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TORQUE VECTORING DIFFERENTIAL

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1. Introduction

Ever since the quest for reaching the highest possible speeds in automobile industry begun, there has always been a question of cornering at maximum speed without the loss of stability and traction of the vehicle.Though many racers use a method of drifting by losing the traction in the rear wheels so as to enable higher cornering speeds there is always the risk of spinning and crashing. In order to attain the stability during the turns the technology of differentials are being used.

1.1 What is a differential? And how it works.

It is observed that car tyres spin at different speeds during the turns.Differential is a device that splits the engine torque to the wheels.The drive gear 2 is mounted on the carrier 5 which supports the planetary bevel gears 4 which engage the driven bevel gears 3 attached to the axles.

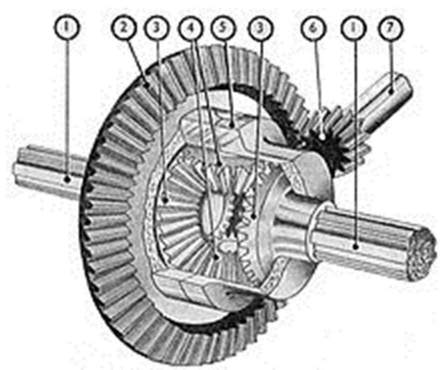

Figure 1. Automotive differential

In automobiles and other wheeled vehicles, the differential allows the outer drive wheel to rotate faster than the inner drive wheel during a turn. This is necessary when the vehicle turns, making the wheel that is traveling around the outside of the turning curve roll farther and faster than the other. The average of the rotational speed of the two driving wheels equals the input rotational speed of the drive shaft. An increase in the speed of one wheel is balanced by a decrease in the speed of the other.

.In a differential the longitudinal input propeller shaft to the pinion, which in turn drives the transverse ring gearof the differential. This also works as reduction gearing. On rear wheel drive vehicles, the differential may connect to half-shafts inside an axle housing, or drive shafts that connect to the rear driving wheels. Front wheel drive vehicles tend to have the engine crankshaft and the gearbox shafts transverse, and with the pinion on the end of the main-shaft of the gearbox and the differential enclosed in the same housing as the gearbox. There are individual drive-shafts to each wheel. A differential consists of one input, the drive shaft, and two outputs which are the two drive wheels, however the rotation of the drive wheels are coupled to each other by their connection to the roadway. Under normal conditions, with small tire slip, the ratio of the speeds of the two driving wheels is defined by the ratio of the radii of the paths around which the two wheels are rolling, which in turn is determined by the track-width of the vehicle (the distance between the driving wheels) and the radius of the turn.

Figure 2. The drive shaft enters from the front and the driven axles run left and right

1.2 Different types of differential

Epicyclic differential

An epicyclic differential can use epicyclic gearing to split and apportion torque asymmetrically between the front and rear axles. An epicyclic differential is at the heart of the Toyota Prius automotive drive train, where it interconnects the engine, motor-generators, and the drive wheels (which have a second differential for splitting torque as usual). It has the advantage of being relatively compact along the length of its axis (that is, the sun gear shaft).

Epicyclic gears are also called planetary gears because the axes of the planet gears revolve around the common axis of the sun and ring gears that they mesh with and roll between. In the image, the yellow shaft carries the sun gear which is almost hidden. The blue gears are called planet gears and the pink gear is the ring gear or annulus Ring gears are also used in starter motors.

Spur-gear differential

A spur-gear differential has two equal-sized spur gears, one for each half-shaft, with a space between them. Instead of the Bevel gear, also known as a mitre gear, assembly (the "spider") at the centre of the differential, there is a rotating carrier on the same axis as the two shafts. Torque from a prime mover or transmission, such as the drive shaft of a car, rotates this carrier.

Mounted in this carrier are one or more pairs of identical pinions, generally longer than their diameters, and typically smaller than the spur gears on the individual half-shafts. Each pinion pair rotates freely on pins supported by the carrier. Furthermore, the pinion pairs are displaced axially, such that they mesh only for the part of their length between the two spur gears, and rotate in opposite directions. The remaining length of a given pinion meshes with the nearer spur gear on its axle. Therefore, each pinion couples that spur gear to the other pinion, and in turn, the other spur gear, so that when the drive shaft rotates the carrier, its relationship to the gears for the individual wheel axles is the same as that in a bevel-gear differential.

A spur gear differential is constructed from two identical coaxial epicyclic gear trains assembled with a single carrier such that their planet gears are engaged. This forms a planetary gear train with a fixed carrier train ratio R = -1.

Active differentials

A relatively new technology is the electronically controlled 'active differential'. An electronic control unit (ECU) uses inputs from multiple sensors, including yaw rate, steering input angle, and lateral acceleration—and adjusts the distribution of torque to compensate for undesirable handling behaviours like understeer. Active differentials used to play a large role in the World Rally Championship, but in the 2006 season the FIA has limited the use of active differentials to only those drivers who have not competed in the World Rally Championship in the last five years.

Fully integrated active differentials are used on the Ferrari F430, Mitsubishi Lancer Evolution, and on the rear wheels in the Acura RL. A version manufactured by ZF is also being offered on

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the B8 chassis Audi S4 and Audi A4. The Volkswagen Golf GTI Mk7 in Performance trim also has an electronically controlled front-axle transverse differential lock, also known as VAQ.

The second constraint of the differential is passive—it is actuated by the friction kinematics chain through the ground. The difference in torque on the road-wheels and tires (caused by turns or bumpy ground) drives the second degree of freedom, (overcoming the torque of inner friction) to equalise the driving torque on the tires. The sensitivity of the differential depends on the inner friction through the second degree of freedom. All of the differentials (so called "active" and "passive") use clutches and brakes (with the exception of the Sparc Drive, which uses a servo motor and worm gear) for restricting the second degree of freedom, so all suffer from the same disadvantage—decreased sensitivity to a dynamically changing environment.

The sensitivity of the ECU controlled differential is also limited by the time delay caused by sensors and the response time of the actuators.

1.3.Difference Between Torque Vector & Active Differential

Torque Vectoring is next step in Active Differential, its contribution being that it can get power to any wheel nearly instantly without having to use the brakes or cut power. Most current Active differentials control wheel spin by braking a spinning wheel or cutting the power from the engine. Torque vectoring is achieved by using redesigned differentials that can distribute power to the wheels or wheels that have traction. That means that wheels don’t need to be stopped, and even better, one would not suffer from a sudden loss of power as youre negotiating an unexpected loss in traction. Some systems in use now or being developed work on FWD, RWD, & AWD cars and get power to any wheel or combination of wheels.

1.4.Different Types of Torque Vectoring Differentials(TVD)

Dynamic torque vectoring differentials:

Over the recent years Toyota has developed two new torque vectoring differentials with the objective of improving the fuel efficiency and provide better handling, manoeuvrability, stability and off road performance.This is known as dynamic torque vectoring and is used in gasoline based engines. Dynamic torque vectoring involves the mechanism of torque vectoring differentials and modifying it to improve the off road handling to steer in the direction intended without the loss of the speed and stability. The innovation of this mechanism lies in the incorporation of the disconnect mechanism, using the world's first ratchet-type dog clutches to stop drive system rotations so as to transmit the force to rear shaft making it a two wheels drive to improve fuel efficiency and significantly reduce the energy loss.

E-Four differential system:

This is a system used in the hybrid vehicles. The design of this system is intended to increase the total torque provided to the rear wheels (which are electric driven) by 30 percent by adopting a control system to optimally distribute the torque to the rear wheels based on the driving conditions.

2. Design aspect of torque vectoring differentials:

Mechanical torque vectoring differentials:

Most of the torque vectoring differential designs involve the usage of two pairs of gear sets in different speed ratios, and utilizes the brakes, clutches and motors to control the direction of transferred wheel torque.

There are two types of TVD designs

1. Stationary clutch design(STC-TVD)
2. Superposition clutch design(SPC-TVD)

The schematic diagrams of SPC-TVD and STC-TVD are illustrated in Figure 1 and their system configurations transferred by the means of function power graph are shown in Figure 2. In Figures 1 and 2, DG denotes the differential gear set; W1 and W2 are left and right wheels respectively,C1 and C2 are clutches,B1 and B2 are brakes; G,G0,G1and G2 are gear pairs; PG1 and PG2 are planetary gears; IN is the input of the engine power.

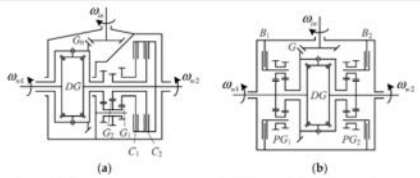

Figure 1. Schematic diagrams of current torque vectoring differential (TVD) designs: (a) superposition-clutch (SPC)-TVD and (b) stationary-clutch (STC)-TVD [15].

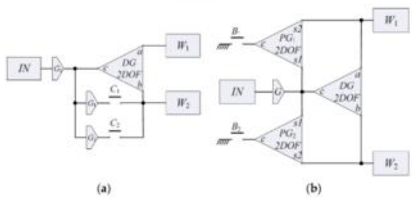

Figure 2. System configurations of current TVD designs: (a) SPC-TVD and (b) STC-TVD.

In Figure 2, the SPC-TVD consists of two gear pairs (G_1 and G_2), and two clutches (C_1 and C_2).When C_1 is engaged, the speed ratio of the left and right wheels is decided by the gear ratio of G_1.Similarly, when C_2 is engaged, the speed ratio of the two wheels is decided by the gear ratio of G_2.With the different gear ratios of G1 and G2, tire slip ratio of the two tires can be controlled with different. Engagements of the clutches, so that different traction distributions can be achieved and the torque vectoring effect can be realized.

A similar operation principle is also observed from the STC-TVD design, in which two planetary gear sets PG_1 and PG_2 are involved, and two brakes B_1 and B_2 are used to select the direction of the torque vectoring effect. When B_1 is engaged, the speed ratio of the left and right wheels is decided by the gear ratio of PG_1. On the other hand, when B_2 is engaged, the speed ratio of the two wheels is decided by the gear ratio of PG_2.

According to the two current TVD designs discussed above, a TVD can be developed when two gear ratios between the left and right wheels are achievable, and the two ratios can be selected by controlling the engagement of the clutches or brakes.

All wheel torque vectoring system design:

This design involves an electric motor at each wheel, the system is able to control the torque produced by each motor 100 times per second. This is done by feedback control system.

AWTV system works with several systems and sensors to make the car to exactly what the driver wants. It communicates with accelerometers, gyroscopes, steering angle sensors, and wheel speed sensors to determine what is happening with the car, then sends the appropriate power to each motor. This technology is implemented in the RIMAC CONCEPT ONEand only 8 cars with the above technology have been made.

3. Potential problems in the torque vectoring differential

The technology of torque vectoring differential has its own share of defects and possible cons.The mechanical differentials can definitely change the wheel speed ratio to a greater extent but using more number of gears to achieve better handling can cause to increase the weight of the body, this results in decreased fuel efficiency.

The mechanical gears cannot completely transmit the 100% of the engine power to the wheels. When using clutches to control the differentials there is always a factor of time to engage and disengage the clutches, lower the time factor, lesser the drop in the speed.

In case of the electric drives the whole systems run on the basis of feedback control systems using a variety of sensors, in this case there is always a possibility of sensor failure, in order to ensure the safety a manual override must be provided along with individual sensor failure indicator so as to ensure the health of the differential system.

4. Combination oftorquevectoring along with the KERS technology

A **kinetic energy recovery system** (often known simply as **KERS**, or **kers**) is an automotive system for recovering a moving vehicle's kinetic energy under braking. The recovered energy is stored in a reservoir (for example a flywheel or high voltage batteries) for later use under acceleration. Examples include complex high end systems such as the Zytek,Flybrid, Torotrak and Xtrac used in racing and simple, easily manufactured and integrated differential based systems. This technology when combined with torque vectoring can result in immense cornering speeds with high stability. This can change the outcome of the racing industry by decreasing the need for drifting and the fatalities of race drivers due to spinning at curves.

5. Enhancements in the TVD and Conclusions

The control and capability benefits of all-wheel drive when one is dealing with the elements—come sand or high water. Dropping an engine's torque down to the ground with four tire patches instead of two would give any vehicle more traction. But headed to market in more and more performance cars are new systems that can seamlessly and instantaneously distribute torque to any single wheel at a time. Welcome to torque vectoring all-wheel drive.

Most modern all-wheel-drive cars and SUVs already offer some type of computer-controlled, part-time engagement to save fuel. When the computer detects that one or more wheels is rotating faster than the vehicle's speed or that the vehicle is yawing off its intended path of travel, the system steps in. First, it engages the other drive axle and applies a proportion of the vehicle's torque to it. If the wheels continue to spin, the computer reduces engine torque or even brakes one of the wheels, if necessary.

In recent times, these systems have taken a fairly radical step forward. Automakers have reinvented front and rear differentials to the point where an engine's torque can be passed around—or vectored—to each corner of the car. In other words, torque can go from front to back like a traditional all-wheel-drive setup and distribute from left to right on a given axle—all very, very quickly. It's like having a computer-controlled, super-speed limited slip differential in each axle. This means not only great foul-weather traction but also eerily competent handling performance on dry roads.

Acura, for instance, has offered its Super Handling All-Wheel-Drive (SH-AWD) system for several years. It monitors vehicle speed, wheel speed, gear position, steering angle, yaw rate, lateral G forces and other inputs, while automatically adding torque to the outside rear wheel in corners to make the car turn quicker. A set of electromagnetic clutches in the rear differential passes the torque from side to side. The system, which normally distributes torque 90 percent up front and 10 percent in the rear, quickly changes to a 50/50 split during acceleration or hard cornering. The system can then send some or all of that 50 percent going to the rear axle directly to the outside tire to make the vehicle bend into a corner more sharply. Mitsubishi, a torque vectoring pioneer, has used a similar system called Active Yaw Control in the rear axle of its high-performance Evolution sport sedan since the late '90s.

Audi, BMW and others are taking it a step further: While SH-AWD only works on the rear axle of a normally front-drive vehicle, new systems from automotive suppliers Ricardo in Britain and ZF in Germany can vector torque to all four tires simultaneously.

The Ricardo Cross-Axle Torque-Vectoring system uses wet clutches and planetary gear sets, in both the front and rear differentials, that are controlled by electrical, electromechanical and electrohydraulic control systems. Ricardo says the system's response time, from the push of the accelerator to the delivery of up to 90 percent of available torque, is only about 0.1 seconds. If Ricardo's vectoring is used only in an all-wheel-drive vehicle's centre differential, the engine torque effectively gets passed around front-to-rear and side-to-side—with split-second accuracy—for every driving condition. Look for it in the new Audi A4 and A5.

German transmission and driveline company ZF has also developed a torque-vectoring system, called Vector Drive—and it's ready for volume production in all-wheel and rear-wheel drive vehicles. The system distributes drive torque individually to each of the rear wheels, generating a yaw movement around the vertical axis. This improves both cornering performance and vehicle stability in less-than-ideal road conditions. When driving straight, the torque vectoring rear axle behaves like an ordinary open differential. Drive torque is distributed equally to the wheels. Torque is only distributed individually along both half shafts on an axle during cornering, controlled by an electromechanically actuated multi-disk brake. The ZF system also generates wheel differential torque independently of the drive torque. When cornering through a downhill section off the throttle, the outer wheel receives more drive torque than the inner wheel, allowing crisper turn-in. The gears of the planetary gear set don't turn when driving straight, so the system saves fuel too. The torque-vectoring drive also acts like a positive-traction or locking differential on dry or uneven traction start-ups, with torque going to the wheel with higher friction potential.

These new torque vectoring systems will undoubtedly join forces with the pre-existing ABS brakes, traction control, stability control, steering and rollover mitigation systems. The result will be smarter, safer and quicker vehicles, whether it's on a rain-soaked freeway, a snowy driveway or a racetrack.

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