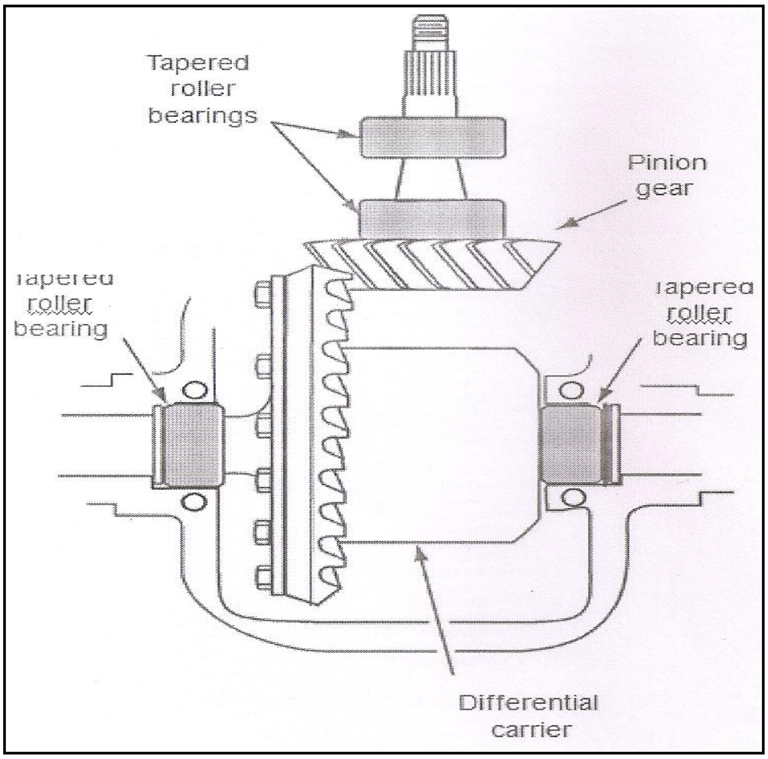

Figure 22. Location of Bearings in a typical integral housing.

2.5 DIFFERENTIAL GEARS AND ITS RATIO

Two types of gears are currently being used as differential gears; spiral bevel and hypoid. Spiral bevel gears are commonly used in heavy duty applications. In a spiral bevel gear set, the centerline of the drive pinion gear intersects the centerline of the ring gear. There designs are noisier than hypoid gears.

Hypoid gear sets are commonly used in RWD passenger car and light truck applications. The pinion gear in a hypoid gear set is mounted well below the centerline of the ring gear. Hypoid gears are quiet running.

This design allows for lower vehicle height and more passenger room inside the vehicle by lowering the driven pinion gear on the ring gear, the entire drive Shaft can be lowered. Lowering the drive shaft allows for a lower drive shaft tunnel, which in turn allows for increased passenger room and lower ride height.

The teeth of the hypoid gear are curved to follow the form of spiral, causing a wiping action while meshing as the gears rotate, the teeth slide against each other. Because this sliding action, the ring and pinion gears can be machined to allow for near perfect mating, which results in smoother action and quiet running gear set because this sliding action produces extremely high pressure between the gear teeth, only a hypoid type lubricant should be used with hypoid gear sets.

The spiral shaped teeth result in different tooth contacts as the pinion and ring gear rotate. The drive side of the teeth is curved in convex shape, and the coast side of the teeth in concave.

The inner end of the teeth on the ring gear is known as the toe and the outer end of the teeth is the heel.

While engine torque is being applied to the drive pinion gear, the pinion teeth exert pressure on the drive side of the ring gear teeth during the coast or engine braking the concave side of the ring gear teeth exert pressure on the drive pinion gear.

Upon heavy acceleration, the drive pinion attempts to climb up the gear and raises the front of the differential. The suspension’s leaf spring or the torque arm on coil spring suspensions absorb much of the torque to limit the movement of the axle housing.

2.6 GEAR RATIOS

Gear ratios express the number of turns the drive gear makes compared to one turn of the driven gear it mates with. The ring gear is driven by the pinion gear, therefore causing torque multiplication. The ring gear is always larger than the pinion. This combination causes the ring gear to turn more slowly but with greater torque.

Many different final drive ratios are used. A final drive ratio of 2.8:1 is commonly used, especially on cars equipped with automatic transmissions. A 2.8:1 final drive ratio means the drive pinion must turn 2.8 times to rotate the ring gear one time. On cars equipped with manual transmissions, more torque multiplication is often needed, therefore a 3.5:1 final drive ratio is often used. To allow a car to accelerate more quickly or to move heavy loads, a final drive ratio of 4:1 can be used. Also, small engine cars with overdrive fourth and fifth gears often use a 4:1 final drive ratio, which allows them to accelerate reasonably well in spite of the engine's low power output.

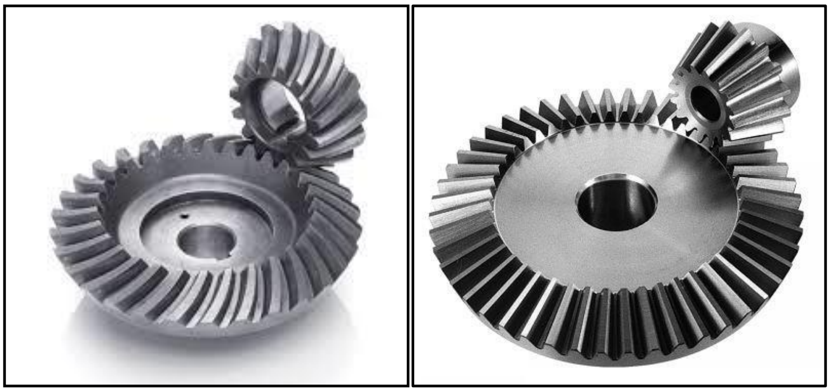

Figure 23. Comparison of a spiral bevel and straight gear set

The overdrive in fourth and fifth gear effectively reduces the final drive ratio when the car is moving in those gears. Trucks also use a final drive ratio of 4:1 or 5:1 to provide more torque to enable them to pull or move heavy loads.

It is important to remember that the actual final drive or overall gear ratio is equal to the ratio of the ring and pinion gear multiplied by the ratio of the speed gear the car is operating in. For example, if a car has a final drive ratio of 3:1, the total final drive ratio for each transmission speed is as follows. Notice that, in this example, the only time the total final drive ratio is the same as the ratio of the ring and pinion gear is when the transmission is in fourth gear, which has a speed ratio of 1:1.

Many factors are considered when a manufacturer selects a final drive ratio for a vehicle. Some of these factors are vehicle weight, engine rpm range, designed vehicle speed, frontal area of the body, fuel economy requirements, engine power output, and transmission type and gear ratios. Cars with final drive ratios around 2.5:1 will take longer to accelerate but will typically give a higher top speed. At the other end of the scale, a 4.11:1 ratio will give faster acceleration with a lower top speed. Since the 1970s there has been an emphasis on fuel economy, and most cars have been equipped with high gears to allow for lower engine speeds at normal driving speeds.

2.7 HUNTING & NON-HUNTING GEARS

Ring and pinion gear sets are usually classified as hunting, no hunting, or partial no hunting gears. Each type of gear set has its own requirements for a satisfactory gear tooth contact pattern. These classifications are based on the number of teeth on the pinion and ring gears.

A no hunting gear set is one in which any one pinion tooth comes into contact with only some of the ring gear teeth. One revolution of the ring gear is required to achieve all possible gear tooth contact combinations. As an example, if the ratio of the ring gear teeth to the pinion gear teeth is 39 to 13 (or 3.00:1), the pinion gear turns three times before the ring gear completes one turn. One full rotation of the pinion gear will cause its 13 teeth to mesh with one third of the ring gear's teeth. On the next revolution of the pinion gear, its teeth will mesh with the second third of the ring gear's teeth and the third revolution will mesh with the last third of the ring gear. Each tooth of the pinion gear will return to the same three teeth on the ring gear each time the pinion rotates.

A partial no hunting gear set is one in which any one pinion tooth comes into con-tact with only some of the ring gear teeth, but more than one revolution of the ring gear is required to achieve all possible gear tooth contact combinations. Is elected a single cylinder the ratio of the ring gear teeth to the pinion gear teeth is 35 to 10 (or 3.5:1), any given tooth of the pinion will meet seven different teeth (seven complete revolutions of the pinion gear) of the ring gear before it returns to the space where it started.

When hunting gear sets are rotating, any pinion gear tooth will contact all the ring gear teeth. If the ring gear has 37 teeth and the pinion gear has 9, the gear set has a ratio of 37 to 9 (or 3.89:1). Any given tooth in the pinion gear meets all of the teeth in the ring gear before it meets the first tooth again.

3. METHODOLOGY

3.1 SPECIFICATIONS OF VEHICLE

3.1.A ENGINE

We have selected a single cylinder, 4 stroke petrol engine for the calculation prerequisites. The engine specifications are shown below. The maximum engine RPM we are using in calculation is 2600 as the engine provides max torque at that RPM.

Table 6. Engine Specifications

Manufacturer	Briggs and Stratton
Model	10 HP, Vanguard
Displacement	305 cc
HP (Gross)	10 HP
Factory Set RPM	3800
Compression Ratio	8.1:1
Maximum Torque	18.98 Nm @ 2600RPM

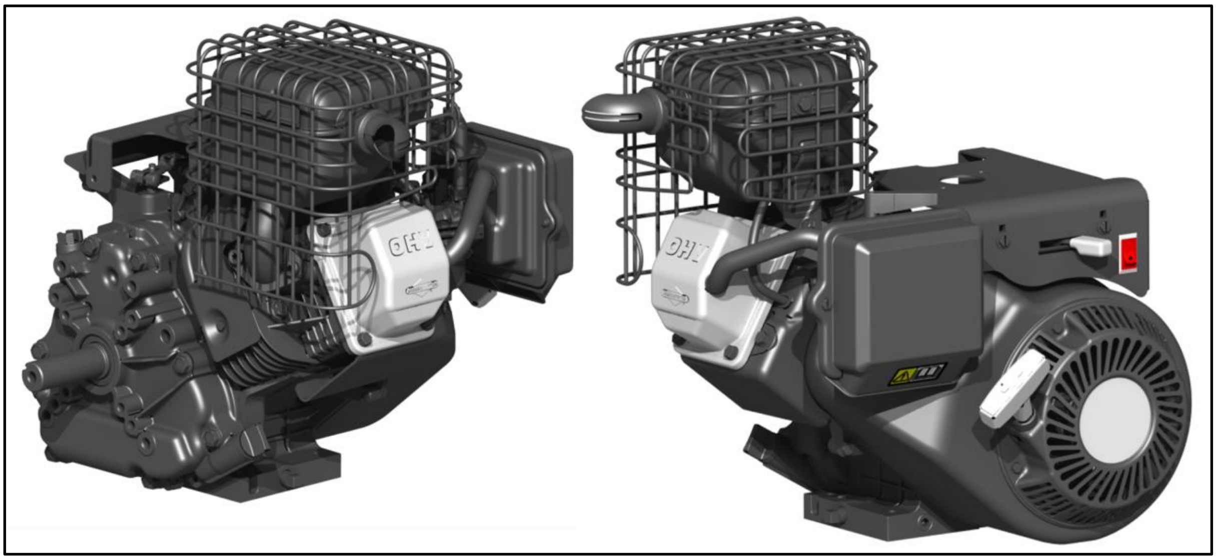

Figure 24. Engine Data used form above Engine Model

3.1.B DRIVELINE LAYOUT

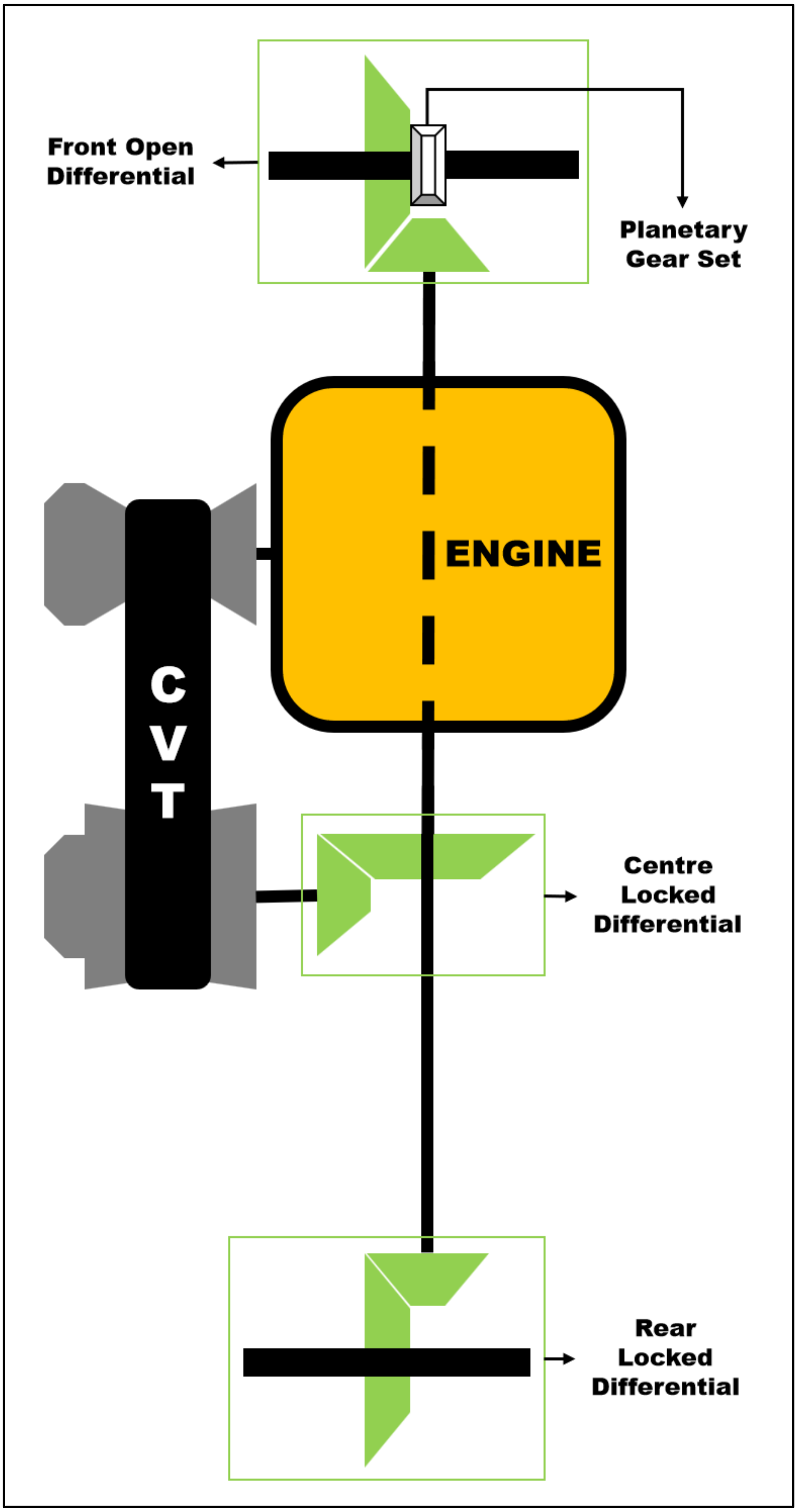

Figure 25. Vehicle Driveline Layout

Continuously Variable Transmission – We have selected CVT as a speed varying transmission. The CVT we have selected is a JIT RC-1. This is a mechanical type of CVT, which uses conical sheeves and rubber belt to vary the ratio. This is a 3 arm-ramp driven, roller helix driver with a low ratio of 3.89:1 and a high ratio of 0.6:1.

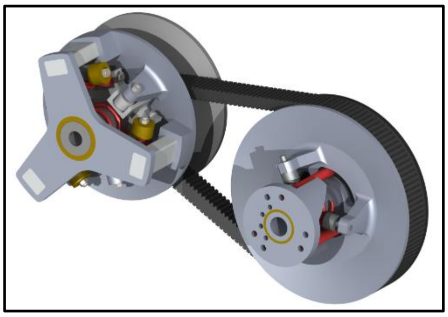

Figure 26. CVT Data used from above CVT Model

Locked Differential – Being a four-wheel drive vehicle. It uses a center differential to transmit the power to both the front and rear axles. As 50% torque split was required, locked differential is the best choice we have. While at the rear, by using locked differential we reduced the wheel slip while still not disturbing the turning of the vehicle to a greater extent.

Open Differential – Being a four-wheel drive, front steering vehicle, we need to have different RPMs on the either side wheels for effective turning. For this we used open differential at front, with planetary gear set. The ratio of the planetary gears is kept equal to the ratio of individual turning radius of either side wheel. This provides the exact RPM difference which is required for effective turning.

3.2 CALCULATIONS

3.2.A VEHICLE SPECIFICATION AND CALCULATION

- Gross Engine Power = 10 HP
- Maximum Engine Torque = 18.98 Nm at 2600 RPM
- Bevel gearing arrangement = 90°
- Ratio of turning Radius = 1.6:1
- CVT Low Ratio = 3.89:1
- CVT High Ratio = 0.6:1
- Centre Differential Ratio = $^{41}/_{17}$ = 2.41:1
- Rear Differential Ratio = $^{45}/_{15} = 3:1$
- Front Differential Ratio = $^{45}/_{15} = 3:1$
- Planetary Gears set Ratio = Ratio of Turning Radius

$$= {}^{24}/_{15} = 1.6:1$$

- Front Differential Input Torque $(M_t) = \frac{18.98 \times 3.89 \times 2.41}{2} = 88.9\ Nm$
- Minimum Front Differential Input RPM = $\frac{\frac{2600}{3.89}}{2.41} = 277.36\ RPM$
- Maximum Front Differential Input RPM $\frac{\frac{2600}{0.6}}{2.41} = 1798.06\ RPM$
- Wheel Torque = $\frac{88.9 \times 3}{2} = 133.35\ Nm$
- Minimum Wheel RPM = $\frac{277.36}{3} = 92.45\ RPM$
- Maximum Wheel RPM = $2600 \div 0.6 \div 2.41 \div 3 = 599.35\ RPM$
- Maximum Vehicle Torque = $4 \times 133.35 = 533.4\ Nm$

3.2.B DIFFERENTIAL PINION AND GEAR CALCULATION

- Gear Reduction Ratio = 3:1
- Number of Teeth of Pinion $(z_p) = 15$
- Number of Teeth of Gear $(z_g) = 45$
- Module (m) = 2.5
- Pressure Angle (Ø) = 20°
- Teeth Profile = 20° full depth involute system
- Shaft Angle (s) = 90°

FOR DIFFERENTIAL PINION

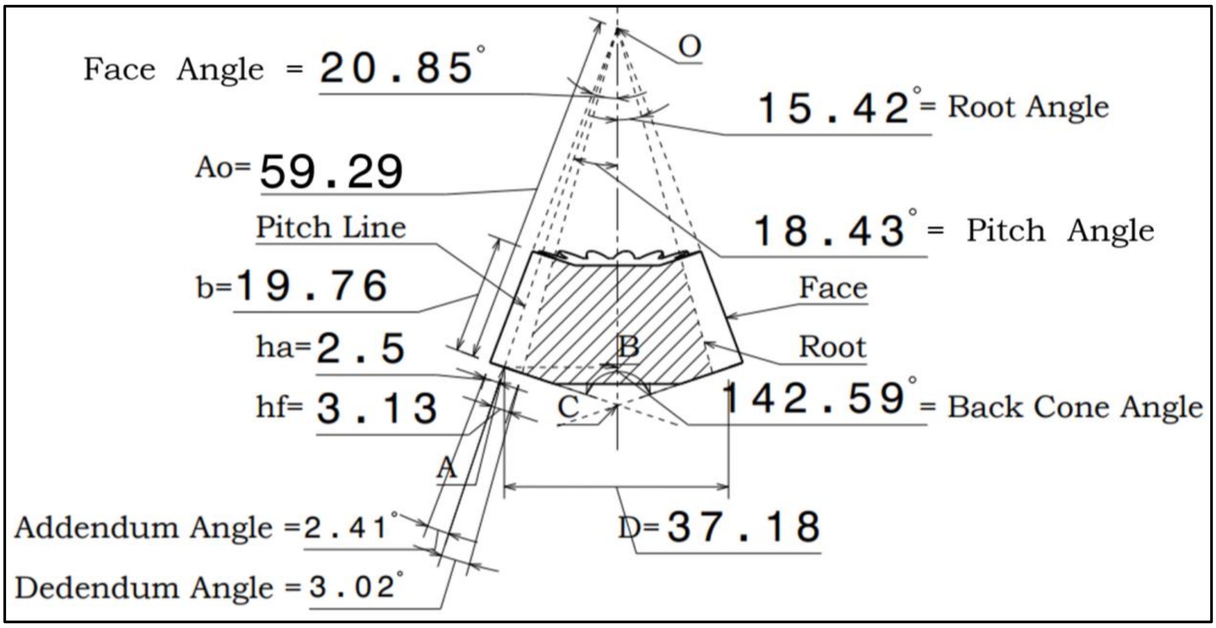

Figure 27. Section View of Differential Pinion

- Pitch Angle $(\gamma_p) = \tan^{-1}(\frac{z_p}{z_g})$

  = 18.435°

- Addendum Angle (α) – It is the angle subtended by the addendum at the cone center. $(\alpha = 2.41°)$ …For module 2.5 mm

- Dedendum Angle (δ) – It is the angle subtended by the dedendum at the cone center. $(\delta = 3.02°)$ …For module 2.5 mm

- Face Angle $= \gamma + \alpha$
  = 20.85°

- Root Angle $= \gamma + \delta$
  = 15.42°

- Back Cone Angle – The back cone is an imaginary cone and its elements are perpendicular to the elements of the pitch cone. (142.59°)

- Cone Distance $(A_o) = \frac{\frac{z_g \times m}{2}}{\sin(s - \gamma_p)}$
  = 59.293 mm

- Face Width $(b) = {}^{1}/_{3}\,(A_o)$
  = 19.76 mm

- Addendum, $h_a = m = 2.5\ mm$

- Dedendum, $h_f = 1.25 \times m = 3.125\ mm$

FOR DIFFERENTIAL GEAR

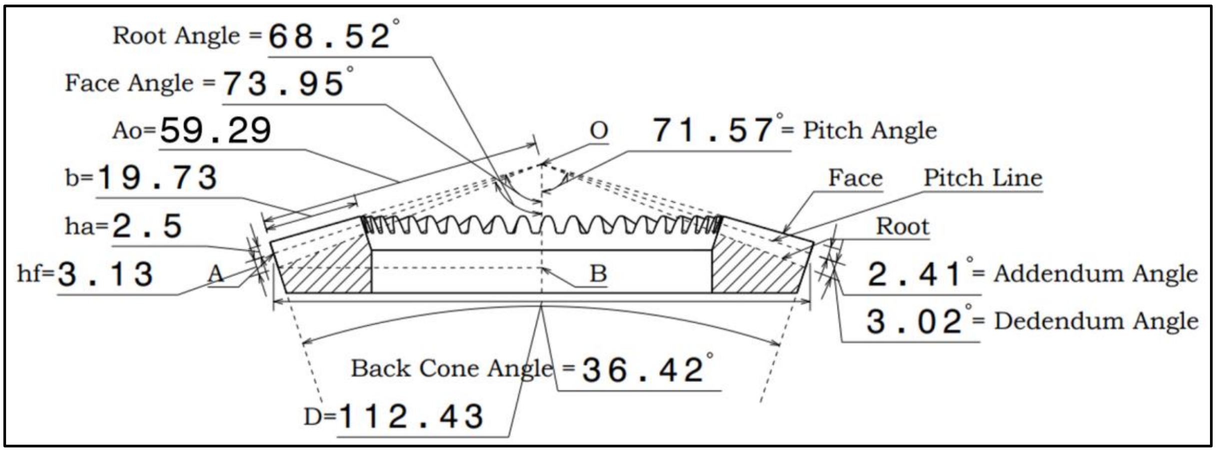

Figure 28. Section View of Differential Gear

- Pitch Angle $(\gamma_g) = s - \gamma_p$
  = 71.565°

- Addendum Angle (α) – It is the angle subtended by the addendum at the cone center. $(\alpha = 2.41°)$ …For module 2.5 mm

- Dedendum Angle (δ) – It is the angle subtended by the dedendum at the cone center. $(\delta = 3.02°)$ …For module 2.5 mm

- Face Angle $= \gamma + \alpha$
  = 73.95°

- Root Angle $= \gamma + \delta$
  $= 68.52°$

- Back Cone Angle – The back cone is an imaginary cone and its elements are perpendicular to the elements of the pitch cone. (36.42°)

- Cone Distance $(A_o) = \frac{\frac{z_g \times m}{2}}{\sin(s-\gamma_p)}$
  $= 59.293$ mm

- Face Width $(b) = {}^1/_3\,(A_o)$
  $= 19.76$ mm

- Addendum, $h_a = m = 2.5\ mm$

- Dedendum, $h_f = 1.25 \times m = 3.125\ mm$

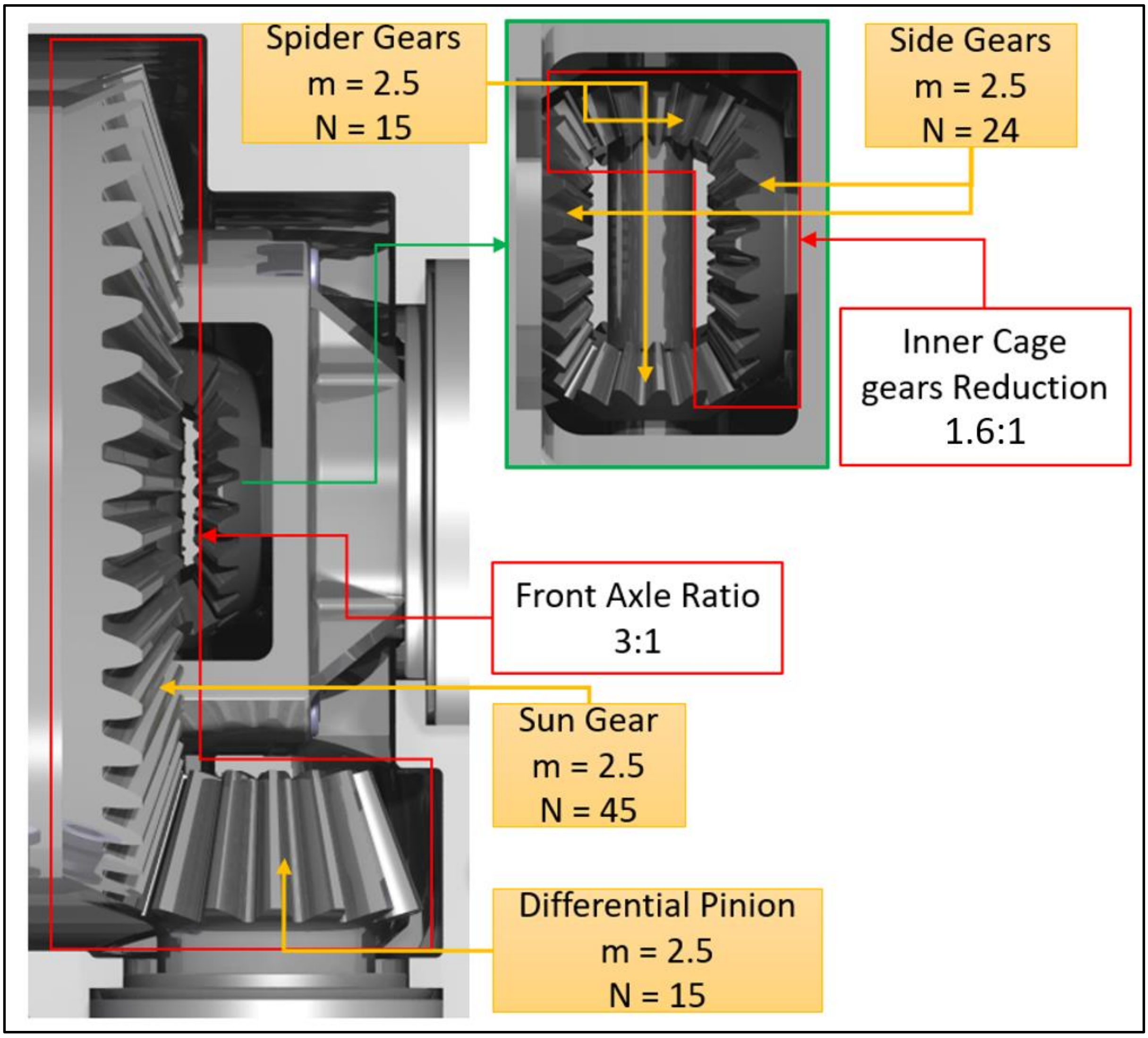

Figure 29. Different Gear Ratios in Open Differential

3.2.C MATERIAL SELECTION AND STRENGTH CALCULATION

- ### Material Properties

We have selected 20MnCr5 material for all gear pairs, as it has high S_{yt} & $enough\ S_{ut}$.

$$S_{ut} of\ 20MnCr5 = 1300\ MPa$$
$$S_{yt} of\ 20MnCr5 = 980\ MPa$$
$$BHN\ of\ 20MnCr5 = 255\ HB\ (+S\ hardness)$$

20MnCr5 has a single alloying element, Chromium. It is a low alloy steel capable of being hardened up-to 60 HRC. This provides a tough core after case-hardened. We case hardened the gear for 56 HRC rising the BHN to 552 HB.

$$Afterpost\ process\ BHN = 552\ HB$$

- ### Strength Calculation

Pressure angle (Ø) = 20°

Power = 10 HP

We know that Velocity Ratio, $(V.R.) = \left(\frac{z_g}{z_p}\right) = \left(\frac{D_g}{D_p}\right) = \left(\frac{\tau_g}{\tau_p}\right) = \left(\frac{n_p}{n_g}\right)$

$$V.R. = \left(\frac{z_g}{z_p}\right) = \frac{45}{15} = 3$$

Now, $n_p(mini.) = 277.36\ RPM$
$n_p(max.) = 1798.06\ RPM$

Therefore, by using, $V.R. = \left(\frac{z_g}{z_p}\right) = \left(\frac{n_p}{n_g}\right)$

We get, $n_g(mini.) = 92.45\ RPM$
$n_g(max.) = 599.353\ RPM$

If both the gear and pinion is made of same material, then the smaller member, (which is pinion) is considered as weaker member. Thus, the design should be based upon the pinion.

We know that formative number of teeth for pinion

$$z'_p = \frac{z_p}{\cos(\gamma_p)} = \frac{15}{\cos(18.435)} = 15.81$$

We know that formative number of teeth for gear

$$z'_g = \frac{z_g}{\cos(\gamma_g)} = \frac{45}{\cos(71.565)} = 142.30$$

Tooth form factor for the pinion

$$Y = 0.289 + \frac{(0.295 - 0.289)(15.81 - 15)}{(16 - 15)}$$
$$= 0.29386 \sim 0.294$$

Allowable static stress $(\sigma_b) = \frac{1}{3} S_{ut}$

Therefore, $\sigma_b = 433.33\ MPa$

- ## Beam Strength of Pinion

$$\boldsymbol{\delta(S_b) = m \times b \times \sigma_b \times Y}$$

where,

$\delta(S_b) = beam\ strength\ of\ elemental\ section\ (N)$

$m = module\ of\ section\ (mm)$

$b = face\ width\ of\ elemental\ section\ (mm)$

$Y = Lewis\ form\ factor\ based\ on\ virtual\ number\ of\ teeth$

Therefore, $\boldsymbol{S_b = 6293.51\ N}$

- ## Wear Strength of Pinion

$$\boldsymbol{S_w = \frac{b \times Q \times D_p \times K}{\cos(\gamma_p)}}$$

where,

S_w = Wear Strength of Teeth

Q = Ratio Factor $= \frac{2 \times z'_g}{z'_g + z'_p}$

K = Material Constant $(N/mm^2) = 0.16\left({BHN}/{100}\right)^2$

Therefore,

$$Q = \frac{2 \times 142.30}{142.30 + 15.81} = 1.8$$

And

$$K = 0.16\left(\frac{552}{100}\right)^2 = 4.87$$

Now, Calculating Wear Strength of Teeth

$$S_w = \frac{19.76 \times 1.8 \times 37.18 \times 4.87}{\cos(18.435)} = \boldsymbol{6788.54\ N}$$

- ## Effective Load on Gear Tooth

$P_t = \frac{2M_t}{D} \ldots (P_t = Tengential\ Load)$

Therefore, $\boldsymbol{P_t} = \frac{2 \times 88.9 \times 1000}{37.18} = \boldsymbol{4782.14\ N}$

$P_{eff} = \frac{C_s \times P_t}{C_v} \ldots (Effective\ Load)$

where,
$C_s = Service\ Factor = 1$ … (from design Data Book)
$C_v = \frac{3}{3+v}$ … (For v < 10 m/s)

$$v = \frac{\pi \times n_p \times m \times z_p'}{60 \times 10^3} = 0.57$$

Therefore,

$$C_v = \frac{3}{3 + 0.57} = 0.84$$

Now, Calculating Effective Load

$$\boldsymbol{P_{eff}} = \frac{1 \times 4782.14}{0.84} = \mathbf{5693.02\ N}$$

- **Factor of Safety**

$S_b = P_{eff}(f_{sb})$ & $S_w = P_{eff}(f_{sw})$

Therefore,

$$f_{sb} = \frac{6293.51}{5693.02} = \mathbf{1.105}$$

And

$$f_{sw} = \frac{6788.54}{5693.02} = \mathbf{1.192}$$

Thus, the design is safe.
The FOS for beam strength is 1.105 and FOS for wear strength is 1.192

3.3 CAD MODEL

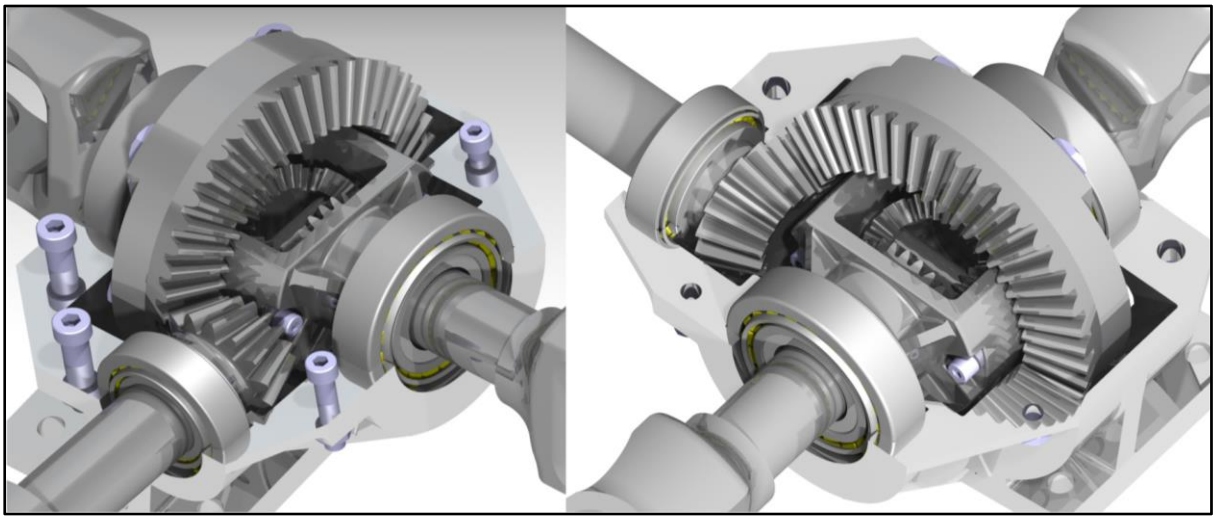

Figure 30. Designed Open Differential

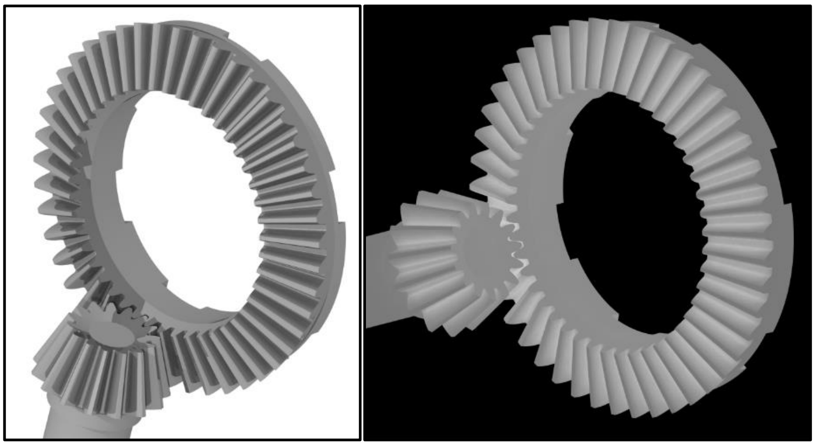

Figure 31. Differential Straight Bevel Pinion and Gear

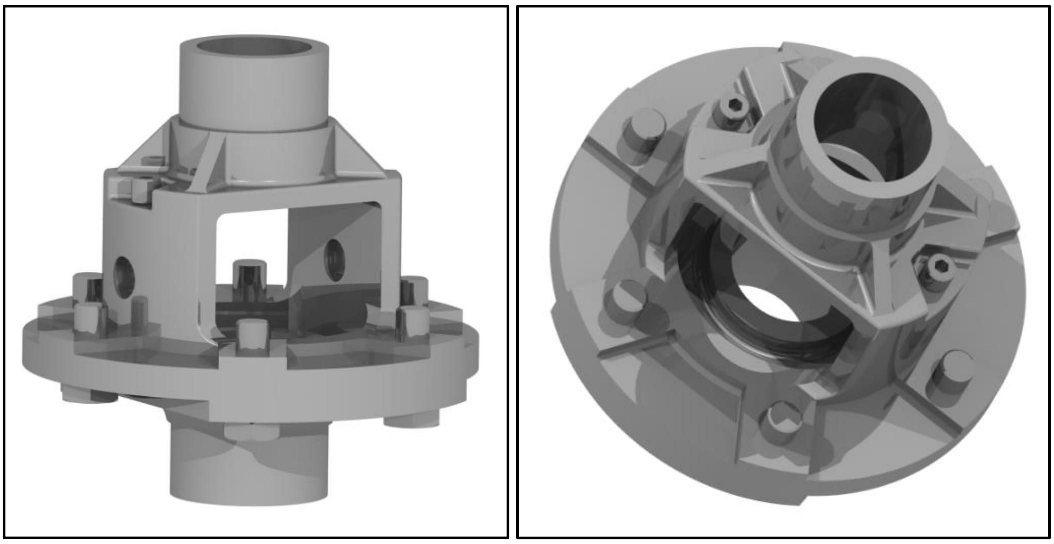

Figure 32. Differential Cage

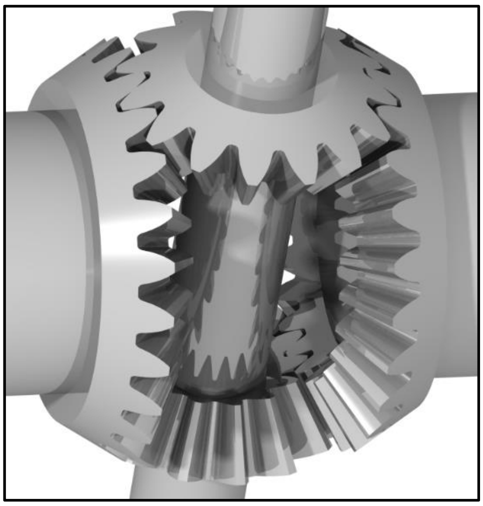

Figure 33. Planetary Gear Set

Figure 34. Open Differential Gear Set

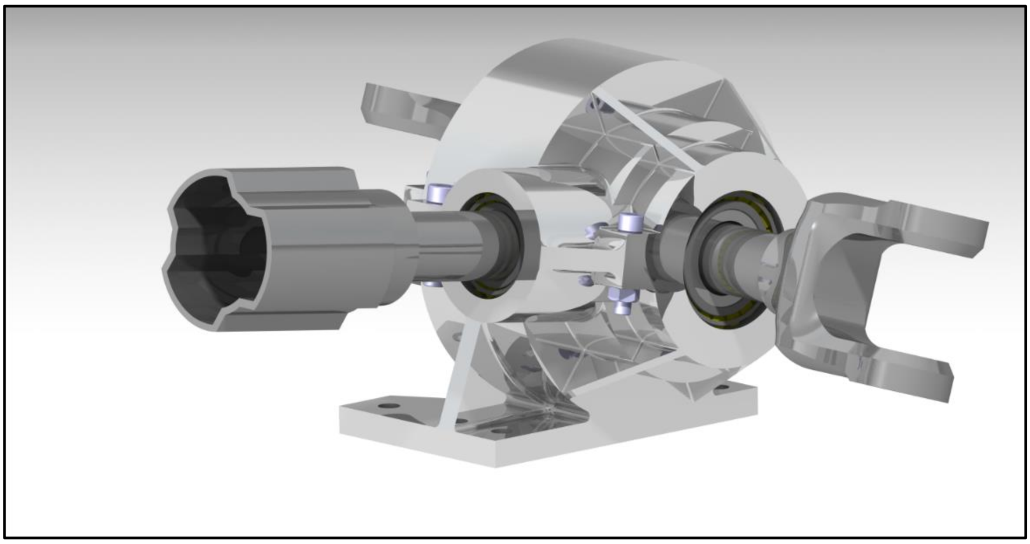

Figure 35. Differential in Casing

3.4 ANALYSIS (FEA)

- **Contact Analysis**

Contact analysis of open differential is performed to see the effects of gears on each other. Tangential, radial and axial loads of the mating teeth are applied, along with the bearing loads and constraints. Maximum displacement of the gear set is 0.07 mm and the maximum stress generated is 420.25 MPa.

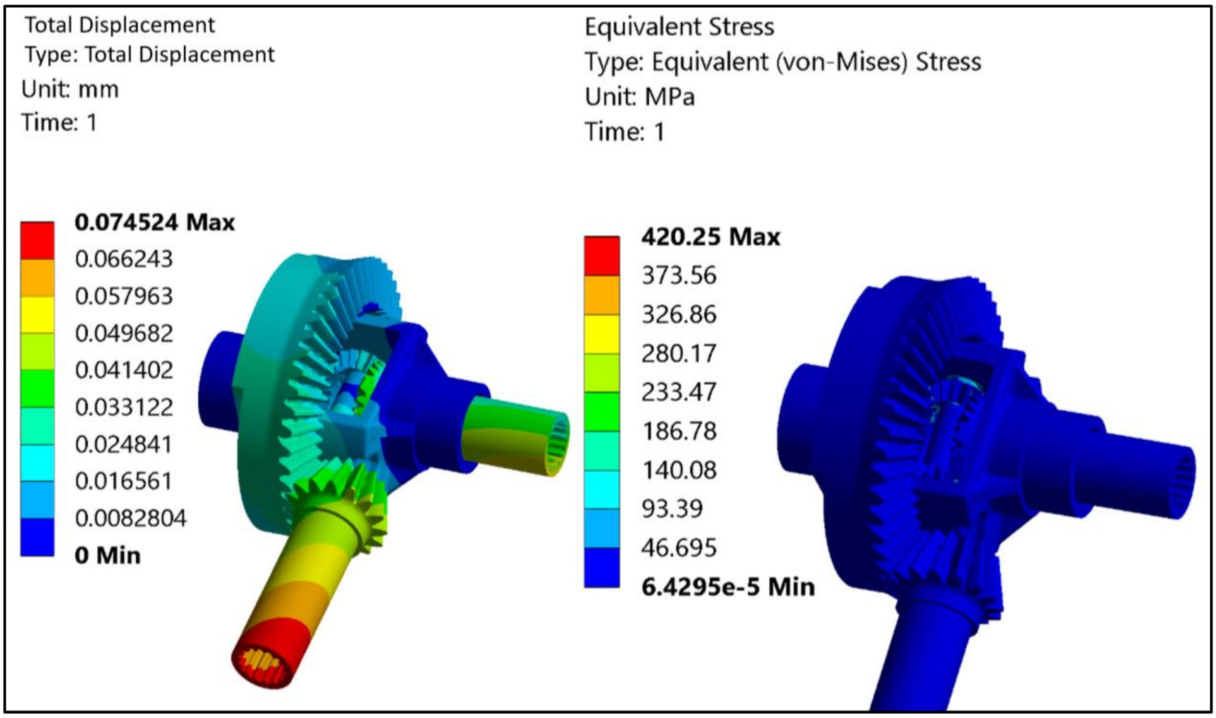

Figure 36. Contact Analysis Open Differential Gear Set

- **Structural Analysis**

Static Structural Analysis of differential casing is performed to find out that is the casing capable of bearing the reaction forces of the bearings, while mounting the differential to the chassis. The maximum stress is generated on the support gasket to the mounting, which is 149.122 MPa. The maximum displacement is 0.197 mm.

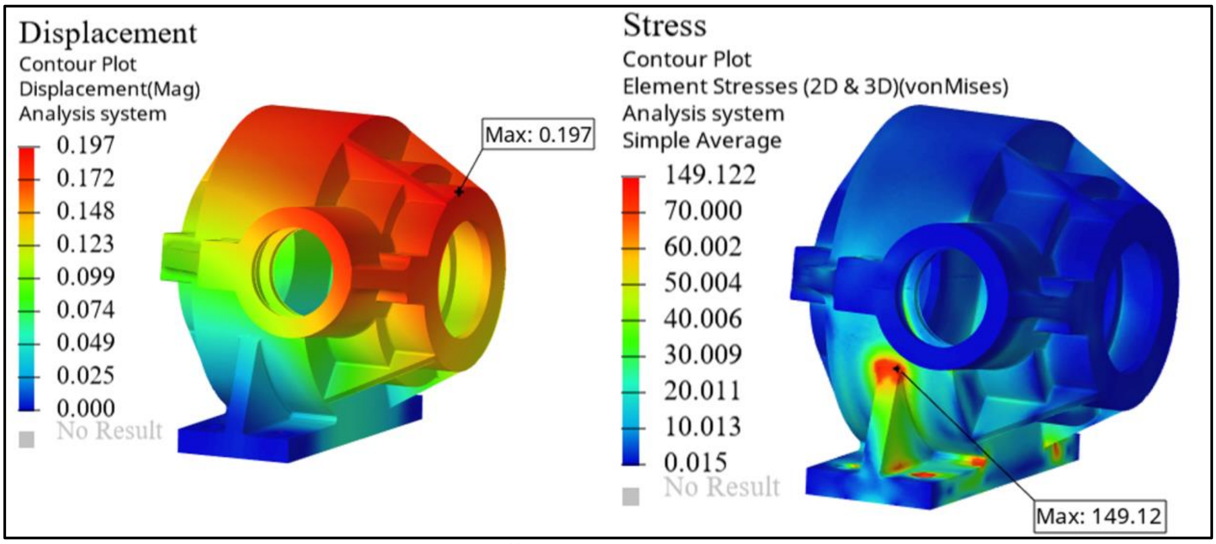

Figure 37. Differential Casing Structural Analysis

4. CONCLUSION

A vehicle's wheels rotate at different speeds, mainly when turning corners. The differential is designed to drive a pair of wheels while allowing them to rotate at different speeds. In vehicles without a differential, such as karts, both driving wheels are forced to rotate at the same speed, usually on a common axle driven by a simple chain-drive mechanism. When cornering, the inner wheel needs to travel a shorter distance than the outer wheel, so with no differential, the result is the inner wheel spinning and/or the outer wheel dragging, and this results in difficult and unpredictable handling, damage to tires and roads, and strain on or possible failure of the entire drive train. Finally, we concluded that the cross-sectional view of differential gear and the working principle of differential gear. According to the principle of geometry of gear.

5. REFERENCES

1. Preston, J.M. (1987), Aveling & Porter, Ltd. Rochester. North Kent Books includes sectional drawing.
2. Chocholek, S. E. (1988) "The development of a differential for the improvement of traction control"
3. Bonnick, Allan. (2001)"Automotive Computer Controlled Systems
4. Bonnick, Allan. (2008). Automotive Science and Mathematics
5. History of the Automobile". Gmcanada.com
6. S.Md.Jalaluddin., 2006, "Machine Design, "Anuradha publications, Chennai.
7. ThirupathiChandrupatla, Ashok D.Belegundu, "Introduction to finite element in Engineering" , 2003
8. PSG, 2008." Design data," KalaikathirAchchagam publishers, Coimbatore, India.
9. S.Mahalingam, R.E.D Bishop, 1974, "Dynamic loading of Gear tooth", Journal of sound and vibration.
10. V.B.Bhandari, Design of Machine Elements.