Automatic Differential Locking System

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Abstract – *The conventional differential supplies almost equal amount of torque to the wheels on the straight path but the problem arises when wheels goes under the action of turning. This dissertation concentrates on introducing Automatic Locking System in the conventional differential unit of an automobile so that a perfect distribution of the torque can be achieved when the vehicle takes a turn and the problems like spinning of wheels are overcome. Engagement or disengagement of this locking system can be activated manually or automatically depending on the driving conditions. If the difference in the speed of driven and rolling wheels is encountered then the differential is exposed to automatic locking. Some additional attachments of shafts and power transmission devices is done to achieve the locking of differential which results in exact distribution of torque so that perfect turning of the vehicle is performed.*

Key Words: conventional differential, torque, Automatic Locking System, spinning of wheels, power transmission, perfect turning

1. INTRODUCTION

1.1 The Transmission System and Layout

The purpose of an engine is to generate the power so that driving of an automobile can take place. Clutch mechanism is used for connecting and disconnecting an engine and the transmission system in a vehicle. The utilization of power generated by an engine needs to be done under certain controls and to achieve this control over the power, Transmission System is used.

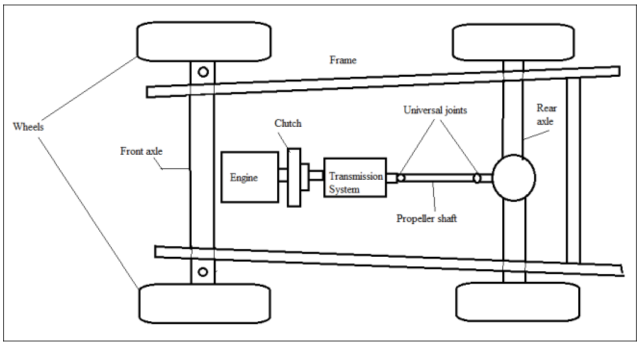

Fig -1: Basic components of an Automobile

Crankshaft is the backbone of internal combustion engines and it is responsible for the proper operation of the engine and transforming a linear motion to a rotational motion. The torque and rotations generated by engine needs to be transferred to a certain distance and this transmission is done with the help of Drive Shaft.

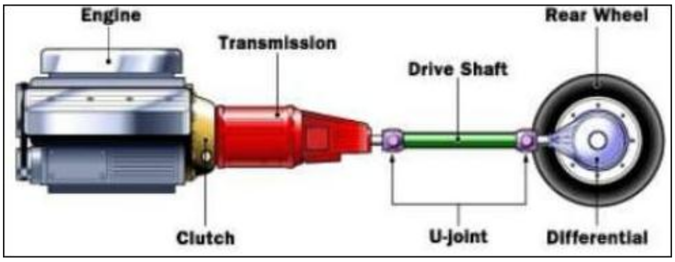

Fig -2: Transmission System Layout

The power carried by the drive shaft needs to be divided between two half axles so the proper rotation of the wheels can be achieved according to the straight driving and turns. This purpose is achieved by introducing Differential Gear System into the unit.

1.2 Differential System

While cornering, the inner wheel needs to travel a shorter distance as compared to outer one to avoid the problem of spinning and dragging, unpredictable handling as well as damage of the tires of vehicle. A system designed to drive a pair of wheels properly at different speeds to achieve perfect turning of the vehicle is called as Differential.

Torque reaches to the final unit of differential through drive shaft. This torque is further used by spiral bevel pinion mounted in the housing of differential unit. The pinion meshes with spiral bevel ring gear also known as Crown Wheel is attached to the differential cage. The Differential Cage has cluster of four opposed bevel gears such as each bevel gear is allowed to mesh with two neighbor gears in perpendicular plane. The two sun wheel gears are aligned on the same axis as the crown wheel gear, and drive the axle shafts connected to the driven wheel. The other two planet gears are aligned on a perpendicular axis which changes orientation with the ring gear's rotation. There is no differential movement of the planetary system of gears when the vehicle is moving in straight direction.

If the driven road wheels are lifted clear of the ground with the engine off, and the drive shaft is held manually rotating, one driven road wheel causes the opposite road wheel to rotate in the opposite direction by the same amount. Therefore rotation of the crown wheel gear is always the average of rotations of the side sun gears.

The unfortunate disadvantage of Conventional Differential is that it limits the traction under less than ideal conditions. Traction is the amount of torque that can be generated between the tire and the road surface, before the wheel starts to slip. If the torque applied to drive wheels does not surpass the threshold of traction, the vehicle will be propelled in the desired direction otherwise one or more wheels will directly spin.

The load on vehicle at a particular position decides the traction required to propel the vehicle also there are multiple factors such as gradient of the road, drag and friction as well as the vehicle's momentum which affects the traction requirements.

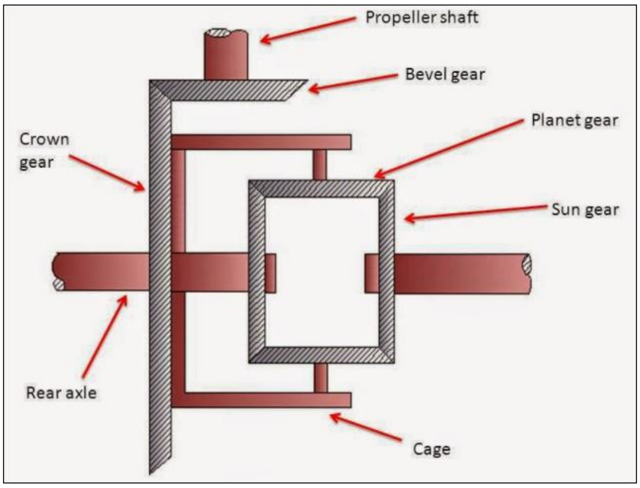

Fig -3: Differential Gear

2. AUTOMATIC DIFFERENTIAL LOCKING SYSTEM

The review reported by Provatidis regarding the concept of gearless differential can be utilized to distribute the power to the wheels. The Anti-lock braking system is also introduced in newer vehicles to limit the slippage of low traction wheel. There are various devices like Positive Traction, Limited Slip Differential, Locking Differential and Active Differential which help to get more usable traction from vehicles with differentials.

The difference between torques of two axles is very high under slip condition and when differential is locked, the value of torque between two axles is approximately equal. In the case of losing traction due to mud, pit or slippery surface, the locking effect will provide it more speed to overcome the problem. Therefore a simple Automatic Locking Mechanism can be designed to get the desired torsion effect.

3. DESIGN AND CALCULATIONS

3.1 Motor

This motor is used to drive the pinion shaft and acts as an engine.

Single phase AC motor
Commutator motor
TEFC construction
Power = 1/15hp=50 watt
Speed= 0-6000 rpm (variable)

Motor is a Single phase AC motor with 50 watt power. Its speed is continuously variable from 0 to 6000 rpm. The speed of motor is varied by means of an electronic speed variation device. The current to this motor is supplied by means of carbon brushes. The power input to motor is varied by varying the current supply to these brushes by an electronic speed variation device.

3.2 Belt Drive

Open belt drive using V-belt
Motor pulley (D1) = 25 mm
Main shaft pulley (D2) = 100 mm
Reduction ratio (D2/D1) = 4
Input Power = 0.05 KW
Input Speed = 1000 RPM
Center Distance (C) = 210 mm
Max. Belt Speed (Vb) = 1600 m/min
= 26.67 m/sec
Groove Angle (2ø) = 400
Co-efficient Of Friction (μ) = 0.25
Between Belt and Pulley allowable tensile stress (fall)
= 8 N/mm2

Table -1: Belt Parameters

C/S symbol	Usual load of drive P (KW)	Nominal top width W (mm)	Nominal thickness T (mm)	Weight per meter M (Kg/m)
FZ	0.03-0.15	6	4	0.05

sin α = (R2-R1)/(C)
= (D2-D1)/(2C)
= (100-25)/(2*100)
= 0.1795
α = 10.29°
Angle of Contact (θs) = π – 2α
= π – 2*0.1795
= 2.783 rad
Centrifugal Tension (Tc) = M*Vb^2
= 0.05*26.67^2
= 35.56 N
Maximum Tension in Belt (Tmax) = fall*Area
= 8*20 = 160 N
Tension in Tight side of belt (Tft);
Tmax = Tc*Tft
160 = 35.56*Tft
Tft = 124.4 N
Tension in slack side of belt (Tfs)
Tft/Tfs = e^[(μ* θs)/sinϕ]
= e^[(0.25*2.78)/sin20]
= 7.75
Tfs = 16 N
Power Transmitting Capacity of Belt;
P = (Tft-Tfs)*Vb
P = (124.24-16)*26.67
= 3.13 KW

3.3 Belt Results

Select belt "FZ 6 x 600" from standard manufacturer's catalogue. MAKE: HELICORD.

Table -2: Belt Result Table

01.	Belt Selected	FZ 6 x 600
02.	Tight Side Tension (Tft)	124.24N
03.	Slack Side Tension (Tfs)	16N
04.	Motor Pulley Diameter (D1)	25mm
05.	Pulley Diameter (D2)	100mm

3.4 Torque

Power (P) $= (2\pi NT)/60$

$T = (60*P)/2\pi N$

$T = (60*50)/ 2\pi*800$

$= 0.5968Nm$

$G = T2/T1$

$T2 = G*T1$

$= 4*4.3*0.5968$

$= 10.265Nm$

Considering 100% overload;

$T2 = 10.256*2$

$= 20.53Nm$

$= 20.53*10^3Nmm$

Force Acting;

$T = F*r$

$F = T*(2/D)$

$= (20.53*10^3)*(2/87)$

$= 471.954N$

3.5 Dog Ring

Pin is located at PCD (D) = 87 mm

Area of Pin (A) $= b*h$

$= 5*3$

= 15 mm sq.

Table -3: Dog ring material properties (PSG Design Data Book Pg.no.1.17)

Designation	Tensile Strength (N/mm sq.)	Yield Strength (N/mm sq.)
EN 24	850	680

Pin on Dog ring is located on PCD as 87 mm. This pin engages in the cage of the spike shaft and act as transmission elements. It can be designed similar to the bush pin in the bush pin type flexible flange coupling. Single pin transmits the entire torque.

Shear Stress = (Shear Force)/(Shear Area)

$\tau act = Ft/A$

$= 471.954/15$

= 31.4639 N/mm sq.

Where;

Ft = Tangential force on each pin

A = Area of pin under shear

τact = Actual shear stress

Allowable Shear Stress (τall) $= (0.5Syt)/FOS$

$= (0.5*680)/3$

= 113.33 N/mm sq.

τact < τall, hence the design is safe.

3.6 Spike Shaft

Table -4: Spike shaft material properties (PSG Design Data Book Pg.no.1.17)

Designation	Tensile Strength (N/mm sq.)	Yield Strength (N/mm sq.)
EN 24	850	680

ASME code for design of shaft

$\tau per = 0.18*Sut$

$= 0.18*850$

= 153 N/mm sq.

Or

$\tau per = 0.3*Syt$

$= 0.3*680$

= 204 N/mm sq.

Consider minimum of the above values.

Shaft is provided with key way; this will reduce its strength. Hence reducing above value of allowable stress by 25%

τper = 114 N/mm sq.

This is the allowable valve of shear stress that can be induced in the shaft material for safe operation.

Torsional shear failure of shaft;

Assuming minimum section diameter on input shaft d = 16 mm

$Td = (\pi/60)* \tau act*d^3$

$\tau act = [16/(\pi*d^3)]*Td$

$= (16*20.53*10^3)/(\pi*16^3)$

= 25.5269 N/mm sq.

τact < τper, Spike shaft is safe under torsional load.

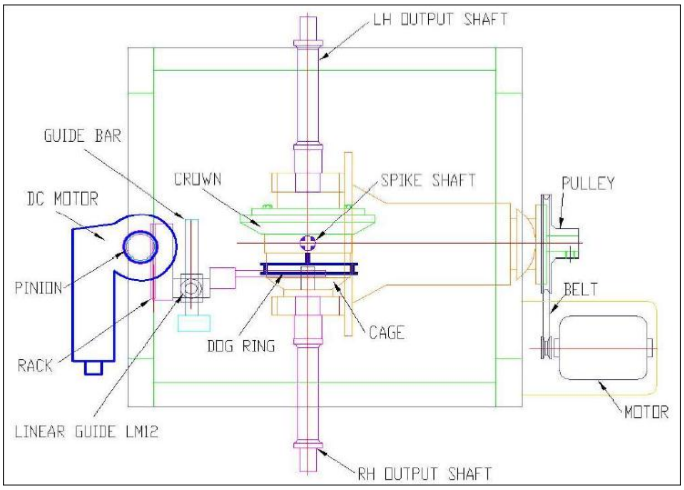

Fig -4: Automatic Differential Locking System

4. ADVANTAGES AND DISADVANTAGES OF AUTOMATIC DIFFERENTIAL LOCKING SYSTEM

4.1 Advantages

1. It improves better traction control for wheels.
2. Can be easily employed in all common vehicles.

3. It ensures better vehicle stability on uneven road conditions.
4. System is better than semi-automatic system with less human effort.
5. Low grade lubricants can be used as heat loss is reduced.
6. As electronic circuitry is used, response time, control and reliability are better than other existing systems.

4.2 Disadvantages

1. Due to assembling spike shaft in cage the strength of cage will be reduced slightly.
2. At high speed it is impossible to engage dog pin into spike shaft, since it will cause system failure.
3. ADLS make clicking or banging noise when locking and unlocking.
4. It can cause loss of control on ice.
5. Because they do not operate as smoothly as standard differential there is increased tire wear.
6. High initial cost.

5. CONCLUSIONS

From the above study, conclusions drawn are;

1. The set-up for automatic engagement of the differential when the loss of traction condition is encountered is designed by introducing automatic differential locking system.
2. Under slip condition, when differential is under action, the difference between torques of two axles is very high as well as the Torque and Speed are inversely proportional to each other.
3. When the differential is working and if one wheel loses its traction due to mud, pit or slippery surface, the locking effect will provide it more speed to overcome traction loosening.

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