SEMI-AUTOMATIC LOCKING DIFFERENTIAL

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Abstract-:'Semi-automatic (manually operating) locking differential' is regarded as an effective method for differential locking system. Day by day differential locking system is gaining more importance for giving more traction to the vehicles. Different techniques have been developed. Each of them has its own advantages and disadvantages. This paper presents a new semi-automatic differential locking system using dog ring and dog pin in differential gear box assembly. In contrast to the existing methods, our locking system is good in operation and cheap as compare to the fully automatic locking system. As per above mention this system consist of three parts; One is assembly of dog ring and pin, second is spike shaft and third is motion providing assembly. It is proposed to analyse the experimental results for effectiveness of the proposed system with existing one.

Keywords— Differential locking system, Spike shaft, Dog ring, Dog pin, Differential, DLS, Spider.

I. INTRODUCTION

For effective rolling of wheels on any ground surface we provide the traction to the wheels. Presents automatic locking system is costly and it requires sensors & circuits. Also it provides traction to the both wheels separately by splined cylinder which lock with the differential case or cage.

One problem with an automotive differential is that if one wheel is held stationary, the other wheel turns at twice (approx. based on law of gearing) its normal speed. This can be problematic when one wheel does not have enough traction, such as when it is in snow, mud or on slippery surface. So that the car does not move.[1]

Presently the traction control devices used in all costly vehicles are:

- Clutch type limited slip differential (LSD)
- Automatic torque baising (ATB)
- Antilock braking system (ABS)
- Electronic stability programe (ESP)
- Four wheel drive (4 WD)
- Fully automatic locking differential.

The question arises that though having 'Fully automatic locking differential' then why to have 'Semi-automatic (manually operating) locking differential'?

-The answer is that due to fully automatic system, the locking effect is done with the use of sensors through circuits. Hence 'fully automatic system' becomes not only too complex but also too costly & only can be implement with vehicles such as Hummer, Toyota pirus & army (defence) vehicles.

Our focus is to bring alternative to this sensor & circuit by simple mechanism & achieving this differential locking system semi-automatic (manually operating) so that it can be easily implemented with all commonly used vehicles.

The axle on which the actual drive is mounted (rear axle in case of rear axle drive & front axle in case of front axle drive) is called the live axle. The live axle has a differential gear system (made of bevel gears or worm gears) which divides the incoming power from the propeller shaft equally between the two half-axles (one leading to one of the two wheels each).[2] While we are travelling on the road, the torque requirements for the vehicle are varied. For example, high torque is needed to get the vehicle moving from a position of rest. Sometimes, you might want to accelerate rapidly - in the case of overtaking. In all of these cases, how the engine's power is leveraged to provide your wheels that power surge? A complex arrangement of gears makes all this possible.

Added to this, there is this fact that while negotiating a corner, the outer wheels must rotate faster than the inner wheels & to achieve this, there is a separate gearing called as 'the differential" which makes that possible.[2]

II. AUTOMOBILE DIFFERENTIAL GEAR SYSTEM:

2.1 Theory of Operation :

The gearing of an automobile differential is illustrated as shown in figure below:

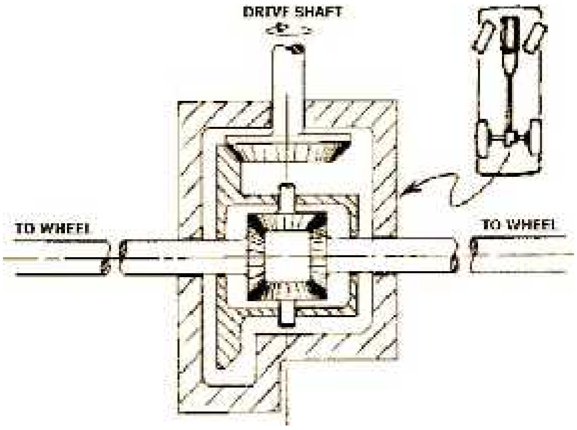


Fig.2.1 Automobile Differential Complete Schematic

Without the "square" set of four gears in the middle of the above diagram (figure 2.1) which yields to the figure below(figure 2.2), both wheels turn at the same angular velocity. This leads to problems when the car moves through turn.

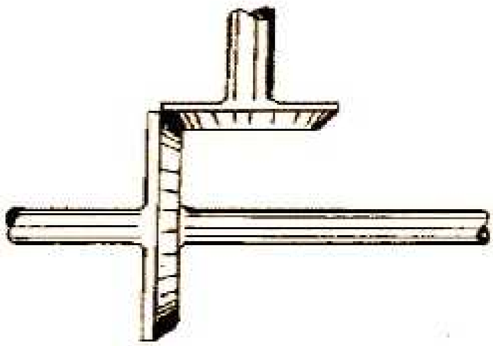


Fig.2.2 Automobile Wheel Drive without Differential

Now imagine the differential "square" alone, as illustrated in the following figure (figure 2.3). It should be apparent that turning one wheel results in the opposite wheel turning in the opposite direction at the same rate.

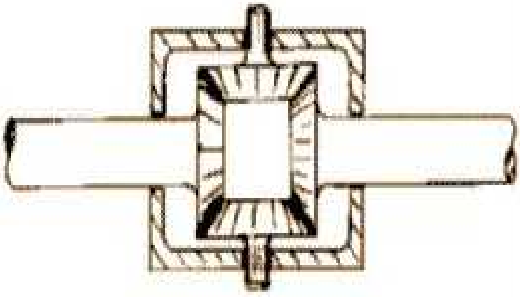


Fig.2.3 Automobile Differential Alone

This is how the automobile differential works. It only comes into play when one wheel needs to rotate differentially with respect to its counterpart. When the car is moving in a straight line, the differential gears do not rotate with respect to their axes. When the car negotiates a turn, however, the differential allows the two wheels to rotate differentially with respect to each other.

2.2 Differential (Mechanical Device) literature review:

The simplified view of Automobile Differential gearing is shown in Figure 2.4. The various parts of it are listed below:

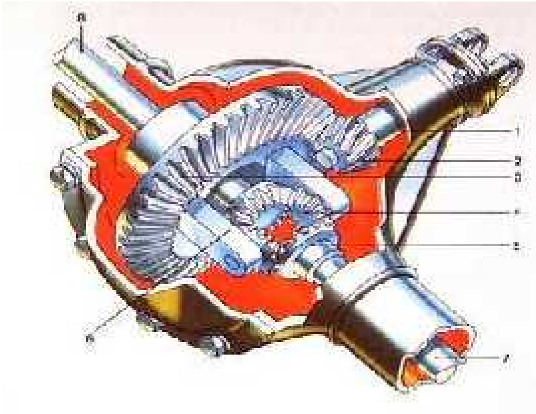


Fig.2.4 Automobile Differential (Simplified view)

- Propeller (Input) Shaft
- Bevel Pinion
- Crown Wheel (Ring Gear)
- Planet Pinion
- Sun Gear (Side Gears)
- Cage (Differential housing)
- RH axle Shaft
- LH axle Shaft

The drive shaft ends in a bevel pinion inside the differential. When the drive shaft turns, the pinion drives a ring gear that is part of the differential housing, so that both housing & ring gear rotate together. Inside the housing are two planet pinions & two side gears; each side gear is connected, via an axle, to a drive wheel. When the car drives straight ahead & the axle shafts turn at the same speed, the differential housing rotates, but no differential action occurs.

When the car negotiates a turn, however, the differential must compensate for the difference in distance traveled by the drive wheels. The pinions roll around the side gears, allowing the inside wheel to turn more slowly & the outside wheel to turn faster.[2]

2.3 Purpose of Differential:

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 &(or) the outer wheel dragging & this results in difficult & unpredictable handling, damage to tires & roads & strain on (or possible failure of) the entire drivetrain.

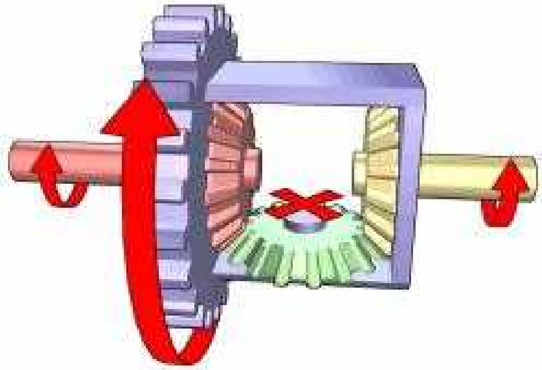


Fig.2.5(a) Automobile Differential on Straight Road Condition

Input torque is applied to the ring gear (blue), which turns the entire carrier (blue). The carrier is connected to both the side gears (red and yellow) only through the planet gear (green). Torque is transmitted to the side gears through the planet gear. The planet gear revolves around the axis of the carrier, driving the side gears. If the resistance at both wheels is equal, the planet gear revolves without spinning about its own axis & both wheels turn at the same rate.

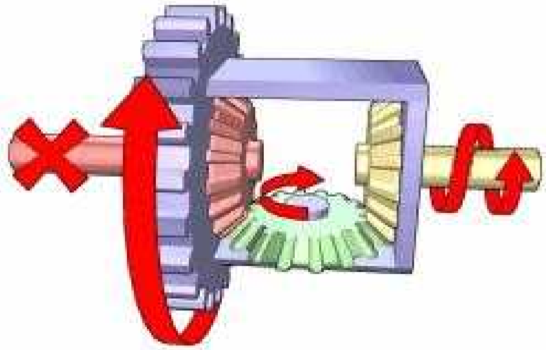


Fig.2.5(b) Automobile Differential While Taking Left Turn

If the left side gear (red) encounters resistance, the planet gear (green) spins as well as revolving, allowing the left side gear to slow down, with an equal speeding up of the right side gear (yellow).

III. PROBLEM DEFINITION & NEED FOR PROJECT:

3.1 Loss of Traction:

One undesirable effect of a conventional differential is that it can limit traction less than ideal conditions. The amount of traction required to propel the vehicle at any given moment depends on the load at that instant & how heavy the vehicle is, how much drag & friction there is, the gradient of the road, the vehicle's momentum, & so on.[1][3]

The torque applied to each driving wheel is a result of the engine, transmission & drive axles applying a twisting force against the resistance of the traction at that roadwheel. It is therefore convenient to define traction as the amount of torque that can be generated between the tire & the road surface, before the wheel starts to slip.[2]

Many newer vehicles feature traction control, which partially mitigates the poor traction characteristics of an open differential by using the anti-lock braking system to limit or stop the slippage of the low traction wheel, increasing the torque that can be applied to both wheels.

IV. SOLUTIONS (DESIGN IDEAS & ALTERNATIVES):

There are various devices for getting more usable traction from vehicles with differentials. These devices are called as 'Traction-aiding devices'. In this, we see some traction-aiding devices & design ideas till now, being used as alternative solution to our problem definition.

4.1 Clutch Type L.S.D. (Limited Slip Differential):

One solution is the Positive Traction (Posi), the most well-known of which is the clutch-type. With this differential, the side gears are coupled to the carrier via a multi-disc clutch which allows extra torque to be sent to the wheel with higher resistance than available at the other driven road wheel when the limit of friction is reached at that other wheel. Below the limit of friction more torque goes to the slower (inside) wheel.

Fig.4.1 Cutch Type Limited Slip Differential

A limited slip differential (LSD) or anti-spin is type of traction aiding device that uses a mechanical system that activates under centrifugal force to positively lock the left & right spider gears together when one wheel spins a certain amount faster than the other. This type behaves as an open differential unless one wheel begins to spin & exceeds that threshold. The LSD will remain open unless enough torque is applied to cause one wheel to lose traction & spin, at which point it will engage. A LSD can use clutches like a posi when engaged, or may also be a solid mechanical connection like a locker or spool. It is called limited slip because it does just that; it limits the amount that one wheel can 'slip' (spin).[2][3]

4.2 Anti-lock Braking System:

Electronic traction control systems usually use the anti-lock braking system (ABS) road wheel speed sensors to detect a spinning road wheel, & apply the brake to that wheel. This progressively raises the reaction torque at that road wheel & the differential compensates by transmitting more torque through the other road wheel the one with better traction.[2]

4.3 Four Wheel Drive (4WD):

A four-wheel drive (4WD) vehicle will have at least two differentials (one in each axle for each pair of driven roadwheels) & possibly a centre differential to regulate torque between the front & rear axles (Figure 4.2) to divide the torque asymmetrically, but at a fixed rate between the front & rear axle.[2]

4WD vehicles without a centre differential should not be driven on dry, paved roads in four-wheel drive mode, as small differences in rotational speed between the front & rear wheels cause a torque to be applied across the transmission.

This phenomenon is known as 'wind-up' & can cause considerable damage to the transmission or drive train. On loose surfaces these differences are absorbed by the tire slippage on the road surface.

A transfer case may also incorporate a centre differential, allowing the drive shafts to spin at different speeds. This permits the four-wheel drive vehicle to drive on paved surfaces without experiencing 'wind-up'.

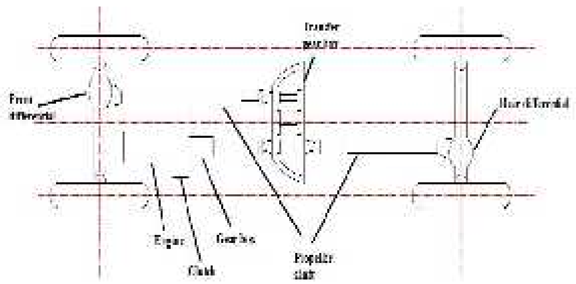


Fig.4.2 Layout of a four wheel drive

4.4 Locking Differential:

A locking differential, such as ones using differential gears in normal use but using air or electrically controlled mechanical system, which when locked allow no difference in speed between the two wheels on the axle. They employ a mechanism for allowing the axles to be locked relative to each other, causing both wheels to turn at the same speed regardless of which has more traction. Automatic mechanical lockers do allow for some differentiation under certain load conditions, while a selectable locker typically couples both axles with a solid mechanical connection like a spool (pin) when engaged.

Fig.4.3 Locking Differential with locking pin (model)

This system also shows in following figure 4.4. This figure shows the semi automatic or manually operating locking system.

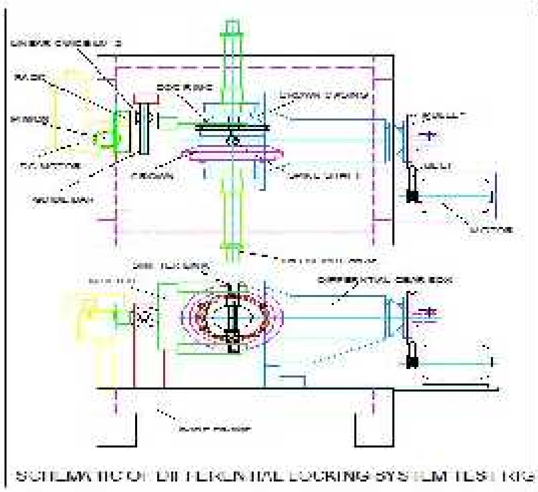


Fig.4.3 Schematic diagram of Differential Locking system test rig.

V. 'SEMI-AUTOMATIC LOCKING DIFFERENTIAL' :

5.1 How it works? :

The main components of 'Semi-automatic Locking Differential' are spike shaft, dog pin, dog ring, shifter, C-clamp, rack & pinion & DC motor etc.

While differential is in action & one wheel looses it's traction due to slippery surface; the angular speed of free wheel increases by large amount & all power goes waste by that wheel & vehicle cannot move further.

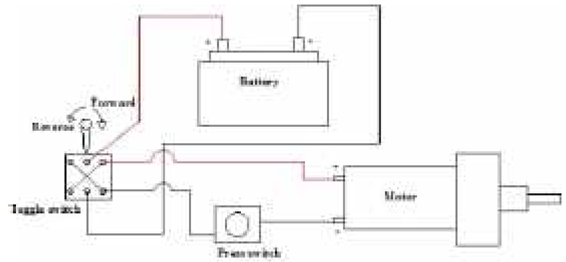


Fig.5.1 Electric arrangement of test rig.

To provide the traction to another stationary wheel, driver can actuate toggle switch & presses press switch to run the DC motor (anti-clockwise) to give forward motion to rack which gives this motion to shifter link to engage dog pin into slots of spike shaft through dog ring (ref. figures nos. 4.3 & 5.1).

As the separate rotations of spike shaft along with it's axis stops; it (spike shaft) stops the planet pinion to roll separately. Hence differential action stops. Thus wheel which was stationary now can get power which was wasted earlier. Then both wheels can get same (50/50) power.

After solving this problem to disengage dog pin; driver can actuate toggle switch in reverse to run the DC motor clockwise to give backward motion to shifter link & thus vehicle can get it's normal condition.

5.2 Trial on differential locking system (semi-automatic) :

- Aim : Trial on 'Differential locking system test rig.'
- Apparatus : Differential locking system test rig., Voltage supplier (12 volts output), Electronic speed regulator, Motor (prime mover), Tachometer etc.

Fig.5.2 Setup of test rig.

- Observations :

1. Input power, Pin = 50 watts
2. Diameter of axle shafts ,d = 16 mm[4] 3.Speed at right axle = NR
4.Speed at left axle = NL

5.Angular velocity at right axle = ωR
6.Angular velocity at left axle = ωL

7.Torque at right axle = TR
8.Torque at left axle = TL

7. 9.Case 1 = When both wheels turns at same speed (straight road condition)
8. 10.Case2=While turning on left side (differential in action)
9. 11.Case 3 = Actuation of locking system (when differential is locked)
10.

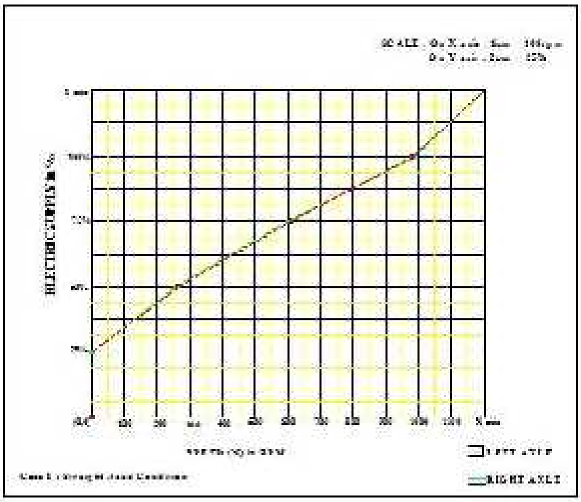
- Formulae used :[5]

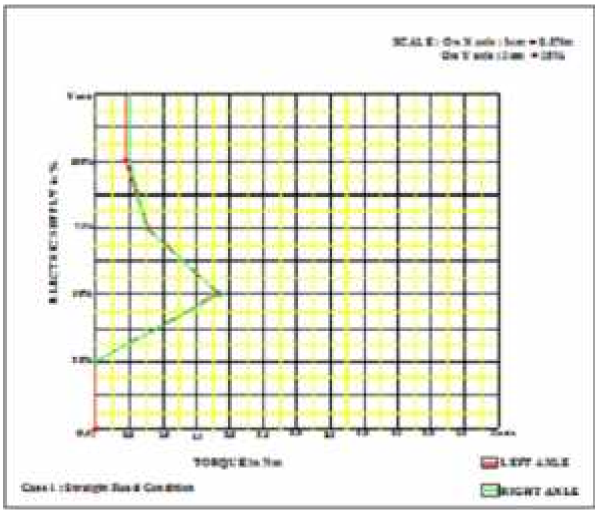
1.Angular speed ,ω = (2*π*N) / 60 ….rad / sec
2.Power input ,Pin = ω*T ………………...watts
3.Actual speed ratio = (Nmotor / Npropeller shaft)

- Observation & Calculation table :

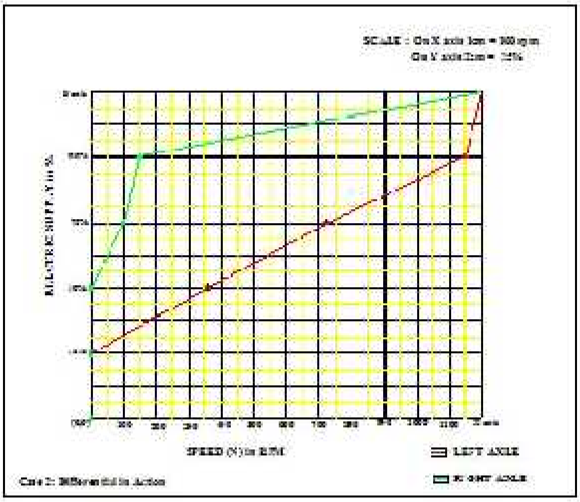
Case 1 : When both wheels turns at same speed (straight road condition)

Sr. No.	Electrical Supply	Speed N (rpm)		Angular Velocity ω (rad/sec)		Torque T (Nm)		Speed Ratio
		N_R	N_L	ω_R	ω_L	T_R	T_L	
1.	0 %	0	0	0	0	0	0	0
		0	0	0	0	0	0	
2.	25%	0	0	0	0	0	0	0
		0	0	0	0	0	0	
3.	50%	267	268	27.96	28.06	1.79	1.78	(5448 / 1544) = 3.53
		250	250	26.18	26.18	1.91	1.91	
		260	261	27.23	27.33	1.84	1.83	
4.	75%	616	610	64.51	63.88	0.78	0.78	(6670 / 2830) = 2.36
		593	596	62.09	62.41	0.81	0.80	
		603	603	63.15	63.15	0.79	0.79	
5.	100%	997	995	104.41	104.19	0.48	0.48	(9756 / 4551) = 2.14
		1005	998	105.24	104.51	0.48	0.48	
		980	985	102.63	103.15	0.49	0.48	


Graph.1.1 Speed v/s Electric supply (case 1)



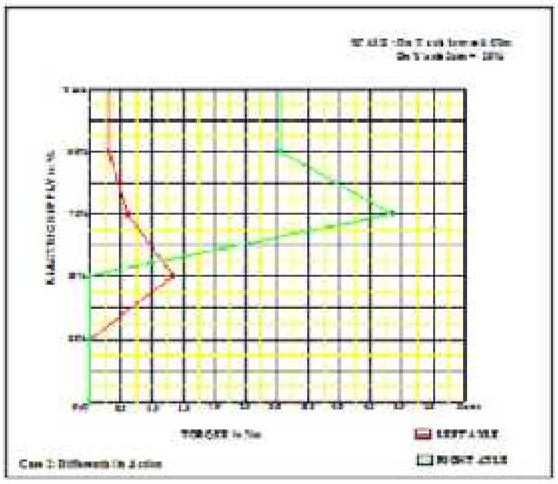
Graph.1.2 Torque v/s Electric supply (case1)



Graph.2.1 Speed v/s Electric supply (case 2)

Case 2 : While turning on left side (Differential in action)

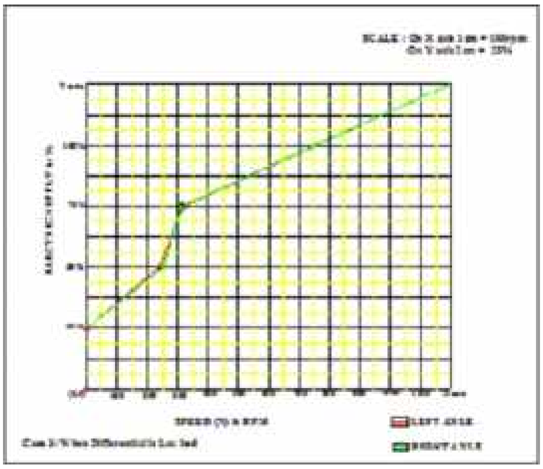
Sr. No.	Electrical supply	Speed N (rpm)		Angular velocity ω (rad/sec)		Torque T (Nm)		Speed ratio
		N_R	N_L	ω_R	ω_L	T_R	T_L	
1.	0%	0	0	0	0	0	0	0
		0	0	0	0	0	0	
2.	25%	0	0	0	0	0	0	0
		0	0	0	0	0	0	
3.	50%	0	365	0	38.22	0	1.31	(5448 / 1544) = 3.53
		0	360	0	37.69	0	1.33	
		0	366	0	38.33	0	1.30	
4.	75%	100	723	10.47	75.71	4.78	0.66	(6670 / 2830) = 2.36
		96	718	10.05	75.19	4.98	0.66	
		100	710	10.47	74.35	4.78	0.67	
5.	100%	150	1415	15.71	148.18	3.18	0.34	(9756 / 4554) = 2.14
		152	1450	15.92	151.84	3.14	0.33	
		153	1432	16.02	149.96	3.12	0.33	



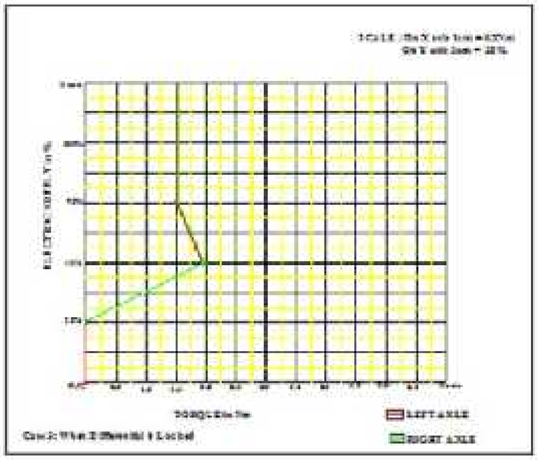
Graph.2.2 Torque v/s Electric supply (case2)

Case 3 : Actuation of locking system (when differential is locked)

Sr. No.	Electrical supply	Speed N (rpm)		Angular velocity w (rad/sec)		Torque T (Nm)		Speed ratio
		N_R	N_L	W_R	W_L	T_R	T_L	
1.	0%	0	0	0	0	0	0	0
		0	0	0	0	0	0	
2.	25%	0	0	0	0	0	0	0
		0	0	0	0	0	0	
3.	50%	250	248	26.18	25.97	**1.91**	**1.93**	(5448 / 1544) = 3.53
		242	245	25.34	25.66	**1.97**	**1.95**	
		258	255	27.02	26.70	**1.85**	**1.87**	
4.	75%	312	320	32.67	33.51	**1.53**	**1.49**	(6670 / 2830) = 2.36
		312	302	32.67	31.94	**1.53**	**1.57**	
		310	312	32.46	32.67	**1.54**	**1.53**	
5.	100%	At high speed it is impossible to engage dog pin into spike shaft; since it will cause system failure.						(9756 / 4551) = 2.14



Graph.3.1 Speed v/s Electric supply (case 3)



Graph.3.2 Torque v/s Electric supply (case 3)

V1. APPLICATIONS:

6.1 Non-automotive applications:

There are some non-automotive applications are present which makes use of differential gearing. This means that differential gearing is not invented only for automotive purpose; some of the examples are explained below:

1) The oldest known example of a differential was once thought to have used such a train to produce the difference between two inputs. A differential gear train can be used to allow a difference between two input axles.

2) Mills often used such gears to apply torque in the required axis.

6.2 Automotive applications:

1) Fully Automated locking differential is used in costly vehicles for better traction control.

2) Race Cars often use locking differential in order to maintain traction during high speed.

3) Some utility vehicles such as tow trucks, forklifts, Military Trucks etc. use locking differential to maintain traction on muddy, slippery & uneven surface.

V11. ADVANTAGES &DISADVANTAGES:

7.1 Advantages:

1) It ensures better vehicle stability on uneven road conditions

2) It improves better traction control for wheels

3) System is less complicated due to absence of sensors & circuits.

4) System is cheaper than fully automatic system & also gives same function of it.

5) Can be easily employed in all common vehicles.

7.2 Disadvantages:

1) At high speed it is impossible to engage dog pin into spike shaft, since it will cause system failure.

2) Due to assembling spike shaft into cage; the strength of cage will reduce slightly.

3) The driver should be active, since the assembly is manually operated.

V111. CONCLUSIONS:

1.Torque & speed are inversely proportional to each other.

2.As we increase the power supply; the speed increases while the torque decreases.

3.At case 2, when differential is under action, the difference between torques of two axles is very high.

4.At case 3, when differential is locked, the value of torque between two axles are approx. same.

5.Thus, while differential is working & if one wheel looses it’s traction due to mud, pit or slippery surface;

The locking effect will provide it more speed to overcome traction loosening.

6.Our focus is to bring alternative to this sensor & circuit by simple mechanism & achieving this differential locking system semi-automatic (manually operating) so that it can be easily implement with all commonly used vehicles.

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