Development of an Online Algorithm for detection of status of power transmission (engaged/ disengaged Gear) for Electronic Stability Control (ESP/ABS)

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April 27, 2017

Declaration

I certify that this research work titled "*Development of an Online Algorithm for detection of status of power transmission (engaged/ disengaged Gear) for Electronic Stability Control ESP/ABS* is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources has been properly acknowledged / referred.

Muhammad Younas

2013-NUST-Ms-Mts-078

Language Correctness Certificate

This thesis has been read by an English expert and is free of typing, syntax, semantic, grammatical and spelling mistakes. Thesis is also according to the format given by the university.

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Copyright Statement

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Abstract

In automobiles, line of transmission consists of Engine, propeller shaft, drive shaft Gears, Clutches and wheels. Power is transmitted via clutches, which engage or disengage in order to open or close the whole power transmission, from engine to wheels. Wheels are the only point of contact to the surface. All the forces acting on the vehicle whether tracking or braking act on the wheels. Knowing exactly maximum forces possible and the actuators participations and roles in the resulting surfaces lets better control of brakes and engine systems. On low mue (μ) surfaces engine drag force may lead to very high braking force resulting instable and not steerable vehicle. Drag torque controller, a sub controller of ABS system is being used to control engine drag after downshift or during ABS braking. Engine Drag Torque Controller (DTC) prevents the driven wheels from locking on slippery surfaces where engine drag is a major cause for locking wheels. DTC maintains steer ability, stability and boosts safety. Missing DTC measure while being engaged at high brake slips would lead to instable and not steerable. In most manually transmitted gearboxes, reliable monitored engaged clutch information is not provided. Correlation between engine speed, wheel speeds and other acting forces may be used to detect drive train engagement status. Engaged gear information is required to allow DTC (Drag torque controller) activations. In order to ensure that power transmission is closed and engine drag is one of the major braking force providers, clutch engaged information has to be detected. Misdetection of engaged gear (no DTC interventions) is safety critical, especially 4WD and RWD vehicles on low mue surfaces. Wrong detection of disengaged gear (wrong DTC intervention) is a comfort issue and may lead to engine noise. The purpose of this thesis is to use the vehicle data (engine speed, wheel speed, ABS control information, drive mode) and detect suspension of Gear engaged for DTC controlled situations

Key Words: *ESP, Gear Engagement, DTC on low mue surfaces, Gear disengagement, steer ability and stability of vehicle, active safety systems, passive safety systems, ABS and gear engagement*

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CHAPTER 1: INTRODUCTION

Engaged or disengaged Status of the power transmission plays a very important role, especially when it comes to safety. Vehicle stability and steering capability are very important for the safety of humans. Therefore, safety programs are being developed ever since the vehicles are being manufactured. Many such programs for improving active safety have already been used in modern vehicles. ESP (electronic stability program) is one of them, along with ESP, ABS, DTE, and DTC are having major roles to ensure safety. However, wrong detection of engaged gear is safety critical and comfort issue, because if DTC intervenes with engaged gear then it is a critical safety issue. Transmission status information is available in the automated vehicles but this information lacks in the manual transmission vehicles. The new safety programs require this information for better execution and better performance of safety algorithms. Drag torque controller is one of the controller that is being used for to prevent locking of wheels, and it requires the transmission status in order to avoid instability and comfort ability issue. A lot of work has already been done on detection of gears. In addition, some onboard algorithms have been developed for transmission detection, but they are first on board diagnostic systems, and secondly they have some issues with low gears. This thesis discusses the transmission status under low mue surfaces and develops two algorithms based on heuristic and driveline model approach. Aim of this work is to provide such an algorithm that detects whether vehicle is in engaged situation or disengaged.

1.1 Background:

According to the World Health Organization (WHO), road traffic injuries claim, more than 1.2 million lives each year causing 50 million injuries per year, thus having a huge impact on health and development. It is considered as the most leading cause of death among the age group of 15 and 29 years, and as a result costs Governments to approximately 3% of gross domestic product (GDP).To prevent these massive and largely preventable human and economic toll, many efforts are being put on specially by the car manufacturing industries. Still which are not good enough. Furthermore the third global status report on road safety, states that low and middle-income countries are being hardly hit by traffic accidents, with double the fatality rates of high-income countries and 90% of global road traffic deaths. Other victims like road users, pedestrians, cyclists and motorcyclists contribute almost half of these fatalities. The WHO expects that road accidents will keep on increasing and can rise up to third place among the major causes of death and illness. The following figure shows the trend of deaths in my country Pakistan due to the traffic road accidents. [1]

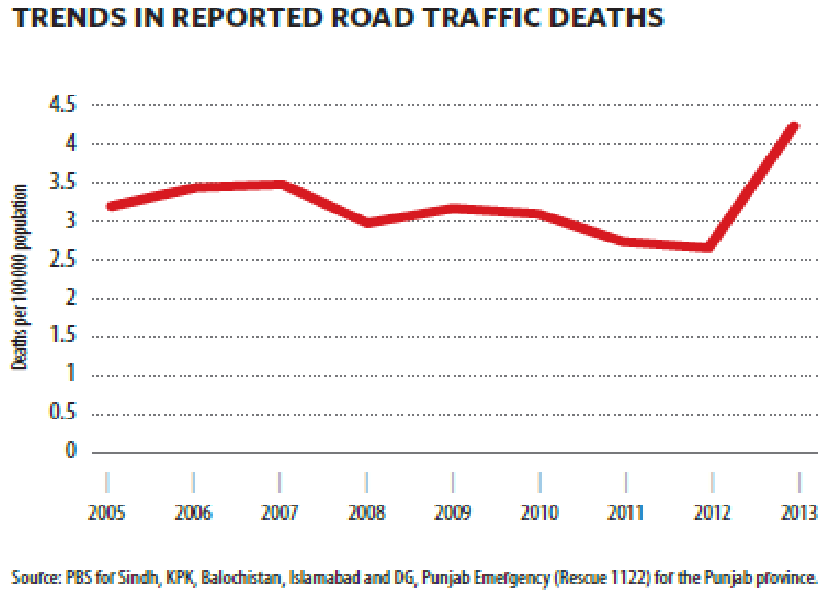

Figure 1.1: Trends in Reported Road Traffic Deaths [1]

However, Safety departments of automobile manufacturers are working hard on improving safety and have developed many methods like Active safety and passive safety systems. Now a day these systems are being highly controlled and monitored by electronics. Moreover, this electronic control has given the new dimensions in driving safety. With years of research and development, engineers have developed now passive safety systems such as seat belts, airbags, headbags, and sidebags. Crash avoidance technologies are also being implemented and have now taken the central role. Electronic Stability Control (ESC) is a key technology in this respect, and was recently described by the U.S National Highway Traffic Safety Authority (NHTSA) as the safety technology with the greatest life-saving potential since the introduction of seat belts. [2]

Robert Bosch is one of the leading companies, making the autos secure, stable and in all circumstances under control, therefore has developed programs like ESP, ABS, DTC, and DTE for the safety of people and vehicles. These control systems will be further discussed in chapter 3.The ESP was invented and set in to serial production by Robert Bosch GmbH in 1995. The system improves vehicle stability by intervening if the car gets into a skid and helps the driver to maintain the vehicle in the desired direction. Whether the car over steer or under steer when cornering, the ESP maintains the vehicle on its course by either braking one or more wheels to correct it. Today ESP more and more becomes standard equipment in many countries. In Germany it has been made compulsory to for all the new cars to be equipped with ESP since 2011.In the USA, all new production cars shall be equipped with ESP in 2012. [3]

1.2 Safety systems:

Vehicle safety depends on many factors. It does not depend only on the condition of the vehicle, on the driver or on the road, but many others. Road safety mainly depends on

- Vehicle condition:

Condition of the vehicle is judged from the installed safety equipment, the condition of tires, Components that have been worn out and need replacement. Whether the braking fluid is enough to apply the brakes or there is any leakage.

- Environment:

Environment consists of the factors that influence the environment. Weather and traffic conditions, Variation in resistive forces like side wind.

- Human being:

Safety is highly dependent on the physical, mental conditions and on the driving capabilities of driver. In past, safety systems included only the brakes and lights. However, over the time, many safety systems in addition to the conventional braking have been introduced. Safety systems are divided into two sub systems

1.2.1 Active safety systems

Unlike passive safety systems, these systems help to prevent the accidents by improving the braking and reducing the causes that can contribute to an accident, i.e. by controlling the vehicle partially or by giving input to some of the vehicle parts. Hence, we can say that, they help to prevent accidents and contribute to preventative safety. Examples of active vehicle safety systems include

- ABS (Antilock Braking System),
- TCS (Traction Control System), and
- ESP (Electronic Stability Program)

These control systems stabilize the vehicle's handling response in critical situations, prevent locking and thus maintain its steer ability and stability.

1.2.2 Passive Safety Systems

The major goal of Passive safety systems is to prevent the passengers from severe injuries in case of an accident. Injury risks and severe consequences of an accident are somehow reduced in this way. Seat belts, air bags, side bags, headbags, Seat belt pre-tensioner and Seat belt travel limiter are the examples of Passive safety systems, which are also mandatory by law in most of the European countries. Their installation position can vary depending upon the vehicle and customer requirements. Figure 1.3 shows the layout of safety systems and sensor installed on a vehicle.

1. Wheel brake with brake disk
2. Wheel speed sensor
3. Gas inflator for foot airbag
4. ESP control unit with ABS and TCS function
5. Gas inflator for knee Airbag
6. Gas inflator for driver and passenger air bags
7. Gas inflator for side Airbag
8. Gas inflator for head Airbag
9. ESP hydraulic modulator
10. Steering angle sensor
11. Airbag control unit

12. Upfront sensor

13. Pre-crash sensor

14. Brake booster with master cylinder and brake pedal

15. Parking brake lever

16. Acceleration sensor

17. Sensor mat for seat occupation detection

18. Seat belt with seat belt tightner

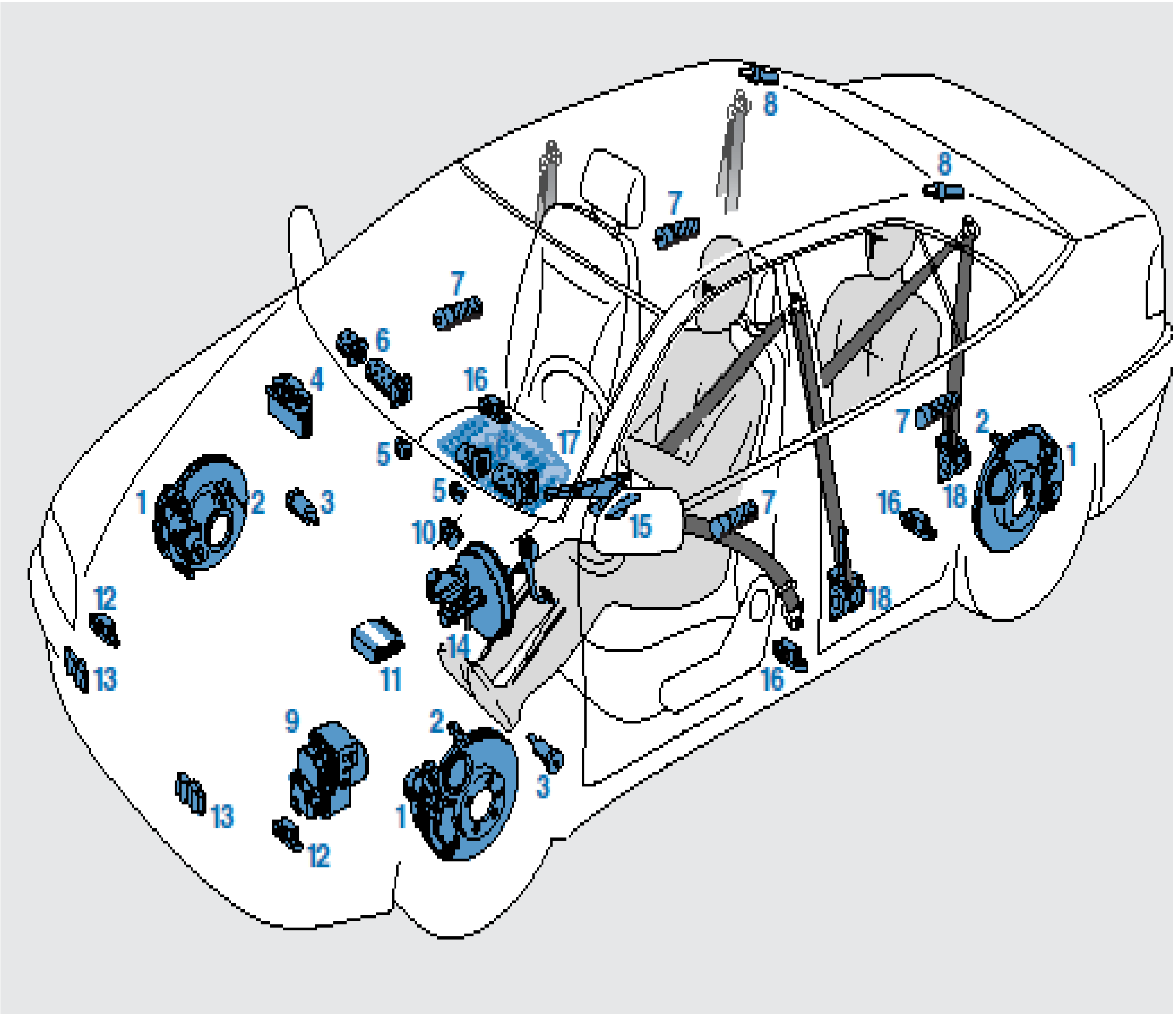

Figure 1.2 Safety Systems installed on a vehicle [4]

1.3 Scope and Motivation

The following figure shows the relationship between the wheel slip and Traction force / Braking moment/ mue. From this figure, we can observe the behaviour of frictional coefficient mue of different road surfaces. We can see that highest coefficient of friction is of Dry surface and lowest mue value is of Ice. Another behavior that we can clearly see from this figure is that with the increase in wheel slip, frictional coefficient reduces. So we can determine that when the mue is low, slip is more, and when value of mue is high, slip will be lesser. Mue is nothing else but frictional coefficient between the wheels and road surface. Therefore, we can develop an inverse proportional relationship between wheel slip and mue. But there is point called max in this figure, after which the vehicle becomes instable. This point separates the stability region from instable

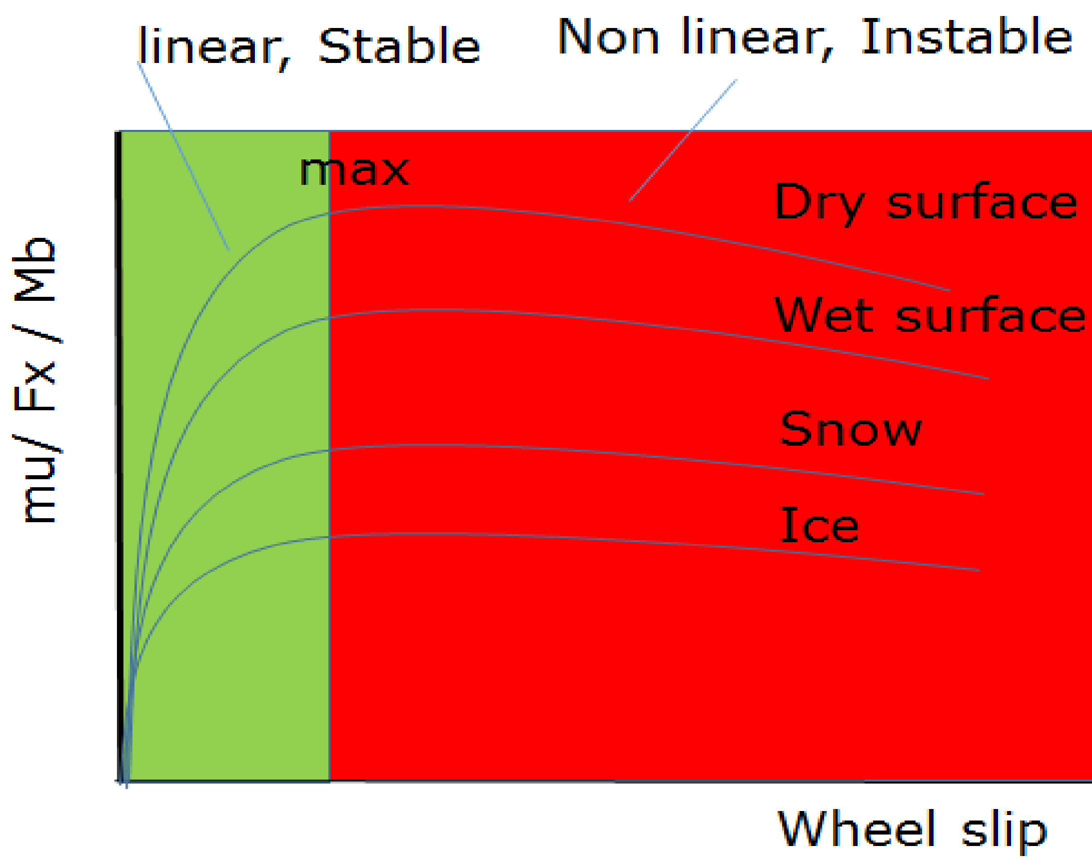

Figure 1.3: Force/ Braking Moment vs Wheel Slip

region. One thing should be noted here , that max point differs for each road surface. So we can say that on ice , we have very low mue value at which vehicle becomes unstable. This picture shows another relationship , which is between the traction force and wheel slip, and depending on the knowledge of these two , one can distinguish whether vehicle is in stable region or is in instable region. Traction force at dry /Asphalt surface is much more as compared to the low mue surfaces before the wheel gets more slip and causes locking , which results in instability and non steerability of the vehicle. From figure below we can understand the concept of maximum braking moment. The Braking moment is defined as the braking moment of Engine along with the braking moment due to brakes applied.

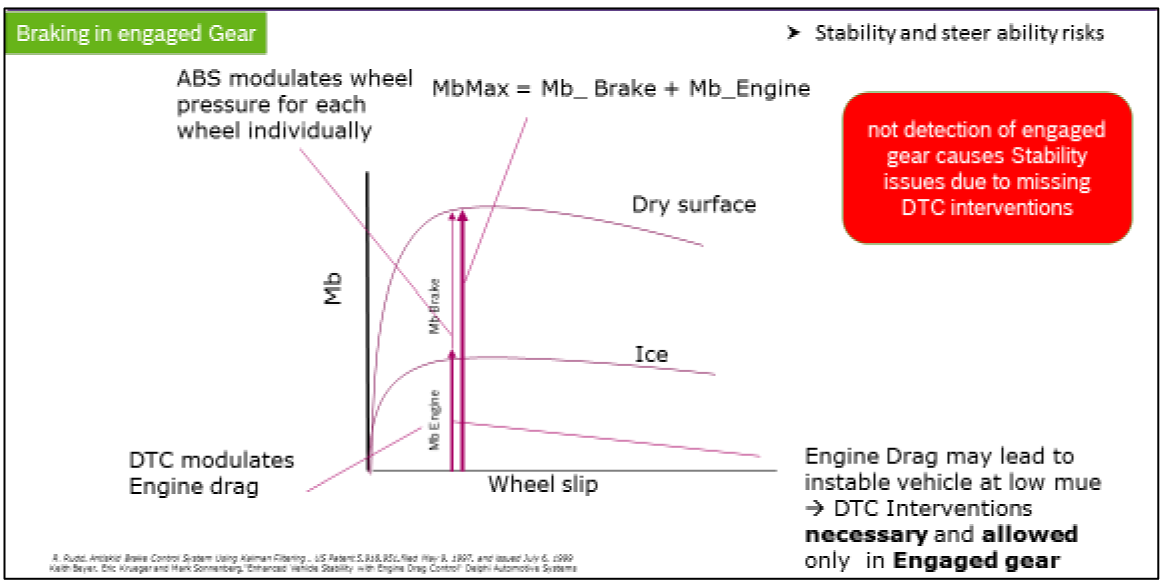

Figure 1.4: Braking moment vs Slip in Engaged Gear

Here we can compare between the two surfaces. Let us consider one high mue surface and one low mue surface. Since Antiolock Braking System (ABS) is responsible for modulating the braking pressure at individual wheels , which means that braking force due to brakes applied are being modulated by ABS. Whereas Drag torque controller (DTC) is responsible for modulating the engine Drag. In situations where the wheels get locked due to slip, DTC has to intervene. However, the intervention of DTC is highly dependent on the information of Engaged/disengaged transmission status. From the Above figure we have determined that braking Moment for Low mue surface is equal to the braking moment due to engine and braking moment due to braking.

$$MbMax = Mb_{Brake}, + Mb_{Engine}$$

But for high mue surfaces we can determine that maximum braking moment is equal to only the moment due to braking. By looking at the figure below it can be clearly seen, that on dry surface i.e. On high mue surface, the only influencing moment is braking Moment Mb_{Brake}.

$$MbMax = Mb_{Brake} + 0$$

Therefore, for low mue surfaces, Engine drag is the major braking force.

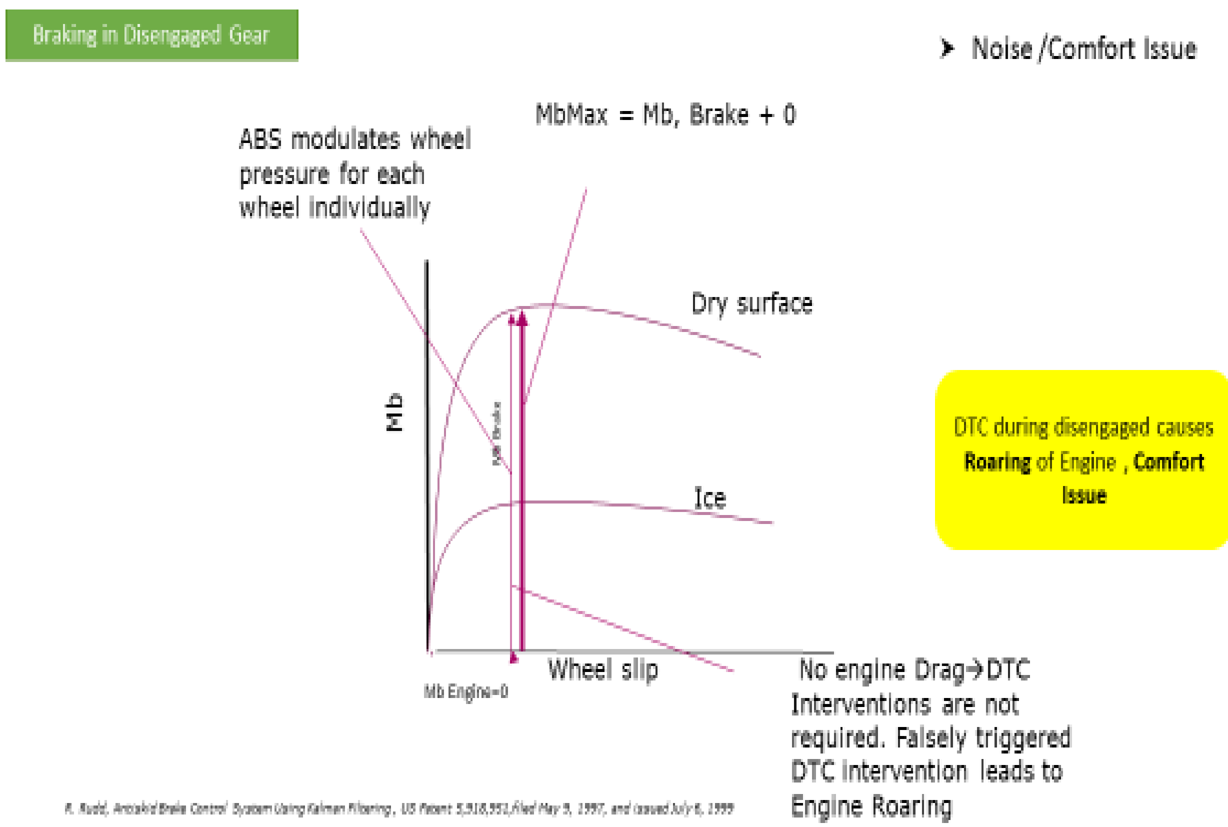

Figure 1.5: Braking Moment Vs Slip in Disengaged Gear

As discussed that Drag torque controller comes in to an active role when wheels are locked in order to prevent locking. The stability of vehicle movement and steering capability depends on which wheels are locked. In addition, wheels get locked depending upon the mue surface as explained earlier. The following diagram shows the case when rear wheels are locked. In this case, a silght braking force applied can result in turnover of the vehicle. The vehicle become highly instable and steering capability is lost. DTC has to act in this situation In order to stabilize the

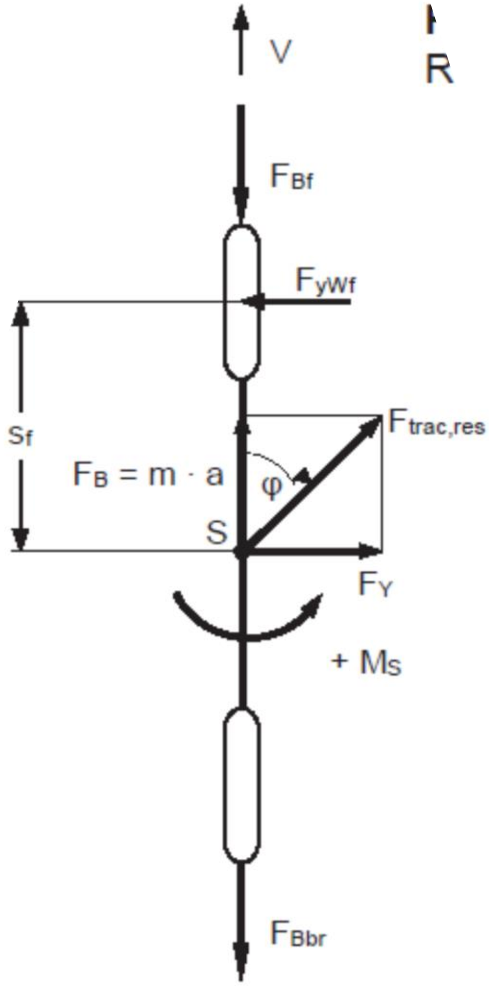

Figure 1.6: Rear Wheel Locked [5]

vehicle. What happens when the front wheels are locked? The following figure shows the behavior when front wheels are locked. When braking force is applied, the lateral forces Fywr supports the vehicle and as a result, vehicle remains in the stability region but can slide. Therefore steering capability is lost. So we can determine that, in a RWD vehicle, when rear wheels are locked, on applying the braking force, vehicle gets instable, and in front wheel case remains stable but non Steerable.

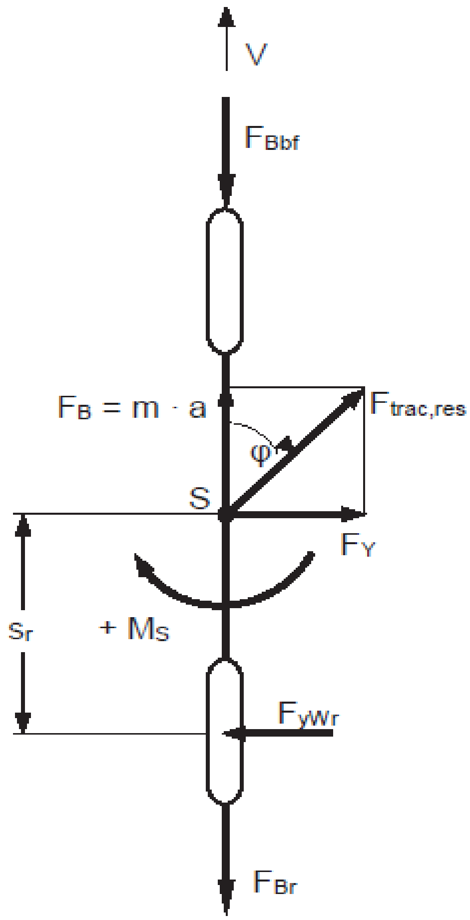

Figure 1.7: Front wheel Locked [5]

DTC prevents this locking of vehicle by applying the traction force in order to stabilize and maintain the steerability of the vehicle. However, DTC intervention can result in two situations depending on the engagement status of transmission.DTC should not intervene when vehicle is engaged, because it leads to instability of the vehicle. Miss detection of gear that is if DTC thinks that vehicle is not engaged and gives gas, but actually, vehicle is disengaged, it results as noise / roaring of engine, which is a comfortability issue. Therefore exact knowledge engagement is necessary for the proper DTC activation.

1.4 Research Objectives

This thesis explores the power transmission properties of the vehicle, and uses the relationship between engine speed and wheel speed and develops heuristic approach to calculate the tolerance speed, which is lost during braking. An online algorithm is developed by applying some filtration techniques. A second algorithm is developed by using driveline model in terms of wheel speed and in terms of engine speed. This study aims to develop an online algorithm to detect transmission engagement status.

1.5 Thesis Organization

Previously carried out studies are discussed in chapter 2. Fundamentals of vehicle dynamics, active safety systems and automotive sensors are elaborated in chapter 3. Experiments and the track used for the experiments is discussed in chapter 4. In addition to that, analysis of different measurements along with the derived knowledge from quarter car model is discussed. Furthermore in chapter 5 algorithm based on two approaches is developed. Before implementation of these algorithms, heuristic approach and drive line model is discussed. Both the algorithms are programmed in ASCET and have been analyzed in UniVW. Chapter 6 discusses the results and the filters used for performance evaluation. Chapter 7 concludes the contribution of current research thesis along with the suggestions for future work in this field of study.

CHAPTER 2 : LITERATURE REVIEW

2.1 Introduction:

Automobile industry is not a new industry instead; it exists since 17th century and ever since is in the process of development. First steam-powered vehicle was created in 1770 [6]. With the passage of time and increasing road accidents safety became critical, therefore, a lot of work is being done in the field of active and passive safety. For active safety programs like ESP, ABS, EDS, DTC and many others programs, transmission status i.e gear information has become very important. A lot work has been done by considering the transmission and driveline models in different ways. However, for the detection of gear engagement very few people have worked on that. The following paragraphs highlight the work of some intellectuals who have worked on gear detection related algorithms and related to the use of transmission or driveline models.

M.d' agostino, m. Naddeo, and g. Rizzo have proposed a model to detect active gear via OBD (online board diagnostic) data for a through the road hybrid electric vehicle [7]. Hybrid Electric Vehicles (HEV'S) have gained great interest recently and possibly will gain even more popularity in future. A through the road (TTR) parallel HEV are in the focus by researchers for electrification of rear wheels in front-drive vehicles. In this paper, a kit has been developed to convert the conventional vehicle in to a Hybrid Solar Vehicle (HSV). For the development of control strategy of motors that are present on the wheels of the vehicle, precise real time knowledge of driver intentions are important and are therefore required. Especially, it is important in which gear vehicle is engaged. The measurements data is taken from different road experiments. This model uses only the onboard diagnostic ports (OBD) data. And validates it over experimental data. This mathematical model compares the gear ratios that we already know from the manufacturer of the vehicle with the mathematically modelled ratio. The ratio is found by comparing the wheel speed and engine speed. They defined a relative error, and depending upon this this threshold identified the gear. However, it has some errors on low gears and is applied in hybrid electric vehicles and tested on Fiat grand Punto. It finds the gear number in which the vehicle is engaged depending on the difference between calculated and original transmission ratios. According to the author, the future work can be done by considering the braking distribution and interacting with the already developed safety systems like ESP and ABS. My thesis will be focusing on this aspect.

Magnus Pettersson has done a thesis on driveline model and principles for speed control and gearshift control [8]. His thesis uses the knowledge of the driveline model with consideration of driveshaft flexibility. The driveline model has been developed by performing the experiments on a heavy truck. Hence, the torsional effects in the driveline are considered. For the understanding of the relationship however, a linear model with drive shaft flexibility explains well enough the measured engine speed and wheel speed. The major critical step is to control the engine in a way that transmission does not transfer any torque so that neutral gear can be engaged. The limiting factor in this system is described by Driveline oscillations .In this paper a torque based transmission model is developed. In order to transmit zero torque a state-feedback controller is used. This controller reduces the wheel speed oscillations. That is how zero torque is achieved. In this way, it is possible to optimize the time needed for a gearshift. Furthermore, under load a neutral gear can be successfully engaged, and is under initial driveline oscillations. The results have shown the significant improvement in the performance and drivability. Author of this thesis has used the driveline model in order to improve the performance and drivability in speed control and gear shift control. The basic driveline model without driveshaft flexibility is considered in my thesis for getting the information of transmission status.

G. Dalpiaz, a. Rivola and r. Rubini in their paper gear fault monitoring, comparison of vibration analysis techniques; discuss gear condition monitoring based on vibration analysis techniques [9].This paper discusses the detection and diagnostic techniques and compares with the experimental results. The results of time-frequency based approaches and cyclostationarity analysis are compared against those obtained by cepstrum analysis, amplitude and phase demodulation of meshing harmonics. Two depths of crack are considered for measuring the severity of the fault. In this paper, the spectral correlation density function is used to identify the failure. Demodulation techniques with appropriate filters and effective transducer position is used for the identification of damaged gear tooth. According to the author, the wavelet transform is a good tool for crack detection. So a method for the detection of fault is presented in this paper.

Chia-Shang Liu, Vincent Monkaba, Hualin Tan, Clive McKenzie, Hyeongcheol Lee and Sophia Suo have written a paper on improving the stability control of the vehicle using driveline torque Bias-Management modeling [10]. In this paper, they have used three electronically controlled Torque biasing devices in order to improve the yaw stability control of the vehicle. For the development of the driveline equations of motion, Bond graph techniques have been used. The vehicle model developed in ADAM is used for monitoring the vehicle response. The torque biasing techniques are integrated in this model, whereas the control algorithm is developed in Matlab and then both these algorithms communicate via co-simulation methodology. Low mue winter test scenarios have been presented in this paper and algorithms have been validated. The goal of control jaw moment is to increase the vehicle stability and steer ability, so that the drivers could maintain better control under non-predicted or sudden situations. The three Torque biasing devices used are as follows

Electromagnetic Coupler (EMC)

Twin Coupler

Electromagnetic Limit slip Differential (EMLSD)

This paper gives a unique concept of yaw moment control, based on torque biasing techniques with mathematical model. In addition, based on this mathematical model, virtual prototype vehicle (developed in ADAM) was used to validate the results, but for real time and real vehicles, these results serve as the upfront analysis of the control strategies. Moreover, before making the real hardware, vehicle response can be observed through simulation. This paper discusses the quasi-static biasing torque models but for accurate dynamic effects of the biasing devices, detailed models needs to be developed.

Mustapha Merzoug, Khalid Ait-Sghir, Abdelhamid Miloudi, Jean Paul Dron, and Fabrice Bolaers have written a paper for early detection of gear failure by vibration analysis [11]. In this paper, authors have used vibration analysis for early detection of condition of the gears. Since gears play an important role in power train of the vehicle. In addition, can prove significantly dangerous when they fail suddenly. Therefore, to avoid the failure of systems, advanced knowledge of gear condition is important and is safety critical especially in automotive. In this paper, a dynamic gear model that includes also the localized tooth defect, is modelled. This model considers pair of spur gears. The excitations that arise due to gear errors like effects of time varying mesh stiffness and damping have been considered in the development. Newmark integration scheme is used for the dynamic modeling of the gears. Signal processing have been simulated and experimented using Wavelet transform in this form. The paper shows that, the sensitive indicator of any error or damage in the gear by kurtosis of the vibration signal. Results show that, although it is possible to detect the fault of gear, but early detection could not be achieved with time signals. By the decomposition of signals, one can trace some defects.

Honda R& D have published a paper on the vehicle stability by controlling the front brakes and engine torque [12]. They have developed an active safety system called VSA (vehicle stability assist) which is addition to the already existing active safety systems like ABS and TCS. VSA compares the yaw rate of the vehicle with the reference value that has been calculated from the lateral acceleration and speed of the vehicle. Moreover, they have used steering angle sensor's information to know the driver intentions and considered in the developed safety system. Furthermore, an original tire model has been introduced in this paper and VSA model is validated. The model developed is not only simple but also an efficient method to control the braking pressure on the front wheels and engine torque. The actual vehicle tests and simulations have also shown that it helps the driver operations.

Ulrich Goennenwein, Muhammad Rauf Hameed, and Ruediger Poggenburg have written a patent on method for detecting the Clutch condition [13]. An algorithm has been developed for detecting the condition of the clutch in engine powered vehicles. In their method, they have sent Torque pulse from engine, and evaluated the response of the vehicle in correspondence to that torque impulse. Since under normal conditions it is possible to detect the clutch engagement by simply evaluating the engine torque and wheel speeds, but under the influence of ABS braking or when the wheels starts to slip, than the results are not that satisfactory. Their work considers this problem and they provide the solution and detect the clutch engagement even in extreme driving situations. The torque impulse from the engine is sent for a very short period, and the corresponding engine characteristic curve is analysed. There is a predefined characteristic curve of the engine, and if after implementation of torque impulse, the engine follows that predefined characteristic curve, then it is assumed engaged condition. Moreover, if it does not follow then it is considered as disengaged condition. Furthermore, atleast one wheel speed is compared with the engine wheel, and if the behavior of wheel speed and engine speed is entirely different, then a disengaged condition is met. The Engine torque ranges between 10 Nm and 40 Nm.

CHAPTER 3 : FUNDAMENTALS OF VEHICLE DYNAMICS

This chapter deals with the study of basics of vehicle dynamics. It discusses power transmission process in a vehicle from engine to the wheels. Power train of the vehicle, along with the basic components of any power train like clutches, gears and differentials are discussed in chapter. It gives the complete overview of the fundamentals of vehicle dynamics. Traction force and resistive forces are also being discussed in this chapter. The fundamental knowledge behind the power transmission of vehicle is discussed in detail.

3.1 Power transmission of Vehicle:

Power transmission of vehicle consists of Engine, Transmission, Driveshaft, final drive and propeller shafts. Figure 3.1 shows the transmission lay out of rear wheel drive. The Power at engine level is transferred to the wheels through the clutch, which transmits the torque to the gears, and from gears, it is transferred to the drive shaft and from drive shaft further transmitted to Differential. Differential is connected with driven wheels through a shaft. Moreover, it transfers torque equally to both the wheels with a differential ratio. A Differential axle is capable of transferring different speeds to both the wheels hence enabling better control when cornering and also when vehicle is on different surfaces. Different arrangements of Differential are available for the better control and torque transmission.

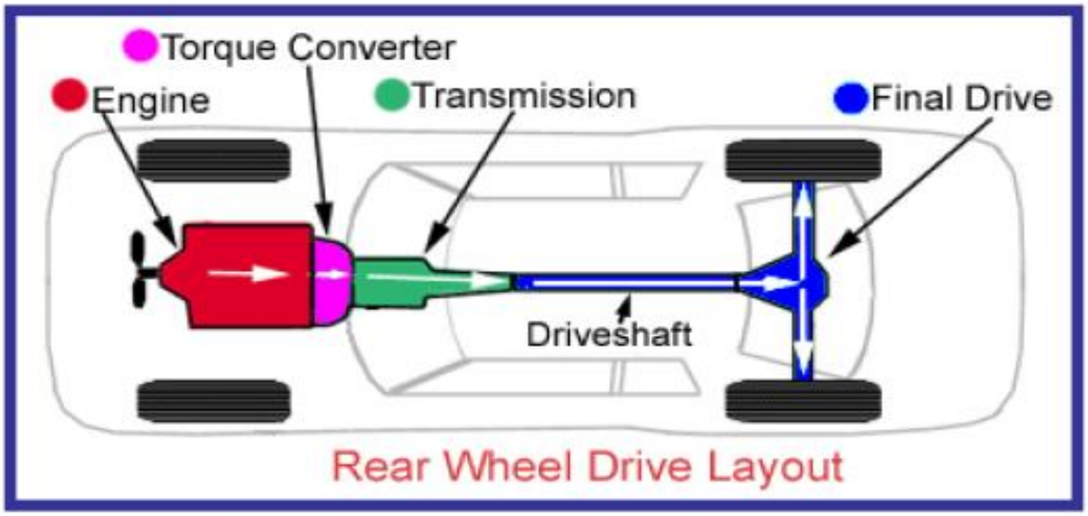

Figure 3.1: power train of Rear wheel Drive vehicle [14]

The principal objectives of the power train development are to ensure less consumption of fuel and better control of the driving dynamics and to ensure the necessary motive power required in all kinds of driving situations. In other words

- High comfort level
- Low emissions

Before discussing the power train model and transmission of torques from engine to the wheel, we need to know the forces that act on the vehicle. After determining the resistive forces and traction force required overcoming the resistive forces, Power train model will be discussed.

3.2 Traction Demand at constant Speed

In this section, we are going to find out the force required to overcome the resistive force in order to move the vehicle. This is sometimes referred as Motive Force, Traction Force or Drive Force .Figure 3.2 gives the overview of the forces that act on the vehicle. Figure 3.3 gives the detailed description of the forces acting on the vehicle; the symbols used are described as below

$F_{RWheel,i}$ = Wheel Resistance

F_{RAir} = Air Resistance

F_{RAir} = Air Drag Force

F_{RA} = Acceleration Resistance

F_{RIn} = Climbing Resistance

F_{trac} = Tractive Forces

F_{RPT} = Tractive Force

m = Mass of the vehicle

g = Acceleration due to gravity

α_{In} = Slope angle

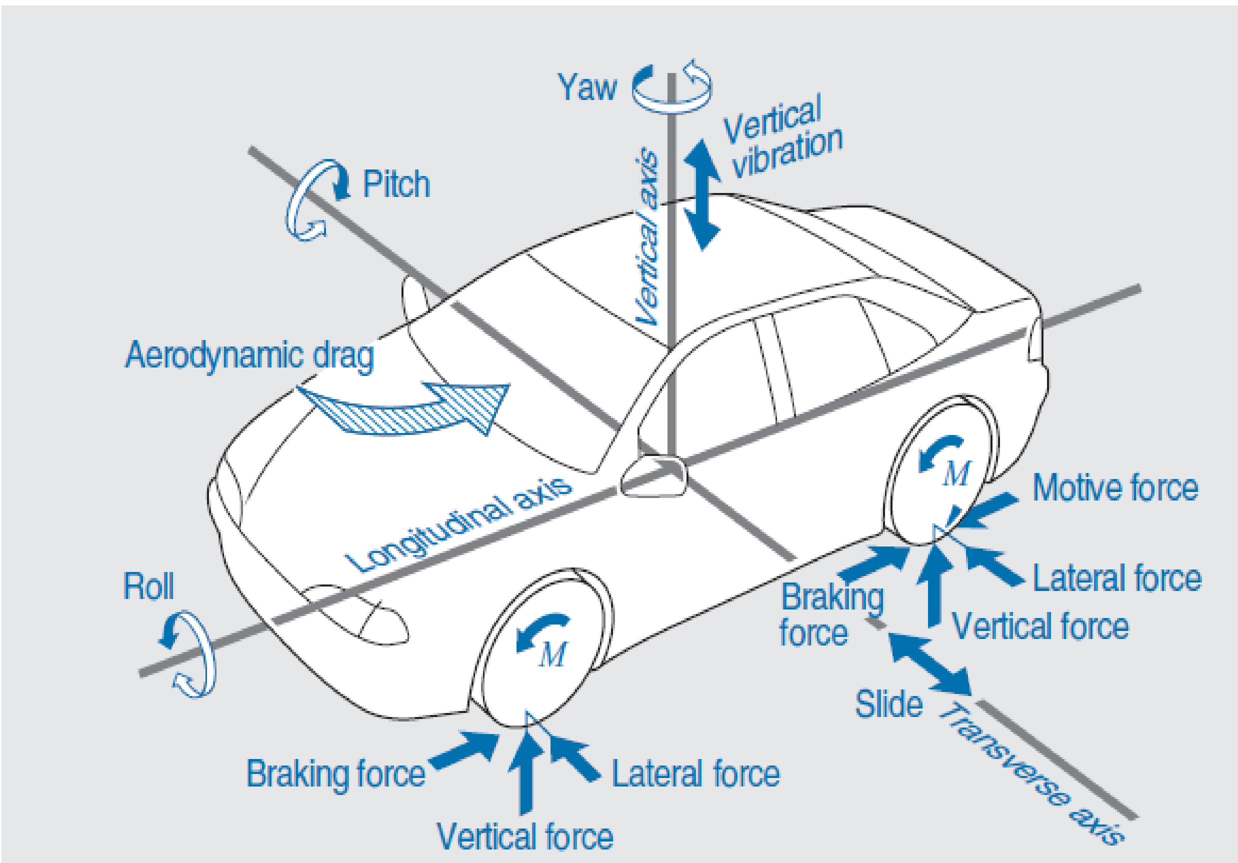

Figure 3.2 over view of the forces acting on a vehicle [15]

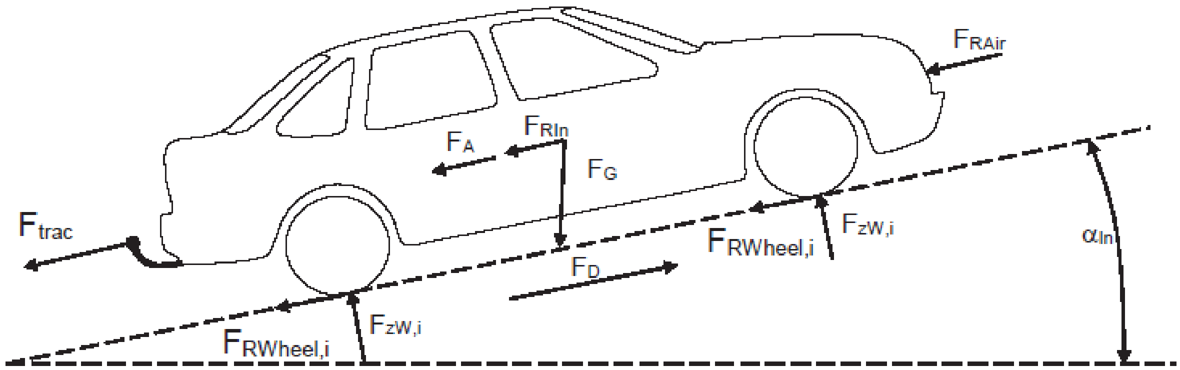

Figure 3.3: Forces acting on an inclined vehicle [16]

3.2.1 Power Train Resistance:

After considering all the losses that occur due to transmission, cordon shaft, and differential, from Engine to wheels, the power train resistance lies between the values of 0.1 and 0.2 of the engine Power and about 15 % of engine power is equal to the power at flywheel.

$$F_{RPT} = \text{Tractive Force} = 0.1 - 0.2 P_{Eng}$$

3.2.2 Wheel Resistance

The resistive forces that occur against the movement of wheels are termed as the Wheel resistance. Wheel resistance is sum of rolling resistance, acceleration resistance and flood resistance. And is given by the formula

$$\text{Frwheel, i} = \text{FRR, i} + \text{FR}\alpha\text{, i} + \text{FRFL, i}$$

3.2.2.1 Rolling Resistance:

It is defined as the resistance to the movement of a wheel, which rolls freely (so there is no drive and brake torques, also not caused by bearing Friction)

In the level plane

Rolling resistance FRR,i consists of

$$FR_{R,i}=R_{FLex,},+FR_{Air,i}$$

- Flexing resistance FRFlex,i :

The main part, about 80 % of $FR_{R,i}$, originates by deformation of the tire when running through the contact patch i.e. contact area of the treads.

- Air resistance $FR_{Air,i}$

Air resistance occurs due to the flow resistance of the moving wheel and constitutes only 10% of the rolling resistance

3.2.2.2 Flood Resistance $FR_{\mathrm{FL,i}}$:

Flood resistance is produced when the vehicle moves through a wet surface. Due to displacement of water, resistance is produced and is described as

$$FR_{FL,i} = f(\frac{Volume\ of\ water}{time})$$

Consider a contact patch, if b represents the width of contact path, l length and h height, then volume can be written as

$$V = b \cdot l \cdot h = \text{Volume}$$

In addition, flood resistance can be found when we know the time. Whereas evaluation of the wheel resistance FRwheel, i is usually done through the rolling resistance because air resistance and flood resistances are very small so they can be neglected.

3.2.3 Air resistance

Air resistance occurs due to the opposite air pressure, due to the movement against the flow of air, and due to the friction resistance.

- **Pressure resistance:**

About 70% of Air resistance is due to formation of pressure on the backside of the vehicle through dynamic pressure, due to which bugs or circular rings are formed and pulling forces that result in the formation of vortex, and vacuum is created.

- **Flow through resistance:**

About 20 % of the air resistance is due to the Flow through the resistance and It is formed at the radiator, engine room and passenger compartment.

- **Friction resistance:**

Wind blows against the movement of direction of vehicle. The air resistance FRAir due to the wind force FWind works against the driving direction of the vehicle. Since Wind acts in the x direction, so we can say that FRAir = FWindx even at inclined flow and is expressed as

$$F_{R,\,Air} = \frac{1}{2} c_x A_f \rho \left(\frac{V_{A,\,rel}}{3.6}\right)^2$$

$F_{R,\,Air}$ = Air Drag Force

C_{air} = air drag coefficient

A_f = cross sectional area

ρ = air density, which is also a constant parameter

3.2.4 *Climbing resistance:*

Climbing resistance is the resistance applied on the vehicle when vehicle is on the slope. For example when the vehicle is moving uphill. It can be calculated by considering the following figure and computing the force component that is acting on the vehicle.

$$F_{RIn} = F_G sin\alpha_{In} \quad [N]$$

$$P_{In} = \frac{F_{RIn}.v}{3600} \quad [KW]$$

3.2.5 Acceleration resistance

The resistance due to acceleration is written as

$$F_{RA} = m.a \quad [N]$$

$$P_A = \frac{F_{RIn}.v}{3600} \quad [KW]$$

3.2.6 Total Driving Resistance:

By adding all the resistance total driving resistance is described as

$$F_{R,tot} = \sum F_{RR,i} + F_{RAir} + F_{RIn} + F_{RA} + F_{trac}$$

Graphically it can be explained in the following figure. The figure shows the total driving forces against the speed of the vehicle. We can clearly observe from the figure , that as the velocity increases, the percentage of resistive forces also increases. Greater the speed of the vehicle , greater is the wheel resistance and air resistance.

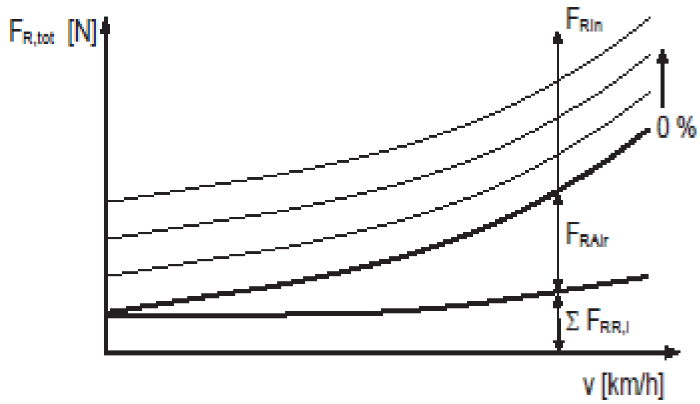

Figure 3.4: Resistive Forces [17]

3.3 Torque Supply

The product of force and velocity is called Power, and is written as

$$P = F.V$$

Whereas the power of vehicle is defined as

$$P_{An} = P_{ICE}.\eta_{ges}$$

Similarly driving torque is expressed as

$$M_{An} = M_{ICE} i_{ges} \eta_{ges}$$

Where

M_{An} = Driving Torque

i_{ges} = Gear Ratio

η_{ges} = over all efficiency

M_{ICE} = Engine Torque

Therefore, by the end of this section we are now well aware of the factors that affect the driving. Moreover, by considering all the resistive forces, we are able to calculate the maximum driving force with which the vehicle moves and the Torque produced. However, it does not give any information about how much power (generated at the engine level) has been transferred to the wheels. For that, need we need to know Clutches, and Gears. And how power is transmitted through these. Furthermore, from the differential drive and drive shafts. The following section explains the basics of clutches.

3.4 Clutches

Clutches are the main parts of the vehicle transmission, which open or close to engage or disengage the vehicle. Clutches are divided in to two types [18].

- Shiftable Clutches/ Dry Clutches
- Non shiftable clutches

Different designed clutches that are present in the market are as follows

- Shiftable friction clutches
- Shiftable dog clutches
- Non shiftable elastic clutches
- Dry friction clutches

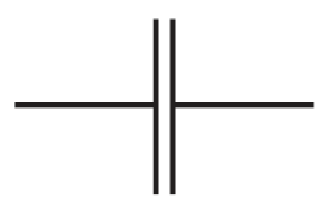

Figure 3.5: clutch symbol

Clutch in special form is similar to the brakes. But in brakes shaft is connected to the case. A clutch is represented as shown in the figure above. Clutches are used for two purposes.

To reduce the speed gap between engine and wheels from standstill and they are also present inside the transmission for shifting from one gear to another.

3.4.1 Torque of Clutches:

Clutch is an autonomous component that connects two shafts and transmits torque to the other parts of the transmission. Clutches perform two major tasks in the vehicle. They allow the vehicle to move from standstill and secondly they determine the torque flow when gear ratio is changed. Torque is determined by the following formula [19]

$$M_k = \mu F_N r_m$$

Where

F_N = Normal Force

r_m = Mean friction Diameter

μ = friction coefficient

There is always a loss between the input torque of the clutch and the output torque.A clutch without slip is called Torque proof connection, and the ratio between input speed and output speed is 1.If the introduced torque is greater than the transferable torque, than the speed of differential transmission increases. If a clutch is slipping, the power will always flow from the faster turning side to the slower turning side. The following figures show the implementation of clutches in manual and automatic transmission.

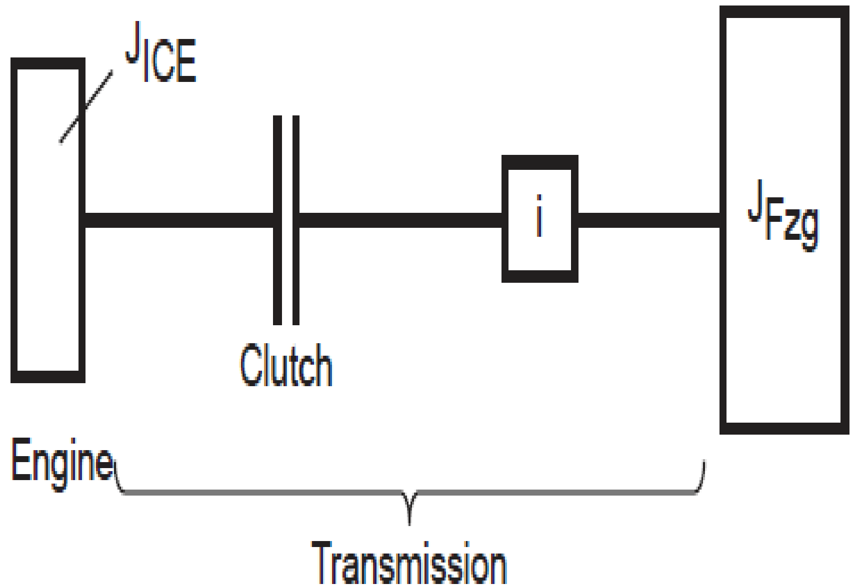

Figure 3.6: simplified Power train model for Manual transmission [20]

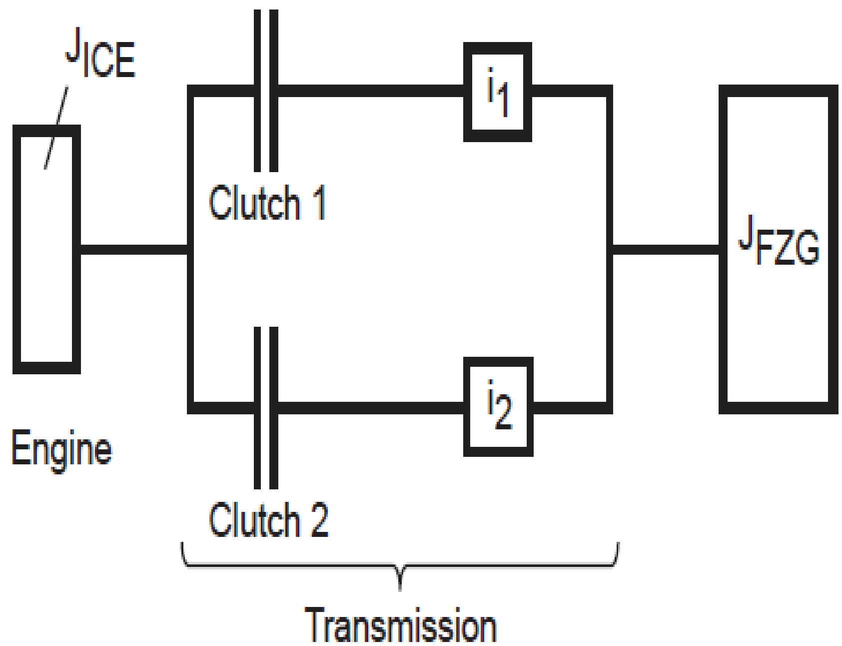

Figure 3.7: Simplified power train model for Automatic transmission [21]

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3.5 Gears

Another important component of the power train is Gear. Torque is transmitted depends on gears. The ratio at which torque is transmitted can be found by the following formula and is called the Gear ratio

$$i = \frac{\omega 1}{\omega 2} = \frac{n1}{n2}$$

Under omission of losses, the output torque is

$$M2 = iM1$$

If the gear ratio is not one, then a torque difference occurs between the input and output shaft.

$$M3 = M2 - M1 = (i-1)M1$$

Some of the general properties of gears, their relationship with speeds and torques is summarized here below, but for complete details, one can refer to any automotive book.

- Larger the wheel, greater the speed, also more torque would be required.
- Higher gear ratio means that high torque is provided, and for large accelerations, higher torque is necessary. Whereas Lower gear ratio provides low torque but more speed
- To obtain the higher speed, the ratio of driven gear must be lower, and ratio of driver gear should be higher. Moreover, inverse relation holds when we want to have high torque instead of higher speed.

3.6 Power Train Model

In the power train of a motor vehicle torsional vibrations can be represented by rotating mass Couplings via springs and dampers. The Figure shown below shows the power train model of the vehicle through dampers and springs. All the masses are represented by their moment of inertias and are indicated with the symbol J. In addition to the inertia of the transmission the gear ratios of transmission is represented by i_G and differential ratio on the rear axle is represented by i_{HA}.

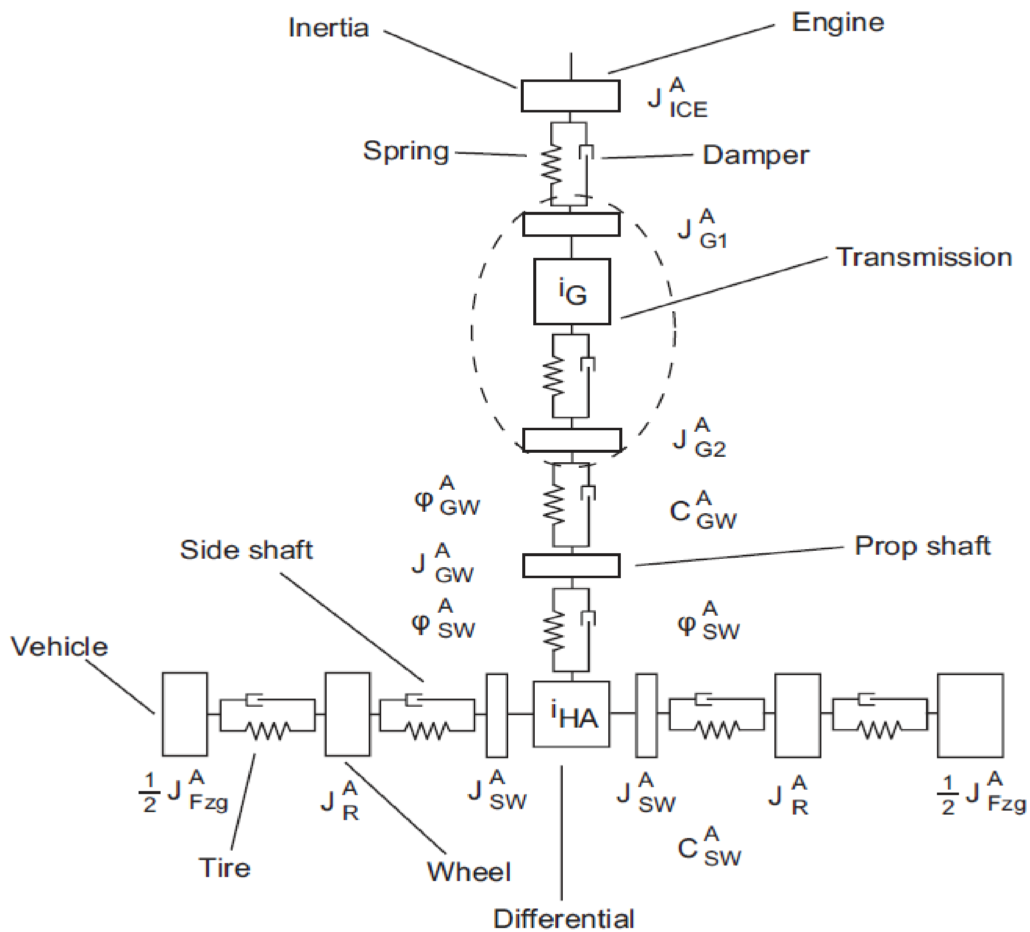

Figure 3.8: Power train model in terms of dampers and springs [22]

Since when a vehicle moves, it has two kinds of motion, translatory as well as rotatory motion. The vehicle mass translates while the wheels rotate. Translator motion can be expressed in terms of rotatry motion by following simple newton laws of motion.

From Newoton's 2nd law of motion for translatory objects

$$F = ma$$

Can be written as

$$F = m_{Fzg} \ddot{x}$$

And for rotating objects

$$J = m_{Fzg} r_{dyn}^2$$

Can be written in terms of torques as

$$M = J_{Fzg} \ddot{\varphi}$$

Figure Motion systems shows both kinds of motion. These both types of motion are coupled together through the rolling motion and using the dynamic tire radius of the wheel.

$$\ddot{x} = r_{dyn}\ddot{\varphi}$$

Therefore torque and equivalent inertia can be found by

$$M = Fr_{dyn}$$
$$J = m_{Fzg}r_{dyn}^{2}$$

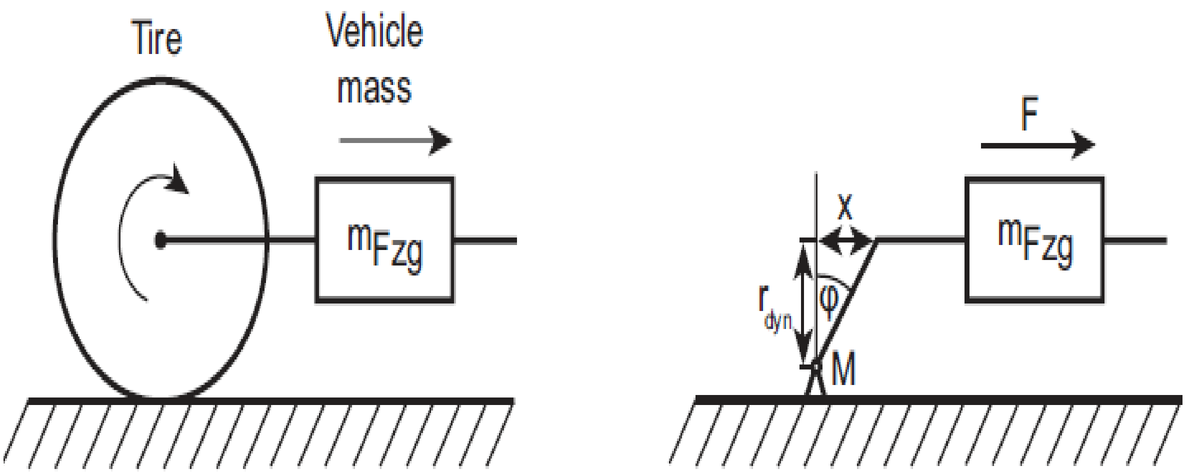

Figure 3.9: Motion systems [23]

A simplified transmission system is shown in the Figure where M1 is the engine torque and M2 is the output torque. In addition to that transmission is supported via mount and is shown as M3.

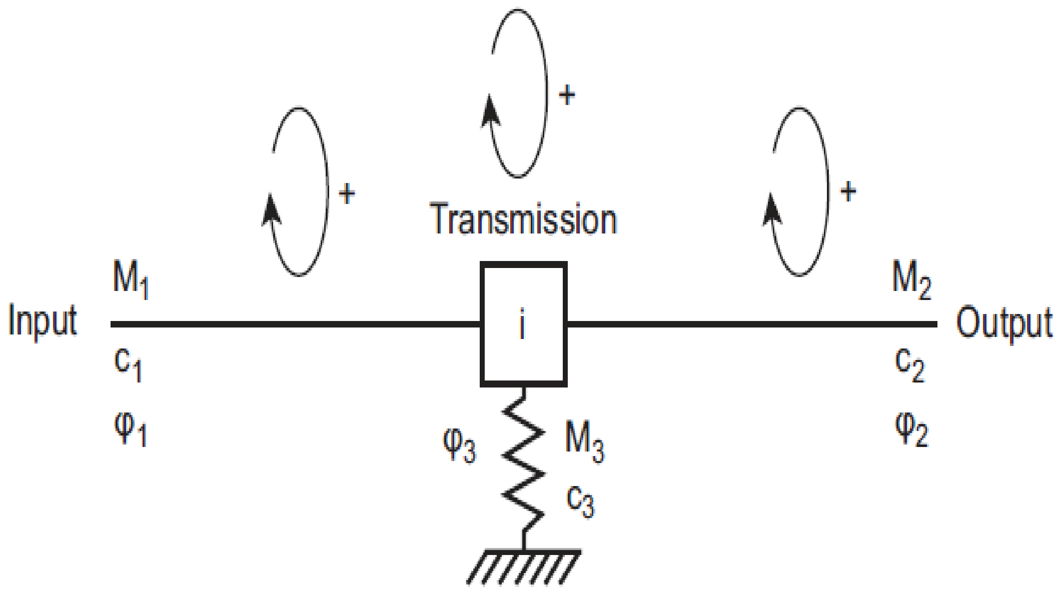

Figure 3.10: Simplified transmission system with mount [24]

The output torque of the clutch M2 is given by

$$M2 = iM1$$

Where 'i' is the gear ratio, mentioned by the manufacturer of the vehicle, and is always known.

$$M3 = M2 - M1 = (i - 1)M1$$

The major components of power train include clutches and transmission, which have been discussed here. In addition, these provide the complete knowledge of how power is transmitted. A complete power train drive model is also discussed in when second algorithm is developed. Which takes in to the consideration the forces acting on the wheels and air drag forces.

CHAPTER 4 : Chassis systems control

4.1 Introduction

This chapter discusses the important control systems of the vehicle. It gives overview and some basic knowledge of antilock braking system, Electronic stability control Program and Traction control Program. These are the important control systems, which are being used in most of the modern vehicles to ensure the safety. These are also the major control systems in active safety systems, and all the new control systems will have somehow the relation with these programs, so before developing any active safety controller, one needs to understand these. Therefore, the basics of these are described here under.

4.2 Antilock Braking System (ABS)

4.2.1 Overview of an ABS System:

There are some driving conditions, when wheels are locked if brakes are applied. The locking of wheels occur depending on different conditions. Different road surfaces differ depending upon their mue coefficient, behave differently, and can cause wheel locking. Locking of wheels occur

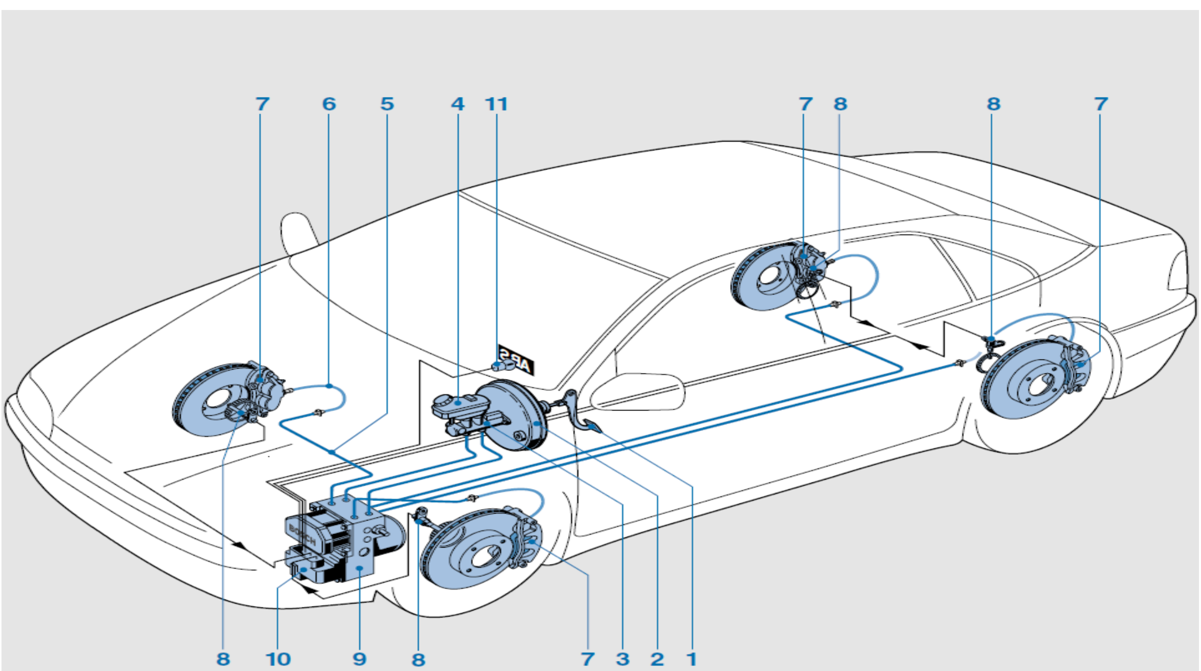

Figure 4.1: Braking System with ABS [25]

especially on low mue surfaces. Locking can also occur due to sharp maneuvers. When wheels are locked, they are no more steer able, instead they slide, and braking takes longer than the expected time.

The other possible cause includes a sudden reaction of the drive due to some unexpected hazard. The antilock braking system (ABS) is responsible for detecting if one or more wheels are about to lock up when vehicle is under braking and if such is the case, then ABS either sustains the constant pressure or reduces pressure at the desired wheel. That is how it prevents the wheels from locking up and vehicle is enable to remain steerable and under control. This way it also helps in braking and instead of taking long time , the vehicle stops at shorter distance, and under complete control and safely.

Fig 4.1 shows the overview of the ABS braking system. The abs braking system is based on the following conventional components

1. Brake pedal
2. Brake booster
3. Master cylinder
4. Reservoir
5. Brake lines
6. Hoses
7. Brakes and wheel-brake cylinders
8. Rotational wheel-speed sensors
9. Hydraulic modulator
10. ABS control unit and
11. Safety lamp, it lights up if there is any failure in ABS.

4.2.2 Working of ABS:

The working of ABS depends on the following factors

Wheel-speed sensors

Wheel speed sensors consists of notched or toothed rotor are located the each wheel of the vehicle and measure the rotation of wheels. This sensor output is very important and is used in many programs other than ABS. Wheel speed sensors differ depending upon the vehicle equipped, but usually there are four-wheel speed sensors. This speed sensor information is sent to the Electronic Control Unit (ECU). Depending on the information of wheel speed sensors , slip of the wheels can be calculated , and as result ABS decides whether locking condition is met or not. The working of wheel speed sensors is explained in the chapter automotive sensors. Here only the use case is explained.

Electronic control unit (ECU)

ECU is very important part of any vehicle. All the signals processing is done in this part according to the defined mathematical procedures. Depending on these control algorithms the signals are transferred to the respective unit, here in ABS case, when the brakes are applied, the wheels speed of rotation changes, this sends a new signal to ECU, if the control unit senses that wheel might lock, it sends a signal to the hydraulic control unit/ hydraulic modulator

Hydraulic modulator

The hydraulic modulator has series of solenoid valves, which open or close the hydraulic circuits between the master cylinder and brakes. This is the main hydraulic part that is controlling the pressure at individual wheels, and these solenoid valves are activated or deactivated depending upon the resultant signal information, obtained from ECU to prevent the locking. The valves are in series to the master Cylinder and brake circuit. One operates for each of the front wheels and one controls both rear wheels. At the start of the engine the abs automatically checks, if there is any failure then a lamp shows at the dash panel that ABS is not working properly. The following figure shows the solenoid valve configurations and the brakes. When brake pedal is pressed, pressure is passed through the intake valve and reaches to the brakes, and when pedal is released, outlet valve is actuated, and pressure is released through output valve.

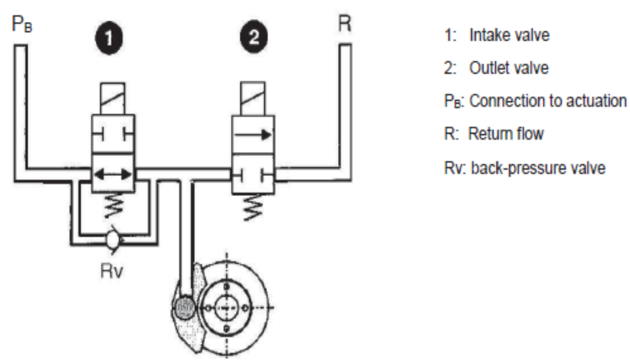

Fig 4.2: ABS Valve Configuration [26]

4.2.3 Requirements and capabilities of ABS

There are many requirements that ABS must have to fulfill to ensure the safety. These requirements are particularly associated with dynamic braking response and the braking system technology

Handling stability and steer ability

ABS must ensure the Steering ability and handling stability on all the road surfaces.

The utilization of adhesion coefficient should be maximum possible, so that handling stability and steer ability gets priority over the minimum braking distance. There should not be difference depending upon abrupt braking or gradual braking.

ABS should be able to recognize the different mue surfaces.

When cornering, the handling stability and steer ability must be ensured, and if brakes are applied, they should, the vehicle should brake as early as possible.

The control system is also responsible for ensuring the handling and steering ability under bumpy or uneven road surfaces.

Aqua planning detection is also important for ABS, thus it should be able to distinguish, whether the surface is having aqua planning effect or not. Aqua planning occurs when a layer of water is formed on the road, and the wheels are not in direct contact with road, instead, there is a layer of water between them.

The braking should be effective on the entire speed range. This means that should be as effective on low speed as on the higher speeds. Higher speeds should not affect the working of ABS.

Minimum Time

Timing adjustments to tackle the hysteresis and engine effects should be as less as possible.

The reaction to the vibrations should also be prevented.

Reliable System

ABS must be reliable, that means there must be counter check circuit, ensuring that ABS is functioning correctly.

4.3 Traction control system (TCS):

There are many conditions and behaviors on which a vehicle can become unstable. Critical conditions are not only the resultant of braking, but can also occur when longitudinal forces with higher magnitude are transferred at the contact area between tires and road surface. Some of the other scenarios when a vehicle response can be critical are as follows

- When starting off and accelerating , especially when road is slippery
- On hills
- When cornering

These kind of situations can trigger the sudden abrupt, wrong reaction of driver, and hence can result in instability of the vehicle. Traction control System (TCS) is the control system that helps to solve these problems and directs the vehicle to remain within the physical limits. Hence, TCS helps to prevent such critical scenarios ensuring more safety. Since ABS prevents the wheels from locking up by lowering the brake pressures of individual wheels. TCS reduces the driving torque at individual wheels in order to prevent the wheels from spinning. So TCS is considered as logical extension of ABS during acceleration. TCS also regulates the optimum slip and thus improves traction of the vehicle.

4.3.1 Working of TCS:

The torque from engine is transferred to wheels through the power train. The power train contains clutch, gear, propeller shaft, differentials and drive shafts. The torque transferred from differential is transferred as in the fifty fifty-ratio i.e. 50: 50, hence the vehicle moves in synchronized manner. However, what happens if the transferred torque is different on both wheels. When the torque differs, then the wheel containing more torque will remain no more in rotary motion without spinning, instead it will be spinning. As a result the motive force will be reduced, which results in the loss of the lateral stability and vehicle becomes unstable. TCS acts in this condition in order to reduce the torque. It regulates the slip of the driven wheels in the minimum possible time to the optimum level. For this purpose, reference slip is necessary to be determined. Reference slip is dependent on many factors, which include effective friction coefficient, external tractive resistance, yaw velocity, lateral acceleration and steering angle of the vehicle. [27]

4.3.2 Advantages of TCS:

Introduction of TCS has brought many advantages for automotive industry, especially in active safety systems. Some of the major advantages include

- TCS helps to avoid the unstable conditions
- Due to regulation of the optimum slip, Traction is increased.
- Engine output is controlled automatically.
- Wear of mechanical parts has been reduced. Since not every mechanical part is equipped with the dampers and spring system, for example tires. Therefore, Tires are saved from more wear.
- Similarly, the wear of drive mechanism transmission and differential is reduced. These play a handy role on the low mue surfaces.
- The warning lamps are present to inform driver, if there is any critical condition.
- TCS uses the ABS hydraulic components effectively

4.4 Electronic Stability Program (ESP):

Why do the accidents occur? Most of the accidents occurs due to the human error. There might be reasons behind those errors. Many external factors also play the role. There can be certain uncertainty behavior, for example, there can be sudden appearance of obstacle on the road, or the driver is driving extremely fast, and tries to take a sharp turn. The driver may tries to make a line change maneuver fast and then wants to come back.

The figure 4.3 shows a typical scenario when a vehicle takes a sharp turn. It can be clearly seen that a vehicle without ESP would result in instability and will completely turn and therefore is instable and safety critical

In all the above-mentioned scenarios driver is not able to control the vehicle and the reason for that is, as when the vehicle reaches to its critical limits, it is no more control able. Hence the equilibrium conditions of lateral forces are not justified. The vehicle can fall in to over steer or under steer. So in order to improve the handling and braking response of the vehicle, Electronic stability Program (ESP) is designed. ESP is a closed loop system that uses an algorithm and intervenes in the braking system and/ or drive train when necessary. The already developed ABS prevents Wheels from locking, whereas TCS is responsible to prevent the wheels from spinning.

In Addition to that, ESP is designed to counteract when vehicle goes under steering or over, which is done by doing the steering corrections. Alongside that, it maintains stability by preventing the vehicle braking away to the side but it is necessary that vehicle does not go beyond its physical limits. Following are the functionalities of ESP system.

ESP improves the driving safety by enhancing the Vehicle stability. The control system is responsible for keeping the vehicle on track and improves directional stability. The directional stability is improved in all the operating conditions. It takes care of emergency stops, load shifts, in braking maneuvers, coasting, cornering, accelerating, decelerating, and trailing throttle and all the possible operating conditions.

ESP also enhances the vehicle stability by controlling the vehicle during sharp steering maneuvers, also known as fast cornering , where the driver can panic and his response can lead to over or understeer, so there exists a very high risk of skidding or braking away.

ESP acts in a variety of different situations. It improves the exploitation of traction potential, when ABS and TCS are active and when Drag torque controller (DTC) is active. DTC gives gas when necessary to avoid the excessive braking. So as a result, vehicle's stability is enhanced, and vehicle becomes control able.

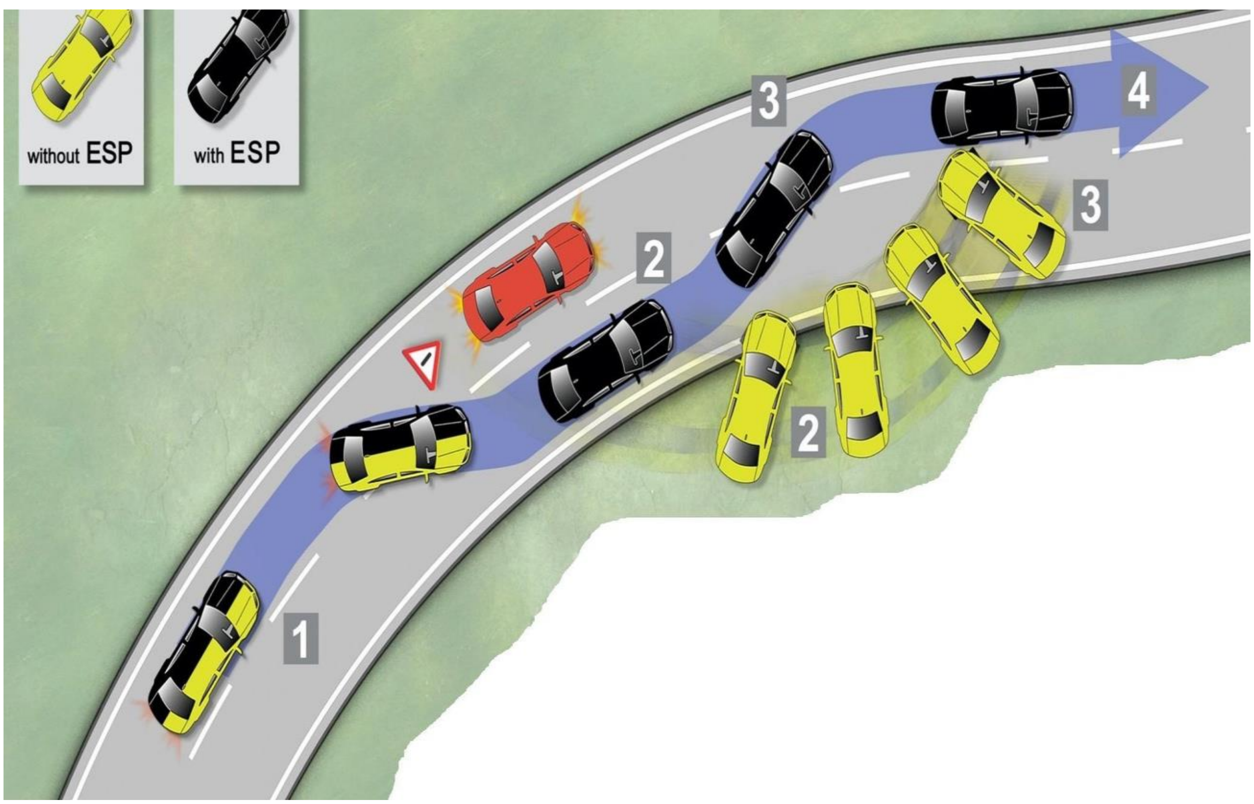

Figure 4.3: Vehicle with and without ESP [28]

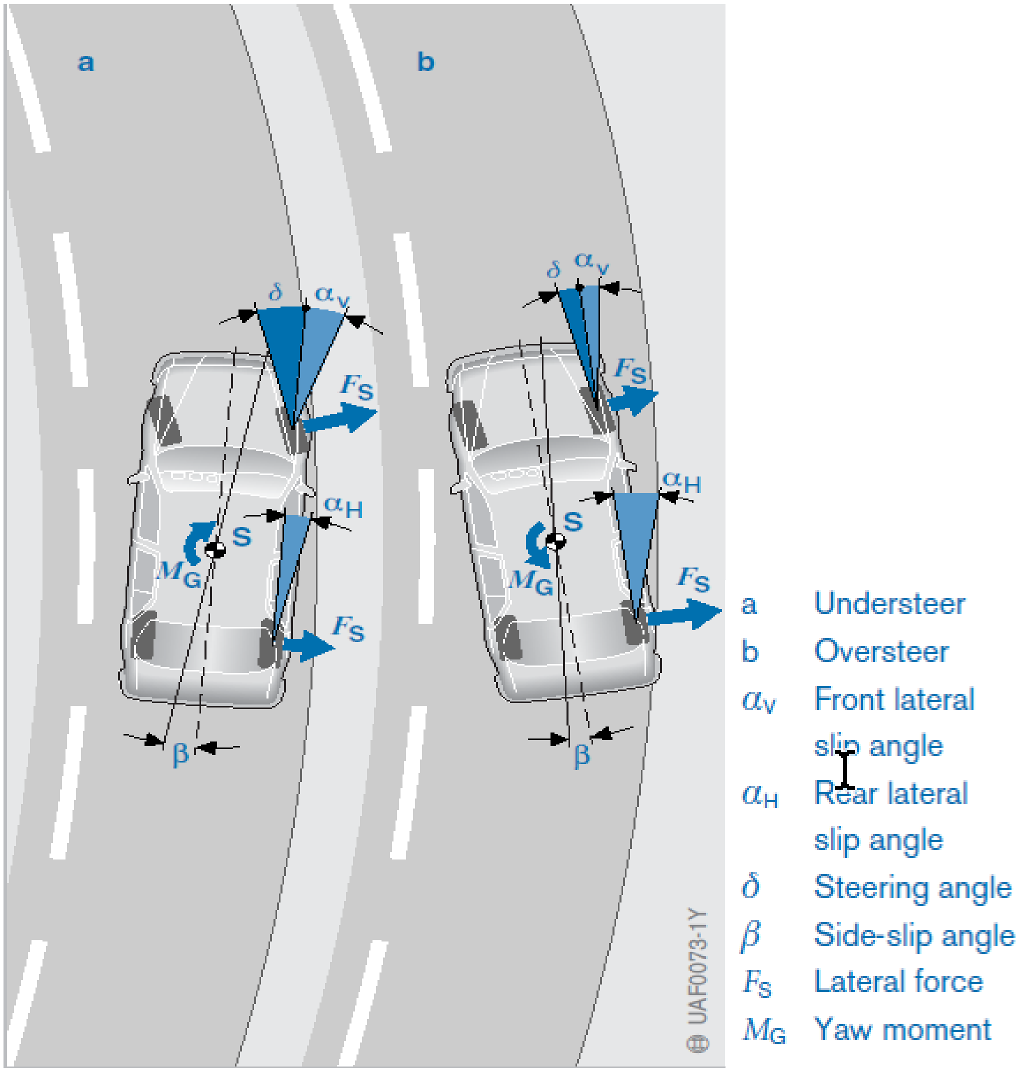

Figure 4.4: Over steer and under steer of a Car without ESP [29]

The major task of ESP is to control the lateral dynamics of the vehicle until they remain within the limit range. Contrary to ABS, that maintains the limit range for longitudinal dynamics. The principal objective of ESP is

- to monitor the Driving condition permanently
- to identify the critical conditions where the vehicle starts skidding
- to Counter the torques that have been initiated when the pressure is applied individually at wheels
- to intervene in Engine Torque
- The control range is the entire slip range from 0 to 100 %

Figure 4.5 shows the two typical behaviors of vehicle when it is not equipped with ESP. Figure 4.5a shows understeer and Figure 4.5b shows over steer, further explained in section 4.4.2.

4.4.1 Working of ESP:

The following Figure shows the components of the ESP. A rotational speed sensor (7) is located at the each wheel of the vehicle. The rotation rate sensor measures the cars rotation around its vertical Axis. Steering Angle sensor (10) registers the drivers steering intentions. From the sensor signals, the ECU (6) has to decide when and how to intervene. The hydraulic unit (2) builds up and reduces the hydraulic pressure in the brakes (5).

Consider a vehicle is travelling on a highway, and suddenly an obstacle is dropped from the vehicle traveling in front. In order to avoid the collision with the obstacle, the driver has to take abrupt action and has to steer left. What happens during the first steering maneuver, the driver has to swirl quickly to the left. Steering angle sensor transmits this to ESP control unit, but the rotation rate sensor signals that the car is under steering, that is it is drifting straight ahead to the obstacle. Straight away ESP brakes left wheel briefly and sharply , this produces the desired counter acting force , so the car responses as the driver intends. What happens when one reacts, when one pulls the wheels over to keep the car in the left lane after avoiding the obstacle, the car tends to over steer? And the rear end tends to brake away to the left. In this way, the torque to the right is higher than the driver wants. Therefore, ESP brakes the left front wheel, and the torque is reduced, instead of going in to a skid, the car stays on the path. This is how ESP works and saves from the major accidents. ESP acts faster than the driver.

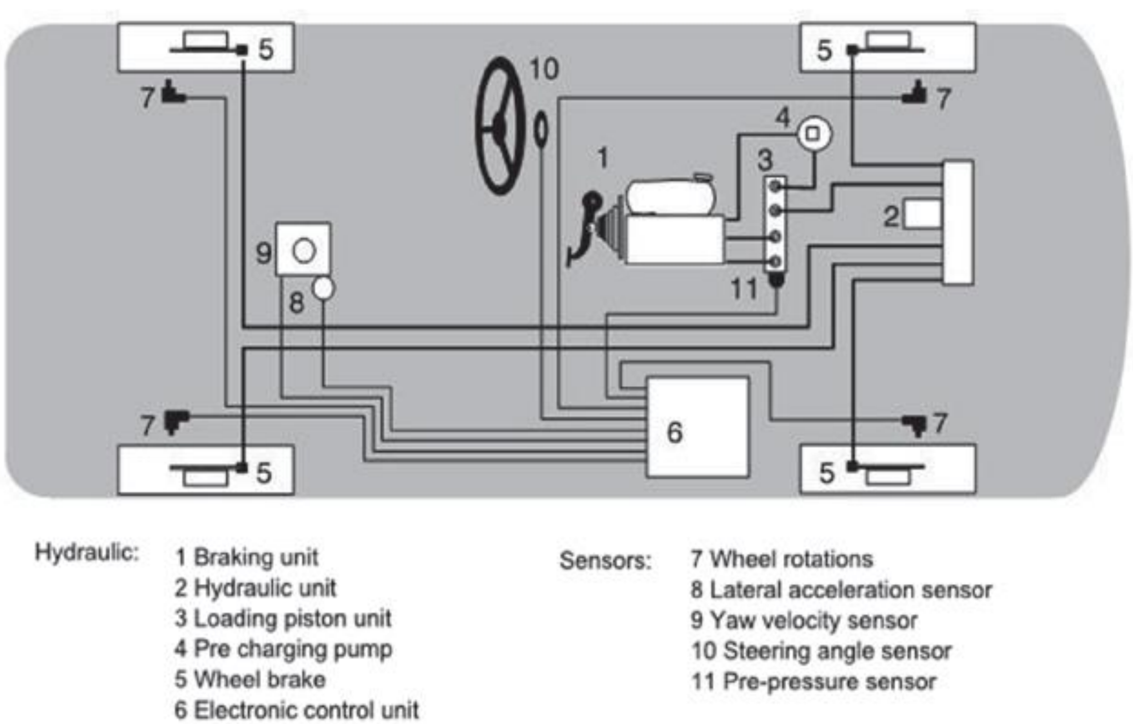

Fig 4.5: Components of the driving dynamics control unit ESP [30]

4.4.2 Over-steering and under-Steering:

The following figures shows the case, when one has to take a sharp turn and the vehicle, without ESP does not take that much turn, hence remains under steer. ESP Stabilizes understeering vehicle through automatic intervention on brakes of rear axle (curve's inner wheel) by doing the following steps

1.) Drive train mangagement reduces the Engine torque on rear axle
   - By reducing the driving force
   - By increasing the lateral force in rear, which increases the counter torque as a result.

2.) Outer front wheel in curve which is rolling freely up till now is braked
   - by increasing the Brake force which results in the increase of the counter torque
   - by reducing the Lateral force in front hence decreasing the counter torque

In addition, in the case when it takes too much turn and gets in to over steer. ESP Stabilizes over steering (skidding) vehicle through automatic intervention on brakes of front axle (curve's outer wheel)

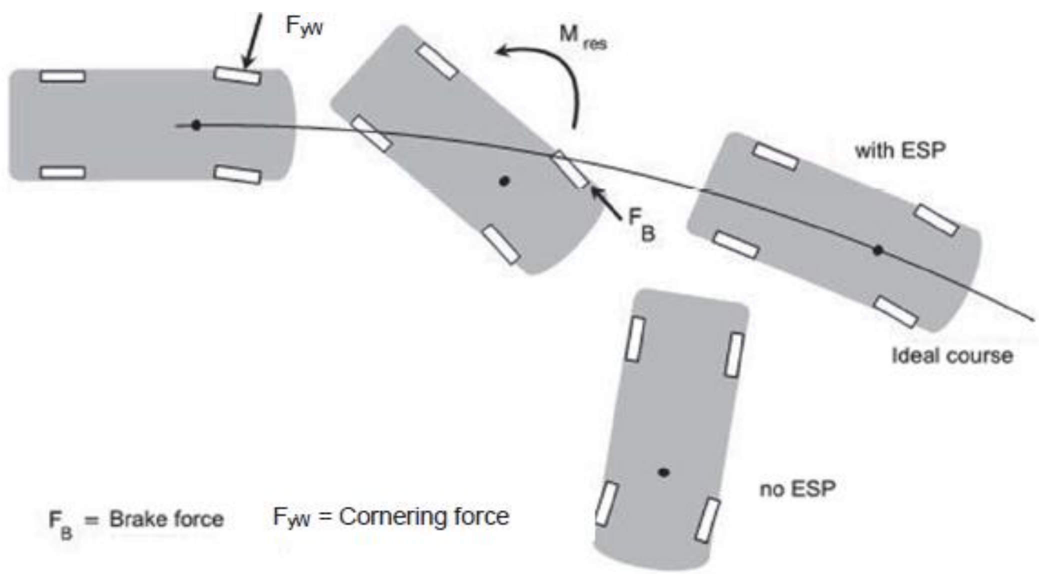

Fig 4.6: ESP application in over steering vehicle: [31]

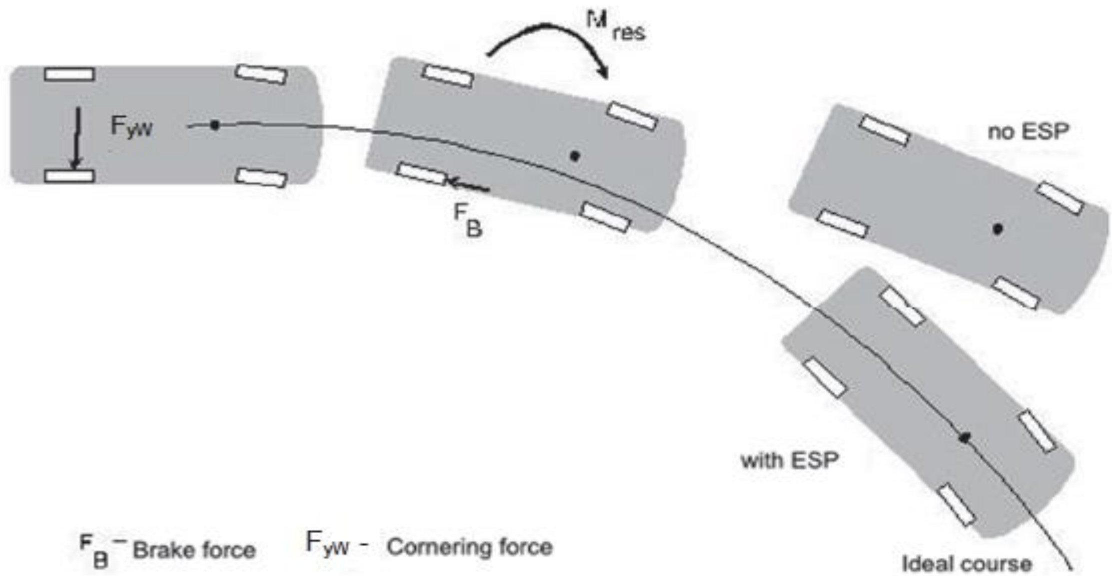

Fig 4.7: ESP application in understeering vehicle [32]

ESP has been built upon ABS (Anti-lock braking system) and TCS (Traction control system). In ESP, sensor technology has been increased for acquisition of driving conditions. Apart from Steering wheel angle sensor, lateral acceleration sensor and yaw rate sensors are also part of ESP. Mercedes Benz first introduced ESP in the vehicle in 1995.

Hydraulic Control Unit:

The hydraulic control unit of ESP is shown in the figure below. ABS has two hydraulic valves, and in all four hydraulic valves, whereas ESP has eight solenoid valves in its hydraulic system. Therefore, hydraulic system for individual deceleration of wheels is expanded. It monitors the driving conditions permanently. The critical conditions are identified at the beginning of the skid. We can examine a single brake circuit. For the corrective action ESP, the brake fluid oil is conveyed from the hydraulic pump to the brake circuit. As a result, the brake pressure is immediately available at the wheel brake cylinder and return flow valve. The inlet solenoid valve is closed, and the exhaust valve is already closed, means there is no way of pressure outlet. So all the pressure is available to the wheel brake cylinder. Now when ESP wants to release the pressure, the exhaust valve gets open and the brake fluid can flow back to the reservoir. Hence, in this way pressure is applied at all the four wheels of the vehicle.

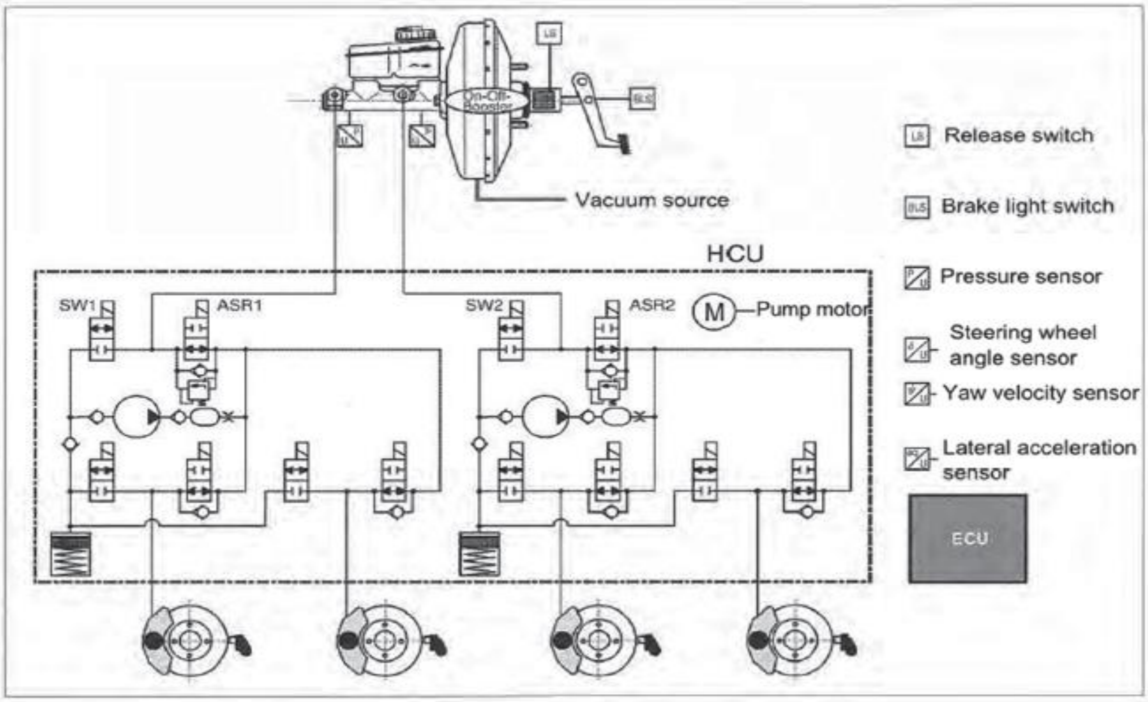

Fig 4.8: Hydraulic system of ESP [33]

Positive influence of ESP on the stats of accidents:

With the development of ESP safety system, many lives have been saved worldwide. The studies on the vehicles show the following results.

According to ("Unfallforschung der Versicherer" (UDV) in the "Gesamtverband der DeutschenVersicherungswirtschaft e.V." (GDV) almost of 25 % less passenger vehicle accidents have occurred with personal injuries in Germany and accidents with deaths have reduced to 35 to 40 % in passenger vehicle accidents in Germany.

Another report suggest that driving accidents from Mercedes vehicles equipped with ESP in Germany have 42% reduced. (DAIMLERCHRYSLER, 2004)

And similar kind of results can been seen in Golf Vehicles equipped with ESP, where 40% less accidents by driving of the road have occurred in Germany.(BECKER et al., VW, 2004)

In addition to that in USA the single vehicle deadly accidents have 36% reduction ratio (SUV: 52 %) and due to rolling over, deadly accidents ration has fallen to 40% (SUV: 73 %) in USA

(GREEN & WOODROOFFE, University of Michigan, Transportation Research Institute, 2006)

Another report of highway safety says that 41% less single vehicle accidents have occurred in USA (Insurance Institute for Highway Safety IIHS, 2006

So from the above figures, one can clearly see that how much has the ESP effected on the ratios of accidents, and is a wonder.

	2008	2011
Vehicles equipped with ESP in Germany	30% (new cars 67%)	90%

Since November 2011, it is mandatory in Germany to manufacture all the vehicles equipped with ESP. Therefore, since then vehicle without ESP is not any question any more.

CHAPTER 5 : AUTOMOTIVE SENSORS:

5.1 Introduction to sensors:

A sensor is a device that converts a physical or chemical quantity to an electrical output quantity. The outputs can be in either the form of current, voltage, amplitude, or frequency. It can also be a function of electrical parameters like resistance (R), capacitance (C) and electrical inductance (L). The output signal can be a waveform from one of Square wave, triangular wave, and sinusoidal wave or in Digital form.

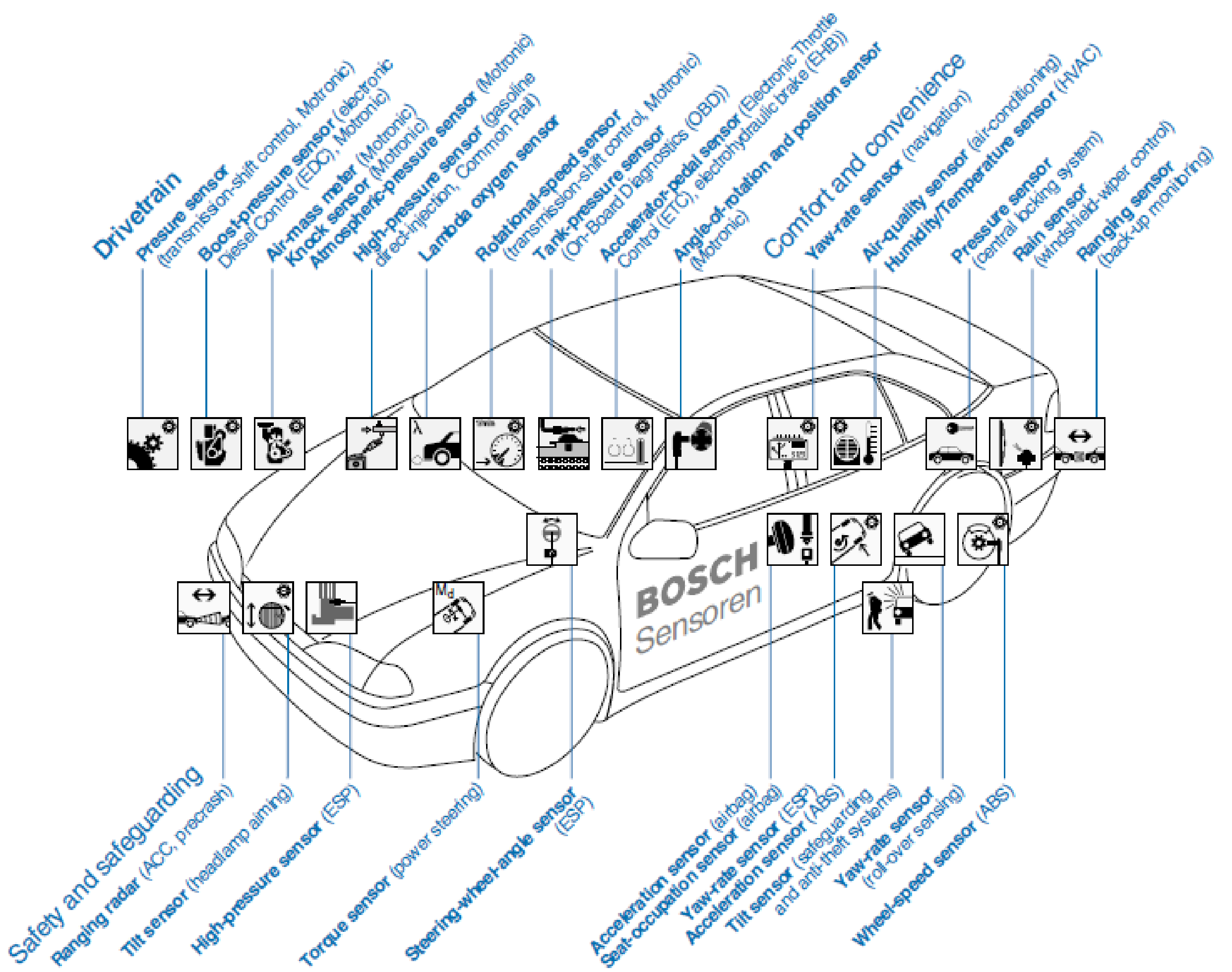

Figure 5.1: Major sensors installed in a vehicle [34]

5.2 Classification of Automotive sensors:

Sensors used in automotive industries can be classified in to the following three categories.

- **Functional sensors**

These are mainly in use for open and closed loop applications

- **Sensors for safety and safeguarding**

Mainly concerned with the safety of the vehicles, for example to avoid stealing

- **Sensors for vehicle monitoring**

Onboard Diagnostic (OBD) sensors are used to obtain the information for fuel consumption, wear parameters and for driver passenger information.

Figure 5.1 shows some of the most commonly used sensors in vehicles. The most important signals for my thesis are the signals, which are being used in ESP, ABS and DTC. These are

Steering Wheel angle sensors

Speed and rpm sensors

Wheel speed sensors

5.3 Steering Wheel Angle Sensors:

To keep the vehicle stable and on the right track The **E**lectronic **S**tability **P**rogram (ESP) applies the brakes selectively to the individual wheels. For stability and steer ability ESP compares the applied braking pressure, and Steering wheel angle sensor (SAS) with the vehicle's actual rotary motion and its road speed. Since a conventional SAS can only measure up to 360°, whereas this range in passenger-car steering wheel is extended up to ±720° (four complete turns), Therefore it is requires to register and store the data continuously on the steering wheel's actual setting.

5.3.1 Types of steering wheel angle Sensors (SAS):

Steering angle sensors are available in following types.

- **Incremental measuring sensors**
- **Absolute measuring sensors(magnetic angle of rotation sensors)**

Absolute measuring sensors are being highly used in automotive industry. Magnetic angle of rotation sensors output the steering wheel X and throughout the complete angular range of 360 at any instant of time

5.3.2 Steering angle sensor (LWS1) based on Hall Effect:

The output of Hall Effect sensor depends on the magnetic field. This sensor is a magnetic angle of rotation sensor and detects the presence or absence of a ferrous flag (the van). A conventional vane switch consists of a Hall Effect switch and a magnet in close proximity. When the flag is not present, the hall sensor detects the magnets field and remains on, when the flag passes between the magnets and the Hall switch, it interrupts the field and the switch turns off.

The angle of Steering wheel is measured using 14 Hall Effect vane switches .Their operation is similar like a light barrier. The magnetic field of adjacent magnet is measured by the Hall-effect element. Along with the steering shaft rotates a magnetic code disc that either reduces the magnet's field very strongly or vanishes it. In this way, angular position is measured in digital form. Nine Hall Effect elements are used for measuring this angular position and the rest measure revolutions, hence being able to measure the 360-degree range by 4:1 step-down gearing. Since LWS1 required large number of sensors, so it is not optimum, so LWS3 is in use now a days.

5.3.3 Magnetoresistive steering-wheel-angle sensor LWS3:

Figure shows the LWS3 sensor.Its operation is also dependent upon AMR (anisotropic magnetoresistive sensors). The electrical resistance of AMR's depends on the direction of an external magnetic field. The angle information across a range of four complete rotations is provided by measuring the angles of two gearwheels. These wheels are then further rotated by a third gearwheel, which is located on the steering-column shaft. The difference between first two gearwheels is only of one tooth which means for every possible steering-wheel position a definite pair of angular variables is associated. Since it measures up to 360°, therefore it is sufficient for ESP.

Figure 5.2: LWS3 [35]

5.4 Speed and RPM Sensors:

Distance travelled per unit time is called the speed, and similarly Speed is measured by measuring the number of revolutions or the distance travelled per unit time. Speed and RPM are measured with respect to some reference, either with respect to the road surface or with respect to the other vehicle. The absolute rotational speed in space or about vehicle axes is known as Jaw rate. ESP requires this jaw rate information about the vehicle's vertical axis. Jaw rate is detected depending on the number and size of the peripheral rotor markings. These sensors are differentiated upon these peripheral markings.

5.4.1 Increment sensor:

These sensors have closely spaced peripheral markings. That enables them to detect instantaneous speed and even fine angular measurements.

5.4.2 Segment sensors:

They have only small number of segments, which are usually equal to the number of engine cylinders.

5.4.3 Simple rpm Sensor:

It has only one peripheral marking, and can only predict average rotational speed.

Incremental sensor is used in measuring relative rotational speed. Examples are

- Relative rotational speed of crankshaft and camshaft
- Wheel speed for ABS/TCS/ESP
- Speed of diesel injection pump

Some of the new applications include the rpm sensors that are incorporated in wheel bearing, speed over ground, and vehicle yaw rate around the longitudinal and pitch axis.

5.5 Inductive Sensors:

Based on measuring principle sensors are either inductive or magnetostatic.Inductive Sensors, also known as passive sensors, and are without any kind of electronic circuit. The sensors that are provided with electronic circuits are known as intelligent sensors and thus are part of active sensors.

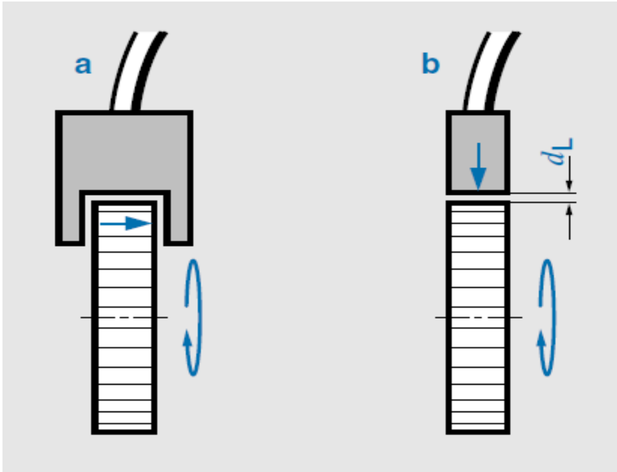

Figure 5.3: Inductive Sensor shapes [36]

Incremental rotational speed sensors utilize the advantage of physical effects and are also being used whereas optical and capacitive sensors are not suitable. Sensors that are currently being used include the following

5.5.1 Rod sensors

These are the most widely used sensors and are located near the rotor. The wheel tooth passes very close to the sensor tip. Although it is most widely used sensor, but has the lowest measuring sensitivity and is problematic when air gap is Large. Fig (a) shows rod sensor and (b) shows Fork shaped sensor, whereas dL is the air gap between the sensor and the wheel.

5.5.2 Fork shaped sensors

It is used only in some cases, and requires to be roughly aligned to the rotor when installed. Ring type sensors, which surround the shaft, are no longer in use now. As compared to rod sensors, these are impervious to the axial and radial play.

5.5.3 Toroidal sensors:

These are insensitive to geometric tolerances.

Disadvantages:

Traditional inductive sensors give output in amplitude form and are not suitable for measuring low rotational speeds. When air gap is excessive they are unable to differentiate between the genuine rotational speed and air gap fluctuations. Other disadvantages include, static detection, efficient measurement in large air gaps, size, and temperature stability is less than 200 centigrade, and identification and sense of direction.

5.6 Magnetostatic sensors:

These sensors (Hall, magnetoresistors, AMR) are highly suitable for measurement in large air gaps and for the static detection. And due to their small size operate without depending on air gap and hence are independent of air gap fluctuations. They sense either radially or tangentially. Difference between radial sensing and tangential sensing is important to understand. This means magneto-static sensors are always able to differentiate between the north and south poles of a magnetically active pole wheel or rotor ring without the influence of Air gap. In the case of magnetically passive rotors, the sign of the output signal is then no longer independent of the air gap when they register the tangential-field strength (here though, the fact that the air gap is often enlarged due to the rotor is a disadvantage).For Radial measurement differential-field or gradient sensors are often used. These always register only the gradients of the radial- field components, the signs of which do not change with the air gap but only with the angle of rotation.

5.6.1 Rotors:

Rotors measure the rotational speed, and are usually provided by the manufacturer. These are also being manufactured from passive materials.

5.7 Wheel speed sensors:

ABS, TCS, ECU, and ESP systems use this sensor’s information to derive the wheel rotation rates. These wheel speeds are the basic signal information, which are being used to prevent the locking, spinning, and blocking of wheels, and hence controlling the stability and steering of the vehicle. Wheel speed sensor’s information is also being used by the navigation systems to calculate the distance travelled. In the following paragrapgh types of sensors are discussed.

5.7.1 Passive (inductive) sensors:

Inductive sensors are made from a soft magnetic pin pole, which is surrounded by a coil winding. It is installed directly above the triggering wheel (rotor). This soft magnetic pole pin is then attached with a permanent magnet, which projects magnetic field towards the triggering wheel. When this triggering wheel rotates, due to its teeth and gap it induces a magnetic flux in the magnetic field, hence inducing alternating Current. The amplitude and frequency of this AC current is directly proportional to the wheel speed (WSS). When wheels are not rotating, then voltage is zero.

Air gap Tolerances between sensor pole pin and wheel are very low and allowable air gab is only 1milimeter. Also inductive sensors must be installed on a stable mounting so as to avoid the oscillation caused when braking. Three type of common inductive sensors are being used

1 Chisel type pole pin, installed radially

2. Rhombus type (lozenges shaped) pole pin for axial installation

3. Round pole pin, precise alignment is so important.

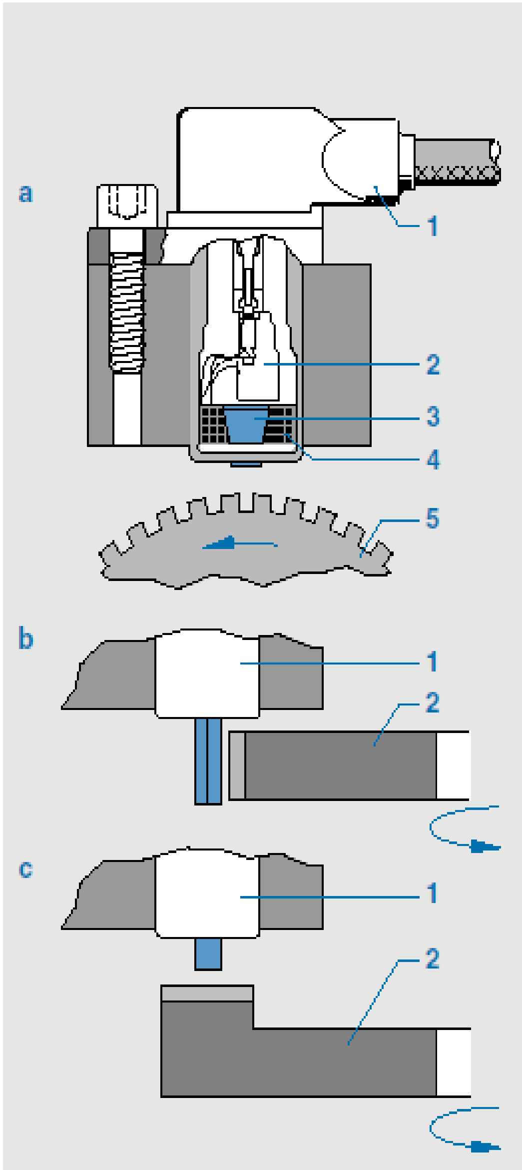

Figure 5.4: Wheel speed sensors [37]

The figure shows these sensors

a. Chisel pole pin, radial installation, and radial scan

b. Rhombus pole pin, axial installation, radial scan

c. Round pole pin, radial installation, axial scan

1. Sensor case with electrical connections
2. Permanent magnet

3. Soft iron core (pole pin)
4. Winding
5. Trigger wheel

5.7.2 Active Sensors:

In active wheel speed sensors, ring teeth concept is not responsible for triggering of output pulse. Instead, peripheral magnets have replaced that by incorporating around the periphery of multi pole ring so that their polarities alternate.

It has very compact size and this low weight compact size allows not only installing on the wheel, but also allows installing in the wheel bearing. In wheel bearing, the seal contains the magnetic powder instead of permanent magnets. In this way, a bearing pole becomes a multi pole device.Most important components of this active wheel speed sensor are either **Hall elements** or **Magnetorisistive elements**. A voltage is generated as an output from both of these elements. This voltage varies according to the change in magnetic flux. In these types of sensors, voltage is independent of wheel speed, which was not the case in passive (inductive) sensors. This fact enables the sensor to measure till the wheel is actually stationary. A local amplifier circuit is also required for this sensor, which is also installed in the same housing as of the sensor element.

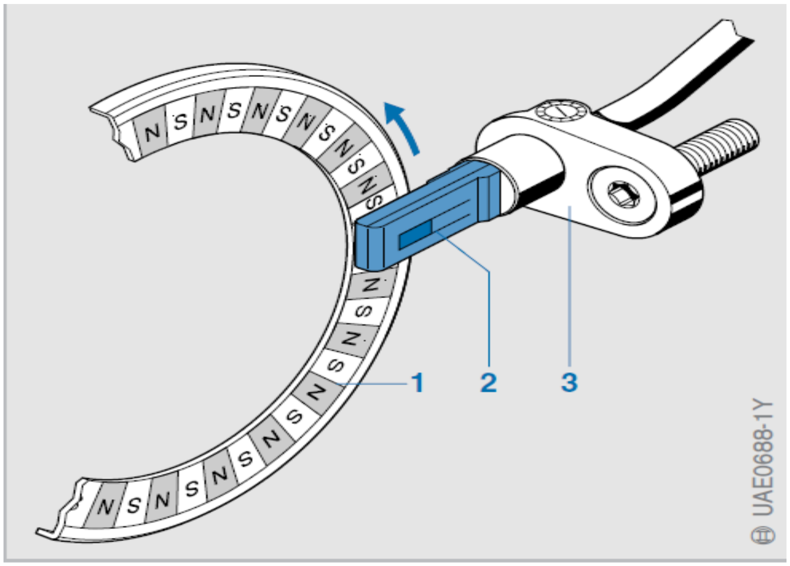

Figure 5.5: Active wheel speed sensor's multipole ring [38]

Figure shows the section of multipole ring where

1. Multipole ring

2. Sensor element
3. Sensor case

Power supplied required is from 4.5 to 20 volts, and two conductor wires are used to connect the sensor with the ECU. The sensor data is sent through one of the two conductors as load independent current. Pre conditioned digital signals are used for this single wire transmission of sensor data. These preconditioned digital signals are less sensitive to interference, where as we know that the signals from the inductive sensors are not less sensitive to interference.

Data transmission also identifies the direction of travel. This direction of travel is also used in another algorithm for hill holding functionality. Where when one is travelling upwards on the hill, and when vehicle stops, it must not move backwards when driver accelerates it again, so in this scenario it is very important to know the direction of travel. So these active sensors are here also of very keen importance. These are also being used in vehicle navigation systems.

There is another information, that indicates whether the vehicle needs to be serviced in order to check the correct functionality of the sensor or not.

CHAPTER 6 : Experiments/Measurements and Algorithm Development

6.1 Introduction/Overview:

This chapter contains the Quarter car model, based on which one can conclude some general relationships between engine speed and wheel speeds. In certain conditions e.g when vehicle is in stationary condition, then what can be the expected behavior of engine speed or wheel speed and what could be the possible behavior of torques. In addition, based on these behaviors some general comments have been concluded. Based on these conclusions, later on measurements are analyzed and general idea is taken. Measurements and measurement tracks are also discussed in this chapter. How different surfaces show the different behaviors have been analyzed on UniVW. After these analyses, two approaches have been made in order to detect the engagement status; First approach is based on relationship between engine speed and wheel speed, by calculating the missing relationship between them. Second approach is based on Basic driveline model, which implements torques, and then their difference is taken. This chapter also discusses how the fixed parameters are calculated, and which signals are directly taken from the sensors. The complete Algorithm of both the models is discussed. Moreover, at the end, results of both the algorithms have been shown and discussed.

6.2 Test Track and Measurements:

Experiments have been performed in the Bosch track facility located at the Boxberg. Different measurements have been taken on Audi A4 B8 Vehicle, equipped with the Bosch measurement system. The vehicle contains all the necessary sensors required for the measurement of speeds, jaw rate, position and all the other required in ESP, ABS and for DTC. The detailed description of the speed sensors, jaw rate sensors and position sensors have been discussed in the chapter Sensors. The Boxberg test track contains all the necessary test tracks required for any kind of tests to carry on. The various road surfaces are as follows

1 Chequerboard

2 Asphalt

3 Wet Tiles

4 Basalt (polished)

5 Concrete

6 Aquaplaning basin

7 Western basalt

Further details of other tracks are available on their official website. The following figure shows the test tracks of Boxberg.it contains the test tracks with different mue surfaces like high mue surface and low mue surfaces also.

Figure 6.1: Boxberg Test track [39]

For the proper detection of gear engagement, all the surfaces response analysis is important, therefore, measurements were taken on dry asphalt surface, low mue surfaces like snow and ice, split surface, positive mue and negative mue jump. Low mue measurements measured in Sweden are used for the low mue scenarios. Measurements are taken with and without ABS activation. Gearshift maneuver suggests the response when a gear is disengaged and when it engages back. After taking the measurements, these measurements are analyzed in an internal software called UniVw. The figures below show, how a measurement looks like. Each measurements duration is about 20 milli seconds. Each measurement contains the information of Wheel speed and Engine speed along with some other signals like pressure values, Engine torque. New signals can be created by performing mathematical operations on the signals obtained from the measurements. Moreover, different results are deducted by keeping in mind the previous knowledge of signals and signal analysis. Table 4.2 shows different behaviors on different mue surfaces. The frictional coefficient mue values as mentioned in the website [39] of Bosch are as follows.

ABS Test Surfaces

- Wet ceramic tile 300' (0.12 mu)
- Wet basalt tile 300' (0.28 mu)
- Wet/dry asphalt 300'
- Rough concrete 300' (1.00 mu)

ESP Test Area

- Wet basalt tile (0.20 mu)
- Wet ceramic tile (0.16 mu)
- Brushed concrete (1.00 mu)
- Gravel/asphalt split test section
- Two-lane ASR circle 210' I.D

The following table shows the overview of some measurements. These measurements show the behavior of vehicle signals on different mue surfaces and with different situations. These measurements are being viewed on a special software.

Table 1: Vehicle behavior and road surface:

Situation	Mue Surface	Figure
Parking	Low Mue	Fig: 6.2
Accelerating and decelerating on wet tiles	Low mue	Fig: 6.3
Braking on wet tiles	Low mue	Fig:6.4
Negative Mue Jump	High to low mue	Fig:6.5
Positive mue Jump	Low to high mue	Fig:6.6
Rough road	High mue	Fig:6.7
Gear Shift 321 with Braking on ice	Low mue	Fig:6.8
Shift down without Braking on ice	Low mue	Fig: 6.9
Shift down with ABS	Low mue	Fig:6.10
Gear Shift on Packed Snow	Low mue	Fig:6.11
ABS Braking on low mue	Low mue	Fig:6.12
Shift down 4-3-2-1 without braking on ice	Low mue	6.13

6.2.1 Parking:

A Vehicle is considered in parking condition, when both driven wheel speeds comes to zero. It is also possible that engine is still in running condition. This can be found out by observing the engine speed, and can be deduced whether the vehicle is also turned off or the engine is still running. The following figure shows this typical response when both the driven wheels speed come to zero, which indicates vehicle is stopped and here we turn this to as in parking situation.

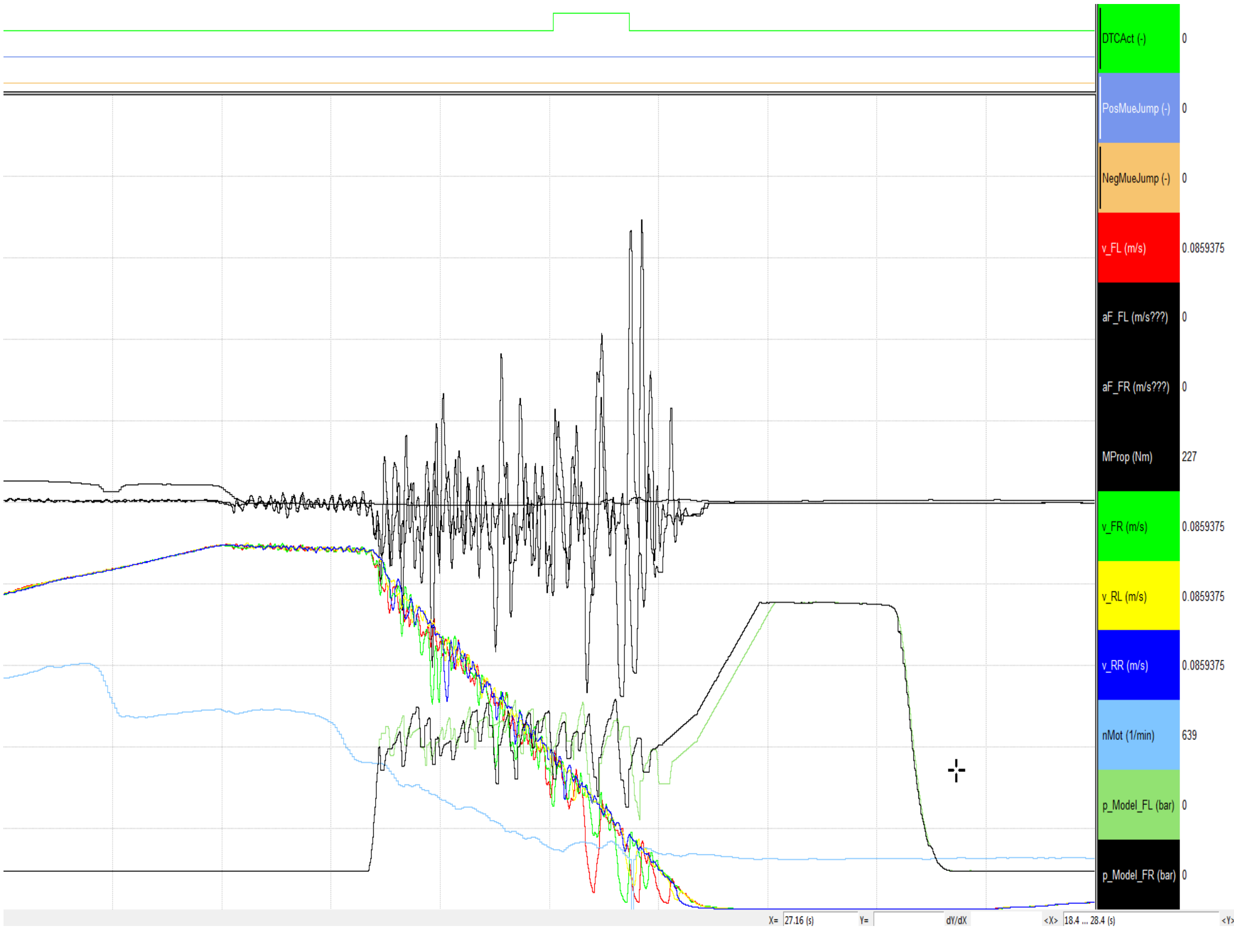

Figure 6.2: Parking

6.2.2 Accelerating and Decelerating on Wet Tiles:

The following Figure shows a situation when the vehicle is accelerating at the start and at the end is decelerating. The relationship between wheel velocity and rpm of engine can be visualized.

Figure 6.3: Accelerating and Decelerating Behavior

6.2.3 Braking on Wet Tiles:

This is the typical behavior of vehicle when it is braking on low mue surface; the braking is removed at the end. The driven wheels speed show this behavior. The figure shows the behavior of driven wheels.

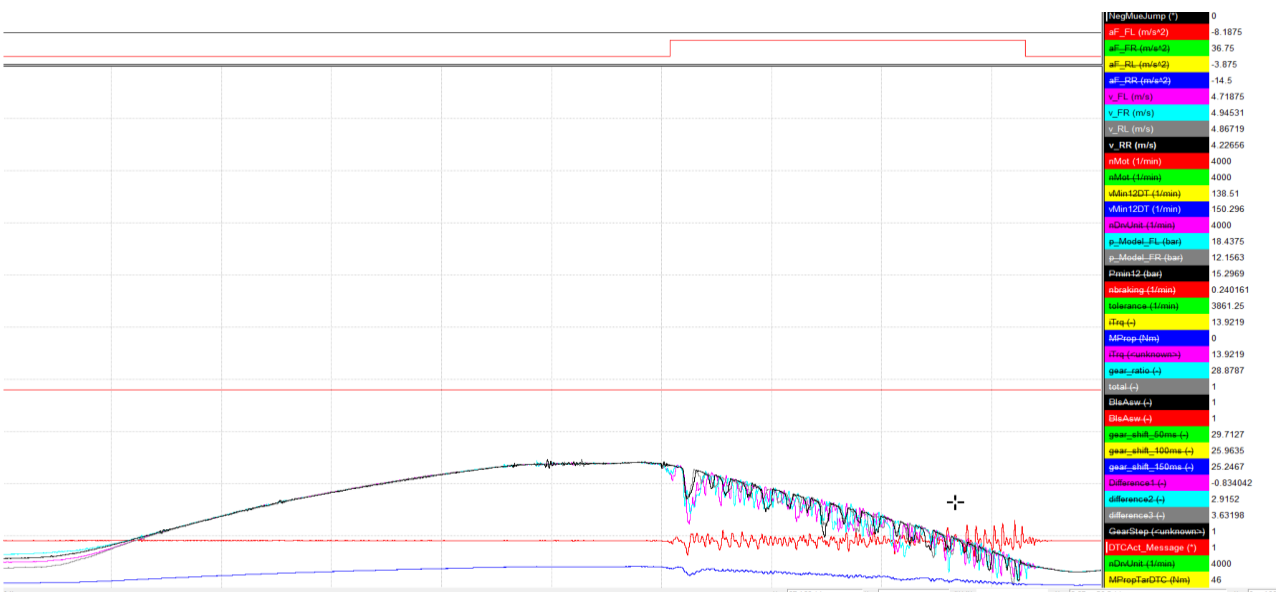

Figure 6.4: Braking on Wet Tiles

6.2.4 Negative Mue Jump:

Sometimes the surface changes suddenly from high mue to low mue. Under this condition the wheel speed behavior is changed dramatically, as a result stability factors like ABS braking of vehicle will also change. Negative mue jump indicates that vehicle has travelled from high mue surface to low mue surface. This figure shows the negative mue jump response under ABS braking.

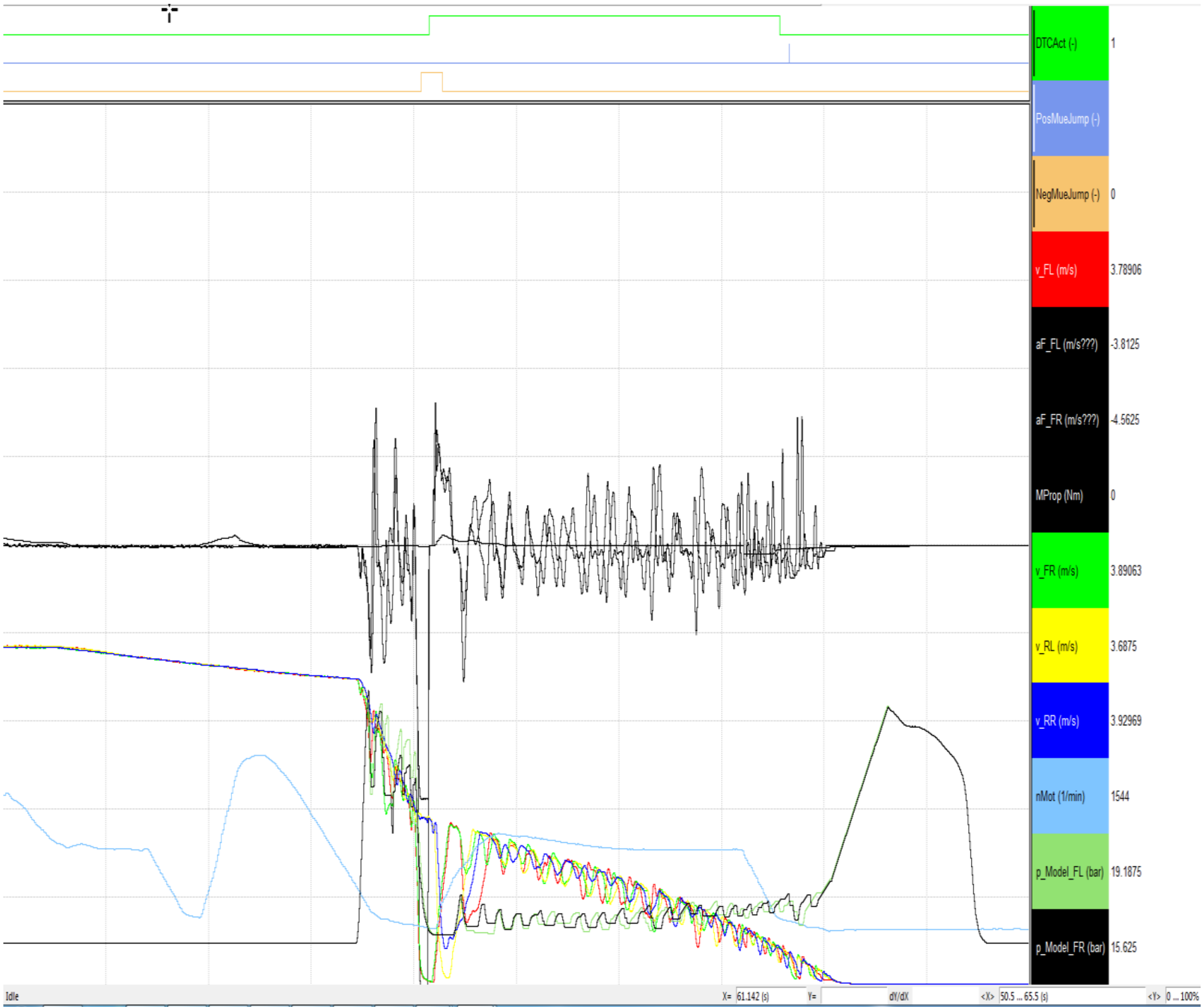

Figure 6.5: Negative Mue Jump

6.2.5 Positive mue Jump:

When the vehicle moves from low mue to high mue surface, this is termed as positive mue jump. The typical behavior in such a condition looks like the following figure.

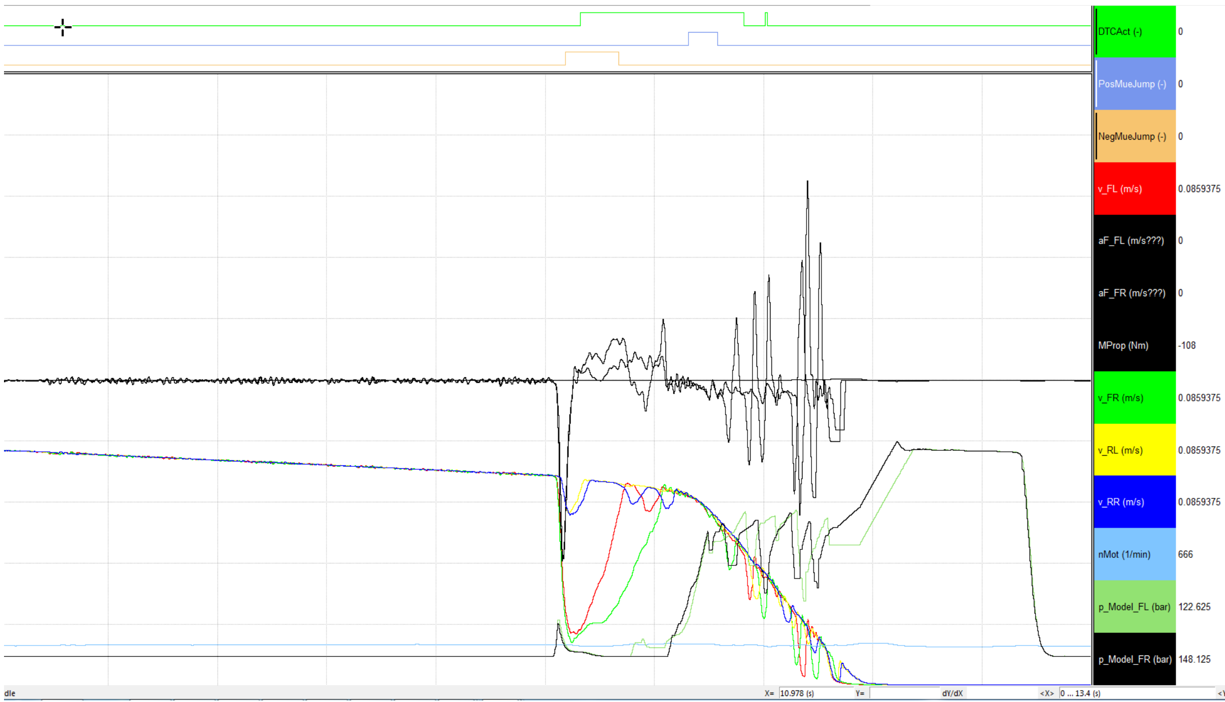

Figure 6.6: positive mue jump

6.2.6 Rough road:

On a rough road track, mue is very high and the behavior is as follows

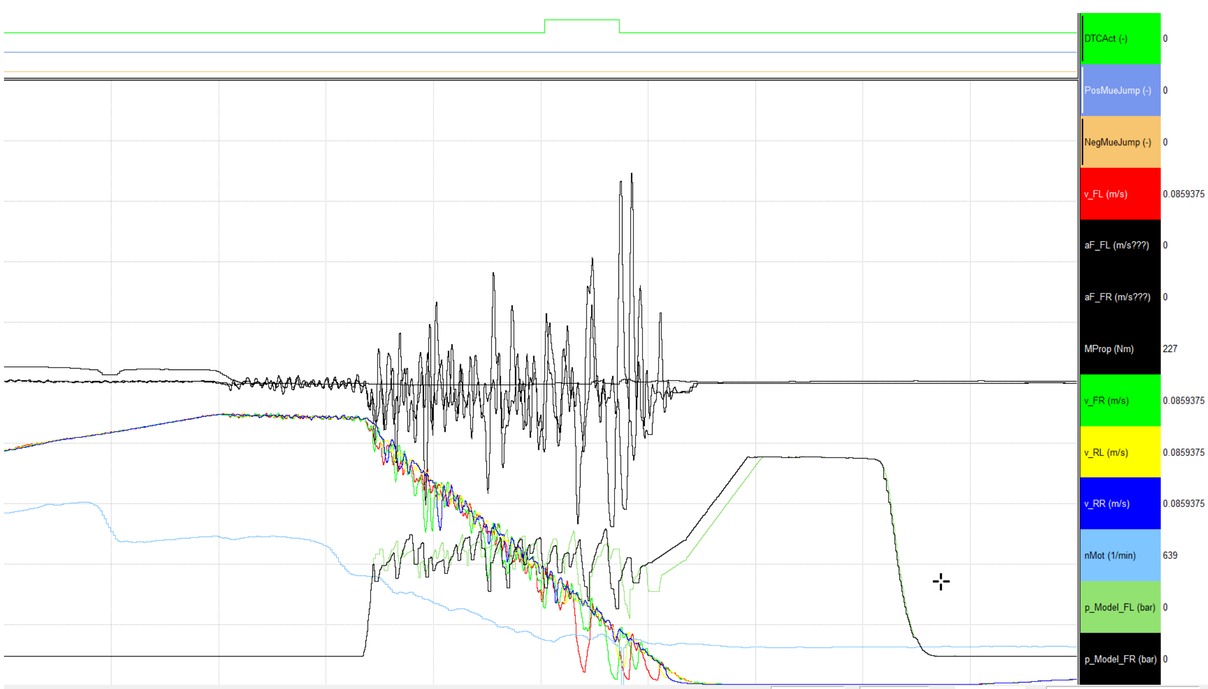

Figure 6.7: Rough Road

6.2.7 Gear shift with braking on ice:

The following figure shows a bit complex behavior. This measurement has been taken on a low mue surface track, i.e on ice. Shift down maneuver is performed from third gear to first gear along with the ABS braking. From the resultant measurement, one can observe the behavior of gear change. Whenever a gear is shifted, clutch is disengaged and then is again engaged. Therefore, with every gearshift, there is an information of gear disengaged and engaged status.

Figure 6.8: Gearshift on Ice

6.2.8 Shiftdown without braking on ice:

The above behoavior is gear shift along with the braking on ice, and the following is the behavior when brakes are not applied.

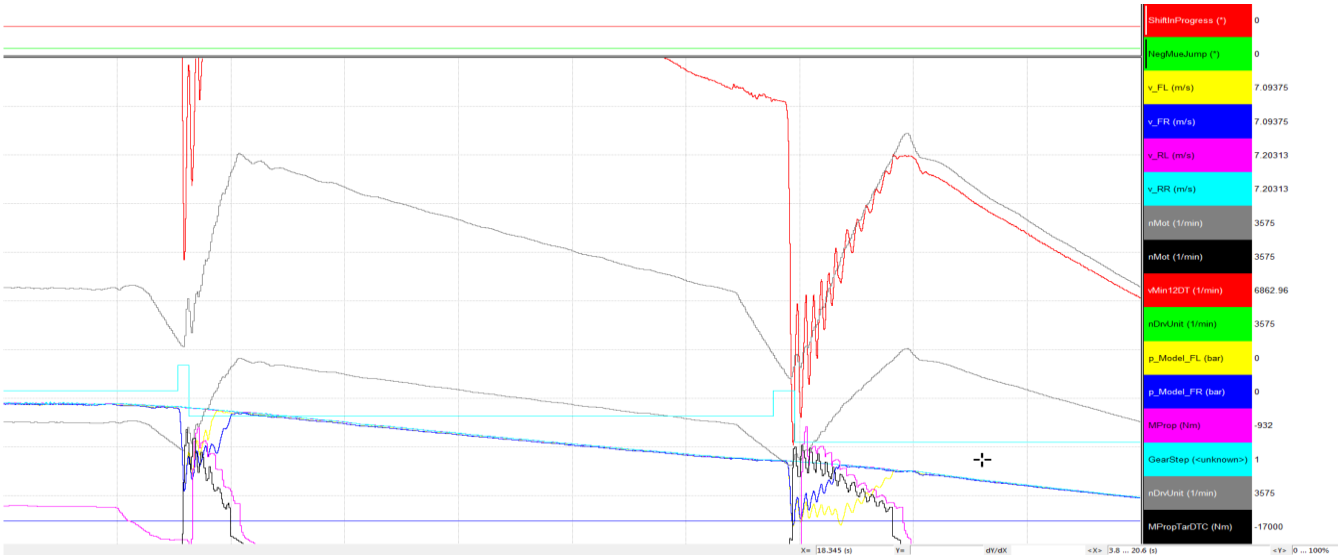

Figure 6.9: Shift down without braking on ice

6.2.9 Shift down with ABS Braking:

Another situation where gear change has occurred along with ABS.

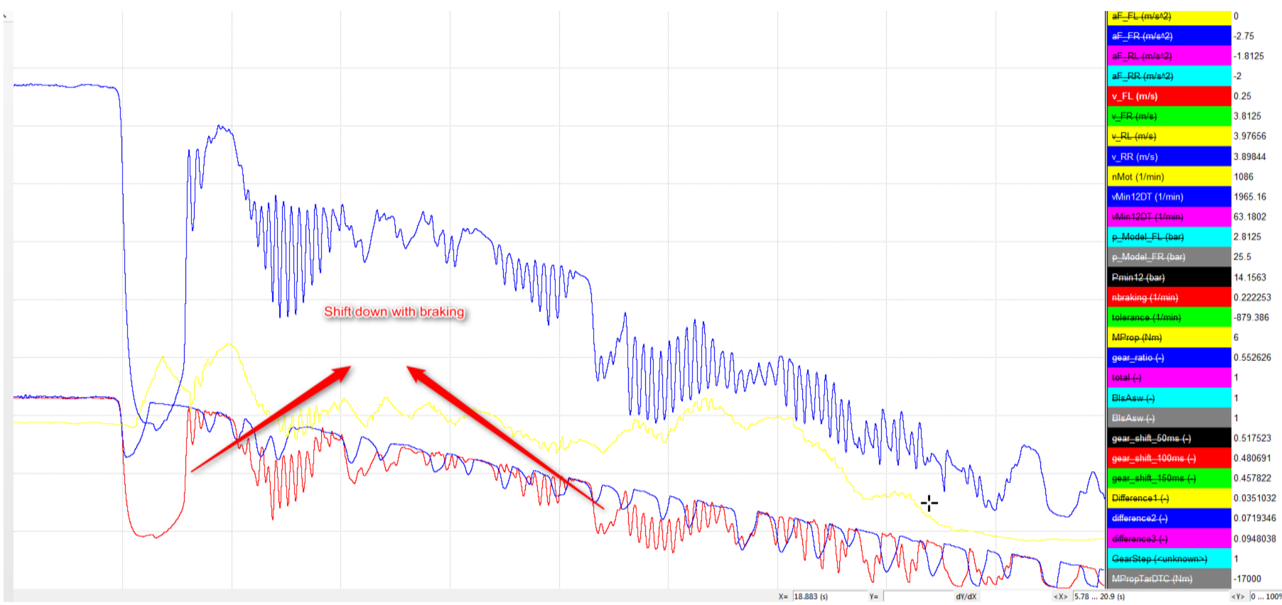

Figure 6.10: Shift down with ABS Braking

6.2.10 Gear shift on packed snow

The following figure shows at first the gear engagement and then gear disengagement.

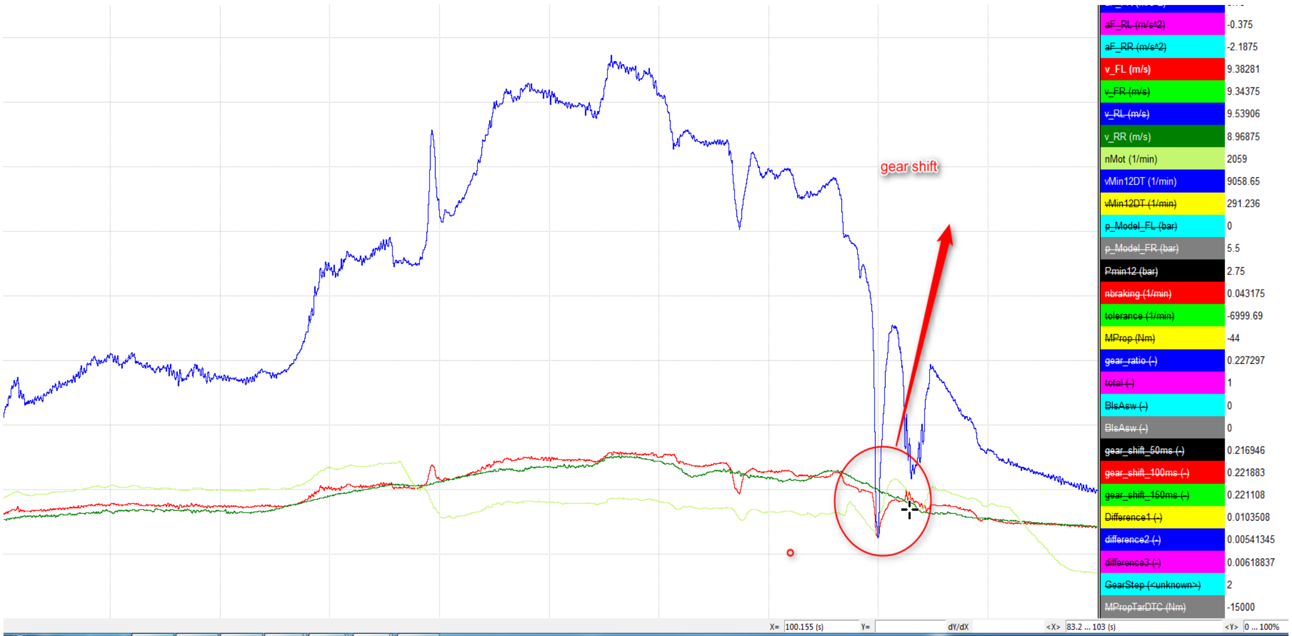

Figure 6.11: Gearshift on Packed Snow

6.2.11 ABS Braking on low mue FN:

This measurement is taken when the vehicle is moving on a low mue surface and Brakes are applied.

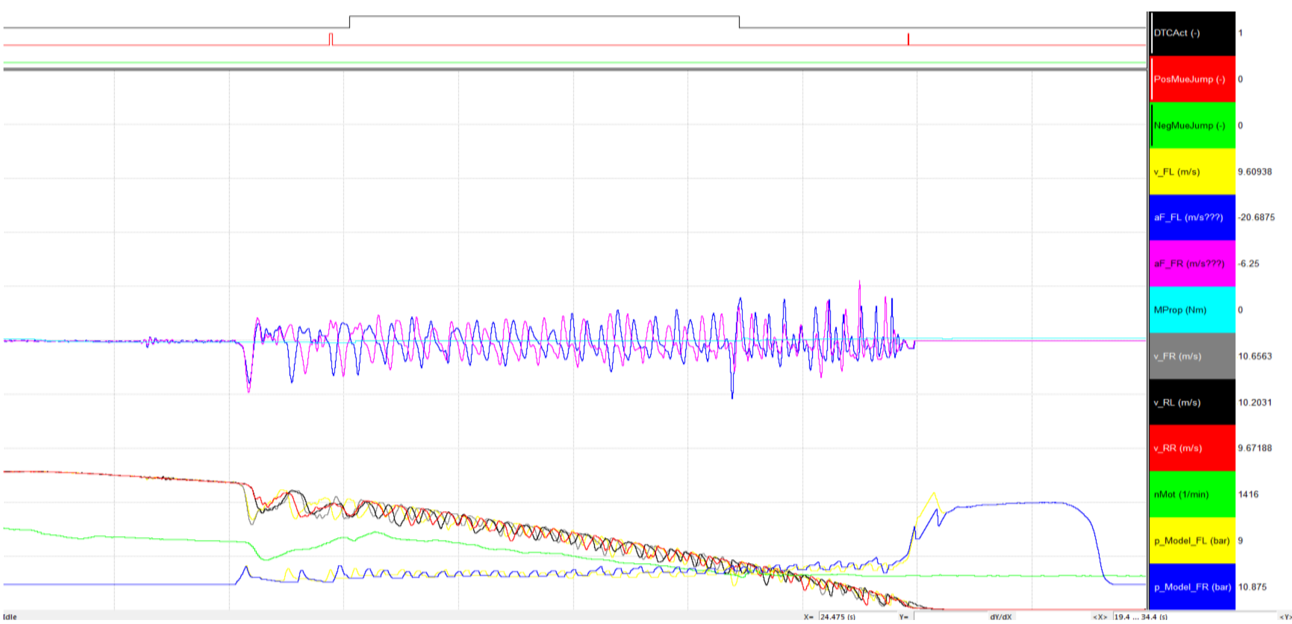

Figure 6.11: ABS Braking on Low mue

6.2.12 Shift down 4- 3- 2-1 on ice:

The following maneuver shows the behavior of gear shifting from 4th to 3rd, 3rd to 2nd and then from 2nd to 1st on ice.

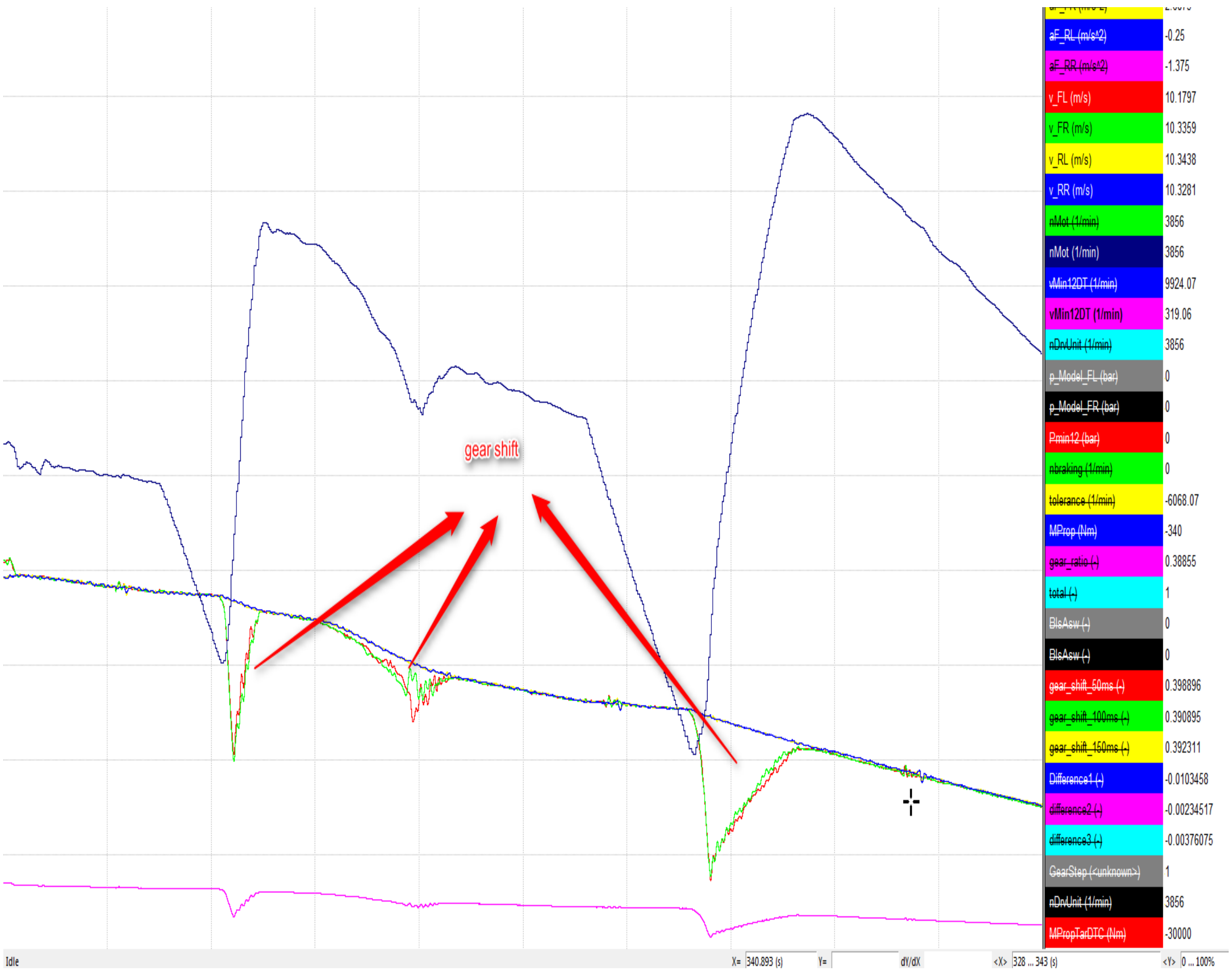

Figure 6.13: Shift down 4-3-2-1 without braking on ice

After analyzing all these measurements and many others, one can draw the conclusion that, there exists some relationship between engine speed and wheel speeds. We need to find this relationship, by keeping in mind this basic knowledge of vehicle behavior under certain conditions and different surfaces. We also know from the basics of Vehicle dynamics that how engine speed and wheel speeds are related to each other. How gear ratio relates with engine speed and wheel speeds, which has also been discussed in chapter Vehicle Dynamics. However, this is not that simple to implement. For an Algorithm to develop we need to know if there are any kind of losses from engine till it reaches to the wheel and further transferred on to the road surface. There are also driveline models available in the literature, in which power transmission through torques is discussed. Basic driveline model will be used in the development of the algorithm.

6.3 Development of Algorithm

Two approaches have been used in order to detect whether the gear is engaged or disengaged. These approaches are as follows

- Heuristic/experimental Approach
- Model based Approach

    Basic Driveline modeling in terms of wheel speed

    Basic driveline modeling in terms of Engine speed

The overall flow of the Algorithm is as follows. Prototype vehicles are used for the measurements and special trained application engineers take the measurements using MM6 software. These measurements are then viewed in UniVw, where they are analysed and evaluated. DTC related signals are extracted in the UniVW and further stimuli are generated.

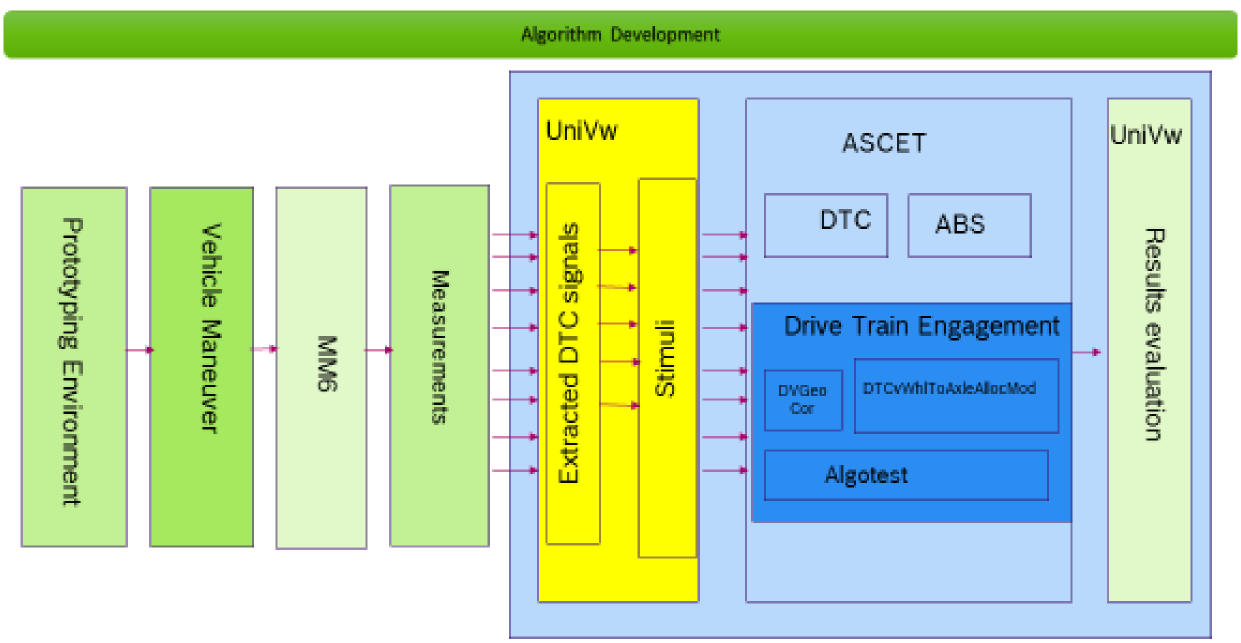

Figure 6.14: Overview of the Algorithm development

This specific information will be mapped later in the ASCET where the programming part has been done. In ASCET, all these approaches have been programmed and implemented. The following paragraph describes development of the Algorithm.

The following figures show the block diagram of the implemented algorithms. Measurements were taken on test vehicles and are then analysed in Univw. DTC related signals were extracted in Univw and input stimulei were identified which led to a new plt file for signals generation.

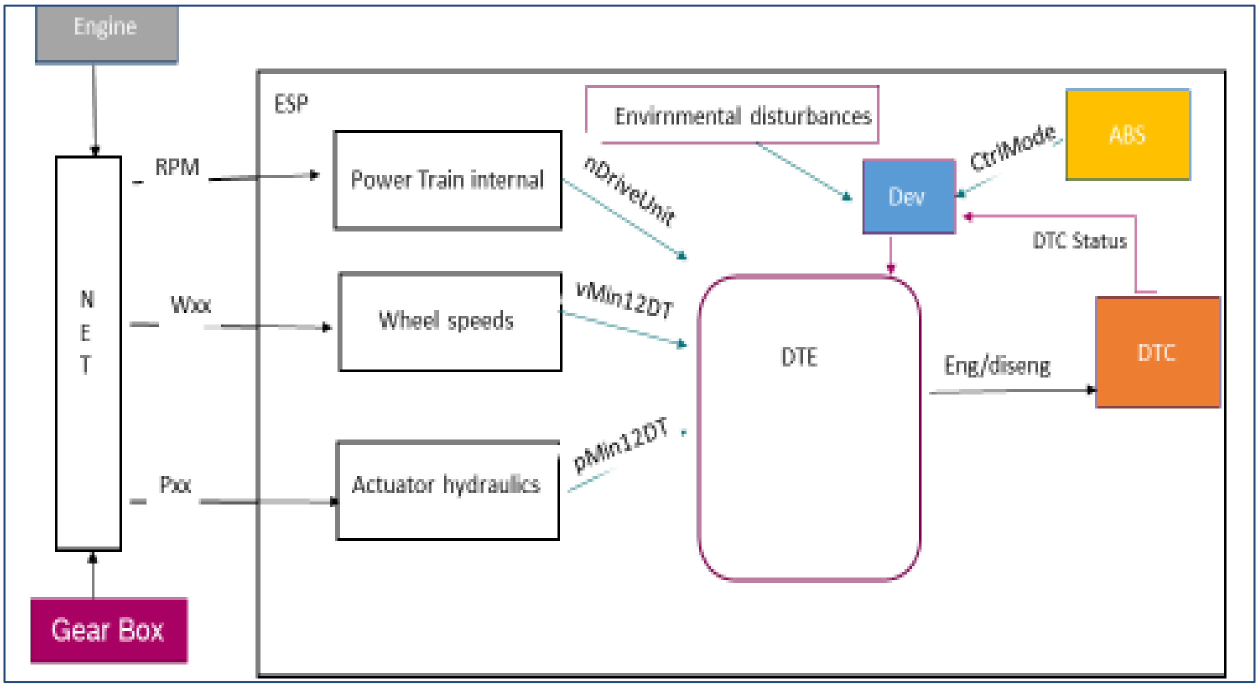

Figure 6.15: Overview of the Implemented Algorithm

The programming part is done in ASCET, which uses the measurements and includes only the extracted and new input signals, which are necessary for the algorithm purpose. It contains some old DTC signals too. The major block of coding is the Drivetrain engagement block, which contains also some sub blocks. In ***DVGeoCor*** contains the algorithm for the correction of wheel speeds. Since we know that whenever a vehicle turns, both wheels do not have the same speed, instead different speeds. The outer wheel has to cover more distance compared to the inner wheel as a result this factor needs to be considered. This subalgorithm contains those correcting factors and as a result, we obtain the exact corrected speeds of the wheels ***DTCvWhlToAxleAllocMod*** is the other bigger sub block of the main algorithm. Since we are considering quarter car model, that means that the driven wheels are replaced by a virtual wheel and all the effects are considered on this virtual wheel. The speeds of driven wheels needs also to be converted to vMin12DT and similarly the pressure applied to pMin12DT and average acceleration to aAvgDT. But speed and pressure values needs to be sorted, where we have know first that which wheels are driven wheels and then we have to take the mean of those driven wheels. When the vehicle is Front wheel drive, then this sorting algorithm v_sorter will take the mean of the front wheels and when the vehicle is rear wheel drive, then v_sorter will take the mean of rear wheels but if the vehicle is ALL Wheel Drive (AWD) then mean of all wheels has to be taken. And the same procedure goes for the pressure values. After getting these quantities they are fed in to the main ''Algobench'' Algorithm. This Algobench contains three approaches for the detection of engaged status.

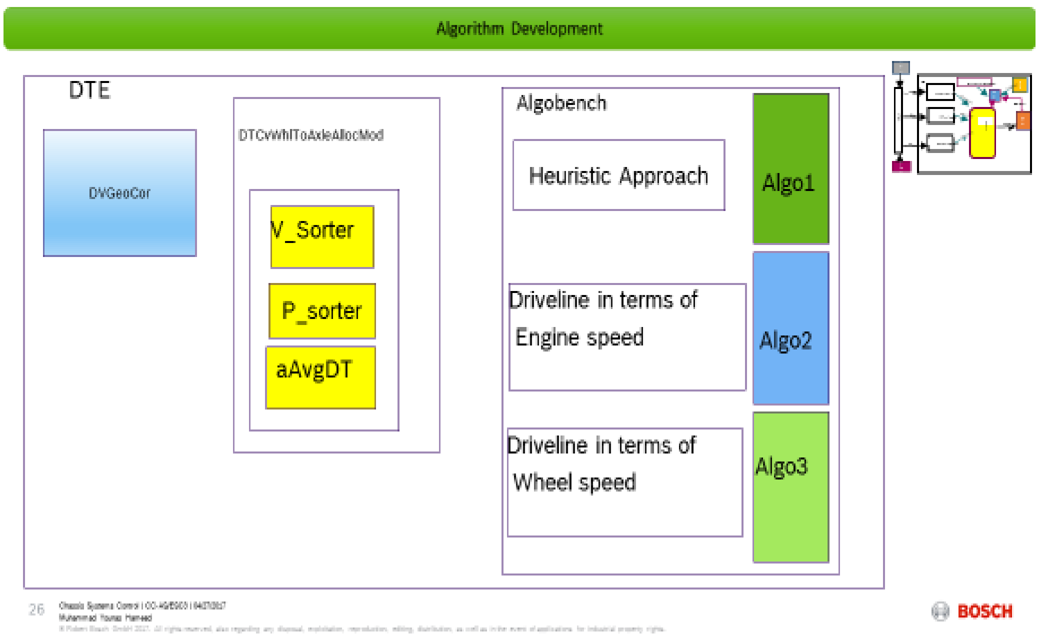

Figure 6.16: DTE Development

6.4 Heuristic/Experimental Approach:

The engine speed and wheel speeds are directly measured by the engine speed and wheel speed sensors. The power is transmitted through gears and via drive shafts and propeller shafts, complete transmission procedure has been discussed earlier. In real all the power at the engine level is not transmitted to the wheels, there are some losses. Now we are going to see in terms of speeds that how much speed is transferred from engine to the wheels. Suppose that clutch is rigid and there is no loss, then we have to compensate the speed lost due to braking and due to the DTC torque.

There would be some other losses too like, due to the torsional effects of propeller shaft and drive shaft flexibilities. As we know that from output drive shaft to differential and from differential to the individual wheels, there are some speed losses. These losses are termed as the tolerance. The major loss arises due to braking, so we have to compensate that.

From Equations of motion, we know that

$$V_f = V_i + at$$

Since the initial speed is zero, so we are left only with

$V_f = at \ [\frac{m}{s}]$

$where\ V_f = nMotbraking\_Theo$

According to newton's 2nd law of motion

$$a = \frac{F}{m} \ [\frac{m}{s^2}]$$

Pressure is defined as force per unit area

$$P = \frac{F}{A} \quad [bars]$$

$$F = PA \quad [bars * m^2]$$

$$a = \frac{PA}{m} \quad [\frac{bars * m^2}{kg}]$$

$$nMotbraking_{Theo} = \frac{PA * dt}{m} \ [\frac{100000\ Nm * m^2 * s}{kg}]$$

Where

dt=0.020 sec

Pressure values can be calculated from pressures applied at the driven axle, and then sorted using the sorting sub algorithm. The pressure sensors mounted on the vehicle are measuring the pressure values. ABS uses the information from these sensors. Area is calculated as under

$$A = \pi r^2$$

So by inserting all the variable values the final equation is written as

$$nMotbraking_{Theo} = \frac{Pmin12DT * 100000}{2} * \frac{\pi r^2 * 0.20}{m/4}$$

$$nMotbraking_{Theo} = 50{,}74 * pMin12DT$$

$$Tolerance = (nMotbraking_{Theo}) * slip * Brake_{request_{ABS}} + Mprop * nMotbraking_{theo} * DTCAct$$

Mass is devided by 4 because we are considering one virtual wheel instead of 4 wheels so the mass applied on one wheel would be equat to quarter of the whole mass of vehicle. Whereas slip is calculated as

$$Slip = (v_{Vehicle} - v_{Wheel})/v_{Vehicle}$$

And $Brake\_request\_ABS$ is the signal obtained from CAN

6.4.1 Unit Conversion:

Since these units are not in SI, so we need to change them in to SI units. First, let us look at the quantities and their units.

Pressure (P) is directly obtained from pressure sensor. And its output is in bars. We have to convert it in to Nm which is the SI unit of pressure.

dt is the delta time , and is constant 20 mili seconds. The manufacturer of the vehicle gives Mass of the vehicle (m), and its units are in Kg. Radius of the wheel varies also depending upon the vehicle. So here, all the parameters have been taken from one vehicle, which are fixed. And all the other varying parameters are directly measured by the sensors installed on the test vehicle.

$$\text{Tolerance} = \frac{[bars] * [m^2] * 10^{-3}[s]}{[kg]}$$

$$\text{Tolerance} = \frac{\left[\frac{1*10^5 kg}{ms^2}\right] * [m^2] * 10^{-3}[s]}{[kg]}$$

$$\text{Tolerance} = 10^2 \left[\frac{m}{s}\right]$$

Since the other speeds are in rev/min, so we need to change m/s to 1/min.

$\text{Tolerance} = 10^2 \frac{[m]}{[s]} * \frac{60}{2\pi \text{r}} \frac{[\ s]}{[\text{min} * \text{m}]}$

Therefore, after unit conversion the equation leads to

$$nMotbraking_{Theo} = \frac{Pmin12 * \pi r^2 * 20 * 10^2}{2m} * \frac{60}{2\pi \text{r}}$$

Where

$$r = 0.3704\ m \text{ and } m = 1750\ kg$$

$\rightarrow\ \ nMotbraking_{Theo} = Pmin12 * 50.74 \left[\frac{1}{\text{min}}\right]$

For synchronization with already developed Algorithms of Drag torque controller, ESP and ABS, this algorithm is developed inside the class of DTC.

Finally, the algorithm statement says that if

|nMot-nMin12DT-Tolerance|> Threshold then vehicle is disengaged

|nMot-nMin12DT-Tolerance|< Threshold then vehicle is Engaged

The parameter and variable implementation is done such that these implementations do not affect other algorithms.

Parameters:

The table 2 shows all the parameters used in the algorithm. These parameters differ for different vehicles. Every manufacture mention their parameters in the vehicle book. Apart from that, every measurement contains a pmsd file, which contains all the parameters used in the vehicle. For the algorithm purpose, parameters are taken from the measurement i.e. from the PMSD file. The following table shows the parameters of Audi A4 B8 [40] and some parameters directly taken from the measurement.

Table 2: Parameters :

Parameters	Quantity	Units
Mass moment inertia of engine	0.203	kgm^2
Mass moment inertia of wheel	0.703	kgm^2
Vehicle mass	1750	kg
Wheel radius	0.307	m
Final drive ratio	3.367	---
Cr1= frictional coefficient of tire	0.012	----
Cr2= frictional coefficient of tire pressure	0.012	----
Air Drag coefficient	0.2810	----
Cross sectional area of vehicle	2.620	m^2
Air density	1.000	kg/m^3
slope of the road	0	°

In the following, all the variables/signals whether they are derived or taken directly from the sensors are being defined.

Sensor output signals:

These signals are directly taken from the sensors. And are used in the algorithm as it is.

Univw Derived Signal:

These are the signals which have been derived in Univw software for different experiments.

DTC, ABS, Derived signal:

The signals that have already been in use in different algorithms especially in Drag torque controller, antlock braking system are termed as DTC, ABS derived Signals.

Ascet programmed signal:

The signals that are defined only in Ascet are mentioned in the following table.

Table 3 Signals and their Description:

Signal Name	Quantity Defining	Category
nMot	Engine speed	Sensor output signal
nDrvUnit	Engine speed	Sensor output signal
dnMot	Difference taken after Shift	Univw Derived Signal
v_FL	Speed of front left wheel	Sensor output signal
v_FR	Speed of front right wheel	Sensor output signal
v_RR	Speed of rear right wheel	Sensor output signal
v_RL	Speed of rear left wheel	Sensor output signal
vMin12DT	Average of the lowest speeds of the driven wheels	DTC, ABS, Derived signal
Dv	Difference of the lowest speeds of the driven wheels after one cycle	Derived Signal
Vavg	Average of the driven wheels	Derived Signal

sl_RR	Slip of rear right wheel	DTC, ABS, Derived signal
sl_FR	Slip of Fear right wheel	DTC, ABS, Derived signal
sl_RL	Slip of rear Left wheel	DTC, ABS, Derived signal
sl_FR	Slip of Front right wheel	DTC, ABS, Derived signal
p_Modal_FA	Pressure on Front Axle	Sensor output signal
p_Modal_RA	Pressure on rear Axle	Sensor output signal
gear_ratio	Gear ratio	Univw Derived Signal
gear_ratio_1	Gear ratio after one cycle	Univw Derived Signal
gear_ratio_2	Gear ratio after two cycles	Univw Derived Signal
difference	Difference between gear ratio and gear ratio after 1st cycle	Univw Derived Signal
difference_1	Difference between gear ration and gear ratio after two cycles	Univw Derived Signal
sum	Summation of the gear ratios	Univw Derived Signal
integration	Integration of the gear ratio	Univw Derived Signal
derivation	Derivative of gear ratio	Univw Derived Signal
DTC active	Status of DTC activation	DTC derived signal

DTCAct	DTC activation signal	DTC derived Signal
Brake_Request_ABS	ABS Braking request signal	ABS derived signal
DTC passive	Status of DTC passive	DTC derived Signal
Tolerance	Tolerance speed lost	Derived Signal
Ctrlmode_FA	Control mode pressure values on front axle for ABS	Sensor output signal
Ctrlmode_RA	Control mode pressure values on Rear axle for ABS	Sensor output signal
Mprop	Engine torque	Sensor output signal
NegmueJmp	Negative mue jump	DTC, ABS, Derived signal
posmueJmp	Positive mue jump	DTC, ABS, Derived signal
Split	Split Surface	DTC, ABS, Derived signal
Rough road	Rough road	DTC, ABS, Derived signal
aF_FL	Acceleration of the front left wheel	DTC, ABS, Derived signal
aF_FR	Acceleration of the front right wheel	DTC, ABS, Derived signal

aF_RL	Acceleration of the rear left wheel	DTC, ABS, Derived signal
aF_RR	Acceleration of the rear right	DTC, ABS, Derived signal
aAvgDT	Average acceleration of driven wheels	DTC, ABS, Derived signal
iTrq		DTC, ABS, Derived signal
ikinraw		DTC, ABS, Derived signal
i	Resulting ratio after multiplying the transmission ratio and final drive ratio	Ascet programmed signal
Td	Torque due to Drag	Ascet programmed signal
Tg	Torque due to gravitational force on wheel	Ascet programmed signal
Tr	Torque due to rolling resistance on wheel	Ascet programmed signal
Tt	Total torque on LHS of the drive line model in terms of wheel speed	Ascet programmed signal
Tt_1	Total torque on left hand side of the drive line model in terms of engine speed	Ascet programmed signal

Tt_rhs	Total torque on right hand side of the drive line model in terms of wheel speed	Ascet programmed signal
Tt_rhs	Total torque on right hand side of the drive line model in terms of Engine speed	Ascet programmed signal
GearStep	Constant input value of Gear step size	Ascet programmed signal
Dynamic_0	Resultatnt of DTE development algorithm based on heuristic/ Experimental approach	UniVw naming convention
Dynamic_LHS	Resultatnt of DTE development algorithm based on Drive line model in terms of Engine speed approach	UniVw naming convention
Gear shift	Major change detection ,Resultatnt of DTE development algorithm based on Drive line model in terms of Wheel speed approach	UniVw,Ascet naming convention

6.5 Flow Diagram

The following figures show the flow of the implemented Algorithm. This is the First level of implementation class of the project in Ascet. This Class contains further sub classes inside it. These subclasses are present inside the above shown class. These subclasses contain modules inside them. In those modules further sorting functions are considered. From every class/subclass, information is used in the major class Algobench that gives us the output in terms of three variables Dynamic_0, Detection_1, and Detection _2.

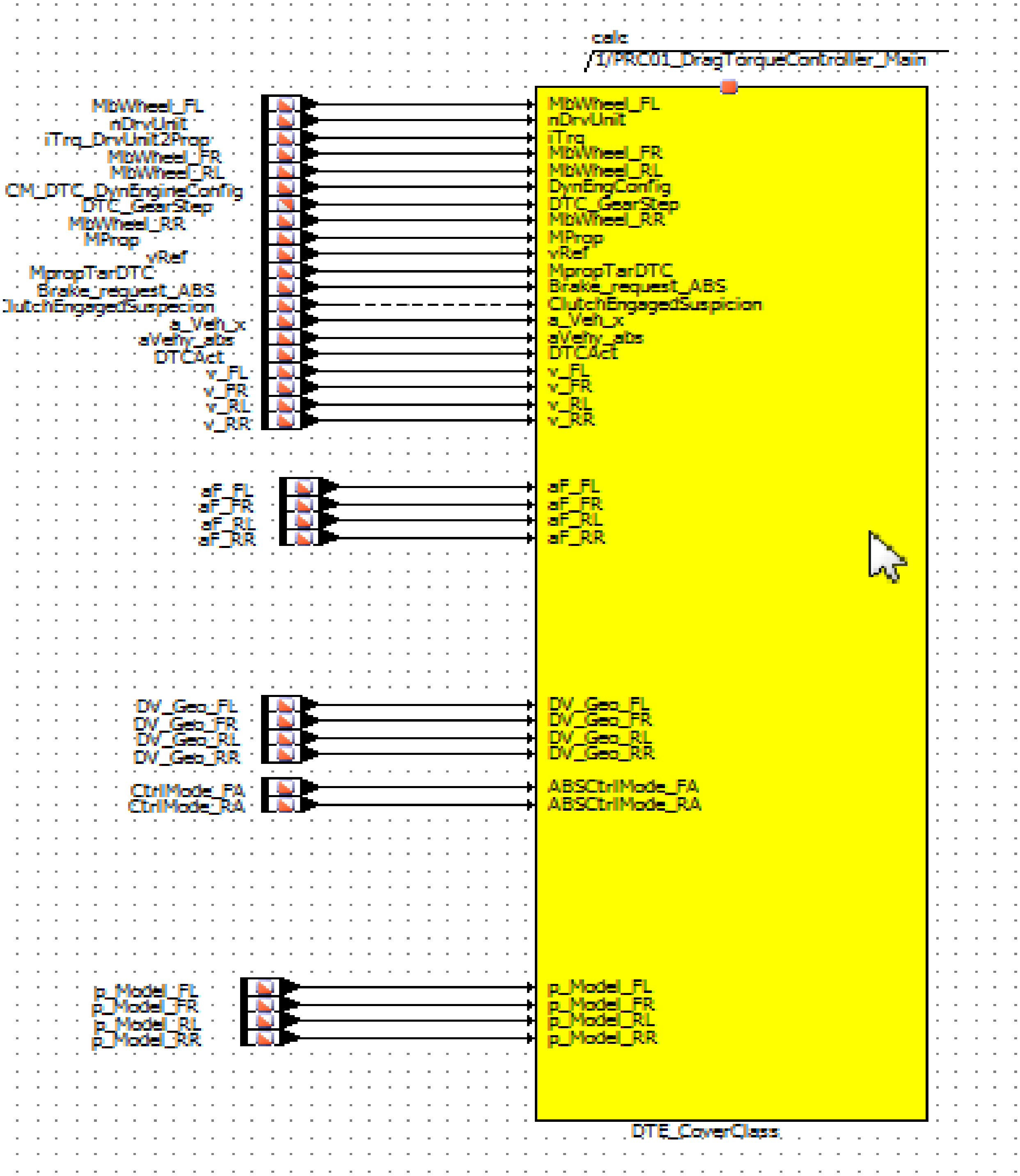

Figure 6.17: 1st level Ascet Implementation

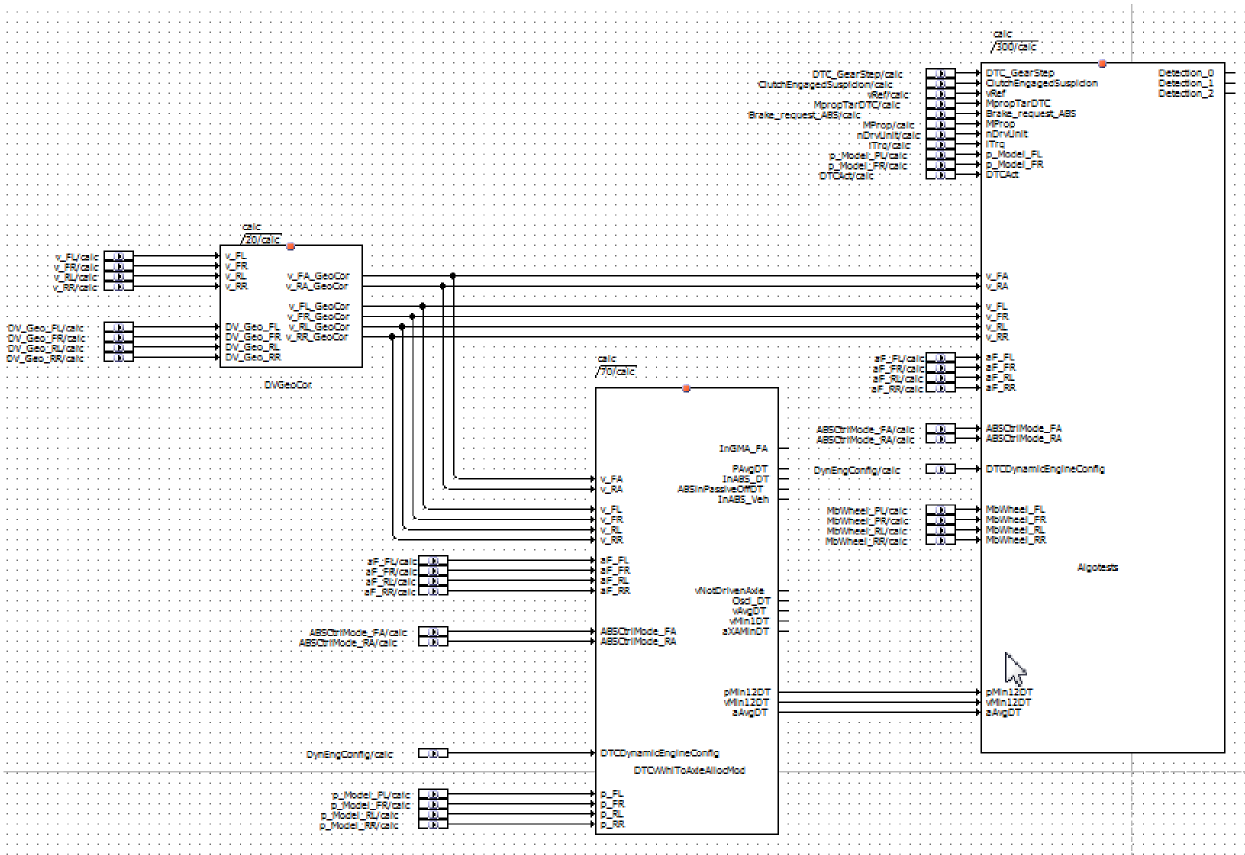

Figure 6.17: Sub classes and Algotest

CHAPTER 7 : Driveline Model based Appraoch:

7.1 Basic driveline Model:

The most important thing in power transmission of vehicle is the power train. How the power is transmitted from engine to the wheels. The main parts of the power train of a vehicle consists of clutch , gear box or transmission , propeller shaft, drive shafts, and a final drive unit (differential). The driveline is the fundamental part of the vehicle, and it has been modeled in different ways depending upon the purpose. Here I will be discussing the two important models in terms of wheel speed and in terms of engine speed. The following figure shows the power train of a rear wheel drive. The basic driveline model is [40]

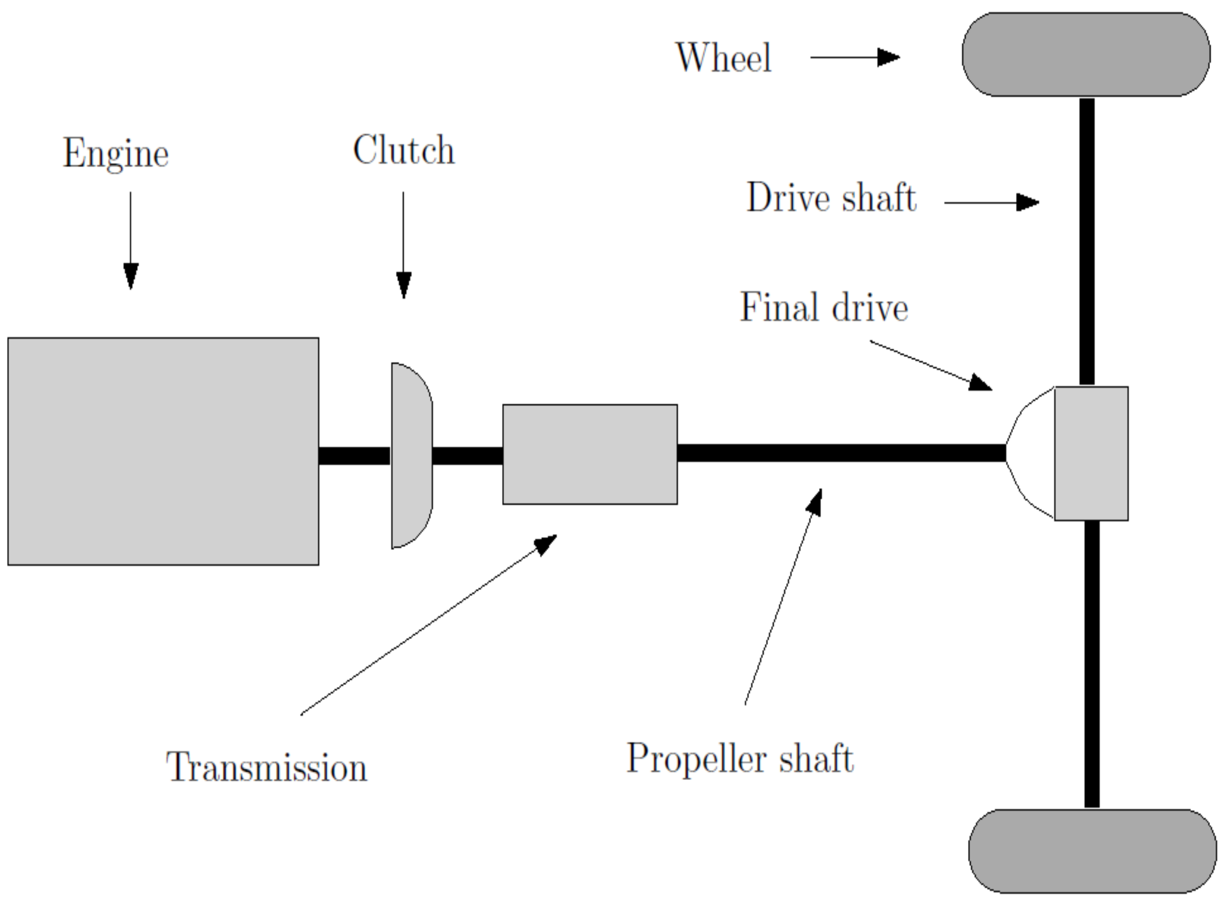

Figure 7.1: RWD power train Driveline model [40]

Driveline Modeling:

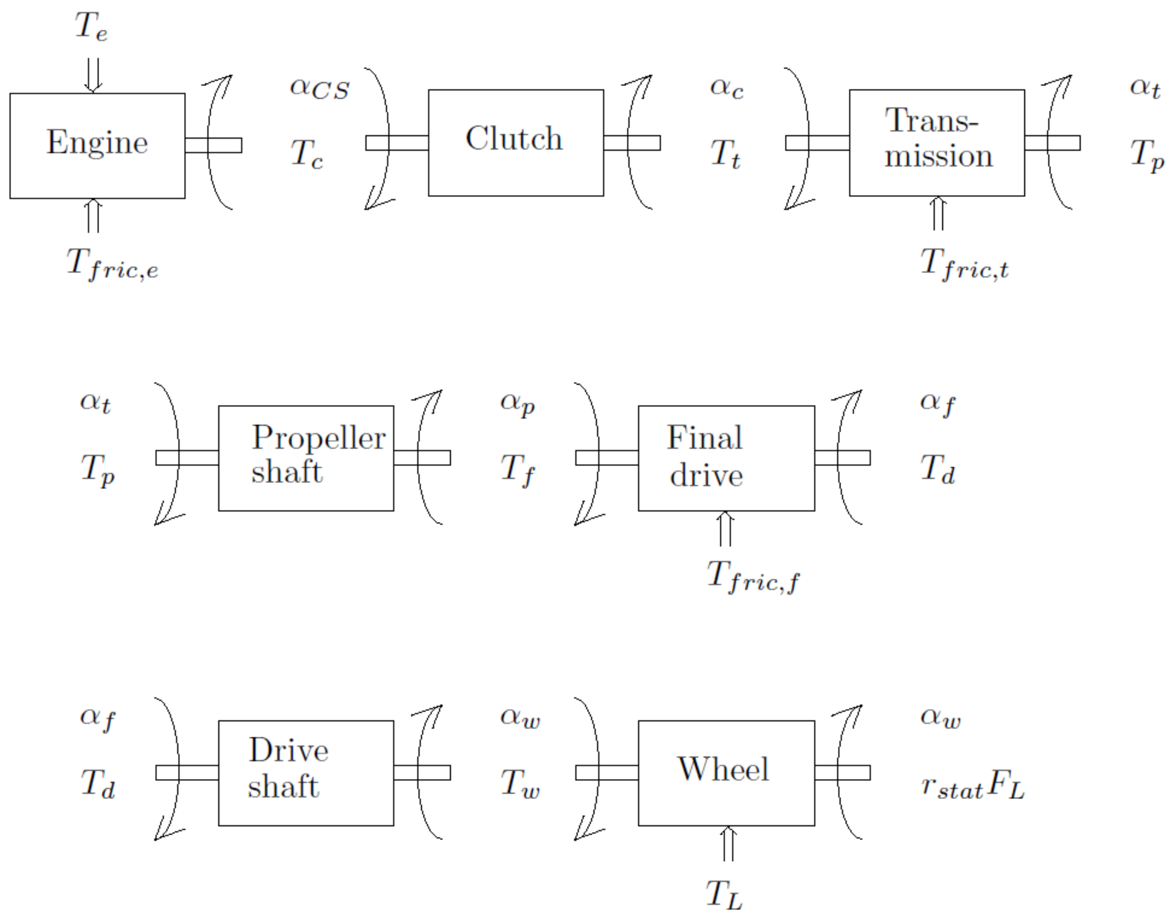

Figure 7.2: subsystems of vehicle Driveline [41]

The above figure shows the subsystems of a driveline their respective angles and torques, depending on that we are going to drive a set of equations representing this complete model. The fundamental equations are derived from the very famous Newton's second law of motion. The relationship between the output and input is derived in the following for each subsystem.

Engine:

T_e denotes the output torque of the engine, J_e is the mass moment of inertia of engine, $T_{fric,e}$ is representing the internal friction from the engine , the crankshaft angle is represented by α_{cs} and engine speed can be calculated from the relationship $\dot{\alpha}_{cs} = 2\pi n$, applying newton's second law of motion

$$J_e \ddot{\alpha}_{cs} = T_e - T_{fric,e} - T_c$$

Clutch:

Clutch is assumed as stiff, that means that clutch torque is same as of the next component that is transmission, in equation form is written as

$$T_c = T_t$$

$$\alpha_{cs} - \alpha_c$$

Transmission:

Transmission consists of set of gears, depending upon the vehicle, vehicle can be equipped with different gears, and each gear has a fixed conversion ratio, called transmission ratio and is denoted by i_t . The input output relationship of torques gives the following equation

$$\alpha_c = \alpha_t i_t$$

$$J_t \ddot{\alpha}_t = T_t i_t - d_t \alpha_t - T_p$$

For simplification of the model we are neglecting the inertia and losses due to damping which results

$$\alpha_c = \alpha_t i_t$$

$$T_t i_t = T_p$$

Propeller Shaft:

The output of propeller shaft is given by

$$T_p = T_f = f_p(\alpha_t - \alpha_p, \dot{\alpha}_t - \dot{\alpha}_p)$$

Since propeller shaft is also assumed to be stiff, that means we are not considering the losses due to vibrations, this leads to

$$T_p = T_f$$

$$\alpha_c = \alpha_p$$

Final Drive :

The final drive can also be modeled by one rotating inertia as done with transmission, and friction torque is described by the viscous damping coefficient d_f .However, for the sake of simple model, we are neglecting the vibrational effects.

$$T_d = f_f(T_f, T_{fric,f}, \alpha_p - \alpha_f i_f, \dot{\alpha}_p - \dot{\alpha}_f i_f, i_f)$$

$$\alpha_p = \alpha_f i_f$$
$$T_f i_f = T_d$$

Drive shaft:

Two drive shafts are connected with drive shaft and then to the wheels. The rotational speed of both the wheels is same. Although with differential gears, it is possible to vary the speeds of both drive shafts, which also helps the vehicles equipped with ESP. by neglecting vehicle dynamics, the rotational equivalent speed of wheels shall be equal to the speed of the vehicle body's Centre of gravity.

$$\dot{\alpha}_\omega = \frac{\upsilon_{Rij}}{r_{stat}} \approx \frac{\upsilon_{CoG}}{r_{stat}}$$

$$T_w = T_d = f_d(\alpha_f - \alpha_w, \dot{\alpha}_f - \dot{\alpha}_w)$$

The stiff drive shaft gives the following equations

$$T_w = T_d$$

$$\alpha_f = \alpha_w$$

Wheel:

The following figure shows the forces acting on a vehicle.

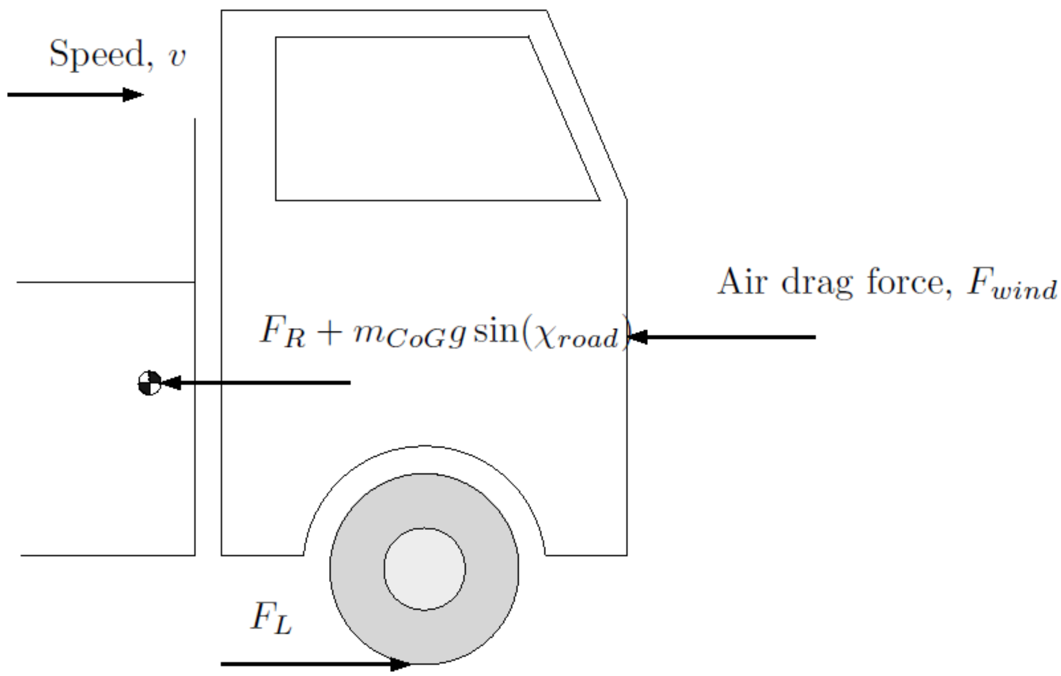

Figure 7.3: longitudinal forces acting on a vehicle [42]

The further description of how to calculate the traction force can be found in the literature books of automotive engineering. Here are only those mentioned which are necessary for the calculation of wheel torque. Newton's second law of motion in longitudinal direction gives

$$F_L = m_{CoG}\dot{\upsilon}_{CoG} + F_{wind} + F_R + m_{CoG}\, g \sin(Xroad)$$

F_L = Friction Force

$Xroad$ = slope of the road

$$F_{wind} = \frac{1}{2} c_{Air} A_L \rho_a \upsilon^2_{CoG}$$

F_{wind} =Air Drag force

c_{Air} = air drag coefficient, which varies with respect to the dynamics of vehicle

A_L = cross sectional area

ρ_a = air density, which is also a constant parameter

The Rolling resistance is calculated as

$$FR = m_{CoG}(c_{r1} + c_{r2} V_{COG})$$

Where c_{r1} *and* c_{r2} depends on tires and tire pressures, and for each tire there value is different. Its value can be found by consulting the corresponding manufacturer of that tire/ vehicle.

The resulting torque due to Frictional force can be found by using

$$T_L = F_L * r_{stat}$$

Newton's second law gives

$$Jw\ddot{\alpha}_w = Tw - F_L r_{stat} - T_L$$

$$(Jw + m_{CoG} r^2 stat)\ddot{\alpha}_w = Tw - TL - \frac{1}{2} c_{air} A_L \rho_a r^3_{stat} * \dot{\alpha}^2_w - r_{stat} m_{CoG}(c_{r1} + c_{r2} r_{stat} \dot{\alpha}_w) - rstat\, m_{CoG}\, g \sin(Xroad)$$

Simplifying the above equations and using the following, a complete model is described as under

$$i_t i_f T_c = T_w$$

$$\alpha_{cs} = i_t i_f \alpha_w$$

Where $T_e - T_{fric,e}$ =Effective torque from engine and the frictional force due to air can be neglected for low gears as the air drag coefficient decreases. Also now, the vehicles are manufactured with the least air drag coefficient.

The second algorithm is implemented based on this model. All the parameters values are given in following table which are taken from the website of vehicle manufacturer.

7.1.1 Basic driveline Model In terms of wheel Speed

Block Diagram :

The following block diagram shows the driveline model based approach. Here instead of comparing the speeds torques will be compared. Hence we require the Torques at each model. Torques at each level are shown in the following block diagram. Mb is the torque due to braking, it is not present in the driveline model of the referenced book , instead it has been added for better detection of the transmission status especially in maneuvers where braking is applied.

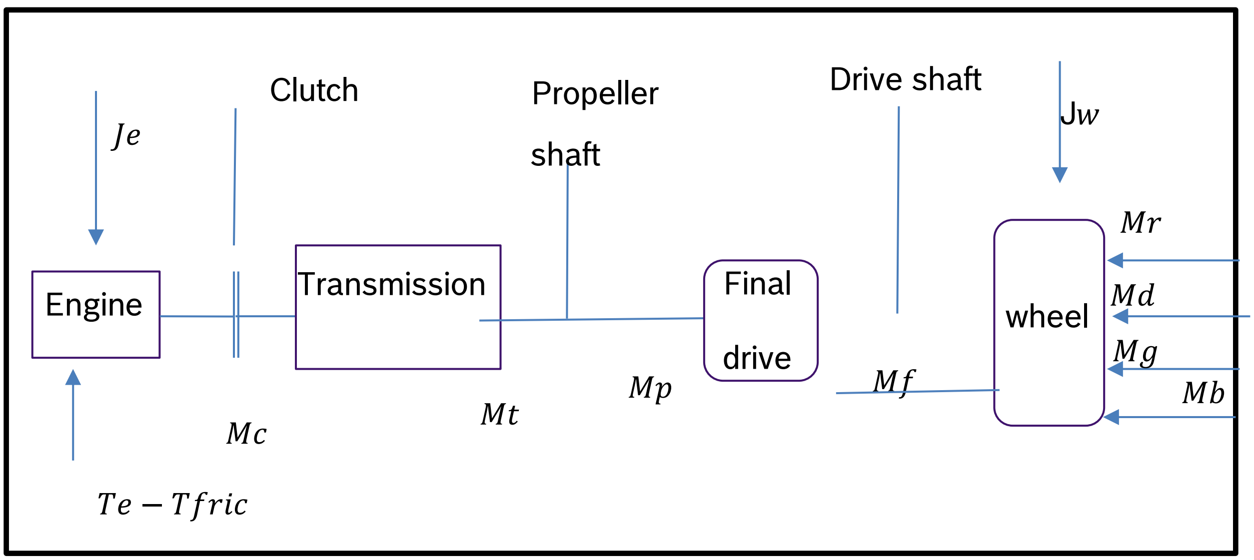

Figure 7.4: Block diagram of driveline model in terms of Torques

$ML = Mr + Md + Mg$= Total Torque due to resistive forces

$Mw = itif * Meng$ = Engine Torque transmitted to Wheel

Mtotal_rhs=Mw-ML-Mb

$$M_{total\_rhs} = i_t i_f (T_e - T_{fric,e}) - m_{CoG} C_{r2} r_{stat}^2 \dot{\alpha}_w - \frac{1}{2} c_{air} A_L \rho_a r_{stat}^3 \dot{\alpha}_w^2 - r_{stat} m_{CoG} (c_{r1} + g \sin(X_{road})) - M_b$$

The implementation and complete layout diagram of this model implemented in ASCET is shown below

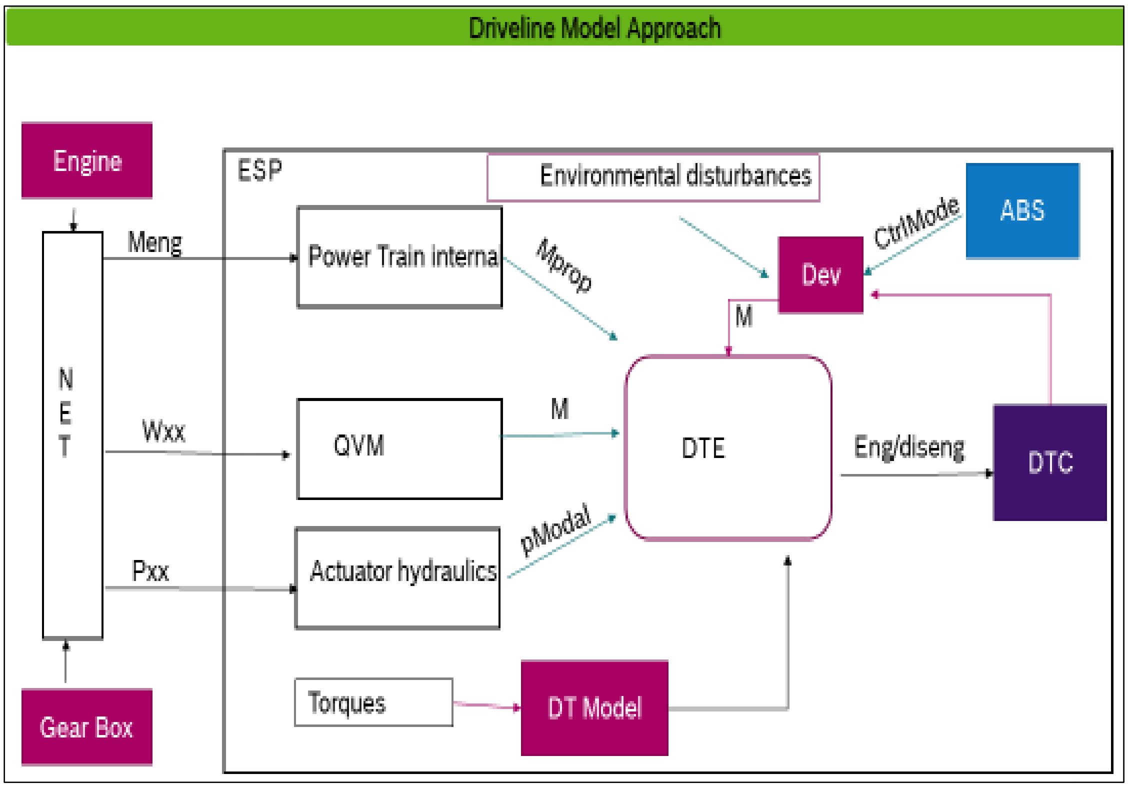

Figure 7.5 Block diagram of Driveline Model approach implemented

7.1.2 Basic driveline Model in terms of Engine Speed:

The above model can be written in terms of Engine speed by performing some mathematical operations and writing the wheel speed in terms of engine speed. Since from the driveline model we know that,

$$\alpha_{cs} = i_t i_f \alpha_w$$

$$\dot{\alpha}_{cs} = i_t i_f \dot{\alpha}_w$$

$$\dot{\alpha}_w = \frac{\dot{\alpha}cs}{itif} = \frac{2\pi\dot{n}}{itif}$$

$$Engine\_speed = \frac{2\pi\dot{n}*0.1}{itif}$$

$$Mtotal = (Jw + m_{CoG} r^2 stat + i_t^2 i_f^2 J_e) * Engine\_Speed$$

Now this equation is completey transformed in terms of engine speed and Moment of inertia. And is implemented in ASCET and tested. The results of this approach are discussed later in chapter 8.

CHAPTER 8 : RESULTS AND DISCUSSION

This chapter discusses the results obtained after implementing all the algorithms. Here only the four measurements results are shown. Simple case without braking and then more complex cases with braking are tested and evaluated.

8.1 Without Braking on Low mue:

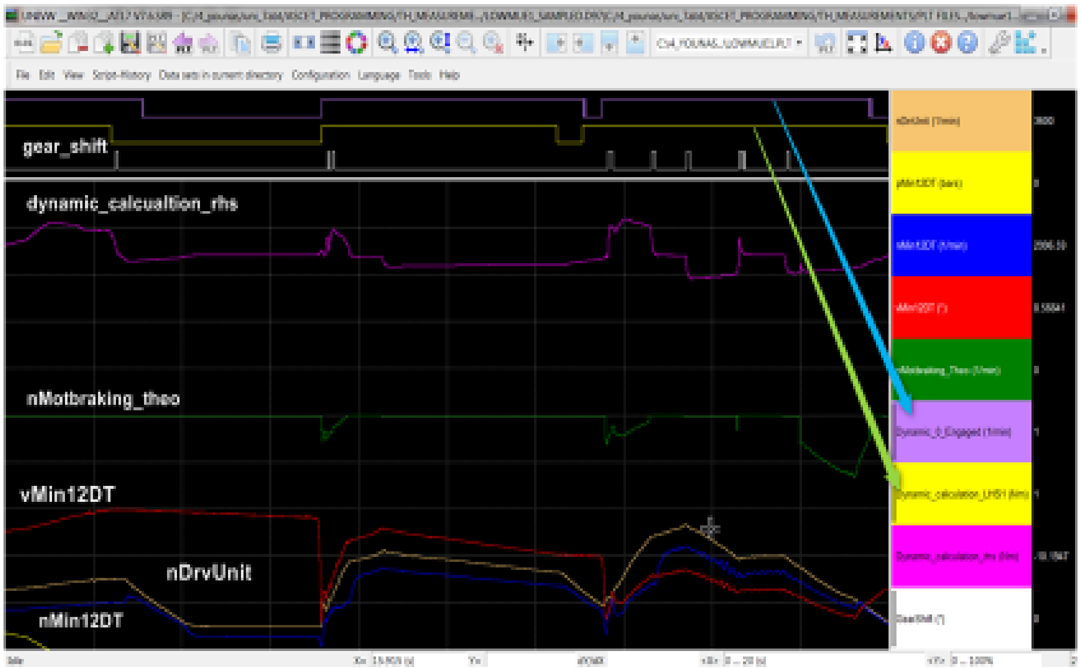

Figure 8.1: Without Braking on Low mue

After programming of the algorithms in ASCET and running the physical experimental setup with correct mapping of the signals with the corresponding signals, results are logged. These logged results contain much more signals than what are being shown, but here only the important signals are shown. Which are then evaluated in UniVw software. In addition, after applying the filtration techniques, results are shown in the following figures.

The figure above shows the maneuver when vehicle is on low mue surface and is not braking. It means we do not have any values of pressure from hydraulic actuators, as result we do not have any effect of braking. i.e. ***PMIN12DT*** is zero. As we know, that ***Dynamic_0_Engaged*** shows the result of the Heuristic approach, whereas ***Dynamic_calculation_LHS*** shows the resultant of driveline model in terms of Engine speed. ***Gearshift*** signal shows the output result of the third approach i.e. implementation of driveline model in terms of wheel speed taking braking moment also in to the consideration. From the figure, it is quite evident that all the algorithms approaches are detecting the status of transmission. First algorithm clearly shows the when it is disengaged, and when it is engaged. For DTC use purpose, this information is sufficient. Similarly, second algorithm is also detecting engagement and disengagement status. The third algorithm gives us the information of major changes that occur. Which is an important information for DTC when it restarts.

8.2 Without braking on ice:

The figure below shows the result of the maneuver without braking on ice. Since mue of the ice is very low, and there is, more slip which is clearly visible by observing the behavior of ***nDrvUnit***. All the algorithms are clearly indicating the engaged and disengaged status and the major change that occurs. ***Pmin12DT*** is zero in this case too.

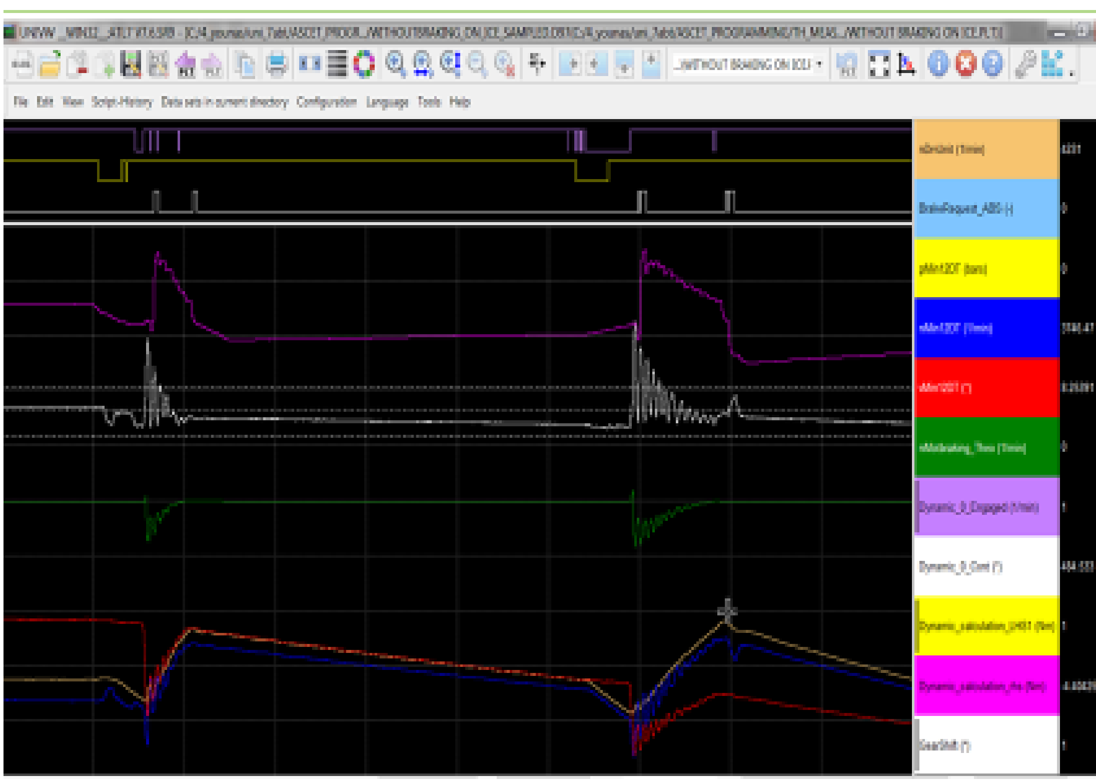

Figure 8.2: Without Braking on ice

8.3 3, 2 ABS Wet Basalt

Basalt is the special surface, which is artificially made to represent the wet surface. In This maneuver, braking is also applied. And the effects of ABS can be clearly seen by observing the oscillations in the ***nDrvUnit*** and ***vMin12DT***. First algorithm detects the points where the gear is engaged correctly. 2nd algorithm also detects, but for more fine tuning filtration techniques can be applied and better results can be achieved. The third algorithm shows the major changes that are an important information for DTC to restart.

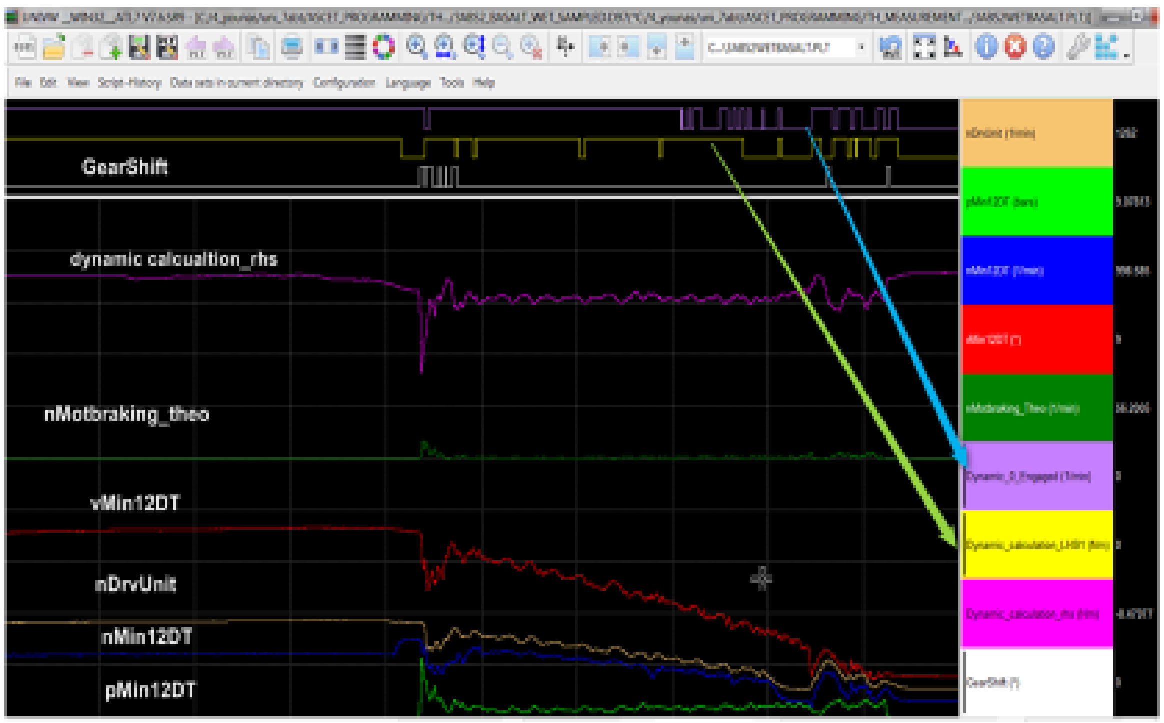

Figure 8.3: 3-2- ABS Wet Basalt

8.4 With ABS braking on Ice:

The following figure shows another scenario where braking is applied on the very low mue surface, that is ice. However, here one can observe that normally it is very difficult to detect whether gear is engaged or not because of the slip. After implantation of the algorithm results show very positive outcome. First 2 algorithms show very satisfactory results. Moreover, when we compare it with the already developed algorithm that is based on simultaneous oscillations, then we observe that both algorithms show the same result. The third algorithm shows too many changes , this is because of the fact that , there is too much slip and whenever there would be some change , it will show that.

Figure 8.4: With ABS Braking on Ice

8.5 Results Comparison and Conclusion:

Heuristic Approach	**Driveline Model in terms of Engine Speed**	**Driveline Model in terms of Wheel Speed**
• Better results in simple conditions • Satisfactory results in Braking conditions	• Better results in simple conditions • Satisfactory results in Braking conditions • Can be more better evaluated with filtration techniques	• Major changes in Drag torque are detected • Can be better evaluated with filtration and correlation with vehicle dynamics

CHAPTER 9 : : Conclusion and Future Work

This thesis analyses the transmission of vehicle, and finds a way to determine the information of engaged and disengaged transmission. It uses the information from different sensors and utilizes the vehicle mechanics, basic principle of vehicle transmission, basic driveline transmission model in terms of wheel speed and in terms of engine speed.

There is always room for improvements to be made in any form of research. The current research uses the basic driveline model without the torsional effects of driveshafts and Flexibilty of driveshaft. In addition, clutch was considered as stiff. A more accurate algorithm can be developed by following the same procedure but just implementing driveline model with drive shaft flexibility.

Moreover, a decoupled neutral gear model is also available in literature which can also be implemented but for that one needs some extra information, which may not be available. However, time constraints have not allowed me to work on them. However, future work can definitely be done by considering these points.

APPENDIX A

ASCET Code:

// ------------------------- Heuristic approach algorithm--------------------------------

//aAvgDT wheel acceleration calculated from the class WhltoAxleAlloc

// pMin12DT taken after sorting with the different drive units FWD, RWD, allWD (p_sorter algorithm)

//vMin12DT taken after sorting with different drive units FWD, RWD; allWD (v_Sorter algrithm)

//r_stat_1 is the radius of the wheel taken directly from the measurement(input parameter)

// calculating nMot theoretically

iGear = PT_GB_GearStep2GearRatio.getAt(DTC_GearStep);// getting gear ratio values at corresponding gear step input

i=3.368*iGear; // i=iDiff*igear ,where idiff=3.368 is fixed parameter,multiplying both ratios

i_square=(iGear*iGear)*(3.368*3.368);

nMin12DT =vMin12DT*(60/(2*3.14*r_stat_1))*i; //theoretical calculated nMin12DT

//--- nDrvunit is measured and taken as input

// Calcualting nMotbraking_theo that is the tolerance

radius_square = (r_stat_1*r_stat_1);

slip=((vRef-(nMin12DT/i))/nDrvUnit);// vref is the refernce speed

nMotbraking_theo = (50.74*pMin12DT)*slip*Brake_request_ABS+MpropTarDTC*slip*DTCAct;

Dynamic_0=(nDrvUnit-nMin12DT-nMotbraking_theo);

//---------------------------Basic Driveline model in terms of wheel speed -------------------

/* clutch , propellershaft and drive shaft are stiff, that means same torque will be transferred to the next element in drive train */

nMin12DT =vMin12DT*(60/(2*3.14*r_stat_1))*iTrq;// depending upon wheel drive,average wheel velocity converted in to [1/min]

iGear = PT_GB_GearStep2GearRatio.getAt(DTC_GearStep);// getting gear ratio values at corresponding gear step input

i=3.368*iGear; // i=iDiff*igear ,where idiff=3.368 is fixed parameter,multiplying both ratios

i_square=(iGear*iGear)*(3.368*3.368);

//radius_square=r_stat_1*r_stat_1;

mr_square=m_GrossVehicleMass_1*radius_square;

MTotal=(Jw_1+ mr_square+i_square*Je_1)*(aAvgDT/r_stat_1); // calculating left hand side of equation

Mw=MProp; // wheel torque (Mprop=T_e)

Mr=m_GrossVehicleMass_1*cr2_1*(radius_square)*(vMin12DT/r_stat_1); // torque on wheel due to rolling resistance

Md=
(0.5*c_air_1*A_L_1*rho_a_1)*(radius_square*r_stat_1)*(vMin12DT*vMin12DT/(radius_square));// torque due to drag force

Mg=((r_stat_1)*(m_GrossVehicleMass_1)*(cr1_1+(g_1*(Xroad_1))));// torque due to slope of the road

// since for small value sin(Xroad_1)=Xroad_1

Mb=pMin12DT*Cp;

MTotal_rhs=Mw-Mr-Md-Mg-Mb;// calculating right hand side of equation

//-------------------------- Basic driveline in terms of wheel speed and engine speed----------------

//vmin12DT=(1/i)*2pi*nDrvUnit, therefore replacing Vmin12DT by Engine_speed

// Te=(HP*5252)/nDrvUnit

Engine_speed=(2*3.14*0.01*nDrvUnit)/(i); // Engine_speed=nMin12DT; wheel speed is replaced by Engine_speed here.

//Mw_1=i*HP_1*5252*(1/nDrvUnit); // 1 HP is 746W , torque=(HP*5252/(RPM))

MTotal_1=(Jw_1+ mr_square+i*Je_1)*2*(3.14*0.01/i);//(aAvgDT/r_stat_1); ndot will be multiplied in univw calculating left hand side of equation

Mw_1=i*((HP_1*5252)/(nDrvUnit));

Mr_1=m_GrossVehicleMass_1*cr2_1*(radius_square)*Engine_speed;

Md_1=(0.5*c_air_1)*(A_L_1*rho_a_1)*(radius_square*r_stat_1)*(Engine_speed*Engine_speed);

```
Mg=r_stat_1*m_GrossVehicleMass_1*(cr1_1+g_1*(Xroad_1));    // torque due to    slope of the road
// since for small value sin(Xroad_1)=Xroad_1

MTotal_rhs_1=Mw_1-Mr_1-Md_1-Mg-Mb;// calculating right hand side of equation
```

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