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Differential Transfer Cases in AWD/4WD Vehicles: Comparative Analysis

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Abstract

Comparative Analysis of Transfer Cases used in Automobiles

In this paper comparison study of different types of transfer case gearboxes used in 4wd, awd (or multi axle) vehicles is presented. Paper focuses briefly on purpose, construction, working and material used in these types of gearboxes. It also includes a review on mechanical design, feasibility of design, operation and cost effectiveness of gear driven transfer cases as well as chain driven transfer cases which can be concluded to choose the suitable type of transfer case gearbox system as per user requirement.

Key Words

Planetary Gear Set, Differential Transfer Case, Gear Driven Transfer Case, Chain Driven Transfer Case

Introduction

In vehicles there can be multiple types based on number of wheels driven by its power unit. There can be single wheel-drive vehicle as motorbike and there can be multiple wheels driven vehicle like train or multi axle road trains. The necessity of power transfer to multiple wheels in a vehicle comes from capability of that vehicle running in various terrains and large load bearing capacity. People use sedan cars for everyday work which are commonly 2 wheel driven. But there are special utility vehicles such as SUVs, pickup trucks, off road vehicles which use 4-wheel drive or all-wheel drive system transmission. Unlike small sedan or hatchback cars (except high performance versions), these 4-wheel drive (4wd) cars use transmission gearbox which is used to vary between different speeds, differentials which transmit power from engine to driven axles and transfer case which are to be explained in further part.

A vehicle will have more pulling power and traction if all of its wheels are driven for its rugged and all terrain operation. 4wd transmission gives advantage for this requirement. In this transmission drive axle at each end of the vehicle, a transfer case, and power transfer unit is required. Transfer case is normally attached to rear of the transmission. Transfer case as name indicates is used to transfer power coming mainly from engine, distributes to front and rear axles. Power is received using single input shaft and distributed using driveshafts or propeller shafts. Some transfer cases are two-speed which include reduction gear set for low speed, high torque requirement of vehicle. Torque is transmitted to front axle generally with gear driven or chain sprocket mechanism.

LITERATURE REVIEW

A vehicle operating on 4-wheel drive system can also operate with 2wd mode. A 4-wheel drive is often designated as 4 x 4. In all wheel drive system, the vehicle compulsorily driven using all the 4 wheels which is indifferent in 4wd vehicles. There is option of selecting drive mode allowing 2wd operation based on road surface which is why transfer case is only used in 4wd and not in awd vehicles. The 2wd mode provides fuel economy and reduced component wear. Selection of drive mode can be 2 high, 4 high (part time/full time), 4 low. Vehicle is mostly operated in 2 high mode as on normal highways. 4wd is operated on steep, wet road, off road tracks, jungles etc. 4 low mode provides extra amount of torque when coupled with reduction gear when engaged so as to

improve traction and stability at low speed. These modes can be changed in various ways either in mechanically, with the help of electric motor, a linear actuator or an electromagnetic actuator etc.

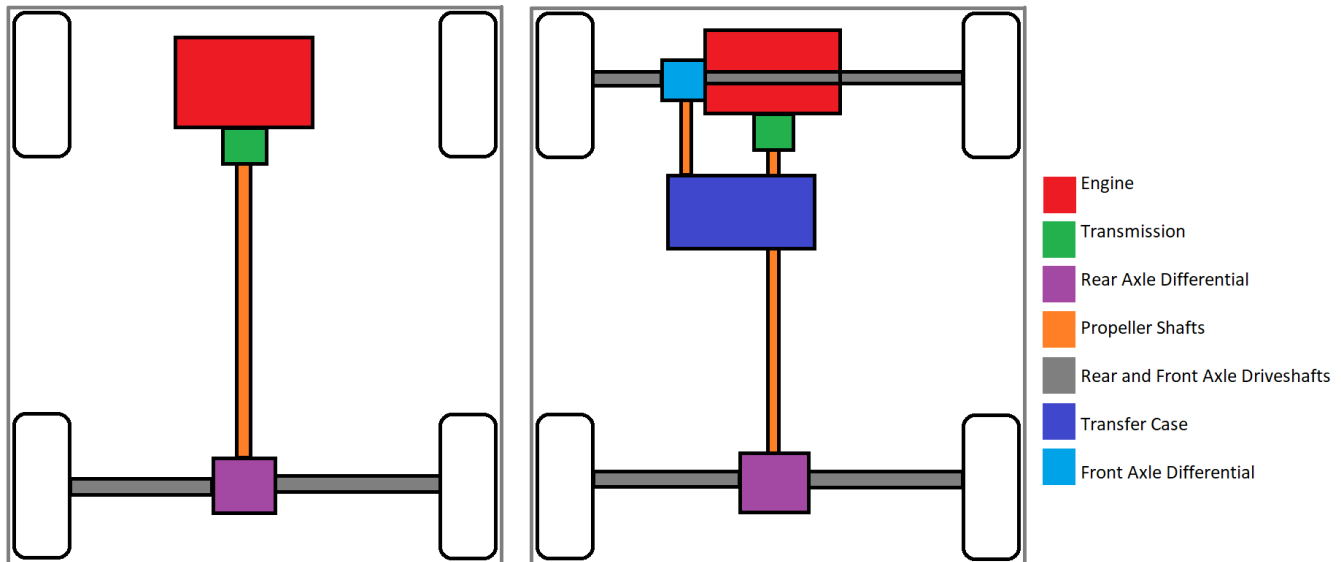


Diagram 1. Basic 2wd and 4wd (4-wheel drive) Vehicle Transmission Components

Based on construction there are major two types of transfer cases as

- i) Gear Driven Transfer Case
- ii) Chain Driven Transfer Case

Based on availability of 4wd system there are 2 types as part time 4wd and full time

- i) Part Time 4wd
- ii) Full Time 4wd
 - a. Full Time (Always On)
 - b. Full Time Multimode
 - c. Full Time on Demand

RESEARCH METHODOLOGY

This paragraph focuses on the plan with which study is conducted. This contains taking leap into the purpose and working of transfer case gearbox system in the first part. In the further section, we mainly focus on how design of transfer case evolves to tackle problem notified in further part and solution came up with. Various types of transfer cases with pictorial data are then focused upon following by end terminology of conclusion.

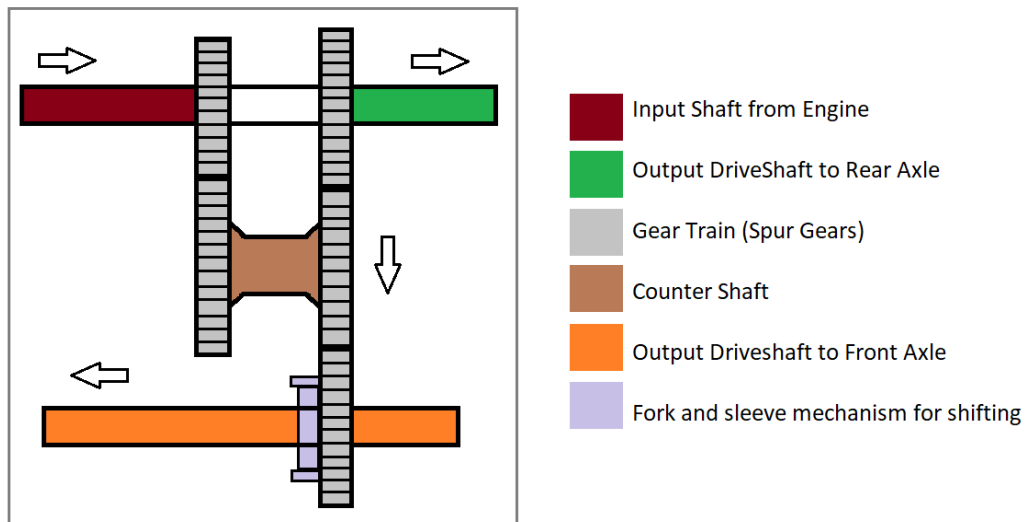
Mechanism and Working of Transfer Case

Construction of Simple Transfer Case with gear driven mechanism without 2 speed reduction and automatic control is stated below as in diagram.

1. Power is transferred through driveshafts or propeller shafts in transfer case.
2. Input shaft is attached to transfer case with universal joint.
3. The input shaft is combined linearly with gears which are combined to output shaft that goes directly to rear axle. This driveshaft is generally fixed and cannot be disengaged.
4. Internal gears are meshed to an idler gear or countershaft which is parallel to both input and output shafts.
5. Another shaft parallel to countershaft or main input shaft is connected such as to transfer power to front axle.
6. In transfer case shafts can be rotated and power is transmitted via gear mechanism. There can be spur or helical type
7. The front output power can be engaged and disengaged as per user's requirement. Gears with internal splines on output shaft can be moved back and forth so as to connect and disconnect. These gears are moved using mechanical sleeves and shift fork mechanism.

- 8. Sleeves are attached around gears meant to be slide by certain distance as to engage internal splines with splines on shaft and power flow is transmitted. Shift fork integrated in housing assembly slides sleeve in place by lever mechanism operated by user either manually, electromagnetically or by using electric motor mechanism.

Diagram 2. Internal gear mechanism of Transfer Case showing input and output shafts



Types Based on Construction and Functionality

Based on operation of 4wd, there can be multiple types of transfer cases starting from their construction as gear driven and chain driven transfer cases. Another parameter for classification is availability of 4wd, that means full time 4wd, full time multiple mode (only for required conditions like in extreme off-road vehicles where torque is increased via gearbox in massive amounts to meet conditions to drive at varying terrains), and the last type can be expressed as on demand 4wd system. With stepping of automation, mechanically operated levers, shifters are replaced with electronic switches, electromagnetic actuators such as solenoids and electric motors. Also, clutches are used to activate front drive system when required. Clutches are used such for e.g., single plate clutch, multi plate clutch, wet clutch etc. Different models of transfer case designs used are discussed below.

1. Centre Differential Gear Driven Transfer Case

This type of gear driven transfer cases was used in Toyota pickups and 4Runners around 1995. Gear driven transfer case can also be called differential transfer case for a reason that input shaft is not directly coupled with output shafts. Primarily open differential transfer cases are designed so as to vary speeds of front and rear axles individually.

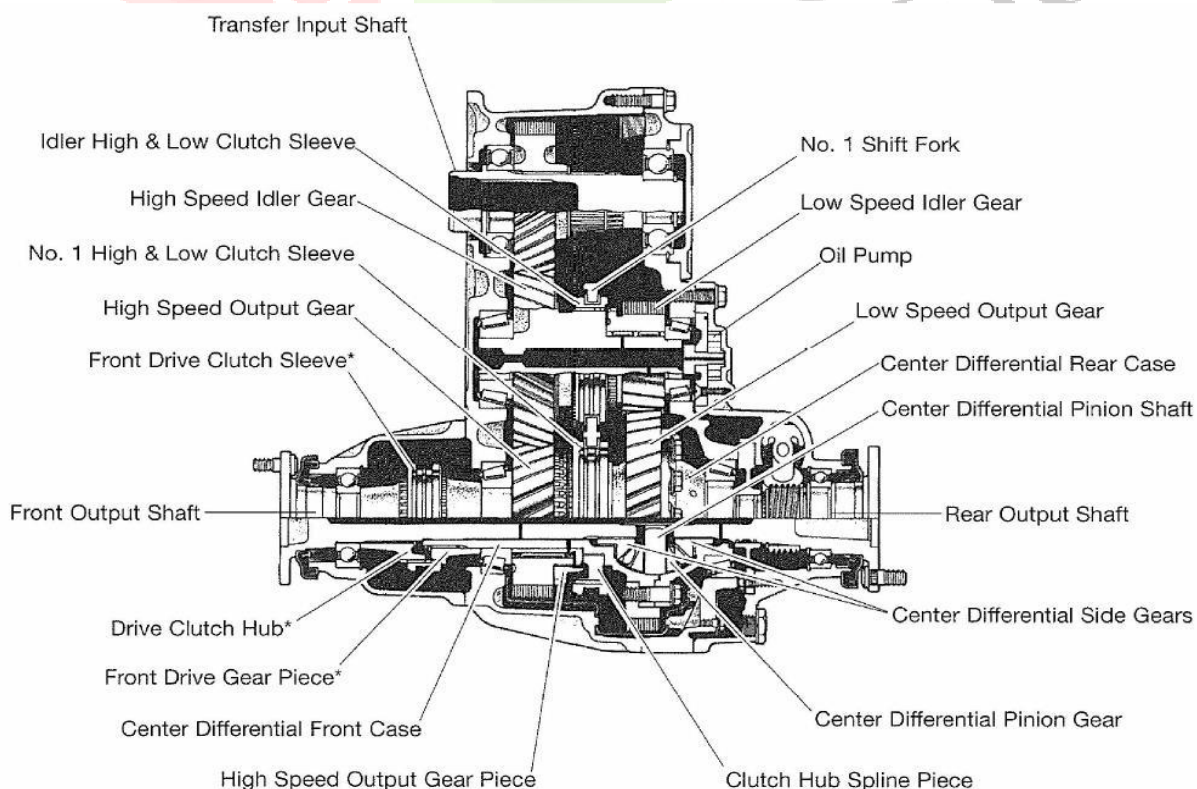


Diagram 3. Centre Differential Gear Driven Transfer Case

The design of transfer case was used in the Toyota Land Cruiser. In this case power flows from input shaft through gears, transmits to rear and front differentials for individual torque transfer. The centre differential can be driven by low or high idler gears that are engaged to centre differential by No.1 high & low clutch sleeve (illustrated in Diagram 3.). Pinion shaft in centre differential transfers the torque through side gears thus by driving both the output shafts. Changing from high speed to low speed for greater reduction ratio is done by stage mounted shifter only when the vehicle is at complete rest. During this shift, idler high/low clutch sleeve moves to the right at the same time as no.1 high/low clutch sleeve move towards centre differential. When selecting low speed, high speed output gear is disengaged with differential while low speed idler gear is engaged with it. With this mechanism, due to high gear ratio of low-speed gear, high torque is transferred to output. When selecting for high speed, high speed output gear engages with centre differential and high-speed idler gear disengages with low-speed idler gear.

An oil pump is provided to circulate fluid throughout the casing of gear box to cool down heating mechanical components and also maintain lubrication. Oil pump is driven by an idler gear, but can also be driven by externally controlled electric motor mechanism.

2. Chain Driven Transfer Case

Function of chain driven transfer case is similar to that of gear driven transfer case. Chain driven transfer case use planetary gearset instead of countershaft to provide large reduction ratio. This type uses chain to transfer torque to drive front output shaft.

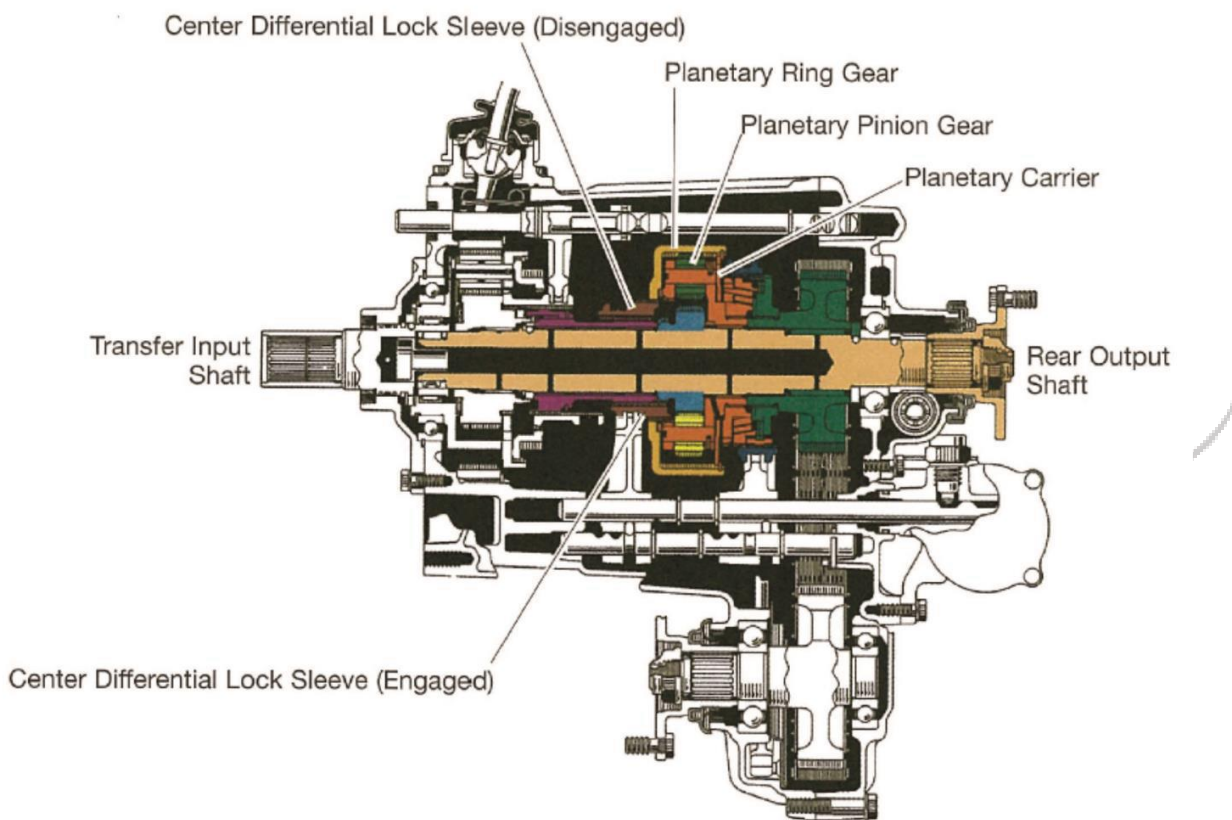


Diagram 4. Chain Driven Differential Transfer Case

Front drive shaft is connected through clutch sleeve to the chain. Planetary gear set acts as centre differential. At straight line motion of the vehicle, both front and rear wheels spin at same speed (except when front and rear tyre sizes are different). At straight line centre differential rotates with same speed as front drive sprocket, rear output shaft and transfer clutch hub which is mounted on planetary gear set to transfer torque from input shaft to ring gear to pinion carrier and sun gear.

But while turning front wheels travel different distance than rear wheels. While turning, inner and outer wheels of an axle travel different distances. That is why differential on an axle is used in between two wheels to compensate difference in speeds. In case of transfer case, centre differential used here is open differential. In 4wd operation, if one wheel loses traction due to patch with low friction, all the torque is sent to wheel having least traction. This forces vehicle to stuck. For this problem, locking of differential is beneficial. When differential is locked, torque is split equally between two shafts.

In similar way, by locking centre differential torque can be split equally between front and rear driveshafts thus by encouraging vehicle better traction in 4wd mode. To achieve locking in chain driven design, a locking sleeve is provided. This when engaged locks planetary gear set with rear output shaft by meshing teeth on lock sleeve with rear output shaft.

For lubrication, an oil pump is used. Oil pump is driven by gear on planetary splines. Oil is circulated on gears and friction clutches through paths and channels machined on outer casing of transfer case.

3. Torsen Limited Slip Differential Transfer Case

This design is based on Torsen limited slip differential which means torque sensing limited slip differential. It allows one wheel spin faster than other, but if one wheel spinning much faster than other then LSD locks up forcing both wheels spinning at same rate with equal torque distribution. Hence it is useful in heavy 4wd application.

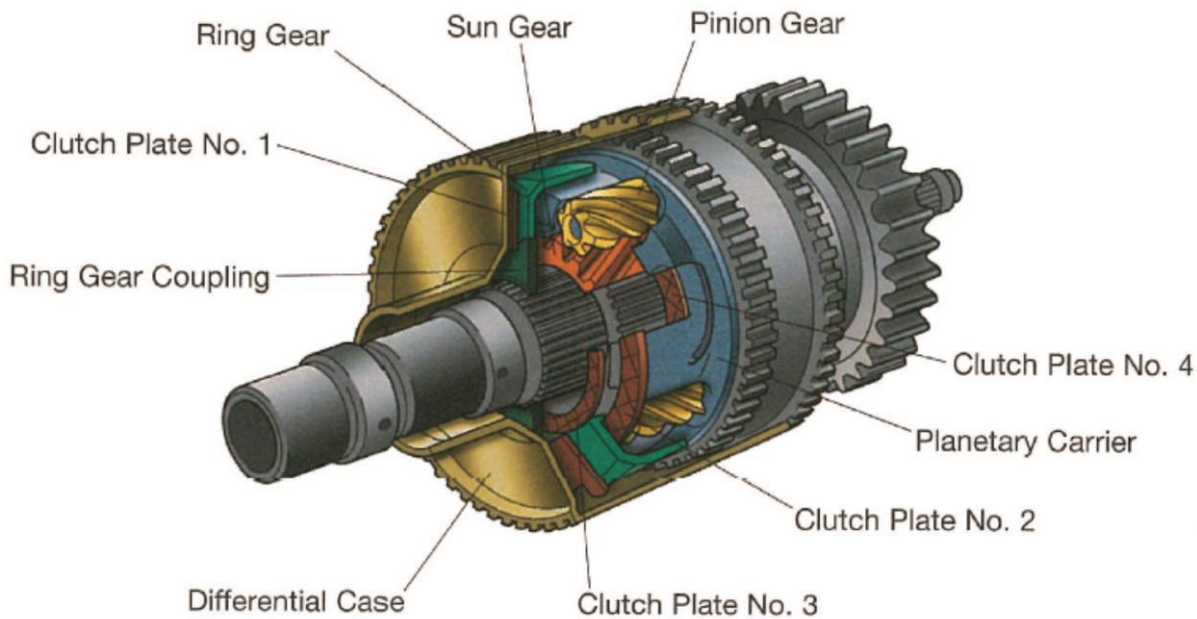


Diagram 5. Torsen Limited Slip Centre Differential

In transfer case design, unequal tyre size cause different speeds. This will cause mugging in transfer cases, resulting in wear at drive axles and/or joints. Therefore, a limited slip centre differential was used by Toyota in 2003 models.

It has planetary gear set with sun and ring gear, including 4 clutch plates distributing power to 4 wheels. Clutches manages to apply instantaneously compensating difference in front and rear wheel speed.

When front wheels spin faster than rear axle, sun gear and ring gear forms thrust and driving force is transferred through clutch plate.

4. Automatic Disconnecting Differential (A.D.D)

This system is fully controlled by ECU, allowing to switch on 4wd system while the vehicle is moving. When shifted to 4wd mode manually or automatically, ECU sends signal to actuator, engaging clutch sleeve into side gear thus indicating ECU with position sensor and activating 4wd system. Instrument cluster permits user to control. The actuator is operated by vacuum or electronically. The system can also be configured with automatic operating 4wd mode as per vehicle requirement. When installed with sensors at wheel ends or axles, actual torque requirement is computed by ECU. These sensors simultaneously work with actuators both in transfer case and/or differential gearboxes operating so as to provide with enough torque to maintain enough traction for each wheel. The ultimate goal of the system is to give output efficiently at certain input of driver (in this case to maintain stability of vehicle with maximum traction at each axle).

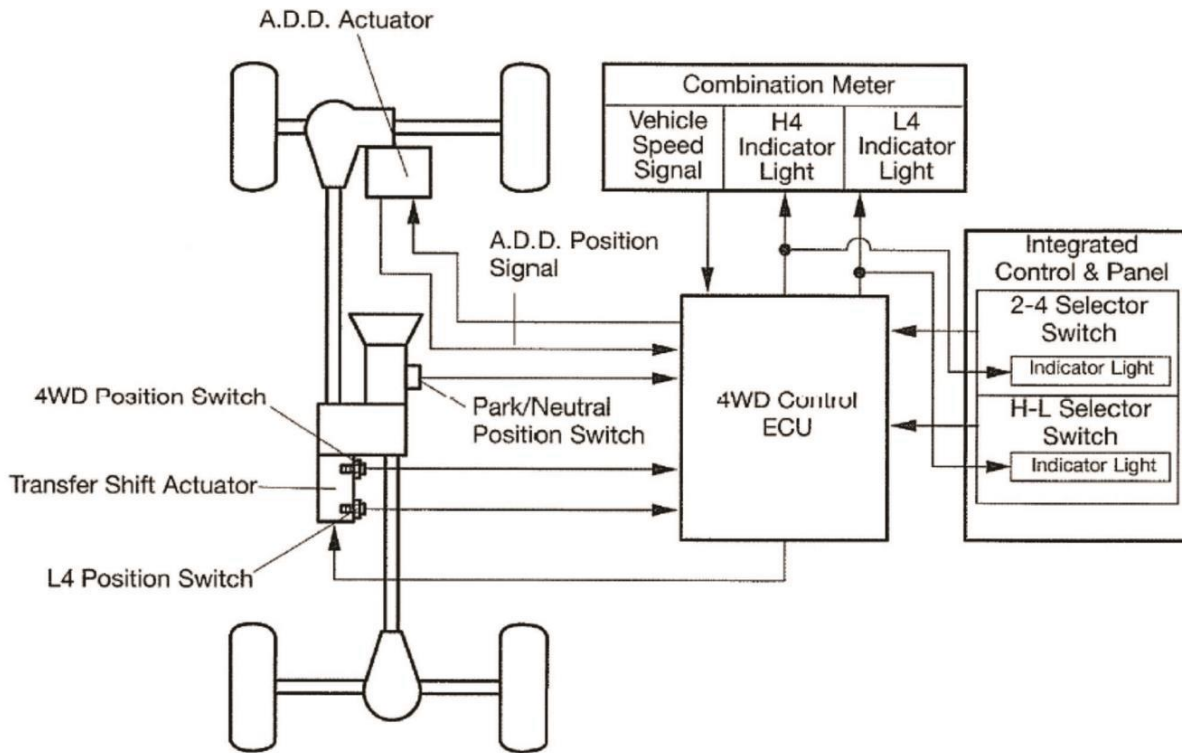


Diagram 6. Automatic Disconnected Differential (A.D.D)

Materials and Methods

The components used in these gearboxes are manufactured with high precision to obtain high efficiency at extreme condition. Gears are usually produced with cast iron by hobbing processes following annealing and tempering allowing it to bear high stresses and wearability. Shafts and similar cylindrical elements are machined with high carbon contained steels. Chain and sprockets are also machined with stainless steels following it with hardening processes. Gearbox housing contains internal channels, paths to let fluid pass through and also have supporting gussets on the external surface for the purpose of mounting with bearing slot intact. Therefore, housing is complex to manufacture which are machined with space grade aluminium T7075 having high yield strength. High efficiency is achieved by using high strength metals to ensure high fatigue life of components.

Conclusion

From data acquired above, one can analyse and compare transfer case gearbox system based on multiple parameters.

- Standard gear driven differential transfer case can be looked into as simple design having spur gear train, countershaft and lever sleeve mechanism. The design use universal components as there are no specially designed components, thus contribute to wide range of applications and availability. It can also be full mechanical case with centre differential.
- Chain driven transfer case with centre differential is modern, compact design which limits excess gears, counter shafts thus by reducing overall weight of the system. When integrated with electronic sensors and actuators, this design can be standardised as per user preference promising high performance and efficiency.
- Torsen limited slip differential (LSD) is efficient in all of the available transfer cases. And hence widely preferred in heavy applications as off road. Due to its self-locking capacity when spin difference between axles exceeds certain limit gains this design a great advantage. Extremely compact system also uses planetary gear set intelligently to get high reduction ratio thus providing high torque output at front and rear axles.
- Automatic disconnecting differential (A.D.D.) with the help of ECU sense precise requirement of traction at each wheel and axle. ECU when required, switches on 4wd system by fluid or electronic actuators. The gearbox is fully automatically operated and efficient due to accurate computing of ECU and actuators.

From conclusions drawn from designs studied and analysed, one will be able to compare and analyse between different types of differential transfer case gearboxes used in all-wheel drive, 4-wheel drive vehicles for best application.

Acknowledgement

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