International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 05 Issue: 05 | May-2018 www.irjet.net p-ISSN: 2395-0072

Recent Advances in Differential Drive Systems for Automobile Propulsion

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Abstract - *First car was invented by Karl Benz in 1887 and car is modifying day by day from last 130 years. Although today's automobile looks different from that first invented, the power transmission system has not changed enough. The engine, clutch, gear box, propeller shaft and simple differential are being used from last 130 years have some limitations as today's lifestyle is 130 year ahead of that system. Generally, some limitations regarding differential can be observed such as one or both wheels of drive system lifted up, on slippery track, stucked into mud or stucked to obstacle then, vehicle struggles to move further. In said situations rate of failure to overcome the problem is very high in conventional as well as some of the modern differentials. Hence a comparative study among all of these differentials becomes essential. It is hoped, this paper will help us to know various differentials available.*

Key Words: *Differential, Automobile, Wheels, Drive system, Torque transmission, Energy Distribution, vehicle propulsion, two wheel Drive, Front axle, Rear axle, slippery track, off road conditions.*

1. INTRODUCTION

The topic 'Recent advances in differential drive system for automobile propulsion' starts with first car on the road. In ancient time for human being there was no way to transport of things, goods, stuffs from one place to another place except handling it manually by lifting on shoulders and keep walking until final destination reached. Later after evolution of human thinking capacity he invented wheel and a cart was made for transporting goods. The cart was firstly manually driven and later animals were used to pull the cart. In 1887 first car was invented by Karl Benz. Rather using animals to pull cart he was thinking for successful self-propelled car by use of steam-engine. The first car was having rear wheel drive with chain system. When a vehicle is travelling along a path and single shaft is used to drive both wheels at same speed, then system fails to turn. The vehicle will move in straight line as both driving wheels are moving with same velocity. To overcome such condition differential was invented. In differential of the vehicle both wheels can receive different torque, also it can turn in any direction without stopping power transmission.

Differential used today has some limitations. When one of the wheels is on slippery track, the power will be transmitted more to the slipping wheel rather than opposite wheel which is on normal surface. In case of vehicle when it is moving in off-road conditions, if one wheel stuck to obstacle then the vehicle will not move from its place. If wheel is passing through mud then, the vehicle will not move further. To avoid such conditions, the locking differential was invented and used in practice. In locking differential, the vehicle can move by transferring power to one wheel by means of clutch or by a centrifugally activated locking mass although another wheel is on slippery track. But again in off-road conditions, it will not work properly. Hence, a concept of all wheel drive is introduced. All-wheel drive provides power to all four wheels. The system can survive in slippery conditions as well as mud-road conditions. It is also useful in hilly areas, but the cost of locking the differential and all-wheel drive will be high. Similar problem is facing by agricultural sector. The tractors, tillers, trucks, power weeder and most of agricultural machines are subjected to same problem. Some manufacturers used locking differential, some used turning purpose clutches on single shaft drive, But using all of the above system increases cost and complexity; hence it is needed to define a technique which will overcome the above mentioned problem. Before going to know what is solution, we have to understand the problem deeply and possible alternative for it.

2. LITERATURE REVIEW

In the view of current research area various journals are referred for up-to-date technical content some of the researches are arranged in following section. (Shree Harsha Bandaru, 2015) [1] Discussed alternative transmission system for four wheeler and generated physical alternative solution for transmission component and smart parking system. In case of turning, friction rollers are used to transfer power from wheel to free rotating disc. When vehicle is moving straight, friction rollers transfer power to the wheels. This system works similar to the simple differential. (Dr. Thomas Smetana et al., 2010) [2] Identified that the active eDifferential system is a drive concept which could form the optimum platform for future control strategies. The final drive unit combines the spur gear differential with an intelligent lateral distribution of torque. When used on both axles, the active differential also enables the distribution of torque in the longitudinal direction of vehicle. (Mahesh Karande et al., 2015) [3] Identified that simple differential does not transmit same power to both wheels when vehicle get stuck into the mud. But due to relative motion between all

gears in the gearbox the stucked wheel rotates at double speed and due to this the vehicle gets again deeply stucked into mud. To move the vehicle out from the mud there is requirement of differential locking, by which both the rear axles are act as a solid shaft. In turning condition, differential should not be locked. It should be used only when the vehicle does not transferring equal torque to both wheels and vehicle is moving in a straight path.

(Qiang Li et al., 2015) [4] Presented paper for a novel controller of differential assist steering system. In this system, the integrated control module in electric vehicle is investigated, in which the front axle is refitted for two in-wheel motors. The genetic algorithm is used to optimize the control decision-making rules of fuzzy controller. This system can be used for practices such as low speed and double lane change operation. (Akshay Aggarwal, 2013) [5] Implied electronic controlled differential provides light weight structure with elimination of the gear box. Also during turn, power transfers to both wheel at different torque. (NISSAN motor company, 2010) [7] produced the four wheel active steer system. This system assists driver by automatically controlling the steering angle of a vehicle's four wheels according to speed. By controlling the steering angle of all four wheels, this active steering system helps to improve stability and response at high speed and helps to reduce steering workload at low speed. AUDI automobile manufacturer [6] Audi Quattro have center differential with cylkro face gear technology. In the crown gear differential, the gears are mounted without backlash. The result is a homogeneous conversion of the torque distribution without any delay. In conjunction with intelligent software in the braking system, the Quattro system assigns optimal torque to every driven wheel. Interventions of ESP system will be reduced to a minimum. This increases the drivability of the Audi RS 5 in every situation.

3. Study of various differentials

Today's available various differential are generated from problems present in simple differential. Steering feel and vehicle steering motion is affected by wheel torques in front wheel drive. The losses over the differential by torque steer can be observed by torque difference in left and right shaft. With a simple differential inside wheel is free to rotate under power at high torque and limits to the acceleration. In case of combined acceleration and turning. When vehicle travels on slippery track, there is possibility of getting one wheel stucked. These types of problem are inspiration to modify simple differential. Following are types of differential under this paper study.

3.1 Helical gear driven differential

The helical gear differential is made of two-components, a sun wheel which will rotate regarding a horizontal axis, and three planet gears that are placed on periphery at equal distance to one another on the axis of rotation and a wheel at body. The housing is made up of two parts that are fixed to one another.

In these spaces at the longitudinal axis into the peripheral space between two of the planet gears that are in contact with one another on the boundary. The planet gears beside one another at the peripheral distance relates to two planet gears that mesh with one another. The respective body provides for four planet pairs, and thus for four mounting sections that mesh partially into the peripheral space in a radial direction.

Figure 1: Helical gear driven differential [9]

3.2 Limited slip differential

LSD looks very similar to simple differential but in case of slippery track condition LSD provides advantage over simple differential by smart power transmission for the wheels. In a case where right wheel is on slippery track, the right wheel tries to turn faster than the other wheel; however, since the right gear is stopped by the clutch, little torque is transferred from the right wheel through clutch to the casing. While the left wheel is stopped and the one gear is turning at minimum speed, the differential case is turning at a high speed, and in compared with the right side, torque is transferred from the differential case through the clutch to the wheels. As a result, the left wheel receives a torque which is transferred from the right wheel through the clutch, differential case, left side clutch and left side gear, also the torque distributed from the pinion through the differential gear.

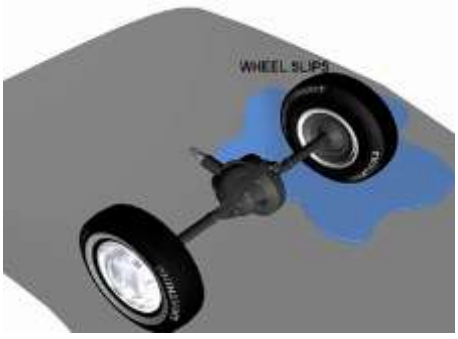


Figure 2: LSD on slippery track [10]

3.3 Clutch pack Differential

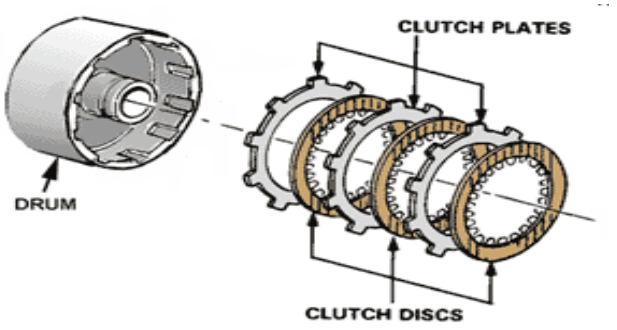


Figure 3: Locking differential by clutch pack [8]

A clutch pack contains alternating plates that sits inside a drum. Same number of the disks is of steel with splines which fits into groves at inner surface of the drum. Same number of disks has a friction surface and has splines on the inner edge that matches groves on the outside plane of the adjacent body. There are two clutch packs on each side and mounted on single shaft. When vehicle moves straight both of the clutches are engaged to shaft. When vehicle takes any turn then the cam is used to disengage wheel from the shaft. The cam is connected to steering system such that when vehicle takes left turn right wheel will disengaged and when right turn is taken the left wheel will disengaged. It is essential to apply clutch manually during any turn otherwise this system will travel straight ahead. Agricultural operations required equal torque for both wheels and clutch pack differential fits for it with low speed range.

3.4 Cylkro faced gear Differential

The Cylkro face gear with the highest number of teeth (first figure) is connected with the shaft to the rear wheel drive. Another face gear takes care of the power to the front wheel drive. In between the face gears, four planetary pinions are placed equally in a planet carrier that is driven by special gearbox with two clutches [6]. In situation, where is same spinning speeds of the face gears and the planet carrier. If any axles starts to rotating, such as, while it is snow, the engagement of self-locking face gear center differential will occur. The differential can distributes the torque for the front and rear axles by a package of plates. Up to 85% of the load can be fed to the rear, and as much as 70% toward the front-end. (Fig. 4) system could recognise this verity by locating and tolerating the connection design for the pinions and face gears. These connection designs have been defined by system with defined limits. This leads to axial loads on the face gears and on the plates pack, resulting in a change of the torque distribution in such a way that system could satisfy all Audi specifications. In the crown gear differential, the gears are mounted without backlash. The result is a homogeneous conversion of the torque distribution instantly. Also with intelligent software in the braking system, the Quattro system provides required torque to each wheel. This differential requires three differential units that are front, center and rear. And an intelligent system utilised when turn is to be taken, this system distributes higher power to inner wheel.

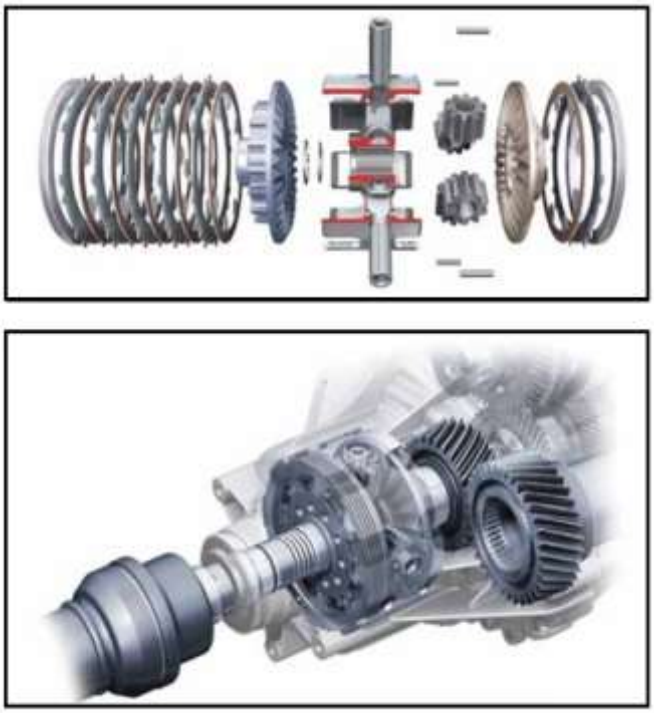


Figure 4: Cylkro faced gear Differential - Audi Quattro [6]

3.5 Electronic controlled differential

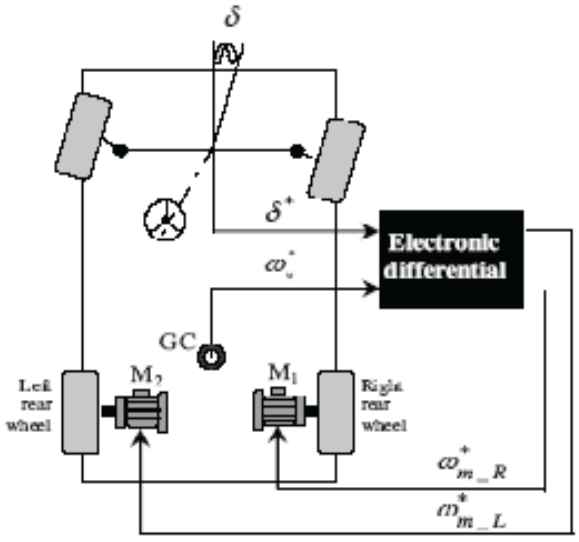


Figure 5: Electronic controlled differential [5]

Recent work is being held on to reduce weight of the body. The main attraction has always been reduction of weight using light weight materials for chassis and design modifications. Recently it is founded that motor control and its design have been modified. Modern configurations include motorized wheels, where motors

are fitted in the wheels and thus no pollution produced, Electronic differentials eliminates use of gear box and manual transmission methods. As gear box eliminated the total mass reduced due to replacement of simple differential. As shown in figure 5, the motor and controller works for speed variation configured with steering angle, also speed of vehicle is adopted and controller performs operations and relative speed difference is achieved. This system works very well during turning as well as conditions where one wheel spins freely. Electronic controlled differential suits for medium speed and both wheels receives individual power from each motor hence it is more reliable. The life of this differential may limits by conductivity and sensitivity of electronic parts.

3.6 Belt driven differential

In recent years, many small wheel-driven units have become popular. Golf carts, riding lawn mowers, small garden tractors, go-carts and many other devices having small gasoline engines or occasionally electrically powered are now sold in great numbers. Most of these devices are propelled through wheels contacting the ground and most have four wheels. The drive of such devices is usually either through a single, off-center wheel, or through two wheels connected to a solid axle. In the first case, the single wheel provides an off center drive so that the steering is effected and the wear on the tire of that wheel is increased.

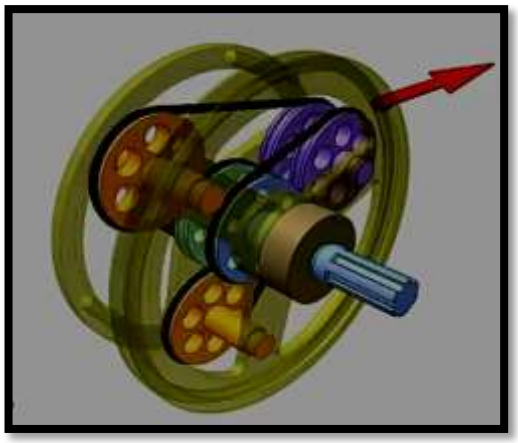


Figure 6: Belt driven differential [11]

In the second case, there must be slippage of one of two wheels on turning corners or the like so that tire wear is increased. The use of a differential mechanism is strongly indicated. However, the usual type of differential such as used in an automobile and having a ring gear and set of pinions and the like is far too expensive for the ordinary small unit. Therefore it is desirable to provide a mechanism which will accomplish the same end result with a less expensive and somewhat smaller unit.

3.7 Continuous variable transmission differential

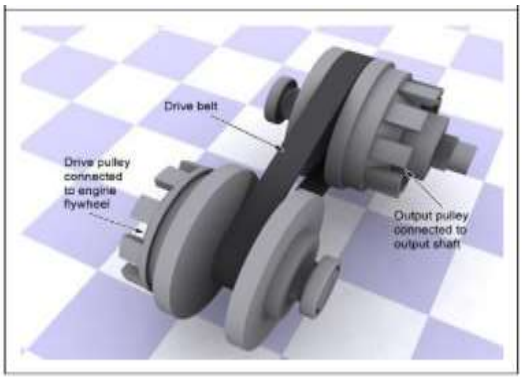
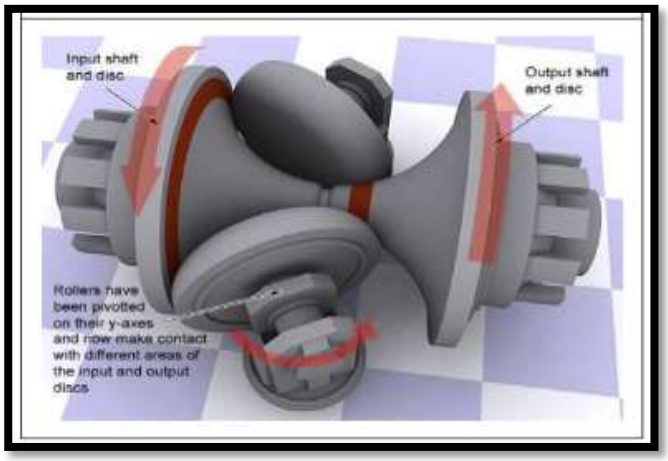


Figure 7: Continuous variable transmission differential [1]

First use of CVT as for non-gear vehicles but now advanced use of CVT is for a car is possible. The differential easily can be replaced with the CVT transmission. Two variable diameter pulleys carrying a single belt gives variation between two wheels. It is obvious that, CVT constructed between two rear wheels. First pulley will be connected to right wheel; another pulley will be connected left wheel. We need a controller which can sense the angle of steer and relative speed of vehicle. This CVT transmission provides reduction in transferred energy. Again the CVT transmission will work similar to the simple differential but if it is controlled well possibility of better performance in case of individual energy transmission to each wheel will increase.



3.8 Toroidal Transmission

Figure 8: Toroidal Transmission [1]

Both wheels on the drive system require unequal speed during turning and there should be a member who will sense the velocity change requirement and transfers unequal torques to both wheels. The variation of area on conical surface will be a speed changing component, the wheel which requires high speed; there will be more contact area between friction cones of driving and driven sides. The driving cones should be contacted with steering

system and this will give additional effect of speed while vehicle turns.

3.9 Locking differential by centrifugal force

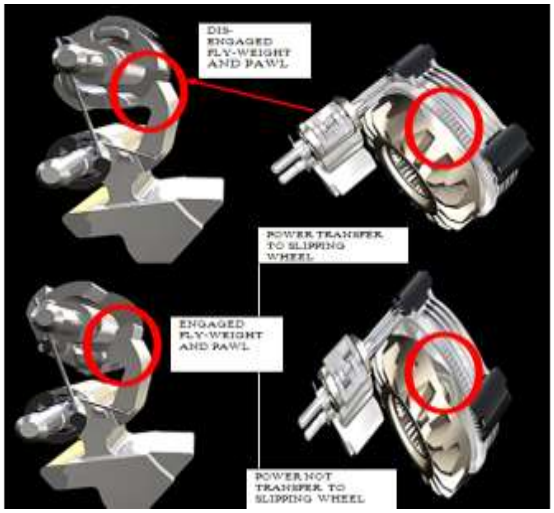


Figure 9: Locking differential by centrifugal force [12]

The centrifugal mass operated differential consist of bevel gear such as conventional differential there are two pinion located on the cross shaft and two side gears splined on the axle shaft. One of the side gears has cam shape machined on the back face, also a locking gear has replica of the same shape which is mounted on axle engaged with side gear. When predetermined torque is applied to the locking gear it will disengaged and power transmission will stop to respective wheel. Behind that geared cam plate, an active disc clutch pack is holding by spring pressure. On the other hand of differential, second side gear and another clutch pack are mounted. The device which activates cam plate is engagement mechanism with pinion. This mechanism consists of two fly-weights spring loaded towards the pinion shaft and shaft rotates when speed difference of both wheels exists. When speed of the engagement mechanism is more than designed speed, the fly-weights move in outward direction and engage with locking mechanism. As the fly-weight engages to the pawl of locking mechanism, the torque required disengaging the side gear and locking gear takes place and side gear and locking gear separates. Hence power transmitted to slipping wheel is disconnected and transferred to the other side wheel.

4. CONCLUSION

The differentials used today have several limitations. This limitations need to be eliminated, but present various differentials are designed for special purpose operations and these are not capable to eliminate all limitations by any single differential. Due to this, there is a requirement for a unique differential which can eliminate all limitations regarding any said situations in this paper. Spur gear differentials work similar to simple differential with compact construction and improved torque transmission capacity. Limited slip differential and centrifugal forced lock differential works better on slippery track. Clutch pack differential has good impact in agricultural industries as it is economical and provides equal torque transmission to wheels. Cylkro faced gear differential is most advanced practical usable differential but use of electronic systems and controller with triple differential set increases manufacturing costs. Electronic controlled differential satisfies in most of the said problems with medium speed and limited life. Belt driven, Toroidal and CVT differentials are economical for special purpose vehicle for which it acts same as the simple differential. This paper focuses on types of differential with several operational methods, so it is possible to create an idea to solve the limitations by combining two or more methods of differential drive system. Also for studies related to available differentials, this paper will help to conduct surveys related to differentials.

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